







Sandpiper Project
Verification Programme

Volume 1: Main Report

Namibian Marine Phosphate (Pty) Ltd
Mining Licence Area No. 170

November 2014



J. Midgley and Associates

CSIR
our future through science

DISCLAIMER

This Verification Programme study was coordinated and prepared by J Midgley and Associates in accordance with reasonable professional standards and the terms of the contract agreed to between Namibian Marine Phosphate (Pty) Ltd and J Midgley and Associates.

J Midgley and Associates makes no warranties, express or implied, whether arising by operation of law, course of performance or dealing, custom, usage in the trade or profession or otherwise, including without limitation implied warranties.

The CSIR provided independent review and process quality control services to the Verification Programme study in accordance with reasonable professional standards and the terms of the contract agreed to between Namibian Marine Phosphate (Pty) Ltd and the CSIR.

The CSIR makes no warranties, express or implied, whether arising by operation of law, course of performance or dealing, custom, usage in the trade or profession or otherwise, including without limitation implied warranties.

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed "Attention: Administration Manager," at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

Sandpiper Project Verification Programme

VOLUME 1: MAIN REPORT

Namibian Marine Phosphate (Pty) Ltd
Mining Licence Area No. 170

Application:

This report has been prepared to verify the findings of the NMP Final EIA (Midgley 2012), as submitted to the authorities, Ministry of Environment and Tourism. The need for, and scope of, the Verification Programme was detailed in the EMP (Midgley 2012), The scope subsequently was expanded following consultations with MFMR, the Fishing Industry, and the NatMIRC scientists (2012 / 2013).

Report co-ordinated and prepared by:

Mr Jeremy Midgley Pr.Sci.Nat
J. Midgley & Associates
PO Box 110
Constantia 7806
South Africa
Email: mwjmidg@mweb.co.za

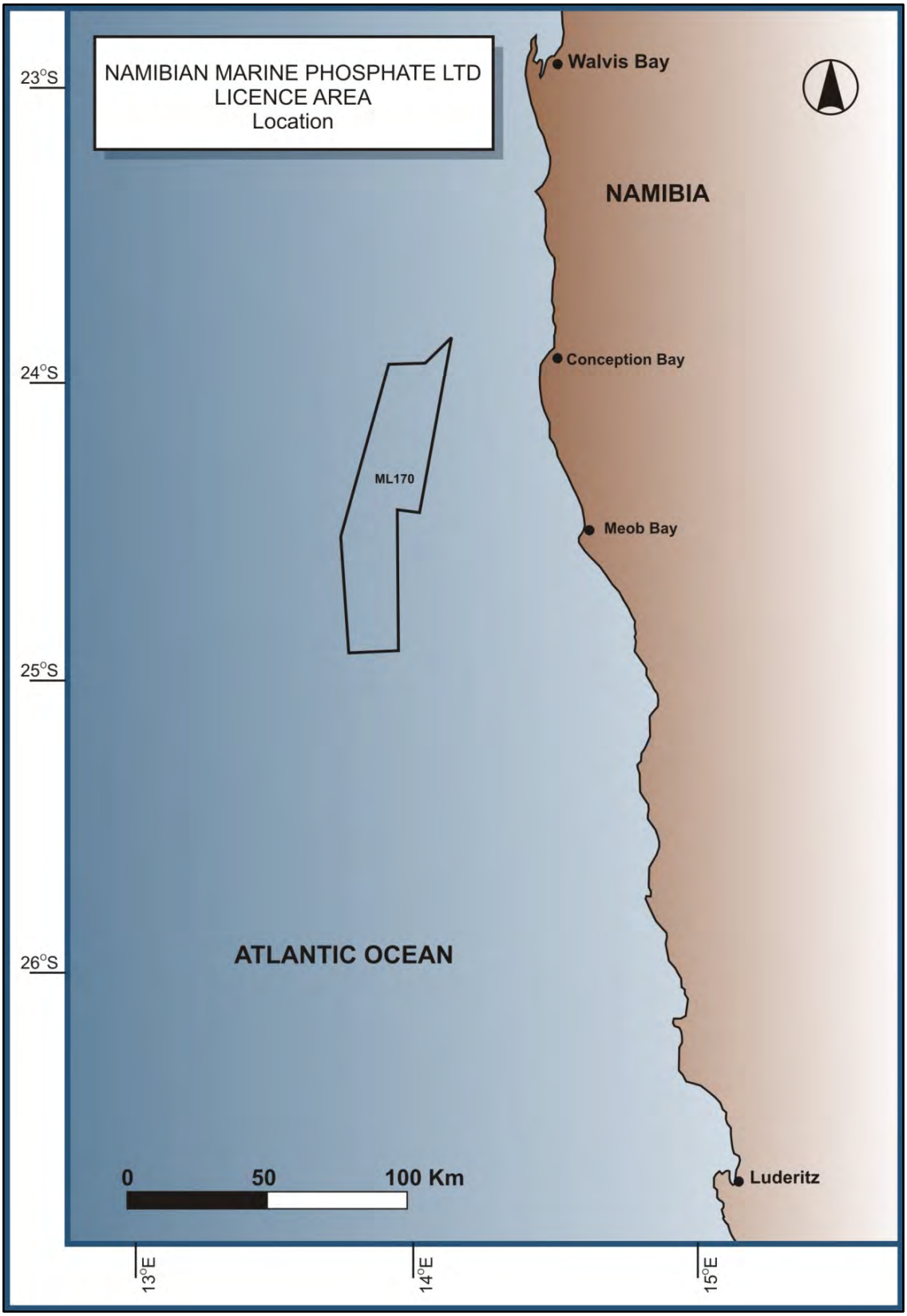
Independent Programme Reviewer and Process Quality Controller:

Mr Patrick Morant Pr.Sci.Nat
CSIR
PO Box 320
Stellenbosch 7599
South Africa
Email: pmorant@csir.co.za



November 2014

© NMP 2014



Frontispiece: Location of Mining Licence ML 170 off shore Namibia

Introduction to the Sandpiper Phosphate Project

Namibian Marine Phosphate (Pty) Ltd (NMP) has applied to recover phosphatic sediments from the seabed on the Namibian continental shelf. Following an extensive exploration programme a mining licence (ML 170) was issued by the Ministry of Mines and Energy (MME) in July 2011 with the standard conditions requiring the issue of an Environmental Clearance Certificate by Ministry of Environment and Tourism (MET) prior to commencement of operations.

The Sandpiper phosphate project (ML 170) is located on the Namibian continental shelf approximately 120 km south southwest of Walvis Bay (see Frontispiece). The eastern boundary of the Mining Licence Area is approximately 60 km off the coast directly west of Conception Bay. The water depths in the licence area range from 180 to 300 m. The Mining Licence Area is 25.2 km wide (greatest width) and 115 km long (longest length) and covers an area of 2233 km^2.

The phosphate-enriched sediments and the defined mineral resources and reserves[1], are located throughout the entire Mining Licence Area. Within the ML 170 area, three initial target dredging areas have been identified namely SP-1, SP-2 and SP-3. The primary target dredge site for the 20 year licence period is SP-1 (176 km^2) which lies in water depths of 200 to 225 m. A trailing suction hopper dredger (TSHD) (Figure 1) will be used to recover approximately 5.5 million tons of sediment annually from an area of up to 3 km^2 in extent. A total area of approximately 60 km^2 will be dredged over the course of the 20 year mine licence period. The other sites SP-2 and SP-3 also contain phosphate resources and may be considered at a later stage, at which time the requisite additional environmental evaluations will be made in accordance with the Environmental Management Act (Act No. 7) of 2007.

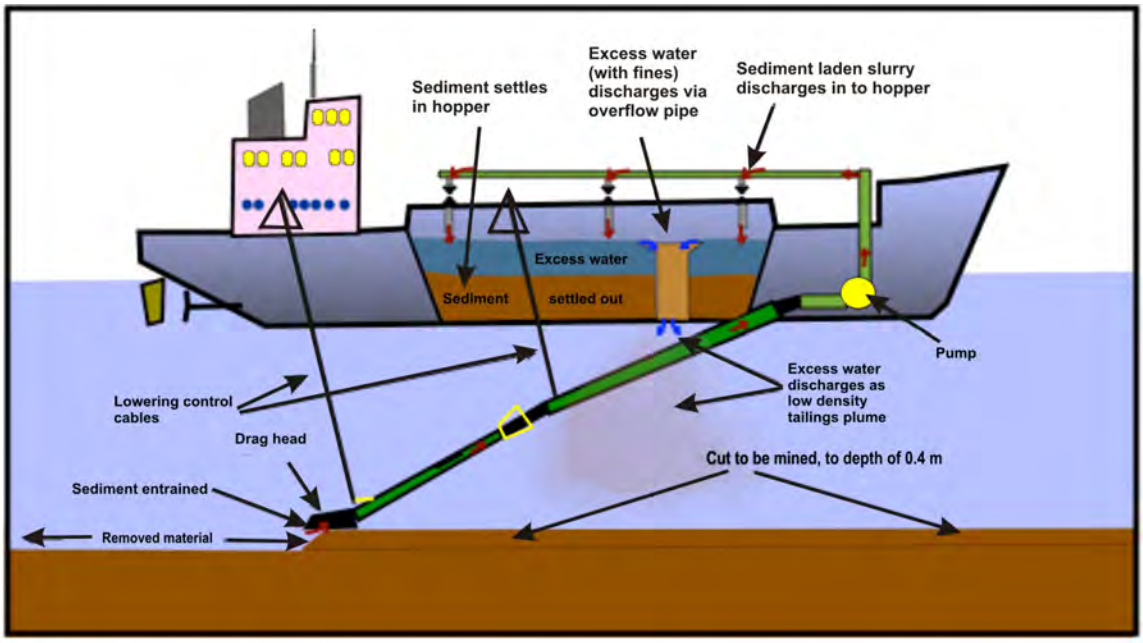


Figure 1: A schematic of a Trailing Hopper Suction Dredger (TSHD).

[1] 1,832 million tons (at 15 % P_2O_5) [comprising: Measured 4,09 Mt, Indicated 220,35 Mt at 20.13 % P_2O_5 and Inferred 1,607.8 Mt at 18.9 % P_2O_5]

© NMP 2014

The Environmental Management Plan (EMP) is an integral component of the Environmental Impact Assessment (EIA). The EMP becomes part of the legally binding contract with MET on issue of the Environmental Clearance Certificate. The EMP included the provision for the completion of an integrated pre-dredging impact verification survey. The survey was designed specifically by the specialists, who determined that the level of *confidence* in their assessment of impacts could be improved with additional *in situ* information. Notwithstanding this, they considered their work to be robust. The primary reason for the uncertainty related to the relatively short period in which their work was undertaken. The terms and conditions of the licence issued by (MME) required the EIA to be submitted in six months. This requirement did not allow any opportunity for fieldwork (sampling and measurement) to be undertaken.

The Verification Programme reported herein presents the results of the various specialist studies that were completed during 2013 and 2014, providing the evidence in support of the original impact assessments contained in the EIA with specific focus of the assessment of the primary target dredge site SP-1.

© NMP 2014

CSIR Independent Review

SANDPIPER PROJECT
MINING LICENCE AREA ML 170
VERFICATION SURVEY AND REPORT

November 2014

INDEPENDENT REVIEW BY CSIR

Mr P. Morant (Pr.Sci.Nat)

In 2012 an Environmental Impact Assessment (EIA) was prepared for Namibian Marine Phosphate (Pty) Ltd's (NMP) proposed marine phosphate dredging operations in ML 170 offshore Meob Bay, Namibia. In order to meet the requirements of the licence issuing authority, the Ministry of Mines and Energy, the entire EIA had to be completed in six months that precluded any field studies. The assessment of impacts made by the specialist scientists was of high quality and made the best use of the information available. However, the specialists recognised that a field-work based verification study was necessary primarily to improve the level of confidence in their scientific predictions of the severity, extent and duration of potential impacts arising from the dredging operations. The plan for the Verification Survey was included in the Environmental Management Plan (Chapter 8 of the EIA 2012) and NMP committed to undertaking the verification assessment prior to the commencement of dredging. This Verification Survey would also serve as an environmental baseline for the target dredge area (SP-1) and serve as a benchmark against which the actual impacts of dredging could be assessed.

As the CSIR's Independent Reviewer and Process Quality Controller appointed to the project I have been directly involved with the environmental aspects of the project since 2011. Throughout I have been impressed by the professionalism of the specialists, the high quality of their scientific studies, and the robustness of their assessment of the potential impacts both for the original EIA 2012 and the subsequent Verification Programme in 2014. I believe that the information now available and the enhanced confidence in their assessment of impacts as a result of the Verification Programme demonstrate that there are no objective scientific reasons why an Environmental Clearance Certificate should not be issued and the project permitted to proceed. The planned monitoring programme and the adaptive management approach (which is an integral component of an EMP) to which NMP is committed further strengthens my view that the project should be permitted to proceed.

© NMP 2014

In reviewing the Verification Survey and the Report emanating from it I have adopted a semi-chronological approach by following the process from its inception to its conclusion in the form of the Verification Survey Report compiled by J. Midgley and Associates. The review is based on my experience of managing numerous marine EIAs along the west coast of Africa. In particular, since 1993 I have managed, or contributed to, EIAs for offshore oil and gas exploration and production, marine diamond mining in Namibian waters, expansion of the ports of Lüderitz and Walvis Bay, and a major field study of the Kunene River mouth as an input to the EIA for the Epupa Falls hydroelectricity project. I assisted with the establishment of the Benguela Current Large Marine Ecosystem programme and was lead author of two Thematic Reports that formed part of the founding documentation for the programme. I am a South African Registered Professional Natural Scientist (Reg. No. 401514/83).

From the time of submission of the EIA in April 2012 until the first deployment of oceanographic instrumentation in SP-1 in June 2013 there was a protracted period in which NMP and its EIA consultant attempted to engage with MFMR and its scientists to approve the contents of the Verification Programme and, most importantly, actively participate in it.

As part of this engagement process I attended two meetings in Swakopmund which contributed to shape the structure and content of the Verification Programme. These meetings were chaired by the Governor of the Erongo Region, the Honourable Cleophas Mutjavikua. The first meeting, held on 4 July 2012, was primarily between representatives of the Namibian Fishing Industry and the Verification Study Team. However, the meeting also was attended by representative of the Namibian National Marine Information and Research Centre (NatMIRC) and Interested and Affected Parties (I&APs). The second meeting, held on 10 September 2012, was between NatMIRC and the Verification Study Team. These meetings allowed for an open exchange of information and the views expressed contributed to the final content of the Verification Programme which was submitted to the authorities in December 2012.

Based on my experience of marine scientists working in the Benguela Large Marine Ecosystem I assisted J. Midgley and Associates with the selection of the specialist scientists who led the various components of the Verification Programme namely:

- Dr Robin Carter, Lwandle Technologies (Pty) Ltd – *Water column and sediments*
- Mr David Japp, Capricorn Fisheries Monitoring cc – *Fish and fisheries, biodiversity, seabirds and marine mammals*
- Dr Nina Steffani, Steffani Environmental Consultant – *Macrobenthos*
- Professor Mark Gibbons, University of the Western Cape – *Jellyfish*

Further, I proposed members of the Peer Review group led by Dr A.I.L.Payne, giving due consideration to their experience, familiarity with the Benguela Current ecosystem and independence from the NMP dredging project.

Scope of the Study

The Verification Report encompasses all the activities associated with the survey from designing and planning the marine surveys, the execution of these surveys, the specialist studies that complement the field work, and the subsequent analysis and interpretation of the data. Finally, the Verification Programme contains a re-evaluation of the assessments of impacts contained in the EIA 2012.

© NMP 2014

I reviewed:

i. The components of the Verification Survey as they were planned and conducted;
ii. The cruise reports;
iii. The scientific reports prepared on completion of the field work, the analysis of the data gathered and complementary specialist studies. Specifically I focused on:
    a) The scientific credentials and experience of the specialists involved;
    b) The planned field data gathering programmes;
    c) The interpretation of the results of these programmes;
    d) The re-assessment of the impacts originally presented in the EIA 2012; and
    e) The revisions to the EMP arising from the site-specific data and experience gained during the Verification Survey.
    iv) The final Verification Programme report.

Technical Completeness of the Verification Programme Report

The Verification Survey comprised two major components:

1. The water column and sedimentary environment study which addressed physical oceanography and the biogeochemistry of the sediments. It also included studies of the macrobenthos, meiofauna and sulphur bacteria since these organisms are either an indication of the biogeochemical regime in the sediments or, as in the case of the sulphur bacteria, intimately involved in the biogeochemical regime.
2. The fisheries and biodiversity study whose primary focus was to establish the contribution of the SP-1 target dredge area and, more broadly, the mining licence area (ML 170) to Namibian commercial fisheries especially the bottom trawl fishery for monkfish and hake. This study also obtained data on the non-commercial fish species, on epibenthic macrofauna in, and around SP-1, and on seabirds and marine mammals.

In addition to these two groups of studies a geophysical survey of the northern portion of the SP-1 area was conducted to characterise the sea floor habitat to determine whether there were any special features of environmental significance and to identify any objects that may present an operational risk and thus would need to be considered during dredging.

Five desk-top studies were conducted in support of the Verification Programme:

1. Geology and Preliminary Model for the Age of the Sandpiper Phosphate deposit. Besides providing an overview of the geology of the phosphate deposit this study provided confirmation of the age and furthered the understanding of the formation of the deposit that aided the interpretation of the biogeochemistry of the sediment.
2. An assessment of the plankton of the northern Benguela region with particular emphasis on the environs of ML 170;
3. Two fisheries modelling studies were undertaken to augment the findings of the biodiversity trawl survey conducted in June 2014. These are:
    i. A modeling review of the monkfish and hake biomass associated with ML 170; and
    ii. A review of the reproductive dynamics and stock distribution of key commercial fish species potentially affected by the planned dredging in SP-1. The data for both these studies were provided by NatMIRC; and,
4. An investigation into the value of ecosystem modeling as a means of determining the impact at the ecosystem level of the proposed phosphate dredging project.

© NMP 2014

Both the field-based and desk-top studies are of a high standard and fully reflect the knowledge and understanding of the various environmental components and their function within the highly dynamic Benguela ecosystem. All the studies have provided valuable new data and information on a hitherto poorly studied part of the Namibian continental shelf.

I attended the Peer Review Workshop, held in Cape Town on 13 and 14 August 2014, at which lead members of the Verification Study Team presented their findings and the Peer Review Team, led by Dr A.I.L. Payne, presented their individual and collective assessment of the work undertaken.

It is not my intention to repeat the findings of the Peer Review Team, with whose findings I am in overall agreement. Their findings were positive with respect to the selection and competence of the Verification Study Team members, the assessments they contributed to the original EIA 2012, and also their re-evaluation following completion of the Verification Programme. It is clear that the work done is of a high standard, credible and deserves to be published in the peer-reviewed scientific literature. The Verification Programme is probably the most comprehensive study of its kind ever conducted on the Namibian continental shelf in support of a marine mining project.

I present here two excerpts from the peer review report, *Independent Peer Reviews, Verification Studies, Sandpiper Project: Namibian Marine Phosphate (Pty) Ltd November 2014,* which comment positively on the quality on the work undertaken in the Verification Programme and on the dredging operation having a minimal potential impact on the marine environment:

(i) Comment on the standard of the scientific studies and assessments made:
*"Overall, the (*peer review*) team finds that the response of the client to issues raised at the earlier review of the EIA through commissioning appropriate verification studies has been appropriate and laudable. The quality of those verification studies is covered elsewhere in this report, but collectively and independently, they have been carried out to the highest scientific and technical standards, using appropriate and up-to-date methodology. The results have almost without fail raised the level of confidence associated with the results in terms of likely impacts (detailed in the 2012 EIA), and the (*peer review*) team wholeheartedly confirms those analyses".*

(ii) Comment on the potential impact of the proposed dredging project on the marine environment:
*"To conclude, the review team is impressed by the quality of the information provided to it and believes that all avenues and disciplines of concern relating to the proposed operation in SP-1 have been addressed adequately. The policy decision on whether to proceed is a national one, but we (*peer review team*) can say that the information provided to us has convinced us that everything points to there being a minimal impact of the proposed operation, should a licence be granted, to the Namibian shelf ecosystem".*

The scientific peer review panel identified the need for a preliminary modelling study of the fate and impact of the fine sediment discharged as overspill by the dredger. Such a study may provide a refinement of the desk-top study, extrapolated from an in-field verified modelling study of a similar dredging operation in southern Namibian waters. However, in my opinion, only direct measurement of the operational dredge plume's behaviour, i.e. duration and extent will enable a definitive assessment of its potential impact. In addition to this physical assessment, surveys of the plankton and fish potentially affected by the plume should be undertaken to complete this impact assessment. Such a midwater (water column) faunal survey requires a specialised vessel and gear, therefore every effort should be made to undertake the study in collaboration with NatMIRC's scientists. The peer review team

© NMP 2014

concurred that further in-field assessments of the dredge plume are not critical to the interpretation of impacts and decision making, however they are important as components of the EMP.

If I have any reservations with respect to the peer review team's recommendations for further studies it is that some of them appear to be more appropriate to a major research programme rather than to an environmental impact verification study. Nevertheless there is value in considering the incorporation of aspects of these recommendations in the monitoring programme. NMP has, after discussion with the specialist and peer review team, integrated many of these recommendations into the EMP.

In addition I reviewed the report prepared by Dr S. Mafwila, the appointed representative of the University of Namibia which was contracted by NMP to provide an independent assessment of the suitability of the equipment, sampling techniques, and analytical methods used for the specific scientific studies in the Verification Programme. The assessment is both positive and comprehensive and Dr Mafwila also concurs with the general findings of the peer review team.

Dr Mafwila's concludes his report with a statement with respect to the importance of the field work undertaken during the Verification Programme.

"As a UNAM representative in this whole verification programme, I am of the conviction that NMP has thus far conducted the most comprehensive scientific studies in their MLA. These studies have addressed uncertainties that were raised by the MFMR and beyond. New data sets were generated and new insights about the area have been brought forth, and improved our understanding of the physical, chemical and biological nature and dynamics of the area, and what would be the potential impacts of dredging. It is imperative to continue with monitoring surveys in the MLA, (detailed in the EMP) in order to support the current assumptions and statements. However, in the regional context, the monitoring of the state of the environment should be a concerted combined effort by government and mining companies".

J Midgley and Associates have demonstrated a high level of professionalism throughout the Verification Programme. The programme has required managing a multiplicity of inputs from the study team, organizing the logistics of the field programme, ensuring the health and safety of all the participants, and most importantly the preparation of the Verification Programme Report itself. The sustained commitment to the programme over a period almost three years is commendable.

Namibian Marine Phosphate (Pty) Ltd is acknowledged for its commitment to the Verification Programme and for making available the resources necessary for its success. The Verification Programme and associated EIA have set a high standard against which all future EIAs in Namibia's marine environment will be compared.

Conclusion

In parallel with the monitoring of NMP's dredging operation the Namibian authorities, particularly MFMR and NatMIRC, should be encouraged to undertake broad scale environmental monitoring of Namibian Continental shelf waters to provide a context in which all individual, site-specific projects can be assessed.

© NMP 2014

In conclusion the Verification Report documents a high quality scientific study that not only has verified, with greater confidence, the findings of the EIA (2012), but also has added significantly to the knowledge of the biogeochemical processes and ecology of the central Namibian continental shelf. In my experience no other environmental impact study in either Namibian or South African waters has been based on such an extensive high quality data gathering, analysis and interpretation programme.

I believe as a result of this work, there are no objective scientific reasons why an Environmental Clearance Certificate should not be issued and the project permitted to proceed.



P.D. Morant (Pr.Sci.Nat)
CSIR Independent Reviewer and Process Quality Controller
November 2014

© NMP 2014

Independent Reviewers

NMP in committing to this extensive and comprehensive Verification Programme recognised the need to have the scientific studies submitted to peer review. Similarly the processes and methods followed during the field acquisition of data were also subject to independent review. These executive summaries of these reviews are presented in this report. The independent reviews are presented in full in: *Independent Peer Reviews, Verification Studies, Sandpiper Project: Namibian Marine Phosphate (Pty) Ltd, November 2014.* In addition the entire Verification Programme report, environmental compliance and verification process has been independently reviewed by the CSIR.

1. Independent External Peer Review: Specialist Studies

The verification assessment reports of the Namibian Marine Phosphate appointed Specialist Consultants, as presented in this report have been independently assessed, via a team of international consultants, the team comprised of:

- [2]Dr Andrew Payne
- [3]Dr Michael O'Toole
- [4]Dr Barry Clark
- [5]Professor Alakendra Roychoudhury

In addition to the above parties, Professor John Rogers, formerly (now retired) of the Marine Geoscience unit at the University of Cape Town participated as a guest reviewer (formal report not required) in the independent review workshop with the team as above. Professor John Rogers, along with colleagues Dr Mike Bremner and Dr Gavin Birch first described the diatomaceous mud belt and phosphatic sands of the Southern African West and Southern Coastlines in the 1970s.

- The approach to the of assessment of water column and sediment biogeochemistry undertaken by Lwandle Technologies (Pty) Ltd was undertaken with guidance of [6]Dr Pedro Monteiro, CSIR Stellenbosch.

2. Independent External Review: Assessment of Processes followed during the verification programme

The methods and approach to the Verification Programme have been independent assessed by the University of Namibia, represented by [7]Dr Samuel Mafwila.

3. Independent Programme Reviewer and Process Quality Control: Verification Programme Report

The entire verification programme report, environmental compliance and verification process has been independently reviewed by the CSIR, represented by [8]Mr. Patrick Morant.

---

[2] A&B Word Ltd, 12 Hill Farm Road, Halesworth, Suffolk, UK. *email*: ailpayne@hotmail.com
[3] Marine Ecosystems Management, Cluain Na Si, Kinvara, Go. Galway, IRE. *email*: otoole.mick@gmail.com
[4] Anchor Environmental, 8, Steenberg House, Silverwood Close, Tokai, RSA.
email: barry@anchorenvironmental.co.za
[5] 57 Pienaar Street, Somerset West, RSA. *email*: roy@sun.ac.za
[6] NRE Research Fellow, CSIR, 11 Jan Celliers Street, Stellenbosch, RSA. *email*: pmsmonteiro@csir.co.za
[7] University of Namibia, Department of Fisheries and Aquatic Science, Faculty of Agriculture and Natural Resources, 30 Mandume Ndemufayo Avenue, Pionierspark, Windhoek, Namibia.
email: smafwila@unam.na

© NMP 2014

Executive Summary

The formal review of Namibian Marine Phosphate's Environmental Impact Assessment (EIA), undertaken through the auspices of the Environmental Commissioner, determined that the assessed impacts required verification by additional site-specific data. A formal Verification Programme was planned and executed to meet this requirement and is documented in this report.

Verification Programme

The 2013 – 2014 Verification Programme reported upon in this document focuses on the primary target dredge site SP-1 (of Mining Licence 170). The programme has both substantiated and significantly raised the confidence levels of the findings presented in the EIA (2012) such that ***"The opinion of the specialists and the independent reviewer is that there are presently no identified issues of environmental significance to preclude the dredging of phosphate-enriched sediments from the Mining Licence Area No. 170***" is now confirmed with a high degree of scientific confidence***.***

The above statement contained in the EIA (2012) has been substantiated through a multi-disciplinary investigations (and reviews) of the biogeochemical and fisheries environment, based on site-specific data collected from in and around the SP-1 target dredge site. The levels of confidence in the analyses and results of the Verification Programme are high.

A key statement made by the Southern African Institute for Environmental Assessment, which was appointed to review the EIA (2012) concluded, with respect to the Verification Programme described in the Environmental Management Plan, that: "*I have no doubt that if these survey activities are undertaken and the parameters listed are sampled and monitored, sufficient data would be collected and processes to allow for the verification of the impact assessment studies and assumptions. These data will establish useful baselines from which further monitoring activities can be undertaken after any of the proposed dredging cycles have been completed".* In line with this recommendation the proponent (NMP) elected to commission the verification study to achieve this objective, following further engagement and consultation with authorities and key I&APs. These discussions resulted in an expanded Verification Programme being undertaken.

The Verification Programme was included as part of the management plan submitted to the authorities in the project EIA (2012). The programme was designed on the basis of recommendations from the specialists, specifically to increase the levels of confidence in their impact assessments EIA (2012). The Verification Programme, to be completed prior to the commencement of dredging, comprised a programme of *in situ* sampling and measurement, complemented by laboratory analyses and interpretation.

To enhance the independence, robustness, transparency and validity of the Verification Programme and its processes additional tiers of external review have been introduced into the Verification Programme process management control, these are:

[8] CSIR: Consulting and Analytical Services – Environmental Management Services, 11 Jan Celliers Street, Stellenbosch, RSA. *email:* pmorant@csir.co.za

© NMP 2014

A panel of four internationally recognised scientists with specific expertise in the Benguela Current Large Marine Ecosystem were commissioned to conduct a peer of the specialist studies completed during the Verification Programme. The independent peer review team co-ordinated by Dr A.I. L Payne stated:

> *"To conclude, the review team is impressed by the quality of the information provided to it and believes that all avenues and disciplines of concern relating to the proposed operation in SP-1 have been addressed adequately. The policy decision on whether to proceed is a national one, but we (peer review team) can say that the information provided to us has convinced us that everything points to there being a minimal impact of the proposed operation, should a licence be granted, to the Namibian shelf ecosystem".*

The University of Namibia was commissioned to act as an observer during the programme's filed and laboratory activities to provide an independent Namibian review of the Verification Programme's technical and operational practices. The reviewer states:

> *"As a UNAM representative in this whole verification programme, I am of the conviction that NMP has thus far conducted the most comprehensive scientific studies in their MLA. These studies have addressed uncertainties that were raised by the MFMR and beyond. New data sets were generated and new insights about the area have been brought forth, and improved our understanding of the physical, chemical and biological nature and dynamics of the area, and what would be the potential impacts of dredging. It is imperative to continue with monitoring surveys in the MLA, (detailed in the EMP) in order to support the current assumptions and statements. However, in the regional context, the monitoring of the state of the environment should be a concerted combined effort by government and mining companies".*

The CSIR provided review and process control functions for the compilation of the EIA (2012). These services were extended to cover the entire work programme of the Verification Programme. Mr P. Morant, the CSIR's appointed representative, provides a review of the Verification Programme report. J Midgley and Associates were re-appointed to project manage the Verification Programme having provided the same services to the EIA (2012).

Background

NMP has applied to recover phosphatic sediments from the seabed on the Namibian continental shelf. Following an extensive exploration programme, a marine mining licence was issued by the Ministry of Mines and Energy (MME) in July 2011 subject to an Environment Impact Assessment being undertaken and approved prior to commencement of operations. In compliance with the conditions of the Mining Licence for ML 170, NMP then completed and submitted the project EIA (2012). The project EIA was initiated prior to the promulgation of the regulations under the Environmental Management Act No. 7 of 2007 (Gazette No. 4878, 6 February 2012). However, the EIA was undertaken in general accordance with the provisions of the Act and Regulations, including the mandatory public scoping and review processes.

The Sandpiper marine phosphate project (ML 170) is located on the Namibian continental shelf approximately 120 km south southwest of Walvis Bay (Figure 1). The eastern boundary of the Mining Licence Area is approximately 60 km off the coast directly west of Conception Bay. The water depths in the licence area range from 180 to 300 m.

© NMP 2014

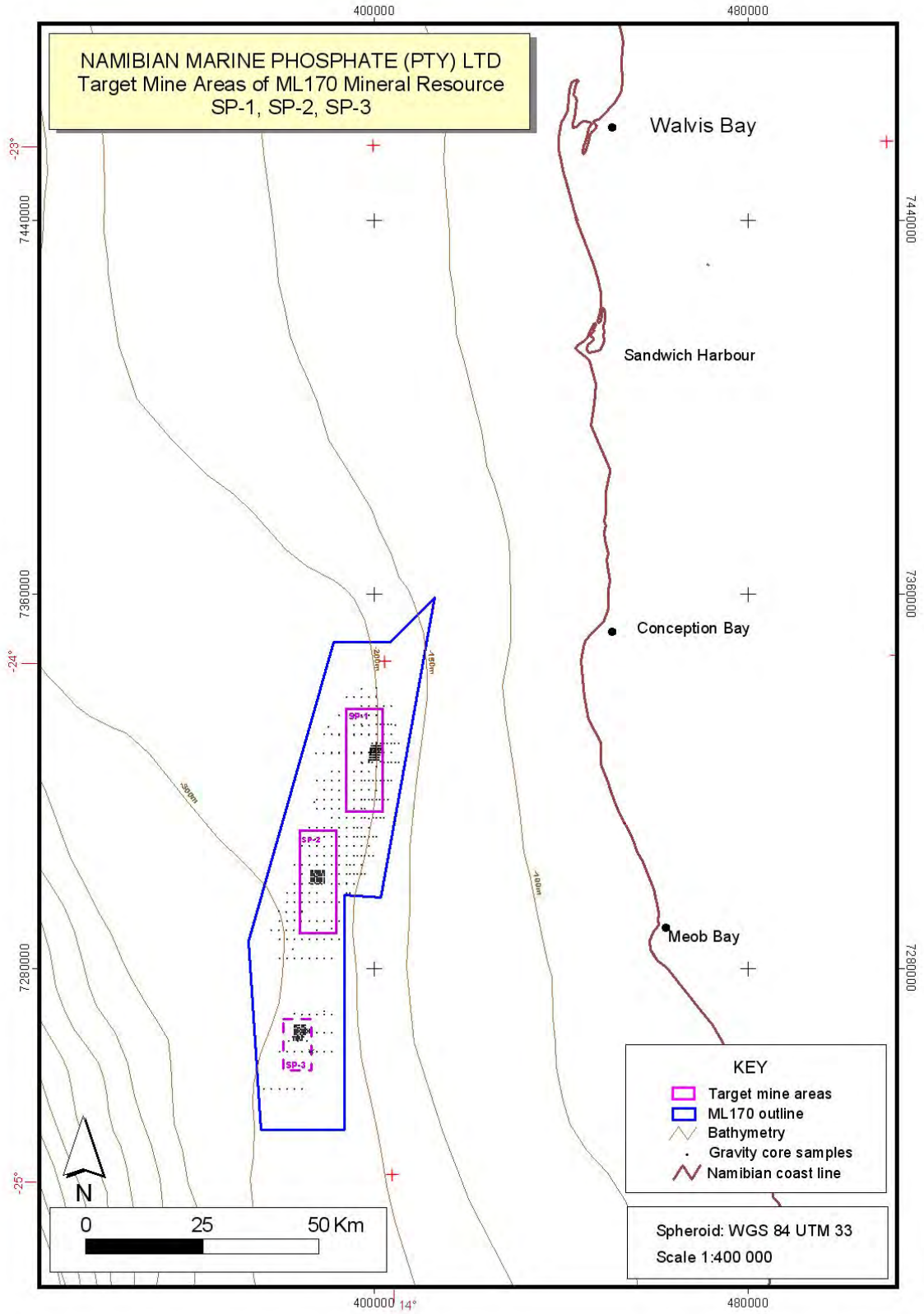


Figure 1: Location of ML 170, showing primary dredge target SP-1

© NMP 2014

Operations Overview

The phosphate-enriched sediments and defined mineral resources are located throughout the entire area of ML 170. Within the licence area, three mineral-rich dredging areas have been identified, SP-1, SP-2 and SP-3 (Figure 1). The primary target dredge site for the 20-year licence period is SP-1, which lies in water depths of 200 to 225 m. A trailing suction hopper dredger (Figure 2) will be used to recover approximately 5.5 million tons of phosphate-rich sediment annually from an area of up to 3 km^2 in extent. A total of approximately 60 km^2 will be dredged over the 20-year mine licence period.

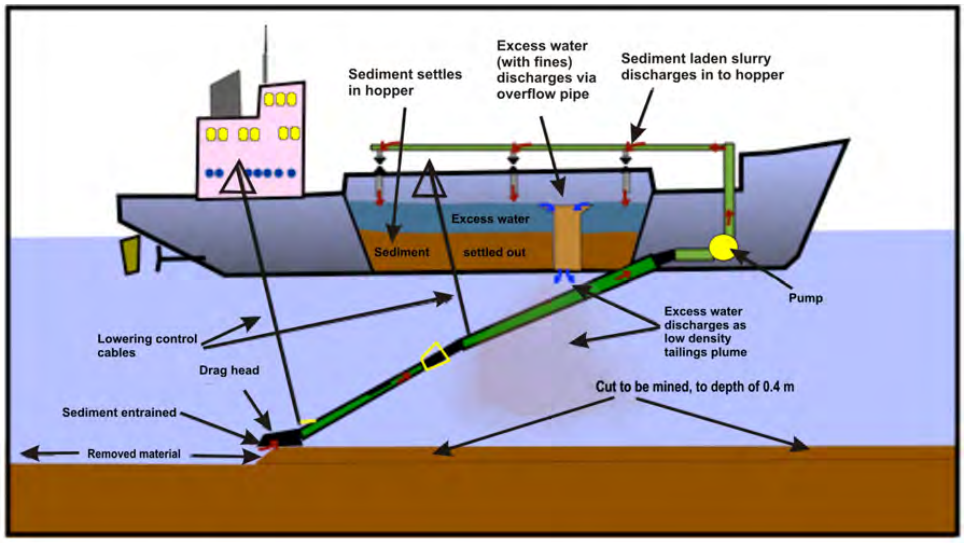


Figure 2: A schematic of a Trailing Hopper Suction Dredger (TSHD).

Scale of the Project

The Mining Licence Area is 25.2 km wide and 115 km long. ML 170 is 2233 km^2 in extent, representing approximately 2% of the Namibian continental shelf area (110 000 km^2)[9]. Within ML 170, the SP-1 target area is 176 km^2 (0.16%) of the total shelf area. Within SP-1 up to 60 km^2 representing 0.06% of the total shelf area, and 2.7% of ML 170 area will be dredged during the 20-year mining licence period. The 3 km^2 annual dredge area represents 0.003% of the total shelf area and 0.13% of the total ML 170 area.

Table 1: The proportions of the Namibian continental shelf, ML 170 and SP-1 affected by the proposed dredging project.

	Continental Shelf	ML 170	SP-1	20 year Mine Plan	Annual Area
Area (km^2)	110000	2233	176	60	3
% ML area		100.%	7.88%	2.69%	0.13%
% Shelf area	100.000%	2.030%	0.160%	0.055%	0.003%

[9] Molloy, F and Reinikaine, T (eds.) 2003. *Namibia's Marine Environment.* Windhoek, Directorate of Environmental Affairs, Ministry of Environment and Tourism. 166pp

EIA Submission and the Verification Programme

The impact assessments contained in the EIA (2012) were considered by the specialists to be robust and established to acceptable levels of confidence. Given that no significant risks that would preclude the project from proceeding had been identified, the EIA was submitted to the Ministry of Environment and Tourism (MET) with the request that an Environmental Clearance Certificate be issued in order that project development could proceed.

The Environmental Commissioner engaged independent external reviewers to assess the EIA (2012). The reviewers identified that the conclusions of the report were unsubstantiated, in that the assessment of impacts were presented largely against regional data extrapolated to the mine site and not based on site-specific data. In general the reviewers supported the recommendations of the EIA (2012) specialists as presented in the EMP (2012), i.e. requiring a verification survey to be undertaken prior to project commencement.

The Verification Programme as detailed in the EMP (2012) was expanded in response to the concerns raised by the Ministry of Fisheries and Marine Resources (MFMR), MET (and the external reviewers), representatives of the fishing industry, I&APs and the Chamber of Mines. The expanded Verification Programme was submitted to the authorities in December 2012.

The Verification Programme reported herein presents the results of the various specialist studies completed during 2013 and 2014. These studies provide evidence supporting the findings of the impact assessments contained in the EIA (2012). The Verification Programme focuses specifically on the primary target dredge site, SP-1, located within the northern portion of ML 170. The Verification Programme was designed to address the potential impacts of the dredging operation at a number of scales, namely within SP-1, within ML 170 and on the ecosystem as a whole.

Specialist Studies

The Verification Programme consisted of multi-disciplinary specialist investigations, undertaken by established consultancies and academic institutions. The findings presented in the specialists' studies were determined from site-specific data collected from in and around the target dredge site SP-1 during 2013 and 2014. The field data were collected during a number of dedicated ship-based surveys and a 90-day instrument deployment (mooring) to characterise the water column and sediments of the licence area. These surveys included a biogeochemical survey of the water column and sediments (including the collection of meio- and macrofauna), core and thiobacteria sampling surveys, and a biodiversity survey using a chartered monkfish trawler, deploying standard commercial gear with a modified (fine-meshed) cod end to collect epibenthic fauna. A geophysical survey was also undertaken over the northern portion of SP-1. The location and extent of the sample coverage for the Verification Programme is shown in Figure 3. The specialist reports were peer reviewed.

© NMP 2014

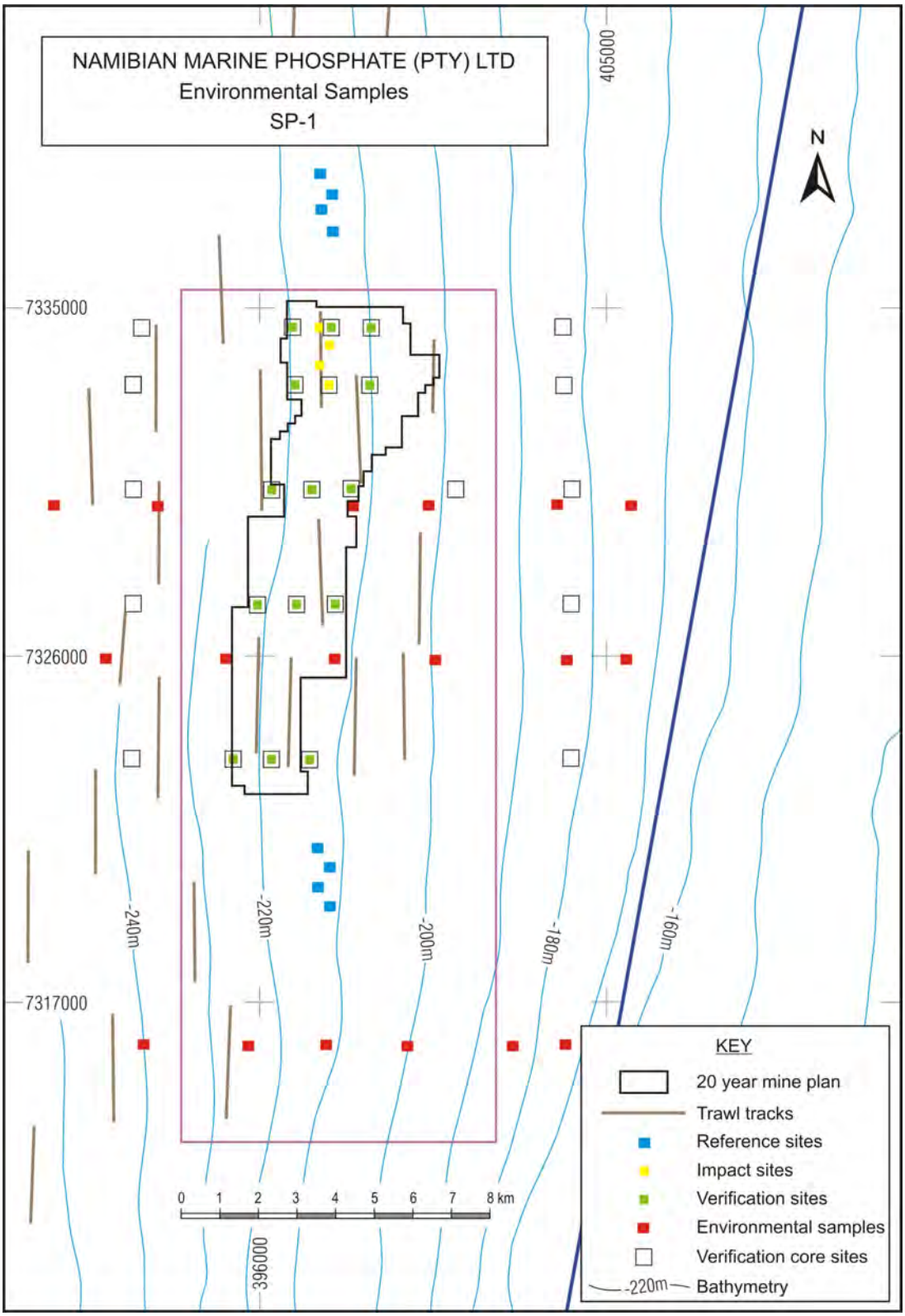


Figure 3: Distribution of the sampling sites of the Verification Programme across the target dredge area SP-1

© NMP 2014

Age and origin of the phosphorite deposits

The age and origin of the phosphorite deposits of ML 170 has been determined by analysis of sediment cores combined with strontium-36 isotope dating. These deposits formed over millions of years, initially by marine algae growing in the highly productive surface waters, dying and sinking to the seafloor where the organic phosphorus contained in the algal cells was incorporated into the mineral carbonate fluorapatite or francolite. Phosphorite grains were concentrated through repeated erosion of the sediment through wave and current activity during sea level lows. The repeated formation and reworking of these deposits has led to a highly enriched phosphorite deposit occurring in areas of the uppermost 2 m of the present day seabed on the Namibian continental shelf, and particularly in ML 170.

The basal phosphorite muddy sand varies from 0.5 to 1.5 m in thickness. The phosphorite grains formed predominantly during the early Pleistocene (2.6 to 1 Ma), and the deposit formed during the early to middle Pleistocene (2.6 to 0.126 Ma). This is overlain by increasingly shelly phosphorite sand of variably 0.5 to 1.5 m thickness, containing 65 to 86 wt% sand and 4-5 wt% mud. The phosphorite is diluted by shell fragments, particular the upper layer. The upper sediment profile displays multiple erosional surfaces formed during sea-level low stands that occurred during the various glacial maxima since 1 Ma. These findings are new to science and provide a robust understanding of the origins and age of the Sandpiper phosphate deposit.

Water Column and Sediments

The evidence gained from the verification survey on the balance of the issues of concern and queries raised by the authorities, reviewers and I&APs, support the assessment of impacts detailed in the EIA (2012).

The measured **currents** reflected consistent northwest (equatorward) flow in the near surface depths, switching between northwest and southward (poleward) flow at mid-depth and near the seabed a period of sustained poleward flow followed by switching between poleward and equatorward flows. The time series measurements at mid-depth were not available at the time of the EIA (2012) and the verification measurements represent new detail for the region. Notable is the fact that seabed current velocities are higher than the <10 cm/s reported in the EIA (2012). In the short-term, velocities ~30 cm/s were recorded at the mooring implying considerable turbulence at the seafloor.

Current velocity data show that most of the variability was in longer period (>3 day) fluctuations with inertial and tidal periods also being important. Lunar tides that were not identified in the data set had been invoked as the probable mechanism preventing accumulation of pelagically produced particulate matter (POM) in mid-shelf sediments immediately offshore of the mud belt. Even in the absence of such a mechanism, however, the ambient current velocities measured were sufficient to exert bottom shear stress forces well in excess of those required to suspend finer sedimenting particles, thereby preventing its accumulation in the survey area. Thus, although the mechanism that was invoked in the EIA was not demonstrated here, the consequences remain and coincide with the conclusions in that analysis.

The characteristics of the **water masses** present in the survey area over the period of measurement are those of the oxygen depleted, saline South Atlantic Central Water flowing south in the poleward undercurrent from the Angola gyre, and the less saline, relatively oxic Eastern South Atlantic Central Water from the Cape Basin. The influence of the latter on the ventilation of bottom water in the area is clearly evident from the temperature, salinity and dissolved oxygen time series measurements that were made.

© NMP 2014

Dissolved oxygen distributions measured during the survey showed that the upper mixed layer was normoxic and that in the sub-thermocline water oxygen concentrations decreased with depth to ~0.5 mg/ℓ. At the seafloor dissolved oxygen concentrations were generally below this (demonstrating periods of severe hypoxia which increased during ventilation events (to ~1.10 mg/ℓ).

Turbidity both in the water column and at the seabed in the presumed benthic boundary layer was typically low (~1 NTU) throughout the survey period. There was no clear association between the recorded turbidity events and current speed and direction (accelerations or switching events). The measurements support the conclusions reported in the EIA (2012) that the observed turbidity events are derived from the farfield, i.e. the nearer shore biogenic mud belt, and are advected past the ML 170 to the outer continental shelf and slope.

The surficial **sediments** are silty sand whilst the underlying sediments are primarily silt. Clay sized material was present in low proportions (<8%) in the deeper sediments only. Important aspects of the sediments were low porosity implying a firmly packed sediment with low pore water volumes and abundant shell material in the surficial and upper layers of the sediment. Both features would make the sediment body resistant to resuspension and reinforce the conclusions drawn in the EIA that local turbidity generation probably is a rare event.

Average **particulate organic matter** (POM) concentrations in the sediments of SP-1 were 7.4%, marginally higher than the upper level of 6.9% quoted in the EIA. C:N ratios in the POM were 11.4 in the surficial layers and higher at 19.8 in the underlying sediments. These ratios are indicative of refractory organic matter.

Inorganic nutrient concentrations in the sediment pore waters showed considerable enrichment of phosphorus compared with the overlying water column and there is a considerable departure from the classical Redfield ratio of 16. The phosphorus level is attributed to enrichment from the pelletal phosphate ore body. Pore water volumes are low, due to the low sediment porosity, and therefore significant modifications to upper water column Redfield ratios through translocation of pore water to the surface are not expected to occur.

Investigation of the **oxidative state** of the sediments included measurement of oxidation reduction potential, nitrate-nitrogen, and acid volatile sulphide (AVS). ORP was moderately high (> 0 ± 100 mv) throughout all of the sediment core samples implying that they were hypoxic. The presence of nitrate-nitrogen in the sediment pore water supports this as it converts to ammonia in anoxic conditions. AVS was below detection levels in the surficial sediments and averaged <2 mMol/kg in the subsurface layers. The absence of AVS is consistent with hypoxia as free sulphide is oxidized to sulphate ($SO4^{2-}$) in the presence of oxygen. This implies that the surficial sediments were hypoxic during the period of measurement. These findings support the conclusion on sediment properties in the EIA (2012), i.e. the sediments in ML 170 were probably hypoxic and would have low sulphide fluxes associated with them.

Dissolved heavy metal concentrations in the water column were close to or below the detection limits of the analytical procedures used. This is expected for a survey area that is distant from any industrial sources of such metals. Nutrient concentrations measured were within those recorded for the region and Redfield ratios (Molar N/P) averaged 17.71. This is marginally higher than the classical 16:1 and may be attributable to a minor nitrate-nitrogen enrichment. Both of these findings support the general contention of the EIA (2012) that water quality in the region of the survey area is at or close to its natural state.

© NMP 2014

Heavy metal concentrations in both surficial and subsurface sediments reflect relatively high concentrations of arsenic, cadmium, chromium, copper and nickel. High concentrations of cadmium and nickel were predicted in the EIA (2012). The bioavailability of these heavy metals in the dissolved phase was investigated by elutriation tests and negligible proportions were released. The low release of the metals into the dissolved phase indicates that, although their natural concentrations exceeded the BCLME sediment quality guidelines, they do not represent a toxicity risk either *in situ* or following physical disturbance in this phase.

Heavy metal concentrations of the Namibian continental shelf sediments are characterised by elevated cadmium concentrations and, although no empirical data could be sourced for this, it is probable that resident demersal fish such as hake and monkfish on the entire Namibian continental shelf would naturally have elevated cadmium concentrations in their livers. Consequentially the proposed NMP dredging operations would not affect them. Trophic transfers of heavy metals associated with sediment plumes generated by the proposed dredging would include ingestion/take-up by planktonic copepods. This uptake of heavy metals would be interrupted at this stage partly due to the rates of digestion of food particles being longer than gut passage time thus leading to loss of metals in faecal pellets. Sinking rates of these pellets are high and the metals would be returned rapidly (hours to days) to the seafloor.

Benthic meiofauna and macrofauna

Benthic meiofauna and macrofauna were abundant in the surficial sediments in the survey area. This is consistent with a mainly hypoxic sediment environment and inconsistent with sulphidic sediments. The relative abundance of benthic macrofauna in the >1 000 µm size class indicates that this condition is persistent as (*Para*)*Prionospio*, which formed a large proportion of the fauna, has a life cycle of 1-2 years and *Diopatra* sp. may be as long-lived. This is consistent with a stable sedimentary environment even though the overlying water body may undergo seasonal changes in terms of its oxygen content with varying contributions of Cape Basin and Tropical Atlantic Central Water. The macrofauna of ML 170 has a larger geographical distribution and/or has been recorded elsewhere from the Namibian and/or South African west coast.

Thiobacteria

The investigation into sulphur bacteria indicated sulphide fluxes were probably low as the large sulphate bacteria, namely from the genera *Thiomargarita*, *Beggiatoa* and *Thioploca*, which play a significant roles in the oxidisation of H_2S were absent from the bacterial assemblages collected. Smaller forms including *Thiobacillus* spp. with relatively lower growth yields were present.

Plankton

The oceanographic environment off Namibia is dynamic and is primarily defined by the Benguela Current upwelling system supporting a productive ecosystem with a high abundance of phytoplankton, zooplankton and ichthyoplankton species. Within the Lüderitz upwelling cell species abundance is low, but further north off the central Namibian coast where ML 170 is located, is a transitional zone between the southern and northern regions of the Benguela ecosystem where species abundance increases. Species abundance tends to decrease further offshore which is important since the proposed dredging site is located 60 km offshore. The species present in the vicinity of the ML 170 area are ubiquitous in the region.

© NMP 2014

Phytoplankton communities in the area are dominated by diatoms and the majority of species present are found elsewhere in the world's oceans. Diatoms occur primarily within inshore waters, with biomass decreasing steadily seawards. The phytoplankton species found within the vicinity of ML 170 are, therefore, not only ubiquitous but also occur in decreased abundance in comparison with inshore waters.

Zooplankton communities in the central Namibian region are dominated by copepods that are not unique to the area. In contrast to the phytoplankton, the zooplankton is found slightly further offshore, where abundance peaks on the shelf-break at depths of approximately 200 m. The proposed dredging activity is located in water depths of 200 to 225 m, and so an increased abundance of zooplankton will be present. However, the species present will not be unique to the area.

Central Namibian waters support several commercial fisheries, with sardine, anchovy, hake and horse mackerel being particularly important. The **ichthyoplankton** of these species found off central Namibia plays a pivotal role in recruitment to the fisheries, and are especially important in the light of the current depleted state of the sardine and anchovy fisheries. Generally, however, fish off the Namibian coast spawn in inshore waters north of Walvis Bay. Therefore, the proposed mining area off central Namibia is not within any important spawning or nursery grounds, particularly for the commercially important fish species.

Overall, although the waters off central Namibia are productive and support large communities of plankton, the proposed dredging site does not occur within any identifiably important area for phytoplankton, zooplankton or ichthyoplankton growth and development.

Plume Modelling

An independent review of the characterisation of the dredge plume by the CSIR indicates that it is possible *(but not certain)* that the actual plume dimensions may exceed the dimensions reported in the EIA (2012) (i.e. plume dimensions may be up to 2 to 5 times larger than indicated). However, the implication of these potentially increased plume dimensions for the overall impact assessment is limited. It is not expected that these *possible*, but modest, changes in the impacted area will materially affect the environmental decision-making for this project. A modelling approach has been recommended in terms of providing greater certainty on the behaviour, extent and duration of the sediment discharge charge plumes. This will be undertaken prior to dredging (base case) and during dredging (operational case), forming part of the monitoring commitments.

Fish, Mammals and Seabirds

The trawl survey showed that the size distribution of the main commercial fish species likely to be impacted (i.e. monk and hake) are consistent with what is known and with what was assumed in the EIA (2012). There is no evidence of unique spawning and recruitment characteristics in ML 170. The abundance of juvenile and pre-recruiting Cape hake is consistent with what is known. Further, the proportions of juveniles and sex ratios (males and females) suggests no irregularities that would establish the dredge area as unique. With regard to monkfish, as expected, the verification survey shows a mix of juveniles, adults and pre-recruiting fish. As the survey used monk-directed gear with a cod-end liner (20 mm mesh) to retain as much as possible, the proportion of juvenile fish caught was higher than would be expected. Both the verification survey outputs and the biomass estimates for SP-1 confirm that the limited extent of the dredging (in particular SP-1) is likely to have only a very small impact relative to the overall abundance of the monk and hake stocks in Namibian waters. The impact in

© NMP 2014

SP-1 on monk reproduction and the recruitment to the commercial fishery as a whole will also be minimal. Sole were also caught in the verification survey, however their abundance was not high. Furthermore, predominantly large sole were caught suggesting that the SP-1 area and adjacent grounds are unlikely to be a significant recruiting area for sole to the monk trawl fishery. The Verification Programme for the fish, mammals and seabirds confirmed the core assumptions of the EIA (2012), confidence levels of the impact assessments are now reported as high.

Fish, Mammals and Seabirds: Verification Activities

The Verification Programme component for fish, fisheries and biodiversity consisted of two modelling studies, a review of ecosystem modelling and its application to ML 170, and a biodiversity (monk trawl) survey. The findings of these assessments included:

1. A modeling assessment of **fisheries biomass** in SP-1 and the MLA concluded that less than 0.2% of the biomass of *Merluccius capensis, M paradoxus* and *Lophius vomerinus* lies directly within the proposed SP-1 dredge site, also the site makes no significant contribution to recruitment or spawner stock biomass for the species considered. Outside of SP-1 but still within the total MLA, the biomass of monk expected to contribute to the fishery recruitment was estimated to be 7%. It was emphasized that the broader impact, however, is likely to be negligible as the proportion of the potential biomass of hake and monk in SP-1 and recruiting to the commercial fisheries in the adjacent areas is extremely small when extrapolated beyond the actual area (a 60 km^2 portion of SP-1, (176 km^2)) to be dredged.

2. A modeling assessment of the **reproductive dynamics** of the main commercial fish species was undertaken. The stock structure and gonad maturation of the main commercial species from NatMIRC data showed that there were no special characteristics of their reproductive dynamics in the proposed dredging area (SP-1). Further, the study showed that there was no deviation expected that would make the area unique with respect to these reproductive biological characteristics. The study also considered cohorts for all the species analysed and showed that a mix of small and large fish for most of the Namibian EEZ was typical and that for the MLA there were no indications of any deviation from this norm. In addition the study showed that the MLA was not a unique spawning area that supported significantly different levels of recruitment of the main commercial species to the fisheries in the proximity of the MLA. Monthly trends also did not indicate any gonad development beyond “maturing stage” of the commercial species found in the MLA. This supported the suggestion that fish move in and out of such grounds over time. Annual maturity trends have also not shown repeated dynamics, implying that spawning grounds for these species are not localized. Multiple cohorts observed per year and by area suggest that high and low recruitment events are a normal occurrence. This again indicated the lack of a “homing behaviour” for adults, with the boundaries for recruitment and spawning grounds not clearly defined.

3. The review of the possible **ecosystem impacts** of dredging within the broader northern Benguela system concluded that the combination of the high uncertainty typically associated with projections by ecosystem models and the small area that will be affected by the proposed dredging means that it is unlikely that ecosystem modelling would expose any unexpected or highly significant threats that have not already been considered and evaluated in the specialist studies.

© NMP 2014

Biodiversity Trawl Survey

The field component of the fish, mammals and seabirds study was an eight-day (June 2014) biodiversity survey of the proposed target dredge area (SP-1). A commercial monkfish trawler, the FV *Zeearend,* was chartered to sample 24 stations in and around the SP-1 target dredge area in water depths greater than 200 m.

A total of 14 fish species including two squid species (*Todarodes angolensis* and *Todaropsis sagittatus*) and one shark (*Hexanchus griseus*) was identified. Cape hake dominated the catch, amounting to 40% of the total fish weight. This was followed by monkfish, 35%, rat tail (*Coelorinchus simorynchus*) 14%, West Coast sole 3%, bearded goby 2%, and horse mackerel 0.4% of the total fish catch. Cape hake, monkfish and gobies were found in most of the trawls and there was little variation in the catches of commercial species throughout the survey area.

The survey provided baseline data on biodiversity. In general fish diversity was lower than reported in the EIA (2012). This is probably due to the fact that in the EIA (2012) data on fish diversity were consolidated from surveys using different gear types (hake, monk, midwater, purse seine). The fauna recorded in the verification survey was notably less abundant than reported in the EIA (2012) since the verification survey deployed dedicated monk trawl gear, no inference from it can be made regarding the availability and abundance of non-demersal species such as horse mackerel, sardine, mesopelagics and gobies (noting that both gobies and horse mackerel were, however, present in small numbers).

Fifteen species of seabird were recorded during the survey, of which 45% were White-chinned Petrel (*Procellaria aequinoactialis*), 20% Subantarctic Skua (*Catharacta antarctica*) and 12% Black-browed Albatross (*Thalassarche melanophrys*).

Only two species of marine mammals were observed during the survey, the Cape fur seal (*Arctocephalus pusillus pusillus*) and the dusky dolphin (*Lagenorhynchus obscurus*).

With respect to demersal fish species mammals and seabirds, no unique features were noted and the results are consistent with the initial assessment in the EIA (2012) (recognising that the abundance of some species, particularly sea birds and mammals will vary seasonally as well as spatially). Regarding mesopelagic species, none was recorded in the trawl catches. Mesopelagic species such as lantern fish are expected in the mid-water, however the gear used would not have targeted these species. Catches between night and day varied as expected i.e. normal diurnal behavioral patterns prevail with regard to fish and crustaceans.

In all, 14 taxa of epifauna were collected by the bottom trawl, including crabs, ascidians (sea squirts), brown sponges, sea pens, mantis shrimps, starfish and whelks. The colonial ascidian (*Molgula* sp.) was numerically the most dominant bottom living organism, contributing up to 60% of the epifauna catch weight during the survey. This was followed by the pennate sea pens (family Veretellidae), which made up 37%. Both these groups were found widely distributed over the area surveyed. Jellyfish, particularly *Chrysaora fulgidia* were also abundant in all trawl catches. With respect to epifauna, the high abundance of ascidians was notable. Their abundance may in part be due to the historically very low density of trawling of the region and in particular in SP-1.

Hydrological data collected during the survey indicated a well-mixed layer of South Atlantic Central Water with typical winter values for temperature and salinity and low oxygen levels near the seafloor.

© NMP 2014

Habitat

Interpretation of the geophysical data conclusively demonstrated a flat, smooth seafloor with a homogeneous surficial sediment cover across the northern part of SP-1. No protruding obstacles (rocks and reefs) were observed. The homogeneity of the meiofauna and macrofauna assemblages reflects the homogeneous nature of the seafloor in SP-1.

Noise

A literature-based assessment of the potential impacts of sound from dredging vessels on a variety of species showed that sound levels in all cases are well below those known to cause damage to marine life.

Ecosystem

With regard to ecosystem impacts as a whole, the survey suggests that the area possesses no unique features and is consistent with the findings in the EIA (2012). The primary issue in the ecosystem context is one of scale and the area of impact (up to 3 km^2 annually and 60 km^2 for the 20-year mining lease period) is so small relative to the overall extent of the Benguela ecosystem that significant impacts on the ecosystem are unlikely.

Impact Assessment Verification

The focus of the Verification Programme was to verify, through the collection and analysis of site-specific samples and measurements, the assessments of impacts contained in the EIA (2012). Overall the level of confidence in the original assessments has been raised from medium to high. Some of the original assessments are unchanged because they were deemed to be of low or no significance with the confidence level being high. A key change with respect to the assessment of fisheries impacts is the reduction of the extent (area of influence) from that of the MLA (2233 km^2) to the specific SP-1 dredge site (176 km^2). The verification of the impacts reported in the EIA (2012) and the revised levels of confidence are presented (Tables 2 to 4).

The **cumulative effects** are addressed in the context of the numerous anthropogenic activities within the Exclusive Economic Zone (EEZ) and the responsibilities for their management. The potential cumulative effects related to the dredging project are identified. Particularly relevant comment is provided on the limited likelihood of the development of a multiplicity of marine phosphate mines on the Namibian continental shelf. This is related to market forces (world demand for phosphate) and the economic entry grade (percent of P_2O_5 in the ore) required to establish a resource. Effectively these resource bodies are limited to two areas on the Namibian continental shelf and mining licences have been issued for both.

© NMP 2014

Table 2: Water Column and Sediments: Summary of impact assessment determinations: Re-evaluated following the verification assessment.

Impact	1	2	3	4	5	6	7	8	9	10	11
Risk Area	**Vessel Operation**		**Overspill discharge**					**Seabed dredging**			
Impact	**Pollution from wastes**	**Alien spp. In ballast water**	**Turbid plume**	**H_2S toxicity at surface**	**Oxygen deficient water at surface**	**Nutrients added at surface**	**Trace/heavy-metal toxicity at surface**	**Trace-metal toxicity on seabed**	**H_2S toxicity on seabed**	**Lowered oxygen levels on seabed**	**Increase of H_2S flux.**
Extent	Dredge area	National	Dredge area	Dredge area	Dredge area	Dredge area	Dredge area	Annual Mining Area	Dredge area	Annual Mining Area	Dredge area
Duration	Very short term	Short term to permanent	Very short term	Short term	Very short term	Short term	Short term	Short term	Medium term	Medium term	Medium term.
Intensity	No lasting effect	None to serious	No lasting effect	Minor effects	No lasting effect	No lasting effect	Minor effects	Minor effects	Minor effects	Minor effects	Minor effects
Probability	Possible	Possible	Possible	Possible	Improbable	Possible	Possible	Possible	Possible	Possible	Improbable
Status	Negative	Negative	Negative	Negative	Negative	Neutral	Negative	Negative	Negative	Negative	Negative
Significance (no mitigation)	None	Can be high	Low	Low	Low	None	Low	Low	Low	Low	Low
Mitigation	System maintenance	IMP guidelines	Built in	None possible	Non	None possible	None possible	None possible	None possible	Not possible	n/a
Significance (with mitigation)	None	None	Low	Low	Low	None	Low	Low	Low	Low	Low
Confidence level 2012	High	High	High	Medium	High	Medium	Medium	Medium	Medium	High	Medium
Re-evaluated 2014 confidence level	High	High	High	High	High	High	High	High	High	High	High

© NMP 2014

Table 3: Fish Mammals and Seabirds: Summary of impact assessment determinations: Re-evaluated following the verification assessment

Impact	1	2	3	4	5
Risk Area	**Seabed dredging: Fish Mammals and Seabirds**				
Nature of the impact	Fishing operations	Ecologically important species	Recruitment of key commercial species	Biodiversity	Seabirds and Mammals
Extent 2012	MLA	MLA	MLA	MLA	MLA
Extent re assessed 2014	Specific mine site	Specific mine site	MLA	Specific mine site	Specific mine site
Duration	Long term	Permanent	Permanent	Permanent	Long term
Intensity	Serious effect	Moderate effect	Minor effect	Minor effect	Minor effect
Probability	Definite	Highly probable	Improbable	Improbable	Probable
Status (- ve of + ve)	Negative	Negative	Negative	Negative	Negative
Significance (no mitigation)	Medium	Medium	Low	Low	Medium
Significance (with mitigation)	Medium to low	Medium	Low	Low	Low
Confidence level 2012	High	Low to medium	Low to medium	Low to medium	Medium
Re-evaluated 2014 confidence level	High	High	High	High	High

© NMP 2014

Table 4: Macrofauna: Summary of impact assessment determinations: Re-evaluated following the verification assessment.

Impact	1	2	3	4	5	6	7	8	9
Risk Area	**Seabed dredging: Benthic Macrofauna**								
Nature of the impact	Sediment removal: benthos re establishment	Exploration activities and removal of benthos	Change of hydrographical conditions	Removal of sulphur oxidizing mats	*Clostridium botulinum I*	Sediment smothering benthos: Drag head	Benthos smothering: Dredge overspill plume	Nutrients added at surface: overspill plume	Increase of H_2S flux.
Extent	Dredge area	Dredge area	Specific mine site	Specific mine site	Specific mine site	Dredge area	Local to regional	Local	Local
Duration	Long term >20 years	Short term	Long term >20 years	Medium to long term	Sort term	Very short	Very short	Very short	Short term
Intensity	Moderate to serious	No lasting effects	Moderate to serious	Moderate to minor	Serious	Minor	Minor	Minor	Moderate
Probability	Definite	Probable	Probable	Improbable	Improbable	Highly probable	Probable	Possible	Probable
Status	Negative	Negative	Negative	Negative	Negative	Negative	Negative	Negative	Negative
Significance (no mitigation)	Medium	Non	Medium	Low	Low	Low	Low	Low	Low
Mitigation	Leave residual sediment layer / un mined areas	None required	Leave residual sediment layer / un mined areas	None	None	None	None	None	None
Significance (with mitigation)	Medium	None required	Low to Medium	Low	Low	None necessary	Low	Low	Low
Confidence level 2012	Medium	High	Medium	Medium	Medium	High	Medium	Medium	Medium
Re-evaluated 2014 confidence level	High	No change	High	High	No change	No change	No change	High	High

© NMP 2014

Appendices: Supporting documentation

The Verification Programme report contains six appendices each presenting substantive information that is valuable in its own right as well as serving to substantiate the assessments of the specialist studies.

There are a number of project execution plans and cruise reports that provide detail on the scope, quality management controls and activities of the four marine surveys including the related protocols for sample analysis. Of particular note is the induction module supporting the fishery and biodiversity survey. The module establishes field analysis standards for this and subsequent surveys. The standards of the surveys and analyses undertaken are favourably commented on in the review of processes (field work and measurement) provided by the University of Namibia.

The thirteen bullet point critique of the EIA (2012) by MFMR is listed. It formed the basis of engagements with the ministry and its scientists. Subsequently, along with other inputs (from authorities, appointed external review parties, the fishing industry and the I&APs) the Verification Programme as originally detailed in the EMP (2012) was expanded.

There is a summary of important project events covering the duration of the Verification Programme. This serves to indicate what was undertaken, why it was undertaken and the related commitment to achieving the objectives of the programme. Of particular importance is the record of meetings and communications with the authorities, and I&APs.

The terms of reference and abbreviated curricula vitae of the specialists, project management team and CSIR reviewer are presented. The qualifications and work experience of the project team provides further confidence in the findings of the Verification Programme report.

A brief description of the proposed dredging method and operation is presented.

Verification Study - Quality Process Control

Peer Reviews

The scientific studies of the Verification Programme were submitted for peer review. The peer review team, Dr A. Payne (lead), Dr M. O'Toole, Dr B. Clark and Professor A, Roychoudhury (internationally recognised experts in fisheries, marine ecology, benthic ecology and biogeochemistry) reviewed the specialist reports contained in the EIA (2012), those of the 2013 – 2014 verification study, and relevant supporting documentation and correspondence. This served to ensure that the review parties were prepared for the specialist presentations at the Cape Town workshop (August 2014). The independent assessment of the specialist studies by the peer review team adds significant credence to the outcomes of the Verification Programme. The peer review team's report "*Independent Peer Reviews, Verification Studies, Sandpiper Project: Namibian Marine Phosphate (Pty) Ltd, November 2014*" is an independent document. A summary of the peer review report is presented in the main body of this report.

© NMP 2014

In their findings the peer reviewers are both critical and complementary, their criticisms required additional work to be undertaken by the specialists (now completed), and modifications (addition of work commitments) to the monitoring programmes as described in the EMP (2012). Their complements related to the thoroughness of the assessments, the high standard of scientific enquiry, the technical and analytical levels of evaluation, confirming that the Verification Programme has been undertaken to international levels of competency.

The peer review team provides a number of key comments, extracts of which are presented here.

The peer review team comments on the standards of the assessments and the technical approaches:

*"Overall, the (*peer review*) team finds that the response of the client to issues raised at the earlier review of the EIA through commissioning appropriate verification studies has been appropriate and laudable. The quality of those verification studies is covered elsewhere in this report, but collectively and independently, they have been carried out to the highest scientific and technical standards, using appropriate and up-to-date methodology. The results have almost without fail raised the level of confidence associated with the results in terms of likely impacts (detailed in the EIA (2012)), and the (*peer review*) team wholeheartedly confirms those analyses".*

The peer review team comments on the management framework with its commitment to ongoing monitoring:

"Future monitoring of all key aspects including an analysis of the potential impacts on the seabed and surrounding areas of the dredging operation needs to be built into any forward-looking management plan, but it will be crucial in doing so to bear in mind potential seasonal effects and the need for consistency in the methodology, gear deployed and even the vessels used".

The peer review team comments on the ingestion of trace heavy metals:

"Although the current scientific output indicates no such likelihood that it will be a problem, any potential risks arising from ingestion by fish and other fauna of trace heavy metals bound to sediment or organic matter in the water column or on the seafloor should be evaluated by means of laboratory-based sediment toxicity studies".

The peer review team recommends the establishment of a preliminary plume model:

"The water column report needs to include a preliminary model applicable to the SP-1 dredging area using data on current measurements and sediment properties that have already been collected in the vicinity, to demonstrate the distribution, dispersal and sinking rate of plume sediments. Such a model can be developed further as additional data are gathered during environmental monitoring and dredging operations".

The peer review team recommends additional assessment of the mesopelagic scattering layer:

"An in-depth analysis of the mesopelagic scattering layer in the MLA. Its presence needs to be confirmed either acoustically using a vessel echo sounder or from upward-looking ADCP instrument data moored in the area".

© NMP 2014

The peer review team, recommendations regarding the biogeochemistry of the deposit:

"The collection in future of site-specific sediment dynamics data would support a better understanding of how MLA 170 will be responding to cumulative anthropogenic and natural effects there".

"Sulphide dynamics will be important, so a better understanding needs to be sought during the operational phase of how oxygen consumption will be affected by the reduced (dredged) sediment reservoir".

The peer review team provides a primary mitigation statement:

"It is also crucial that, by way of mitigation of potential impact on the macrobenthos and to minimize the possibility of jellyfish polyps establishing in an area, a residual layer of sediment is left on the clay footwall underlying the mineral deposit. Further and if feasible, "lanes" or areas of sediment be left untouched; these two exercises will together facilitate the re-establishment of benthic macrofaunal assemblages on the substratum".

The peer review team further suggests that adaptive management:

"……..future dredging operations be authorized only within an adaptive management framework (i.e. coupled with intensive monitoring and careful scrutiny of such monitoring data by independent experts and the authorities) and that the authorities retain the right to require that the scale or scope of dredging be adjusted or that additional mitigation measures be implemented to ameliorate any unforeseen impacts that may arise".

In summary, the peer review team confirms the Verification Programme undertakings, findings, and the commitments therein. Further, they recommend as precautionary measures additional work (which has been undertaken) and monitoring requirements, detailed in the EMP (2012).

The **University of Namibia** (UNAM) was specifically engaged to provide independent review services of the Verification Programmes technical and operational practices. This agreement was formally established (May 2013) between Namibian Marine Phosphate (Pty) Ltd and the Central Consulting Bureau of the University of Namibia, with Dr S Mafwila designated to provide these services.

The reviewer comments, that not all of the concerns were dealt with by NMP, however, he acknowledges that the company "…. *has addressed the most critical ones to the best of their ability and in a more transparent and practically feasible way*".

The reviewer participated in the 10-day marine **biogeochemical survey** (July – August 2013). He attended the pre-survey induction and familiarisation presentation and took up an observer's role during the survey. He was accompanied by two UNAM fisheries students who gained valuable experience and insights into conducting scientific research at sea. He observed equipment deployment, sample recovery sample collection, packaging and storage. During this survey, an instrument-mooring buoy (configured to evaluate oceanographic dynamics) located adjacent to SP-1 in 190 metres of water, was recovered for maintenance, data downloaded and subsequently re-deployed for a further 45 days. He provides a review of the equipment used and its appropriateness. Noting that it is preferable to use the Van Veen grab as opposed to Day grab for the sampling of macrofauna, he recommends use of the latter for future monitoring. Although a multi-corer is considered preferable to the Day grab for collection of biogeochemical samples he notes, however, that multi-core devices are susceptible to poor penetration in compact sediments such as those of ML 170.

© NMP 2014

Typically, **field operations** are beset with challenges, and this instance that during the in situ measurements of oxidation-reduction potential the sediments are exposed to air, and thus these particular results may be questionable. Notwithstanding these observations, his general comments are, "*the sample handling onboard and processing was adequately conducted with care and good workmanship"*. He further notes, that: "*Reliable data were generated for both benthic macrofauna and meiofauna within the primary dredge target area of SP-1. Verification was done on the sediment characteristics, which have confirmed the area is not within a mud belt, with very little, or no Hydrogen Sulphide and organic-rich sediments'.*

The **laboratory and processing** facilities of the CSIR (Stellenbosch) and the University of the Western Cape were inspected. A favourable report is provided on the capacities of these institutions.

A review of the June 2014 **biodiversity trawl survey** (considering demersal fish biomass distribution and diversity, epibenthic fauna, and mammals and seabirds) conducted over the target dredge site SP-1 is provided. The survey was conducted from a monkfish side trawler the FV *Zeearend*, chartered from the Benguella Fishing Company. The report on the survey concludes *'the survey generated a wealth of information, the level of which is unique to the area".* The survey execution, sample processing and data reliability are regarded as high.

Finally the reviewer attended the **peer review workshop** in Cape Town during August 2014, with the primary functional role to validate the independent process. He notes that the peer review team was carefully selected and had appropriate experience and skills to evaluate the required disciplines thoroughly. It is noted that the review team had the opportunity to review the relevant documentation prior to the workshop, and that the workshop was conducted in a fair and transparent manner.

The report prepared by UNAM "*Independent Peer Reviews, Verification Studies, Sandpiper Project: Namibian Marine Phosphate (Pty) Ltd, November 2014,*" is an independent document.

Conclusion

The major concern that large quantities of **hydrogen sulphide** would be released by dredging is extremely unlikely, since the biogeochemical study has shown that, unlike the mud belt further inshore, the sediments in ML 170 do not contain significant quantities of hydrogen sulphide that could enter the water column.

The **biodiversity** survey has demonstrated that the fauna of the ML 170 area is no different from that of the wider Namibian continental shelf. The seafloor in ML 170 is remarkably uniform i.e. there is no diversity of habitats and no unique faunal communities have been identified as being present. The surficial sediment character is homogeneous.

With respect to the main **commercial fish species**, the data obtained showed that there were no special characteristics of their reproductive dynamics in ML 170 and it is not a unique spawning area that supports significantly different levels of recruitment of the main commercial species to the fisheries.

© NMP 2014

Heavy metal concentrations in both surficial and subsurface sediments reflect relatively high concentrations of arsenic, cadmium, chromium, copper and nickel. High concentrations of cadmium and nickel were predicted in the EIA. The low release of the metals into the dissolved phase indicates that although their natural concentrations exceeded the sediment quality guidelines for the region they do not represent a toxicity risk in this phase either *in situ* or following physical disturbance. The bioavailability of these heavy metals in the dissolved phase was investigated by elutriation tests and negligible proportions were released.

With regard to **ecosystem**, the surveys indicate that ML 170 possesses no unique features.

The Verification Programme has enabled the level of confidence in the original assessments made in the EIA (2012) to be raised from medium to high. The Verification Programme report and the integrated independent reviews have determined that there are no identified ecological risks of a significant nature that would preclude the project from being authorised. Ongoing monitoring of the assessed impacts is required as a mitigation, management and intervention tool, with responsibilities for this lying both with the proponent and the authorities.



J. Midgley (Pr.Sci.Nat)
Project Co-coordinator
November 2014

© NMP 2014

Contributors

The following companies / persons have contributed to this report:

Jeremy Midgley
J Midgley and Associates cc
PO Box 110 Constantia 7806 Cape Town
mwjmidg@mweb.co.za

Project Co-ordinator



Dr Robin Carter, Kate Munnik, Laura Weston
Lwandle Marine Environmental Services (Pty) Ltd
Old Warehouse, Fir Road Observatory Cape Town
Robin@lwandle.co.za

Water Column and Sediments

Dave Japp, Melanie Smith, Dr Kevern Cochrane,
James Gaylard, Dr Hilkka Ndjaula
Capricorn Fisheries Monitoring cc
Unit 15 Foregate Square, Table Bay Boulevard, Foreshore
Cape Town
dave@capfish.co.za

Fish, Fishery and Biodiversity

Dr Nina Steffani
Steffani Marine Environmental Consulting
21 Skippers End, Zeekoevlei Cape Town
nina@steffanienviro.co.za

Benthic Macrofauna

Timothy McClurg
KZN Costal Impact Consultants
PO Box 230, Kloof, Kwazulu Natal
mcclurgs@telkomsa.net

Epifauna

Roy Van Ballegooyen
CSIR
11 Jan Celliers Street, Stellenbosch
RvBalleg@csir.co.za

Plume Modelling

Dr Bronwen Kirby
Department of Biotechnology:
University of the Western Cape
Robert Sobukwe Road Bellville Cape Town
bkirby@uwc.ac.za

Thiobacteria assessment

Gordon Rigg
Marine Data Consultants
1A Carlton Close, Sun Valley Cape Town
gordon.rigg@marinedataconsultants.co.za

Geophysics Interpretation

Bruce Spolander, Sanette Gildenhuys
Metocean Services International
Unit 13 Constantia Business Park, 31 Princess Vlei Road
Diep River Cape Town
Bruce@metoceanservices.com

Oceanographic deployments and monitoring

Dr Simon Forster
Physalia Ltd
Little Pook Hill, Heathfield Road, Burwash Weald
Etchingham East Sussex UK
Simon.forster@physalia.demon.co.uk

Meiofauna

Jeremy Midgley
J Midgley and Associates cc
PO Box 110 Constantia 7806 Cape Town
mwjmidg@mweb.co.za

Habitat Mapping

© NMP 2014

Approval

Title	Sandpiper Project, Verification Programme, Volume 1: Main Report, Namibian Marine Phosphate (Pty) Ltd Mining Licence Area No. 170.	
Date	November 2014	
Prepared for	Namibian Marine Phosphate (Pty) Ltd 127 Theo-Ben Gurirab Street Walvis Bay: Tel + 264 64 278 150 Fax + 264 64 855 8000 13	
Prepared by	J Midgley & Associates, Po Box 110 Constantia 7806 Cape Town South Africa.	
Project coordinator	Mr. Jeremy Midgley (MSc) (Pr.Sci.Nat)	
Verification Programme report review	CSIR. Mr Patrick Morant (MSc) (Pr.Sci.Nat)	
External review: Specialist reports	Prof. A. Roychoundhury, Dr A. Payne, Dr M. O'Toole, Dr B. Clark (Dr A. Payne coordinating party)	
External review: Technical and operational practices	University of Namibia: Dr S Mafwila	
Application	This report has been prepared to verify the findings of the NMP Final EIA (Midgley 2012), as submitted to the Ministry of Environment and Tourism. The need for, and scope of, the Verification Programme was detailed in the EMP (Midgley 2012), The scope subsequently was expanded following consultations with MFMR, NatMIRC scientists and Fishing Industry (I&APs).	
Report preparation	**J Midgley & Associates** Mr. Jeremy Midgley (Pr.Sci.Nat) *Date: November 2014 Signature:*	
CSIR Independent Reviewer and Process Quality Controller	**CSIR** Mr. Patrick Morant (Pr.Sci.Nat) *Date: November 2014 Signature:*	
Report acceptance	**Namibian Marine Phosphate (Pty) Ltd** Mr. Michael Woodborne (MAusIMM) *Date: November 2014 Signature:*	

© NMP 2014

Contents

Introduction to the Sandpiper Phosphate Project iii
CSIR Independent Review v
Independent Reviewers xi
Executive Summary xii
Contributors xxxiii
Approval xxxv

SECTION A: Verification Programme

A1.0 The Verification Programme
A1.1 Contents of the Verification Programme Report
A1.2 Peer Review of the Verification Programme

SECTION B: Impact Assessment Verification

B1.0 Impact Assessment Verification
B1.1 Water Column
B1.2 Fisheries, mammals and seabirds
B1.3 Macrofauna
B1.4 Jellyfish
B2.0 Cumulative Effects

SECTION C: Specialist Studies

C1.0: Geology and History of Deposit
C1.1: Preliminary Model for the Origin and age of the Sandpiper Deposit

C2.0: Water Column and Sedimentary Environment
C2.1: Water column and sediments
C2.2: Sediment plume
C2.3: Thiobacteria
C2.4: Meiofauna
C2.5: Macrobenthos
C2.6: Epifauna
C2.7: Plankton

C3.0: Fisheries and Biodiversity
C3.1: Verification Survey Report: Fish, Mammals and Seabirds
C3.2: Assessment of Fisheries Biomass and Stock Assessment
C3.3: Opinion on the Ecosystem Impacts related to Dredging of Phosphates offshore Namibia
C3.4: Reproduction Dynamics and Stock Distribution Study
C3.5: Review of the spawning activity, ichthyoplankton drift routes and the recruitment of Namibian marine fauna

Glossary

© NMP 2014

SANDPIPER PROJECT

Verification Programme Report: Mining Licence Area No. 170

SECTION A: VERIFICATION PROGRAMME

A1.0: The Verification Programme
A.1.1: Contents of the Verification Programme Report
A.1.2: Peer Review of the Verification Programme

SECTION A – VERIFICATION PROGRAMME

A1.0 The Verification Programme
A1.1 Contents of the Verification Programme Report
A1.2 Peer Review of the Verification Programme

Verification Programme (2013 – 2014)

Prepared for:
Namibian Marine Phosphate (Pty) Ltd.

Prepared by
Jeremy Midgley
Jeremy Midgley and Associates

Reviewed by
Patrick Morant
CSIR

November 2014

Primary Contributing authors:

Dr A Payne	*Peer Review*	AB Word Ltd
Dr M O'Toole	*Peer Review*	Marine Ecosystems Management
Dr B Clark	*Peer Review*	Anchor Environmental
Prof. A Roychoudhury	*Peer Review*	Specialist Review Consultant
Dr S Mafwila	*Peer Review*	University of Namibia
Dr R Carter	*NMP responses*	Lwandle Technologies (Pty) Ltd
Dr N Steffani	*NMP responses*	Steffani Marine Environmental Consulting
Mr D Japp	*NMP responses*	Capricorn Fisheries Monitoring (Pty) Ltd
Mr J Midgley	*NMP responses*	J Midgley and Associates cc

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed "Attention: Administration Manager," at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

contents

A1.0 THE VERIFICATION PROGRAMME 1

A1.1 CONTENTS OF THE VERIFICATION PROGRAMME REPORT 1

1.1.1 Introduction – the Verification Programme 1
1.1.2 Contents of the Verification Programme report 5

A1.2 PEER REVIEW OF THE VERIFICATION PROGRAMME 9

A 1.2.1 INTRODUCTION 9
A1.2.2 PEER REVIEW REPORT ON SPECIALIST STUDIES OF THE VERIFICATION PROGRAMME 10
A1.2.3 RESPONSES: EIA SPECIALISTS 17
A1.2.4 INDEPENDENT REVIEW OF THE NMP VERIFICATION PROGRAMME PROCESS 28

© NMP 2014

A1.0 THE VERIFICATION PROGRAMME

A1.1 CONTENTS OF THE VERIFICATION PROGRAMME REPORT

Namibian Marine Phosphate (Pty) Ltd (NMP) has applied to recover phosphatic sediments from the seabed on the Namibian continental shelf. Following an extensive exploration programme a mining licence (ML 170) was issued by the Ministry of Mines and Energy (MME) on the 13 July 2011 with the standard conditions requiring the issue of an Environmental Clearance Certificate by Ministry of Environment and Tourism (MET) prior to commencement of operations.

The Sandpiper marine phosphate project (ML 170) is located on the Namibian continental shelf approximately 120 km south southwest of Walvis Bay (see Frontispiece). The eastern boundary of the Mining Licence Area is approximately 60 km off the coast directly west of Conception Bay. The water depths in the licence area range from 180 to 300 m. The Mining Licence Area is 25.2 km wide (greatest width) and 115 km long (longest length) and covers an area of 2233 km^2.

The phosphate-enriched sediments and the defined mineral resources and reserves, are located throughout the entire Mining Licence Area (ML 170). Within the ML 170 area, three initial target dredging areas have been identified namely SP-1, SP-2 and SP-3 (Figure 1). The primary target dredge site for the 20 year licence period is SP-1 (176 km^2) which lies in water depths of 200 to 225 m. A Trailing Suction Hopper Dredger (TSHD) (Figure 2) will be used to recover approximately 5.5 million tons of sediment annually from an area of up to 3 km^2 in extent. A total area of approximately 60 km^2 will be dredged over the course of the 20 year mine licence period. The other sites SP-2 and SP-3 also contain phosphate resources and may be considered at a later stage, at which time the requisite additional environmental evaluations will be made in accordance with the Environmental Management Act (Act No. 7) of 2007.

1.1.1 Introduction – the Verification Programme

The Environmental Management Plan (EMP) is an integral component of the Environmental Impact Assessment (EIA) submitted to the Environmental Commissioner in April 2012. The EMP becomes part of the legally binding contract with MET on issue of the Environmental Clearance Certificate. The 2012 EMP included the provision for the completion of an integrated pre-dredging impact verification survey. The survey was designed specifically by the specialists, who determined that the level of *confidence* in their assessment of impacts could be improved with additional *in situ* information. Notwithstanding this, they considered their literature-based work to be robust. The primary reason for the uncertainty related to the relatively short period in which their work was undertaken. The terms and conditions of the licence issued by (MME) required the EIA to be submitted in six months. This requirement did not allow any opportunity for fieldwork (sampling and measurement) to be undertaken.

© NMP 2014

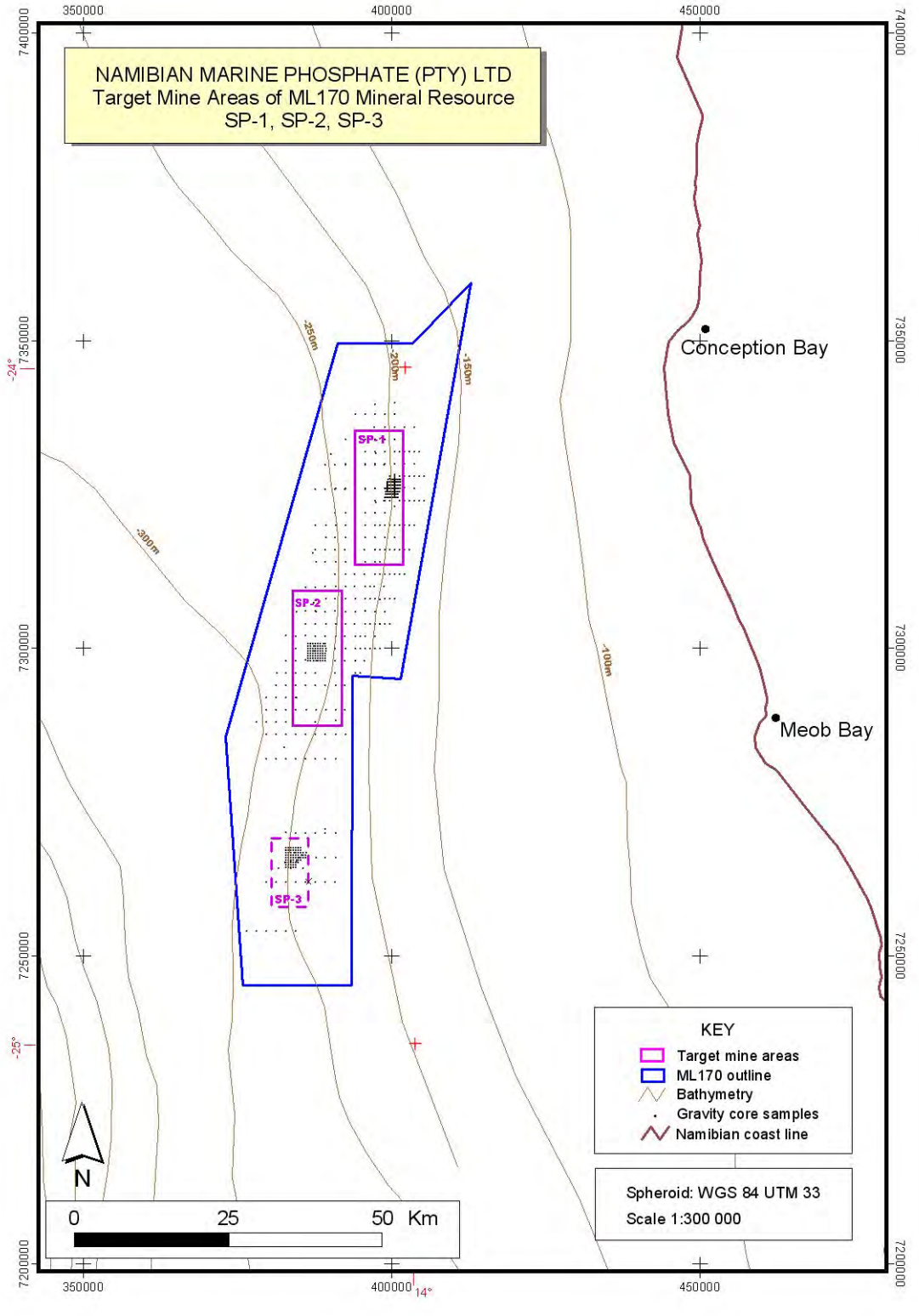


Figure 1: Location of ML 170, showing primary dredge target SP-1

© NMP 2014

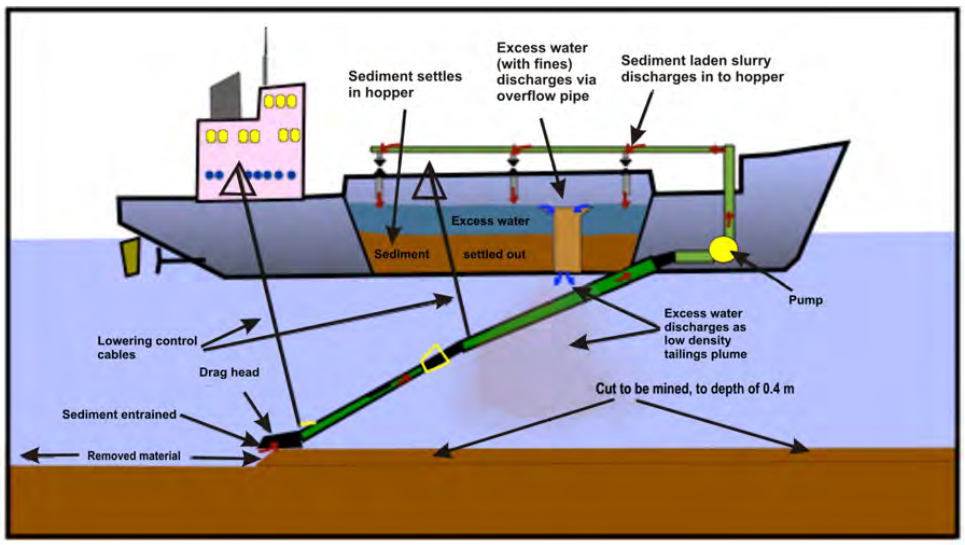


Figure 2: A schematic of a Trailing Hopper Suction Dredger (TSHD).

The 2012 EMP committed NMP to undertake the verification component of the EMP prior to the commencement of dredging, with subsequent adjustments (if required) to the monitoring and management elements of the EMP as a function of the outcomes of the Verification Programme. Given that the impact assessments in the EIA were considered to be suitably robust and had established, to acceptable levels of confidence, that there were no significant risks that would preclude the project from proceeding, the EIA was submitted to the authorities (MET), with the request that an Environmental Clearance Certificate be issued so that the project development could proceed.

During the authorities' process of reviewing the 2012 EIA, MET commissioned independent external reviews of the 2012 EIA. A key conclusion of one of the independent external review parties, the Southern African Institute for Environmental Assessment (SAIEA), was that the proposed Verification Programme was well designed and should be carried out in order to address the residual concerns around the project. The proponent, therefore, elected to follow this advice and appointed an environmental consultant team to undertake the Verification Programme.

The Verification Programme reported herein presents the results of the various specialist studies that were completed during 2013 and 2014, providing the evidence in support of the original impact assessments contained in the 2012 EIA with specific focus of the assessment of the primary target dredge site SP-1. In considering impact assessment, the scale of the proposed dredging project in the context of the mining licence area and the larger ecosystem is of particular importance. ML 170 is 2233 km^2 in extent, which represents approximately 2% of the Namibian continental shelf area (110 000 km^2)[1]. Within ML 170, the SP-1 target area is 176 km^2 or 0.16% of the total shelf area. Within SP-1 only 60 km^2 representing 0.06% of the total shelf area and 2.7% of the total ML170 area will be dredged during the 20-year mining licence period. The 3 km^2 annual dredge area represents 0.003% of the total Namibian Continental shelf area and 0.13% of the total ML 170 area. In contrast bottom trawling directly impacts approximately 30% of the Namibian continental shelf annually.

[1] Molloy, F and Reinikainen, T (eds.) 2003. *Namibia's Marine Environment.* Windhoek, Directorate of Environmental Affairs, Ministry of Environment and Tourism. 166pp

© NMP 2014

As is typical of many mining projects in the Twenty-first Century, the proposed dredging project has attracted a significant amount of environmental resistance. This is a function of several factors, including worldwide and local environmental (state of the environment) sensitivity, public access to social media and general information and the actions of pressure groups. In respect of the interaction during the statutory public engagement process and the additional consultation processes completed in 2013 as required by the Environmental Commissioner, a number of parties have provided written comment on the EIA. This feedback has contributed to an expansion of the original work scope as described in the Verification Programme detailed in the EMP (2012 EIA). This expanded scope of work was adopted by NMP following consultations with, and advice from, a number of authorities, the fishing industry, and I&APs (Section D, Appendix 4.3). These consultations included consideration of:

- The concerns of the Ministry of Fisheries and Marine Resources (MFMR), which are expressed in their communication to the Minister of Environment and Tourism, with the listing of 13 requirements (Section D, Appendix 4.2);
- The concerns of the fishing industry (as represented by their various federation spokespersons in the press and public presentations;
- The concerns of the public and I&APs;
- The matters raised by the three independent reviewers of the 2012 EIA, appointed by the Environmental Commissioner; and,
- Meetings with MFMR, NatMIRC, MET, MME and the Chamber of Mines

The key procedural and operational activities undertaken by the proponent, Namibian Marine Phosphate (Pty) Ltd in the two years from submission of the EIA in April 2012 up to the completion of this Verification Programme report in November 2014 are summarised in Section D, Appendix 4.1.

The Verification Programme focuses on the assessed impacts (2012 EIA) in the primary target dredge site SP-1.

The CSIR and J Midgley and Associates were appointed by the proponent to lead the implementation of the Verification Programme.

The CSIR undertook the overall responsibility for the quality of the Verification Programme and its compliance with the scope of work.

The proponent also commissioned the University of Namibia (UNAM) as an independent external observer to monitor the activities, procedures and quality of the activities conducted on the verification programme.

The CSIR was responsible for identifying and selecting the specialists to conduct the scientific work. This work programme comprises two main groups of studies:

1) Water column and sediments: A specialist team led by Dr R. Carter of Lwandle Technologies (Pty) Ltd. This covered: biogeochemistry (water column and sediments), fauna (macro- and meio-fauna) and plankton; and,
2) Fish, mammals and birds: A specialist team led by Mr. D. Japp of Capricorn Fisheries Monitoring cc. This covered: a biodiversity survey, a modelling assessment of fisheries biomass and stocks, ecosystem impact assessment, and a recruitment assessment.

© NMP 2014

The Verification Programme has also been reviewed independently at a number of interrelated levels. These reviews included:

- External Independent Peer review of the final individual specialist studies, undertaken by a panel of internationally acknowledged experts on the Benguela ecosystem and related fields; and,
- The University of Namibia, whose representative assessed the field work (sampling and measurements) and the subsequent chemical and biological analyses.

The reader is referred to the 2012 EIA document which contains the original impact assessment which has now been substantiated, with an overall increase in the levels of confidence in the assessed impacts by means of the Verification Programme. Appropriate content and continuity information has been integrated into the Verification Programme report so that it can be considered as a body of work in its own right. However, it should be read in conjunction with the 2012 EIA which provides valuable supporting material. Of particular relevance is the EMP (Chapter 8 of the 2012 EIA), which can now be updated following the completion of the Verification Programme.

1.1.2 Contents of the Verification Programme report

VOLUME 1: MAIN REPORT

The detail that follows provides information on the structure of the Verification Programme report which is presented in two volumes:

- **Volume 1:**
  - Summary;
  - Introduction and scene setting;
  - Impact assessment: verification of Impacts; and,
  - Specialist studies.
- **Volume 2:**
  - Appendices.

- **Executive Summary**

The executive summary provides a synthesis of the report and also reports on the independent reviews to which the report in its entirety has been subjected.

- **Section A: Verification Programme**

Section A, Chapter 1.1 provides an introduction to the Verification Programme, the reasons and need for undertaking it. The executive summaries of the independent peer reviews of the Verification Programme are presented in this section (Section A, Chapter 1.2).

- **Section B: Impact Assessment**

Section B, Chapters 1.0 to 1.4 provides a comparative assessment of the impacts as presented in the 2012 EIA and as re-evaluated following the completion of the Verification Programme. The cumulative impacts of multiple competing users of the resources in the Namibian Exclusive Economic Zone (EEZ) are discussed in Section B, Chapter 1.5.

© NMP 2014

- **Section C: Specialist Studies**

Section C comprises three main parts:

1.0 Geology and Preliminary Model for the Origin and Age of the Sandpiper Phosphate deposit;
2.0 Water Column and Sedimentary Environment; and,
3.0 Fisheries and Biodiversity.

Chapter 1.1, Geology and Preliminary Model for the Origin and Age of the Sandpiper Phosphate deposit is of major significance as it serves to establish the nature (origin and age) and characteristics of the deposit.

Chapter 2.1, Water Column and Sedimentary Environment provides a detailed biogeochemical assessment of the water column above, and the sediments in, the Sandpiper deposit. Sediments are evaluated both as surficial sediments (from the seabed) and from cores that penetrated through the phosphate-rich sand horizon to the clay footwall.

Several of the studies in Section C, Chapter 2 have been commissioned through, and in cooperation with, Lwandle Technologies (Pty) Ltd. These included: the dredge plume (Mr. R. van Ballengooyen, Coastal Research Group, CSIR), Thiobacteria (Dr B. Kirby, Next Generation Sequencing Facility Department of Biotechnology University of the Western Cape (UWC)), Meiofauna (Dr S. Forster, Physalia Ltd (UK)), Macrobenthos (Dr N. Steffani, Steffani Environmental Consultant, Cape Town) and a review of Plankton (Ms. L. Weston, Lwandle Technologies (Pty) Ltd).

The plume study (Section C, Chapter 2.2) provides an assessment of the utility of a plume modelling study in reducing any existing residual uncertainties in the specialist assessments of potential water column and related impacts associated with the dredge plume.

Quantitative polymerase chain reaction analysis was used to identify the types of thiobacteria present in the samples collected from the SP-1 target dredge area (Section C, Chapter 2.3). The quality control and standards of compliance are detailed in Section D, Appendix 1.3 and 1.4.

Meiofauna samples were collected during a cruise of the MV *DP Star* (Section D, Appendix 1.1 and 1.2) and sent to the UK for analysis at the Physalia laboratory. The assessment is presented in Section C, Chapter 2.4.

The analysis of the macrobenthos collected on the verification cruise, was undertaken by Dr N. Steffani (Section C, Chapter 2.5). The suite of samples collected augments the earlier baseline collection (Steffani, 2010)i[2].

The epifauna assessment (Section C, Chapter 2.6) was commissioned by CapFish, with the samples being collected during the biodiversity cruise aboard the FV *Zeearend* (June 2014).

A comprehensive literature-based review of plankton in northern Benguela continental shelf waters is presented in Section C, Chapter 2.7.

[2] Steffani, N, 2010: Biological Baseline Survey of the Benthic Marcofauna Communities in the Phosphate Licence Blocks EPL 3415 an EP 3323 in the Sandpiper / Meob JV Project area. Namibian Marine Phosphate (Pty) Ltd unpublished report.

© NMP 2014

A comprehensive report on the verification assessment of fish, mammals and seabirds is provided in Section C, Chapters 3.1 to 3.5. The primary component of this section is the findings of the June 2014 biodiversity survey conducted in and around the target dredge site SP-1 (Chapter 3.1). In support of the fish and biodiversity survey four desk-top studies were commissioned by CapFish. These are:

- The fisheries mathematician James Gaylard conducted a modelling review of the monk and hake biomass associated with the ML 170 (Section C, Chapter 3.2).
- The value of ecosystem modelling as an investigative tool for determining ecosystem level impacts likely to be generated from the proposed phosphate dredging project was investigated by Dr K. Cochrane (Section C, Chapter 3.3).
- Dr H. Ndjaula provides an extensive review of the fisheries reproductive dynamics and stock distribution (Section C, Chapter 3.4).
- Ms. M. Smith and Mr D. Japp reviewed the literature (from the 1970s to the present day) regarding the spawning activity, ichthyoplankton drift routes and the recruitment of Namibian marine fauna, for a variety of pelagic and demersal species (Section C, Chapter 3.5).

The key findings of these studies have been incorporated in the Verification Survey Report: Fish, Mammals and Seabirds (Chapter 3.1).

VOLUME 2: APPENDICES

- **Section D: Appendices 1 to 6.**

There are six main appendices, these are:

1. Water Column and Sedimentary Environment;
2. Fisheries and Biodiversity;
3. Geophysics
4. Process documentation related to the verification programme;
5. The curricula vitae and Terms of Reference; and,
6. Dredging project description.

- **Appendix D1.0: Water Column and Sedimentary Environment**

These appendices describe the project execution plans (PEP), cruise reports (CR) for the water column and sediment sampling, the collection of core, and for thiobacteria sampling.

There are two reports by Metocean (Section D, Appendix 1.8 and 1.9), providing the detail of the 90-day deployment of the moored instrument string located in ML 170.

The CSIR's chemical analysis methodology statement provides details of the methods used in subsampling the cores, sample preparation, and the analysis of the samples (Section D Appendix 1.10).

- **Appendix D2.0: Fisheries and Biodiversity**

These appendices (Section D, Appendix 2.1 to 2.5) describe the project execution plans (PEP) and cruise reports (CR) for the biodiversity survey conducted from the FV *Zeearend,* sailing orders are also presented (Section D, Appendix 2.3).

© NMP 2014

- **Appendix D3.0: Geophysics and Geophysical Habitat Mapping**

The details of the geophysical survey (Section D, Appendix 3.1) and the interpretation of the benthic habitat (Section D, Appendix 3.2) are reported in this appendix.

- **Appendix D4.0: Process Documentation**

A listing of the primary activities of the Verification Programme is provided in Section D, Appendix 4.1. The Ministry of Fisheries and Marine Resources' thirteen requirements for inclusion in the Verification Programme are presented in Section D, Appendix 4.2. The full scope of the Verification Programme (November 2012), as amended (July 2013), is provided in Section D, Appendix 4.3.

- **Appendix D5.0: Reviewing Parties: Terms of reference and Curricula Vitae**

The curricula vitae of the persons undertaking the reviews and specialist assessments and the Terms of Reference of the reviewing parties and the specialist consultants to NMP are presented Section D, Appendix 5.1 and 5.2.

- **Appendix D6.0: Dredging Project Description**

The appendix provides a description of the dredging location, the dredging vessel, the dredging process, the dredging cycle, the positional controls during dredging, safe operating zones and the volumes to be dredged.

© NMP 2014

A1.2 PEER REVIEW OF THE VERIFICATION PROGRAMME

A 1.2.1 INTRODUCTION

NMP in committing to this extensive and comprehensive Verification Programme recognised the need to have the scientific studies submitted to peer review. Similarly the processes and methods followed during the field acquisition of data were also subject to independent review. The executive summary reports of these reviews are presented below. The independent reviews are presented in full in: *Independent Peer Reviews, Verification Studies, Sandpiper Project: Namibian Marine Phosphate (Pty) Ltd, November 2014.* In addition the entire Verification Programme report, environmental compliance and verification process has been independently reviewed by the CSIR. This report is presented in the cover pages of the Verification Programme report.

The verification assessment reports of the Namibian Marine Phosphate appointed Specialist Consultants, as presented in this report have been independently assessed, via a team of international consultants, the team comprised of:

- [3]Dr Andrew Payne
- [4]Dr Michael O'Toole
- [5]Dr Barry Clark
- [6]Professor Alakendra Roychoudhury

In addition to the above parties, Professor John Rogers, formerly (now retired) of the Marine Geoscience unit at the University of Cape Town participated as a guest reviewer (formal report not required) in the independent review workshop with the team as above. Professor John Rogers, along with colleagues Dr Mike Bremner and Dr Gavin Birch first described the diatomaceous mud belt and phosphatic sands of the Southern African West and Southern Coastlines in the 1970s.

The methods and approach to the Verification Programme have been independent assessed by the University of Namibia, represented by [7]Dr Samuel Mafwila.

The entire verification programme report, environmental compliance and verification process has been independently reviewed by the CSIR, represented by [8]Mr. Patrick Morant.

[3] A&B Word Ltd, 12 Hill Farm Road, Halesworth, Suffolk, UK. *email*: ailpayne@hotmail.com
[4] Marine Ecosystems Management, Cluain Na Si, Kinvara, Go. Galway, IRE. *email*: otoole.mick@gmail.com
[5] Anchor Environmental, 8, Steenberg House, Silverwood Close, Tokai, RSA.
email: barry@anchorenvironmental.co.za
[6] 57 Pienaar Street, Somerset West, RSA. *email*: roy@sun.ac.za
[7] University of Namibia, Department of Fisheries and Aquatic Science, Faculty of Agriculture and Natural Resources, 30 Mandume Ndemufayo Avenue, Pionierspark, Windhoek, Namibia.
email: smafwila@unam.na
[8] CSIR: Consulting and Analytical Services – Environmental Management Services, 11 Jan Celliers Street, Stellenbosch, RSA.
email: pmorant@csir.co.za

© NMP 2014

A1.2.2 PEER REVIEW REPORT ON SPECIALIST STUDIES OF THE VERIFICATION PROGRAMME

EXECUTIVE SUMMARY



12 Hill Farm Road
Halesworth
Suffolk IP19 8JX
United Kingdom
Tel: +44 (0)1986 875627
Mob: +44 (0)7733 227279
e-mail: ailpayne@hotmail.com

EXECUTIVE SUMMARY

Peer Review Assessment of NMP Specialist Reports: Verification Programme.

Collated and compiled by Dr Andrew I. L. Payne, with input from Dr Barry Clark, Dr Michael J. O'Toole and Prof. Alakendra N. Roychoudhury

The review team (the authorship above) was contracted in mid-2014 to evaluate in an unbiased and scientifically robust manner, using their own specific scientific expertise, the various reports provided by local specialists in response to comments made on the original Environmental Impact Assessment 2012 (EIA) of Namibian Marine Phosphate (NMP) by stakeholders and reviewers. Two of the panel are based in South Africa (Clark and Roychoudhury) and two are Europe-based (Payne and O'Toole), but had spent many years working off southern Africa, in both Namibia and South Africa. All four, though, have significant international experience, which they were able to bring to their expert evaluation.

The Terms of Reference for the study required that each of the appointed reviewers thoroughly read and assimilated the contents of the documentation prepared as part of the EIA (i.e. the EIA summary report, supporting specialist studies, comments from various reviewers and stakeholders, and the reports on verification studies undertaken to address comments from those reviewers, to attend a two-day workshop in Cape Town (13th to 14th August 2014) where Namibia Marine Phosphate's (NMP's) appointed specialist consultants were required to present a summary of the work that they had done, to prepare a report or statement on the quality and thoroughness of the various specialist studies, the relevance of datasets, opinions and conclusions of the NMP specialist consultants presented in their EIA assessments and the verification reports, and to identify if further work or assessments were required to quantify some of the risks and impacts associated with the proposed project.

A list of the specialist study topics, the lead authors, and independent experts appointed to review each topic is provided below.

© NMP 2014

Topic	Lead author	Reviewers
Biomass and stock estimates Recruitment Jellyfish Ecosystem assessment	James Gaylard Dr Hilkka Ndjaula Prof. Mark Gibbons Dr Kevern L. Cochrane	Dr Andrew I. L. Payne (Team leader)
Water column and sediments	Dr Robin Carter (Lwandle Technologies)	Prof. Alakendra N. Roychoudhury
Fish, fishery, marine mammals and birds Jellyfish Ecosystem assessment	David W. Japp Prof. Mark Gibbons Dr Kevern L. Cochrane	Dr Michael J. O'Toole
Macrobenthos Meiofauna	Dr Nina Steffani Physalia, UK	Dr Barry Clark

Up front, it must be said that the client (NMP) and its supporting agencies and consultant specialists were totally open and frank about their aims and their work and were refreshingly receptive at the workshop to criticism and comment, positive and negative, about their overall *modus operandi* and findings. The target extraction area, Mining Licence Area 170, hereafter MLA 170) southwest of Walvis Bay on the Namibian shelf is an extensive one (2230 km^2), but the target area for phosphorite extraction (Sandpiper 1, hereafter SP-1) is much smaller (176 km^2), from which up to 60 km^2 will be dredged during the 20-year mine licence period. The extraction area is totally outside the 200 m isobath that limits any bottom-trawling activities on the Namibian shelf. It is also necessary here to stress that the proposed operation about which the reviewers are commenting is one of dredging of the seabed, not mining of the seabed, which by definition will include the onward processing of material extracted, in this case well away from the proposed dredge target area SP-1. Throughout the text that follows, the words "dredge" and "mine" are used alternately, but they all refer to the same activity, which is what we as reviewers were requested to evaluate, namely the dredging activity.

All four reviewers worked and provided their reports independently, though they did collaborate at the workshop and remotely subsequently. Each of the following sections were indeed drafted by each reviewer working independently, with the leader merely formatting the reports for consistency, correcting minor typographic errors throughout. However, all four reflect each named reviewer's own opinions and comments, not necessarily those of the whole team, and should not be amended in any way without their express permission. They are provided not necessarily to influence the result of the formal application, but to provide educated scientific back-up or criticism of the findings to date (August 2014).

The purpose of the Executive Summary is to provide an overview of the findings of the team at the time of writing. Some of the findings are generalities, but for ease of subsequent use and application, a bulleted list of recommendations and important suggestions drawn from each of the peer review reports is also provided. That list is made as the unanimous findings of the whole team, in other words, we support each other's views. To start, there are a few observations, including some proposals that we wish to share with the reader; these are provided below, in no particular order of priority.

- The whole expert evaluation process has, from a scientific perspective, been followed throughout its existence professionally, credibly and appropriately.

© NMP 2014

- Comments have been made in writing and verbally about the impacts of the more-extensive Namibian inshore marine diamond-extraction effort relative to that proposed in this application for phosphate mining. In our opinion, one needs to be cautious when comparing the two marine extraction exercises.
- It is gratifying to know that the positional accuracy of the dredge head and resolution of the extraction (dredging) process is (technologically) so good; being able to query the technology with the potential dredger operators present at the workshop was valuable.
- The overarching scientific disciplines covered in the specialist inputs and verification procedures are correct and complete.
- One will need to be alert to any cumulative (of mining and of mining plus other operational) impacts in future.
- Future monitoring of all key aspects including an analysis of the potential impacts on the seabed and surrounding areas of the dredging operation needs to be built into any forward-looking management plan, but it will be crucial in doing so to bear in mind potential seasonal effects and the need for consistency in the methodology, gear deployed and even the vessels used.
- Credible analyses of effect or impact cannot really be developed in opposition to or isolated from government scientists' opinions based on their official data (the latter data include the seemingly inaccessible Norwegian data collected for Namibia and stored in the database of the Nansen project). The relationship with state scientific institutions needs to be continually refreshed.
- It is recommended strongly that all specialists contributing data and analyses formally publish the outcome of their analyses as soon as feasible; peer-review adds to the scientific credibility and cannot be countered professionally.
- As with all such comprehensive and multi-disciplinary analyses as those presented to the review team here, regular, though infrequent, independent review will add to international scientific credibility.

Overall, the team finds that the response of the client to issues raised at the earlier review of the EIA through commissioning appropriate verification studies has been appropriate and laudable. The quality of those verification studies is covered elsewhere in this report, but collectively and independently, they have been carried out to the highest scientific and technical standards, using appropriate and up-to-date methodology. The results have almost without fail raised the level of confidence associated with the results in terms of likely impacts, and the team wholeheartedly confirms those analyses. A number of pertinent suggestions did arise through the course of the team's evaluation of the material presented and through discussion at the workshop. Some are mentioned in the observations above. However, for the sake of completeness, the proposals below are taken from the texts of each of the reviewing parties, and where appropriate commented upon, with their order here reflecting generally their mention in text. Some, of course, were mentioned by more than one member of this review team (i.e. appear in more than one review), meaning that suggestions had to be merged, so do not reflect a specific order of priority of either a specific review team member or the team as a whole. The client and his advisors are urged strongly to consider them carefully, either now or during implementation of any management plan established for consideration as part of the application by Namibian national decision-makers.

1. It is recommended that future dredging operations be authorized only within an adaptive management framework (i.e. coupled with intensive monitoring and careful scrutiny of such monitoring data by independent experts and the authorities) and that the authorities retain the

right to require that the scale or scope of dredging be adjusted or that additional mitigation measures be implemented to ameliorate any unforeseen impacts that may arise.

2. Potential cumulative impacts arising from any future expansion in phosphate mining/dredging in the region will need to be considered by the authorities in their own right, or at the minimum a clear body of evidence will need to be presented that can confirm that the probability of there being a cumulative impact of all current plus extra activities is extremely low.
3. Monitoring surveys must be undertaken by NMP after dredging has commenced to confirm that the levels of impact do not exceed those predicted.
4. It is also crucial that, by way of mitigation of potential impact on the macrobenthos and to minimize the possibility of jellyfish polyps establishing in an area, a residual layer of sediment is left on the clay footwall underlying the mineral deposit. Further and if feasible, "lanes" or areas of sediment be left untouched; these two exercises will together facilitate the re-establishment of benthic macrofaunal assemblages on the substratum.
5. Although the current scientific output indicates no such likelihood that it will be a problem, any potential risks arising from ingestion by fish and other fauna of trace heavy metals bound to sediment or organic matter in the water column or on the seafloor should be evaluated by means of laboratory-based sediment toxicity studies.
6. The review team is concerned at the absence of any in-depth analysis of the mesopelagic scattering layer in the MLA. Its presence needs to be confirmed either acoustically using a vessel echosounder or from upward-looking ADCP instrument data moored in the area. It is a phenomenon well known in Namibian waters, and some information needs to be provided in the documentary evidence to be provided in support of the application. The potential impacts of sediment plumes (physical and biogeochemical) on this scattering layer (which could comprise zooplankton, myctophids, other bathypelagic fish, bearded gobies and/or jellyfish) need to be evaluated now given the significant biomass of zooplankton that migrates through the water column and its importance in the ecological functioning of the pelagic environment off Namibia.
7. The water column report needs to include a preliminary model applicable to the SP-1 dredging area using data on current measurements and sediment properties that have already been collected in the vicinity, to demonstrate the distribution, dispersal and sinking rate of plume sediments. Such a model can be developed further as additional data are gathered during environmental monitoring and dredging operations.
8. The collection in future of site-specific sediment dynamics data would support a better understanding of how MLA 170 will be responding to cumulative anthropogenic and natural effects there.
9. Sulphide dynamics will be important, so a better understanding needs to be sought during the operational phase of how oxygen consumption will be affected by the reduced (dredged) sediment reservoir.
10. Attempts should be made to calculate a geo-accumulation index relative to average marine shale, in order to determine whether there is preferential deposition of trace and heavy metals in the target area.
11. In terms of confirming the reproductive dynamics of the commercially important demersal fish species in MLA 170, with focus on the target dredge area SP-1, it will be necessary to monitor on an ongoing basis the reproductive biology of hake and monkfish in the area, collecting appropriate samples as part of a future management plan that includes sample monitoring.
12. Consideration should be given to establishing a zooplankton time-series in and adjacent to SP-1; Such additional information is not crucial to the submission of a dredging application and management plan for SP-1, but would aid the evaluation of future applications in the same or adjacent areas.

© NMP 2014

13. Two of the review team are concerned at the high value of 7% (of all Namibian monkfish recruits) calculated for MLA 170. That value needs to be checked carefully, but in any case a sampling strategy needs to be devised to seek any evidence of there being a regular influx of young monkfish into the area (they do not appear to be spawning extensively there) to support such a high value calculated for the recent sampling years.
14. The recent CapFish biodiversity verification survey was well designed and fulfilled, but it used a net designed to catch bottom fish and particularly monkfish, so would not have captured many, if any, mesopelagic or bathypelagic fish. The same area in the 1970s was important for mesopelagic fish such as lanternfish, so the biodiversity report needs specifically to state that those fish were not available to the survey because of the selectivity of the monkfish-dedicated trawl sampling gear. Future sampling in the area (to be integrated into the monitoring programmes established for any operational phase) would benefit from at least a few samples being taken of fish scattering layers, deploying if feasible a research midwater trawl (RMT) to prove or disprove their presence in the area. Such information, positive or negative, would supplement the biodiversity baseline dataset compiled from the recent survey.
15. Acoustic monitoring needs to be integrated into future monitoring programmes and undertaken at the proposed extraction site to determine background noise levels and to monitor any local whale or dolphin populations. Ideally, this should be initiated before any dredging takes place, though not necessarily before submission of the revised application. Doing so with passive acoustic monitoring devices (PAMs) is a standard international technique when extraction or abstraction of water on an industrial scale is being considered for the marine environment.
16. Efforts must be redoubled to gain access to the valuable datasets collected off Namibia by the RV “Dr Fridtjof Nansen” programme. Some of those data (especially those collected around MLA 170) could be subjected to rigorous scientific analysis in future to support the current analysis; ideally too, the full Nansen datasets should be made available to the marine science community of the Benguela region and also preferably released into the public domain.
17. In future, effort should be made in the impressively conceived reproductive dynamics work to follow annual cohorts through the samples. This may prove particularly rewarding in terms of pelagic fish, and will certainly enhance confidence in the conclusion currently drawn that marine resources are not being damaged by such industrial-scale activity on part of the Namibian shelf.
18. Although ecosystem modelling is in its relative infancy and in this context currently not able (for reasons of inherent modelling projection uncertainty given the scale of dredging, scarcity of data and their resolution) to evaluate the potential impact of the proposed dredging, its use should not be written off, especially if there is future expansion of phosphorus-mining. Monitoring data collected from this project should be earmarked for future contributions to input data for ecosystem modelling assessments, with the collection of high-resolution data.
19. In terms of the biodiversity survey, regularity and consistency of methodology, gear, vessel and season needs to be maintained and the survey established within the management plan proposed.
20. Effort should be redoubled to coordinate NMP-supported and official Namibian survey effort in future, if the licence to operate is granted.
21. For now, no further meiofaunal surveying is considered necessary, but baseline data have been established, so occasional sampling and comparison with these baseline data during a future operational phase could be revealing.
22. Perhaps in future, given the availability of these new data, the Namibian authorities will be able to commission an exercise to evaluate whether there are any specific lessons that can be learned about the ecosystem effects, including recolonization, plume dispersal and sedimentation rates, of marine industrial mining/dredging as an additional anthropogenic effect on the Namibian shelf.

© NMP 2014

23. Effort should be escalated in future to try to integrate any impact models from the current extraction proposal exercise with similar assessments undertaken on the fishing industry and the fishery, using industry, government and Nansen data. MFMR and/or the Benguela Current Commission could coordinate such an exercise, to the benefit of understanding water dynamics throughout Namibia.

To conclude, the review team is impressed by the quality of the information provided to it and believes that all avenues and disciplines of concern relating to the proposed operation in SP-1 have been addressed adequately. The policy decision on whether to proceed is a national one, but we can say that the information provided to us has convinced us that everything points to there being a minimal impact of the proposed operation, should a licence be granted, to the Namibian shelf ecosystem.

Finally, we thank the client and his advisors for entrusting us with this important evaluation and for allowing us to meet with the NMP-appointed specialists providing the background scientific information and to quiz them intensively at the two-day workshop in Cape Town.

Dr Andrew I.L Payne
August 2014

© NMP 2014

A1.2.3 RESPONSES: EIA SPECIALISTS

This section provides a summary of the responses of the NMP EIA Specialists and consultants, to the issues raised by the Peer Review Team, as summarised in the executive summary.

© NMP 2014



12 Hill Farm Road
Halesworth
Suffolk IP19 8JX
United Kingdom
Tel: +44 (0)1986 875627
Mob: +44 (0)7733 227279
e-mail: ailpayne@hotmail.com

NMP Specialist Consultants responding to the matters raised by the Peer Review Team

To whom it may concern

Peer Review Assessment of NMP Specialist Reports: Verification Programme

In the peer review report (August 2014) compiled by myself and the peer review team comprising Dr Barry Clark, Dr Michael J. O'Toole, Prof. Alakendra and N. Roychoudhury, we identified a number of matters that we considered required further attention.

These identified concerns have been considered by the NMP Specialist Consultants and an Issues and Response Matrix has been provided which identifies the actions taken to address the concerns raised by the peer review team.

Dr Andrew I.L Payne
October 2014

© NMP 2014

ISSUES AND RESPONSE MATRIX

1.	**Peer review comment:** The whole expert evaluation process has, from a scientific perspective, been followed throughout its existence professionally, credibly and appropriately. ***NMP team response:*** Noted with appreciation
2.	**Peer review comment:** Comments have been made in writing and verbally about the impacts of the more-extensive Namibian inshore marine diamond-extraction effort relative to that proposed in this application for phosphate mining. In our opinion, one needs to be cautious when comparing the two marine extraction exercises. ***NMP team response:*** The need for caution is duly noted. In 2013 marine diamonds were recovered from an area of approximately 12 km^2 in extent and approximately 14 M tonnes of sediment were mined. The maximum water depth within which diamond mining takes place is approximately 125 m, while the sedimentary depositional environments (flat) and ocean processes are similar to those of ML 170. The comprehensive De Beers Marine plume study, which included both modelling and in situ verification, allows it to be applied realistically to the assessment of the dynamics of the fate of the fines discharged by the dredger. We note the statement of caution and primarily intend to use site-based (ML 170) information.
3.	**Peer review comment:** It is gratifying to know that the positional accuracy of the dredge head and resolution of the extraction (dredging) process is (technologically) so good; being able to query the technology with the potential dredger operators present at the workshop was valuable. ***NMP team response:*** Noted
4.	**Peer review comment:** The overarching scientific disciplines covered in the specialist inputs and verification procedures are correct and complete. ***NMP team response:*** Noted
5.	**Peer review comment:** One will need to be alert to any cumulative (of mining and of mining plus other operational) impacts in future. ***NMP team response:*** Data collected by NMP as a baseline, and as acquired during the monitoring programmes (described in the Environmental Management Plan) will be made available to the authorities (or appropriately authorised commissions or organisations) for their utilisation in conducting cumulative and other environmental assessments. Similarly, NMP's data will be evaluated continuously by the Company in respect of site-specific and cumulative impacts arising from dredging in SP-1 and the possible expansion of operations within ML 170. An additional commentary on environmental effects is provided in the verification programme report (Section A).

© NMP 2014

6. Peer review comment:
Future monitoring of all key aspects including an analysis of the potential impacts on the seabed and surrounding areas of the dredging operation needs to be built into any forward-looking management plan, but it will be crucial in doing so to bear in mind potential seasonal effects and the need for consistency in the methodology, gear deployed and even the vessels used.

NMP team response:
These requirements are built into the NMP Environmental Management Plan at a number of levels, e.g. from, regular site geophysical surveying (real time with active dredging, and recovery profile sediment surveys), annual biodiversity surveys (monk trawls, mesopelagic and epifauna assessments), cooperative surveys with MFMR (their cooperation will need to be sought); project based in-plume gathering of data using various platforms for measurements of dredge plume dimensions and effects on water quality, collection and analysis of water column and sediments; macrofauna recovery surveys in dredged areas; periodic collection of meiofaunal samples and their analysis; Also included are on board (dredger) monitoring and observation of ocean conditions, marine mammals and seabirds.

7. Peer review comment:
Credible analyses of effect or impact cannot really be developed in opposition to or isolated from government scientists' opinions based on their official data (the latter data include the seemingly inaccessible Norwegian data collected for Namibia and stored in the database of the Nansen project). The relationship with state scientific institutions needs to be continually refreshed.

NMP team response:
Relationship building continues to be a priority consideration for NMP in all aspects of the project, with particular emphasis on the authorities, (MFMR – MET and MME) and including I&APs. Effective relationships are based fundamentally on the principle of reciprocity. Efforts by NMP in this regard will be maintained and formal requests for access to the Nansen data will be re-submitted to MFMR. If provided, the received information will be assessed and where recommended by specialists, it will be worked up into the project data sets and used to optimise annual biodiversity and related surveys.

8. Peer review comment:
It is recommended strongly that all specialists contributing data and analyses formally publish the outcome of their analyses as soon as feasible; peer-review adds to scientific credibility and cannot be countered professionally.

NMP team response:
Noted and it is intended that this recommendation will be implemented. The information of a biogeochemical nature gathered during the verification assessment is new to science. Formal publication in the scientific literature is a priority.

9. Peer review comment:
As with all such comprehensive and multi-disciplinary analyses as those presented to the review team here, regular, though infrequent, independent review will add to international scientific credibility.

NMP team response:
Noted and the recommendation is accepted. NMP will institute a process of regular independent review of the environmental monitoring plan.

10. Peer review comment:
It is recommended that future dredging operations be authorized only within an adaptive management framework (i.e. coupled with intensive monitoring and careful scrutiny of such monitoring data by independent experts and the authorities) and that the authorities retain the right to require that the scale or scope of dredging be adjusted or that additional mitigation measures be implemented to ameliorate any unforeseen impacts that may arise.

© NMP 2014

NMP team response:
This is a regulatory matter and is contained in the requirements of the Minerals Act 1992 and the Environmental Act of 2007. Through this regulatory framework, NMP is committed to comply with the legally binding requirements of the Environmental Management Plan and the annual authority reporting requirements. Furthermore the 3-yearly re-application for environmental clearance from MET provides an opportunity for the EMP to be revised / modified in the light of findings from the monitoring programme. The EMP is a dynamic document with changes in the listed requirements being reflected by the (growing) knowledge base and associated re-assessment of the impacts and risk significance. These standards, compliance and management requirements, (as may be amended from time to time) are incorporated into the Environmental Contract issued by MET.

11. Peer review comment:
Potential cumulative impacts arising from any future expansion in phosphate mining/dredging in the region will need to be considered by the authorities in their own right, or at the minimum a clear body of evidence will need to be presented that can confirm that the probability of there being a cumulative impact of all current plus extra activities is extremely low.

NMP team response:
Noted. This is a matter that has been initiated by the Namibian Government (represented by MFMR): A scoping study, with the intention thereafter of undertaking a strategic environmental Assessment (SEA) on the cumulative effects of marine phosphate mining has been commissioned. Currently the Norwegian group SINTEF is preparing the scoping report. Prior to this the Benguela Current Commission commissioned its own SEA scoping study, formal feed back from this initiative is awaited. All information gathered during the implementation of the Environmental Management Plan will be evaluated in the light of cumulative effects and made available to the authorities for similar local and regional assessments.

12. Peer review comment:
Monitoring surveys must be undertaken by NMP after dredging has commenced to confirm that the levels of impact do not exceed those predicted.

NMP team – Closeout response:
A detailed environmental monitoring programme has been submitted as part of the regulatory requirements of the Environmental Act (No.7) of 2007. This requirement is addressed in the EMP. Management and compliance indicator reports will be generated on a regular basis, with composite reports being submitted to MET in accordance with the requirements of the Environmental Contract (issued by MET).

13. Peer review comment:
It is also crucial that, by way of mitigation of potential impact on the macrobenthos and to minimize the possibility of jellyfish polyps establishing in an area, a residual layer of sediment is left on the clay footwall underlying the mineral deposit. Further and if feasible, “lanes” or areas of sediment be left untouched; these two exercises will together facilitate the re-establishment of benthic macrofaunal assemblages on the substratum.

NMP team response:
Noted. This recommendation is in line with the recommendation submitted in the original EIA and has been included in the EMP with the intention being not to dredge to the clay footwall and to leave approximately 10% of the sediment thickness as a residual layer. This will almost completely eliminate the risk of providing a suitable substrate for the establishment of jellyfish polyps. The clay footwall (from a processing perspective) is an unwanted sediment horizon. The vertical positional accuracy and dredging operational techniques are optimised to extract the upper phosphate-rich horizons and to leave residual phosphate sediments so as not to dredge the clay footwall. The resource extraction plan calls for parallel three metre wide dredge cuts (3 m wide cutter suction head) of up to 4 km long to

© NMP 2014

dredge the sediment. The horizontal repositioning from cut lane to cut lane will in instances result in un-dredged sediments being left in areas with the original sediment profile remaining intact. The orientation of these cut lanes is controlled by the dominant swell direction. Hence, depending on swell orientation, there will be occasions where the cuts will not be parallel but at some angle to the usual dredging orientation. This will result in "slivers" of un-dredged ground being left in situ, with the original sediment profile remaining intact. This original material will serve as "seed stock" to enhance benthic faunal recovery. Multibeam geophysical surveys are to be carried out during dredging. Subsequently this will allow for the compilation of composite images of the dredged terrain. These data cross-referenced with independent benthic faunal recovery surveys will optimise the assessment of the post dredging status of the benthic fauna.

14. Peer review comment:

Although the current scientific output indicates no such likelihood that it will be a problem, any potential risks arising from ingestion by fish and other fauna of trace heavy metals bound to sediment or organic matter in the water column or on the seafloor should be evaluated by means of laboratory-based sediment toxicity studies.

NMP team response:

Through the implementation of the Environmental Management Plan samples of the main commercial fish species will be taken on future biodiversity surveys, analysed for heavy metals and compared with the fishing industry standards to check for any deviations from the norm.

Assessments of trophic transfers of heavy metal contaminants now included in the Verification Survey report (section C of the Verification Programme Report) indicate that, in pelagic food webs, these are generally attenuated at the primary consumer level, dominated by copepods, with low transfer efficiencies to fish. In benthic food webs with carnivorous molluscan whelks as top predators appreciable bio-magnification can occur as whelks sequester and store metals derived from their prey. However the proposed mining operations in the survey area are not expected to increase exposures of benthic fauna to heavy metals such as cadmium over and above that which occurs naturally in the region.

15. Peer review comment:

The review team is concerned at the absence of any in-depth analysis of the mesopelagic scattering layer in the MLA. Its presence needs to be confirmed either acoustically using a vessel echosounder or from upward-looking ADCP instrument data moored in the area. It is a phenomenon well known in Namibian waters, and some information needs to be provided in the documentary evidence to be provided in support of the application. The potential impacts of sediment plumes (physical and biogeochemical) on this scattering layer (which could comprise zooplankton, myctophids, other bathypelagic fish, bearded gobies and/or jellyfish) need to be evaluated now given the significant biomass of zooplankton that migrates through the water column and its importance in the ecological functioning of the pelagic environment off Namibia.

NMP team response:

A specialist review of the upward looking ADCP information from the current meter string (90 day site deployment) has been undertaken and is discussed in the verification programme report (Section C of the Verification Programme Report), in order to address the query on the mesopelagic species.

The ADCP data from the proposed dredge area does indeed show acoustic signals indicative of diurnal vertical migrations of zooplankton and ichthyoplankton. It is apparent from published information that light triggers for such migrations occur at very low light intensity and therefore any alteration of the underwater light field such as may occur under a turbidity plume potentially can disrupt migration patterns. The scale of this, if it occurs, should be limited in terms of space and time (turbidity plume dissipation rates and non-continuous plume generation in the proposed dredging cycle). At least it will be possible to show temporal patterns in vertical migrations from the suite of ADCP measurements (downward and upward looking) planned for the initial phases of the proposed dredging programme.

© NMP 2014

While the EMP can accommodate for future surveys to be designed (a combination of acoustics and satellite imagery) to incorporate the specific sampling of the mesopelagic species and the scattering layers this is a matter for the competent authority as well. There are few surveys of mesopelagic species on record and they are a difficult group of fish species to sample requiring specialized gear and vessels. If the ML 170 area is indeed deemed to be of importance for the mesopelagic fish and other species there is a clear need for MFMR to include the area in its regular sampling programme using the specialised vessel and gear available to it. NMP will engage with the authorities about partnering to meet this recommendation.

16. **Peer review comment:**
The water column report needs to include a preliminary model applicable to the SP-1 dredging area using data on current measurements and sediment properties that have already been collected in the vicinity, to demonstrate the distribution, dispersal and sinking rate of plume sediments. Such a model can be developed further as additional data are gathered during environmental monitoring and dredging operations.

NMP team response:
In response to this recommendation, NMP has commissioned the CSIR to provide an assessment of the value of undertaking the recommended plume modelling to further constrain the environmental risks associated with the sediment plume (beyond that determined in the EIA (2012) specialist study). The CSIR report is included in the Verification Programme Report (Section C) and determines that, while it is likely that the modelled analysis would provide additional characterisation of the extents, and duration (physical parameters) of the plume using the data already collected from site, it is unlikely to provide any further significant information in evaluating the impact risk associated with dredging. In light of this, the advice to NMP is that plume modelling is not material to the assessment of impacts in the area. However, modelling will be undertaken prior to the commencement of dredging as the first step towards building a comprehensive plume model.

17. **Peer review comment:**
The collection in future of site-specific sediment dynamics data would support a better understanding of how MLA 170 will be responding to cumulative anthropogenic and natural effects there.

NMP team response:
Post-dredging multibeam surveys coupled with post-dredging interpretation of sediment and water column characteristics will contribute information to the assessment of cumulative anthropogenic and natural effects. These data collection activities are described in the EMP.

18. **Peer review comment:**
Sulphide dynamics will be important, so a better understanding needs to be sought during the operational phase of how oxygen consumption will be affected by the reduced (dredged) sediment reservoir.

NMP team response:
An assessment of the potential of sulphide derived from iron pyrites dissolution in the water column, i.e. which may be associated with the dredging turbidity plume has been included in the Verification Programme Report. The assessment indicates that a minor proportion of the total iron pyrite pool may contribute reduced sulphide to the water column. This sulphide pool is predicted to be oxidised to sulphur, as opposed to sulphate, therefore no effects on the dissolved oxygen reservoir are predicted to emanate from this. Further details are to be found in Section C of the Verification Programme Report.

19. **Peer review comment:**
Attempts should be made to calculate a geo-accumulation index relative to average marine shale, in order to determine whether there is preferential deposition of trace and heavy metals in the target area.

© NMP 2014

NMP team response:
Data presented in the Verification Survey report show that all of the heavy metals with the exception of cadmium covary with aluminium (an indicator of clay minerals). The elevated cadmium concentration has been explained via published analyses indicating scavenging of this metal by the reduced sulphide pool. This is supported by higher cadmium concentrations in mud belt sediments inshore and north of the proposed dredging site (NatMIRC and CSIR). In view of these features the value of calculating of enrichment factors is moot, especially if global values have to be used for this as local Namibian data on shale composition is not readily available. More information on this topic is presented in Section C of the Verification Programme Report.

20. Peer review comment:
In terms of confirming the reproductive dynamics of the commercially important demersal fish species in MLA 170, with focus on the target dredge area SP-1, it will be necessary to monitor on an ongoing basis the reproductive biology of hake and monkfish in the area, collecting appropriate samples as part of a future management plan that includes sample monitoring.

NMP team response:
The recommendation is noted. This is a core component of the EMP and the recommendation is addressed through the annual biodiversity survey sampling programme, where refinements can be made to the work programme to improve data gathering regarding the reproductive biology of the main commercial fish species occurring in SP-1 and immediate surrounds.

21. Peer review comment:
Consideration should be given to establishing a zooplankton time-series in and adjacent to SP-1; Such additional information is not crucial to the submission of a dredging application and management plan for SP-1, but would aid the evaluation of future applications in the same or adjacent areas.

NMP team response:
Cautionary statement: The value of such sampling in a limited area (SP-1) needs to be considered objectively since, if the area is deemed to be too small from a statistical standpoint, then it is questionable and is likely to be of little value to the further understanding of the impacts of dredging. Notwithstanding, the annual surveys provided for in the EMP will incorporate appropriate acoustic surveys for assessment of scattering layers.

22. Peer review comment:
Two of the review team are concerned at the high value of 7% (of all Namibian monkfish recruits) calculated for MLA 170. That value needs to be checked carefully, but in any case a sampling strategy needs to be devised to seek any evidence of there being a regular influx of young monkfish into the area (they do not appear to be spawning extensively there) to support such a high value calculated for the recent sampling years.

NMP team response:
The modelling undertaken was intended to only provide a first order estimate of the abundance of the main commercial species relative to the population of each species as a whole. The reviewers recognized that the area modelled was extremely small and that extrapolations based on typical fisheries approaches would result in high variance, erring on the conservative side of the estimates provided. The data used and variance can only be strengthened by an increased number of samples from the actual dredge area (SP-1 in ML 170), along with the subsequent re-modelling of the acquired data. This can be improved in two ways:

1) Persisting with the current biodiversity sampling programme until a reasonable time series of data can give greater confidence in the model outputs. The sampling regime would focus on the recruitment, meaning the availability and dynamics of juvenile monk in the area. 2) NatMIRC could significantly strengthen these modelled estimates if they undertook biomass trawls in and around the area during

© NMP 2014

their standard annual hake and monk surveys. NMP will engage with the authorities about partnering to meet this recommendation.

23. Peer review comment:

The recent CAPFISH biodiversity verification survey was well designed and fulfilled, but it used a net designed to catch bottom fish and particularly monkfish, so would not have captured many, if any, mesopelagic or bathypelagic fish. The same area in the 1970s was important for mesopelagic fish such as lanternfish, so the biodiversity report needs specifically to state that those fish were not available to the survey because of the selectivity of the monkfish-dedicated trawl sampling gear. Future sampling in the area (to be integrated into the monitoring programmes established for any operational phase) would benefit from at least a few samples being taken of fish scattering layers, deploying if feasible a research midwater trawl (RMT) to prove or disprove their presence in the area. Such information, positive or negative, would supplement the biodiversity baseline dataset compiled from the recent survey.

NMP team response:

The recommendation is noted. This is of course specialist surveying, requiring specialist equipment and vessels. Again, NatMIRC has the vessels and gear to do this type of sampling and their support and involvement will be encouraged. NMP will engage with the authorities about partnering to meet this recommendation. Notwithstanding this, for future monitoring purposes, provision to utilize a combination of acoustics and satellite imagery to incorporate some measures for sampling of mesopelagic species and the scattering layers has been made in the EMP

24. Peer review comment:

Acoustic monitoring needs to be integrated into future monitoring programmes and undertaken at the proposed extraction site to determine background noise levels and to monitor any local whale or dolphin populations. Ideally, this should be initiated before any dredging takes place, though not necessarily before submission of the revised application. Doing so with passive acoustic monitoring devices (PAMs) is a standard international technique when extraction or abstraction of water on an industrial scale is being considered for the marine environment.

NMP team response:

This recommendation has been considered within the Verification Programme Report (Section C) and in response, site based monitoring of pre-dredging acoustic conditions will be undertaken. Acoustic monitoring will be integrated with fisheries monitoring surveys. Similar monitoring will take place during dredging. This is described in the EMP.

25. Peer review comment:

Efforts must be redoubled to gain access to the valuable datasets collected off Namibia by the RV "Dr Fridtjof Nansen" programme. Some of those data (especially those collected around MLA 170) could be subjected to rigorous scientific analysis in future to support the current analysis; ideally too, the full Nansen datasets should be made available to the marine science community of the Benguela region and also preferably released into the public domain.

NMP team response:

The recommendation is noted. While in broad agreement with the position of the reviewers, the custodianship of the data resides with the countries (and the Benguela Current Commission (BCC)) wherein the surveys are undertaken. The proponent has already requested these data. However, ultimate control over access to the data resides with the competent authority. To address the recommendation, the responsible authorities (MFMR) and the Secretariat of the BCC will again be approached to provide access to this database. The consultants advise, however, that the Nansen data will not necessarily strengthen the EIA as the available data provided by MFMR/NatMIRC is extensive.

© NMP 2014

26. Peer review comment:
In future, effort should be made in the impressively conceived reproductive dynamics work to follow annual cohorts through the samples. This may prove particularly rewarding in terms of pelagic fish, and will certainly enhance confidence in the conclusion currently drawn that marine resources are not being damaged by such industrial-scale activity on part of the Namibian shelf.

NMP team response:
The recommendation is noted and is taken to refer to the ongoing monitoring activities encompassed in the EMP. As part of the EMP assessment cohort analysis will be undertaken from the results of the annual (year on year) biodiversity surveys.

27. Peer review comment:
Although ecosystem modelling is in its relative infancy and in this context currently not able (for reasons of inherent modelling projection uncertainty given the scale of dredging, scarcity of data and their resolution) to evaluate the potential impact of the proposed dredging, its use should not be written off, especially if there is future expansion of phosphorus-mining. Monitoring data collected from this project should be earmarked for future contributions to input data for ecosystem modelling assessments, with the collection of high-resolution data.

NMP team response:
The recommendation is noted. All data collected and reports generated during the monitoring programmes of the EMP will be made available to competent authorities for input into their ecosystem modelling.

28. Peer review comment:
In terms of the biodiversity survey, regularity and consistency of methodology, gear, vessel and season needs to be maintained and the survey established within the management plan proposed.

NMP team –response:
The recommendation is accepted and addressed in that all planned surveys described in the EMP will be standardised. Modifications to any such surveys will be managed in consultation with the Company's appointed consultants as well as the competent authorities through the terms of the Environmental Contract.

29. Peer review comment:
Effort should be redoubled to coordinate NMP-supported and official Namibian survey effort in future, if the licence to operate is granted.

NMP team response:
NMP will continue to engage with the authorities to establish a reciprocal relationship and to secure their partnering to conduct relevant research and data gathering in the ML 170 area in line with this recommendation.

30. Peer review comment:
For now, no further meiofaunal surveying is considered necessary, but baseline data have been established, so occasional sampling and comparison with these baseline data during a future operational phase could be revealing.

NMP team response:
This recommendation is addressed under the current EMP provisions. Additional samples will be collected and analysed on an infrequent basis. This will be managed through the EMP. Samples will be collected from both the dredged and un-dredged (reference) areas.

© NMP 2014

31. Peer review comment:

Perhaps in future, given the availability of these new data, the Namibian authorities will be able to commission an exercise to evaluate whether there are any specific lessons that can be learned about the ecosystem effects, including recolonization, plume dispersal and sedimentation rates, of marine industrial mining/dredging as an additional anthropogenic effect on the Namibian shelf.

NMP team response:

The recommendation is noted and the sentiment is shared. NMP will collaborate with the authorities in this regard and provide annual reports and relevant data to the authorities, or managing commission.

32. Peer review comment:

Effort should be escalated in future to try to integrate any impact models from the current extraction proposal exercise with similar assessments undertaken on the fishing industry and the fishery, using industry, government and Nansen data. MFMR and/or the Benguela Current Commission could coordinate such an exercise, to the benefit of understanding water dynamics throughout Namibia.

NMP team response:

The recommendation is noted and the proponent agrees with the sentiments presented.

© NMP 2014

A1.2.4 INDEPENDENT REVIEW OF THE NMP VERIFICATION PROGRAMME PROCESS

EXECUTIVE SUMMARY

UNIVERSITY OF NAMIBIA

EXECUTIVE SUMMARY

Independent Review of the NMP Verification Programme Process
2013 – 2014

Collated and compiled by Dr Sam Mafwila

Namibian Marine Phosphate (Pty) Ltd. (NMP) is proposing to extract marine pelletal phosphate ore from deposits off the Namibian central coast. The phosphate will be extracted by dredging and the assessment of the environmental impacts associated with the project was conducted during the environmental impact assessment (EIA) stage of the project. However, some stakeholders had raised a number of concerns and issues regarding the then prepared EIA, and recommended some follow up specialist studies to verify the significance of the findings previous presented in the NMP EIA (2012) which was based on both historical and limited recently collected data. NMP in their quest to address the issues and concerns raised by stakeholders, commissioned the verification survey. The purpose of the verification survey was to confirm the sediment properties, water quality, local oceanographic processes of the seafloor and water column, benthic macrofauna and meiofauna within the proposed dredge area. In addition a biodiversity survey was also conducted mainly to address aspects of the demersal fish species, and epifaunal species diversity. All the information was then used, in conjunction with previous scientific investigations of the region, to further inform the assessment of impacts on the marine environment as a result of the proposed dredging operations. Finally the information is synthesized in the Verification Programme Report and Environmental Management Plan for the Mining Licence Area (MLA).

Apart from the various specialist consultants appointed to conduct specific tasks of the verification survey, NMP also entered into three-tier agreement with the University Central Consultancy Bureau (UCCB) of the University of Namibia (UNAM). Part of the agreement was that UNAM provides Specialist Marine Scientists to be independent observers of the field operations of the verification programme, verify and comment on the suitability of equipment and sampling techniques, on-board sample processing and handling of samples (on board processing, storage, marking, transportation, record keeping), completion of the sampling operation and general comments on the overall operation. Furthermore, assess and comment on the laboratory facilities and sample processing in the laboratories, analytical processes, data analysis and interpretation results, biodiversity survey methods, and results, and finally, the peer-review process and workshop.

This independent observer report documents the verification survey and comments on the abovementioned terms of reference. The first verification survey, which dealt with the water column, sediment characteristics, and local oceanographic conditions as well as the benthic macrofauna and meiofauna, was well planned and coordinated. Detailed sampling methods and sample processing were careful chosen to appropriately address and fulfill the comments and concerns that were raised by the Ministry of Fisheries and Marine Resources (MFMR) and other stakeholders. Although not all the concerns were dealt with, NMP has striven to address the most critical ones to the best of their

ability in a more transparent and practically feasible way. Among the issues, notably the mooring on the seafloor deployed for 90 days, has thus far generated good data for the local oceanographic conditions of the MLA. The use of the Day Grab and the Box-Corer instead of the Van Veen Grab was one of the recommendations, and was implemented during the first verification survey. Reliable data were generated for both benthic macrofauna and meiofauna within the primary dredge target area of SP-1. Verification was done on the sediment characteristics, which have confirmed the area is not within a mudbelt, with very little, or no hydrogen sulphide and organic-rich sediments. In situ measurements of the water column parameters such as oxygen, temperature, pH and salinity were captured using suitable instruments. Issues regarding benthic macrofauna and meiofauna were fully addressed. The sample handling onboard and processing was adequately conducted with care and good workmanship. However, field operations are faced with challenges, the oxidation-reduction potential (ORP) measurements in situ was challenging as the sediment gets exposure to open air. Generally, the whole operation for the first verification survey was successful.

The second verification survey dealt with the demersal fish biomass distribution and diversity, as well as the epibenthic fauna within the MLA and the surrounding nearby areas. Although a hake trawl was not available for use in this survey, a similar but slightly heavier monk directed trawl net was deployed during this survey. This survey generated a wealth of information, the level of which is unique to the area. The sample processing was handled by qualified personnel and data reliability is high. Upon interpretation, the results confirmed and improved our understanding of the potential impacts that dredging may have on the local fish resources and epifauna, as well as mammals and seabirds. Other specialist studies looked at the recruitment dynamics of the fish stocks off Namibia, with emphasis on the MLA; the fish stock dynamics in terms of biomass; and a review of ecosystem models in the northern and southern Benguela. Specialist consultants performed these tasks, and the results have convincingly supported and enhanced the earlier studies in the area.

It is a custom in natural science that scientific work should undergo thorough peer-review in order to have a high quality output. NMP has gone the mile extra to subject all the scientific studies conducted on their behalf by specialist consultants to a peer-review process. A carefully selected panel of internationally profiled experts in biogeochemistry, fisheries, marine ecology, and benthic ecology was appointed to review the specialist work conducted during the verification surveys in conjunction with the earlier EIA and comments there in. The peer-review panel had a chance to review the work at their convenience, and eventually attended a two-day peer-review workshop in Cape Town, where all the work were presented. The whole process was appropriate and efficient. The peer-review workshop was the best thing to do, as it provided a good platform for information sharing and review in a short period of time. A fair and transparent peer-review was the order of the day. Critiques and comments were dealt with immediately, and if not, then the specialist consultants were given the opportunity to re-analyze their data or re-run their analytical process where possible. The final results were incorporated into the final reports.

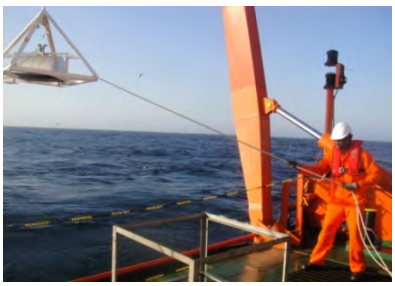
As a UNAM representative in this whole verification programme, I am of the conviction that NMP has thus far conducted the most comprehensive scientific studies in their MLA. These studies have addressed uncertainties that were raised by the MFMR and beyond. New data sets were generated and new insights about the area have been brought forth, and improved our understanding of the physical, chemical and biological nature and dynamics of the area, and what would be the potential impacts of dredging. It is imperative to continue with monitoring surveys in the MLA, (detailed in the EMP) in order to support the current assumptions and statements. However, in the Regional context, the monitoring of the state of the environment should be a concerted combined effort by government and mining companies.

© NMP 2014

Overall, the NMP verification programme was a great effort, and has augmented the original EIA, and responded to the queries put forward by the MFMR. The sampling design, sampling methods, sample handling and processing, analytical procedures, data generated and results thereof are reliable, high quality and trustworthy, and were validated by the peer-review process.

Dr Sam Mafwila
September 2014





SANDPIPER PROJECT

Verification Programme Report: Mining Licence Area No. 170

SECTION B:

IMPACT ASSESSMENT VERIFICATION

B1.1: Water Column
B1.2: Fish, Fisheries, Mammals and Seabirds
B1.3: Macrofauna
B1.4: Jellyfish
B2.0: Cumulative Effects

SECTION B
IMPACT ASSESSMENT VERIFICATION

B1.1 Water Column and Sediments
B1.2 Fisheries Mammals and Seabirds
B1.3 Macrofauna
B1.4 Jellyfish
B2.0 Cumulative Effects

Prepared for:
Namibian Marine Phosphate (Pty) Ltd.

Prepared by:
Jeremy Midgley
Jeremy Midgley and Associates

Reviewed by:
Patrick Morant
CSIR

November 2014

Primary Contributing authors:

Dr R Carter	*Water Column and Sediments*	Lwandle Technologies (Pty) Ltd
Dr N Steffani	*Benthic Macrofauna*	Steffani Marine Environmental Consulting
Mr D Japp	*Fish, Mammals and Seabirds*	Capricorn Fisheries Monitoring (Pty) Ltd
Prof. M Gibbons	*Jellyfish*	University of the Western Cape

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed “Attention: Administration Manager,” at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

contents

SUMMARY vi
INTRODUCTION 1
IMPACT CRITERIA 3
THE ASSESSMENT PROCEDURE AND THE DETERMINATION OF SIGNIFICANCE 3

B1.1 VERIFIED ASSESSMENT OF IMPACTS: SEDIMENTS AND WATER COLUMN 6
INTRODUCTION 6
Table 1.1.1 Impact 1: Discharge to Sea of Ships Wastes: Potential impact of releasing vessel wastes into the sea. 8
Table 1.1.2 Impact 2: Exchange of Ballast Water: Alien marine species may displace indigenous species and reduce indigenous biodiversity. 9
Table 1.1.3 Impact 3: Increased Suspended Sediment Concentrations: Dredging generates plumes of suspended sediments that adversely affect organisms in the water column. 10
Table 1.1.4 Impact 4: Changed Biogeochemical Properties of near Surface Waters: Sulphidic sediment pore-water entrained in the dredged sediment is discharged with the over-spill water. 11
Table 1.1.5 Impact 5: Changed Biogeochemical Properties of Surface Waters: Potential impact of lower oxygen levels in overflow water. 12
Table 1.1.6 Impact 6: Changed Biogeochemical Properties of Surface Waters: Potential impact of higher nutrient levels in overflow water. 13
Table 1.1.7 Impact 7: Changed Biogeochemical Properties of Surface Waters: Potential impact of higher levels of heavy metals in overflow water. 14
Table 1.1.8 Impact 8: Changes to Biogeochemical Properties of Bottom Waters: Potential impact of exposing heavy metals on the seabed 15
Table 1.1.9 Impact 9: Changes to Biogeochemical Properties of Bottom Waters: Potential impact of releasing hydrogen sulphide from the seabed 17
Table 1.1.10 Impact 10: Changes to Biogeochemical Properties of Bottom Waters: Potential impact of exposing anoxic sediment surfaces on the seabed 18
Table 1.1.11 Impact 11: Changes to Biogeochemical Properties of Bottom Waters: Potential impact of removing the thio-bacteria mat 19

B1.2 VERIFIED ASSESSMENT OF IMPACTS: FISHERIES MAMMALS AND SEABIRDS 20
INTRODUCTION 20
Table 1.2.1 Impact 1: The impact on fishing operations of the main Namibian fishing sectors by phosphate dredging. 26
Table 1.2.2 Impact 2: The impact of phosphate dredging on the ecologically important demersal and pelagic fish species. 33
Table 1.2.3 Impact 3: The impact of phosphate dredging on the recruitment of key commercial fish stocks 42
Table 1.2.4 Impact 4: The impact of phosphate dredging on species diversity. 50
Table 1.2.5 Impact 5: The impact of phosphate dredging on seabirds and marine mammals 53

B1.3 VERIFIED ASSESSMENT OF IMPACTS: MACROFAUNA 56
INTRODUCTION 56

© NMP 2014

Table 1.3.1 Impact 1: The removal of the upper 1 to 2.5 m of sediment by dredging will result in the loss of the benthic biota. 58
Table 1.3.2 Impact 2: Further exploration and environmental work will be conducted in the larger ML 170 that will remove benthic biota. 60
Table 1.3.3 Impact 3: The depth of the dredged area might change local near bottom hydrographical conditions and thus act as trap for very fine material. 61
Table 1.3.4 Impact 4: Dredging removes mats of large sulphur-oxidising bacteria from the sediment surface and from the upper layer. 63
Table 1.3.5 Impact 5: The anaerobic bacterium Clostridium botulinum type E might proliferate in the dredged area, and may pose a health risk to humans and wildlife when entering the food chain. 65
Table 1.3.6 Impact 6: High suspended sediment concentrations near the sea bottom generated by the drag head and subsequent re-deposition of the material causes smothering effects. 67
Table 1.3.7 Impact 7: Re-deposition of particles in the overflow plume causes smothering of benthic organisms, particularly in the depo-center on the continental slope. 69
Table 1.3.8 Impact 8: Dredging may mobilise dissolved nutrients from the sediments which could be released into the water column with the overflow from the dredger. 70
Table 1.3.9 Impact 9: Release of hydrogen sulphide from the sediments affects benthic communities. 72

B1.4 VERIFIED ASSESSMENT OF IMPACTS: JELLYFISH 74

INTRODUCTION 74

Table 1.4.1 Impact 1: Blocking of vessel seawater intake system by dense surface aggregations of jellyfish. 76
Table 1.4.2 Impact 2: Hydrogen sulphide released from dredge sediments causing mortalities to jellyfish. 78
Table 1.4.3 Impact 3: Lean water overflow sediments, if present in sufficient quantities, may cause mortalities to jellyfish. 80
Table 1.4.4 Impact 4: Removal of seabed sediments will change the nature of the sediment surface. Jellyfish populations are known to increase in areas where there is an increase of hard substrate. 82

B2 CUMULATIVE EFFECTS ASSESSMENT 83

B2.1 INTRODUCTION 83

B2.2 SHIPPING INTERACTIONS 84

B2.3 DREDGING 85

B2.4 EXPANSION OF PHOSPHATE MINING ACTIVITIES 86

B2.5 REFERENCES 87

© NMP 2014

figures

Figure 1. Illustration of zones and areas defined in the fisheries impact assessment (original EIA) (Japp 2012). 22
Figure 2. Hake commercial data (2004-2009). Each dot represents the position per trawl relative to the MLA. n=63351 29
Figure 3. Hake commercial longline data. Each dot represents the position per throw relative to the MLA. n = 4553 29
Figure 4. Monk commercial data (2005-2010). Each dot represents the position per trawl. n=36798 30
Figure 5. Horse mackerel commercial data (1997-2011). Dots are the position of the last trawl per day. n=39697 30
Figure 6. Small pelagic commercial data (anchovy, sardine and round herring) 2000 – 2011. n=2260 31
Figure 7. Location of anchovy catches from commercial data (2000 – 2011). n=552 31
Figure 8. Location of sardine catches from commercial data (2000 – 2011). n=1099 32
Figure 9. Location of round herring catches from commercial data (2000-2011). n=83 32
Figure 10. Distribution of hake from hake-survey data (1995-2010). Dots show the cumulative weights per station. n=678 36
Figure 11. Horse mackerel from hake-survey data (1995-2010).). Dots show cumulative weight per station. n=78 36
Figure 12. Monk from hake- survey data (1995 – 2010). Dots show cumulative weight station. n=134 37
Figure 13. Monk from monk-survey data (2007-2010). Dots show cumulative weight per station. n=100 37
Figure 14. Pelagic (anchovy, sardine and round herring) weights from pelagic-survey data (2002 – 2011). n=2557 38
Figure 15. Total catch per station for snoek from hake-survey data (1997-2010). n=8 38
Figure 16. Distribution of goby from hake-survey data (1995 – 2010). n=93 39
Figure 17. Distribution of goby from monk-survey data (2007 – 2010). n=24 39
Figure 18. Total catch per station for west coast sole from hake-survey data (1997 – 2010). n=48 40
Figure 19. Total catch per station for west coast sole from monk- survey data (1997 – 2010). n=42 40
Figure 20. Distribution of orange roughy from hake-survey data (1995 – 2010). n=4 41
Figure 21. Distribution of orange roughy from monk-survey data (2007 – 2010). n=29 41
Figure 22. Hake juvenile numbers (<21cm) from length frequency hake- survey data (1995-2010). n=6649 45
Figure 23. Hake stage 4 represented as a percentage of the total number of all stages per station form hake-survey data (1995-2010). n=8769 45
Figure 24. Horse mackerel juvenile numbers (<21cm) from hake- survey data (1995-2010). n = 1368 46
Figure 25. Juvenile monk (<21 cm) from hake- survey data (1995-2010) represented as numbers per station. n=263 46
Figure 26. Pelagic (anchovy, sardine, and herring) juveniles numbers (< 8cm) from pelagic-surveys 2002-2011. n=10714 47
Figure 27. Distribution of anchovy eggs (grey) and Larvae (black) from Spanish survey data. n=333 47
Figure 28. Distribution of sardine eggs (grey) and larvae (black) from Spanish survey data. n=333 48
Figure 29. Horse mackerel eggs and larvae from Nansen survey data (1999-2005). n=2811 48
Figure30. Distribution of sardine (grey) and anchovy (black) eggs from SWAPELS survey data (1978-1985). n=265 49
Figure 31. Distribution of sardine eggs (grey) and larvae (black) from Nansen survey data (1999 – 2005). n=2811 49
Figure 32. Dots represent number of species counted per coordinate (lat/long) from the hake-survey data, monk-survey data, and small pelagic-survey n=9116 52

© NMP 2014

tables

Table 1.0: Impact Criteria 4

Table 1.1: Water Column and Sediments. Summary of impact assessment determinations: Re-evaluated following the verification assessment**.** 7

Table 1.2: Fish Mammals and Seabirds. Summary of impact assessment determinations: Re-evaluated following the verification assessment**.** 25

Table 1.3: Macrofauna: Summary of impact assessment determinations: Re-evaluated following the verification assessment**.** 57

Table 1.4: Jellyfish. Summary of impact assessment determinations 75

© NMP 2014

SUMMARY

The verification programme addresses the impacts associated with dredging within the target dredge area SP-1.

The Environmental Impact Assessment (of 2012) concluded, "***The opinion of the specialists and the independent reviewer is that there are presently no identified issues of environmental significance to preclude the dredging of phosphate-enriched sediments from the Mining Licence Area No. 170. In order to verify these conclusions, a programme of work specified by the relevant specialists, has been included in the Environmental Management Programme that will be undertaken prior to the commencement of dredging to substantiate the findings provided in the impact assessment. Going forward, all environmental matters will need to be managed through the environmental management plan."***

An expanded verification programme was undertaken following discussions with and information provided by external reviewers, (as commissioned by the Environmental Commissioner, MET) MFMR and I&APs) during 201 and 2014. NMP's specialist consultants and the independent reviewing parties confirm, based on the results of the verification programme that the assessments as presented in the EIA (2012) are reliable and that these assessments now can be reported with a high degree of confidence.

The impacts assessed in the 2012 EIA are reassessed here. Details of various specialist assessments that allowed for the confirmation of the impact risk and its significance are to be found in the individual specialist reports (Section C). The content and approach to the verification programme and its findings have been subjected to:

1. Independent peer review of the specialist study reports, supporting studies and documentation;
2. Independent review by the University of Namibia of the processes followed during the undertaking of the Verification Programme; and,
3. Independent review of the Verification Programme Report by the CSIR.

The full scope of the verification programme is detailed in Section D, Appendix 4, with the specialists' assessments reported in Section C. The programme considered three main categories of assessment, including:

- Water column and sediments;
- Fish, mammals and seabirds; and,
- Benthic fauna.

These three main categorises of assessment, included a several integrated programmes. A verification programme related to jellyfish (which were assessed in the EIA of 2012) was not undertaken, primarily because of the significance of the four impacts assessed being reported as low (2) and very low (2). However, the impact tables for jellyfish are presented here, since the general outcome of the verification programme has information relevant to the impact assessment of jellyfish.

The verified impact statements of the respective specialists are presented in this section. All confirmed their original assessments with a greater degree of confidence as determined from site-specific data.

© NMP 2014

Overall the level of confidence in the original assessment has been raised from medium to high. Some of the original assessments are unchanged because they were deemed to be of low or no significance with the confidence level being high. A key change with respect to the assessment of fisheries impacts is the reduction of the extent (area of influence) from that of the MLA (2233 km^2) to the specific site SP-1 dredge site (176 km^2).

The significance ratings of the impacts re-evaluated following the completion of the verification programme are presented in the table on pages viii to xi.

© NMP 2014

Water Column and Sediments: Summary of impact assessment determinations: Re-evaluated following the verification assessment.

Reference table number refers to the individual impact table number found in the specialists section.

Ref. Tbl No.	1.1.1	1.1.2	1.1.3	1.1.4	1.1.5	1.1.6	1.1.7	1.1.8	1.1.9	1.1.10	1.1.11
Risk Area	**Vessel Operation**		**Overspill discharge**					**Seabed dredging**			
Impact	**Pollution from wastes**	**Alien spp. in ballast water**	**Turbid plume**	**H_2S toxicity at surface**	**Oxygen deficient water at surface**	**Nutrients added at surface**	**Trace/heavy-metal toxicity at surface**	**Trace-metal toxicity on seabed**	**H_2S toxicity on seabed**	**Lowered oxygen levels on seabed**	**Increase of H_2S flux.**
Extent	Dredge area	National	Dredge area	Dredge area	Dredge area	Dredge area	Dredge area	Annual Mining Area	Dredge area	Annual Mining Area	Dredge area
Duration	Very short term	Short term to permanent	Very short term	Short term	Very short term	Short term	Short term	Short term	Medium term	Medium term	Medium term.
Intensity	No lasting effect	None to serious	No lasting effect	Minor effects	No lasting effect	No lasting effect	Minor effects	Minor effects	Minor effects	Minor effects	Minor effects
Probability	Possible	Possible	Possible	Possible	Improbable	Possible	Possible	Possible	Possible	Possible	Improbable
Status	Negative	Negative	Negative	Negative	Negative	Neutral	Negative	Negative	Negative	Negative	Negative
Significance (no mitigation)	None	Can be high	Low	Low	Low	None	Low	Low	Low	Low	Low
Mitigation	System maintenance	IMP guidelines	Built in	None possible	Non	None possible	None possible	None possible	None possible	Not possible	n/a
Significance (with mitigation)	None	None	Low	Low	Low	None	Low	Low	Low	Low	Low
Confidence level 2012	High	High	High	Medium	High	Medium	Medium	Medium	Medium	High	Medium
Re-evaluated 2014 confidence level	**High**	**High**	**High**	**High**	**High**	**High**	**High**	**High**	**High**	**High**	**High**
Reason	MARPOL 73/78 discharge standards apply	IMO guidelines for ballast water apply	Dredge area >20mg/ℓ suspended sediment concentration. Plume disperses 1 to 2 days	Mine site sediment property data indicate low H_2S presence, pyrite sulphide will have low solubility	Mixing factors are therefore <1%; and dissolved oxygen concentration reductions will be negligible (<0.1ml/ℓ).	Mine site sediment pore water volumes are low	Mine area Heavy metals have low solubility and bioavailability, trophic transfers are attenuated at primary consumer level	Mine area Heavy metals have low solubility and bioavailability, dredging should not increase exposures	Mine site sediment property data indicate low H_2S presence	POM in sediments is relatively refractory	Mine site sediment property data indicate low H_2S presence and release from iron pyrites should be low.

© NMP 2014

Fish Mammals and Seabirds: Summary of impact assessment determinations: Re-evaluated following the verification assessment.

Reference table number refers to the individual impact table number found in the specialists section.

Ref. Tbl No.	1.2.1	1.2.2	1.2.3	1.2.4	1.2.5
Risk Area	**Seabed dredging: Fish Mammals and Seabirds**				
Nature of the impact	Fishing operations	Ecologically important species	Recruitment of key commercial species	Biodiversity	Seabirds and Mammals
Extent 2012	MLA	MLA	MLA	MLA	MLA
Extent re assessed 2014	**Specific mine site**	**Specific mine site**	**MLA**	**Specific mine site**	**Specific mine site**
Duration	Long term	Permanent	Permanent	Permanent	Long term
Intensity	Serious effect	Moderate effect	Minor effect	Minor effect	Minor effect
Probability	Definite	Highly probable	Improbable	Improbable	Probable
Status (- ve of + ve)	Negative	Negative	Negative	Negative	Negative
Significance (no mitigation)	Medium	Medium	Low	Low	Medium
Significance (with mitigation)	Medium to low	Medium	Low	Low	Low
Confidence level 2012	High	Low to medium	Low to medium	Low to medium	Medium
Re-evaluated 2014 confidence level	**High**	**High**	**High**	**High**	**High**

© NMP 2014

Macrofauna: Summary of impact assessment determinations: Re-evaluated following the verification assessment.

Reference table number refers to the individual impact table number found in the specalists section.

Ref. Tbl. No.	1.3.1	1.3.2	1.3.3	1.3.4	1.3.5	1.3.6	1.3.7	1.3.8	1.3.9
Risk Area	**Seabed dredging: Benthic Macrofauna**								
Nature of the impact	**Sediment removal: benthos re establishment**	**Exploration activities and removal of benthos**	**Change of hydrographical conditions**	**Removal of sulphur oxidizing mats**	***Clostridium botulinum exposure***	**Sediment smothering benthos: Drag head**	**Benthos smothering: Dredge overspill plume**	**Nutrients added at surface: overspill plume**	**Increase of H_2S flux.**
Extent	Dredge area	Dredge area	Specific mine site	Specific mine site	Specific mine site	Dredge area	Local to regional	Local	Local
Duration	Long term >20 years	Short term	Long term >20 years	Medium to long term	Sort term	Very short	Very short	Very short	Short term
Intensity	Moderate to serious	No lasting effects	Moderate to serious	Moderate to minor	Serious	Minor	Minor	Minor	Moderate
Probability	Definite	Probable	Probable	Improbable	Improbable	Highly probable	Probable	Possible	Probable
Status	Negative	Negative	Negative	Negative	Negative	Negative	Negative	Negative	Negative
Significance (no mitigation)	Medium	Non	Medium	Low	Low	Low	Low	Low	Low
Mitigation	Leave residual sediment layer / un mined areas	None required	Leave residual sediment layer / un mined areas	Non	Non	Non	Non	Non	Non
Significance (with mitigation)	Medium	None required	Low to Medium	Low	Low	None necessary	Low	Low	Low
Confidence level 2012	Medium	High	Medium	Medium	Medium	High	Medium	Medium	Medium
Re-evaluated 2014 confidence level	**High**	**No change**	**High**	**High**	**No change**	**No change**	**No change**	**High**	**High**

© NMP 2014

Jellyfish. Summary of impact assessment determinations: A verification assessment specifically related to jellyfish was not undertaken.

Reference table number refers to the individual impact table number found in the specialists section.

Ref. Tbl No.	1.4.1	1.4.2	1.4.3	1.4.4
Risk Area	**Dredging: Jellyfish**			
Nature of the impact	Blocking sea water intakes of vessel	H_2S mortalities to Jellyfish	Turbidity cause mortalities	Hard substrate exposed
Extent	Dredge event	Dredge event	Dredge event	Annual mining area
Duration	Extremely short term	Extremely short term	Extremely short term	Very short term
Intensity	No lasting effects	No lasting effects	Minor effects	Minor effects
Probability	Highly probable	Possible	Rare	Rare
Status (- ve of + ve)	Negative (to Jellyfish)	Negative (to Jellyfish)	Negative (to Jellyfish)	Positive (to jellyfish)
Significance (no mitigation)	Low	Low	Very low	Low
Significance (with mitigation)	Very low	Low	Very low	Very low
Confidence level 2012	High	Low	Low	High
Re-rated 2014 confidence level	**High**	**Low**	**Low**	**High**

© NMP 2014

Introduction

In September 2011 an impact assessment for the proposed offshore phosphate dredging project was initiated and submitted to the Environmental Commissioner on 12 of April 2012. Following processes guided by the office of the Environmental Commissioner and the management commitments of the 2012 EMP, Namibian Marine Phosphate undertook through their specialist consultants a Verification Programme during 2013 to 2014. The impacts as described in the EIA of 2012 were reconsidered in light of the information gathered during the Verification Programme. The collection and interpretation of these site-specific data (collected from within ML 170, primarily the target dredge site SP-1) has served to increase the robustness of the determinations by the specialists, where they now can confirm with a high degree of confidence their assessments made in 2012.

Within this section an effort has been made to provide an all-inclusive report, eliminating the need for the reader and reviewers to consult the 2012 EIA. However, that EIA was a significant report in its own right, and should not be overlooked.

The assessment of impacts is the primary component of an environmental impact assessment (EIA). Impacts are evaluated at the individual and at the project level. The Environmental Commissioner by issuing the Environmental Clearance Certificate (Record of Decision) becomes the final assessor of risk at both the individual and the project level. These risks / impacts (residual) are managed through the requirements listed in the Environmental Management Plan (EMP). The EMP is a dynamic document, containing performance criteria that may be adjusted as a result of findings of the monitoring programme detailed in the EMP. These adjustments require motivation both from the licence holder and approval by the regulatory authorities.

The potential primary project level risks (impacts) have been identified as:

1. Possible release of toxins (from the exposed sediments) into the water column from dredge overspill (tailings plume) or from a benthic plume generated from the engagement of the dredge suction and cutting head with the seabed sediments. The primary concerns here being: contamination of the water column, contamination of the fauna and flora that live within it, and the consequences to the ecosystem, to other users, i.e. the fishing industry, and the population that it serves;
2. The removal of marine sediments (dredging of the seabed) and the loss of the functions and services that this area of sediment provides to the ecosystem and consequently a loss of benefits to the users of these services. Primarily this is the fishing industry and the population that it serves;
3. The intrinsic loss of natural (undisturbed) ecosystem functions and services caused by the dredging project.

Project level risks (impacts) are evaluated by considering the individual level risks (impacts) and the determined significance of these risks (impacts). The individual risks (impacts) and their significance originally were assessed in the 2012 EIA. The significance of the impact was determined from the combined assessment of the following criteria: 1) Extent; 2) Duration; 3) Intensity; and 4) Probability. The criteria for assessment of 1 to 4 against which each of the impacts are evaluated is presented in Table 1.0.

The significance assessment of the risks (impacts) at the project and individual levels were collectively identified as being medium to low (risk). A criticism of these determinations was that there were

© NMP 2014

inadequate data collected from the Mining Licence Area (ML 170) and target dredge sites (SP-1, SP-2 and SP-3) to ensure confidence in the assessments provided. This criticism levelled at the impact assessments by external review parties and the authorities was shared in varying degrees (dependent on the individual impact assessed and the source of information for its determination) by the consultants who assessed the risks (impacts). This is reflected in the levels of confidence (in their assessment) that the consultants expressed for the particular impact assessed.

Overall the level of confidence in the original assessments has been raised from medium to high. Some of the original assessments are unchanged because they were deemed to be of low or no significance with the confidence level being high. A key change with respect to the assessment of fisheries impacts is that the reduction of the extent (area of influence) from that of the MLA (2233 km^2) to the specific site SP-1 dredge site (176 km^2).

The varying levels of confidence can be ascribed to the paucity of site-specific data on which the interpretations were made. Despite this the consultants determined that their assessments were robust. Steffani in her assessment of the benthic macrofauna comments *"In general, the confidence level in the assessments is medium, as most of the impact evaluations are based on assumptions that are derived from publicly available literature data, whereas data from ML 170 itself are very limited. A verification survey is therefore critical to confirm these assumptions."* This sentiment was similarly expressed by the rest of the consultant team.

The Verification Programme was undertaken to collect data from the target dredge area (SP-1), in order that the specialist consultants could re-evaluate (improve the level of confidence) their findings as detailed in the 2012 EIA. Not only did these data allow for the improvement of the levels of confidence in the assessed work but importantly will allow the authorities, external review parties, and I&APs to re-assess their criticisms of the original 2012 EIA.

In the following sections the impact tables from the 2012 EIA are reproduced in their original format, with the findings of 2012 listed against those of the 2013 – 2014 verification assessment.

© NMP 2014

Impact Criteria

In order that the reader is not required to consult the original EIA (2012), the criteria for the assessment of significance is replicated in this section.

The Assessment Procedure and the Determination of Significance

To ensure consistency in the evaluation of the impacts the specialists were provided with a set of definitions to apply for their determination of the significance of the impacts. In consultation with the specialists the set of definitions was revised from that detailed in the scoping report. This was done so as to accommodate for the extreme scales of potential impacts as identified during their investigations. The specialists in their evaluation of the impacts applied the revised definitions. The impact assessments are based on the professional opinions of the specialists, fieldwork and desk top analysis (available information). The definitions are identified as robust and in line with commonly applied impact criteria used in Southern Africa and recognised internationally.

The following methods have been used to determine the significance rating of impacts identified in this specialist study:

1. Description of impact - reviews the type of effect that a proposed activity will have on the environment;
2. What will be affected; and
3. How will it be affected.

Points 1 to 3 above are to be considered / evaluated in the context of the following impact criteria:

- *Extent*;
- *Duration*;
- *Probability*; and
- *Intensity / magnitude*.

These impact criteria are to be applied as prescribed in the table below:

© NMP 2014

Table 1.0: Impact Criteria

Impact Criteria:						
Extent	**Dredge Area** Per vessel cycle i.e. ~66,000 m^2 or 6.6 ha	**Annual Mining Area** Up to 3 km^2	**Specific Mine Site** (SP1 or SP2) each is 22x8 km or 176 km^2	**Local** 25-50 km or 2,000 km^2- 8,000 km^2	**Regional** 50-100 km or 8,000 km^2 – 30,000 km^2	**National** 100 km to EEZ (200 nautical miles)[1] 100 to 370 km, or >30,000 km^2

Duration	**Very Short Term** 3 days	**Short term** 3 days – 1 year	**Medium term** 1 - 5 years	**Long term** 5 – 20 years	**Permanent** > 20 years (life of mine)

Intensity/ Magnitude	**No lasting effect** No environmental functions and processes are affected	**Minor effects** The environment functions, but in a modified manner	**Moderate effects** Environmental functions and processes are altered to such extent that they temporarily cease	**Serious effects** Environmental functions and processes are altered to such extent that they permanently cease
Probability	**Improbable**	**Possible**	**Probable**	**Highly Probable/ Definite**

The status of the impacts and degree of confidence with respect to the assessment of the significance are stated as follows:

Status of the impact: A description as to whether the impact is positive (a benefit), negative (a cost), or neutral.

Degree of confidence in predictions: The degree of confidence in the predictions, based on the availability of information and specialist knowledge. This has been assessed as high, medium or low.

Based on the above considerations, the specialist provides an overall evaluation of the significance of the potential impact, which is described as follows:

[1] 1 nautical mile = 1,85 kilometres

© NMP 2014

	None	Low	Medium	High
Impact Significance	A concern or potential impact that, upon evaluation, is found to have no significant impact at all.	Any magnitude, impacts will be localised and temporary Accordingly the impact is not expected to require amendment to the project design	Impacts of moderate magnitude locally to regionally in the short term Accordingly the impact is expected to require modification of the project design or alternative mitigation	Impacts of high magnitude locally and in the long term and/or regionally and beyond Accordingly the impact could have a 'no go' implication for the project unless mitigation or re-design is practically achievable

Furthermore, the following are being considered:

- Impacts are described both **before** and **after** the proposed **mitigation** and management measures have been implemented;
- Where possible the impact evaluation takes into consideration the **cumulative effects** associated with this project. Cumulative impacts can occur from the collective impacts of individual minor actions over a period of time and can include both direct and indirect impacts;
- **Mitigation / management actions:** Where negative impacts were identified, the specialists specified practical mitigation measures (i.e. ways of avoiding or reducing negative impacts); and
- **Monitoring (forms part of mitigation):** Specialists recommend monitoring requirements to assess the effectiveness of mitigation actions, indicating what actions are required, the timing and frequency thereof.

© NMP 2014

B1.1 VERIFIED ASSESSMENT OF IMPACTS: SEDIMENTS AND WATER COLUMN

The verification programme addresses the impacts associated with dredging within the target dredge site SP-1.

INTRODUCTION

The Sediments and Water Column Specialist Study (Carter in Midgely, 2012) conducted within the framework of the 2012 EIA identified impacts to the water column and sediments that can be expected from the proposed Sandpiper Phosphate Project and assessed their significance. For seven of the impacts assessed, the confidence levels were only rated medium since data directly from the target area (SP-1) were lacking. The verification survey was specifically designed to tackle this issue, and to verify whether the assessment rating will remain unchanged in view of the newly acquired empirical data. These data were primarily of a biogeochemical nature and are dealt with in the Verification Survey Programme Report (Section C, Chapter C2.0). A series of eleven impact tables which present the impacts as they were assessed in original 2012 EIA and as re-evaluated using site-specific information gathered during 2013 are presented below.

A total of eleven negative impacts were identified in the original assessment study with six impacts having medium significance, and the remainder high. In sum, all changes to the original assessments centre on the level of confidence, increasing the level from medium to high as the verification survey largely confirmed the assumptions on which the assessments were based. This applied to six of the impact assessments while four remained unchanged.

© NMP 2014

Table 1.1: Water Column and Sediments. Summary of impact assessment determinations: Re-evaluated following the verification assessment**.** Reference table number refers to the individual impact table number found in the specialists section.

Ref. Tbl No.	1.1.1	1.1.2	1.1.3	1.1.4	1.1.5	1.1.6	1.1.7	1.1.8	1.1.9	1.1.10	1.1.11
Risk Area	**Vessel Operation**		**Overspill discharge**					**Seabed dredging**			
Impact	**Pollution from wastes**	**Alien spp. In ballast water**	**Turbid plume**	**H_2S toxicity at surface**	**Oxygen deficient water at surface**	**Nutrients added at surface**	**Trace/heavy-metal toxicity at surface**	**Trace-metal toxicity on seabed**	**H_2S toxicity on seabed**	**Lowered oxygen levels on seabed**	**Increase of H_2S flux.**
Extent	Dredge area	National	Dredge area	Dredge area	Dredge area	Dredge area	Dredge area	Annual Mining Area	Dredge area	Annual Mining Area	Dredge area
Duration	Very short term	Short term to permanent	Very short term	Short term	Very short term	Short term	Short term	Short term	Medium term	Medium term	Medium term.
Intensity	No lasting effect	None to serious	No lasting effect	Minor effects	No lasting effect	No lasting effect	Minor effects	Minor effects	Minor effects	Minor effects	Minor effects
Probability	Possible	Possible	Possible	Possible	Improbable	Possible	Possible	Possible	Possible	Possible	Improbable
Status	Negative	Negative	Negative	Negative	Negative	Neutral	Negative	Negative	Negative	Negative	Negative
Significance (no mitigation)	None	Can be high	Low	Low	Low	None	Low	Low	Low	Low	Low
Mitigation	System maintenance	IMP guidelines	Built in	None possible	Non	None possible	None possible	None possible	None possible	Not possible	n/a
Significance (with mitigation)	None	None	Low	Low	Low	None	Low	Low	Low	Low	Low
Confidence level 2012	High	High	High	Medium	High	Medium	Medium	Medium	Medium	High	Medium
Re-evaluated 2014 confidence level	High	High	High	High	High	High	High	High	High	High	High
Reason	MARPOL discharge standards apply	IMO guidelines for ballast water apply	Dredge area >20 mg/ℓ suspended sediment concentration. Plume disperses 1 to 2 days	Mine site sediment property data indicate low H_2S presence, pyrite sulphide will have low solubility	Mixing factors are therefore <1%; and dissolved oxygen concentration reductions will be negligible (<0.1 ml/ℓ).	Mine site sediment pore water volumes are low	Mine area Heavy metals have low solubility and bioavailability, trophic transfers are attenuated at primary consumer level	Mine area Heavy metals have low solubility and bioavailability, dredging should not increase exposures	Mine site sediment property data indicate low H_2S presence	POM in sediments is relatively refractory	Mine site sediment property data indicate low H_2S presence and release from iron pyrites should be low.

© NMP 2014

Table 1.1.1 Impact 1: Discharge to Sea of Ships Wastes: Potential impact of releasing vessel wastes into the sea.

Note: Original assessment table (Carter in Midgley 2012) for the impact assessment.

Nature of the impact	**1: Potential deterioration in water quality from discharges to sea of wastes such as oily water, sewage, food, grey water, from the dredger.**
Extent	Within the actual **dredge area** per event (~6.6 ha)
Duration	The effects of the event are "**very short**" because normal mixing would rapidly dilute the discharge material
Intensity	**No lasting effect**, because effects will not be measurable.
Probability (of pollution)	**Possible**
Status	**Negative**
Significance (no mitigation)	**None**
Mitigation	Ensure vessel discharge systems are in good working order and do not malfunction.
Significance (with mitigation)	**None**
Confidence level	**High**

Explanation: (Table 1.1.1: Impact 1)

Original EIA – Impact assessment
Discharges to sea from the dredger of wastes such as oily water, sewage, food and grey water occur under normal ship operations. These wastes are controlled in terms of MARPOL, to which convention Namibia is a signatory. This limits what can be disposed of to sea, and specifies monitoring and record keeping required. Therefore compliance with these regulations will, under normal operating conditions, limit *pollution* effects in the water column.

Post Verification Programme – Re-evaluated impact assessment
A re-evaluated assessment of this impact was not required in terms of the scope of the verification programme. The original assessment stands.

© NMP 2014

Table 1.1.2 Impact 2: Exchange of Ballast Water: Alien marine species may displace indigenous species and reduce indigenous biodiversity.

Note: Original assessment table (Carter in Midgley 2012) for the impact assessment.

Nature of the impact	**2: Alien marine species may displace indigenous species and reduce indigenous biodiversity and/or affect aquaculture and/or aquaculture products.**
Extent	**National**: introduced aliens can spread throughout central and northern Namibia (from the Lüderitz upwelling cell to the Angola Benguela front).
Duration	**Unknown**, depends on the introduced organisms but likely to be very long term or permanent when an introduced alien becomes invasive
Intensity	**None to serious.** Unknown, depends on behaviour of the introduced organisms.
Probability	**Possible** (i.e. it can occur)
Status	**Negative**
Significance (no mitigation)	Can be high – ecosystem changing
Mitigation	Follow IMO guidelines on ballast water management
Significance (with mitigation)	**None.** (Alien introductions would become "improbable" but if introductions were to occur the consequences (significance) would still be high).
Confidence level	**High**

Explanation: (Table 1.1.2: Impact 2)

Original EIA – Impact assessment

The dredger to be used will probably be travelling unladen into the mining area from a foreign port. For safe navigation it will have taken on ballast water which will be gradually discharged during the initial dredging cycle. Uncontrolled ballast water discharges have been identified as important vectors for alien and/or noxious species (IMO, http://www.imo.org).

Post Verification Programme – Re-evaluated impact assessment
A re-evaluated assessment of this impact was not required in terms of the scope of the verification programme. The original assessment stands.

© NMP 2014

Table 1.1.3 Impact 3: Increased Suspended Sediment Concentrations: Dredging generates plumes of suspended sediments that adversely affect organisms in the water column.

Note: Original assessment table (Carter in Midgley 2012) for the impact assessment.

Nature of the impact	**3: Dredging generates plumes of suspended sediments that adversely affect organisms in the water column**
Extent	**Dredge Area** - > 20 mg/ℓ suspended sediment concentration
Duration	**Very short term** – plume disperses within 1-2 days
Intensity	**No lasting effect** – within water quality guidelines for suspended sediment (chronic effects ensue after 3 days exposure to > 20 mg/ℓ)
Probability	**Possible**
Status	**Negative**
Significance (no mitigation)	**Low**
Mitigation	Built in, with discharge below dredger's hull (10-15 m below sea surface)
Significance (with mitigation)	**Low**
Confidence level	**High**

Explanation: (Table 1.1.3: Impact 3)

Post Verification Programme – Re-evaluated impact assessment
A re-evaluated assessment of this impact was not required in terms of the scope of the verification programme. The original assessment stands.

© NMP 2014

Table 1.1.4 Impact 4: Changed Biogeochemical Properties of near Surface Waters: Sulphidic sediment pore-water entrained in the dredged sediment is discharged with the over-spill water.

Note: Original assessment table (Carter in Midgley 2012) for the impact assessment (left column) and the re-evaluated impact assessment after the verification programme (right column).

Nature of the impact	**4: Sulphidic sediment pore-water entrained in the dredged sediment is discharged with the over-spill water thereby affecting organisms in the water column**	
Report	***Impacts assessed EIA (2012)***	***Impacts re-evaluated: Verification programme***
Extent	**Dredge area** – the amount of H_2S entrained will be minimal due to predicted low concentrations in the target dredge sediments.	b – the amount of H_2S entrained will be minimal due to apparent low concentrations in the target dredge sediments evident from proxy measurements.
Duration	**Short term** – because entrained H_2S will de-gas in the dredger hopper (turbulence) and rapidly dilute if released to the upper water column; however if toxicity effects do occur recovery periods can be longer than 3 days but definitely less than 1 year.	
Intensity	**Minor effects** – there may be short term toxicity effects on plankton (regeneration rates for plankton are days to weeks)	
Probability	**Possible**	
Status	**Negative**	
Significance (no mitigation)	**Low**	
Mitigation	None possible	
Significance (with mitigation)	**Low**	
Confidence level	**Medium** – the assessment relies on a prediction of a low H_2S concentration in the target dredge area sediments.	
Confidence level Post Verification Assessment		**High**: Mine site sediment property data indicate low H_2S presence, pyrite sulphide will have low solubility

Explanation: (Table 1.1.4: Impact 4)

Post Verification Programme – Re-evaluated impact assessment

Measurements of mine site sediment properties indicate that the probability of the presence of appreciable concentrations of H_2S in the sediments is low. This empirical data for the site supports the conclusions initially reached in the 2012 EIA assessment. Evaluations of potential sulphide generation from oxidation of iron pyrite following translocation of seabed sediments to the upper water column in the dredging process indicate that negligible amounts will be liberated and that associated effects on dissolved oxygen concentrations will be minimal. The latter is due to elemental sulphur being the end-point of the oxidation of sulphide as opposed to sulphate.

© NMP 2014

Table 1.1.5 Impact 5: Changed Biogeochemical Properties of Surface Waters: Potential impact of lower oxygen levels in overflow water.

Note: Original assessment table (Carter in Midgley 2012) for the impact assessment.

Nature of the impact	**5: Hypoxic/ anoxic bottom water is entrained in the discharged overflow water so reducing dissolved oxygen concentrations in the upper water column where it can affect organisms.**
Extent	**Dredge area**
Duration	**Very short – as mixing will reduce the oxygen debt.**
Intensity	**No lasting effect** – in a worst case scenario approximately 31 680 m^3 of anoxic water may be discharged along a 4 km long dredge path during dredging. This will be mixed into approximately $5x10^6$ m^3 of normal oxic water. Mixing factors are therefore <1%; and dissolved oxygen concentration reductions will be negligible (< 0.1 ml/ℓ). Such levels are not generally measurable at sea.
Probability	**Improbable**
Status	**Negative**
Significance (no mitigation)	**None**
Mitigation	N/a
Significance (with mitigation)	**None**
Confidence level	**High**

Explanation: (Table 1.1.5: Impact 5)

Original EIA – Impact assessment
In a worst case scenario approximately 31 680 m^3 of anoxic water may be discharged along a 4 km long dredge path during dredging. This will be mixed into approximately $5x10^6$ m^3 of normal oxic water. Mixing factors are therefore <1%; and dissolved oxygen concentration reductions will be negligible (< 0.1 ml/ℓ).

Post Verification Programme – Re-evaluated impact assessment
A re-evaluated assessment of this impact was not required in terms of the scope of the verification programme. The original assessment stands.

© NMP 2014

Table 1.1.6 Impact 6: Changed Biogeochemical Properties of Surface Waters: Potential impact of higher nutrient levels in overflow water.

Note: Original assessment table (Carter in Midgley 2012) for the impact assessment (left column) and the re-evaluated impact assessment of the verification programme (right column).

Nature of the impact	**6: Increased availability of nutrients (ammonium and phosphorus) promote phytoplankton growth. Following senescence, the phytoplankton will add to the POM flux to the seabed eventually further reducing dissolved oxygen concentrations through remineralisation**	
Report	***Impacts assessed EIA (2012)***	***Impacts re-evaluated: Verification programme***
Extent	**Dredge area**	
Duration	**Short term**	
Intensity	**No lasting effect** (silicate is probably the limiting nutrient for diatoms)	**No lasting effect (**silicate is probably the limiting nutrient for diatoms) and amounts of nutrients transferred to the euphotic zone will be low due to low pore water volumes
Probability	**Possible**	
Status	**Neutral**	
Significance (no mitigation)	**None**	
Mitigation	None possible	
Significance (with mitigation)	**None**	
Confidence level	**Medium** – due to there being no nutrient data specific to the proposed dredging areas	
Confidence level Post Verification Assessment		**High**: Mine site sediment pore water volumes are low

Explanation: (Table 1.1.6: Impact 6)

Post Verification Programme – Re-evaluated impact assessment

Measurements of sediment properties in the proposed dredge site show that the subsurface sediment pore water contained moderate nitrate-nitrogen concentrations but high phosphate-phosphorus concentrations and that the pore waters showed a considerable departure from the water column Redfield ratio observed in the survey area (8.2 vs 17.7) The measured moisture content of the sediment was low, however, indicating that the affected pore water volume is also low (~35 litres/m^3 sediment). Dilution in the dredged sediment slurry and with surface waters after discharge from the dredger will limit nutrient enrichment and consequent elevated phytoplankton production.

© NMP 2014

Table 1.1.7 Impact 7: Changed Biogeochemical Properties of Surface Waters: Potential impact of higher levels of heavy metals in overflow water.

Note: Original assessment table (Carter in Midgley 2012) for the impact assessment (left column) and the re-evaluated impact assessment after verification programme (right column).

Nature of the impact	**7: Heavy metals (cadmium and nickel) bound in the dredged sediment are discharged with the over spill water thereby affecting organisms in the water column.**	
Report	***Impacts assessed EIA (2012)***	***Impacts re-evaluated: Verification programme***
Extent	**Dredge area** – the affected area would be that of the suspended sediment plume.	
Duration	**Short term** – equivalent to the life of the plume.	
Intensity	**Minor effects** – there may be short term toxicity effects on plankton specifically from cadmium (240 hr EC_{50} equals >1000 µg/ℓ). Regeneration rates for plankton are days to weeks.	
Probability	**Possible** but unlikely due to required exposure periods being much longer than the predicted plume durations (< 40 hours) as the 240 hr EC_{50} concentration is >1000 µg/l).	**Possible** but direct toxicity effects are unlikely due to required exposure periods being much longer than the predicted plume durations (< 40 hours) as the 240 hr EC_{50} concentration is >1000 µg/l) and measurements indicate that metal solubilities are low. Toxicity effects due to ingestion would be limited to the primary consumer level (zooplankton) as trophic transfers are constrained by low absorption efficiencies in fish..
Status	**Negative**	
Significance (no mitigation)	**Low**	
Mitigation	None possible	
Significance (with mitigation)	**Low**	
Confidence level	**Medium** – due to there being no trace metal data specific to the proposed dredging areas	
Confidence level Post Verification Assessment		**High**: Mine area Heavy metals have low solubility and bioavailability, trophic transfers are attenuated at primary consumer level

Explanation: (Table 1.1.7: Impact 7)

Post Verification Programme – Re-evaluated impact assessment

Heavy metal elutriation measurements conducted on sediment samples retrieved from the proposed dredge site confirm that solubilities are low. Assessment of trophic uptake by particle ingestion and trophic transfers in the pelagic ecosystem (primarily zooplankton to fish) shows that these are inefficient due to the combined effects of low effective heavy metal assimilation in copepods (the dominant zooplankton group) and low assimilation efficiency in fish.

© NMP 2014

Table 1.1.8 Impact 8: Changes to Biogeochemical Properties of Bottom Waters: Potential impact of exposing heavy metals on the seabed

Note: Original assessment table (Carter in Midgley 2012) for the impact assessment (left column) and the re-evaluated impact assessment after the verification programme (right column).

Nature of the impact	**8: Heavy metals held within the target dredge area sediments are remobilized; they become bio-available through exposure to the overlying water during dredging with deleterious effects on filter and/or deposit feeding benthos.**	
Report	***Impacts assessed EIA (2012)***	***Impacts re-evaluated: Verification programme***
Extent	**Annual dredging area**	
Duration	**Short term** – bio-availability will reduce with time as heavy metals become bound into the sediments again.	
Intensity	**Minor effect** - the toxicity risk is from cadmium and /or nickel. Concentrations are below the probable effects level and therefore the risks of toxicity effects are considered to be low as is the potential for bio-magnification in the food chain.	
Probability	**Possible**	
Status	**Negative**	
Significance (no mitigation)	**Low**	
Mitigation	None possible	
Significance (with mitigation)	**Low**	
Confidence level	**Medium** – due to there being no trace metal data specific to the proposed dredging areas	
Confidence level Post Verification Assessment		**High**: Mine area Heavy metals have low solubility and bioavailability, dredging should not increase exposures

Explanation: (Table 1.1.8: Impact 8)

Post Verification Programme – Re-evaluated impact assessment

- Demersal fish inhabiting sedimentary areas with relatively high authigenic cadmium can have elevated concentrations of cadmium in their livers compared with the same species from areas with lower authigenic cadmium levels with take-up probably via predation on benthic invertebrates.
- Trophic transfers of heavy metals in pelagic food chains, phytoplankton/zooplankton (mainly copepods)/fish, show bio-diminution, as opposed to bio-magnification, due to the efflux of metals by copepods and low assimilation efficiencies in fish. In contrast benthic food chains comprising deposit feeders and predatory whelks show bio-magnification of metal concentrations primarily due to effective sequestration of dietary metals by whelks.

© NMP 2014

- As Namibian continental shelf sediments are characterized by naturally elevated cadmium concentrations and, although empirical data are apparently lacking, it is probable that resident demersal fish such as hake and monkfish would naturally have elevated cadmium concentrations in their livers. If present these patterns should extend across the region and the proposed NMP mining operations would not affect them. Trophic transfers of heavy metals associated with sediment plumes generated in the water column by the proposed mining would include ingestion/take-up by planktonic copepods and be interrupted at this stage. Note that the diminution would be partly due to rates of digestion of food particles being longer than gut passage leading to loss of metals in fecal pellets. Sinking rates of these are high and metals would be returned rapidly (hours to days) to the seafloor.

Hence although the process would probably occur through the dredging activities trophic transfers into especially fish are considered to be limited in extent and intensity.

© NMP 2014

Table 1.1.9 Impact 9: Changes to Biogeochemical Properties of Bottom Waters: Potential impact of releasing hydrogen sulphide from the seabed

Note: Original assessment table (Carter in Midgley 2012) for the impact assessment (left column) and the re-evaluated impact assessment after the verification programme (right column).

Nature of the impact	**9: Sulphidic sediment pore-water is exposed by dredging, and the flux of dissolved H_2S into the lower water column is increased, so affecting benthos.**	
Report	***Impacts assessed EIA (2012)***	***Impacts re-evaluated: Verification programme***
Extent	**Dredge area** – the amount of H_2S released will be minimal due to predicted low concentrations in the target dredge sediments.	**Dredge area** –the amount of H_2S released will be minimal due to low concentrations estimated from proxy measurements and measured low volumes of pore water present in the mine target area sediments.
Duration	**Medium term** –pulses of H_2S escaping from the trench walls will be extremely short term with toxicity effects on benthos being experienced over benthos life cycles.	
Intensity	**Moderate effects**	**Minor effects**
Probability	**Possible**	
Status	**Negative**	
Significance (no mitigation)	**Low**	
Mitigation	None possible	
Significance (with mitigation)	**Low**	
Confidence level	**Medium** – the assessment relies on a prediction of low H_2S in the target dredge area sediments.	
Confidence level Post Verification Assessment		**High**: Mine site sediment property data indicate low H_2S presence

Explanation: (Table 1.1.9: Impact 9)

Post Verification Programme – Re-evaluated impact assessment

Measurements of proxy variables indicative of presence or absence of H_2S, AVS, POM C/N, sediment pore water nitrate-nitrogen and sediment oxidation/reduction potential (ORP) all show that, at the time of measurement, H_2S concentrations in the pore water were low. Measured pore water volumes were also low, a variable likely to be stable over time in the subsurface sediments, and therefore even if H_2S concentrations were relatively high mass flux to the adjacent water body would be low. Consequently effects on resident biota would also be low.

© NMP 2014

Table 1.1.10 Impact 10: Changes to Biogeochemical Properties of Bottom Waters: Potential impact of exposing anoxic sediment surfaces on the seabed

Note: Original assessment table (Carter in Midgley 2012) for the impact assessment (left column) and the re-evaluated impact assessment after the verification programme (right column).

Nature of the impact	**10: Exposure of anoxic sediments by dredging reduces the already low concentrations of oxygen that occur in the lower water column so affecting resident biota, primarily benthos.**	
Report	***Impacts assessed EIA (2012)***	***Impacts re-evaluated: Verification programme***
Extent	**Annual dredging area** – it is expected that oxygen distributions that existed prior to dredging would re-establish themselves with time, and the effects on benthos will diminish.	
Duration	**Medium term**	
Intensity	**Minor effects** – The area is already identified as being hypoxic and therefore any additional effects from dredging will be relatively small.	**Negligible effects** – measurement of sediment properties in the target mine area indicate that they are severely hypoxic as opposed to being anoxic.
Probability	**Possible**	
Status	**Negative**	
Significance (no mitigation)	**Low**	
Mitigation	Not possible	
Significance (with mitigation)	**Low**	
Confidence level	**High** - the supporting evidence about sediment properties in the target dredge areas is robust.	
Confidence level Post Verification Assessment		**High**: POM in sediments is relatively refractory

Explanation: (Table 1.1.10: Impact 10)

Post Verification Programme – Re-evaluated impact assessment

The presence of anoxic sediments in the dredge area at the time of the verification survey was not apparent from the physical appearance of the grab (surficial) and gravity core (subsurface) layers nor was it indicated by measurements of sediment properties. The presence of large epibenthic organisms revealed by demersal fish trawls in and adjacent to the target mine site are also indicative of the absence of anoxic sediments. Thus risks of severe disruptions to lower water column dissolved oxygen concentrations and effects on biota are considered to be unlikely.

© NMP 2014

Table 1.1.11 Impact 11: Changes to Biogeochemical Properties of Bottom Waters: Potential impact of removing the thio-bacteria mat

Note: Original assessment table (Carter in Midgley 2012) for the impact assessment (left column) and the re-evaluated impact assessment after the verification programme (right column).

Nature of the impact	**11: Removal of thio-bacteria mats by dredging increases the flux of H_2S to the lower water column.**	
Report	***Impacts assessed EIA (2012)***	***Impacts re-evaluated: Verification programme***
Extent	**Dredge area** – the footprint of physical disturbance.	
Duration	**Long term** – the overall amount of H_2S in the dredge furrow sediments has been reduced and requires significant POM flux re-establish itself; only then could the thiobacteria return.	**Long term** – the overall amount of H_2S in the dredge furrow sediments is estimated to be low from measured proxies. The establishment of a significant H2S flux would require significant POM flux; only then could the thiobacteria return.
Intensity	**Minor effects**	**Negligible effects**
Probability	Possible – Thiobacterial mats have been observed at depth ranges similar to the proposed dredging areas so despite predicted low H_2S flux rates there can be a net supply of this compound to the lower water column until re-establishment of these thiobacterial mats.	
Status	**Negative**	
Significance (no mitigation)	**None**	
Mitigation	n/a	
Significance (with mitigation)	**None**	
Confidence level	**Medium** – the assessment relies on a prediction of low H_2S in the target dredge area sediments.	
Confidence level Post Verification Assessment		**High**: Mine site sediment property data indicate low H_2S presence and release from iron pyrites should be low.

Explanation: (Table 1.1.11: Impact 11)

Post Verification Programme – Re-evaluated impact assessment

Concentrations and thus possible fluxes of H_2S in sediment pore water are estimated to be low from measurements of proxy variables within the sediments in the target dredge area. Circumstantial evidence in support of this is the absence the large sulphate oxidising bacteria from the survey area during the period of the thiobacteria survey July/August 2014. Further, evaluation of pyrite-S mobilisation from sediments indicate that this is low. Consequently H_2S fluxes to the lower water column are considered to be negligible and the absence of large sulphur oxidising bacteria, due to either natural causes or disruption from dredging, would have little effect on these.

© NMP 2014

B1.2 VERIFIED ASSESSMENT OF IMPACTS: FISHERIES MAMMALS AND SEABIRDS

INTRODUCTION

The verification programme addresses the impacts as associated with dredging occurring from within the target dredge area SP-1.

The Fisheries Mammals and Seabirds (Japp in Midgley 2012) conducted within the framework of the 2012 EIA identified impacts that can be expected from the proposed Sandpiper Phosphate Project, and assessed their significance. For many of these assessments of impacts, the confidence levels were only medium as data directly from the target area were lacking. The verification survey was specifically designed to tackle this issue, and to verify whether the assessments will remain in view of the newly acquired empirical data. These data are dealt with in the Verification Survey Programme Report (Section C, Chapter 3.0). A series of five impact tables, which present the impacts as they were assigned in the original impact, study (2012 EIA) and as re-evaluated using site-specific information gathered during 2014 are presented below.

A total of five negative impacts was identified in the original assessment study with one impact having medium significance, one medium to low, and three of low significance. In sum, all changes to the original assessments centre on the level of confidence, increasing the level to high as the verification survey largely confirmed the assumptions on which the assessments were based.

The concept of sustainability and precautionary approaches underpin much of the current fisheries and environmental legislation globally. This is expressed through the ecosystems approach to fisheries which is still in its infancy of application. This impact assessment undertaken for the fisheries sector addresses the specific impact on the fishing industry, fish, biodiversity etc. of the dredging and does not explicitly address the Precautionary Approach. The relevant government authority (MET) is the mandated institution responsible for evaluating the EIA and applying other considerations (such as political and social aspects and the precautionary approach).

From a fisheries and broad ecosystem perspective there will always be data deficiencies suggesting that monitoring of the dredging operation is required and that a baseline is established prior to dredging. This has been attended to in the verification programme, however, monitoring should be ongoing, and the requirements of this are described in the Environmental Management Plan. It should be noted however that Namibia already has many years of monitoring data in the proximity of the MLA (although the sampling stations may not coincide with the exact location of the area to be dredged). Adaptation of current monitoring as well as extrapolation of current knowledge to the MLA is a prerequisite for the use of the best available information to understand the potential impacts prior to dredging

Data and methodology of impact assessment

The data used in the specialist study (refer to the 2012 EIA) to assess the impact of dredging on fish, fisheries, mammals and seabirds is listed in Appendix 1a – 4 (refer 2012 EIA) is here in this document revised in consideration of the results of the Verification Programme. These include commercial catch and effort data of the main commercial fisheries sectors, fisheries survey data and numerous historical data sets provided by the Namibian Ministry of Fisheries and Marine Resources (MFMR).

© NMP 2014

These data were used primarily in a spatial context to identify areas of overlap between fisheries and the Mining Licence Area (ML 170).

The distribution maps (Figures 2 to 32) were created in ArcGIS 9, to show the position of the MLA and the target dredging areas (SP-1, SP-2 and SP-3) relative to the different fishing sectors as well as numerous other data to help identify the impact of the proposed dredging. To quantify the extent of the impacts due to phosphate dredging, six impact zones (Figure 1) were considered:

1) Target mining area SP-1,
2) The MLA (whole area inclusive of SP-1, SP-2 and SP-3)
3) *Zone 1.* The area extending from the margins of the MLA to approximately 25 km seawards in all directions;
4) *Zone 2.* The area extending from Zone 1 seawards in all directions to 50km;
5) *Zone 3.* The area extending from Zone 2 seawards in all directions to 100 km;
6) *Zone 4.* The area extending from Zone 3 seawards in all directions to the Namibian EEZ.

These areas and zones are illustrated in Figure 1.

NOTE also that the areas beyond Zone 1 are probably of little overall significance. The area of greatest potential impact and risk to both the fisheries and the resources are most likely to occur within the MLA and outwards to the 25 km (Zone 1 outer margin) i.e. a consolidation of the MLA and Zone 1. We classify this as “MLA + Zone 1” The rationale for this is as follows:

Data supplied by MFMR (NatMIRC) had limitations and only single daily locations were provided for most fishing sectors (Figures 2 – 32). In lieu of having vessel track data or start and end points of actual fishing events it must be assumed that on average a tow distance or line set (longline) will approximate 25 km (for trawling 3 hour trawl at 3.5 knots approximating no more than 25 km) from the border of the MLA.

In a further analysis a modified methodology to estimate the levels of historical activity in and around each area (SP-1, SP-2 and SP-3) was used in order to consolidate the expected levels of marine traffic in these areas (Figures 2 to 32).

© NMP 2014

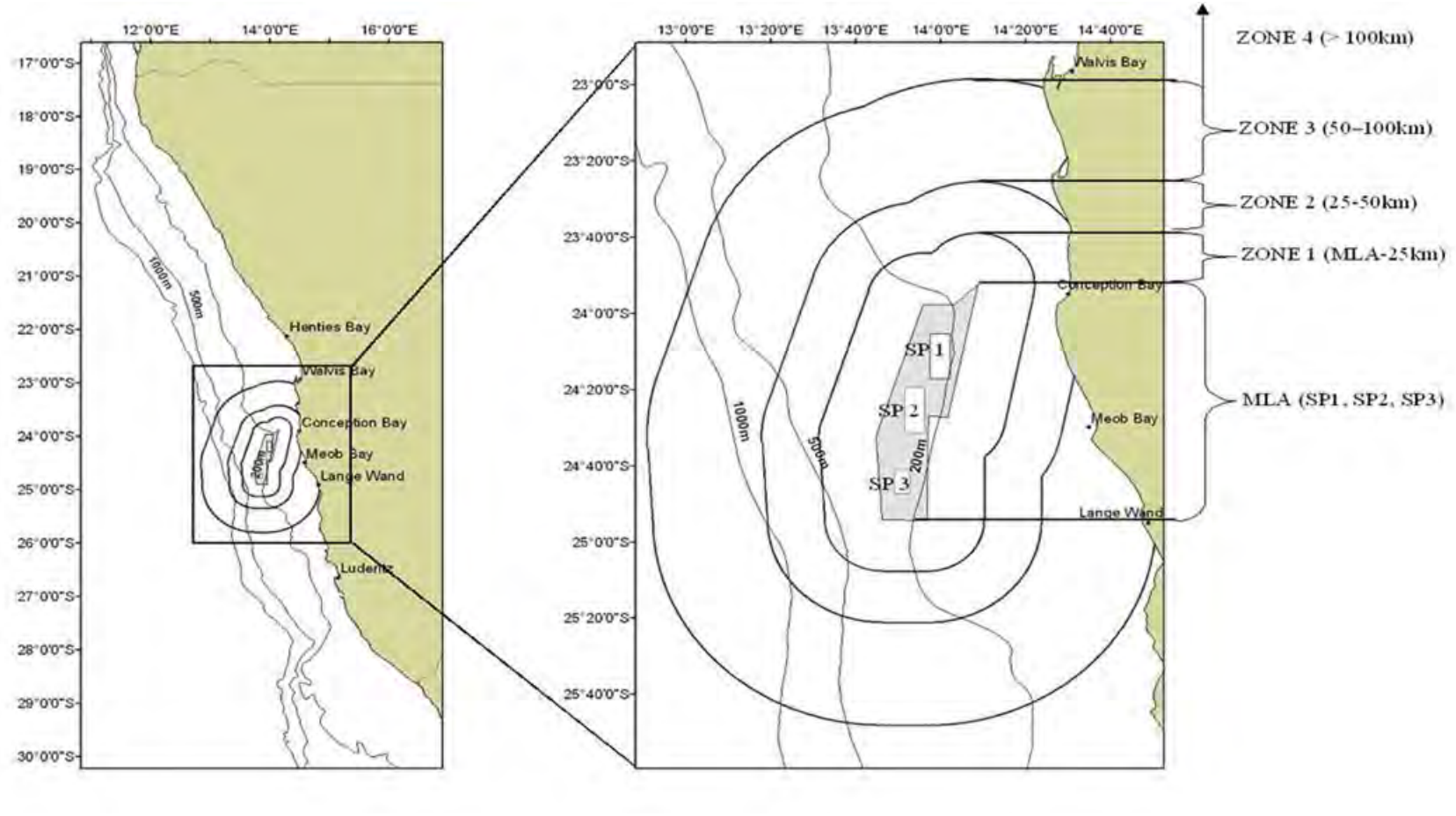


Figure 1. Illustration of zones and areas defined in the fisheries impact assessment (original EIA) (Japp 2012).

The impact on ecologically important species was identified by estimating the presence/absence (yes/no) of data inside SP-1, SP-SP-3. The data used for this assessment are given in Table a. Further, recruitment is identified as the mechanism by which most fish species spawn, migrate and ultimately become available for exploitation. The data used for this assessment are given in Table b.

Table a: Visual assessment based on MFMR survey and other data used to estimate the potential impacts of phosphate dredging on ecologically important commercial fish species

Dataset	Dates	Species	Data inside		
			SP-1	SP-2	SP-3
Hake survey data	1995-2010	Horse mackerel	No	No	No
		Snoek (*Thyrsites atun*)	No	No	No
		Bearded goby (*Sufflogobius bibarbatus*)	No	Yes	No
		Monk	No	Yes	No
		Hake	No	Yes	No
		Orange roughy (*Hoplostethus atlanticus*)	No	No	No
		Sole (*Austroglossus microlepis*)	No	Yes	No
Monk survey data	2007-2010	Monk	No	No	No
		Goby	No	No	No
		Orange roughy (*Hoplostethus atlanticus*)	No	No	No
		Sole	No	No	No
Small pelagic survey data	2002-2011	Horse mackerel, anchovy, sardine and round herring	No	No	No
Hake, monk and small pelagics survey data combined	1995-2011	All species counted per sample station	No	Yes	Yes
Biodiversity verification survey data	2014	Weight and number of: monk, hake, sole, squid, horse mackerel, bearded goby, jacopever, mackerel, angelfish, cape gurnard	Yes	No	No

© NMP 2014

Table b: Data (surveys) used in the assessment of the potential impacts of phosphate dredging on fish recruitment

Dataset	Dates	Species	SP-1	SP-2	SP-3
Hake length-frequency survey data	1995 - 2010	Horse mackerel juveniles (< 21 cm)	No	No	No
		Hake juveniles (< 21 cm)	No	Yes	No
		Monk juveniles (< 21 cm)	No	Yes	No
Pelagic length-frequency survey data	2002 - 2011	Horse mackerel, anchovy, sardine and round herring juveniles (< 8 cm)	Yes	No	No
Hake maturity survey data	1995 - 2010	Hake stage 4 (spawning stage)	No	Yes	No
Pelagic egg and Larvae from Spanish survey data		Anchovy eggs and larvae	No	No	No
		Sardine eggs and larvae	No	No	No
Pelagic egg and Larvae from Nansen survey data	1999 - 2005	Sardine eggs	No	No	No
		Horse mackerel eggs and larvae	No	No	No
Pelagic egg from SWAPELS survey data	1978 - 1985	Sardine	No	No	No
		Anchovy eggs	No	No	No
Biodiversity verification survey data	2014	Hake juveniles (< 21 cm)	Yes	No	No
		Monk juveniles (< 21 cm)	Yes	No	No
		Sole juveniles (< 25 cm)	Yes	No	No
		Hake stage 4 (spawning stage)	Yes	No	No
		Monk stage 4 (spawning stage)	Yes	No	No

© NMP 2014

Table 1.2: Fish Mammals and Seabirds. Summary of impact assessment determinations: Re-evaluated following the verification assessment**.** Reference table number refers to the individual impact table number found in the specialists section.

Ref. Tbl No.	1.2.1	1.2.2	1.2.3	1.2.4	1.2.5
Risk Area	**Seabed dredging: Fish Mammals and Seabirds**				
Nature of the impact	Fishing operations	Ecologically important species	Recruitment of key commercial species	Biodiversity	Seabirds and Mammals
Extent 2012	MLA	MLA	MLA	MLA	MLA
Extent re assessed 2014	Specific mine site	Specific mine site	MLA	Specific mine site	Specific mine site
Duration	Long term	Permanent	Permanent	Permanent	Long term
Intensity	Serious effect	Moderate effect	Minor effect	Minor effect	Minor effect
Probability	Definite	Highly probable	Improbable	Improbable	Probable
Status (- ve of + ve)	Negative	Negative	Negative	Negative	Negative
Significance (no mitigation)	Medium	Medium	Low	Low	Medium
Significance (with mitigation)	Medium to low	Medium	Low	Low	Low
Confidence level 2012	High	Low to medium	Low to medium	Low to medium	Medium
Re-evaluated 2014 confidence level	High	High	High	High	High

© NMP 2014

Table 1.2.1 Impact 1: The impact on fishing operations of the main Namibian fishing sectors by phosphate dredging.

Note: Original assessment table (Japp in Midgley 2012) for the impact assessment (left column) and the re-evaluated impact assessment after the verification programme (right column).

Nature of the impact	**1: The impact on fishing operations of the main Namibian fishing sectors by phosphate dredging; a) hake trawl and b) hake longline, c) monk trawl d) horse mackerel mid-water trawl, and e) small pelagic purse seine fisheries. The fishing sectors will not be able to operate in certain areas due to 1) actual dredging operations, 2) associated sediment plumes 3) exclusion zones around the dredging site and 4) increase levels of maritime traffic associated with the mining operation.**	
Report	***Impacts assessed EIA (2012)***	***Impacts re-evaluated: Verification programme***
Extent	**MLA** - fishing operations will be affected in the MLA and beyond to within a 25 km boundary of the actual target mining sites SP-1, SP-2 and SP-3.	**Specific mine site**. Fishing would not be possible in the actual areas dredged (SP-1). Outside of these areas extending to the whole of the MLA and up to 25 km from the dredging location some disturbance of fishing operations would be expected. Given the Impact criteria specified above the Extent would therefore include the MLA and Zone 1 out to 25km. This assumes that bottom trawl times based on the start trawl locations provided could mean that trawls approximating 3-4 hours at 3-4 knots would extend outwards from the MLA for approximately 25 km. The verification survey confirmed the assumed operational characteristics of typical bottom-trawl directed operations as assumed in the original EIA assessment. This extent is assumed to apply equally to hake and monk trawling and to a much lesser extent to midwater trawling and purse seines as these fisheries activities in SP-1 are relatively much smaller in scale than the bottom trawl operations. For hake longline, bottom set longlines for hake are assumed to be of similar range as the bottom trawl (25 km) from the MLA boundary. MLA - fishing operations will only be affected in the MLA and beyond to within a 25 km boundary of the actual target mining sites SP-1, SP-2 and SP-3.
Duration	**Long term** - the direct impact will cease once the mining activity ends after 20 years (the period for which the mining licence is issued). Thereafter the recovery of the fishing grounds (habitat) and fish abundance to levels prior to the commencement of mining operations is expected to take up to 20 years (long term). **No change of assessment**	

© NMP 2014

Table 1.2.1, Impact 1: The impact on fishing operations of the main Namibian fishing sectors by phosphate dredging *continued*.....

Nature of the impact	**1: The impact on fishing operations of the main Namibian fishing sectors by phosphate dredging; a) hake trawl and b) hake longline, c) monk trawl d) horse mackerel mid-water trawl, and e) small pelagic purse seine fisheries. The fishing sectors will not be able to operate in certain areas due to 1) actual dredging operations, 2) associated sediment plumes 3) exclusion zones around the dredging site and 4) increase levels of maritime traffic associated with the mining operation.**	
Report	***Impacts assessed EIA (2012)***	***Impacts re-evaluated: Verification programme***
Intensity	**Serious effects** - significant impacts will occur for the duration of mining in the MLA, moderate effects are expected to occur in the long term once mining ceases (up to 20 years).	**Serious effects** - significant impacts will occur for the duration of dredging in the dredged location i.e. SP-1. Possibly outside of the dredging locations extending to the boundary of the MLA, moderate effects are expected to occur in the long term up to the cessation of the dredging (up to 20 years). Beyond the MLA extending into Zone 1 and beyond only minor effects are expected which will also cease once dredging has ended.
Probability	**Definite**- consequences will occur in all instances for the duration of mining. Once mining ceases consequences are expected to occur in some instances (moderate effects) within the MLA and persist at a reduced level in the long term within the 25 km boundary zone. **No change of assessment**	**Definite** - consequences will occur in all instances for the duration of mining in the actual mined locations e.g. SP-1 but is less probable further outwards to the MLA and less still into Zone 1. Once dredging is completed the probability of further disruption of fishing operations will cease.
Status (+ or -)	**Negative** - the impact will result in a direct loss in fishing operations in the target mine site (SP-1) and to a lesser extent in the MLA. **No change of assessment**	
Significance (no mitigation)	**Medium** - the project design might require modification to accommodate certain fishing operations. **No change of assessment.**	
Mitigation	Consider options to minimise impact on fishing operations for example options with respect to spatial and temporal area closures.	Consider options to minimise impact on fishing operations for example options with respect to spatial and temporal area closures. Dredging should be restricted to SP-1, until such time that the annual fisheries monitoring (see EMP) assessment of 5 yrs of dredging is evaluated to determine if the impacts match the limited 'risks' as identified in this assessment.
Significance (with mitigation)	**Medium to low. No change of assessment**	
Confidence level	**High** - the evaluation is based on good qualitative and quantitative, historical and current fisheries related data. **No**	

© NMP 2014

Table 1.2.1, Impact 1: The impact on fishing operations of the main Namibian fishing sectors by phosphate dredging *continued*.....

Nature of the impact	**1: The impact on fishing operations of the main Namibian fishing sectors by phosphate dredging; a) hake trawl and b) hake longline, c) monk trawl d) horse mackerel mid-water trawl, and e) small pelagic purse seine fisheries. The fishing sectors will not be able to operate in certain areas due to 1) actual dredging operations, 2) associated sediment plumes 3) exclusion zones around the dredging site and 4) increase levels of maritime traffic associated with the mining operation.**	
Report	***Impacts assessed EIA (2012)***	***Impacts re-evaluated: Verification programme***
	change of assessment	
Confidence level Post Verification Assessment		**High** - Verification has shown that the actual biomass of commercial fish in the proposed dredging locations is extremely low in the MLA and even more so in SP-1.

Explanation: (Table 1.2.1: Impact 1)
There was a minor change to the fisheries impact assessment table with clearer explanations provided. The verification programme confirmed that catches (and effort) taken from with MLA (including SP-1) comprise a very small proportion of the entire Namibian EEZ.

Original EIA – Impact assessment
In the original EIA the following conclusions were made about the impact on the fisheries:
Within the MLA the historical hake trawl catch was 0.86 % or about 1 % of total hake trawl effort. For monk trawl historically 6.34 % of the catches were taken in the MLA or 4.93 % of the effort was spent in the MLA. The hake longline catch distribution is similar to the trawl in that in the MLA the fishery overlaps on the fringes of their catch distribution profile. The demersal longline fishery should therefore only be impacted in the southwestern portion of the MLA. The horse mackerel fishery operates further north of the MLA and only a small proportion of fishing occurs within the MLA. The current small pelagic fishing grounds do not overlap with the MLA, although historically the range of the sardine and anchovy resource did overlap with the MLA

Post Verification Programme – Re-evaluated impact assessment
After the verification process all of these (above) conclusions were confirmed by results taken from the biomass and stock assessment study (Section C, Chapter 3.2) and the biodiversity survey analysis (Section C, Chapter 3.1). It was concluded that the MLA contained less than 1.6 % of the Namibian biomass for *M. capensis*, 0.2 % for *M. paradoxus* and less than 2 % for *L. vomerinus,* suggesting that only a small proportion of the biomass will be recruiting to the fishery from inside the MLA and therefore the overall impact on these fisheries is likely to be minimal. The biomass of hake and monk in the dredged locations e.g. SP-1 is extremely small (0.14 % for *M. capensis* and 0.8 % for monk). During the biodiversity survey only 143 horse mackerel individuals, amounting to 0.005 % of the total fish catch, were measured and recorded. No small pelagics (sardine, anchovy and red eye) were caught during the survey because the bottom trawl gear is not designed to catch these species.

© NMP 2014

The following figures are extracted from the EIA (2012) to provide diagrammatic representation of the data analysed supporting the above conclusions:

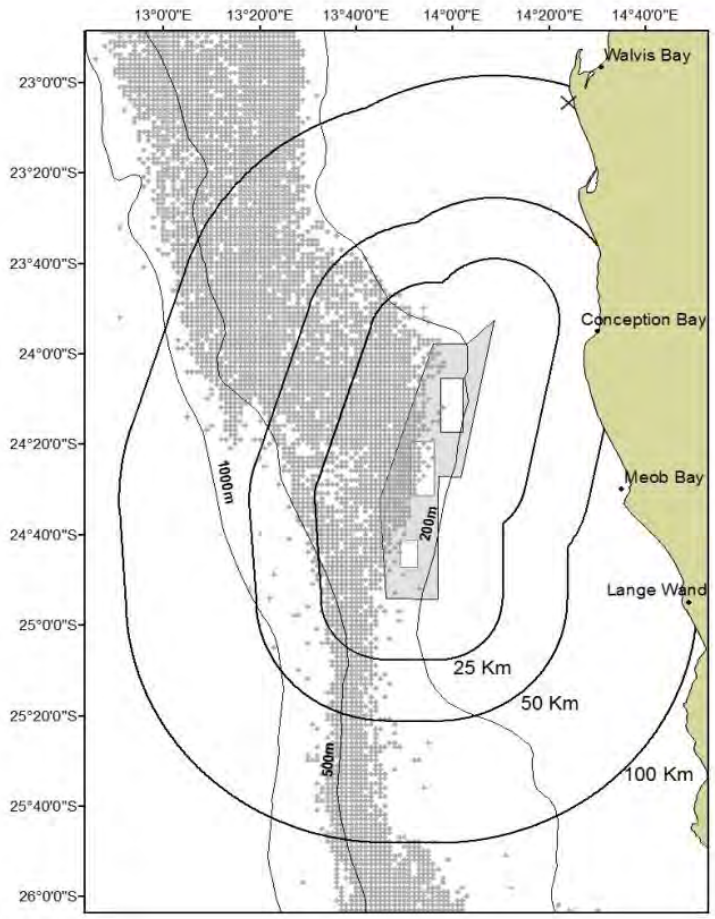


Figure 2. Hake commercial data (2004-2009). Each dot represents the position per trawl relative to the MLA. n = 63351

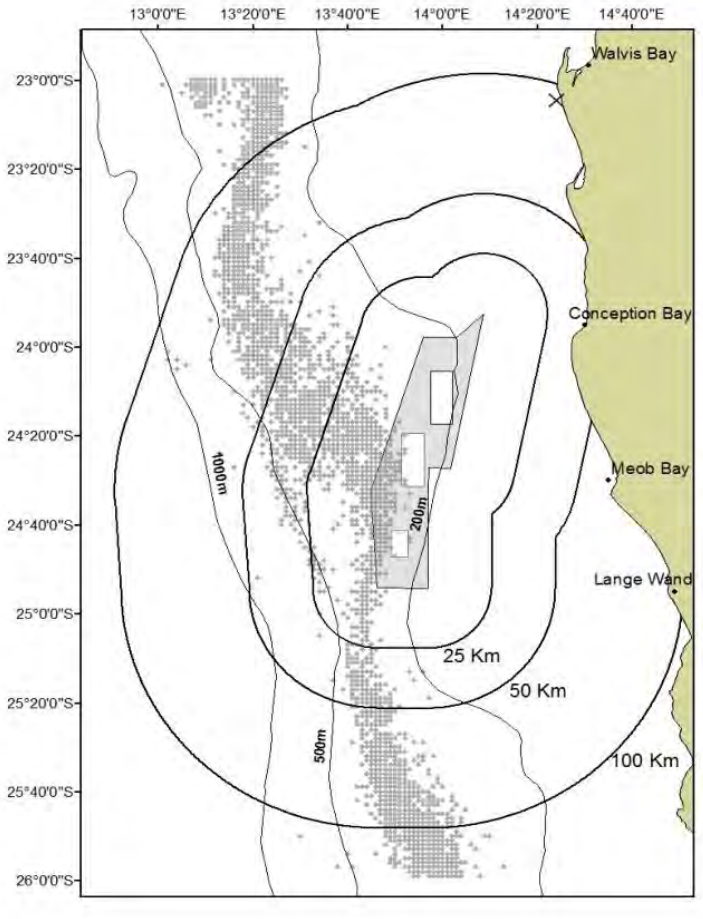


Figure 3. Hake commercial longline data. Each dot represents the position per throw relative to the MLA. n = 4553

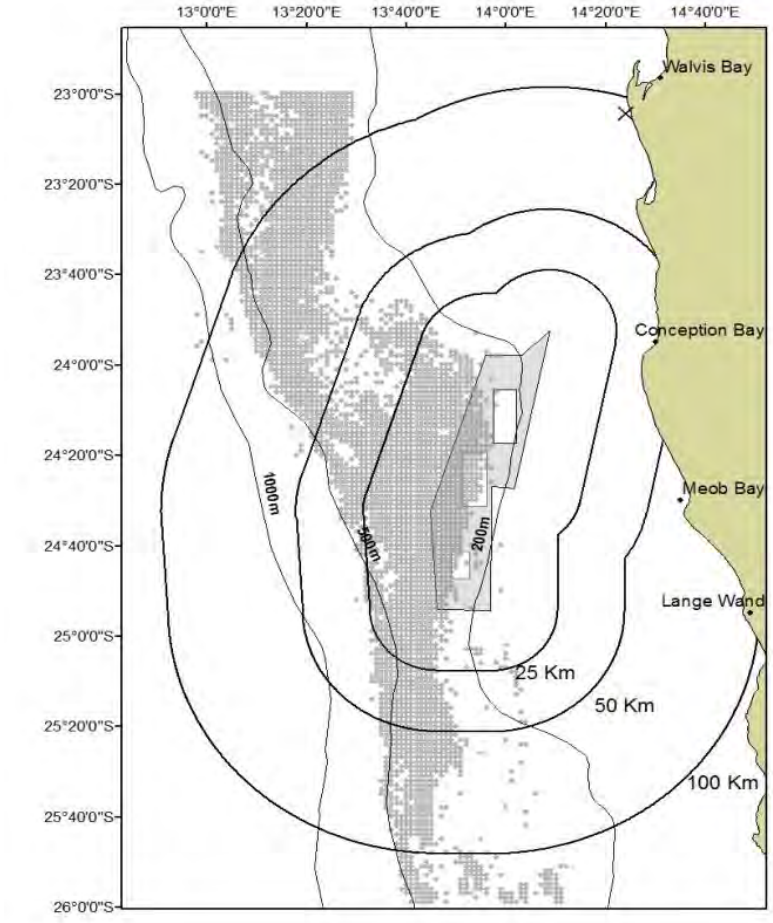


Figure 4. Monk commercial data (2005-2010). Each dot represents the position per trawl. n = 36798

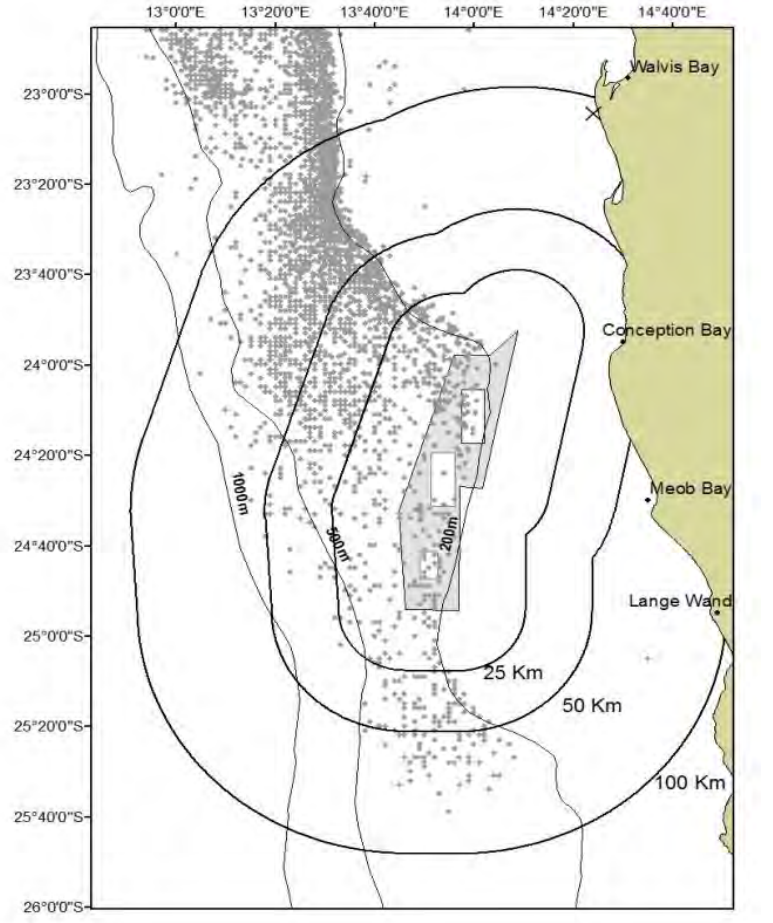


Figure 5. Horse mackerel commercial data (1997-2011). Dots are the position of the last trawl per day. n = 39697

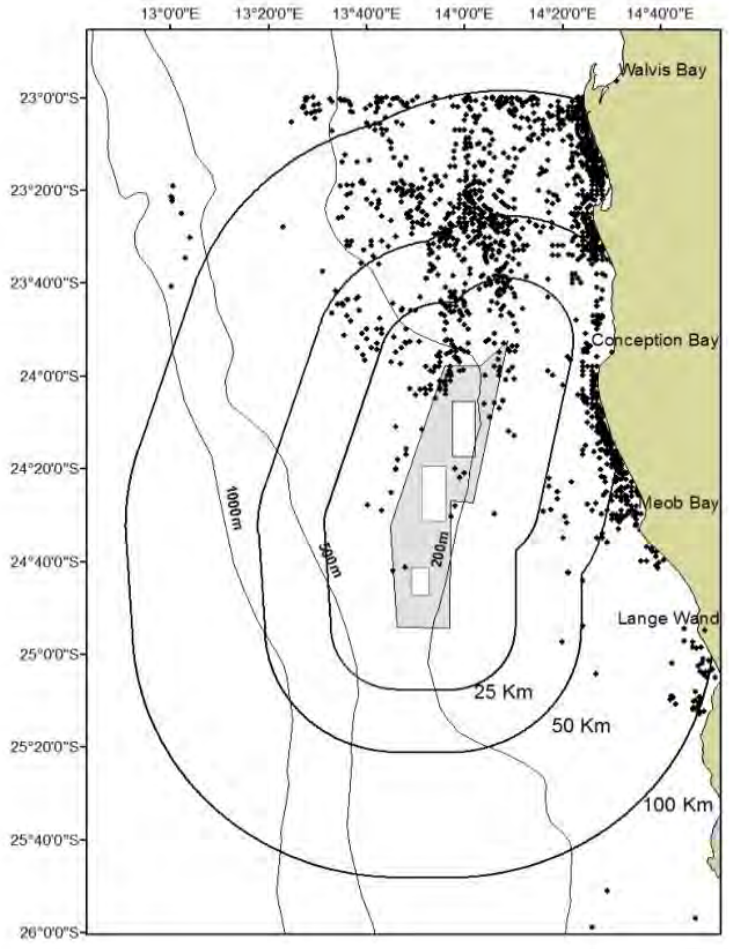


Figure 6. Small pelagic commercial data (anchovy, sardine and round herring) 2000 – 2011. n = 2260

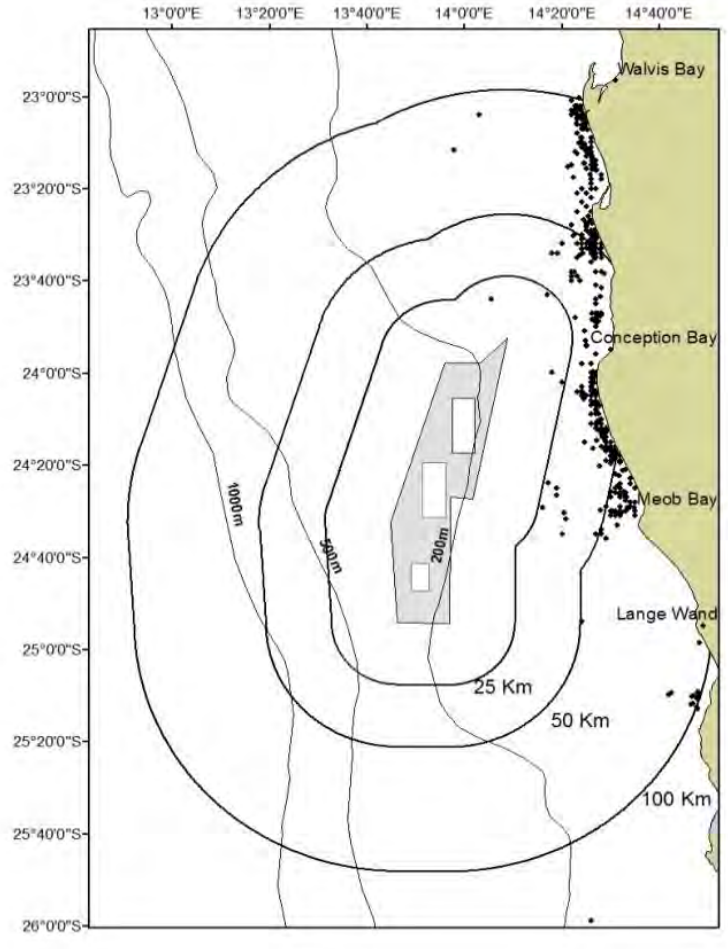


Figure 7. Location of anchovy catches from commercial data (2000 – 2011). n = 552

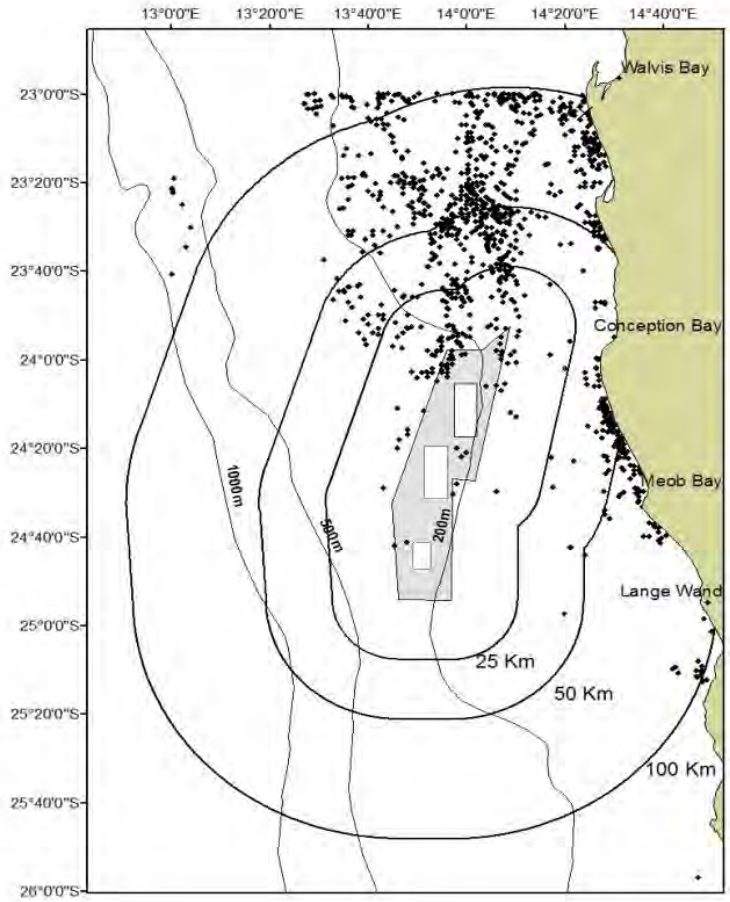


Figure 8. Location of sardine catches from commercial data (2000 – 2011). n = 1099

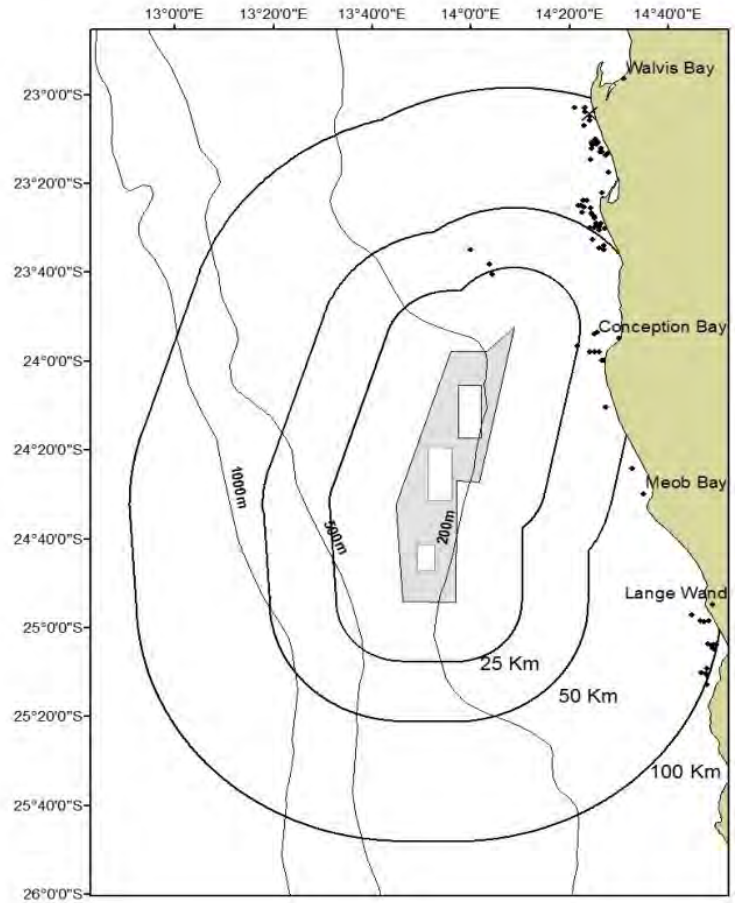


Figure 9. Location of round herring catches from commercial data (2000-2011). n = 83

© NMP 2014

Table 1.2.2 Impact 2: The impact of phosphate dredging on the ecologically important demersal and pelagic fish species.

Note: Original assessment table (Japp in Midgley 2012) for the impact assessment (left column) and the re-evaluated impact assessment after the verification programme (right column).

Nature of the impact	**2: The impact of phosphate dredging on the ecologically important demersal and pelagic fish species. The impact will result in the redistribution and/or displacement of hake, monk, horse mackerel, sole, orange roughy, bearded goby populations and small pelagics because of 1) actual mining activities 2) habitat disturbances and 3) sediment plumes (turbidity)**	
Report	***Impacts assessed EIA (2012)***	***Impacts re-evaluated: Verification programme***
Extent	**MLA** - demersal and pelagic fish species will be displaced or redistributed from inside the MLA and possibly from the surrounding areas (i.e. Zone 1).	**Specific mine site**. Impact will be restricted to the target mine site (SP-1) and possibly within the MLA. Demersal and pelagic fish species will be displaced or redistributed away from the mined locations e.g. SP-1 probably extending to the perimeter of the MLA and to a decreasing extent further outwards into Zone 1.
Duration	**Permanent** (>20 yrs) - the impact will cease once the mining activity ends after 20 years (the period for which the mining licence is issued) however habitat and fish recovery is expected to take longer. **No change of assessment**	
Intensity	**Moderate effects** - only a small fraction (compared with the regional extent) of fish inhabit the MLA and fish populations will recover or settle in areas after mining operations ceases however habitat destruction may cause a longer period of recovery particularly for monk and sole.	**Moderate effects** - only a small fraction (compared with the regional extent) of fish inhabit the MLA and fish populations will recover or settle in areas after mining operations ceases however habitat destruction may cause a longer period of recovery particularly for monk and sole. The verification survey confirms that the actual biomass of the main commercial fisheries affected (hake and monk) is proportionately (to total biomass) very low.
Probability	**Highly probable** - fish (and in particular demersal fish) are expected to move away from the dredging activity resulting in displacement of biomass. **No change of assessment**	
Status (+ or -)	**Negative. No change of assessment**	
Significance (no mitigation)	**Medium** - the duration of the impact is permanent but recovery of fish populations in the area may occur in the long term. The intensity is moderate and the extent is confined to the MLA and Zone 1	**Medium** - the duration of the impact is permanent but recovery of fish populations in the area may occur in the long term.

© NMP 2014

Table 1.2.2, Impact 2: The impact of phosphate dredging on the ecologically important demersal and pelagic fish species *continued...*

Nature of the impact	**2: The impact of phosphate dredging on the ecologically important demersal and pelagic fish species. The impact will result in the redistribution and/or displacement of hake, monk, horse mackerel, sole, orange roughy, bearded goby populations and small pelagics because of 1) actual mining activities 2) habitat disturbances and 3) sediment plumes (turbidity)**	
Report	***Impacts assessed EIA (2012)***	***Impacts re-evaluated: Verification programme***
Mitigation	In terms of the ecosystem as a whole there are no particular mitigation measures that can be implemented. **No change of assessment**	
Significance (with mitigation)	Not applicable (not mitigation alternatives). **No change of assessment**	
Confidence level	**Low to medium** - assumptions based on fish ecology is limited by the data available.	
Confidence level Post Verification Assessment		**High** – the evaluation of the impact on fish ecology is based on results from the biomass and stock assessment (Gaylard: Section C, Chapter 3.2), professional opinion on the ecosystem impact of phosphate mining (Cochrane: Section C, Chapter 3.3) and in situ data from the biodiversity verification survey.

Explanation: (Table 1.2.2: Impact 2)

Post Verification Programme – Re-evaluated impact assessment
After the verification process the confidence level is Re-evaluated and changed from Low/Medium to High due to the increased ecosystem information and data gathered during the verification programme. The rest of the impact assessment table remained the same and was verified by the results from Cochrane (Section C, Chapter 3.3) Gaylard (Section C, Chapter 3.2), Ndjaula (Section C, Chapter 3.4), and the biodiversity survey (Section C, Chapter 3.2). It should be noted that leaving areas un-dredged within the target mine areas may facilitate recovery of some ecosystem components.

Trophic modelling of the Benguela ecosystem has been done although the specific application to Namibia and in particular the MLA can only be inferred from these broad studies (Cochrane Section C, Chapter 3.3). Trophic modelling is inclusive of top predators as well as species lower in the food chain including benthic organisms removed with the substrate in the dredging process. We have enquired regarding the status of trophic marine modelling in Namibia to the Benguela Current Commission (BCC) but have as yet no better conclusive models or data on which to give a more informed assessment of the impacts on the ecosystem other than produced by Cochrane (Section C, Chapter 3.3). Equally this problem applies to all aspects of the Benguela ecosystem including fishing and other anthropogenic effects. Cochrane (Section C, Chapter 3.3), however, concluded that the combination of the high uncertainty typically associated with projections by ecosystem models and the small area that will be impacted by the proposed

© NMP 2014

dredging mean that it is unlikely that ecosystem modeling would expose any unexpected, highly significant threats that have not already been considered in the specialist studies.

The hake and monk biomass and stock assessment analysis conducted by Gaylard (Section C, Chapter 3.2) concluded that the proportion of the potential biomass in SP-1 and the proportion recruiting to the respective commercial fisheries in the adjacent areas is extremely small. The SP-1 site also makes no significant contribution to recruitment or spawner stock biomass for monk or hake to the surrounding areas (Gaylard Section C, Chapter 3.2).

Similarly, the reproductive dynamics analysis by Ndjaula (Section C, Chapter 3.4), concluded that the area proposed for dredging has no special biological reproductive characteristics for the main commercial species found in the area compared to the rest of the Namibian waters. For example, there are no specific indicators suggesting the proposed dredge area is exclusively home to adult fish (spawner biomass), and has no pronounced recruitment of small and young fish.

During the biodiversity survey (Section C, Chapter 3.1), gobies were caught at every station. They have been identified as having a key trophic role in the ecosystem. As gobies are mobile they will be displaced, however mortality is only expected at the dredging location (SP-1). As gobies extend throughout the Namibian ecosystem, the relative abundance noted in the verification survey suggested that displacement and mortality of gobies is likely but that the limited scale of the dredging will not have a significant ecological impact as a result of the displacement or mortality of gobies.

The following figures have been extracted from the 2012 EIA to provide diagrammatic representation of the data analysed supporting the above conclusions.

© NMP 2014

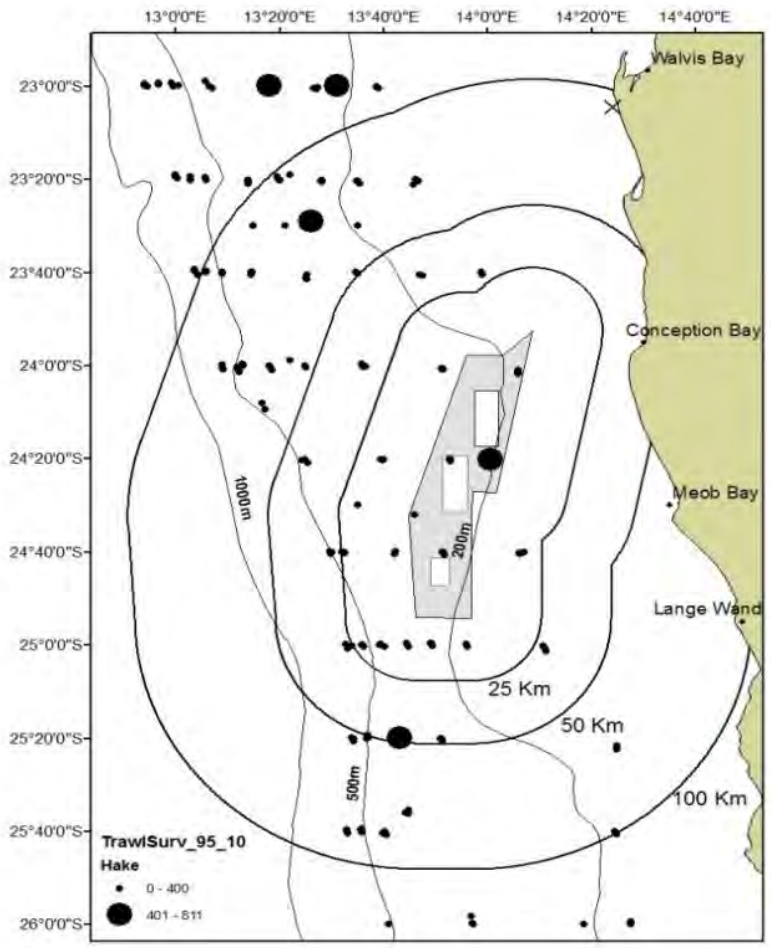


Figure 10. Distribution of hake from hake-survey data (1995-2010). Dots show the cumulative weights per station. n = 678

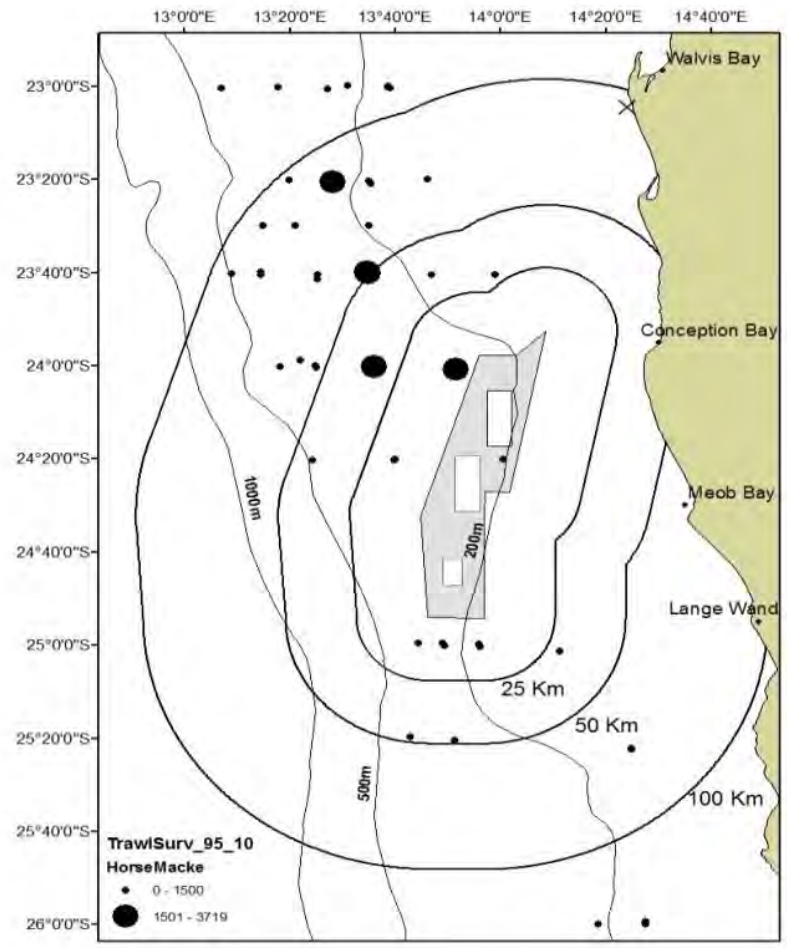


Figure 11. Horse mackerel from hake-survey data (1995-2010). Dots show cumulative weight per station. n = 78

© NMP 2014

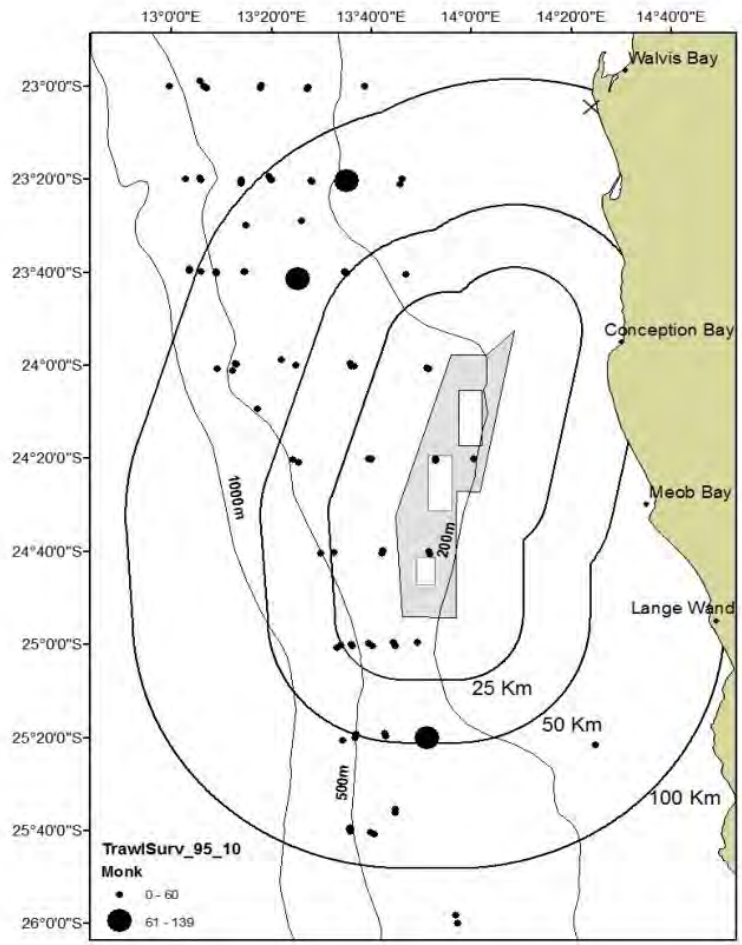


Figure 12. Monk from hake- survey data (1995 – 2010). Dots show cumulative weight station. n = 134

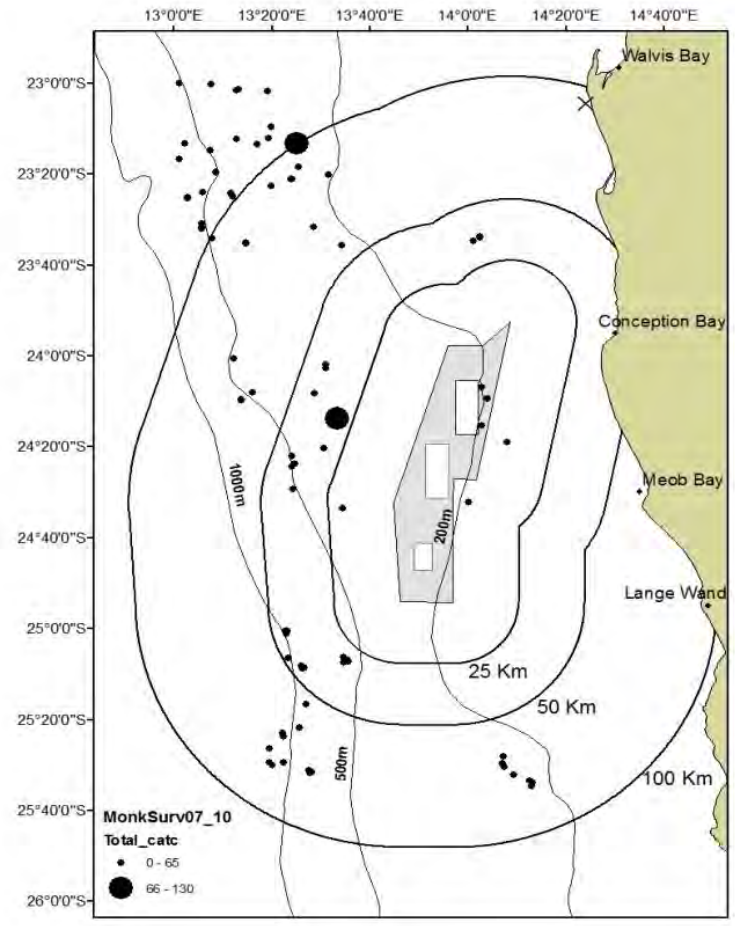


Figure 13. Monk from monk-survey data (2007-2010). Dots show cumulative weight per station. n = 100

© NMP 2014

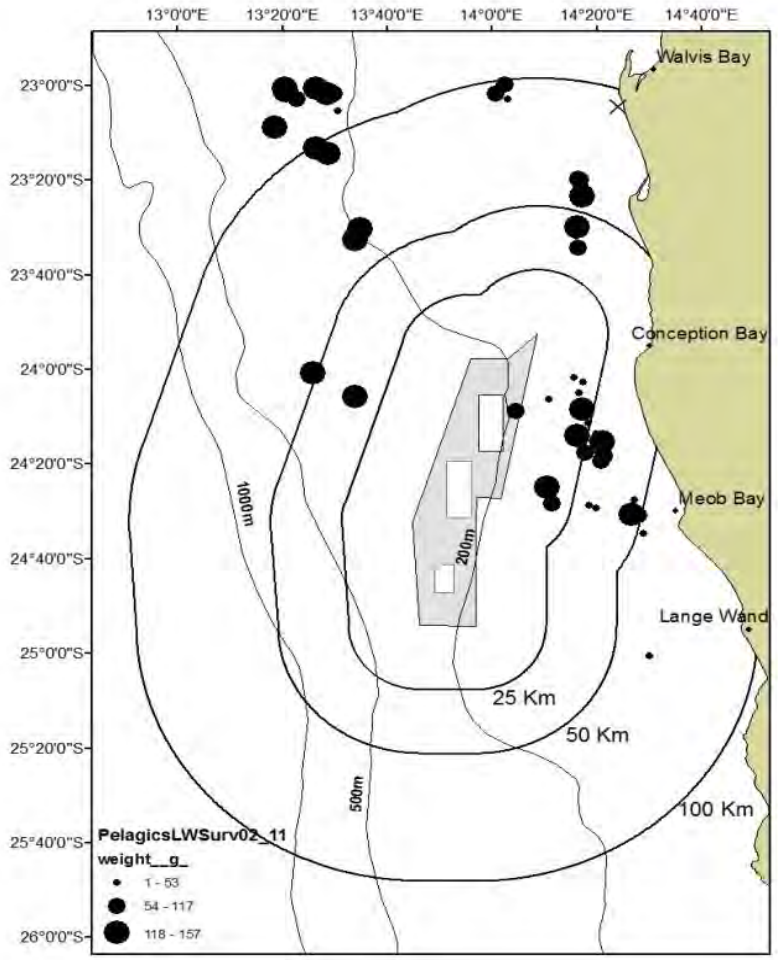


Figure 14. Pelagic (anchovy, sardine and round herring) weights from pelagic-survey data (2002 – 2011). n = 2557

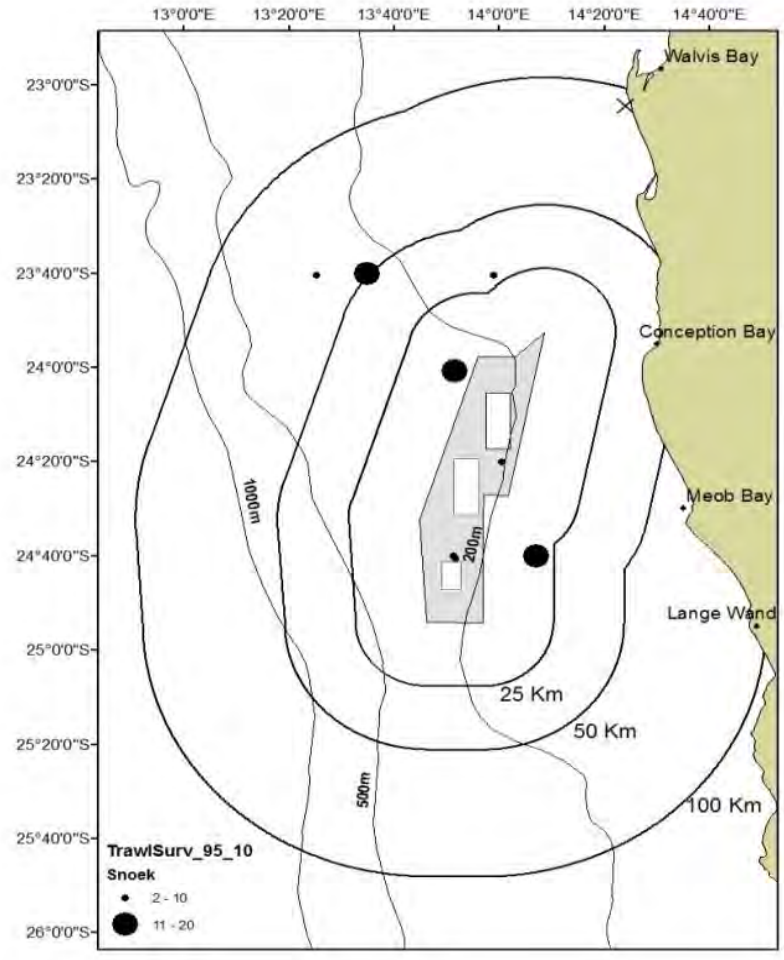


Figure 15. Total catch per station for snoek from hake-survey data (1997-2010). n = 8

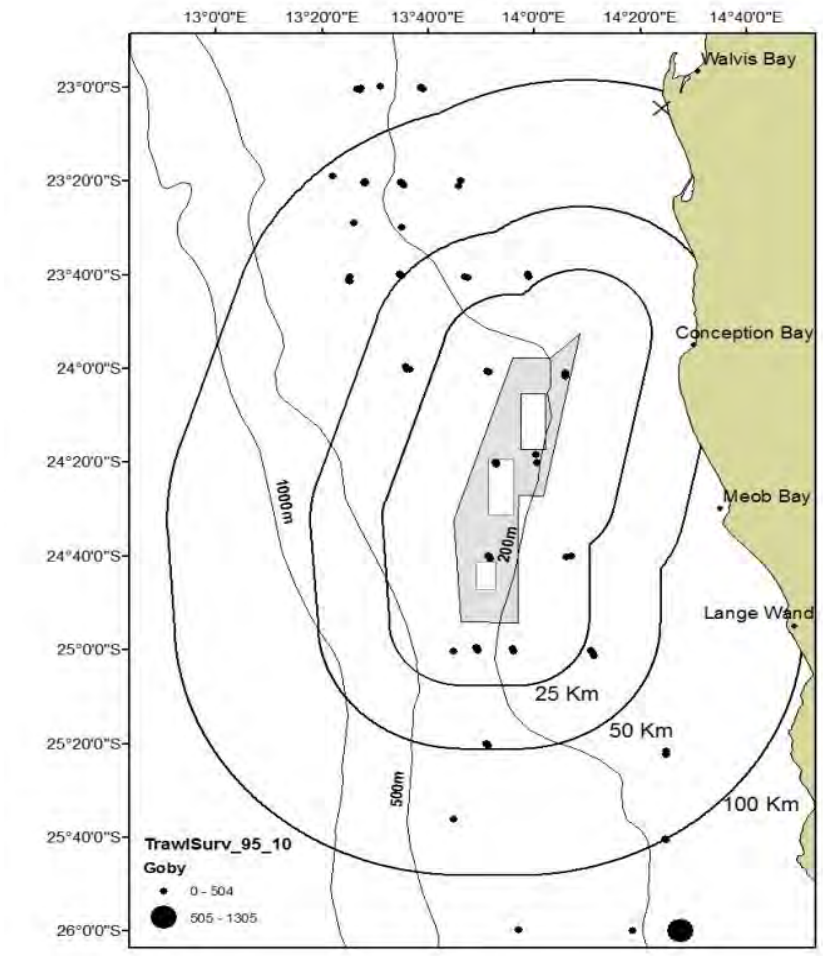


Figure 16. Distribution of goby from hake-survey data (1995 – 2010). n = 93

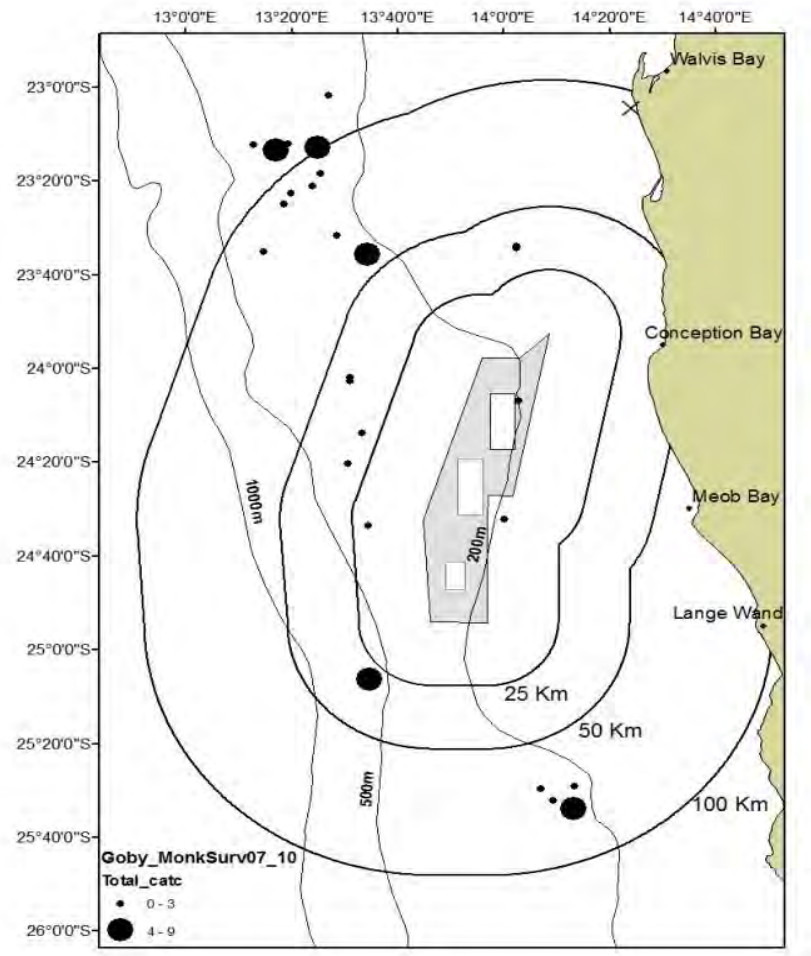


Figure 17. Distribution of goby from monk-survey data (2007 – 2010). n = 24

© NMP 2014

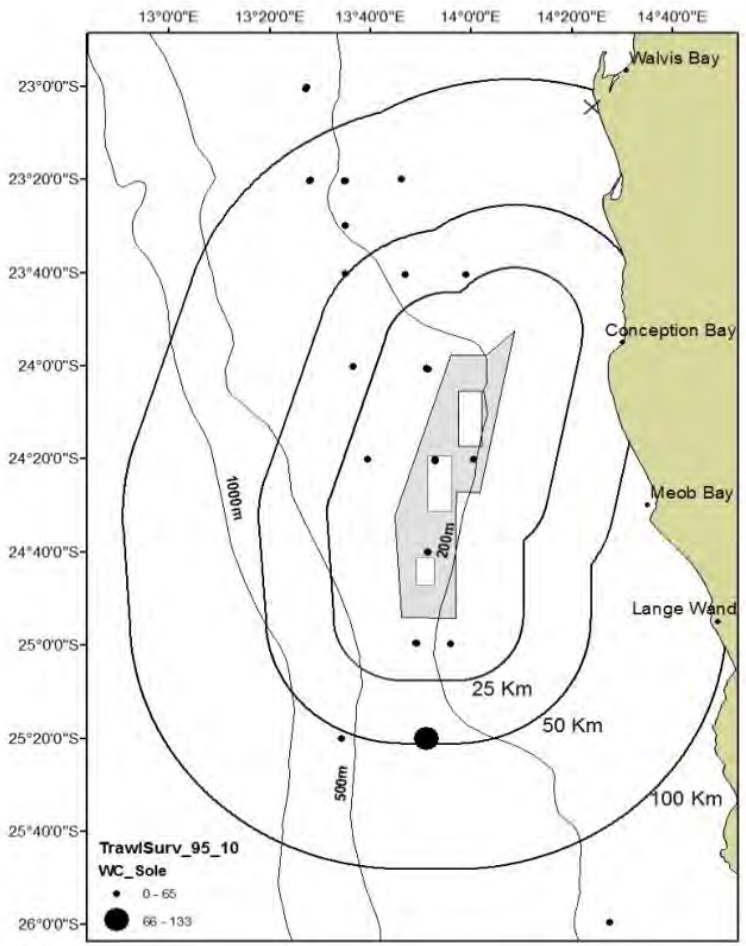


Figure 18. Total catch per station for west coast sole from hake-survey data (1997 – 2010). n = 48

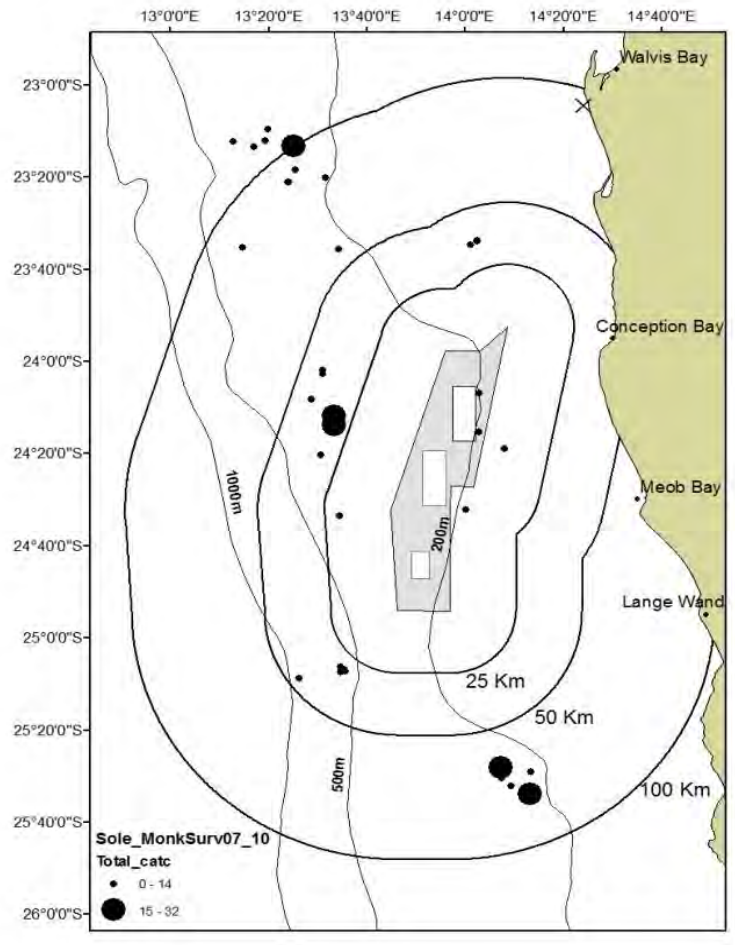


Figure 19. Total catch per station for west coast sole from monk- survey data (1997 – 2010). n = 42

© NMP 2014

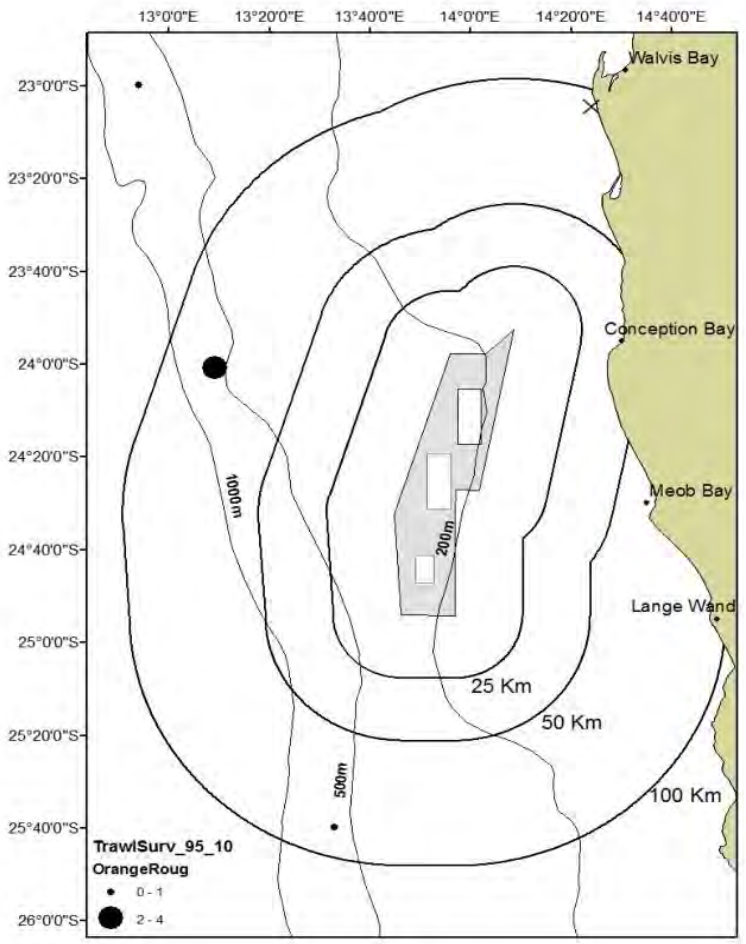


Figure 20. Distribution of orange roughy from hake-survey data (1995 – 2010). n = 4

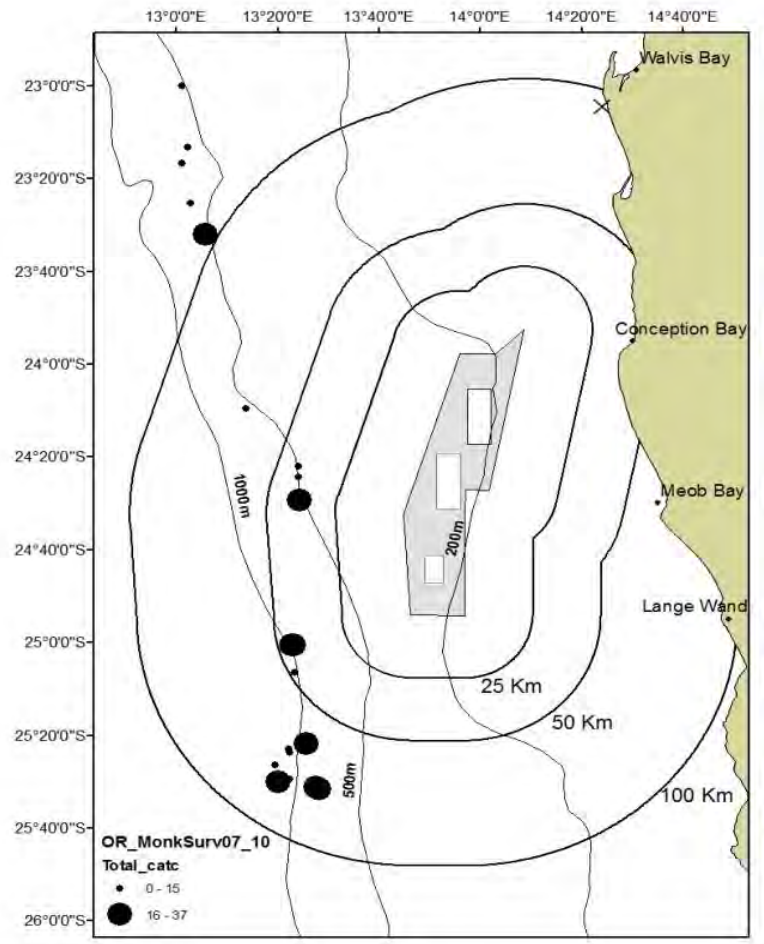


Figure 21. Distribution of orange roughy from monk-survey data (2007 – 2010). n = 29

Table 1.2.3 Impact 3: The impact of phosphate dredging on the recruitment of key commercial fish stocks

Note: Original assessment table (Japp in Midgley 2012) for the impact assessment (left column) and the re-evaluated impact assessment after the verification programme (right column).

Nature of the impact	**3: The impact of phosphate mining on the recruitment of key commercial fish stocks a) hake b) horse mackerel c) monk and d) small pelagic species. The dispersal and survival of juveniles, eggs and larvae are effected by 1) physical disturbance of the fishing grounds and 2) sediment plumes (turbidity)**	
Report	***Impacts assessed EIA (2012)***	***Impacts re-evaluated: Verification programme***
Extent	**MLA** - impacts on recruitment is restricted to areas inside the mining licence area and possibly the surrounding areas up to the 25 km impact zone	**MLA** - impacts on recruitment is restricted to areas inside the mining licence area and possibly the surrounding areas up to the 25 km impact zone. Verification survey confirms the abundance of monk and hake pre-recruits i.e. recruiting to the monk, sole and hake fisheries.
Duration	**Permanent** (>20 yrs) - the impact will only cease once the mining activity ends after 20 years (the period for which the mining licence is issued)	**Permanent** (>20 yrs) - the impact will only cease once the dredging activity ends after 20 years (the period for which the mining licence is issued) and ecosystems will progressively recover at some rate (unknown) after the cessation of dredging. The verification supported the initial assessment where it was assumed that the pre-recruiting fish of commercial interest would be found and possibly impacted and displaced within the actual dredging locations. This would persist for as long as the mining occurred and after mining ceases.
Intensity	**Minor effect** - only a small fraction (compared to the regional extent) of juveniles and eggs and larvae occur in the MLA. Impacts will decrease even further in this area after mining operations cease	**Minor effect** - only a small fraction (compared to the regional extent) of juveniles and eggs and larvae occur in the MLA. Impacts will decrease in this area after mining operations cease. Verification supports this assessment. Although Gaylard (Section C, Chapter 3.2) showed that up to 7% of monk recruit in the MLA, only 0.2 % is expected in SP-1. (Note, it has been suggested that the 7% (value) of the recruits in MLA is likely to be an over estimation, Payne pers comm). Mortality of monk and other less mobile species is likely in the dredging site but the relative (to total) impact on recruitment due to the small area is expected to have minor effect.
Probability	**Improbable** - mass mortality of juveniles and eggs and larvae may occur under extreme circumstances but is highly unlikely	**Improbable** - mortality of pre-recruiting commercial fish species, other juvenile fish species and spawn (eggs and larvae) may occur but the relative level (to total recruitment) is expected to be extremely low. The probability

© NMP 2014

Table 1.2.3, Impact 3: The impact of phosphate dredging on the recruitment of key commercial fish stocks *continued...*

Nature of the impact	**3: The impact of phosphate mining on the recruitment of key commercial fish stocks a) hake b) horse mackerel c) monk and d) small pelagic species. The dispersal and survival of juveniles, eggs and larvae are effected by 1) physical disturbance of the fishing grounds and 2) sediment plumes (turbidity)**	
Report	***Impacts assessed EIA (2012)***	***Impacts re-evaluated: Verification programme***
		that the impact would occur for monk however is higher (probable) than the other species (improbable) since monk recruits make up 7 % of the overall biomass in the MLA and 0.2 % in SP-1.
Status (+ or -)	**Neutral**	**Neutral** - changed to negative for monk within SP-1 only. Neutral for all other species
Significance (no mitigation)	**Low**. **No change of assessment**	
Mitigation	No practical mitigation measures are possible. **No change of assessment**	
Significance (with mitigation)	Not Applicable (no mitigation). **No change of assessment**	
Confidence level	**Low to medium** - assumptions based on fish recruitment is limited by the data available.	
Confidence level Post Verification Assessment		**High** – assessment assumptions on fish reproduction have been confirmed by a comprehensive fish reproductive dynamics and stock dynamics study (Ndjaula, Section C, Chapter 3.4) and in-situ size structure data from the biodiversity verification survey.

© NMP 2014

Explanation: ***(Table 1.2.3: Impact 3)***

Post Verification Programme – Re-evaluated impact assessment

After the verification process the confidence level changed from Low/Medium to High due to the improved fish reproduction information and data gathered during the verification process. According to Gaylard (Section C, Chapter C3.2) the MLA is estimated to contain less than 1.6% of the Namibian biomass for *M. capensis*, which reduces to 0.14% if the SP-1 mining site only is considered. No notable departure from these proportions is estimated for either the recruits or the spawning adults. The 23^0S to 26^0S latitude band is a breeding ground for *M. capensis*, containing a large proportion of juveniles, however the overwhelming majority of these are at depths less than 200 m, whereas most of the MLA lies in deeper waters (SP-1 extraction area lies exclusively between 225 and 200 m). *M. paradoxus* adults are scarce in depths of less than 300 m, and the younger fish (less than 27 cm) are predominantly found south of 26^0 S. Thus the MLA and in particular the SP-1 site have very little interaction with *M. paradoxus* (less than 0.2% of biomass in the entire MLA). For monk, the MLA is estimated to contribute about 2% to overall biomass. This is less (0.8%) among the mature stock which tend to lie in deeper water and further south. The monk recruits however are more prevalent in the MLA than for hake, with an estimated 7% of recruits in the MLA. (Note, it has been suggested that the 7% (value) of the recruits in MLA is likely to be an over estimation, Payne per comm). Most of this contribution to recruitment however is in the 250 to 300 m depth range and is not in the area to be dredged (SP-1). The specific SP-1 target dredge area (200 – 225 m) is shallower than 250 m, and so this SP-1 area is estimated to contribute only 0.2% of recruitment to the fishery. We stress also that recruitment will be affected by many factors, including fishing pressure and variability in environmental and oceanographic conditions and will not necessarily remain constant from year to year.

Ndjaula (Section C, Chapter 3.4), stated that observed multiple cohorts both in spatial and temporal analysis suggest that factors other than habitat preference are responsible for the distribution of Namibian marine species. It was also concluded that no significant spawning areas were observed, specifically not in the areas surrounding the proposed dredging site. While the data show there are certain dynamics relating to stock structure (mainly offshore-onshore and vertical with depth for all species analysed, as well as latitudinal for *M. paradoxus*), growth seems to be generally poorly defined by the stock structure, as shown by the cohort indicators. The area proposed for dredging (i.e. the MLA) has no special biological reproductive characteristics for the main commercial species found in the area to be dredged compared to the rest of the Namibian waters. For example, there are no specific indicators suggesting the dredged area is exclusively home to adult fish (spawner biomass), and has no pronounced recruitment of small and young fish.

During the biodiversity survey both monk and hake length and maturity stage were measured. The mean length was 29 cm and 26 cm for monk and hake respectively. A large proportion of the monk catch was immature whereas the hake were generally mature. Juvenile hake are expected to be displaced from the dredging area, but their mobility should limit the likelihood of mortality. The distributions of Stage 4 adult hake is an indicator that these fish are spawning, however data collected during the survey suggested that spawning hake are not commonly found in the MLA and are generally found in the areas north of the MLA away from the mining site. Hake recruitment is therefore not expected to be impacted significantly. Juvenile monk (Stage 1) were found throughout the survey area and the local impact on juvenile monk as a direct result of the dredging operation will be high (mortality). However the extent of the mining area is small compared to the overall distribution of monk. Total recruitment effects on monk are therefore expected to be low.

The following figures have been extracted from the 2012 EIA to provide diagrammatic representation of the data analysed supporting the above conclusions.

© NMP 2014

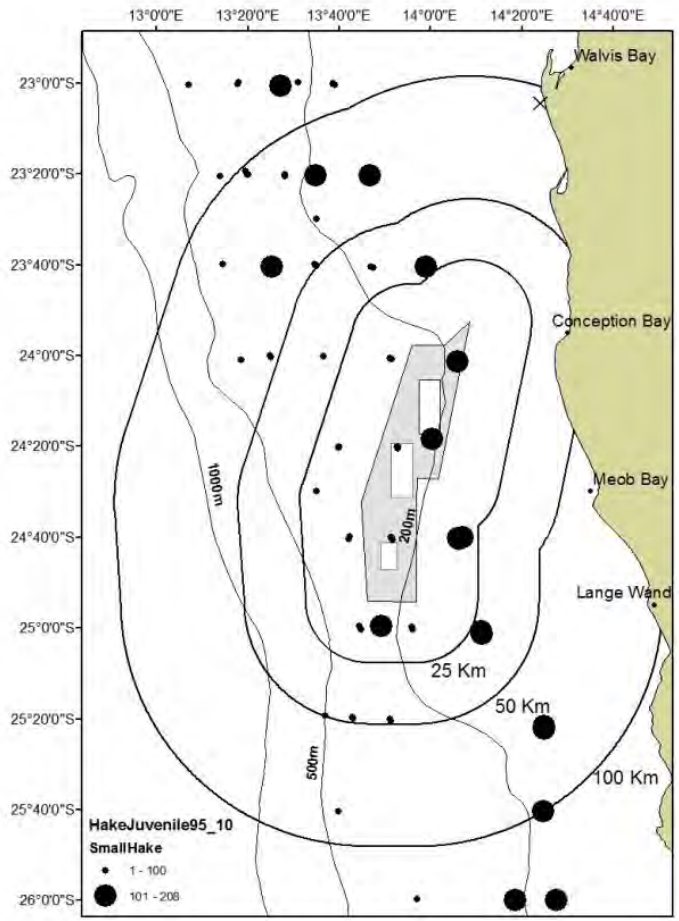


Figure 22. Hake juvenile numbers (<21 cm) from length frequency hake- survey data (1995-2010). n = 6649

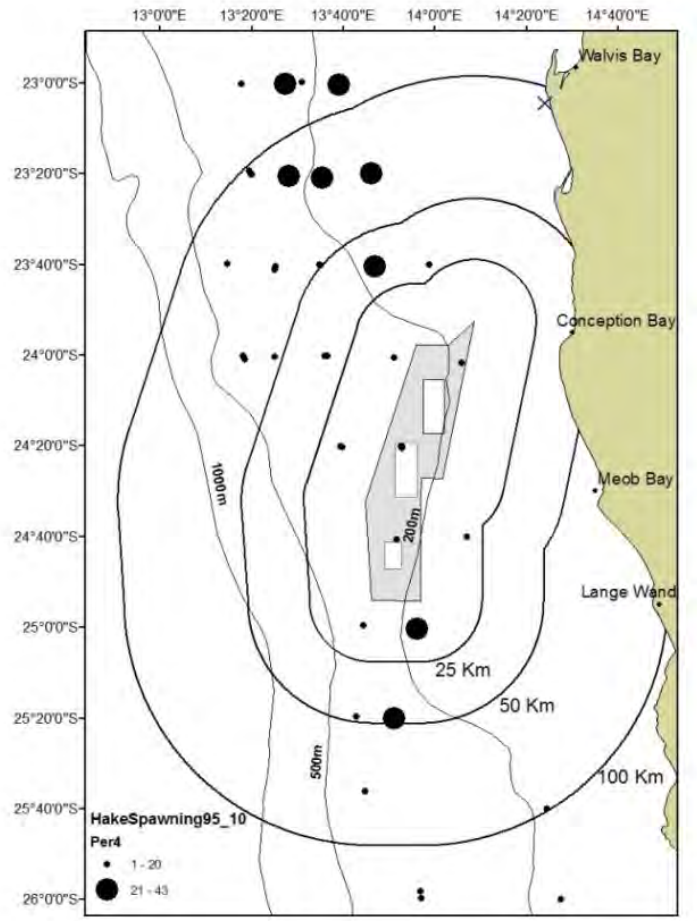


Figure 23. Hake stage 4 represented as a percentage of the total number of all stages per station from hake-survey data (1995-2010). n = 8769

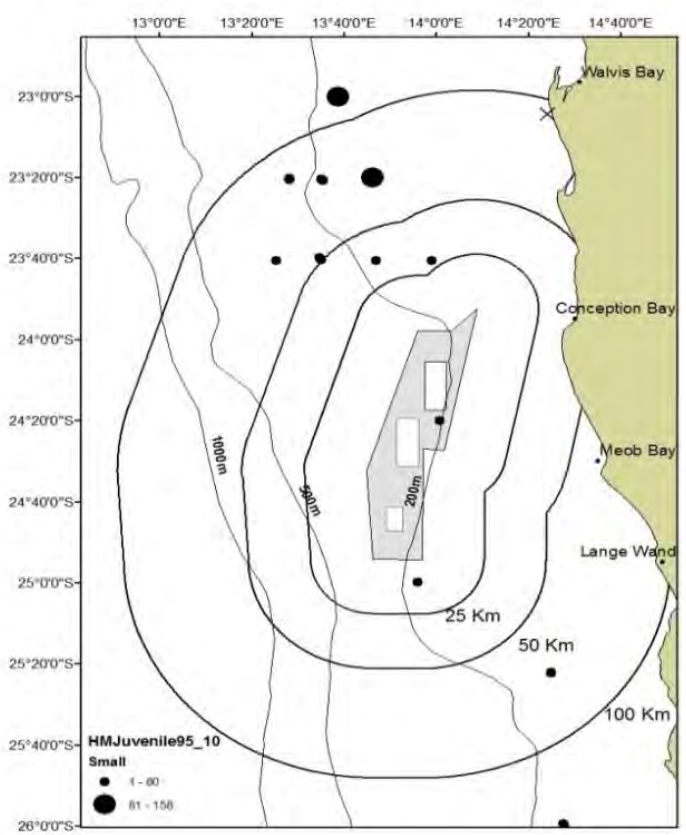


Figure 24. Horse mackerel juvenile numbers (<21 cm) from hake-survey data (1995-2010). n = 1368

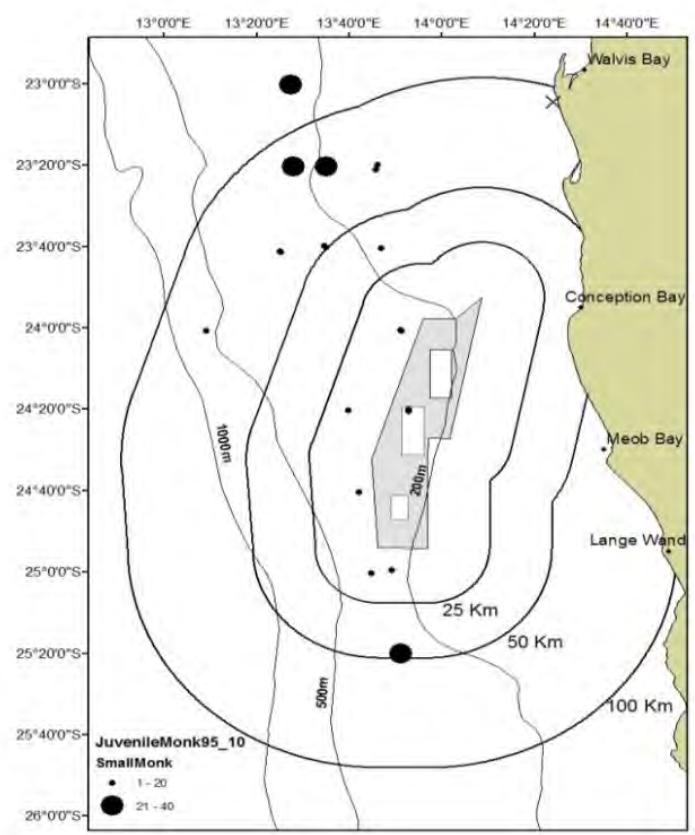


Figure 25. Juvenile monk (<21 cm) from hake- survey data (1995-2010) represented as numbers per station. n=263

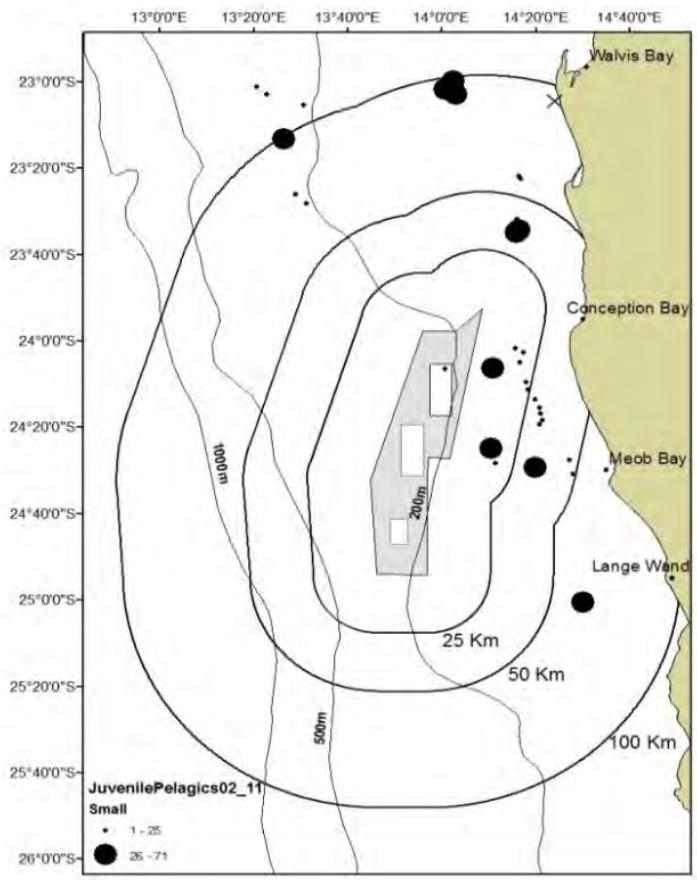


Figure 26. Pelagic (anchovy, sardine, and herring) juveniles numbers (< 8 cm) from pelagic-surveys 2002-2011. n = 10714

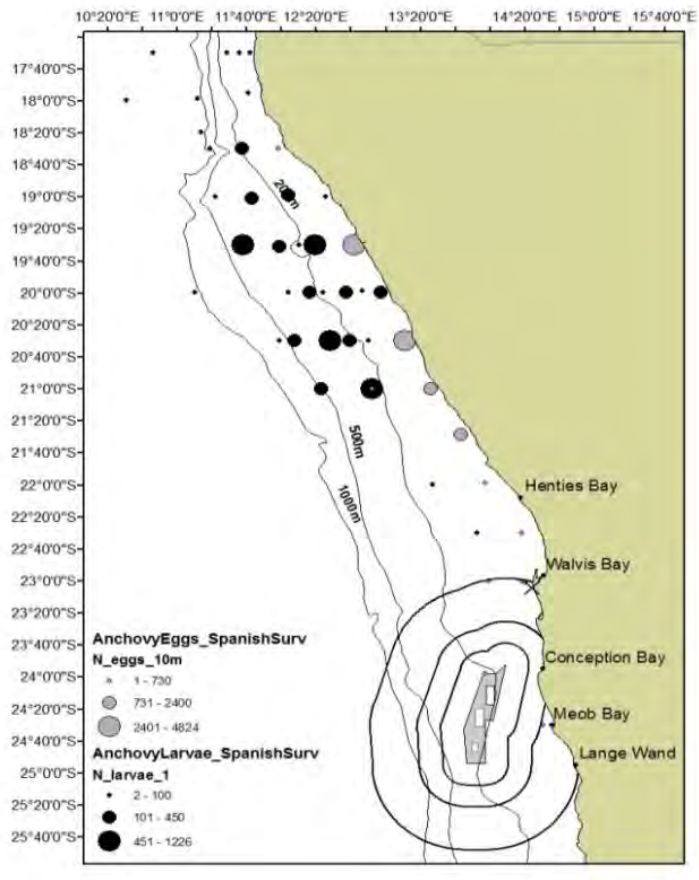


Figure 27. Distribution of anchovy eggs (grey) and larvae (black) from Spanish survey data. n = 333

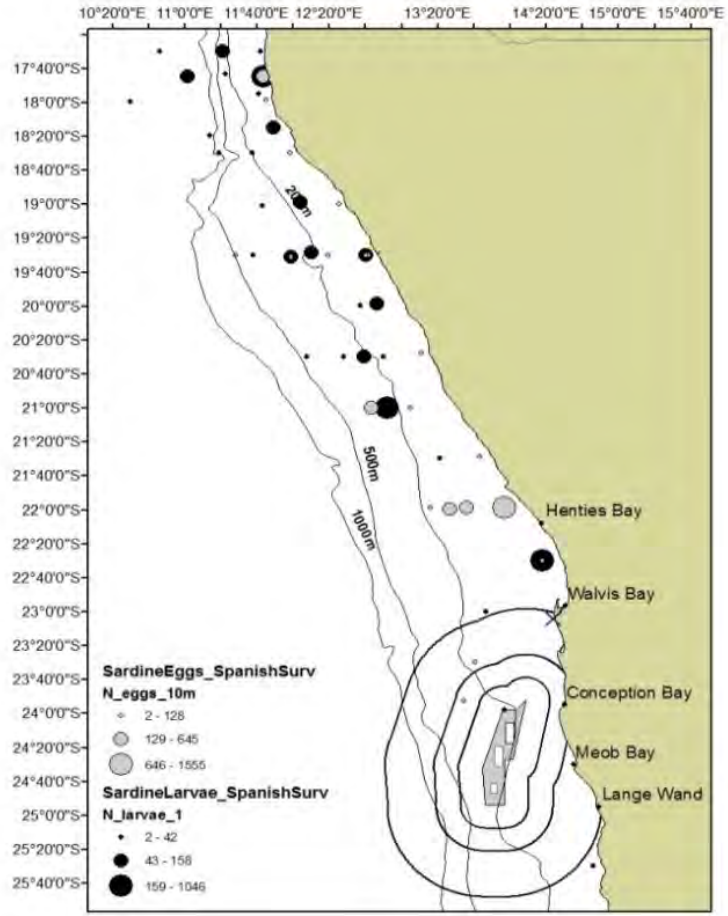


Figure 28. Distribution of sardine eggs (grey) and larvae (black) from Spanish survey data. n = 333

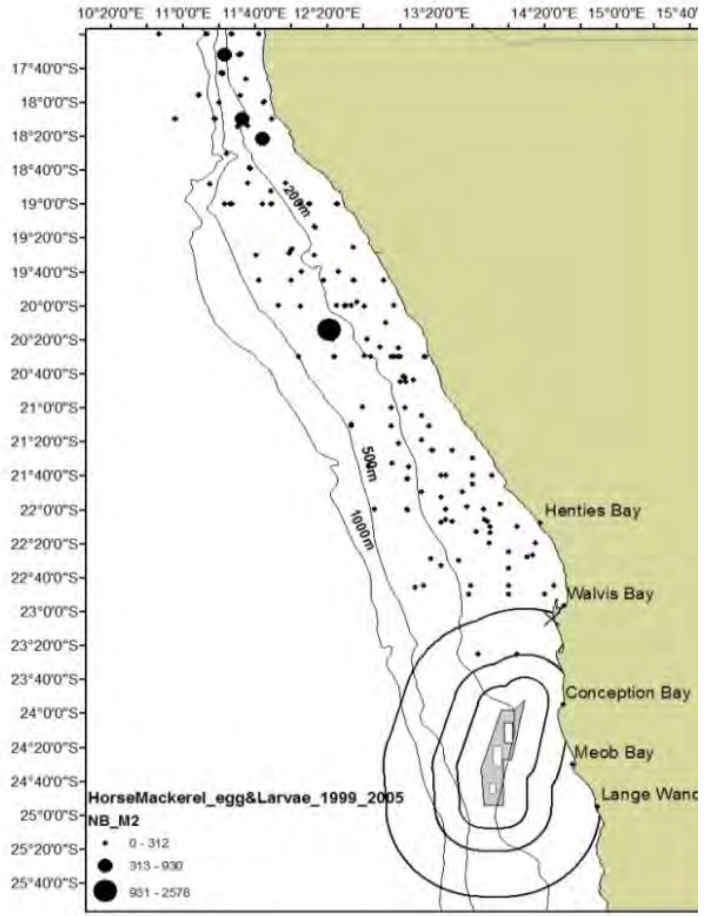


Figure 29. Horse mackerel eggs and larvae from Nansen survey data (1999-2005). n = 2811

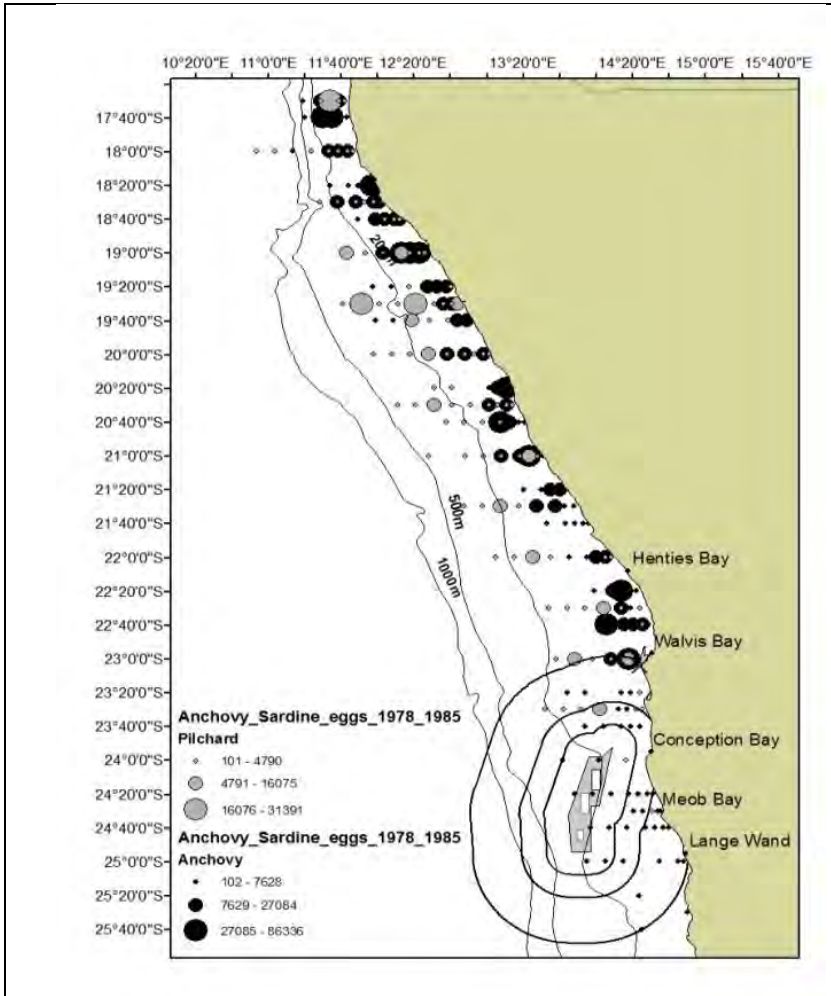


Figure 30. Distribution of sardine (grey) and anchovy (black) eggs from SWAPELS survey data (1978-1985). n = 265

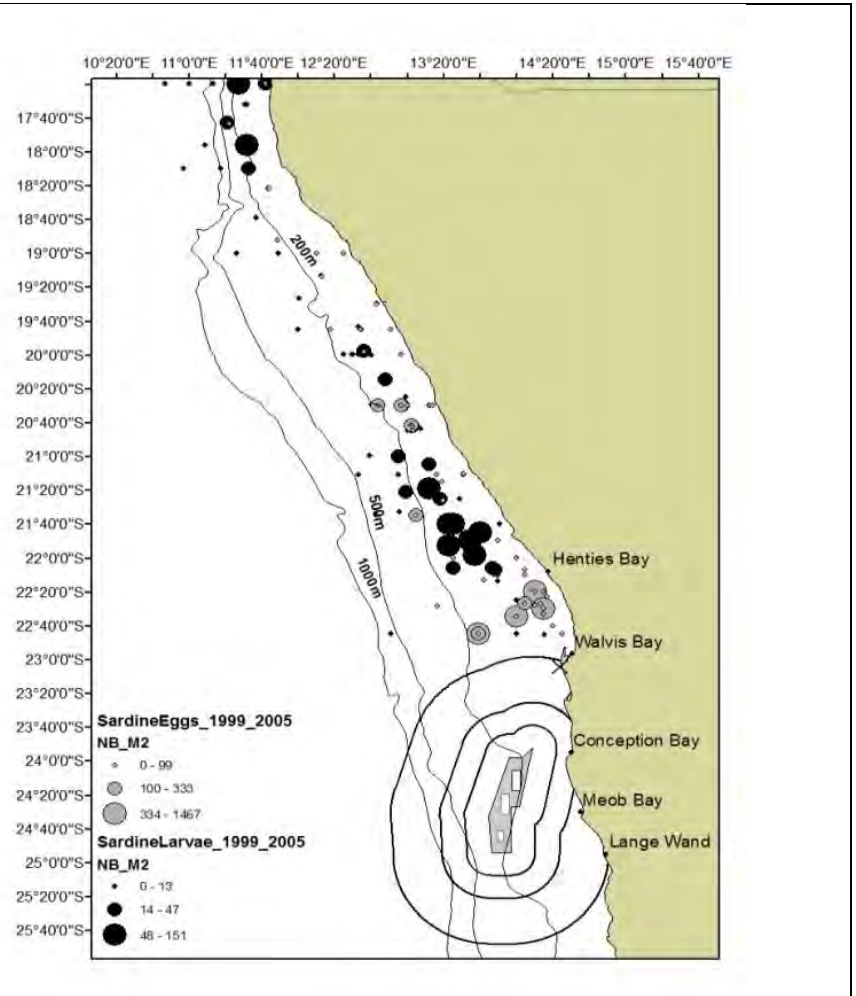


Figure 31. Distribution of sardine eggs (grey) and larvae (black) from Nansen survey data (1999 – 2005). n = 2811

Table 1.2.4 Impact 4: The impact of phosphate dredging on species diversity.

Note: Original assessment table (Japp in Midgley 2012) for the impact assessment (left column) and the re-evaluated impact assessment after the verification programme (right column).

Nature of the impact	**4: The impact of phosphate mining on species diversity. Dredging operations will result a reduction or loss in biodiversity because of the 1) actual mining operations, 2) the habitat destruction and 3) sediment plumes**	
Report	***Impacts assessed EIA (2012)***	***Impacts re-evaluated: Verification programme***
Extent	**MLA** – impact on species diversity is restricted to areas inside the mining licence area (ML 170) and possibly the surrounding areas up to the 25 km buffer zone (Zone 1)	**Specific Mining Site**: impact on species diversity is likely to be restricted to the actual mined area (SP-1). The verification survey showed no significant difference from what was initially assumed from the data provided. Fish diversity was uniform throughout the survey. Diversity of epifauna also did not suggest the presence of unique species and was dominated a by few main species. Few marine mammal species were recorded although abundance and diversity may change seasonally. The comprehensive list of seabirds observed was consistent with the initial EIA (2012).
Duration	**Permanent** (>20 yrs) - the impact will only cease once the mining activity ends after 20 years (the period for which the mining licence is issued) and could persist for an indefinite period thereafter. If biodiversity is lost, the impact is permanent.	**Permanent** (> 20 yrs) - the impact will only cease once the dredging activity ends after 20 years (the period for which the licence is issued) and could persist for an indefinite period thereafter, with decreasing levels of severity. If biodiversity is lost, the impact is permanent. Note that this applies primarily to the specific target dredge site (SP-1). Recovery of biodiversity in the specific area of extraction within the MLA once mining has stopped is likely to be slow and will follow a natural process of ecological succession that is dependent upon the rate of recover of the substrate
Intensity	**Minor effect** – biodiversity in the MLA is expected to be comparatively low. Loss of biodiversity in the MLA is likely although at the regional level the limited extent of the mining locations is unlikely to cause permanent loss of regional biodiversity. Recovery of biodiversity in the specific area of extraction within the MLA	**Minor effect** – biodiversity in the MLA is expected to be comparatively low. Loss of biodiversity in the MLA is not likely although it cannot be stated conclusively that the dredging operation will not impact biodiversity in the specific mine site. At the regional level the limited extent of the dredging locations is highly unlikely to cause permanent loss

© NMP 2014

Table 1.2.4, Impact 4: The impact of phosphate dredging on species diversity *continued*...

Nature of the impact	**4: The impact of phosphate mining on species diversity. Dredging operations will result a reduction or loss in biodiversity because of the 1) actual mining operations, 2) the habitat destruction and 3) sediment plumes**	
Report	***Impacts assessed EIA (2012)***	***Impacts re-evaluated: Verification programme***
	once mining has stopped is likely to be slow and will follow a natural process of ecological succession that is dependent upon the rate of recover of the substrate.	of regional biodiversity.
Probability	**Improbable** –Diversity loss may occur in the specific dredge site but is highly unlikely beyond this specific area. **No change of assessment**	
Status (+ or -)	**Negative**. **No change of assessment**	
Significance (no mitigation)	**Low** – the impact on species diversity is not expected to influence project design provided the current area limitations are maintained. Expansion of dredging in the current or alternate lease areas without baseline monitoring of biodiversity and controls must be a prerequisite to the commencement of mining.	**Low** – the impact on species diversity is not expected to influence project design provided the current area limitations are maintained. Expansion of dredging in the current or alternate lease areas will require further baseline surveys of the biodiversity. This must be a prerequisite to the commencement of dredging in SP-2, SP-3 or else where in the MLA. The verification survey strengthens the knowledge base as will further data collection during regular monitoring for changes that may occur.
Mitigation	No practical mitigation measures are possible.	No practical mitigation measures are possible as the area of impact applies only to the specific mine site.
Significance (with mitigation)	Low. **No change of assessment**	
Confidence level	**Low to medium** - assumptions based on marine biodiversity in the MLA is limited to the nature of the data available.	
Confidence level Post Verification Assessment		**High** – the evaluation and assumptions based on species biodiversity has been verified by the results of the in-situ data collected from SP-1 and adjacent areas within the MLA during the biodiversity survey.

© NMP 2014

Explanation: (Table 1.2.4: Impact 4)

Post Verification Programme – Re-evaluated impact assessment

After the verification process the confidence level changed from Low/Medium to High due to the increased biodiversity information and data gathered during the biodiversity verification survey. The rest of the impact assessment table remained the same and has been verified by the results from the biodiversity survey. A total of 32 species (fish and epifauna species) was identified during the survey. Critical to biodiversity is the permanent loss of any unique species to the area. No unique species was found in SP-1 and adjacent areas within the MLA during the survey. We conclude that the diversity of fish and epifauna in and immediately adjacent to the SP-1 is comparatively low in terms of the Benguela ecosystem in Namibia.

The associated figure (to the right) is extracted from the EIA (2012), in order to provide diagrammatic representation of the data analysed supporting the above determined conclusions.

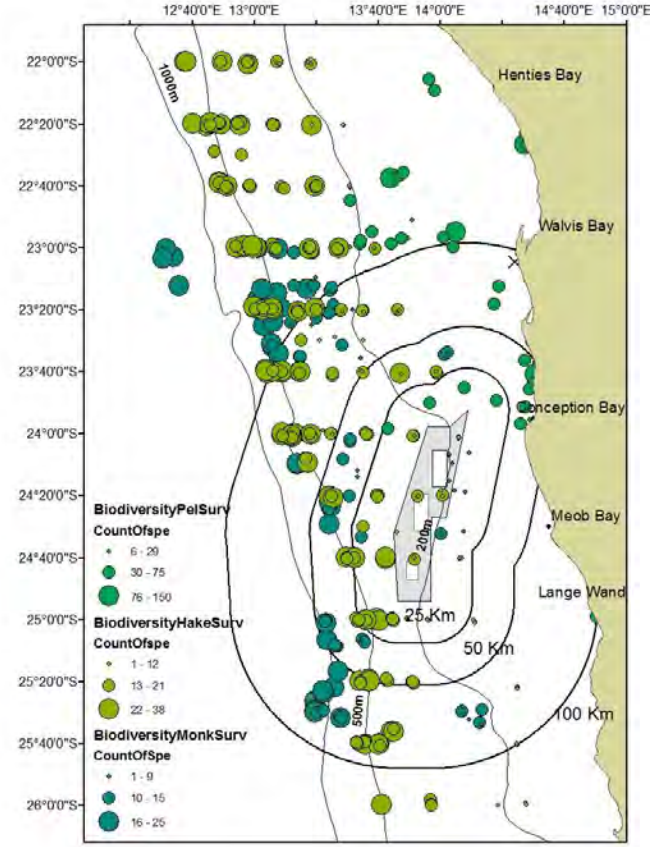


Figure 32. Dots represent number of species counted per coordinate (lat/long) from the hake survey data, monk-survey data, and small pelagic survey n = 9116

© NMP 2014

Table 1.2.5 Impact 5: The impact of phosphate dredging on seabirds and marine mammals

Note: Original assessment table (Japp in Midgley 2012) for the impact assessment (left column) and the re-evaluated impact assessment after the verification programme (right column).

Nature of the impact	**5: The impact of phosphate dredging on seabirds and marine mammals. Mining operations might result in the displacement and/or redistribution of seabirds and mammals because of 1) disturbance of the ecosystem and availability of feed and 2) physical disturbance of the dredgers including noise pollution**	
Report	***Impacts assessed EIA (2012)***	***Impacts re-evaluated: Verification programme***
Extent	**MLA** - impact on seabirds and mammals is restricted to areas inside the mining licence area (ML 170) and possibly the surrounding areas including Zone 1	**Specific Mine Site** - impact on seabirds and mammals is restricted to the mine site (SP-1). Areas adjacent to the dredged area may result in disturbance of mammals and seabirds extending into the rest of the MLA and possibly the surrounding areas but this cannot be stated explicitly.
Duration	**Long term** – The impact on sea birds and mammals will be for the term of the exploitation. Occasional interaction between the dredging operations and mammals and seabirds is likely although the actual level cannot be determined without more specific information on these groups for the MLA and Zone 1. Once mining ceases these groups will no longer be affected by the presence of the dredger although the alteration of behaviour of some species due to possible loss of foraging options cannot be determined.	**Long term** – The impact on sea birds and mammals will be for the term of the exploitation within the mine site only. Occasional interaction between the dredging operations and mammals and seabirds is likely although the actual level cannot be determined without more specific information on these groups for the MLA and Zone 1. Once dredging ceases these groups will no longer be affected by the presence of the dredger although the alteration of behaviour of some species due to possible loss of foraging options cannot be determined.
Intensity	**Minor effects** - Trophic disturbances could have an impact on the behaviour of seabirds and marine mammals. Noise pollution is a consideration for marine mammals whose acoustic communications may be affected resulting in avoidance of the area. Night strikes of birds due to deck lights is likely.	**Minor effects** - Trophic disturbances due to mining operations could have an impact on the behaviour of seabirds and marine mammals. Noise pollution is a consideration for marine mammals whose acoustic communications may be affected resulting in avoidance of the area. Night strikes of birds due to deck lights are likely.
Probability	**Probable** - consequences of trophic interaction, disturbances and noise pollution is highly likely.	
Status (+ or -)	Negative **No change of assessment**	

© NMP 2014

Table 1.2.5, Impact 5: The impact of phosphate dredging on seabirds and marine mammals *continued...*

Nature of the impact	**5: The impact of phosphate dredging on seabirds and marine mammals. Mining operations might result in the displacement and/or redistribution of seabirds and mammals because of 1) disturbance of the ecosystem and availability of feed and 2) physical disturbance of the dredgers including noise pollution**	
Report	***Impacts assessed EIA (2012)***	***Impacts re-evaluated: Verification programme***
Significance (no mitigation)	**Medium** – Most sea birds and mammal species found in the area will be affected but at a low level due to the limited extent of the mining operations. **No change of assessment**	
Mitigation	Maintain a bridge watch for large mammal species. Although the dredger will have limited manoeuvrability a protocol to limit interaction should be followed – in this regard JNCC guidelines are recommended. Lighting control to minimise night strikes by birds.	Maintain observations for occurrence of mammals and seabirds. Although the dredger will have limited manoeuvrability a protocol should be established to minimise disturbance when endangered and threatened mammals and other species are observed in the area and recognised mitigation guidelines should be followed. Lighting control to minimise night strikes of birds.
Significance (with mitigation)	**Low No change of assessment**	
Confidence level	**Medium** - information based on seabirds and mammals was provided by scientific specialists, however spatial data is limited. Baseline applies to the whole Namibian coast for most bird and mammal species – confidence relating to impact in the actual MLA is therefore low.	
Confidence level Post Verification Assessment		**High** – seabird and marine mammal spatial information was collected from SP-1 and adjacent areas inside the MLA during the Biodiversity survey and suggested no variation from the initial EIA (2012) assessment.

© NMP 2014

Explanation: ***(Table 1.2.5: Impact 5)***

Post Verification Programme – Re-evaluated impact assessment

After the verification process the confidence level changed from Low/Medium to High due to the increased seabird and marine mammal information and data gathered during the biodiversity verification survey. During the biodiversity survey (Section C, Chapter 3.1) 16 species of sea birds were identified, three of which were albatrosses. Only two species of mammals (Cape fur seal and dusky dolphin) were recorded during the survey. Most mammal species are naturally inquisitive and certainly, any dredging activity will attract small marine mammals e.g. dolphins and seals. Larger, mostly migrating mammals (i.e. baleen whales) are expected to avoid areas where maritime activity is high (although this does not exclude the possibility that large mammals will occasional be found in or near the MLA).

Impacts on birds and marine mammals will be limited to the actual dredging site and immediate areas. Disturbance of the substrate is also likely to result in higher levels of biological activity, increased particulate matter (assumed of poor nutritional value) in the water column and at the surface. This will alter bird behaviour as they will be naturally attracted to these areas.

© NMP 2014

B1.3 VERIFIED ASSESSMENT OF IMPACTS: MACROFAUNA

INTRODUCTION

The verification programme addresses the impacts associated with dredging within the target dredge area SP-1.

The Benthos Specialist Study (Steffani 2012) conducted within the framework of the EIA (Midgley 2012) identified impacts on the benthic communities that can be expected from the proposed Sandpiper Phosphate Project, and assessed their significance. For many of these impact assessments, the confidence levels were only medium as data directly from the target area were lacking. The verification survey was specifically designed to tackle this issue, and to verify whether the assessments will remain in view of the newly acquired empirical data. These data were primarily of biogeochemical nature and are dealt with in the Verification Survey Programme Report (Section C, Chapter 2.0). A series of nine impact tables which present the impacts as they were assessed in original benthic impact study in the 2012 EIA and as re-evaluated using site information gathered during 2013 are presented below.

A total of nine negative impacts were identified in the original assessment study with one impact having medium significance, one low to medium, and seven low significance. In sum, all changes to the original assessments centre on the level of confidence, increasing the level from medium to high as the verification survey largely confirmed the assumptions on which the assessments were based. This applied to five of the impact assessments while four remained unchanged.

© NMP 2014

Table 1.3: Macrofauna: Summary of impact assessment determinations: Re-evaluated following the verification assessment.

Reference table number refers to the individual impact table number found in the specalists section.

Ref. Tbl. No.	1.3.1	1.3.2	1.3.3	1.3.4	1.3.5	1.3.6	1.3.7	1.3.8	1.3.9
Risk Area	**Seabed dredging: Benthic Macrofauna**								
Nature of the impact	Sediment removal: benthos re establishment	Exploration activities and removal of benthos	Change of hydrographical conditions	Removal of sulphur oxidizing mats	*Clostridium botulinum I*	Sediment smothering benthos: Drag head	Benthos smothering: Dredge overspill plume	Nutrients added at surface: overspill plume	Increase of H_2S flux.
Extent	Dredge area	Dredge area	Specific mine site	Specific mine site	Specific mine site	Dredge area	Local to regional	Local	Local
Duration	Long term >20 years	Short term	Long term >20 years	Medium to long term	Sort term	Very short	Very short	Very short	Short term
Intensity	Moderate to serious	No lasting effects	Moderate to serious	Moderate to minor	Serious	Minor	Minor	Minor	Moderate
Probability	Definite	Probable	Probable	Improbable	Improbable	Highly probable	Probable	Possible	Probable
Status	Negative	Negative	Negative	Negative	Negative	Negative	Negative	Negative	Negative
Significance (no mitigation)	Medium	Non	Medium	Low	Low	Low	Low	Low	Low
Mitigation	Leave residual sediment layer / un mined areas	None required	Leave residual sediment layer / un mined areas	None	None	None	None	None	None
Significance (with mitigation)	Medium	None required	Low to Medium	Low	Low	None necessary	Low	Low	Low
Confidence level 2012	Medium	High	Medium	Medium	Medium	High	Medium	Medium	Medium
Re-evaluated 2014 confidence level	High	No change	High	High	No change	No change	No change	High	High

© NMP 2014

Table 1.3.1 Impact 1: The removal of the upper 1 to 2.5 m of sediment by dredging will result in the loss of the benthic biota.

Note: Original assessment table (Steffani in Midgley 2012) for the impact assessment (left column) and the re-evaluated impact assessment after the verification programme (right column).

Nature of the impact	**1: The removal of the upper 1 to 2.5 m (possibly up to 3 m) of sediment by dredging will result in the loss of the benthic biota associated with the sediment. The exposed sediments are likely to be different to the original superficial deposits, and sediment refill rates at this depth are likely to be very slow. Colonising assemblages are likely to differ to those present prior to the dredging activity.**	
Report	***Impacts assessed EIA (2012)***	***Impacts re-evaluated: Verification programme***
Extent	**Dredge area** - the loss of the benthic community is restricted to the dredged-out areas. Target areas are 22 x 8 km (176 km^2) in size but only a maximum of 3 km^2 per annum will mined, which amounts to a total of 60 km^2 after 20 years of mining (the period for which the mining licence is issued). **No change of assessment**	
Duration	**Permanent** (>20 years life of mine) - the recovery to the original community is likely to take longer than the life of mine or may even not be achieved in a meaningful time-scale. Recovery to functionally similar communities that provide similar ecosystem services as the original communities might, however, occur sooner (Long term). **No change of assessment**	
Intensity	**Moderate to serious effects** - recovery to the original community is likely to take very long (several decades, whereby beyond life of mine is classified as permanent), but recovery to a community providing similar ecosystem functioning is likely to occur sooner, e.g. environmental functions and processes are altered to such an extent that they temporarily cease. **No change of assessment**	
Probability	**Definite. No change of assessment**	
Status (+ or -)	**Negative. No change of assessment**	
Significance (no mitigation)	**Medium** - the duration of the impact is permanent in view of recovery to original community but recovery to a different community but providing similar ecosystem services may occur sooner, and the intensity is moderate to serious but the extent is confined to the mine site, maximum of 60 km^2 after 20 years of dredging. **No change of assessment**	
Mitigation	Leave behind a residual sediment layer of at least 30 cm of the original deposit thickness to cover the clay footwall. Leave behind undredged trenches to enable migration of mobile organisms from these areas. **No change of assessment**	
Significance (with mitigation)	**Medium** - the residual sediment layer will provide a substrate to be colonised by benthic organisms. Nonetheless, the recovering communities will be very different to those prior to dredging. **No change of assessment**	
Confidence level	**Medium** - the assessment is based on assumptions that are arrived from publicly available data, while data directly from the target areas are limited. A monitoring programme is needed to confirm the assumptions.	
Confidence level Post Verification Assessment		**High** - the verification survey confirms the assumptions on which the assessment was based, i.e. low dissolved bottom water conditions but not anoxic conditions nor significant amounts of HS^- flux from the sediments based on conditions measured.

© NMP 2014

Explanation: (Table 1.3.1: Impact 1)

Original EIA – Impact assessment

TSHD trial dredging that was undertaken near the mud belt in Atlantic 1 MLA in 105 m water depth is in terms of operational procedure comparable to the Sandpiper project as all of the dredged sediment was transported to shore. The dredged area was 200 x 500 m in size with an estimated average dredged depth of 5.28 m (Steffani 2010c). Monitoring surveys revealed that three years after mining the re-colonisation by macrofauna was relatively advanced, although abundance, biomass, species number, and species diversity were still lower than before the dredging and also when compared with a nearby unmined control site (Steffani 2010c). Differences in community structure were related primarily to a shift in the relative abundance of common species, and not due to a change in species composition. Interpretation of the data in terms of natural temporal variability was, however, compromised due to limited sampling of the control site. Although recovery was not fully accomplished three years after dredging, the recovery process was much faster than has been anticipated for such depths

Post Verification Programme – Re-evaluated impact assessment

The characteristics of the water masses present in the survey area over the period of measurement are those of the oxygen depleted, saline SACW flowing south in the poleward undercurrent from the Angola gyre, and the less saline, relatively oxic ESACW from the Cape Basin. The influence of the latter on ventilation of bottom water in the area is clearly evident from the temperature, salinity and dissolved oxygen time series measurements that were made. This is consistent with the findings in the EIA.

© NMP 2014

Table 1.3.2 Impact 2: Further exploration and environmental work will be conducted in the larger ML 170 that will remove benthic biota.

Note: Original assessment table (Steffani in Midgley 2012) for the impact assessment (left column) and the re-evaluated impact assessment after the verification programme (right column).

Nature of the impact	**2: Further exploration and environmental work will be conducted in the larger ML 170 that will remove benthic biota.**	
Report	***Impacts assessed EIA (2012)***	***Impacts re-evaluated: Verification programme***
Extent	**Dredge Area** – Gravity cores are ~2 inch in diameter, van Veen grab samples an area of max. 0.2 m^2 and larger grabs sample 3 m^2 bite. The total area disturbed by these tools even after extensive exploration campaigns will be very small. **No change of assessment**	
Duration	**Short term** – it is expected that slumping from the side of the holes will quickly fill in the disturbed area and migration from the adjacent area is fast. **No change of assessment**	
Intensity	**No lasting effects** – recovery will be very rapid as many animals will be transported into the disturbed area with the material slumping from the sides. **No change of assessment**	
Probability	**Probable**. **No change of assessment**	
Status (+ or -)	**Negative**. **No change of assessment**	
Significance (no mitigation)	**None** – recovery will be very rapid and effects on the system will not be measurable. **No change of assessment**	
Mitigation	No mitigation necessary	
Significance (with mitigation)	**None** – recovery will be very rapid and effects on the system will not be measurable. **No change of assessment**	
Confidence level	**High**. N**o change of assessment**	

Explanation: (Table 1.3.2: Impact 2)

Original EIA – Impact assessment
The footprint of exploration activity is minuscule, causing no discernable impact.

Post Verification Programme – Re-evaluated impact assessment
A re-evaluated assessment of this impact was not required in terms of the scope of the verification programme. The original assessment stands.

© NMP 2014

Table 1.3.3 <u>Impact 3</u>: The depth of the dredged area might change local near bottom hydrographical conditions and thus act as trap for very fine material.

Note: Original assessment table (Steffani in Midgley 2012) for the impact assessment (left column) and the re-evaluated impact assessment after the verification programme (right column).

Nature of the impact	**3: The depth of the dredged area might change local near bottom hydrographical conditions and thus act as trap for very fine material. This could lead to high decomposition rates and consequently anoxic conditions and H_2S concentrations in the sediments.**	
Report	***Impacts assessed EIA (2012)***	***Impacts re-evaluated: Verification programme***
Extent	**<u>Specific mine site</u>** - Target areas are 22 x 8 km (176 km^2) in size but only a maximum of 3 km^2 per annum will be mined, which amounts to a total of 60 km^2 after 20 years of mining (the period for which the mining licence is issued). **No change of assessment**	
Duration	**<u>Permanent</u>** - sediment refill rates are expected to be very low at the water depth of the target areas. **No change of assessment**	
Intensity	**<u>Moderate to Serious effects</u>** - anoxic conditions are deadly for most benthic communities but large sulphur-oxidising bacteria can thrive under these conditions. **No change of assessment**	
Probability	**<u>Probable</u>** – localised anoxic conditions may occur in the deeper trenches and pits. **No change of assessment**	
Status (+ or -)	**<u>Negative</u>**. **No change of assessment**	
Significance (no mitigation)	**<u>Medium</u>** - duration is permanent and intensity moderate to serious, but extent is restricted to the mine area and large areas of the inner shelf are naturally subjected to anoxic conditions. **No change of assessment**	
Mitigation	Leave behind a residual sediment layer of at least 30 cm, which will reduce the depth of the dredged-out area. **No change of assessment**	
Significance (with mitigation)	**<u>Low to medium</u>** - a dredged depth of an average of 1.7 m (possibly up to 3 m) over a relatively large area is unlikely to reduce bottom current speeds to such an extent that very fine material will significantly accumulate in the dredge area. **No change of assessment**	
Confidence level	**<u>Medium</u>** - the assessment is based on assumptions that are arrived from publicly available data, while data directly from the target areas are limited. A recovery survey is needed to confirm the assumptions.	
Confidence level Post Verification Assessment		**<u>High</u>** - the verification survey confirms the assumptions on which the assessment was based, i.e. high natural near bottom current speeds sufficient enough to exert shear stress forces that prevent accumulation of sedimenting fine particulate matter.

© NMP 2014

Explanation: (Table 1.3.3: Impact 3)

Original EIA – Impact assessment

The total removal of the phosphate deposits in the Sandpiper target areas would expose the footwall, which consists of firm clay, compared with the sandy/shelly deposits of the original surface layer. Hard consolidated clay is less than ideal for small burrowing fauna, and the clay may function more like a hard bottom substrate. This would lead to the area being colonised by a very different suite of animals. Dredging of the clay footwall, however, is undesirable from a technical perspective and it is proposed to leave behind a residual layer of phosphate sand to avoid direct contact of the draghead with the footwall. Mitigation recommendations will also include leaving behind a minimum layer of approximately 30 cm of sediments. New sediment in the dredged out area can accumulate through bedload transport of mobile sand, by natural deposition of fines from the water column, through slumping from the undredged pit walls (and potentially undredged corridors between trenches), and/or by deposition of outwash fines from the dredger

Post Verification Programme – Re-evaluated impact assessment

- The measured currents reflected consistent NW (equatorward) flow in the near surface depths, switching between NW and S (poleward) flow at mid-depth and near the seabed a period of sustained poleward flow followed by switching between poleward and equatorward flows. The near surface and seabed currents are consistent with those predicted in the EIA. Time series measurements at mid-depth were not available to the EIA and the verification measurements represent new detail for the region.
- Current flow velocities were variable temporally and with depth. In general surface flows averaged 17 cm/s, mid-depth flows ~10 cm/s and near seabed flows 18 cm/s for poleward flow but were lower at 9 cm/s in oscillating pole/equatorward flows. These are in general agreement with the information in the EIA. Seabed current velocities are higher than the <10 cm/s predicted by Shillington et al (2006) as quoted in the EIA. In the short term velocities ~30 cm/s were recorded at the mooring implying considerable turbulence at the seafloor.
- The characteristics of the water masses present in the survey area over the period of measurement are those of the oxygen depleted, saline SACW flowing south in the poleward undercurrent from the Angola gyre, and the less saline, relatively oxic ESACW from the Cape Basin. The influence of the latter on ventilation of bottom water in the area is clearly evident from the temperature, salinity and dissolved oxygen time series measurements that were made. This is consistent with the findings in the EIA.

© NMP 2014

Table 1.3.4 Impact 4: Dredging removes mats of large sulphur-oxidising bacteria from the sediment surface and from the upper layer.

Note: Original assessment table (Steffani in Midgley 2012) for the impact assessment (left column) and the re-evaluated impact assessment after the verification programme (right column).

Nature of the impact	**4: Dredging removes mats of large sulphur-oxidising bacteria from the sediment surface and from the upper layer.**	
Report	***Impacts assessed EIA (2012)***	***Impacts re-evaluated: Verification programme***
Extent	**Specific mine site** - Target areas are 22 x 8 km (176 km^2) in size but only a maximum of 3 km^2 per annum will mined, which amounts to a total of 60 km^2 after 20 years of mining (the period for which the mining licence is issued). **No change of assessment**	
Duration	**Medium to long term** – the recovery of bacterial mats depends on the development of sufficient H_2S concentrations. This requires anoxic conditions that can only develop when high concentrations of organic matter accumulate in the dredge area. Although higher organic loading might be a possibility as the dredge area may act as trap, it will take a long time to build up enough material for anoxic conditions and high H_2S concentrations. **No change of assessment**	
Intensity	**Moderate to minor effects** – the large sulphur bacteria are important in oxidising the toxic H_2S thereby reducing its diffusion into the water column. Their removal will disrupt this, on the other hand, the removal of the sediments will also remove any H_2S contained in the sediments, and H_2S fluxes from the dredge area are thus not expected unless the system turns anoxic. If this happens, the bacterial mats are likely to return. **No change of assessment**	
Probability	**Improbable** – evidence from published data strongly suggests that offshore the mud belt at 24°S and beyond the 200-m isobaths concentrations of large sulphur bacteria are low or absent.	**Improbable**: the verification survey (Section C, Chapter 2.3) has confirmed the absence of large sulphur bacteria in SP-1 as neither *Thiomargarita, Beggiatoa*, nor *Thioploca* were found in the investigated samples, these species being typically associated with the formation of bacterial mats
Status (+ or -)	**Negative. No change of assessment**	
Significance (no mitigation)	**Low** – concentrations of large sulphur bacteria is assumed to be low or absent.	**Low**: Confirmed from the verification survey (Section C, Chapter 2.3)
Mitigation	No mitigation necessary	
Significance (with mitigation)	**Low** – concentrations of large sulphur bacteria is assumed to be low or absent.	**Low**: Confirmed from the verification survey (Section C, Chapter 2.3)
Confidence level	**Medium** - the assessment is based on assumptions that are arrived from publicly available data, while data directly from the target areas are limited. An initial survey is needed to confirm the assumptions.	
Confidence level Post Verification Assessment		**High** – the verification surveys has confirmed the assumption of absence of large sulphur bacteria in SP-1 as neither *Thiomargarita, Beggiatoa*, nor *Thioploca* were found in the investigated samples (Section C , Chapter 2.3).

© NMP 2014

Explanation: (Table 1.3.4: Impact 4)

Post Verification Programme – Re-evaluated impact assessment

The investigation into sulphur bacteria indicated that, at the time of sampling, sulphide fluxes were probably low as the large sulphate bacteria, namely from the genera *Thiomargarita*, *Beggiatoa* and *Thioploca*, which play a significant roles in the oxidisation of H_2S, were absent from the bacterial assemblage. Smaller forms including *Thiobacillus* spp. with relatively lower growth yields were present; however, indicating that although the concentration was estimated to be low (hydrogen) sulphide was present in the sediments.

© NMP 2014

Table 1.3.5 Impact 5: The anaerobic bacterium Clostridium botulinum type E might proliferate in the dredged area, and may pose a health risk to humans and wildlife when entering the food chain.

Note: Original assessment table (Steffani in Midgley 2012) for the impact assessment (left column) and the re-evaluated impact assessment after the verification programme (right column).

Nature of the impact	**5 The anaerobic bacterium Clostridium botulinum type E might proliferate in the dredged area if the system turns anoxic, and may pose a health risk to humans and wildlife when entering the food chain.**	
Report	***Impacts assessed EIA (2012)***	***Impacts re-evaluated: Verification programme***
Extent	**Specific mine site** - Target areas are 22 x 8 km (176 km^2) in size but only a maximum of 3 km^2 per annum will mined, which amounts to a total of 60 km^2 after 20 years of mining (the period for which the mining licence is issued). **No change of assessment**	
Duration	**Short term** – if the system turns anoxic this will be of long term or permanent duration, but *C. botulinum* proliferation is linked to periodic massive die-offs of fish and other aquatic life that might occur during extreme events such as H_2S eruptions. Once these bacteria proliferate they may enter the food chain by ingestion of contaminated sediments from the dredge area. **No change of assessment**	
Intensity	**Serious effects** – botulism caused by the bacteria can be lethal to humans and wildlife. **No change of assessment**	
Probability	**Improbable** – no in situ contamination of fish populations by the bacterium has been reported for southern African fish populations. Literature data suggest that the distribution of the bacteria is limited in deeper saline waters. If the bacteria are a problem in Namibian waters, it is unlikely that the addition of 60 km^2 of anoxic seafloor will add any measurable risk of bacteria proliferation to the already large areas of anoxic zone. **No change of assessment**	
Status (+ or -)	**Negative – No change of assessment**	
Significance (no mitigation)	**Low** – proliferation of bacteria is assumed to be a rare probability. **No change of assessment**	
Mitigation	No mitigation necessary but this should not indemnify the fishing industry from complying with any regulations regarding *C. botulinum* contamination. **No change of assessment**	
Significance (with mitigation)	**Low** – proliferation of bacteria is assumed to be a rare probability. **No change of assessment**	
Confidence level	**Medium** – very little is known about the natural life-cycle of the bacteria and this assessment is based on data from the northern hemisphere	
Confidence level Post Verification Assessment		No assessment undertaken during the verification programme. Based on existing risk (impact) determination there is no justifiable cause for further evaluations of the possible impacts of *Clostridium botulinum* type E. **No change of assessment**

© NMP 2014

Explanation: (Table 1.3.5: Impact 5)

Original EIA – Impact assessment

In the worst case scenario, changes in the small-scale near bottom hydrographical conditions as a result of dredging might create an anaerobic environment over an area of 60 km^2 after 20 years of dredging. Put into a regional context, the addition of 60 km^2 anaerobic environment where the bacterium could occur to the naturally occurring vast area of the azoic zone, is negligible. If proliferation of *C. botulinum* in anaerobic zones was a problem in Namibian waters it is unlikely that it would be aggravated by this spatial addition, and the impact is thus regarded as negligible.

Post Verification Programme – Re-evaluated impact assessment

A re-evaluated assessment of this impact was not required in terms of the scope of the verification programme. The original assessment stands.

© NMP 2014

Table 1.3.6 Impact 6: High suspended sediment concentrations near the sea bottom generated by the drag head and subsequent re-deposition of the material causes smothering effects.

Note: Original assessment table (Steffani in Midgley 2012) for the impact assessment (left column) and the re-evaluated impact assessment after the verification programme (right column).

Nature of the impact	**6: High suspended sediment concentrations near the sea bottom generated by the drag head and subsequent re-deposition of the material causes smothering effects.**	
Report	***Impacts assessed EIA (2012)***	***Impacts re-evaluated: Verification programme***
Extent	**Dredge area** – sedimentation effects will only be relevant along a narrow strip around the dredge site as any re-depositions inside the dredge area will have no impact since the animals are removed. **No change of assessment**	
Duration	**Very short term** – smothering of a particular area occurs only during the dredging activity, maximum dredging activity per area is assumed to be < 10 days for intermittent (16 hour-cycle) dredging. **No change of assessment**	
Intensity	**Minor effects** – some organisms in the immediate vicinity of the dredge site may be impacted on a lethal level but the majority of impacts can be expected on a sub lethal level as many animals can cope with relatively high short-term suspended material concentrations. **No change of assessment**	
Probability	**Highly probable**. **No change of assessment**	
Status (+ or -)	**Negative**. **No change of assessment**	
Significance (no mitigation)	**Low** – very small extent, very short duration and low intensity. **No change of assessment**	
Mitigation	No mitigation necessary. **No change of assessment**	
Significance (with mitigation)	**Low** – very small extent, very short duration and low intensity. **No change of assessment**	
Confidence level	**High** – studies on draghead plumes have shown that the affected area is very small.	
Confidence level Post Verification Assessment		No assessment undertaken during the verification programme. Based on existing risk (impact) determination there is no justifiable cause for further evaluations. **No change of assessment**

© NMP 2014

Explanation: (Table 1.3.6: Impact 6)

Original EIA – Impact assessment

Sediment re-suspension from the draghead increases with hopper filling speed and travel speed of the dredger, but is mainly dependent on the properties of the sediments (Johnson and Parchure 1999). Suspended sediment concentrations generated at the point of dredging tend to decline as the sediments become coarser. The size fractions of greatest consequence are the silts, muds and clays (<63 µm) as these create the highest level of turbidity (Johnson and Parchure 1999). Near-bottom dredge plumes usually decrease rapidly with distance from the dredger. Kirby and Land (1991), for example, recorded suspended sediment concentrations decreasing from a maximum of 1,100 mg/ℓ at the cutter head of a cutter suction dredger to 20-90 mg/ℓ only 50 m away. The overburden in the target areas is described as silty sand with significant gravel component and will thus have relatively rapid settlement rates, and the re-suspended sediment should disperse only over short distances.

Post Verification Programme – Re-evaluated impact assessment

A re-evaluated assessment of this impact was not required in terms of the scope of the verification programme. The original assessment stands.

© NMP 2014

Table 1.3.7 Impact 7: Re-deposition of particles in the overflow plume causes smothering of benthic organisms, particularly in the depo-center on the continental slope.

Note: Original assessment table (Steffani in Midgley 2012) for the impact assessment (left column) and the re-evaluated impact assessment after the verification programme (right column).

Nature of the impact	**7: Re-deposition of particles in the overflow plume causes smothering of benthic organisms, particularly in the depo-center on the continental slope**	
Report	***Impacts assessed EIA (2012)***	***Impacts re-evaluated: Verification programme***
Extent	**Local to regional** – the fines (<63 micron) in the plumes may be transported for several kilometres but upon entering the nepheloid layer, material may be transported to the depo-center ~100 km south-west of the licence area. Significant deposition-thicknesses are, however, expected to occur only in the immediate vicinity of the dredge area. **No change of assessment**	
Duration	**Very short term** – the overflow plumes will only be generated during dredging which occurs for approximately 16 hrs within a 37-hour dredge cycle for approx. 16 hours. **No change of assessment**	
Intensity	**Minor effects** – animals in the immediate vicinity of the dredge area may be affected by smothering, elsewhere sedimentation rates are expected to be very low. **No change of assessment**	
Probability	**Probable**. **No change of assessment**	
Status (+ or -)	**Negative. No change of assessment**	
Significance (no mitigation)	**Low.** – although widespread, re-deposition rates are expected to be low, and higher rates are limited to the immediate vicinity of the dredge area. Communities in the depo-center where higher settling rates may occur, are also likely to be adapted to sedimentation as this is a naturally high sedimentation area. **No change of assessment**	
Mitigation	No mitigation necessary.	
Significance (with mitigation)	**Low** – although widespread, re-deposition rates are expected to be low, and higher rates are limited to the immediate vicinity of the dredge area. Communities in the depo-center where higher settling rates may occur, are adapted to sedimentation as this is a naturally high sedimentation area. **No change of assessment**	
Confidence level	**Medium** – assumed low sedimentation rates are based on a study conducted in shallower waters (105-130 m) of southern Namibia with different hydrographical conditions. **No change of assessment**	

Explanation: (Table 1.3.7: Impact 7)

Post Verification Programme – Re-evaluated impact assessment

This review indicates that it is possible (but not certain) that the actual plume dimensions may exceed the dimensions assumed in the 2012 EIA assessment (i.e. plume dimensions may be 2 to 5 times larger than indicated). However, the implication of these potentially increased plume dimensions for the overall impact assessment and subsequent environmental decision-making is limited. Should the plume dimensions exceed those estimated in the 2012 EIA study, the extent of the plume reported in the impact assessment tables of this study may increase from being limited to the "Immediate Dredge Area" to affecting possibly the "Annual Mining Area". It is not expected that this change in the extent of the impact would be such that it affected the "Specific Mining Site". Therefore it is not expected that these possible, but modest, changes in the impacted area will materially affect the environmental decision-making surrounding this project.

© NMP 2014

Table 1.3.8 Impact 8: Dredging may mobilise dissolved nutrients from the sediments which could be released into the water column with the overflow from the dredger.

Note: Original assessment table (Steffani in Midgley 2012) for the impact assessment (left column) and the re-evaluated impact assessment after the verification programme (right column).

Nature of the impact	**8: Dredging may mobilise dissolved nutrients from the sediments which could be released into the water column with the overflow from the dredger. The increased nutrient level may result in extensive phytoplankton blooms, which upon death cause aggravated decomposition rates leading to anoxic conditions at the seafloor.**	
Report	***Impacts assessed EIA (2012)***	***Impacts re-evaluated: Verification programme***
Extent	**Local** – the released nutrients will spread with the overflow plume. **No change of assessment**	
Duration	**Very short term** – the overflow plumes will only be generated during dredging which occurs for approximately 16 hrs within a 37-hour dredge cycle for approx. 16 hours. **No change of assessment**	
Intensity	**Minor effects** – literature data suggest that dissolved nutrient concentrations in the target areas are relatively low, which means that only low amounts of nutrients will be mobilised. **No change of assessment**	
Probability	**Possible** – it is likely that some nutrients will be mobilised but it is unlikely that this will result in massive dying phytoplankton-blooms reaching the sea bottom in such locally dense concentrations that this will cause anoxic seafloor conditions. **No change of assessment**	
Status (+ or -)	**Negative**. **No change of assessment**	
Significance (no mitigation)	**Low** – due to potentially low dissolved nutrient concentrations in the target areas. **No change of assessment**	
Mitigation	No mitigation necessary.	
Significance (with mitigation)	**Low** – due to potentially low dissolved nutrient concentrations in the target areas. **No change of assessment**	
Confidence level	**Medium** - the assessment is based on assumptions that are arrived from publicly available data, while data directly from the target areas are limited. An initial survey is needed to confirm the assumptions.	
Confidence level Post Verification Assessment		**High** - the verification survey confirms the assumptions on which the assessment was based, i.e. moderately high nutrient levels in the sediments but generally low pore water volumes that could release nutrients when disturbed. Therefore nutrient loading to the euphotic zone through dredging will be unlikely.

© NMP 2014

Explanation: (Table 1.3.8: Impact 8)

Post Verification Programme – Re-evaluated impact assessment

Measurements of sediment properties in the proposed dredge site show that the subsurface sediment pore water contained moderate nitrate-nitrogen concentrations but high phosphate-phosphorus concentrations and that the pore waters showed a considerable departure from the water column Redfield ratio observed in the survey area (8.2 vs 17.7) The measured moisture content of the sediment was low, however, indicating that the affected pore water volume is also low (~35 litres/m^3 sediment). Dilution in the dredged sediment slurry and with surface waters after discharge from the dredger will limit nutrient enrichment and consequent elevated phytoplankton production.

© NMP 2014

Table 1.3.9 Impact 9: Release of hydrogen sulphide from the sediments affects benthic communities.

Note: Original assessment table (Steffani in Midgley 2012) for the impact assessment (left column) and the re-evaluated impact assessment after the verification programme (right column).

Nature of the impact	**9: Release of hydrogen sulphide from the sediments affects benthic communities**	
Report	***Impacts assessed EIA (2012)***	***Impacts re-evaluated: Verification programme***
Extent	**Local** – released hydrogen sulphide may spread along the sea bottom affecting undredged areas and the associated biotic life. **No change of assessment**	
Duration	**Short term** – the spread of hydrogen sulphide across the seafloor will be very short term and the gas will eventually mix with the seawater. The gas is, however, very toxic and will kill many animals in its path. Recovery of the benthic communities will be relatively rapid if hydrogen sulphide conditions are only temporary. **No change of assessment**	
Intensity	**Moderate effects** – hydrogen sulphide is very toxic and will kill many animals but its presence is temporary. **No change of assessment**	
Probability	**Probable** – literature data suggest that hydrogen sulphide concentrations in the near-bottom waters, pore waters and in the upper sediment layers in the target areas are very low. It can, however, not be excluded that deeper sediment layers may contain hydrogen sulphide. If hydrogen sulphide is present, it is presumably sucked up with the sediments and residual hydrogen sulphide at the seafloor will be minimal. **No change of assessment**	
Status (+ or -)	**Negative**	
Significance (no mitigation)	**Low** – hydrogen sulphide concentrations are assumed to be low, and the dredging process will also remove any gas contained in the sediments. **No change of assessment**	
Mitigation	No mitigation necessary	
Significance (with mitigation)	**Low** – hydrogen sulphide concentrations are assumed to be low, and the dredging process will also remove any gas contained in the sediments. **No change of assessment**	
Confidence level	**Medium** - the assessment is based on assumptions that are arrived from publicly available data, while data directly from the target areas are limited. An initial survey is needed to confirm the assumptions.	
Confidence level Post Verification Assessment		**High** - the verification survey confirms the assumptions on which the assessment was based, i.e. low dissolved bottom water conditions but not anoxic conditions nor significant amounts of HS^- flux from the sediments based on conditions measured.

© NMP 2014

Explanation: (Table 1.3.9: Impact 9)

Post Verification Programme – Re-evaluated impact assessment

Concentrations and thus possible fluxes of H_2S in sediment pore water are estimated to be low from measurements of proxy variables within the sediments in the target dredge area. Circumstantial evidence in support of this is the absence the large sulphate oxidising bacteria from the survey area during at least the period of the thiobacteria survey July/August 2014. Further, evaluation of pyrite-S mobilisation from sediments indicate that this is low. Consequently H_2S fluxes to the lower water column are considered to be negligible and the absence of large sulphur oxidising bacteria, due to either natural causes or disruption from dredging, would have little effect on these.

© NMP 2014

B1.4 VERIFIED ASSESSMENT OF IMPACTS: JELLYFISH

INTRODUCTION

The verification programme addresses the impacts associated with dredging within the target dredge area SP-1

The Jellyfish Specialist Study (Gibbons 2012) conducted within the framework of the EIA (Midgley 2012) identified impacts on the jellyfish communities that can be expected from the proposed Sandpiper Phosphate Project, and assessed their significance. A series of four impact tables which present the impacts as they were assigned in original jellyfish impact study in the 2012 EIA are presented below.

The proposed mining activities are not considered to have a significant and lasting impact on the abundance and distribution of jellyfish populations: the tailings plume is limited in spatial/temporal extent and jellyfish have no specialized respiratory surfaces that could get clogged; alterations to the benthos are unlikely to increase the habitat for polyp establishment if a layer of soft sediment is allowed to remain, and whilst hydrogen sulphide could kill individuals in the affected water column, this is likely to be on a very limited scale since dredging will take place seawards of the mud belt which is the main source of H_2S. More serious impacts are likely to be effected by jellyfish on mining operations, though not through clogging at the drag-head as jellyfish are uncommon at depth. However, at the surface, where water will be drawn into the vessel for cooling (etc.), they could cause a major problem for vessel activities.

A total of four negative impacts were identified in the original assessment study with one impact having low significance, three, very low significance.

© NMP 2014

Table 1.4: Jellyfish. Summary of impact assessment determinations

Note: A verification assessment specifically related to jellyfish was not undertaken.

Reference table number refers to the individual impact table number found in the specialists section.

Ref. Tbl No.	1.4.1	1.4.2	1.4.3	1.4.4
Risk Area	**Dredging: Jellyfish**			
Nature of the impact	Blocking sea water intakes of vessel	H_2S mortalities to Jellyfish	Turbidity cause mortalities	Hard substrate exposed
Extent	Dredge event	Dredge event	Dredge event	Annual mining area
Duration	Extremely short term	Extremely short term	Extremely short term	Very short term
Intensity	No lasting effects	No lasting effects	Minor effects	Minor effects
Probability	Highly probable	Possible	Rare	Rare
Status (- ve of + ve)	Negative (to Jellyfish)	Negative (to Jellyfish)	Negative (to Jellyfish)	Positive (to jellyfish)
Significance (no mitigation)	Low	Low	Very low	Low
Significance (with mitigation)	Very low	Low	Very low	Very low
Confidence level 2012	High	Low	Low	High
Re-evaluated 2014 confidence level	No change	No change	No change	No change

© NMP 2014

Table 1.4.1 Impact 1: Blocking of vessel seawater intake system by dense surface aggregations of jellyfish.

Note: A verification assessment specifically related to jellyfish was not undertaken.

Nature of the impact	**1: Blocking of vessel seawater intake system by dense surface aggregations of jellyfish.** **Dense surface volumes of jellyfish have been known to block the seawater intakes. This incoming seawater is used to cool the vessel's engines and any blockage of the intake system could cause the engines to overheat and fail, if remedial action is not taken.**	
Report	***Impacts assessed EIA (2012)***	***Impacts re-evaluated: Verification programme***
Extent	**Dredge Event:** The extent is limited to immediately adjacent to the vessel during all operations. **No change of assessment**	
Duration	**Extremely short term:** The duration is limited to the period of time when dense aggregations of jellyfish are around the vessel: probably no more than a few hours in duration. **No change of assessment**	
Intensity	**No lasting effect**: This impact would involve a relatively limited number of jellyfish and is more likely to have adverse impact to the vessel if not mitigated. **No change of assessment**	
Probability	**Highly probable**: Although it is not possible to predict exactly when dense jellyfish aggregations may appear around the vessel, they do tend to occur more commonly during late winter / early spring: it is inconceivable, given how many jellyfish there are off Namibia, that this threat will not arise. **No change of assessment**	
Status (+ of -)	**Negative** to individual jellyfish, possibly positive for fisheries. **No change of assessment**	
Significance (no mitigation)	**Low: No change of assessment**	
Mitigation	In the case of blockage, jellyfish will have to be physically removed or flushed from the system. Sailing the vessel to areas with less dense aggregations of jellyfish Forward looking sonar could be installed on the vessel to identify dense masses of sub-surface jellyfish during operations. A "jellyfish observer" on deck should be able to identify jellyfish aggregations at the surface.	
Significance (with mitigation)	**Very Low: No change of assessment**	
Confidence level	**High**:	
Confidence level Post Verification Assessment		**High No change of assessment**

Explanation: (Table 1.4.1: Impact 1)

Original EIA – Impact assessment
Although jellyfish can be found throughout the water column, more than 80% of biomass is found in the upper 50 m (Flynn *et al.,* in press). This means that jellyfish are unlikely to be entrained in large quantities in dredged sediments. However, it does mean that jellyfish could block seawater cooling intakes on the dredging vessel itself, which could pose a significant technical risk.

Post Verification Programme – Re-evaluated impact assessment
A re-evaluated assessment of this impact was not required in terms of the scope of the verification programme. The original assessment stands.

© NMP 2014

Table 1.4.2 Impact 2: Hydrogen sulphide released from dredge sediments causing mortalities to jellyfish.

Note: A verification assessment specifically related to jellyfish was not undertaken.

Nature of the impact	**2: Hydrogen sulphide released from dredge sediments causing mortalities to jellyfish. The mining operation is located seaward of the mud belt where high levels of hydrogen sulphide are known to be associated with soft sediments. Hydrogen sulphide releases from the sediments in the Mining Licence Area (which is adjacent to, but not in the mud belt) are thus envisaged to be significantly less frequent and intense.**	
Report	***Impacts assessed EIA (2012)***	***Impacts re-evaluated: Verification programme***
Extent	**Dredge Event: No change of assessment**	
Duration	Extremely short term: The duration is short (hours), related to the pulsed release of hydrogen sulphide. **No change of assessment**	
Intensity	**Minor effects:**	**No lasting effects:** individuals may be affected, however, environmental functions and processes are not adversely affected.
Probability	**Probable**: In the event that the combination of adverse factors comes together at any one time, jellyfish moralities will occur. **No change of assessment**	**Possible**: the possibility of H_2S poisoning of jellyfish cannot be eliminated entirely, the probability rating is adjusted, as a result of data collected from SP-1 confirming the limited presence of H_2S.
Status (+ of -)	**Negative**: to individual jellyfish, possibly positive for fisheries. **No change of assessment**	
Significance (no mitigation)	**Low: No change of assessment**	
Mitigation	No mitigation is presented	
Significance (with mitigation)	**Low: No change of assessment**	
Confidence level	**High**: Although there is no information on the tolerance of jellyfish to hydrogen sulphide, they are unlikely to have special adaptations to cope with it. More research on this is needed.	
Confidence level Post Verification Assessment		**High**: data collected from across SP-1 confirms the limited presence of H_2S. (section C 2.1)

© NMP 2014

Explanation: (Table 1.4.2: Impact 2)

Original EIA – Impact assessment

The liberation of large quantities of hydrogen sulphide by dredging activities has the potential to kill off any jellyfish present in the affected water column as these organisms possess no special tolerance to this metabolic toxin, although both medusa and polyps are remarkably tolerant of hypoxic water (Purcell *et al*., 2001; Condon *et al*., 2001).

Post Verification Programme – Re-evaluated impact assessment

A re-evaluated assessment of this impact was not required in terms of the scope of the verification programme. However, concentrations and thus possible fluxes of H_2S in sediment pore water are estimated to be low from measurements of proxy variables within the sediments in the target dredge area. Circumstantial evidence in support of this is the absence the large sulphate oxidising bacteria from the survey area during the period of the thiobacteria survey in July/August 2014. Further, evaluation of pyrite-S mobilisation from sediments indicate that this is low. Consequently H_2S fluxes to the lower water column are considered to be negligible and the absence of large sulphur oxidising bacteria, due to either natural causes or disruption from dredging, would have little effect on these.

© NMP 2014

Table 1.4.3 Impact 3: Lean water overflow sediments, if present in sufficient quantities, may cause mortalities to jellyfish.

Note: A verification assessment specifically related to jellyfish was not undertaken.

Nature of the impact	**3: Lean water overflow from the vessel generates a tailings plume of fine sediments which settle out through and are dispersed in the water column. These fine sediments if present in sufficient quantities may cause mortalities to jellyfish, though this is considered unlikely**	
Report	***Impacts assessed EIA (2012)***	***Impacts re-evaluated: Verification programme***
Extent	**Mine site**: < 25 km. It is understood that whilst dredging a sediment plume of ~1500 m long and 800 m wide will be generated over the cut length of up to 22 km. This plume is determined to sink to the seabed over a distance of 500-1500 m from the point of discharge. The maximum concentrations of sediments in the sediment plume are envisaged to be <50 mg/l but most of the plume area will have total suspended sediment concentrations <10 mg/l above background (1-4 mg/l), these are regarded as low.	**Dredge event:** It is understood that whilst dredging a sediment plume of ~1500 m long and 800 m wide will be generated over the cut length of up to 4 km. This plume is determined to sink to the seabed over a distance of 500-1500 m from the point of discharge. The maximum concentrations of sediments in the sediment plume are envisaged to be <50 mg/l but most of the plume area will have total suspended sediment concentrations <10 mg/l above background (1-4 mg/l), these are regarded as low. (Revised: cut length is reported, not 22 km as originally listed (left column), but corrected to 4 km (this column). This correction, serves to reduced the spatial extent of the impact.
Duration	**Extremely short term: No change of assessment**	
Intensity	**Minor effects: No change of assessment**	
Probability	**Rare: No change of assessment**	
Status (+ of -)	**Negative**: to individual jellyfish, possibly positive for fisheries. **No change of assessment**	
Significance (no mitigation)	**Very Low: No change of assessment**	
Mitigation	No mitigation is presented	
Significance (with mitigation)	**Very Low: No change of assessment**	
Confidence level	**Low**: – research on this is needed	
Confidence level Post Verification Assessment		**Low**: – research on this is needed. **No change of assessment**

© NMP 2014

Explanation: (Table 1.4.3: Impact 3)

Original EIA – Impact assessment

The plume of fine sediment that will be generated in the water column during dredging operations has a limited potential to be deleterious to individual jellyfish, with population level impacts being dependent on the numbers of animals moving through the licence areas. That said. it must be stressed that no research has been conducted in this area. The "fines" could settle out on individual jellyfish, but as the organisms have no specialized respiratory surfaces that could be blocked, they should be able to continue swimming, and through swimming they should be able to rid themselves of settled particles. Whilst it could be argued that jellyfish might ingest particles in the tailing plume, this is considered unlikely.

© NMP 2014

Table 1.4.4 Impact 4: Removal of seabed sediments will change the nature of the sediment surface. Jellyfish populations are known to increase in areas where there is an increase of hard substrate.

Note: A verification assessment specifically related to jellyfish was not undertaken.

Nature of the impact	**4: Removal of seabed sediments will change the nature of the sediment surface. Jellyfish populations are known to increase in areas where there is an increase of hard substrate. Typically this occurs where rock, concrete or iron structures are erected. The removal of the upper relative soft layers of sediment, leaving a relative hard clay footwall surface may provide such a hard surface.**	
Report	***Impacts assessed EIA (2012)***	***Impacts re-evaluated: Verification programme***
Extent	**Annual Mining Area: No change of assessment**	
Duration	**Very Short term: No change of assessment**	
Intensity	**Minor effects: No change of assessment**	
Probability	**Rare: No change of assessment**	
Status (+ of -)	**Positive** for jellyfish, negative for fisheries. **No change of assessment**	
Significance (no mitigation)	**Low: No change of assessment**	
Mitigation	None: If between 10 - 15 % of the original thickness of the sediment is not recovered, there will sufficient soft substrata to preclude polyp settlement.	
Significance (with mitigation)	**Very Low: No change of assessment**	
Confidence level	**High:**	
Confidence level Post Verification Assessment		**High:** Slivers of undisturbed ground will be left in situ, as well as a covering of sediments over the harder (relatively) clay footwall. **No change of assessment**

Explanation: (Table 1.4.4: Impact 4)

Original EIA – Impact assessment

The removal of surficial sediments from the benthic environment, as a result of dredging, will alter the nature of the seabed environment. Whilst this has no impact on jellyfish in the water column, it could increase the area suitable for polyp attachment should large areas of hard substrata be exposed. That said, polyps of other species seem to require a sediment-free surface for persistent establishment. This is unlikely to be realized given the immediate fallout from the tailings plume, and from the persistent sedimentation of photic zone production

Post Verification Programme – Re-evaluated impact assessment

A re-evaluated assessment of this impact was not required in terms of the scope of the verification programme. The original assessment stands.

© NMP 2014

B2 CUMULATIVE EFFECTS ASSESSMENT

B2.1 INTRODUCTION

The assessment of cumulative effects is widely accepted as an integral part of an EIA and more so of an SEA. However, it is acknowledged that actually achieving this objective, particularly at the individual project level, can be difficult. Cumulative effects are commonly understood as the impacts, which combine from different projects, and activities, which jointly result in significant change, which is larger than the sum of all the impacts (DEAT 2004).

Ideally cumulative effects assessments should be undertaken by, or for, the national managing authority in the country in which the individual projects take place. In other words, cumulative effects assessment should be undertaken as part of a strategic environmental assessment (SEA). In order to assess cumulative effects the following need to be understood:

- Interactions between stressors that may have cumulative effects on components of the ecosystem;
- interactions between these components; and
- The response of the ecosystem to these multiple stressors (Clarke *et al*., 2014).

At best understanding of these inputs to the assessment of cumulative effects will be incomplete. A solution is to assess potential cumulative effects with the best available information, identify and monitor indicators of change in the ecosystem, and adapt management in response to changes as, and when, necessary. Adaptive management is a foundation element and integral component of the project based environmental management plan. The difficulty in the marine environment is that it is dynamic. Yet within those limits of change (thresholds beyond which the point of change under irreversible), there is a dynamic stability. Thus, within this envelope of dynamic stability there are determinable standards of compliance that are acceptable. These standards form the conditions in which the project may be pursued. These standards are described in the project EMP, and may include additional performance standards prescribed by the authorities in the record of decision.

In the context of the Namibian Exclusive Economic Zone (EEZ) there are numerous anthropogenic activities, e.g. port infrastructure development, port access channel dredging and spoil disposal, fishing, merchant shipping, coastal and deep water diamond mining, fish processing, mariculture, waste water disposal, desalination plant effluent and saltworks biterns discharges, all of which have both direct and indirect effects on the marine ecosystem. For example, bottom trawling not only results in the direct mortality of the target species but also causes bycatch mortality, habitat destruction (smoothing of the sea floor) and suspension of sediments. In the case of Namibian demersal fishing these activities occur within an area of approximately 70 000 km^2, with approximately 40% of the area being bottom trawled annually. In addition, the trawler itself will interact with vessels at sea, emit exhaust fumes and discharge sewage, galley and other wastes. Similarly other vessels operating in Namibian waters interact with each other and discharge effluent to sea and the atmosphere. The larger the vessel, the larger the impact, with a commercial passenger liner discharging significant amounts of effluent.

It is clear that at the individual licence area and/or project level it is unrealistic that this multiplicity of actions and interactions (pathways of cumulative effects) resulting from a multiplicity of anthropogenic activities and natural processes (over which the individual project proponent has no

© NMP 2014

control), can be assessed effectively in a cumulative manner in an EIA, which is by design, an assessment at a project level. At this level the opportunity for assessing cumulative effects is generally limited to "more of the same" actions, e.g. more area dredged, greater volumes of fine materials discharged, etc. The provision of more of the same assessment reporting is a primary output of the annual environmental assessment report submitted to the authorities, this report being the annual compliance statement in respect of the project EMP. This, in turn requires the authorities to accept the responsibility for integrating information from a multiplicity of sources, e.g. from individual project monitoring, scientific surveys, and fisheries resource monitoring, to determine thresholds for individual project / industry sector use of the common resource. Ideally this should take place within the overall marine spatial planning context.

At the project level, in the case of the proposed NMP dredging operations a single vessel will operate on an intermittent but regular basis i.e. dredging a full load from the target area in SP-1 and then steaming to Walvis Bay to discharge the phosphate ore. This amounts to 16 hours of dredging in every 37 hour dredge cycle.

The significance of the cumulative effects of the proposed project at both the project level and also in regard to regional considerations are presented and discussed in the following sections.

B2.2 SHIPPING INTERACTIONS

2.2.1.1 Interactions with commercial vessel traffic

The mining licence area (MLA) lies well seawards of the main coastal shipping lane and to the east of the main Cape to Europe shipping routes. Thus the dredger will only interact with this traffic when travelling between the MLA and Walvis Bay. The vessel will be an insignificant addition to the overall shipping traffic which has grown considerably in recent years notably as the result of 38% of all Angolan oil production being shipped to China along this route (*China Daily,* quoted by allAfrica.com).

2.2.1.2 Interactions with fishing vessels

The location of the SP-1 target dredging area will be advertised by means of a Notice to Mariners and will be marked on hydrographic charts so as to inform fishing and other vessels that a vessel (the dredger) with restricted ability to manoeuvre (in particular whilst the dredge head is engaged with the seabed) will be operating in the area. The area of the MLA (2233 km^2), and in particular SP-1 (176 km^2), make an insignificant contribution to the total annual Namibian bottom trawl catch, primarily of monkfish, since almost no bottom trawling is, or has been, undertaken in the area. During 2005 to 2010 there was no monk bottom trawling within SP-1 (Japp in Midgley 2012) The dredging activity in SP-1, therefore, will have an insignificant *operational* impact on bottom trawling activities.

2.2.1.3 Operational discharges from the dredger

The dredger will be MARPOL compliant in terms of all operational emissions and discharges from the vessel and thus will have a minimal individual impact and similarly will make a negligible contribution to the cumulative emissions and discharges from vessels currently operating in the Namibian EEZ. However, the EMP will require the recording of emissions, which will be reported annually. This

© NMP 2014

information is then available to the authorities for cumulative assessments along with similar reporting from other marine users.

B2.3 DREDGING

2.3.1.1 Disturbance of the benthic environment

The EIA has determined that dredging in SP-1 (up to 3 km^2 annually and up to 60 km^2 for the period of licence issue) which is an area of 176 km^2 will have a severe local impact on the benthic communities in the areas actually dredged, but in terms of the benthic habitat in ML 170 (2233 km^2) and the broader mid-continental shelf (93695 km^2)[2] of Namibia the effect of dredging (3 km^2 annually) in SP-1 will be insignificant for the proposed 20-year dredging programme. However, since no data on the actual impact on, and recovery times of, the benthic habitat affected by bottom trawling are available, the contribution of dredging in SP-1 to the overall impact on the benthic environment and wider marine ecosystem can only be estimated, on the basis of relative scales, to be insignificant. In Section C, Chapter 3.3, Cochrane comments "The impacts of extraction in the specific area planned to be dredged can be expected to have considerably greater, and longer-lasting, direct impacts on the biota in that area than does bottom trawling. However, the limited area currently designated to be dredged means that, overall, these impacts will almost certainly be considerably less across the northern Benguela shelf and southern slope environments as a whole than have been the impacts of trawling on these environments, noting that the impacts of trawling are well-managed and considered to be sustainable."

2.3.1.2 Discharge of fines to the water column

It is estimated that the dredger will discharge 500 000 tonnes of fines (particles < 100 microns) annually as lean water overflow (discharged at -10 m below the sea surface) when running at full production, 5.5 M tonnes per annum. The discharge will only occur during the dredging of each lane as the vessel's hopper is filled with phosphate ore. Four 4 km-long lanes will be dredged over a period of approximately 16 hours, this being the time required to fill the vessel's hopper, after which it will leave the site for a period of approximately 20 hours to discharge the dredged sediments, and then return to start dredging again. The plume of fine material is thus generated in a spatially dispersed manner for approximately 40% of the time (the plume is only generated whilst the dredge head is engaged with the seabed). The effect of this plume on water column physics, chemistry and ecology has been assessed to be insignificant (Section C, Chapter 2.1). Attempting to place the impact of the episodic fine material discharge from the dredger into an EEZ-wide cumulative context is probably unrealistic. Apart from natural turbidity events, suspended sediment plumes are generated either at the seafloor by trawling (net and trawl gear engaging with the sediments, more so with monk dedicated gear than other demersal fishing) and to a much lesser extent by dredgers or at the surface by dredger overspill discharge or 'over and undersize' sediment discharge as is the case with marine diamond mining. In the Namibian EEZ sediment plumes are generated in geographically widely separated areas on a range of spatial and temporal scales. Plume or suspended sediment-generating activities include; maintenance and capital dredging at the ports of Walvis Bay and Lüderitz, coastal and deep water diamond mining (mostly south of the latitude of Lüderitz), the proposed phosphate ore dredging in SP-1 and from the LL Phosphate project (ML 159) and, most extensively, from bottom trawling. In terms of relative scale, or size of "footprint," bottom trawling plume generation far

[2] www.seaaroundus.org/eez/516.aspx

exceeds any other anthropogenic sources of suspended fine material on the Namibian continental shelf. However, the effects of both the trawl plume and the physical disturbance of the benthic communities by trawling on the Namibian shelf has not been evaluated.

B2.4 EXPANSION OF PHOSPHATE MINING ACTIVITIES

One of the primary concerns raised by I&APs is the potential risks to the environment and fishing industry arising from a sudden massive expansion of phosphate mining activities across the continental shelf area. It is feared that, as a consequence, there could then be a multiplicity of phosphate mining activities occurring over a wide area of the continental shelf resulting in cumulative impacts on the marine.

Currently there are only two issued mining licences for phosphate. However, the primary basis for the concern is the existence of a large number of exclusive exploration licences (EPLs) that have been issued by the Ministry of Mines and Energy (MME). These current EPLs cover a large part of the continental shelf which is considered prospective for phosphate.

There are a number of existing controls that limits the perceived threat of this phosphate-mining cumulative impact, thus making it an implausible outcome.

i) Conversion of an EPL to a Mining Licence

Taking out an EPL does not automatically result in the opportunity to convert to a mining licence (ML). There is significant historical marine mining industry experience to show that a very low percentage of exploration projects/targets ever make it through to development of a successful mine. In order to make application for a Mining Licence, the economic viability of a project needs to be demonstrated. Fundamentally, the in situ value (i.e. grade or concentration) of the target mineral needs to be higher than the total cost of production in order for a project to be economically viable.

Current feasibility studies indicate that in situ phosphate grades below 15% P_2O_5 are unlikely to be viable. While phosphate occurs in a variety of forms (pelletal, concretionary, crusts) over the Namibian continental shelf, the areas with concentrations above 15% are restricted to two main areas, the largest of which lies to the southwest of Walvis Bay off Meob Bay.

Using the marine diamond industry by way of example, in the early to mid 1990s almost the entire continental shelf off Namibia was covered by EPLs issued for precious stones (diamonds), which resulted in issuing of approximately 5 mining licences in total.

ii) Mineral Market Constraints

The rate of supply of any commodity, inducing phosphate, is controlled by the market demand for that commodity. The capacity of the market therefore dictates the supply of new material to that market. An oversupply of commodity will force a reduction in the market price which in turn will affect the economic viability of any mines supplying product. Therefore there is a limit to the quantity of new material that can be supplied to the market from existing or new mine production.

In 2011, the world trade in phosphate rock from current producing mines was 30 million tonnes. Of this 80% (24 Mt) was utilised for phosphoric acid production, 10% (3 Mt) for Single

© NMP 2014

Super Phosphate and 10% (3 Mt) for Direct Application. Growth in the market requiring new production is around 10% per annum (3 Mt)[3]. In the phosphate industry, existing mines are most favourably placed to meet demand for new product thereby providing increased pressure on prospective new entrants.

Therefore, even if Namibia has the capacity to allow for several new mines to be developed, along with competition from other potential new phosphate mines around the world, the size of the global market for new phosphate rock supply provides a natural economic barrier that further limits the probability of a sudden rapid increase in the number of viable and sustainable marine phosphate mines in Namibia

iii) Existing Legal Controls

Through current legislation the government of Namibia has a range of powers available to manage and regulate the scale and rate of development of various sectors within the mining industry. The authority for issue of mining licences rests with the Ministry of Mines and Energy. The Minerals Act of Namibia 1992, also makes provision for the Minister to declare a moratorium on the issue of new mining licences under certain conditions. This power was invoked by the Ministry in regard to the rapid development of the uranium industry in Namibia.

B2.5 REFERENCES

Clarke Murray, Cathryn, Mach, Megan E, and Martone, Rebecca, G (2014). Cumulative effects in marine ecosystems: scientific perspectives on its challenges and solutions. WWF-Canada and Venter for Ocean Solutions. 60pp.

DEAT (2004) Cumulative Effects Assessment, Integrated Environmental Management, Information Series 7, Department of Environmental Affairs and Tourism (DEAT), Pretoria.

Japp 2012. Appendix 1a. Namibian Marine Phosphate – Environmental Impact Assessment of Fish, mammals and seabirds: Proposed monitoring and verification of Impacts in the proposed Mining Area). In: Midgley 2012. Sandpiper Project Environmental Impact Assessment Report http://www.namphos.com/project/sandpiper/environment/item/57-environmental-marine-impact-assessment-report.html.

[3] CRU 2013, Independent Market Consultant's Report for the Sandpiper Project. Prepared for Namibian Marine Phosphate Internal Report.

SANDPIPER PROJECT

Verification Programme Report: Mining Licence Area No. 170

SECTION C : SPECIALIST STUDIES

Section C.1: Geology and History of Deposit
Section C.2: Water Column and Sedimentary Environment
Section C.3: Fisheries and Biodiversity

SANDPIPER PROJECT

Verification Programme Report: Mining Licence Area No. 170

SECTION C : SPECIALIST STUDIES

Section C.1

Geology and History of Deposit

C1.1: Preliminary Model for the Origin and Age of the Sandpiper deposit

SPECIALIST STUDIES – SECTION C

C1.1 Preliminary Model for the Origin and Age of the Sandpiper Deposit

NAMIBIAN MARINE PHOSPHATE

A REVIEW OF OFFSHORE PHOSPHORITE DEPOSITS ON THE NAMIBIAN MARGIN AND A PRELIMINARY MODEL FOR THE ORIGIN, AGE AND DEPOSITION OF PHOSPHORITE IN ML 170

Prepared for:
Namibian Marine Phosphate (Pty) Ltd.

Prepared by:
Dr JS Compton

Associate Professor

October 2014

DEPARTMENT OF GEOLOGICAL SCIENCES
UNIVERSITY OF CAPE TOWN

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed "Attention: Administration Manager," at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

contents

SUMMARY iv

1 INTRODUCTION 1

2 GEOLOGICAL AND OCEANOGRAPHIC SETTING OF THE NAMIBIAN MARGIN 2

3 PHOSPHORITE DEPOSITS ON THE WESTERN MARGIN 11

4 GEOCHEMISTRY OF PHOSPHORITE GRAINS 13

5 AGE OF PHOSPHORITE DEPOSITS AND THE AGE OF PHOSPHORITE FORMATION 17

6 ORIGIN OF PHOSPHORITE GRAINS 18

7 HOW DO ECONOMIC PHOSPHORITE DEPOSITS FORM? 22

8 PHOSPHORITE DEPOSIT ON THE NAMIBIAN SHELF 23

9 DETAILED STUDIES OF PHOSPHORITE DEPOSITS IN ML 170 AND ITS IMMEDIATE VICINITY 28

9.1 GRAVITY CORES ANALYSED BY DINGLE *ET AL*. (1996) 28
9.2 SAMPLES ANALYSED BY HIKUMUAH (2008) 31
9.3 GRAVITY CORES ANALYSED BY BERGH (2009) 34

10 STRONTIUM ISOTOPE STRATIGRAPHY (SIS) 42

11 STRONTIUM ISOTOPE STRATIGRAPHY (SIS) OF CORES BON1313, BON1408 AND BON1460/1463/1469 45

12 AN IDEALISED COMPOSITE STRATIGRAPHY FOR ML 170 49

13 A DEPOSITIONAL AND DIAGENETIC HISTORY FOR ML 170 51

14 CONCLUSIONS 57

15 REFERENCES 58

Annexure: 1. Summary of SR analyses of Samples discussed in this Report 62
Annexure 2: Photomicrographs of Samples analysed for SR isotopes in this Study 64

figures

Figure. 1: Bathymetry of the Namibian margin between Sylvia Hill and the Kunene River 3
Figure 2a: Geophysical profiles of the Namibian margin off Walvis Bay 4
Figure 2b: Bathymetric profiles of sub-bottom seaward-dipping reflectors 5
Figure 3: Currents of the Benguela Current offshore (Shannon and Nelson, 1986) 6

© NMP 2014

Figure 4: Conceptual model of upwelling (Shannon and Nelson, 1996). 7
Figure 5: Satellite image of chlorophyll in surface waters (warm colours) off southern Africa showing high productivity along the Namibian margin. 8
Figure 6: Organic carbon distribution in the surface sediments on the continental margin 9
Figure 7: Seawifs image of dust plumes blowing sediment out to sea. 10
Figure 8: Distribution of phosphorite rock types 12
Figure 9: A general schematic model for how phosphorite (authigenic CFA, carbonate fluorapatite) forms in marine sediment 20
Figure 10: Carbon and sulphur isotope variations during early diagenesis across the oxic, suboxic and anoxic sediment boundaries 21
Figure 11: Distribution of phosphorite along the Namibian margin from the Kunene River to 25ºS (redrawn from Bremner, 1977). 24
Figure 12: Weight percentage P2O5 along the Namibian margin from the Kunene River to 25ºS 25
Figure 13: Distribution of phosphorite rich deposits on the central to southern Namibian shelf 27
Figure 14: General stratigraphy of cores studied by Dingle *et al.* (1996). 29
Figure 15: Location of cores in the vicinity of ML 170 30
Figure 16: Photomicrograph of pelletal phosphorite sand from offshore Namibia. 31
Figure 17: Photomicrographs of thin-sections of phosphorite pellets (plane-polarised light). 32
Figure 18: Photomicrograph of thin-section (plane-polarised light) showing structured pelletal phosphorite grains. 33
Figure 19a: Grain size profiles of vibrocores from offshore Conception Bay 35
Figure 19b: Grain size profiles of vibrocores from offshore Meob Bay 36
Figure 20: A representative core log of sediment recovered from offshore Conception Bay 38
Figure 21: A representative core log of sediment recovered from offshore Meob Bay 40
Figure 22: Photomicrographs of polished sections of phosphorite grains 41
Figure 23: Strontium Isotope Curves. 44
Figure 24: Stratigraphy of Core BON1313 46
Figure 25: Stratigraphy of Core BON1408 47
Figure 26: Stratigraphy of Cores BON1463, 1460 and 1469 including Sr ages. 48
Figure 27: A proposed idealised stratigraphy for ML 170 based 50
Figure 28: Relation of deposition and phosphogenesis in ML 170 to sea level since the Pliocene 52
Figure 29: A comparison of the Sr-derived ages of phosphorite and calcareous shell. 54
Figure 30: Comparison of the Pliocene to Pleistocene 600 m thick succession. 55

tables

Table 1: Average major element compostion of concretionary Phosphorites 14
Table 2: Average major element composition of pelletal phosphorite (pP) 15
Table 3: Major (wt %) and minor (ppm) element composition of Namibian phosphorites (Thomson *et al.* 1984). 16
Table 4: Chemical Compositon of phosphorite nodules, wt % (Baturin 2002) 16

© NMP 2014

SUMMARY

Offshore phosphorite deposits are abundant on the western margin of southern Africa particularly in the mid shelf region offshore Namibia. Phosphorite is a rock type rich in phosphorus (>18 wt% P_2O_5), a non-renewable resource essential in the production of fertilizer to increase agricultural yield. To date, most phosphorite is mined on land but increasing demand and prices combined with advances in offshore mining technology have resulted in the exploration of offshore phosphorite deposits. Surface and subsurface unconsolidated sands containing >25 wt% phosphorite grains occur over an extensive area on the middle to outer shelf of Namibia at 150 to 400 m water depth with bulk sediment grades of 17 to 24 wt% P_2O_5. These phosphorite-rich deposits formed over millions of years through the concentration of phosphorus (P) initially by marine algae growing in the highly productive surface waters and the transfer of this organic P to the mineral carbonate fluorapatite or francolite in the form of rounded (pelletal) sand grains. Phosphorite grains were concentrated through repeated erosion of the sediment by energy dissipated on the margin through wave and current activity during sea level lowstands. The repeated formation and reworking of these deposits has led to a highly enriched phosphorite deposit occurring in the uppermost 2 m of the present day seabed.

This desk top study provides an overview of the phosphorite deposits on the Namibian shelf, their occurrence, geochemistry, age and origin. Namibian Marine Phosphate's Mining Licence 170 occurs within the large north-south trending middle to outer shelf phosphorite deposit offshore Namibia between Conception Bay and Meob Bay at 150 and 350 m water depth. The large extent of phosphorite-rich surface sediments on the Namibian shelf has been appreciated since the 1960s however the true extent of these phosphorite deposits has only recently been understood from the recovery of cores that have penetrated below the seafloor. These cores provide a far more complete picture of the highly condensed 2 m thick phosphorite deposit. The stratigraphy of the phosphorite deposit is fairly consistent across ML 170 and the age of deposition and phosphorite formation is informed by 36 strontium isotope derived ages. The base of the deposit is underlain by Pliocene terrigenous mud (Unit 5) but in some areas, the phosphorite deposit may be underlain by middle to late Miocene calcareous sediment (Unit 6). The base of the economic phosphorite deposit is marked by an erosional contact across which the pelletal phosphorite sand content increases from <1 wt% in the underlying Pliocene mud to 40-68 wt% in the lower portion of the overlying muddy phosphorite sand (Unit 4b) which grades into a muddy phosphorite sand with 68 to 80 wt% pelletal phosphorite sand (Unit 4a). The muddy phosphorite sand of Unit 4 varies from 0.5 to 1.5 m thick deposited during the early to middle Pleistocene age while the phosphorite grains formed predominantly during the early Pleistocene (2.6 to 1 Ma). The phosphorite sand content of Unit 4 is variable across ML 170, but represents the most enriched deposit with bulk sediment containing on average 19-24 wt% P_2O_5. Unit 4 is overlain by increasingly shelly phosphorite sand of Units 1-3 containing 65 to 86 wt% sand and 4-5 wt% mud with bulk sediment containing on average 17-21 wt% P_2O_5, the phosphorite diluted by carbonate shell. Units 1-3 have multiple erosional surfaces formed during sea-level lowstands of glacial maxima since 1 Ma. The highly condensed 2 m thick Plio/Pleistocene shelf succession can be compared with the 600 m thick Plio/Pleistocene succession of organic-rich diatomaceous/calcareous ooze recovered from the upper slope. The age of the majority of the phosphorite on the shelf corresponds to an increase in coastal upwelling intensity during the early Pleistocene and the economic concentration of phosphorite in the coarsening upward shelf sediment reflects an overall lowering of global sea levels and increasingly high-amplitude sea-level fluctuations in response to Northern Hemisphere glaciation since the Pleistocene (2.6 Ma) and in particular since the middle Pleistocene (0.78 Ma).

© NMP 2014

1 INTRODUCTION

The element phosphorus (P) is essential for plant growth and has economic value through its application as a fertilizer to enhance the yield of agricultural crops as well as other uses. World population is now estimated at 7 billion people and one reason the human population has been able to double in size since 1970 is the use of fertilizer to increase food production, the so-called 'Green Revolution.' However, it is estimated that 40% of the land surface is currently utilized by humans and that much of the arable land is threatened by degradation related to soil loss and climate change. The continued production of sufficient food resources to feed a global population projected to reach 9 billion by 2050 (Roberts, 2011) will increase demand for fertilizers. Nitrogen fertilizer can be manufactured through the Haber process, but P and potassium (K) are essential elements for plant growth which must be mined from Earth deposits. Rocks which contain abundant P (generally >18 wt% P_2O_5) are called phosphorite. To date most P has been obtained from mining large phosphorite deposits which originally formed on ancient ocean margins that are now exposed on land through uplift or relative lowering of sea level. Some additional P is mined from igneous rocks such as at Phalaborwa Igneous Complex in South Africa (Roux *et al*., 1989), but P-rich igneous rocks are rare and constitute a relatively small amount of the total P mined globally. Existing land deposits are becoming increasingly depleted and no substantial new deposits have yet been discovered on land. As a result high-grade offshore phosphorite deposits, which were historically uneconomic, are being re-examined for their resource potential as the demand for P and the price of P increase. The technology of offshore mining has also improved through, for example, the offshore diamond mining industry which has been mining seabed sediment from the inner and mid shelf regions offshore Namibia since the 1970s.

The western margin of southern Africa is renowned for its phosphorite deposits. Phosphorite was first recovered in 1873 during dredging of the seafloor south of Cape Town on the Agulhas Bank by the HMS *Challenger* Expedition (Murray and Renard, 1891). The full extent and richness of the deposit was confirmed much later by systematic seafloor sampling carried out first by Russian oceanographers during expeditions of research vessels of the Atlantic Research Institute of Fishery and Oceanography in the 1960s (Senin, 1970) and then later by the marine geology group at the University of Cape Town and the Geological Survey on the vessel *TB Davie* during the 1970s (Summerhayes *et al*., 1973). Samples from these and later surveys formed the basis for early mapping of the marine geology offshore South Africa and Namibia (Birch, 1975; Rogers, 1977; Bremner, 1977). These surveys revealed that the unconsolidated surface sediment offshore had regions of unusually high P content with bulk sediment ranging from 0.5 to in excess of 15 wt% P_2O_5 (Summerhayes *et al*., 1973). Since this initial large-scale sampling, additional offshore surface and subsurface sediment samples have been obtained and there have been a large number of studies documenting the grain size, petrography, mineralogy and chemistry of the offshore phosphorite rich deposits (Baturin, 1969; 2000; Birch, 1975; 1979; 1990; Birch *et al*., 1983; Bremner, 1977; Bremner and Rogers, 1990; Rogers, 1977; Compton *et al*., 2002; 2004; Wigley, 2005; Wigley and Compton, 2006; 2007). For a comprehensive review of the literature prior to 1990 refer to Rogers and Bremner (1991).

The mining of phosphorus-rich deposits has long been of interest in the region and early on the easily exploited island guano deposits were mined as fertilizer in the 1840s (Watson, 1930). Phosphorite deposits were mined onshore of St Helena/Saldanha Bay in the Western Cape South Africa at Langebaanweg by CHEMPHOS up until 1994 (Hendey and Dingle, 1989). Exploration continues on the coastal plain of the Western Cape, but no phosphate mining is currently taking place onshore. Offshore diamond mining and an increased interest in possible offshore mining of both P and K (in the form of glauconite-rich green sands) have resulted in more sampling and studies of offshore deposits (e.g., Wigley, 2007).

© NMP 2014

A large area of the phosphorite rich sediments on the Namibian shelf is held by Namibian Marine Phosphate (Pty) Limited in its Mining Licence (ML) 170 making up part of their Sandpiper Project. This report provides a general overview of the marine geology and geochemistry of phosphorite deposits on the western margin of southern Africa (Part I) and summarizes the work that has been done to date on the Namibian offshore phosphorite deposits in the vicinity of ML 170 (Part II). This report includes the latest results from cores recovered from areas offshore of Conception Bay and Meob Bay within ML 170 and includes 36 strontium isotope analyses to develop an age model for phosphorite formation and sediment deposition.

PART I. GENERAL OVERVIEW

2 GEOLOGICAL AND OCEANOGRAPHIC SETTING OF THE NAMIBIAN MARGIN

The Namibian continental margin formed after the breakup of Gondwana and has been a passive margin since the Cretaceous. The bathymetry of the margin includes a broad and deep shelf that extends out to a water depth of 400 m (Figure 1). The shelf can be divided into an inner, middle and outer shelf (Rogers, 1977). The inner shelf is from 0 to approximately 100-130 m water depth commonly marked by a wave cut terrace or notch formed when the inner shelf area of the margin was exposed during sea level lowstands of Quaternary glacial periods. The middle shelf is a relatively low gradient area that extends to approximately 200 m water depth. The outer shelf extends from 200 to 400 m water depth and has a steeper gradient than the middle shelf. The shelf break occurs at approximately 400 m and separates the low gradient shelf from the steep gradient upper continental slope. Seismic profiles of the margin (Figure 2) indicate a series of seaward dipping reflectors off Walvis Bay (Figure 2a; Bremner, 1977) and Sylvia Hill (Figure 2b; Rogers, 1977). Precambrian basement rocks are exposed on the rocky shoreline and extend onto the inner shelf with seaward dipping reflectors further offshore on the shelf interpreted to be Cretaceous to Cenozoic deposits. The majority of the deep (up to 4 km thick) offshore succession is Cretaceous sediment derived from erosion of the continent after break up.

The Cenozoic succession is relatively thin and poorly documented but Neogene limestone and stiff clay have been dredged from areas of the shelf (Bremner, 1977). Neogene seaward dipping beds form a largely erosional surface which is variably overlain by Pleistocene to Recent (Holocene) sediment. The inner shelf is dominated by terrigenous sediment and the Holocene diatomaceous mud belt which stretches along the Namibian inner shelf from approximately 18° to 23°30'S between depths of 50-60 m and 120-140 m (Bremner, 1977). The diatomaceous mud belt is up to 15 m thick and is associated with Recent phosphorite formation (Baturin, 2000). Outside of the offshore in the vicinity of the Kunene River mouth, the middle to outer shelf is dominated by carbonate rich sediments with a mix of relict shelly gravel and foraminiferan (foram) sand on the middle shelf which become increasingly muddy nannofossil foram sand on the outer shelf and slope. Relict phosphorite and glauconite sands are focused on the middle shelf. The highly condensed and mostly relict sediments on the middle to outer shelf expand into a 600 m thick succession of Plio/Pleistocene organic rich, nannofossil and diatomaceous mud as revealed by cores recovered from the upper slope in 2000 m water depth by the Ocean Drilling Program (ODP) offshore of Lüderitz at Site 1084 (Wefer *et al*., 1998).

© NMP 2014

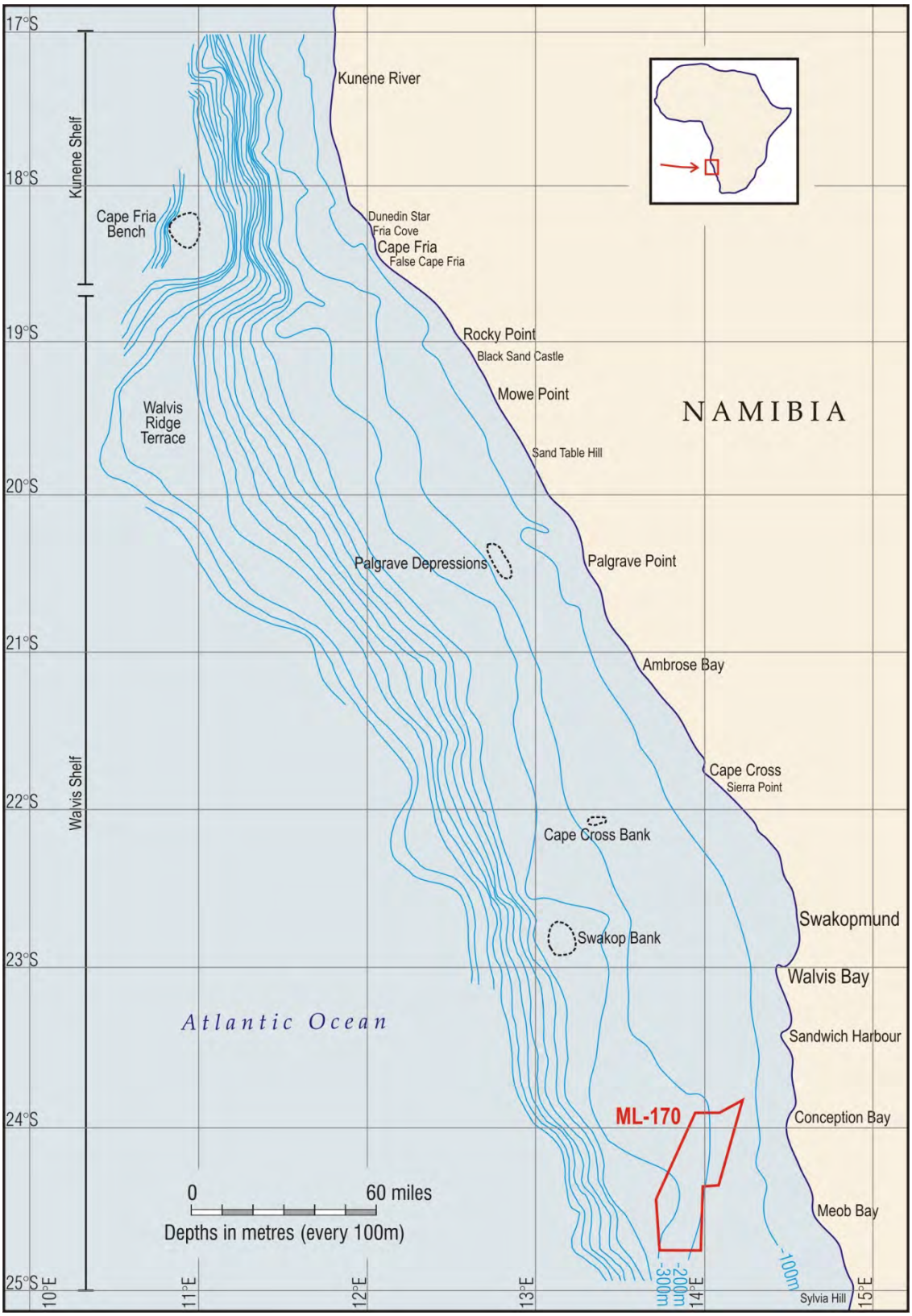


Figure. 1: Bathymetry of the Namibian margin between Sylvia Hill and the Kunene River (modified from Bremner, 1977) with ML 170 outlined in red.

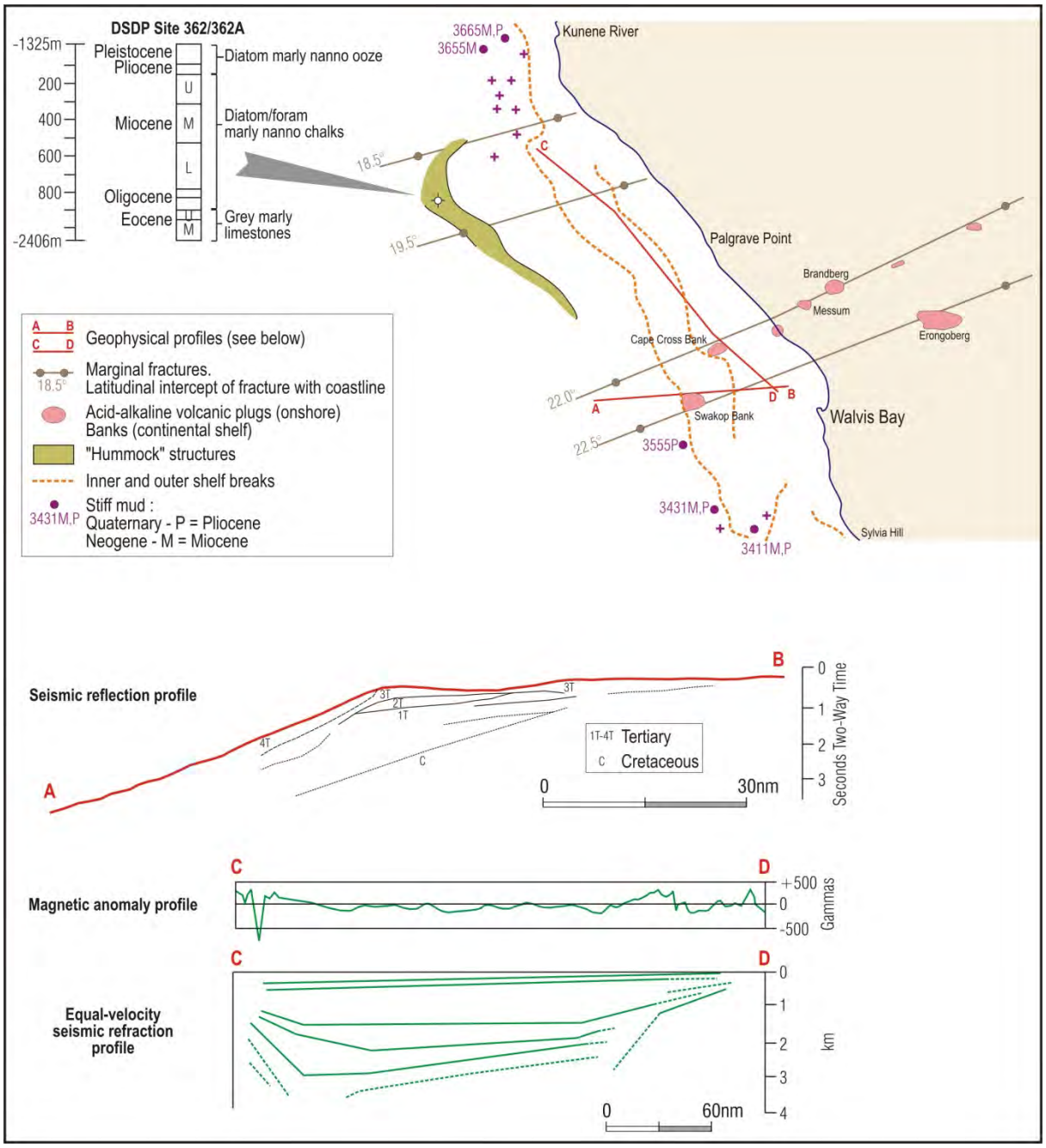


Figure 2a: Geophysical profiles of the Namibian margin off Walvis Bay
showing seismic reflection profile of Cretaceous (C) and overlying Cenozoic (Tertiary: 1T-4T) strata (Bremner, 1977).



Figure 2b: Bathymetric profiles of sub-bottom seaward-dipping reflectors from the shelf immediately to the south of ML 170 and location of pelletal phosphorite sand (Rogers, 1977).

The Namibian margin borders the South Atlantic Ocean and occupies a classic eastern boundary setting having significant upwelling (Shannon and Nelson, 1996). The Benguela Upwelling System (BUS) occurs on the western margin of southern Africa. The BUS is not to be confused with the Benguela Current which forms the eastern limb of the South Atlantic gyre and occurs further offshore from the BUS flowing equatorward (Figure 3). The BUS is driven by winds which are seasonally strong and predominantly from the south and drive the coastal upwelling through the Ekman transport of surface waters away from the coast which are replaced by deeper, nutrient-rich waters from below (Figure 4). Persistent upwelling of relatively cold deeper waters along the margin since the latest Miocene (Siesser, 1980) results in dry, hyperarid conditions along the Namibian coast expressed as the Namib Desert with extensive active sand dunes. The upwelling of nutrient-rich waters results in the high productivity of the BUS, measured as one of the world's most productive eastern boundary upwelling systems (Carr, 2002; Carr and Kearns, 2003) which supports a large commercial sea fisheries industry (Figure 5).

© NMP 2014

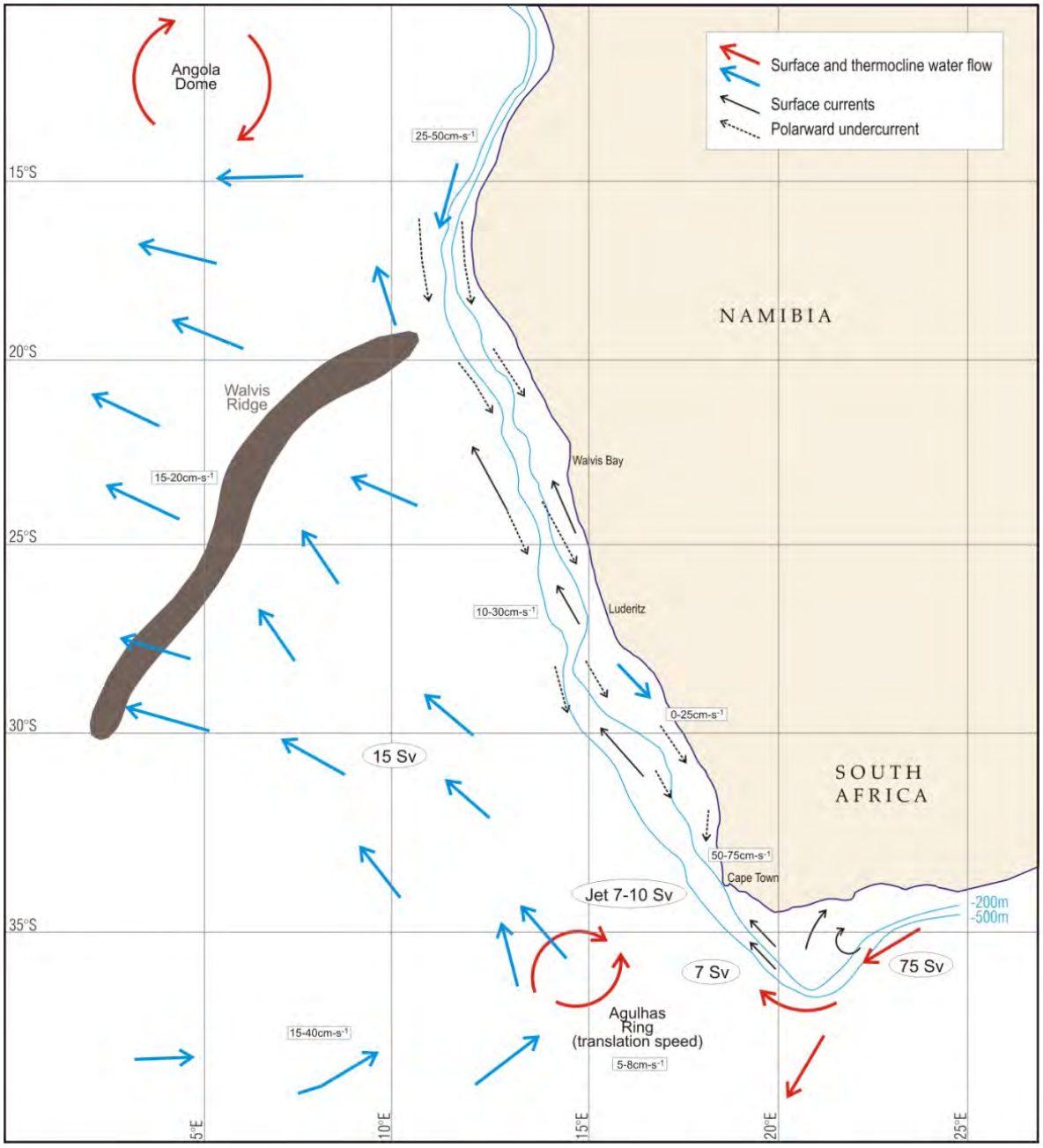


Figure 3: Currents of the Benguela Current offshore (Shannon and Nelson, 1986)

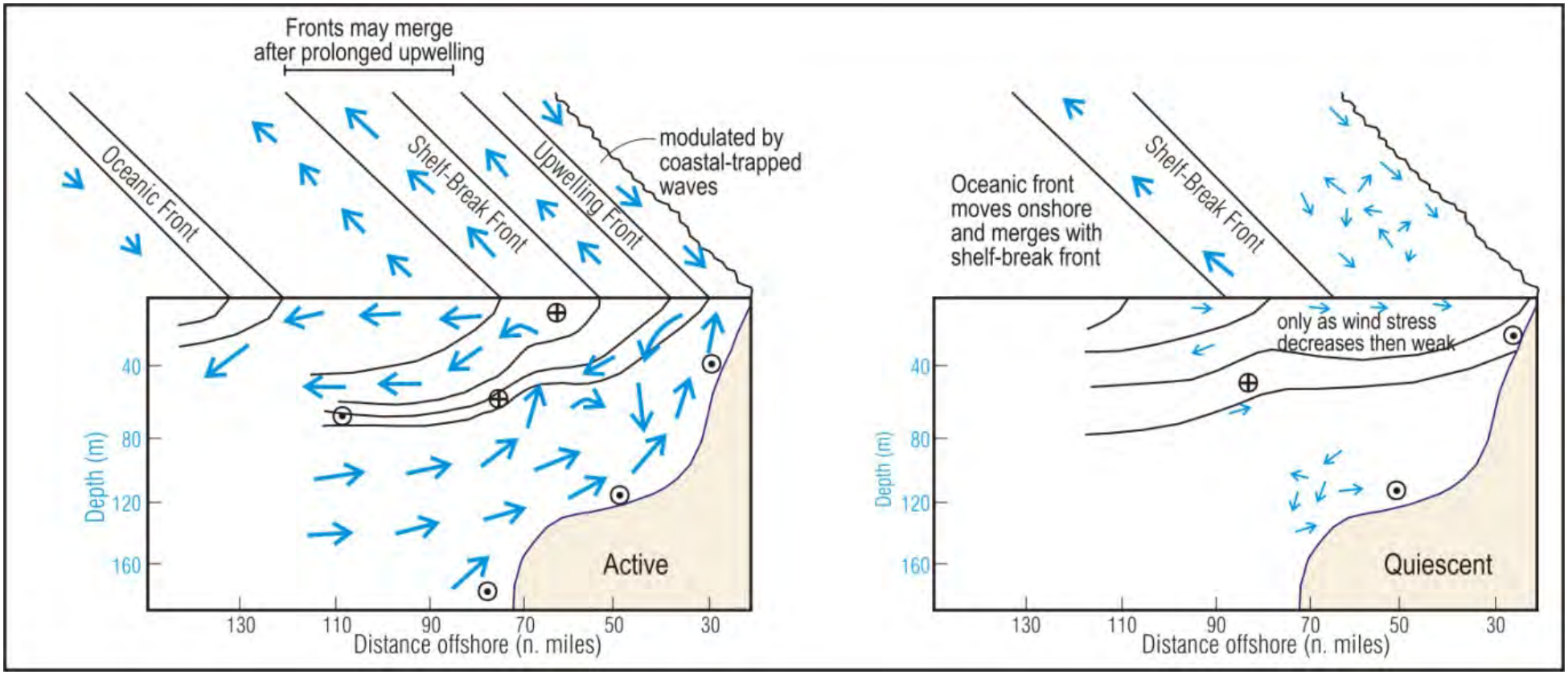


Figure 4: Conceptual model of upwelling (Shannon and Nelson, 1996).

© NMP 2014

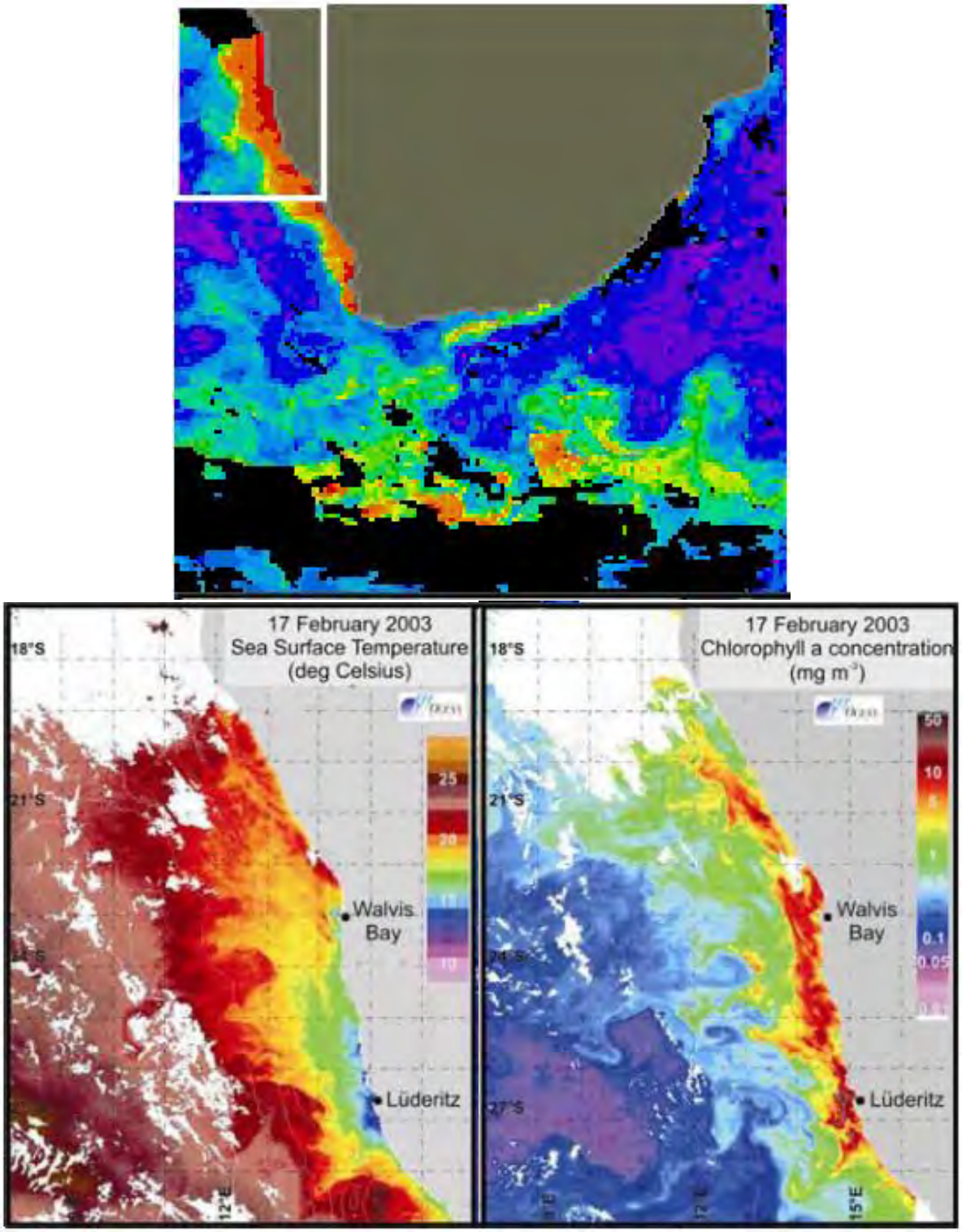


Figure 5: Satellite image of chlorophyll in surface waters (warm colours) off southern Africa showing high productivity along the Namibian margin.
Blow up of cold surface waters upwelling along the margin and corresponding high chlorophyll in the surface waters offshore Namibia, recorded with the SeaWiFS satellite on 17 February 2003 (Inthorn, 2006).

Surface currents along the western margin are complex with seasonal equatorward drift, coastal filaments and Ekman drift (Figure 5; Shannon and Nelson, 1996). Bottom currents on the shelf flow primarily to the south as the poleward undercurrent (Figure 4) and sediment on the shelf, particularly the middle to outer shelf is influenced by the energy dissipation of internal waves (Monteiro *et al*., 2005). Energy dissipation on the middle and outer shelf suspends and removes much of the mud from the seafloor which is deposited on the deeper water upper slope areas having high organic carbon content (Figure 6) (Inthorn *et al*., 2006; Compton and Wilshire, 2009). Terrigenous sediment is delivered to the margin by the Kunene River at the Namibian/Angolan border to the north where suspended mud is transported south by the south flowing bottom water currents along the margin to form a terrigenous and diatomaceous mud belt to the south (Bremner, 1977) in many respects analogous to the Holocene Orange River mud belt off South Africa (Compton *et al*., 2010). All other rivers draining into the Atlantic Ocean between the Orange and Kunene rivers are ephemeral and only episodically deliver sediment to the coast during floods.

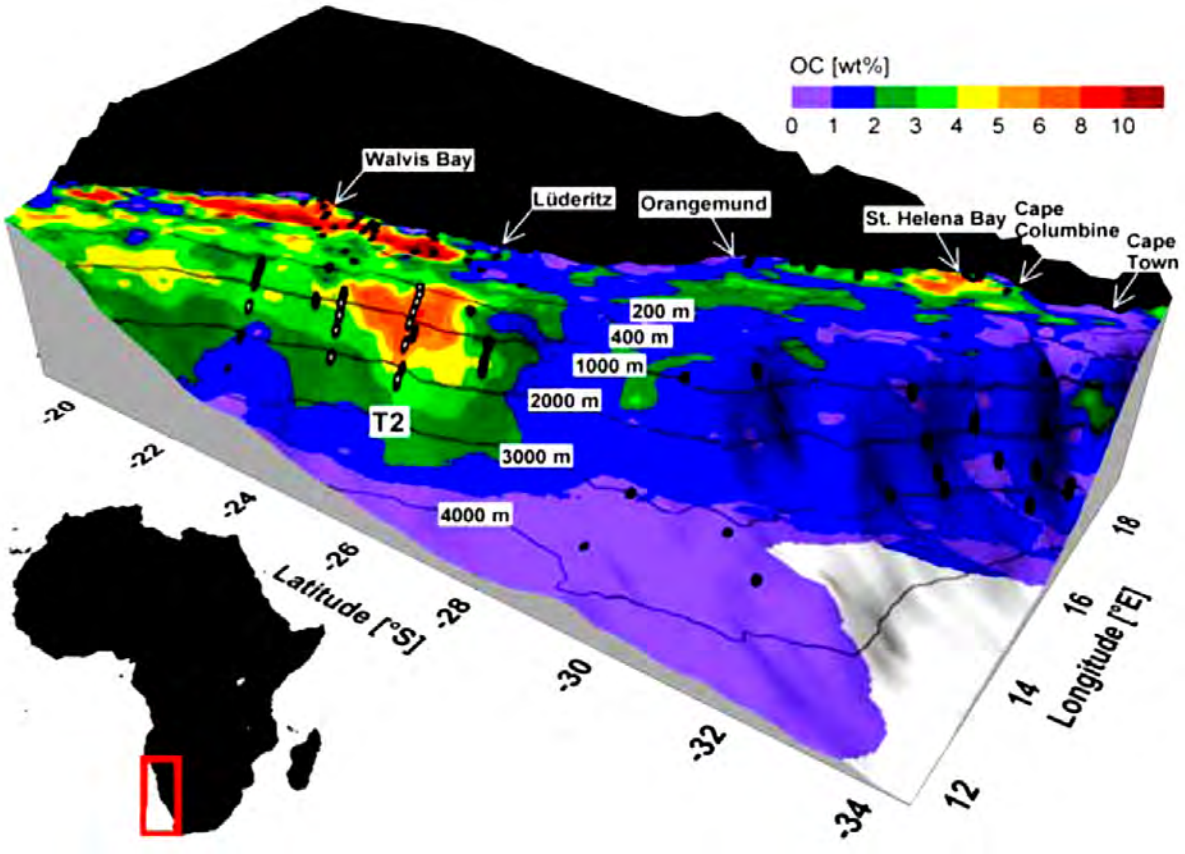


Figure 6: Organic carbon distribution in the surface sediments on the continental margin of southern Africa related to the BUS (Inthorn *et al*., 2006).

A significant amount of terrigenous sediment is delivered to the shelf by wind, primarily during Berg wind conditions when air descends from the Great Escarpment and transports dry riverbed sediment offshore (Figure 7; Eckardt and Kuring, 2005). Berg wind conditions occur episodically with strong hot and dry winds descending from the interior plateau blowing dust out to sea and providing a major source of detrital quartz and mica minerals on the shelf (Bremner, 1977). Coastal fog is common throughout the year with a higher incidence during the summer months. The swell direction is variable, with a strong southwest component. Wave periods range from 7 to 12 seconds and wave height ranges from 1 to 5 m resulting in a high-energy coastal zone. Periodic storms with wave heights exceeding 5 m can occur throughout the year (Rossouw, 1984). Net longshore drift of coastal beach sands is to the north with most of the sand in the Namib Desert is being derived from the Orange River.

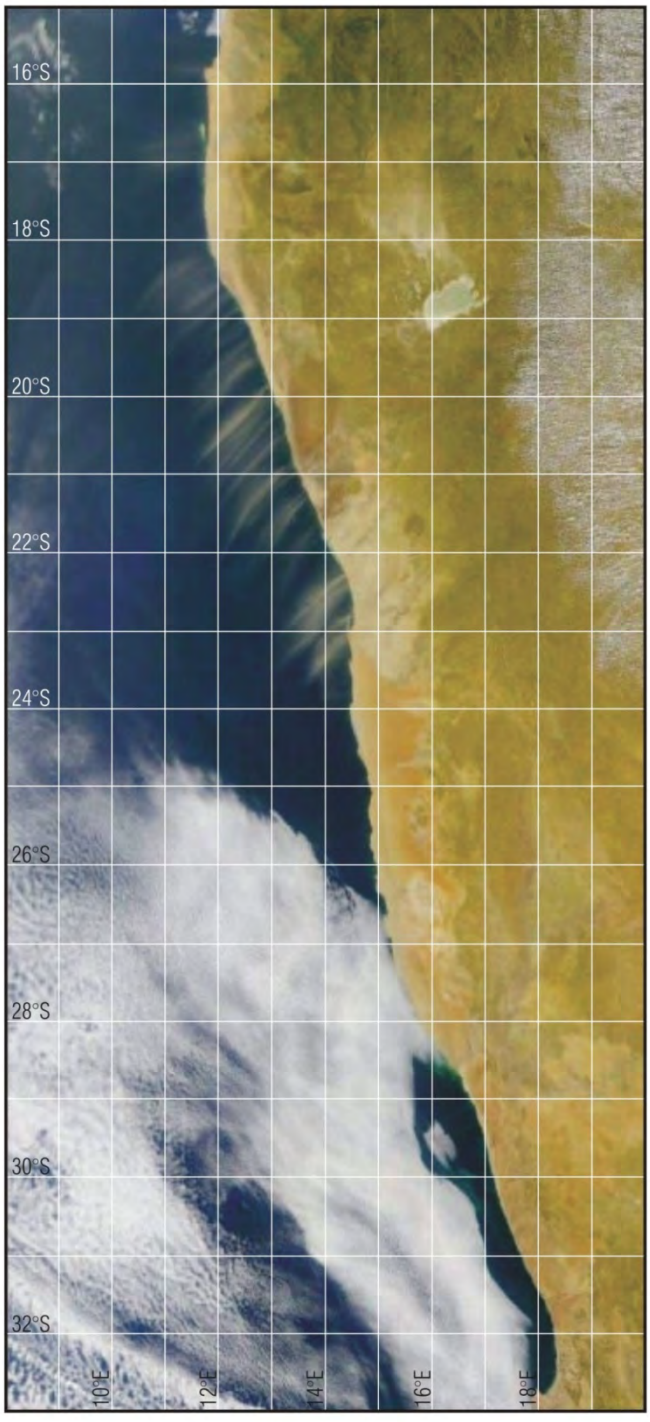


Figure 7: Seawifs image of dust plumes blowing sediment out to sea. Etosha Pan is inland between 18 and 19ºS and the Namib Desert is to the south of plumes along the coast from 23 to 29ºS (Eckardt and Kuring, 2005).

3 PHOSPHORITE DEPOSITS ON THE WESTERN MARGIN

The distribution of the rock type phosphorite in surface sediments of the continental margin of southern Africa is indicated in Figure 8 (Bremner and Rogers, 1990). Three main types of phosphorite have been identified: rock phosphorite, sand-size pelletal phosphorite and pebble-size concretionary phosphorite (Bremner and Rogers, 1990). Phosphorite is also divided into authigenic (formed in place) pelletal phosphorite and diagenetic rock phosphorite which forms during early burial most commonly by replacement of limestone bedrock. A clear regional pattern exists in the distribution of phosphorite rock types. The southern margin of the Agulhas Bank is dominated by diagenetic rock phosphorite (Dingle, 1974). On the western margin diagenetic rock phosphorite deposits occur mainly south of Lüderitz, whereas authigenic pelletal phosphorite occurs primarily north of Lüderitz (Figure 8). The other common phosphorite grain type is skeletal phosphorite represented by bone, fish scales and shark teeth whose original structures are intact but have been remineralised from their original hydroxyapatite to carbonate fluorapatite (see Geochemistry of phosphorite grains below). The phosphorite grains are associated with other sediment grains and components, the most common of which are carbonate shell and fossils (primarily foraminifera), siliceous fossils (primarily diatoms), detrital quartz, mica and clay minerals, organic matter and diagenetic glauconite. Pelletal phosphorite usually occurs in unconsolidated sediment whereas phosphorite rock usually occurs as unconsolidated gravel or as partially phosphatized limestone (Bremner and Rogers, 1990; Compton *et al*., 2002).

An area of unconsolidated pelletal phosphorite sand and shelly pelletal phosphorite sand about 70-90 km wide, lies on the outer shelf and extends seaward of the 200 m isobath from 26°S (NW of Lüderitz) to 23°S (Walvis Bay) (Summerhayes *et al.*, 1973). The richest phosphatic sediments (>2.5% P_2O_5) are concentrated on the outer shelf (200-500 m), except between Lüderitz and the Orange River where they occur on the middle shelf (150-250 m) (Summerhayes *et al.*, 1973).

© NMP 2014

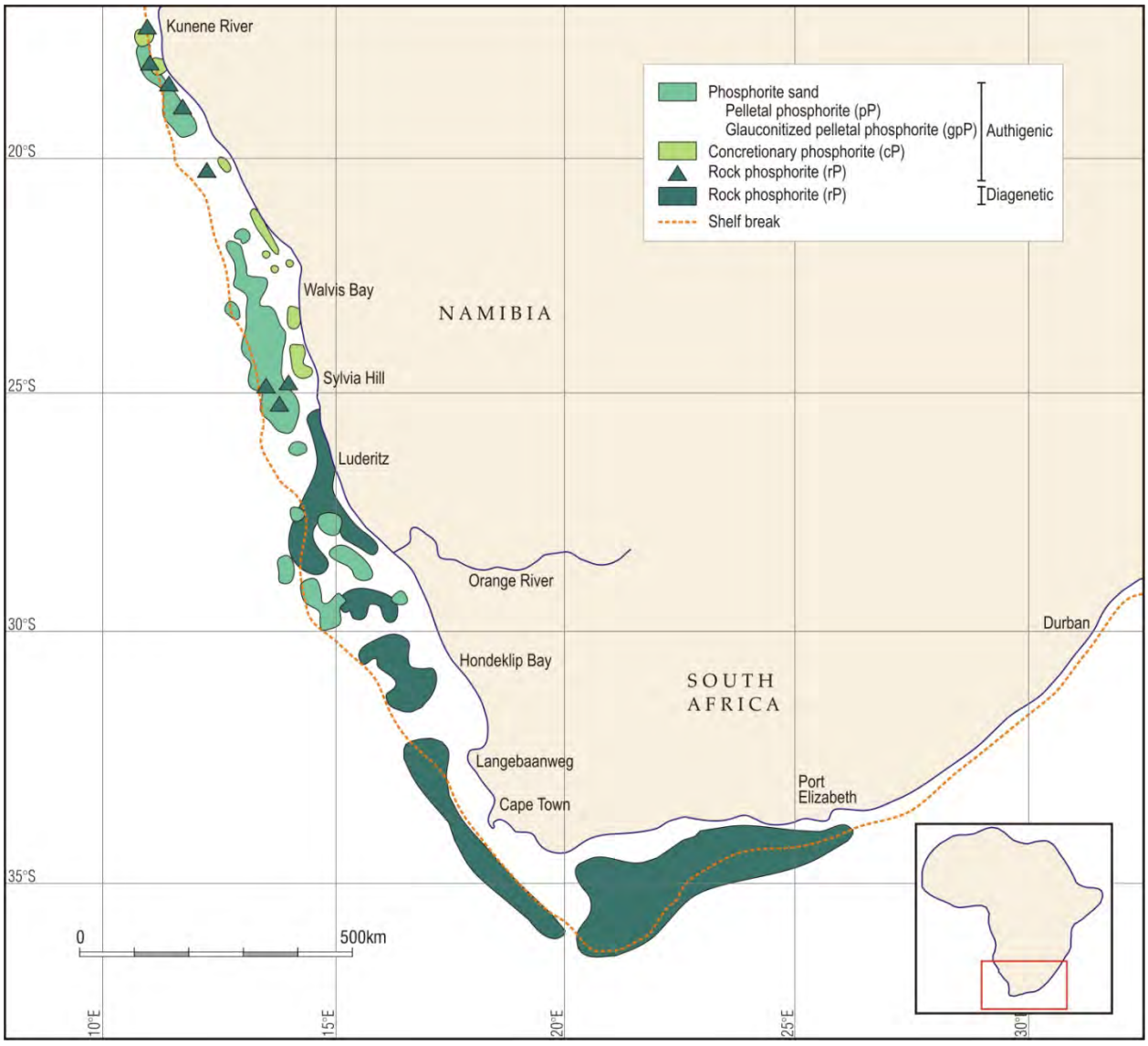


Figure 8: Distribution of phosphorite rock types
(redrawn from Bremner and Rogers, 1990).

4 GEOCHEMISTRY OF PHOSPHORITE GRAINS

Phosphorite is a rock type that has a high phosphorus content, usually >18wt% P_2O_5. The P-bearing mineral in phosphorite is apatite,

$Ca_5(PO_4)_3(OH, F)$

For most marine phosphorite the P-bearing mineral is francolite, an apatite with carbonate ion substitution for phosphate ion and significant amounts of fluoride (>1wt% F) in place of hydroxide (OH).

A typical chemical formula for marine francolite is:

$Ca_{4.7}Na_{0.2}Mg_{0.1}(PO_4)_{2.6}(CO_3)_{0.4}F_{1.28}$

Where the carbonate ion (CO_3) substitutes for the phosphate ion (PO_4) and the charge balance is maintained from the substitution of Na and Mg for Ca. A trace element common in francolite is strontium because the strontium ion (Sr^{2+}) can substitute for the somewhat smaller Ca^{2+} ion. As a result francolite is commonly found to contain between 1000-4000 ppm strontium. The relatively high Sr content makes francolite a useful mineral for strontium isotope stratigraphy (see Age of phosphorite deposits below).

The chemical composition of marine francolite having the chemical formula
$Ca_{4.7}Na_{0.2}Mg_{0.1}(PO_4)_{2.6}(CO_3)_{0.4}F_{1.28}$
expressed as weight percent major oxides is:

CaO	52.6%
Na_2O	1.2%
MgO	0.8%
P_2O_5	36.9%
CO_2	3.5%
F	4.9%

The chemical composition of different types of phosphorite grains from the Namibian shelf including concretionary and pelletal phosphorite grain types have been determined by a number of workers (Bremner, 1977; Thomson *et al*., 1984; Baturin, 2002). The major element data reveal that the chemical composition of the phosphorite grains is largely similar with P_2O_5 ranging from 28 to 33 wt%.

The following two tables from Bremner (1977) give the average chemical composition of concretionary and pelletal phosphorite from the outer Namibian shelf:

© NMP 2014

Table 1: Average major element compostion of concretionary Phosphorites (cP) from the study area, and from other locations (weight %) (Bremner, 1977)

Analytical method	This study		SWA[1] SWA[2]		Chile [3]
	XRF EMP		XRF ? XRF		? XRF
No. of analyses	3	8	2	?	?
SiO_2	-	,11	1,40	,15	12,30
Al_2O_3	-	,03	,37	,04	3,31
FeO*	,03	,01	,79	,18	2,01
MgO	,79	1,47	,60	1,70	1,60
CaO	48,36	50,31	51,25	46,42	38,64
Na_2O	,95	,96	-	-	-
K_2O	-	,04	,13	-	-
P_2O_5	32,62	33,07	32,10	32,74	25,62
MnO	,01	ND	-	-	-
TiO_2	,04	ND	,06	-	-
S	,79	,59	-	-	-
L.O.I. + H_2O^-	16,21	ND	-	12,20	8,65
CaO/P_2O_5	1,48	1,52	1,60	1,42	1,51
F/P_2O_5	,098	,097	,074	,092	,100
CO_2[(a)]	5,2		4,20	6,33	3,04
F[(b)]	5,2		2,39	3,02	2,55
C_{org}[(c)]	1,3		-	,92	,60

XRF = X-ray fluorescence, EMP – electron microprobe
* Total iron reported as FeO
\- This study, not detected; other studies not reported
ND Not determined

1. Price and Calvert (in press). Consolidated phosphorite concretions
2. Baturin (1971c). Hard nodules
3. Baturin and Petelin (1972). Compact grey concretions

(a) This study and 1 – Gasometry and X-ray diffraction; 2 and 3 – not reported.
(b) This study – specific ion electrode; 1 – XRF; 2 and 3 – not reported.
(c) This study – wet oxidation; 2 and 3 – not reported.

© NMP 2014

Table 2: Average major element composition of pelletal phosphorite (pP)

from unconsolidated sediment, bedrock and other locations, and of glauconitized pelletal phosphorite (gpP) from the sediment (weight %) (Bremner, 1977)

Analytical method	Pelletal phosphorite (pP)					Glauconitized pelletal phosphorite (gpP)			
	Unconsolidated sediment				Rock *	Unconsolidated sediment			
	This study		SWA[1]	Cape West coast[2]	This study	This study			
	XRF	EMP	XRF	EMP	EMP	XRF	EMP	EMP	EMP
No. of analyses	4	31	2	12	16	4	59	24 (nucleus)	35 (rim)
SiO_2	4,97	2,70	4,80	5,51	3,30	8,06	4,17	3,78	4,44
Al_2O_3	1,12	1,11	1,21	1,40	,93	1,66	1,16	1,11	1,19
FeO*	2,29	4,95	2,63	4,13	8,48	6,02	6,31	6,57	6,13
MgO	,83	,90	,90	1,10	,80	,96	,68	,62	,72
CaO	46,93	45,18	44,15	44,90	43,26	38,73	39,70	41,52	38,46
Na_2O	,50	1,09	-	,84	1,06	,34	,61	,70	,55
K_2O	,38	,34	,39	,56	,34	,60	,42	,38	,45
P_2O_5	28,04	28,62	28,30	34,00	25,05	25,25	25,12	27,65	23,38
MnO	,03	ND	-	-	ND	,09	ND	ND	ND
TiO_2	,46	ND	,11	-	ND	,89	ND	ND	ND
S	2,31	4,27	-	1,67	8,16	2,00	1,98	2,68	1,50
L.O.I.+H^2O^-	12,03	ND	-	-	ND	16,85	ND	ND	ND
CaO/P_2O_5	1,67	1,58	1,56	1,32	1,73	1,53	1,58	1,50	1,64
F/P_2O_5	,114	,112	,086	-	ND	,100	,100	ND	ND
CO_2	3,6		3,70	-	ND	4,1			
F	3,2		2,42	-	ND	2,6			
C_{org}	2,7		-	-	ND	1,4			

* Pelletal phosphorite in granular fabric of phosphorite infillings (Chapter 4)
XRF = X-ray fluorescence, EMP = electron microprobe
* Total iron reported as FeO
ND Not determined (this study), - = not reported (other studies)
1. Price and Calvert (in press)
2. Birch (1975)

© NMP 2014

The following table from Thomson *et al*. (1984) gives the chemical composition of recent concretionary phosphorite grains from the diatomaceous mud belt on the inner Namibian shelf between Walvis Bay and Cape Cross:

Table 3: Major (wt %) and minor (ppm) element composition of Namibian phosphorites (Thomson *et al.* 1984).

	3424	3429	3903	5798C	5799	5799B	5799D	5800	5801	5801A
SiO_2	4.5	8.4	7.4	6.7	2.4	4.8	0.5	0.4	13.52	0.7
Al_2O_3	0.26	1.69	1.73	1.06	0.69	0.81	0.16	0.03	4.54	0.32
TiO_2	0.07	0.11	0.12	0.07	0.05	0.06	0.04	0.02	0.21	0.04
Fe_2O_3[a]	0.16	3.56	7.98	0.48	0.46	0.33	0.03	0.02	1.52	0.09
CaO	19.35	41.78	37.57	44.56	45.26	40.01	46.53	46.21	36.02	47.70
MgO	3.97	0.50	0.43	0.74	0.63	0.51	0.61	0.71	0.72	0.35
K_2O	0.16	0.63	1.03	0.21	0.18	0.24	0.12	0.09	0.71	0.13
P_2O_5	27.9	28.0	27.7	30.2	30.5	27.5	31.4	30.7	24.9	30.8
CO_2[b]	13.24	6.27	2.90	5.83	5.57	5.35	6.67	6.71	6.60	6.53
CO_2[c]	2.3	4.1	3.7	2.7		2.3	2.6	1.1	1.5	2.3
F	1.77	1.76	1.76	1.91	2.42	1.73	2.78	2.74	2.06	2.99
Ba	25	<5	<5	1365	1185	31070	5850	275	5585	<5
Cu	9	41	23	6	<2	26	5	7	13	3
Ni	14	86	44	6	5	4	<3	<3	15	<3
Pb	<4	15	4	<4	<4	6	9	<4	<4	6
Rb	2	<2	17	4	4	<2	<2	<2	46	<2
Sr	245	1140	960	1600	1490	2800	1775	1650	1700	1200
Th[d]	0.4	25	20	1	0.5	1	0.3	0.3	3	0.6
U[d]	18	130	95	107	76	82	49	58	61	35
Y	29	348	330	19	5	20	29	4	11	15
Zn	<3	5	10	<3	52	3	36	20	10	8
Zr	75	285	200	320	285	500	345	335	375	250

a Total iron reported as Fe_2O_3.
b Acid-soluble carbon expressed as CO_2.
c Francolite CO_2 determined by the method of Gulbrandsen (28).

The following table from Baturin (2002) gives the chemical composition of a number of different phosphorite nodules obtained from the outer Namibian shelf:

Table 4: Chemical Compositon of phosphorite nodules, wt % (Baturin 2002)

Sample type	P_2O_5	CaO	MgO	SiO_2	Al_2O_3	Fe_2O_3	Na_2O	CO_2	C_{org}	SO_3	F	H_2O
Small concretions	30.75	48.4	1.12	1.44	0.61	1.50	0.92	5.03	1.28	3.76	3.44	10.1
Large concretion	32.45	49.5	1.45	0.40	0.05	0.43	1.52	6.03	0.88	-	-	-
Concretion fragment	30.98	-	1.52	0.29	0.16	1.06	1.66	6.47	0.93	-	-	-
Tabular concretion	32.82	-	1.39	2.65	0.69	2.85	1.58	3.40	0.57	-	-	-
Pelecipod cast	26.22	43.2	1.29	9.21	1.71	2.63	1.47	4.35	1.01	-	-	-
Gastropod cast	31.05	47.5		2.17	0.09	-	-	-	-	-	-	-
Small coprolite	33.10	-	1.39	0.49	0.08	0.17	1.35	5.92	1.08	-	-	-
Larger coprolite	32.28	50.9	1.39	0.30	0.03	0.46	1.47	6.22	0.97	-	-	-

© NMP 2014

The major element compositions shown in the tables above indicate that phosphorite is not composed of pure francolite. The reason for this is that the francolite grows as microcrystalline cement which fills in the interstitial pore spaces of the sediment and does not generally replace the sediment grains as it grows except in the case of limestone and fossil bone material which may approach the composition of 100% francolite and would have a maximum P_2O_5 content of around 37wt%. As a result the francolite cemented concretions and nodules contain inclusions of other minerals as well as organic matter. Outside of phosphatised shell and bone material (skeletal phosphorite grains), most marine phosphorite grains are not composed of pure francolite but have inclusions of quartz (SiO_2), glauconite (rich in iron), clay minerals (rich in Al_2O_3), organic matter (Corg) and pyrite (FeS_2) all of which can occur in highly variable amounts, but generally constitute between 5-40 wt% of the phosphorite grain. Therefore pelletal, concretionary and rock phosphorite grain separates will typically have a maximum P_2O_5 content of between 22 and 35 wt% as reflected in the tables above.

5 AGE OF PHOSPHORITE DEPOSITS AND THE AGE OF PHOSPHORITE FORMATION

Phosphorite grains, especially in economic deposits, typically occur as reworked grains which can make it difficult to determine the age of the phosphorite as opposed to the age of the sediment in which it occurs. The age of the sediment in which it occurs is usually estimated from biostratigraphy of the youngest occurring fossils, but reworked fossils and phosphorite grains can be significantly older than the age of the deposit in which they occur, such that the fossils associated with them date their final reworking event but do not indicate necessarily when the reworked phosphorite grains formed (Compton *et al*., 2004). This problem has since been addressed by the development and application of strontium isotope stratigraphy (SIS). SIS works on the principle that the strontium isotope composition ($^{87}Sr/^{86}Sr$ ratio) of seawater has varied through time and that once this variation through time has been established by measuring the Sr isotope ratio of marine fossils of known age, a sample of unknown age which contains Sr incorporated from seawater at the time of its formation can be dated by comparison with the seawater curve (McArthur *et al*., 2001). The age resolution possible using SIS depends on how steep the seawater curve is or how quickly the ratio changed with time in seawater. A particularly rapid Sr increase in seawater occurred from the Oligocene through to the late Miocene and, therefore, reliable and relatively high resolution dates can be obtained for grains formed during this interval (Compton *et al*., 2004). SIS can also be applied outside this time interval, such as during the Plio-Pleistocene but at lower resolution.

Our understanding of the complex evolution of phosphorite deposits, as indicated by their petrography, has been vastly improved with the application of SIS. SIS has enabled individual phosphorite grains to be dated from a sediment sample because the Sr content of most phosphorite grains is high enough (1000-4000 ppm) to analyse the Sr isotope composition of individual grains. The age dating results support the sedimentological and petrographic evidence of a complex reworking and multiple formation history of most phosphorite grains from the western margin of South Africa between the Orange River and Cape Columbine (Compton *et al*., 2002; 2004). SIS has allowed the different textural components of the sediment deposit to be dated separately and this has allowed for a far more detailed basis for reconstructing the history of phosphorite deposits.

Unfortunately, the SIS dating technique has yet to be applied fully to the Namibian phosphorite deposit with only a few Sr derived ages (McArthur *et al*., 1990; Jarvis *et al*., 1994), but the potential

© NMP 2014

of the SIS technique can be illustrated by some examples from similar phosphorite deposits off South Africa. Phosphorite grains from offshore South Africa range in age from latest Oligocene to Pleistocene and individual phosphorite rock samples can have formation histories spanning several million years as indicated by concentric growth layers of individual grains (Compton *et al*., 2002; 2004). Most phosphorite grains are older than the age of the sediment in which they occur. For example, Pleistocene gravels off the Orange River and Cape Columbine have phosphorite grains that range in age from early Miocene to Pleistocene. The dating of separate grain types within the same deposit reveals that shark teeth can be older than pelletal phosphorite sand which are older than fragmented mollusc shell which are older than well preserved benthic foraminifera whose youngest age is inferred to be the final depositional age of a mixture of grains formed over many millions of years (Compton *et al*., 2002; 2004).

Refer to Part II of this report for the SIS results obtained for ML 170.

6 ORIGIN OF PHOSPHORITE GRAINS

There have been a number of theories concerning the origin of phosphorite. The origin of phosphorite requires the precipitation of the mineral francolite, a carbonate fluorapatite rich in phosphorus (37 wt% P_2O_5), whereas the origin of an economic phosphorite deposit requires in addition the physical reworking of phosphorite once formed into a concentrated deposit, typically a sand or gravel erosional lag deposit (Compton *et al*., 2000).

Phosphorite is a marine authigenic mineral that forms in place (authigenically) within sediment that has an unusually high phosphate ion concentration in its pore waters. Relatively high phosphate ion concentrations have been measured in organic matter rich sediments, those that contain greater than 0.5wt% organic carbon. Organic-rich sediments typically are associated with areas of the ocean having high primary productivity in their surface waters. A world class example would be the Namibian margin and its highly productive Benguela Upwelling System where wind driven coastal upwelling supplies nutrient rich deeper waters to the surface resulting in large algal productivity such as bloom events (Figure 4). For example, the phosphate ion concentration increases rapidly from only several micromolar in bottom seawater to close to 600 micromolar in pore waters analysed from organic-rich sediments recovered from the uppermost 100 metres of ODP Site 1084 (Wefer *et al*., 1998). The abundance of phosphorite sediments on the shelf off Namibia is linked to the upwelling of phosphate-enriched oceanic water and subsequent high biological productivity (Summerhayes *et al.*, 1973). Modern concretionary phosphorite nodules are currently forming today in the Holocene diatomaceous ooze which extends along the Namibian middle shelf with organic carbon contents as high as 18wt% (Baturin, 2000).

The connection between phosphorite formation and organic matter accumulation was already appreciated and argued for by those who described phosphorite recovered during the HMS Challenger expedition (Murray and Renard, 1891).

© NMP 2014

> *"Organic remains must sometimes accumulate in vast numbers on the sea-bed, and sometimes be buried in the sediments; it seems to us that the decomposition of such organic remains is the immediate source of the phosphates in the concretions here described."* (p.398)

> *"But whatever may be the nature of the substance serving as a first centre for these concretions, we are led to believe that the phosphate of which they are constituted has passed through living matter. Its cycle may be traced by saying that, after having been concentrated by living beings, it is rendered to the mineral world again, after solution by sea-water, in a concretionary form, and is thus placed in a more stable form in reserve for the future wants of life."* (p. 400)

The production of organic matter in the surface ocean by algae (phytoplankton) requires the uptake of phosphorus in the Redfield molar ratio of 1 phosphorus atom for every 106 carbon atoms fixed as organic matter. The sinking of the organic matter upon death or consumption and transport as faecal pellets represents a source of food to organisms living on the seafloor. The consumption or degradation by bacteria of organic matter results in the release of organically bound P to the pore waters as phosphate ion and where these concentrations rise to high enough levels, supersaturation and precipitation of francolite can occur (Figure 9). The presence of carbonate minerals such as calcareous shells enhances francolite precipitation by supplying calcium ions and is most likely why phosphatised limestone is so commonly observed. The necessary fluoride ion is supplied by diffusion from overlying seawater. An excellent example of where this is occurring today is on the Namibian inner shelf off Walvis Bay, where diatomaceous algal remains are accumulating in sediment with as much as 18 wt% organic carbon and where silt and sand sized phosphorite grains are observed to be actively growing (Baturin, 2000). Phosphorite forming in organic rich mud could extend up into shallow water areas, possibly even estuaries, but the model proposed for a gel-like phosphorite formation in estuaries or lagoons (Bremner, 1977; Bremner and Rogers, 1990) is not observed today and has not been supported by geochemical studies.

© NMP 2014

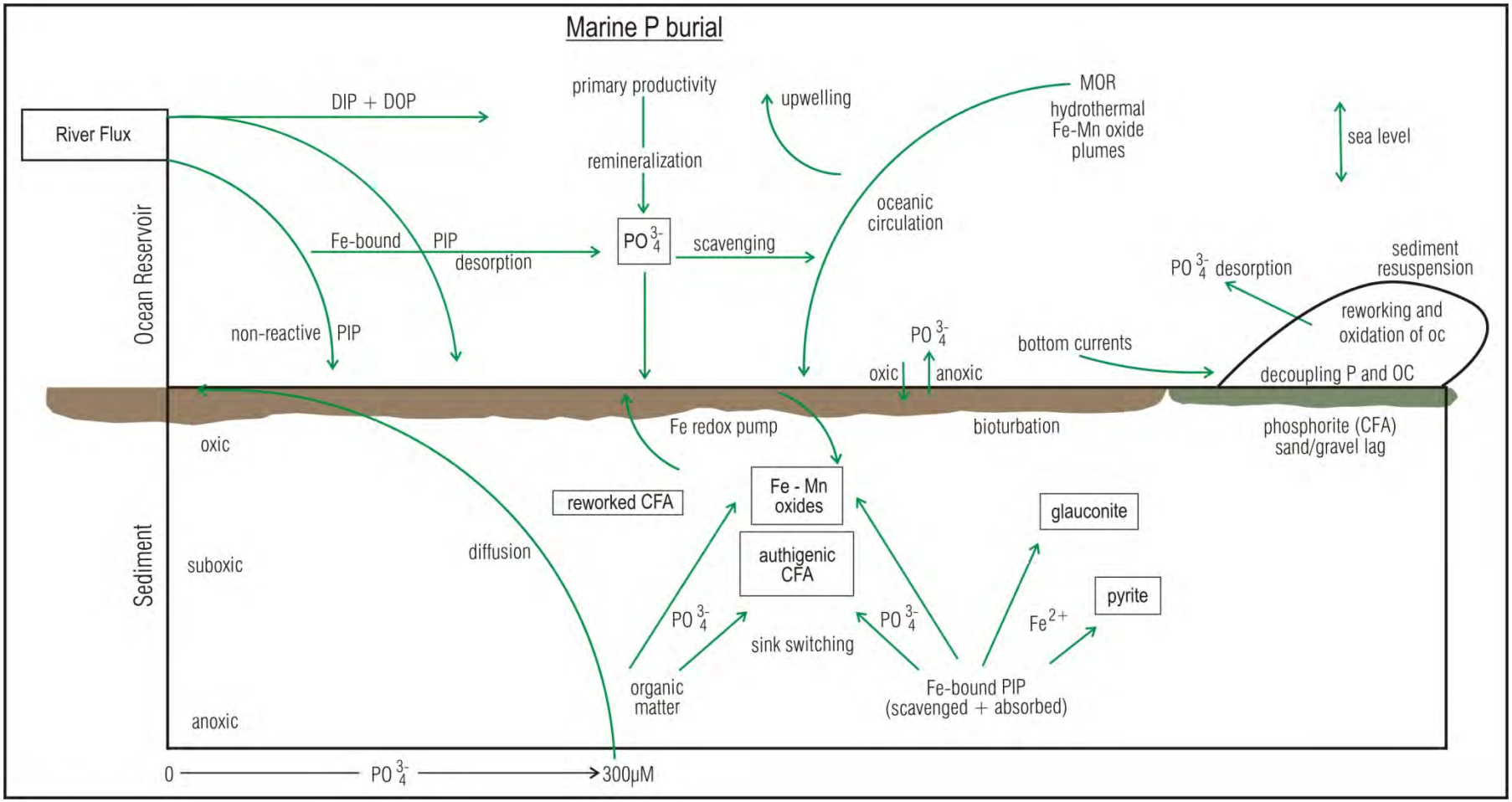


Figure 9: A general schematic model for how phosphorite (authigenic CFA, carbonate fluorapatite) forms in marine sediment from the burial of organic matter under areas of high surface productivity, the release of phosphate ion to pore waters and precipitation of CFA (francolite). Phosphorite is commonly associated with the diagenetic minerals pyrite and glauconite. Reworking of organic rich mud deposits can then concentrate the phosphorite grains in sand or gravel lag deposits (Compton *et al.*, 2000).

© NMP 2014

An origin during the early diagenesis of organic-rich marine sediments has been well supported by geochemical studies of, for example, carbon and sulphur isotopes of carbonate and sulphate ion substituted in francolite (McArthur *et al*., 1986; Mallinson and Compton, 1998). Recall from the previously presented elemental analysis of phosphorite from the Namibian shelf that phosphorite was found to contain between 3.2 and 6.5 wt% CO_2 which occurs in the francolite as carbonate ion ($CO_3^{=}$) substituting for the phosphate ion. In the geochemical analysis of phosphorite from the Namibian shelf it was found that the carbon isotope composition of carbonate substituting in the francolite structure ranges from -3 to -9‰ and the sulphur isotope values were slightly depleted relative to seawater from the oxidation of hydrogen sulphide diffusing up from below (McArthur *et al*., 1986). This combination of depleted carbon and sulphur isotope values indicates that the francolite formed near the suboxic to anoxic boundary where intense microbial processes rapidly remove oxygen from the sediment (Figure 10).

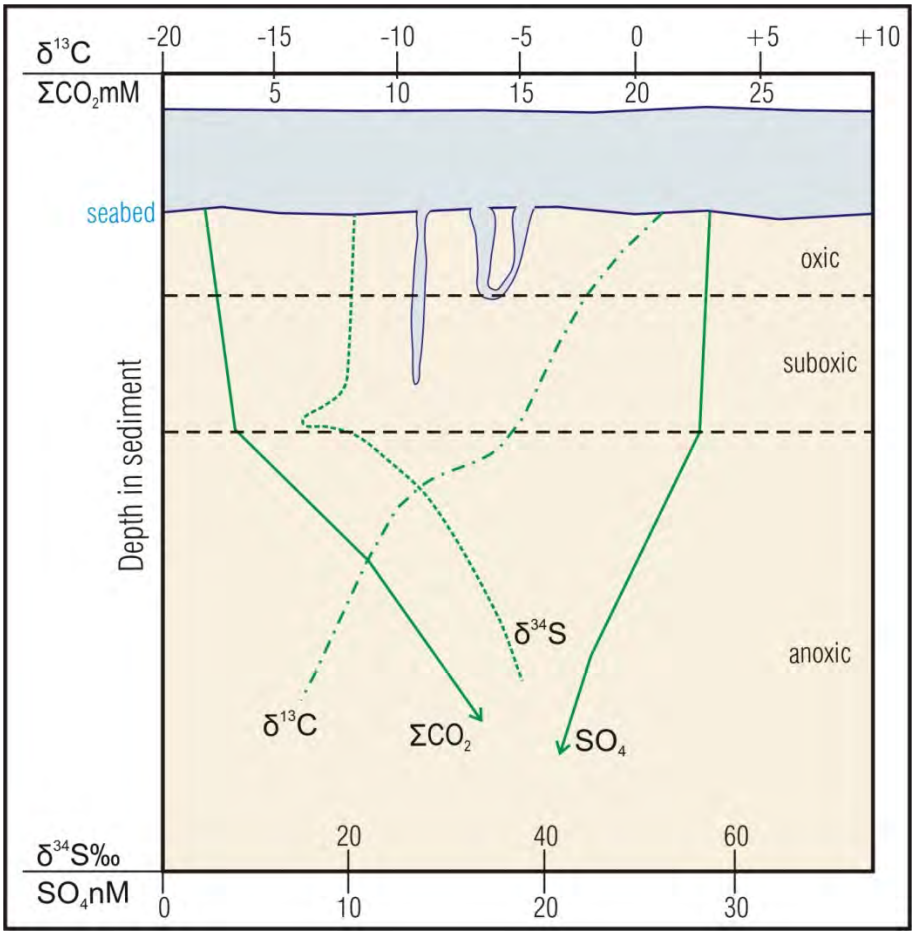


Figure 10: Carbon and sulphur isotope variations during early diagenesis across the oxic, suboxic and anoxic sediment boundaries
(McArthur *et al*. 1986).

Other authigenic marine minerals commonly associated with phosphorite (francolite) are glauconite, pyrite and dolomite (Figure 9). The reason for these common associations is that the early diagenetic environment of organic-rich sediment produces reducing conditions and the formation of hydrogen sulphide which can combine with reduced iron to form pyrite. Glauconite forms at the interface of reducing and oxidizing environments in iron-rich marine sediments and glauconite-rich deposits occur separately from or are intermixed with phosphorite deposits on the southern African western shelf (Birch, 1975; 1979). Glauconite on the Namibian shelf is most abundant in the vicinity of the Kunene River because of the large amounts of iron-rich terrigenous sediment delivered to the offshore. Phosphorite tends to be more abundant where there is intense upwelling. Glauconite and phosphorite often occur together and can form synchronously. For example, glauconite is commonly observed to form in microenvironments such as the interior chambers of fossil foraminifera tests where the original calcareous test wall has been replaced by francolite (Wigley and Compton, 2007). Dolomite is found on the inner shelf of Namibia (Compton *et al*., 2001) but the dolomite has an origin linked to sea-level lowstands and the interaction of meteoric (fresh) and marine waters. Dolomite has not yet been reported from the middle to outer shelf areas off Namibia perhaps because these areas were never exposed during sea level lowstands.

7 HOW DO ECONOMIC PHOSPHORITE DEPOSITS FORM?

Phosphorite is commonly observed in organic-rich sedimentary rocks where it formed in place; however, such occurrences of phosphorite are nearly always subeconomic because the phosphorite is too diluted by other sediment components. For example, in place, concretionary phosphorite actively forming in the Holocene diatomaceous mud belt is not abundant enough to be mined. In order to form economic deposits the phosphorite must be reworked and concentrated by the preferential removal of non phosphatic grains (Figure 9). On the continental shelf the mechanism for alternating between phosphorite formation in organic rich mud deposits and reworking into an erosional phosphorite lag deposit is commonly related to changes in sea level (Compton *et al*., 2002; 2004). The specific depositional histories of phosphorite deposits will vary from margin to margin. Refer to Part II for a proposed depositional history of the phosphorite occurring in ML 170.

© NMP 2014

8 PHOSPHORITE DEPOSIT ON THE NAMIBIAN SHELF

The Namibian shelf contains phosphorite-rich surface sediment (Figure 11) that is also reflected in the bulk sediment weight percent P_2O_5 content (Figure 12). There are two areas of the shelf that are particularly enriched in phosphorite. Surface sediment sampled from the northern Namibian shelf contains between 5-50 wt% pelletal phosphorite. The phosphorite-rich sediment extends in a north-south trend just inboard of the 200 m isobath from 18 to 20ºS with the highest phosphorite content occurring directly offshore of Rocky Point (Figure 11). The nature of the northern phosphorite deposit is not well known and will not be discussed further in this report with the exception of one Sr age date included in the section below on Sr isotope stratigraphy. The second area of the Namibian shelf with between 5-50 wt% phosphorite is located on the middle shelf between 180 and 300 m water depth extending from 23ºS offshore of Walvis Bay to 25.5ºS offshore of Hottentot Bay. The deposit was independently determined by Russian (Senin, 1970) and South African (Bremner, 1977; Rogers, 1977) surveys. The phosphorite rich sediment similarly extends in a north-south trend but is more broadly diffused on either side of the 200 m isobath in comparison to the northern area. The central, phosphorite-rich core of the deposit is defined by surface sediment having greater than 50 wt% phosphorite that are located just to the south offshore of Conception Bay, Meob Bay and Spencer Bay (Figure 13). The deposit partially overlaps with the modern upwelling cells of the BUS and the deposit runs parallel to shore most likely reflecting the position of intense upwelling in the past several million years as well as the redeposition of phosphorite from the inner to middle shelf during sea level lowstands (refer to depositional model below). The three dimensional architecture of the phosphorite deposit is not known, but the richest areas grade into less rich areas to the west and east of the central phosphorite-rich areas. Unlike the northern area, the southern area has received a fair amount of recent attention which is summarised in the following section.

© NMP 2014

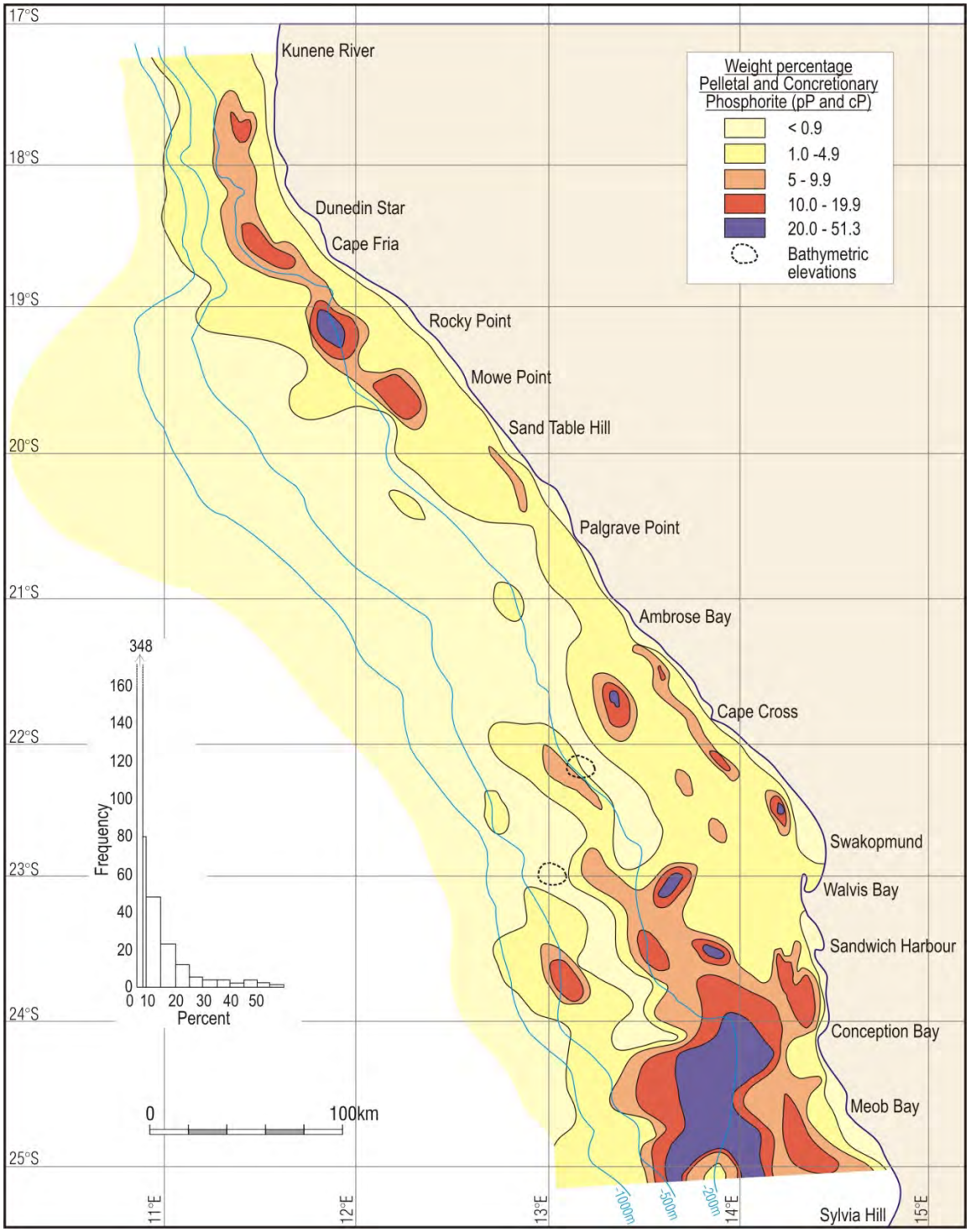


Figure 11: Distribution of phosphorite along the Namibian margin from the Kunene River to 25ºS (redrawn from Bremner, 1977).

Modern phosphorite concretions occur on the inner to middle shelf between Sandwich Harbour and Ambrose Bay. Reworked, mostly pelletal phosphorite occurs south of Walvis Bay on the middle and outer shelf and north of Palgrave Point to the Kunene River on middle to outer shelf.

© NMP 2014

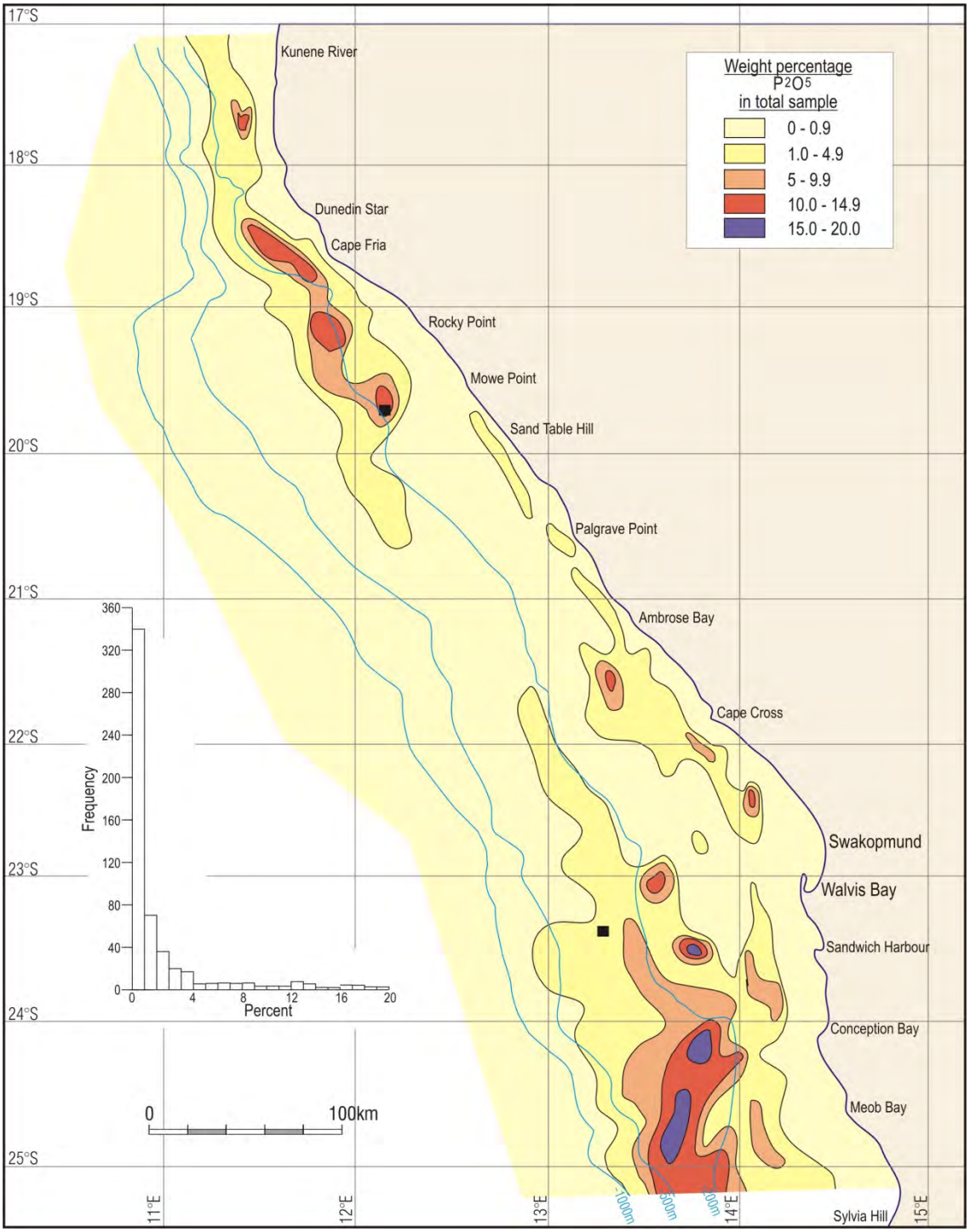


Figure 12: Weight percentage P2O5 along the Namibian margin from the Kunene River to 25ºS (redrawn from Bremner, 1977). The locations of pelletal phosphorite samples dated by McArthur *et al*. (1990) are shown in red.

Part II. A preliminary model for the origin, age and deposition of phosphorite in ML 170

The second part of this report focuses on the southern middle to outer shelf phosphorite rich area and, in particular, the area of Mining Licence 170 which occupies the middle and outer shelf between 150 and 350 m water depth between roughly 24 and 25ºS (Figure 13). Surface sediment within ML 170 contains from 10 to >50 wt% phosphorite and two areas within ML 170, one offshore and to the south of Conception Bay and the other offshore and south of Meob Bay, are particularly enriched in phosphorite, containing >50 wt%.

Figure 13/...

© NMP 2014

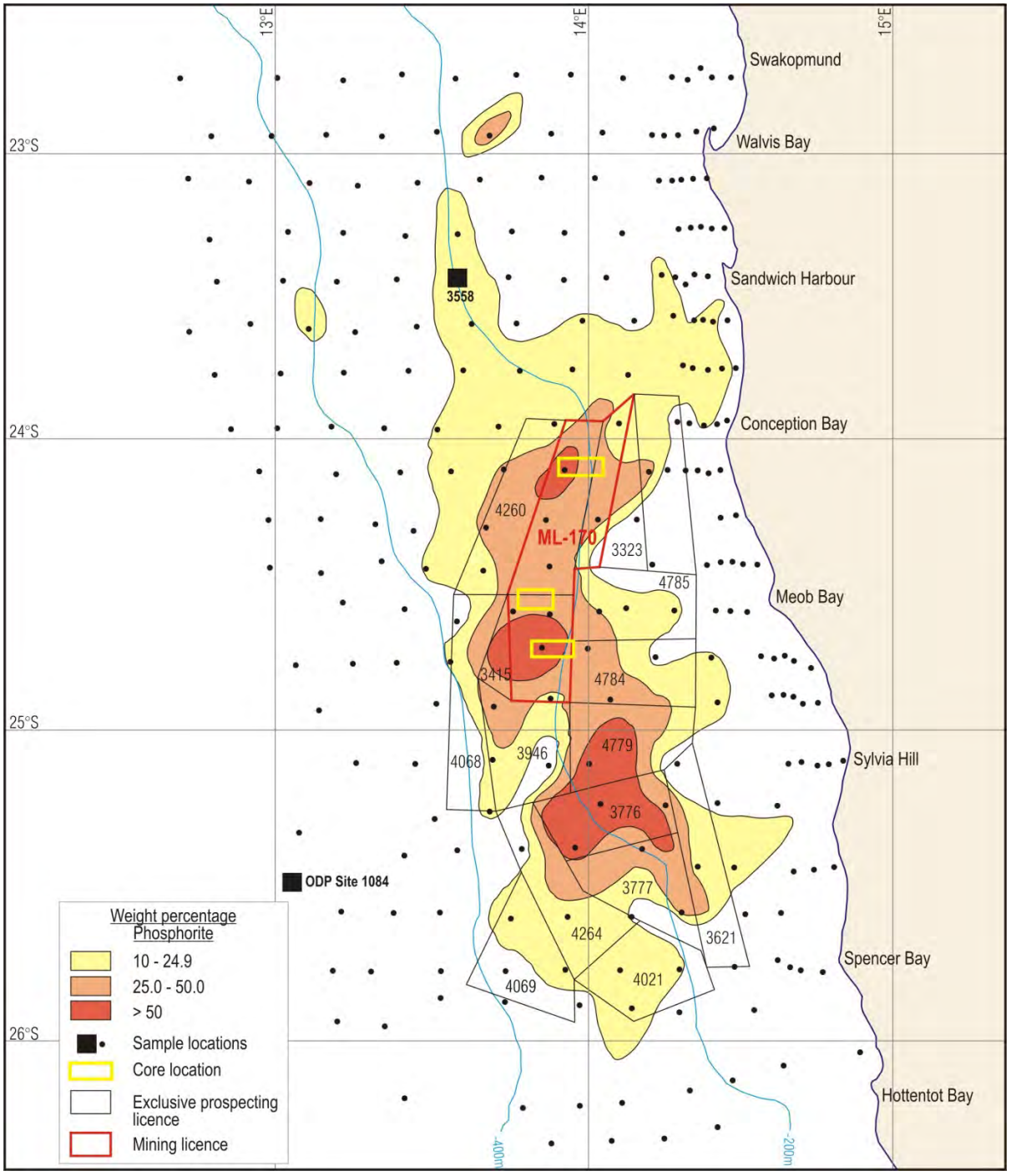


Figure 13: Distribution of phosphorite rich deposits on the central to southern Namibian shelf (modified from Coles *et al.*, 2002; Bremner, 1992) showing the location of ML 170 outlined in red. The core cluster areas offshore of Conception Bay and Meob Bay discussed in this report are outlined in yellow.

9 DETAILED STUDIES OF PHOSPHORITE DEPOSITS IN ML 170 AND ITS IMMEDIATE VICINITY

9.1 GRAVITY CORES ANALYSED BY DINGLE *ET AL*. (1996)

Dingle *et al*. (1996) conducted a study on three gravity cores from the Namibian outer shelf offshore of Meob Bay and Sylvia Hill (Figure 14). One of the cores occurs within ML 170, one occurs at the southern boundary of ML 170 and the third core 30 km to the southeast (Figure 15). The cores were obtained from the research vessel *Professor Logachev* from water depths of 181 to 256 m. Core lengths range from 2.8 to 3 m. The *Logachev* cores were investigated to determine the palaeo-upwelling characteristics of the shelf SW of Walvis Bay and NW of Lüderitz. The focus of the study was on the ostracod fauna, sedimentary textures and mineralogy of the sediment recovered. All the *Logachev* cores show an overall coarsening-upward sequence. The age of the sediment was determined using nannofossil biostratigraphy which indicated a range in age from a basal Pliocene mud to muddy sand and a middle Pleistocene shelly sand overlain by a late Pleistocene aged shelly sand. Phosphorite is reported to be most abundant in the two cores from deep water where it dominates in the early and middle Pleistocene units. In the shallow water core, phosphorite was abundant only in the upper Pleistocene layer. The phosphorite content of the cores ranges from 0 to 64% with the phosphorite content correlated with the percent sand content of the cores. Siliceous fossils (diatoms) give way to calcareous fossils (molluscs, foraminifera, ostracods) in the upper sections of the cores. Unfortunately, the lithology and composition of the core sediment were not described in any detail making it difficult to compare them to the results of Bergh (2009) or to make any estimation of the phosphorite content or grade.

© NMP 2014

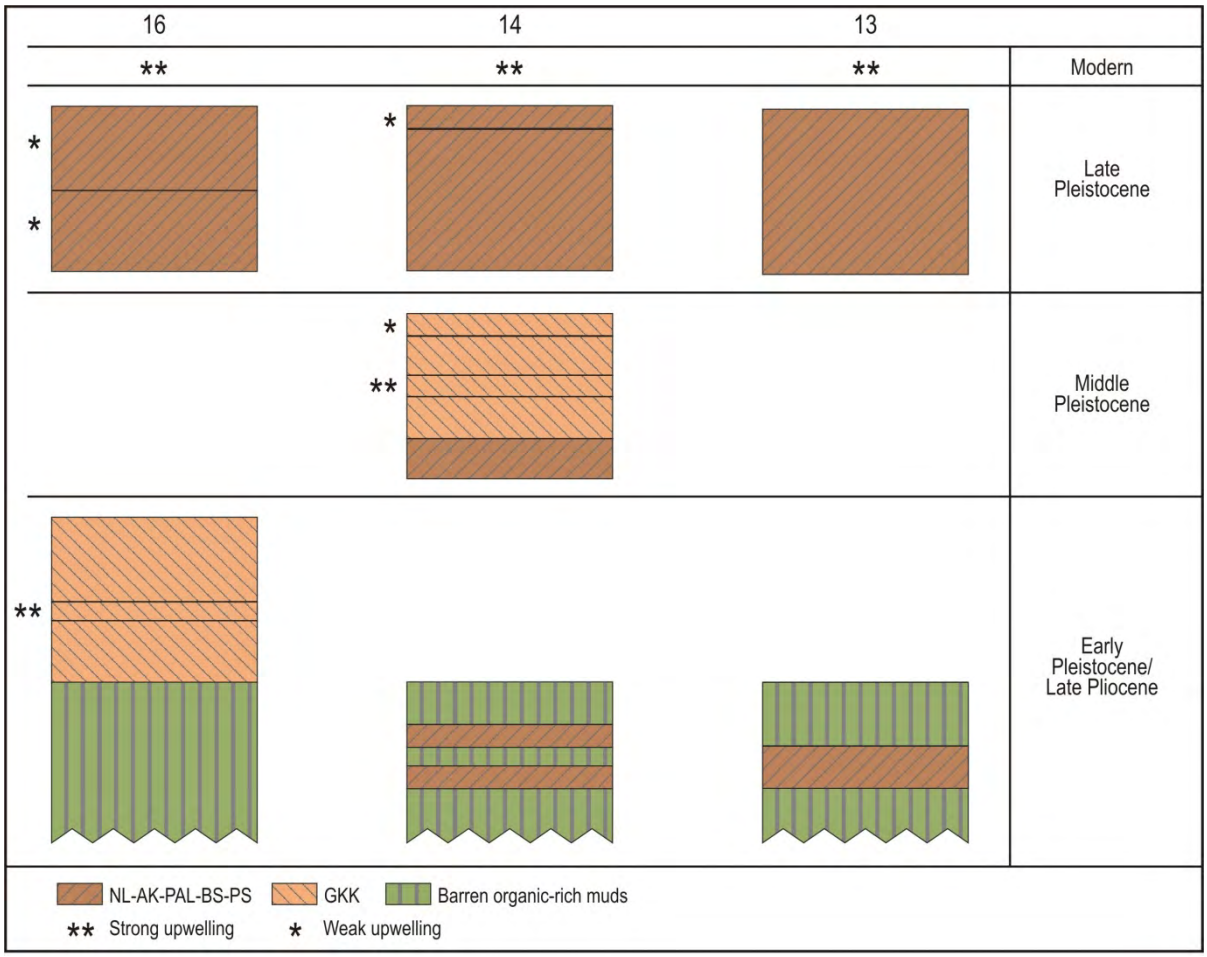


Figure 14: General stratigraphy of cores studied by Dingle *et al*. (1996).
Note relatively weak upwelling during the late Middle to Late Pleistocene compared to the Early Pleistocene, early Middle Pleistocene and Modern periods.

© NMP 2014

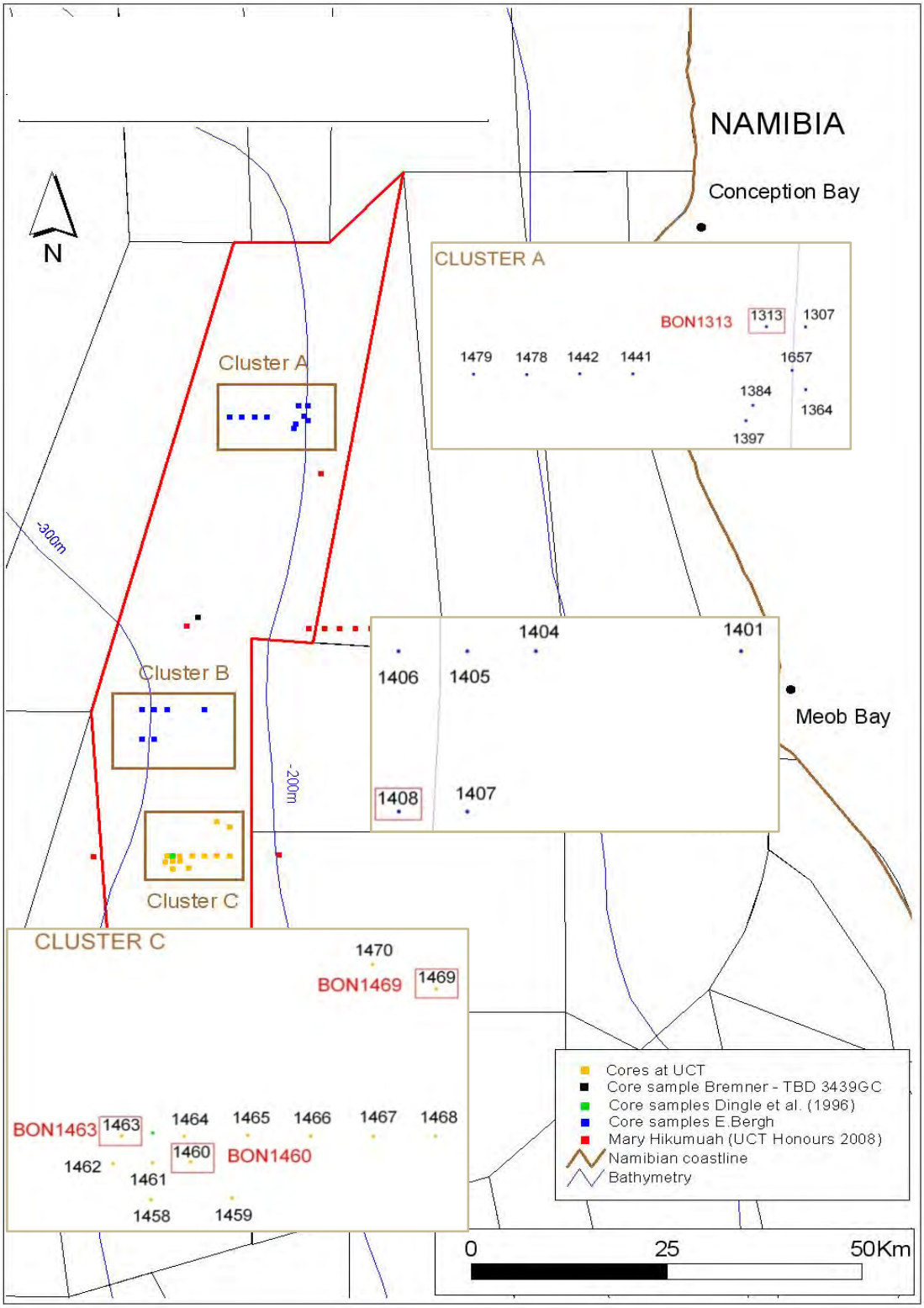


Figure 15: Location of cores in the vicinity of ML 170
(modified from Namibian Marine Phosphate maps). Each of the three core clusters is enlarged to show the position (red boxes) of the cores discussed in this report.

© NMP 2014

9.2 SAMPLES ANALYSED BY HIKUMUAH (2008)

Hikumuah (2008) compared the texture and petrography of phosphorite deposits on the Namibian shelf with those from the onshore phosphorite deposit at Langebaanweg. Samples from the Namibian shelf consist of surface grab samples some from mining exploration and some originally collected by the RV *Thomas B. Davie* and reported on by Bremner (1977) and Rogers (1977). Both of these areas have a mix of pelletal phosphorite sand and rock phosphorite. The rock phosphorite was found to consist of phosphatised limestone and the phosphorite content was focused on the upper exposed surfaces of the limestone. In addition to these thin rims of phosphorite on limestone bedrock, phosphorite rock can consist of massive, irregular pebble to boulder size composite phosphorite rock (concretionary phosphorite) with varying amounts of reworked phosphorite pebbles, quartz, biogenic calcite (shell fragments and foraminifera) and glauconite grains. The rock phosphorite petrography typically indicates a complex history of formation with multiple reworking and cementation episodes. Extensive phosphorite rock also occurs at the Langebaanweg mine, but only the overlying unconsolidated pelletal phosphorite sands were mined. Similarly, the mining of offshore deposits would not likely include large phosphorite rock but focus on the mining of unconsolidated pelletal phosphorite sand.



Figure 16: Photomicrograph of pelletal phosphorite sand from offshore Namibia.
Image shows pelletal phosphorite (pP), phosphorite intraclasts (Pi), phosphatised shell fragment (Psh), phosphatised echinoid spine (PEch), shark tooth, fish tooth and quartz (Qtz). Sample recovered from the outer Namibian shelf offshore Sylvia Hill (TBD3222G; Hikumuah, 2008).

© NMP 2014

The pelletal phosphorite sand is dominated by rounded, polished pelletal grains but also includes skeletal phosphorite (fish bone), shark's teeth, phosphatized shell fragments and phosphorite intraclasts (Figure 16). The dominant grains were pelletal phosphorite, which were found to have a highly variable petrography. Some pelletal phosphorite grains are observed to encase foraminifera tests (Figure 17). Some grains are composites of several smaller grains cemented together, some are homogeneous while others have concentric growth layers; many have a core inclusion of bone, foraminiferal test or shell fragment (Figure 18). Bremner (1977) reports that 20% of the pelletal phosphorite he studied had concentric growth layers. Intraclasts of quartz and glauconite sand are common as are organic matter and sulphide minerals (mostly pyrite). The pelletal phosphorite grains are well sorted, medium to coarse sand with polished dark brown surfaces. Most grains are well rounded to subrounded and ranged from nearly spherical to ellipsoidal in shape. Phosphatized bone, shark teeth and phosphatised bioclasts are also commonly associated with the pelletal phosphorite grains.

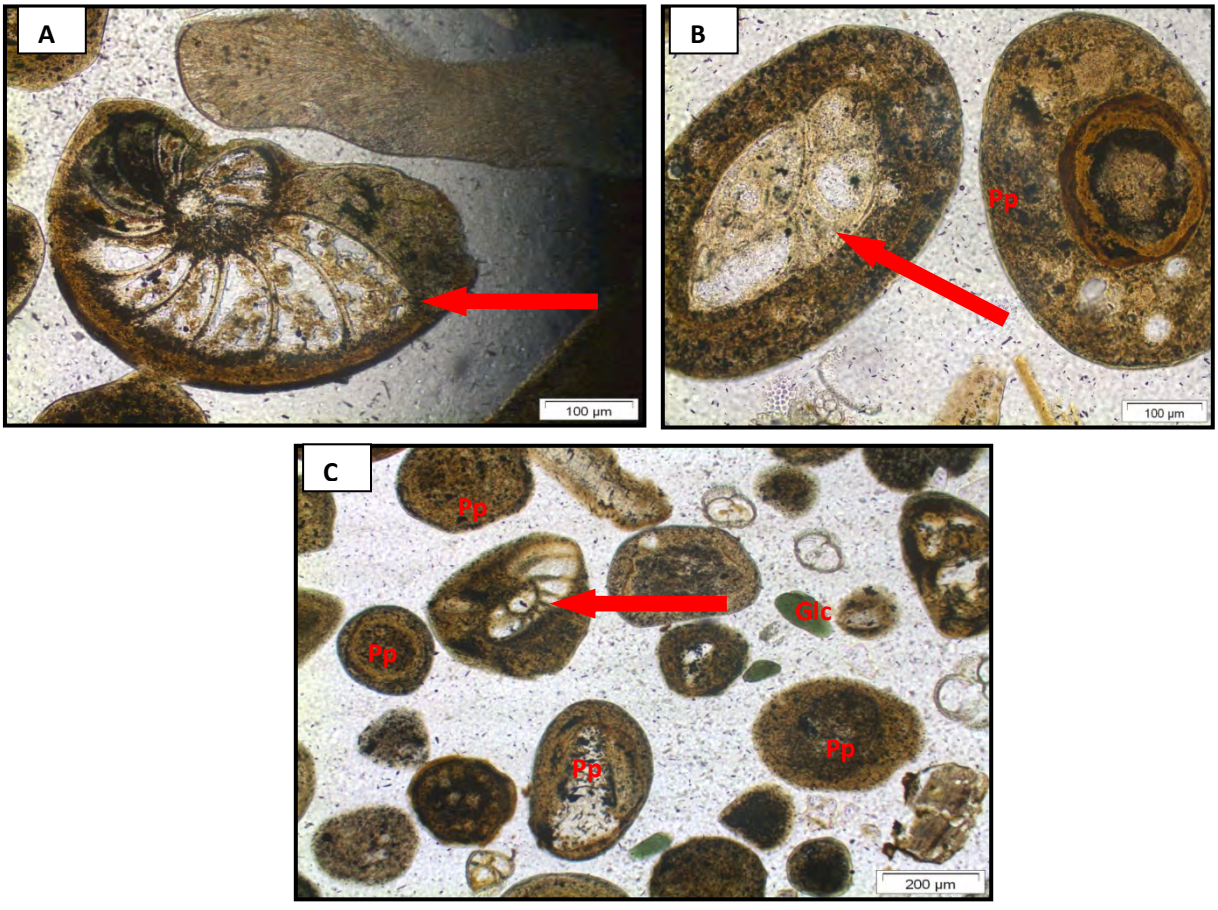


Figure 17: Photomicrographs of thin-sections of phosphorite pellets (plane-polarised light). The images show phosphorite pellets with inclusions of early Pleistocene foraminifera (arrowed). (A) *Zeaflorilus* or maybe *Hanzawaia*. (B) *Brizalina*. (Samples TBD3413, TBD3452G, EPL3323-3). Identification and age determination according to I.McMillan, pers. comm., 2008 (Hikumuah, 2008).

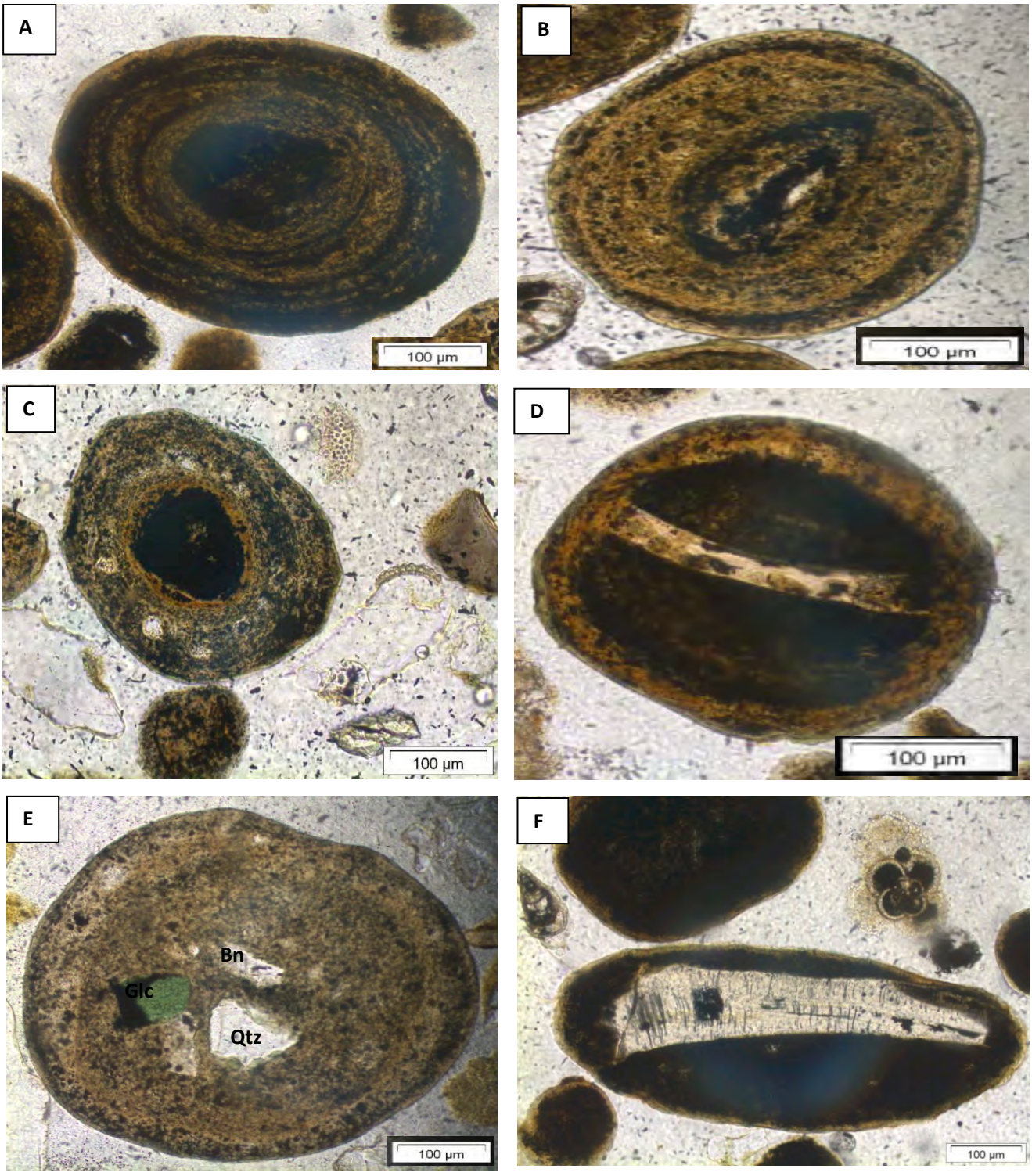


Figure 18: Photomicrograph of thin-section (plane-polarised light) showing structured pelletal phosphorite grains. (A,B) Multiple laminated grains. (C) Laminated grain with intraclasts along laminae. (D, E) Rimmed grains with (D) bone nucleus and (E) quartz (qtz), glauconite (glc) and bone fragment (Bn) inclusions. (F) Elongated grain with a bone-fragment nucleus (Hikumuah, 2008).

© NMP 2014

9.3 GRAVITY CORES ANALYSED BY BERGH (2009)

Bergh (2009) worked on two clusters of gravity cores recovered from off Conception Bay and off Meob Bay (Figure 15). A total of 16 gravity cores up to 1.8 m long were described in terms of their lithology, sediment composition and ages from fossil foraminiferal assemblages in consultation with Dr I McMillan, Iziko South African Museum, Cape Town. All cores exhibit a coarsening upward succession with basal muddy sediment, which varies from massive, mottled or laminated in structure (Figure 19a and b). The lower mud unit grades into a brownish black phosphorite sand unit of variable thickness and mud content. The phosphorite sand to muddy sand is overlain by shelly phosphorite sands, which are divided into three units: a lowermost slightly shelly, muddy phosphorite unit, a slightly shelly phosphorite sand unit and a very shelly, gravelly phosphorite sand unit. Biogenic carbonate (mollusc shells) tends to increase upcore but with whole, unbroken shells restricted to the uppermost 10-30 cm of the core tops. The basal mud unit was recovered in all cores but the presence and thicknesses of the overlying units was variable both within a cluster and between the two clusters studied.

© NMP 2014

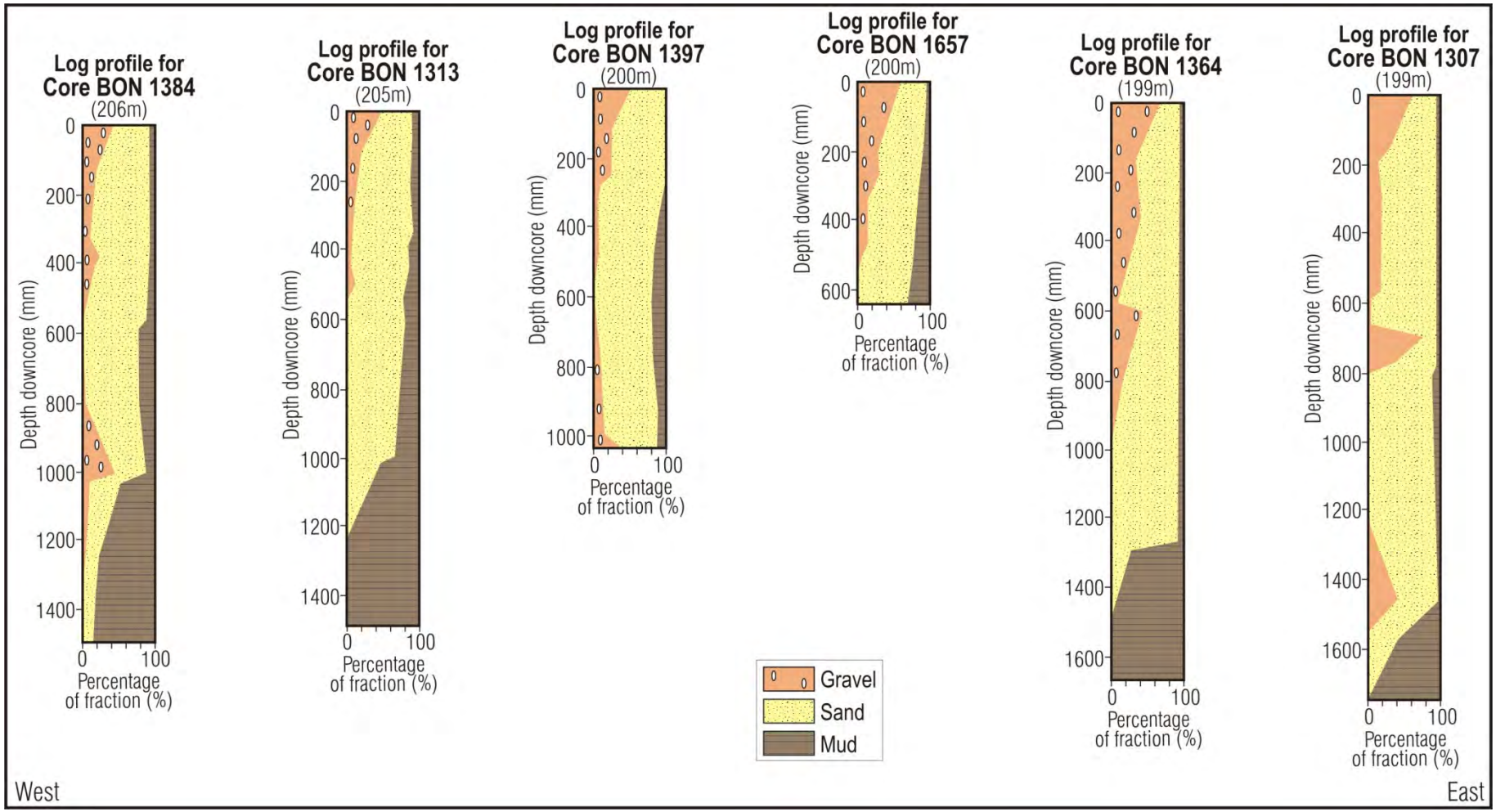


Figure 19a: Grain size profiles of vibrocores from offshore Conception Bay analysed by Bergh (2009) showing overall coarsening upcore.

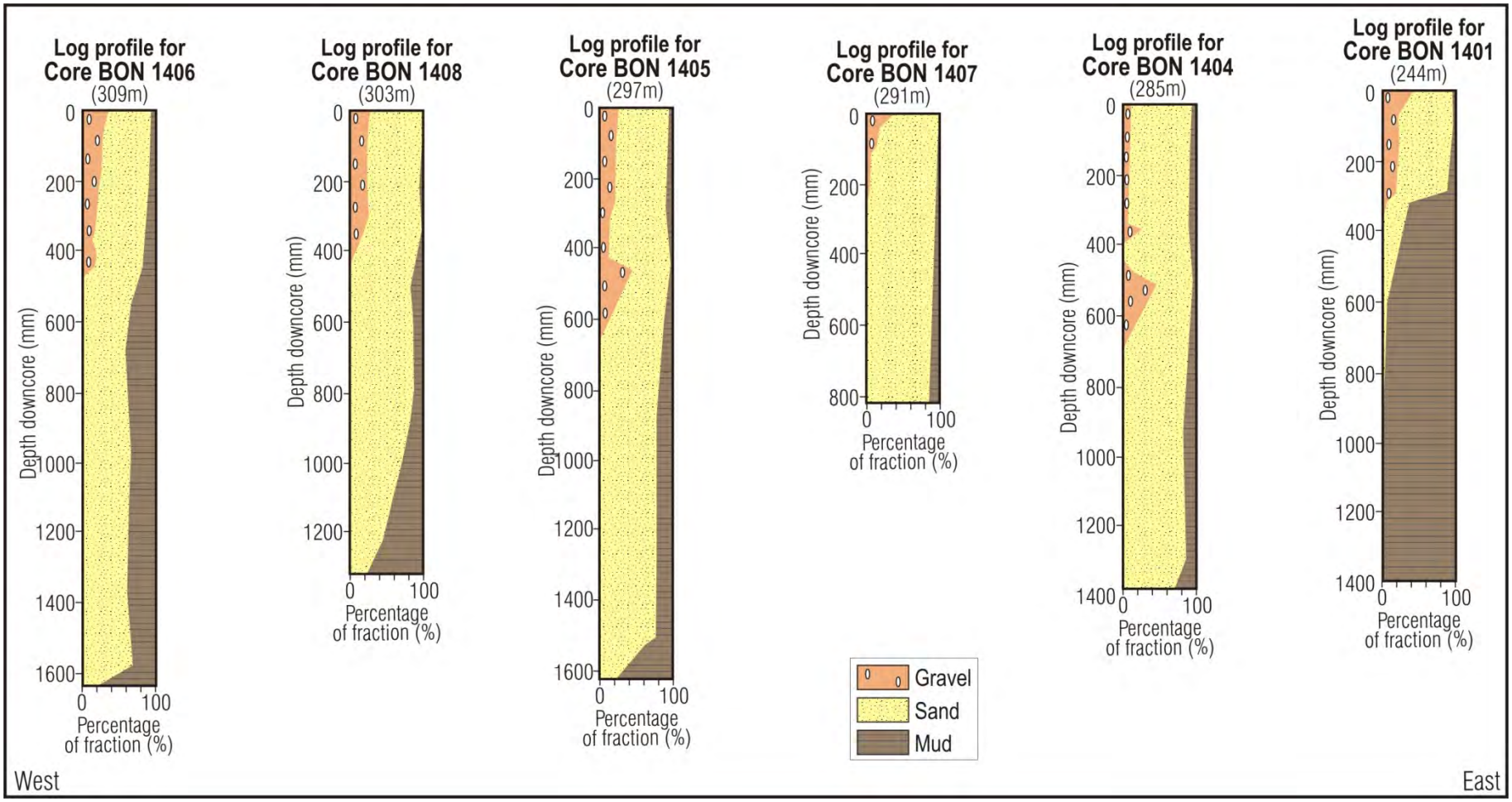


Figure 19b: Grain size profiles of vibrocores from offshore Meob Bay analysed by Bergh (2009) showing overall coarsening upcore.

Although the gravity cores penetrated less than 2 m total thickness, the value of Bergh's 2009 study is that it provides data on the subsurface extent of phosphorite deposits that were previously largely known only from surface samples. The stratigraphy of the area offshore of Conception Bay is shown by a representative core log BON1364 (Figure 20). The basal mud can be divided into a basal clayey mud unit (Unit 5) that is nearly 100% mud with no gravel and less than one percent pelletal phosphorite sand. Although nearly all of the sand in Unit 5 is phosphorite the mud contains <1 wt% sand and therefore < 1 wt% P_2O_5. The basal clayey mud unit grades into a sandy mud to muddy sand unit with between 20 and 80% sand composed of 79-97% pelletal phosphorite grains (Unit 4b). Although the sand fraction is predominantly pelletal phosphorite grains, the sand content of the basal mud and sandy mud to muddy sand of Unit 4b is highly variable and generally low (1-43% in one core; 1-66% in another core). As a result Unit 4b has relatively low grades of 8-20 wt% P_2O_5. The sandy mud to muddy sand unit has an erosional contact with the overlying muddy phosphorite sand unit (Unit 4a) containing 80-90% sand composed of 74-93% pelletal phosphorite grains and bulk sediment grades of 20-24 wt% P_2O_5. An erosional contact separates the underlying muddy phosphorite sand unit from the overlying slightly shelly muddy phosphorite sand unit (Unit 3), which is in turn overlain by a shelly muddy phosphorite sand unit (Unit 2) and a very shelly phosphorite sand unit (Unit 1). These increasingly shell-rich units are separated by erosional contacts. The gravel fraction is mostly composed of mollusc shell with some pebble rock phosphorite. The gravel content, mostly mollusc shell, increases up core from 17 to 52%, the sand content decreases from 78 to 42% and the mud content remains more or less constant at 5-6%. The sand fraction is again dominated by pelletal phosphorite grains, which make up 38-81% of the sand grains. These upper shelly units are on average 0.5 m thick and have bulk sediment grades of 17-21wt% P_2O_5. The lower grade in comparison to the underlying muddy phosphorite sand Unit 4a reflects the dilution by carbonate grains mostly present as mollusc shell fragments as well as variable amounts of foraminifera tests.

© NMP 2014

CORE LOG SHEET

CORE NUMBER: BON 1364 LOGGED BY: Eugene Bergh

LOCATION: SW of Conception Bay DATE: 15 / 07/ 09.

LATITUDE (S): 24°10.859'.. LENGTH OF CORE (mm) 1760

LONGITUDE (E): 14°1.458' DIAMETER (mm) 53

NORTHING (m) 7325390 EASTING (m) 400897 WATER DEPTH (m) 199

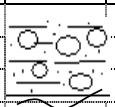
DEPTH (mm)	TEXTURE (%G%S%M)	Lithology	Bed Thickness (mm)	Sampling Interval (mm)	REMARKS, INTERPRETATION, OTHER Description, colour, fossils, samples, readings, etc.
50	msG		190	0-40	0 to 190mm. Very shelly muddy gravel.
100					Phosphorite sand present.
150	gS			150-190	(Matrix) 10YR 1|2. (Shells) 10YR 7|3 Grayish orange
200	gS		330	190-230	190-520mm: Shelly, muddy gravelly phosphate sand.
250					(Matrix) 5YR 2|1; Brownish black
300	sG				(Shells) 10YR 7|3 Grayish Orange
350				330-370	
400					
450	gS			480-520	
500	gM		100	520-540	520-620mm: Slightly shelly muddy phosphate sand.
550					Colour: Brownish black; 5YR 2/1
600	gM		720	600-620	620-1340mm: Phosphate sand
650	msG			620-640	Colour: Brownish black; 5YR 2/1
700					
750					
800	gmS			840-860	
850					
900					
950					
1000					
1050	(g)M			1060-1080	
1100					
1150					
1200					
1250					
1300	(g)M			1320-1340	
1350	M		420	1340-1360	1340-1760mm: Clayey mud.
1400					Colour: Olive gray 5Y 5/1
1450					
1500					
1550	M			1560-1580	
1600					
1650					
1700				1740-1760	
1750	M				
1795					

Figure 20: A representative core log of sediment recovered from offshore Conception Bay Namibia (Bergh, 2009).

© NMP 2014

The stratigraphy of the area offshore Meob Bay is shown by a representative core log BON1405 in Figure 21 (Bergh, 2009). Similar to the Conception Bay core cluster, the basal mud unit can be divided into a basal clayey mud unit composed of 90% mud with no gravel and relatively minor amounts (10%) of pelletal phosphorite sand. The sand content tends to increase upcore within the lower mud unit to become muddy phosphorite sand with 35-82% sand and 18-65% mud and only minor gravel. For example, in core BON1405 (Figure 21), the basal 1 to 1.6 m of core is composed of 40-70% mud and 30-60% sand with the sand composed of 64-96% pelletal phosphorite grains with a bulk sediment grade of 20 wt% P_2O_5. In the same muddy phosphorite sand unit from a depth of 0.5 to 1 m below the seafloor, the composition is 19-32% mud and 68-81% sand composed of 82-96% pelletal phosphorite grains with a bulk sediment grade of 21 wt% P_2O_5. In general, the muddy phosphorite sand in the Meob Bay core cluster contains more mud than in the Conception Bay core cluster. This difference may reflect greater reworking and removal of mud from the Conception Bay cores.

Similar to the Conception Bay core cluster, an erosional contact separates the underlying muddy phosphorite sand unit from the overlying slightly shelly muddy phosphorite sand unit, which is in turn overlain by a shelly muddy phosphorite sand unit and a very shelly phosphorite sand unit. These increasingly shell-rich units are separated by erosional contacts. The gravel fraction is mostly composed of mollusc shell with some pebble rock phosphorite. The gravel content increases from 5 to 24% up core and the sand content decreases from 83 to 72% while the mud content ranges between 4-13%. The sand fraction is dominated by pelletal phosphorite grains, which make up 60-82% of the sand grains. Similar to the Conception Bay area cores, these upper shelly units are on average 0.5 m thick and have bulk sediment grades of 17-21wt% P_2O_5. The lower grade in comparison to the underlying muddy phosphorite sand units reflects the dilution by carbonate shell.

© NMP 2014

CORE LOG SHEET

CORE NUMBER: BON 1408... **LOGGED BY:** Eugene Bergh

LOCATION: West of Meob Bay **DATE:** 14 / 07/ 09.

LATITUDE (S): 24°34.342' **LENGTH OF CORE (mm)** 1360

LONGITUDE (E): 13°48.725' **DIAMETER (mm)** 53

NORTHING (m): 7281900.1 **WATER DEPTH (m)** 303

EASTING (m): 379700.2

DEPTH (mm)	TEXTURE (%G%S%M)	Lithology	Sampling Interval (mm)	Bed Thickness (mm)	REMARKS, INTERPRETATION, OTHER Description, colour, fossils, samples, readings, etc.
50	gS		0-40	300	**0 to 300mm**. Very shelly gravelly phosphate sand.
100					Colour of shells: Greyish yellow 5Y 7/3
150					Colour of sand: Moderate olive brown 5Y 4/3
200					
250	gmS		260-300		
300	gmS		300-320	70	**300-370mm:** Less shelly muddy phosphate sand.
350	gM		350-370	180	**370-550mm:** Slightly shelly muddy phosphate sand.
400	(g)M		370-390		Colour: Olive Black 5Y 2/1.
450					Burrows.
500	(g)M		530-550		
550	(g)M		550-570	660	**550-1210mm:** Mud
600					Colour: Olive Black 5Y 2/1.
650					
700					
750	M		770-790		
800					
850					
900					
950	(g)M		990-1010		
1000					
1050					
1100					
1150	M		1190-1210		
1200	M		1210-1230	150	**1210-1360mm:** Clayey mud
1250					Colour: Light olive grey 5Y 6/2
1300	M		1340-1360		
1350					END

Figure 21: A representative core log of sediment recovered from offshore Meob Bay Namibia (Bergh, 2009)

Similar to the Hikumuah (2008) study, the pelletal phosphorite sand grains show a variety of internal structures such as homogenous, concentric layering and multiple generations of phosphorite growth (Figure 22). Phosphatized bone, shark teeth and phosphatised bioclasts as well as detrital quartz, glauconite and foraminifera are also commonly associated with the pelletal phosphorite grains. The

pelletal phosphorite grains are well sorted and range from fine to coarse sand size with polished dark brown surfaces. Most grains are well rounded to subrounded and range from nearly spherical to ellipsoidal in shape. The dominant mollusc in both areas from the lower shelly layers is the bivalve *Lucinoma capensis* and the dominant mollusc from the uppermost very shelly unit is *Dosinia lupinus*. Other bivalves include *Cardium* sp., *Carditella similis* and *Tellina analogica* and *Pecten* sp. The most abundant gastropods are *Nassarius vinctus* and *Turritella declivis*. Both areas also include abundant foraminifera, most of which are benthic and include *Ammonia japonica* and other species indicative of low oxygen (dysoxic) to no oxygen (anoxic) bottom waters.

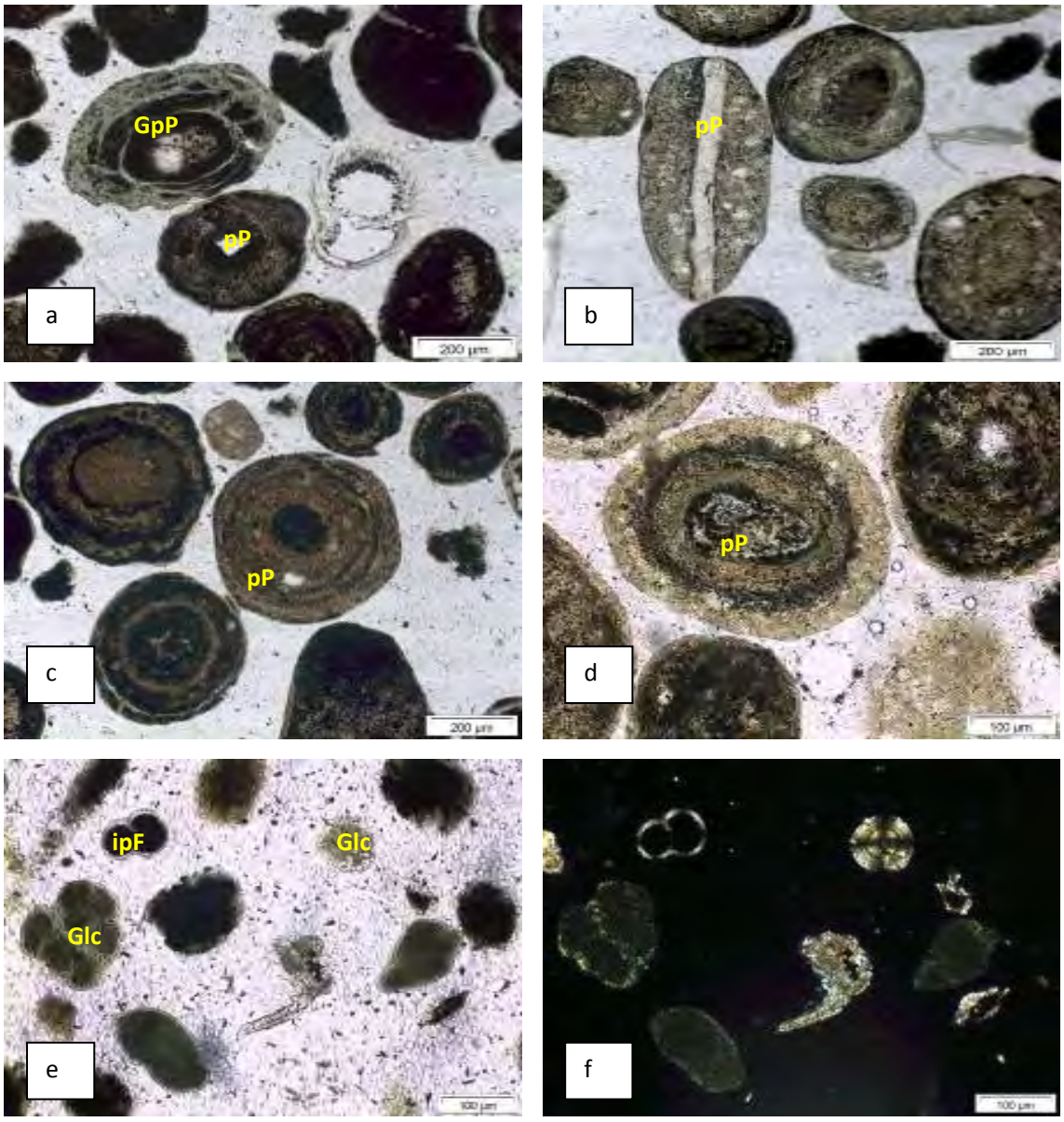


Figure 22: Photomicrographs of polished sections of phosphorite grains (pP pelletal phosphorite, Gl glauconite) from the Namibian shelf offshore of Conception Bay and Meob Bay (Bergh, 2009).

10 STRONTIUM ISOTOPE STRATIGRAPHY (SIS)

As discussed above, strontium isotope stratigraphy **(**SIS) can provide ages for the phosphorite grains and associated grains such as carbonate shell and foraminifera tests. The value of SIS is it can differentiate between when the phosphorite formed and when it was last reworked based on the youngest age of associated biogenic grains (carbonate shell or skeletal phosphorite). Previous to this report, the age of the deposits from offshore Conception Bay and Meob Bay were determined based on the nannofossil (Dingle *et al*., 1996) and foraminiferal assemblages (Bergh, 2009). The lower mud to sandy phosphorite mud unit is considered to be Miocene to Pliocene in age and the overlying shelly phosphorite sands are considered to be Pleistocene to Holocene in age. This is in agreement with the two strontium isotope ages available which indicate phosphorite formation in the Pliocene (4.1-5.8 Ma) and Pleistocene (0.4-1.3 Ma) (McArthur *et al*., 1990; Sr-derived ages updated to the look-up table V4: 08/04 from McArthur *et al*., 2001).

In an attempt to improve upon the existing age model for the Namibian phosphorite deposit grains were selected for strontium isotope analysis from a number of cores recovered from ML 170 (Figure 15). The strategy was to do detailed sampling of the most complete cores available. Core BON1313 was considered the longest and most complete core from the Conception Bay area and core BON1408 was considered the longest and most complete core from Meob Bay area. In addition, the basal sections of three cores (BON1460, 1463 and 1469) from south of the Meob Bay area were sampled for comparison with the two areas to the north. These cores are widely separated within ML 170 and were selected to see how uniform ages were across the area. Samples were selected to provide as complete coverage as possible of the cores available. Core intervals targeted for sampling included the core bases to provide the maximum age of the deposit and across significant lithological boundaries to determine if they correspond to depositional hiatuses. Core samples were further selected for those which had a number of different grain types that could be analysed for strontium, such as skeletal phosphorite (fossil fish bone such as vertebra or fish scales) and biogenic carbonate (foram tests or mollusc shell) to compare with the age of pelletal phosphorite grains. The reason for this strategy is that it was found in previous studies that biogenic carbonate and skeletal phosphorite grains, although not always, tend to be younger than pelletal phosphorite and can provide final depositional ages to complement pelletal and rock phosphorite ages (Compton, 2002; 2004). Not all samples contained enough grains to be sampled, so for some samples only pelletal phosphorite could be analysed. Only the least altered and morphologically similar grains were selected for analysis.

The different grain types were separated from the sand size fraction and thoroughly cleaned of any sediment adhering to the grains to obtain as pure as possible grain separates. For example, it was common to have sediment within foram tests or small pelletal phosphorite grains within the pore spaces of skeletal phosphorite grains and these were removed by washing the sample in an ultrasonic bath until the grains could be seen to be clean of any extraneous material. The separate grain type samples were then submitted to the isotope analytical facility at UCT where the samples were digested in concentrated nitric acid. After digestion, the acid was separated from the insoluble residue (organic matter, quartz, clay minerals, pyrite and other substances that did not dissolve in the nitric acid). The strontium dissolved in the acid was separated using cation exchange resin columns and run on a Nu multicollector ICP-MS to measure the ^{87}Sr to ^{86}Sr ratio. The within run precision on single measurements of a sample ranged from ±8 to ±16 $x10^{-6}$ (2 sigma error) and sample reproducibility was $\pm 39x10^{-6}$ based on 17 replicates of an internal UCT carbonate standard Namaqualand Marble 95 (NM95).

© NMP 2014

The age of the samples was obtained from the Sr look-up table (V4: 08/04) after subtracting 0.000007 to adjust for the National Institute of Standards and Technology (NIST) Standard Reference Material 987 value of 0.710248 used by McArthur *et al*. (2001). The use of the Sr isotope ratio to determine the age of the phosphorite or carbonate grains assumes that the Sr ratio reflects that of ambient seawater at the time of grain formation and that the Sr ratio has not altered since it was incorporated into francolite, the principal mineral of phosphorite, or calcite of mollusc shells and forams. Mollusc shell and foraminifera tests are assumed to precipitate directly from seawater and phosphorite grains are assumed to have formed very near the seabed with a Sr isotope ratio essentially the same as contemporaneous seawater. Additional sources of Sr, from for example clay minerals included in the pelletal phosphorite grains, is not considered to be significant because the Sr content of francolite is so much higher (on the order of 1-2 wt%) than other Sr-bearing minerals that may have dissolved and only minor amounts of other Sr-bearing minerals, such as illite and mica, are present in the phosphorite samples analysed (< 10 wt%).

A total of 36 samples were analysed for strontium isotopes and the results are listed in Table 1 in the Annexure 1 along with photomicrographs of all the samples analysed. Table 1 includes the age range for both the within run precision which varies for each sample between ±8 to ±16 $x10^{-6}$ (2 sigma error) and sample reproducibility of the standard NM95 of ±$39x10^{-6}$. The age is determined from the corresponding Sr isotope ratio independently determined for seawater, with the minimum age corresponding to the minimum Sr ratio of the seawater curve and the maximum age corresponding to the maximum Sr ratio of the seawater curve (Figure 23). The age range using sample reproducibility of ±$39x10^{-6}$ is greater than the age range using within run precision for each sample between ±8 to ±16 $x10^{-6}$. The uncertainty depends primarily on the steepness of the seawater strontium isotope curve with Pleistocene ages back to 2.6 Ma less uncertain than Pliocene ages between 2.6 and 5.3 Ma owing to the fact that the Sr isotope seawater curve flattens out in the Pliocene (2.6 to 5.3 Ma) and then steepens in the Pleistocene (Figure 23). Similarly the age resolution from the late Oligocene to mid Miocene (25 to 15 Ma) is better than from the mid Miocene to the late Miocene.

The Sr derived ages range from mid to late Miocene to Recent (Holocene). The two oldest samples are biogenic carbonate from the base of core BON1408 with foram tests having a middle Miocene age (9.9-14.5 Ma) and associated mollusc shell fragments having a late Miocene age (7.6-11.2 Ma). The remaining 34 samples are Pliocene or Pleistocene in age. Note that the Pliocene/Pleistocene boundary has been changed relatively recently from 1.81 Ma to 2.59 Ma, such that in the older literature the late Pliocene is now part of the early Pleistocene. Only 2 of the 29 phosphorite samples (both pelletal and skeletal grains) are Pliocene in age (2.2 to 6 Ma); 10 are Plio/Pleistocene in age (1 to 5 Ma) and 17 are Pleistocene in age (0-2.6 Ma). Most of the cores analysed have a Pleistocene depositional age (<2.6 Ma) with the possible exception of the base of core BON1313 and BON1408 which have Plio/Pleistocene age ranges of 1.6-5.5 Ma and 1-3.5 Ma, respectively. In general, the Sr-derived ages become younger up-core.

© NMP 2014

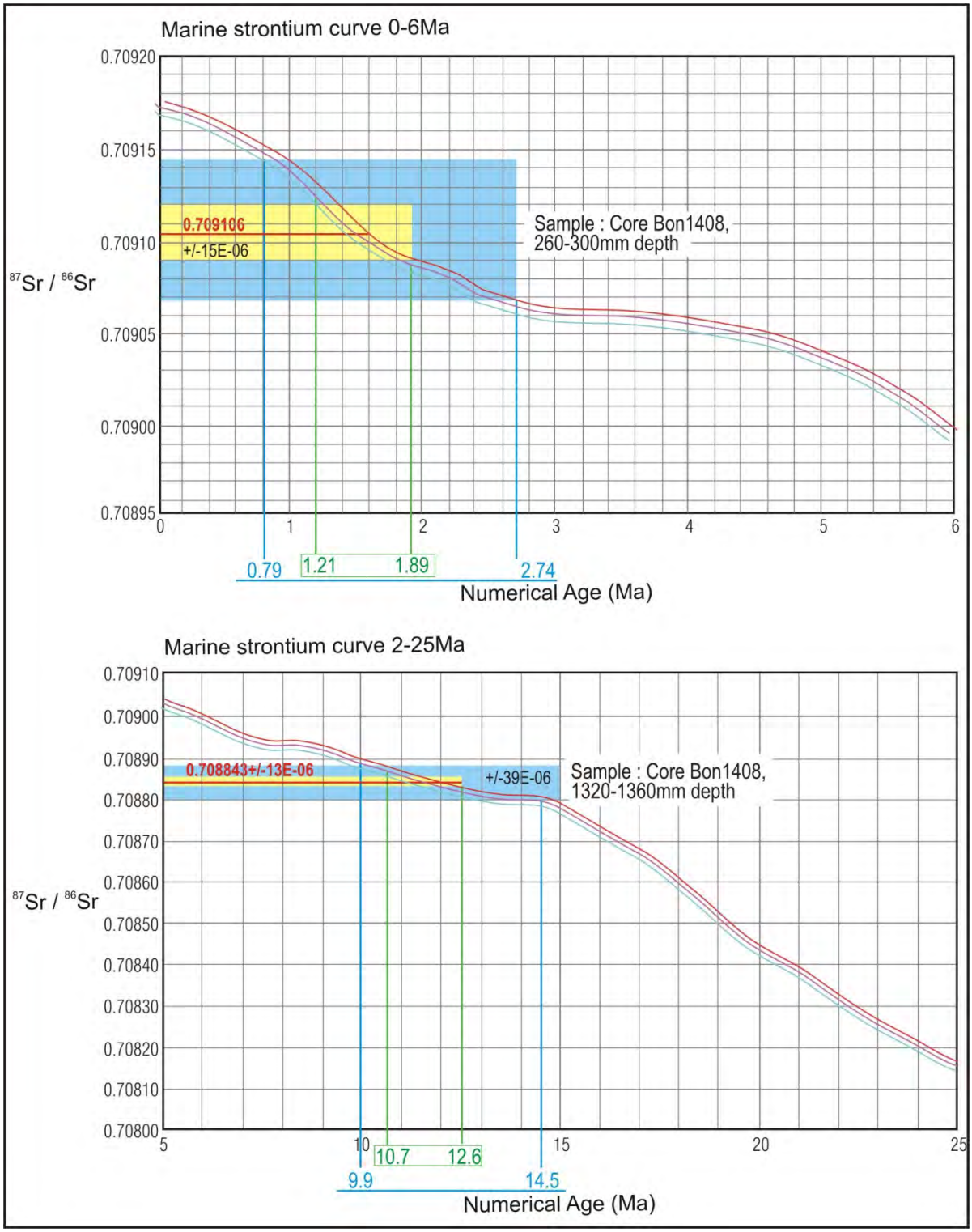


Figure 23: Strontium Isotope Curves.

The marine (seawater) curve of the strontium-87 to strontium-86 ratio for the periods 0 to 6 Ma and from 5 to 25 Ma (McArthur *et al.*, 2001; look up table V4: 04:08). The method used to determine the Sr ages of the samples is shown for the within run precision (green) and for the reproducibility of the internal standard NM95 (blue).

© NMP 2014

11 STRONTIUM ISOTOPE STRATIGRAPHY (SIS) OF CORES BON1313, BON1408 AND BON1460/1463/1469

The stratigraphy of core BON1313 (Figure 24) is similar in most respects to the core BON1364 (Figure 20) and representative of the stratigraphy of the area offshore of Conception Bay. The basal mud is divided into a basal clayey mud unit (Unit 5) that is nearly 100% mud with no gravel and less than one percent pelletal phosphorite sand. Although nearly all of the sand in Unit 5 is phosphorite, the mud contains <1 wt% sand and therefore < 1 wt% P_2O_5. The basal olive gray clayey mud of Unit 5 can therefore be considered uneconomic. The age of Unit 5 in BON1313 based on the Sr isotope ratio of the small amount of phosphorite sand is between 1.6 and 5.5 Ma (Plio-Pleistocene). There is a fairly abrupt transition to the overlying muddy phosphorite sand of Unit 4. The basal sample from Unit 4 has 2% gravel (very fine phosphorite pebbles), 76% sand and 22% mud. The sand is composed of >80% pelletal phosphorite grains having an age of 0.5 to 2.3 Ma and includes fish scales with a Sr age of 1.3 to 5.1 Ma and skeletal phosphorite with an age of 0.6 to 2.4 Ma. Unlike core BON1364, the composition of Unit 4 is fairly consistent with between 1-2% gravel, 74-80% sand and 19-25% mud and is not divided into subunits 4a and 4b. Skeletal phosphorite from the top of Unit 4 indicates a Pleistocene age (0-1.5 Ma) associated with older pelletal phosphorite (1.2-4.8 Ma) and phosphorite pebbles ((1.4-5.2 Ma). The basal and top ages indicate an early to middle Pleistocene age for Unit 4. The transition from Unit 4 to Unit 3 is marked by an increase in gravel present mostly as shell fragments but also with some phosphorite pebbles. The skeletal, pelletal and fine pebble phosphorite from Unit 3 all indicate a similar Pleistocene age of 0.6 to 2.5 Ma. The shell content increases from 10% to 32% in Unit 2 where shell fragments from the top of Unit 2 have an age of 0-1.1 Ma and are associated with pelletal phosphorite with an age of 0.8 to 2.7 Ma. The shell content increases to 49% in the overlying Shelly Phosphorite Sand of Unit 1. The stratigraphy of core BON1408 (Figure 25) is similar in most respects to the core BON1405 (Figure 21) and representative of the stratigraphy of the area offshore Meob Bay. Similar to the Conception Bay core cluster, the basal mud unit can be divided into a basal clayey mud unit composed of 90% mud with no gravel and relatively minor amounts (10%) of pelletal phosphorite sand. Only a relatively small amount of Unit 5 was recovered in core BON1408 composed of 91% mud and 9% sand. The pelletal phosphorite sand has a Sr age of 1.0-3.5 Ma, the skeletal phosphorite has a Sr age of 1.5-5.4 Ma, shell fragments 7.6-11.2 Ma and foram tests 9.9-14.5 Ma. This sample represents an interesting exception to the rule with biogenic carbonate grains significantly older than, as opposed to younger than, associated phosphorite grains. These older biogenic carbonate grains are interpreted to be reworked from underlying Neogene calcareous ooze which has been documented elsewhere on the Namibian slope (Wefer *et al*., 1998), but is rarely exposed on the outer shelf (Bremner, 1977). The erosional contact with the overlying Unit 4 is associated with a marked increase in sand content to 34-36% sand mostly pelletal phosphorite having Sr derived ages of 1-4 Ma and 1.4-5.2 Ma. These basal samples could be considered part of the muddier Unit 4b with Unit 4a marked by an increase in sand to 62-84%. Shell fragments from the top of Unit 4a have an age of 0-1.1 Ma, associated skeletal phosphorite 0.8-2.7 Ma and pelletal phosphorite 1.1–4.7 Ma. The overlying Unit 3 is marked by an increase in gravel from <1% to 3-4% with shell fragments and associated phosphorite pebbles from the top of Unit 3 having a Sr age of 0.8-2.6 Ma and associated pelletal phosphorite 1.1-4.1 Ma. The shell gravel content of Unit 2 increases to 7-15% and ranges from 10% at the base of Unit 1, where shell fragments have an age of 0-1.4 Ma, associated pelletal phosphorite are 0.2-1.9 Ma and phosphorite pebbles are 0.8-2.7 Ma, to 18% shell gravel at the top of Unit 1 where shell fragments are 0-0.1 Ma and associated pelletal phosphorite is 0.2-1.9 Ma.

© NMP 2014

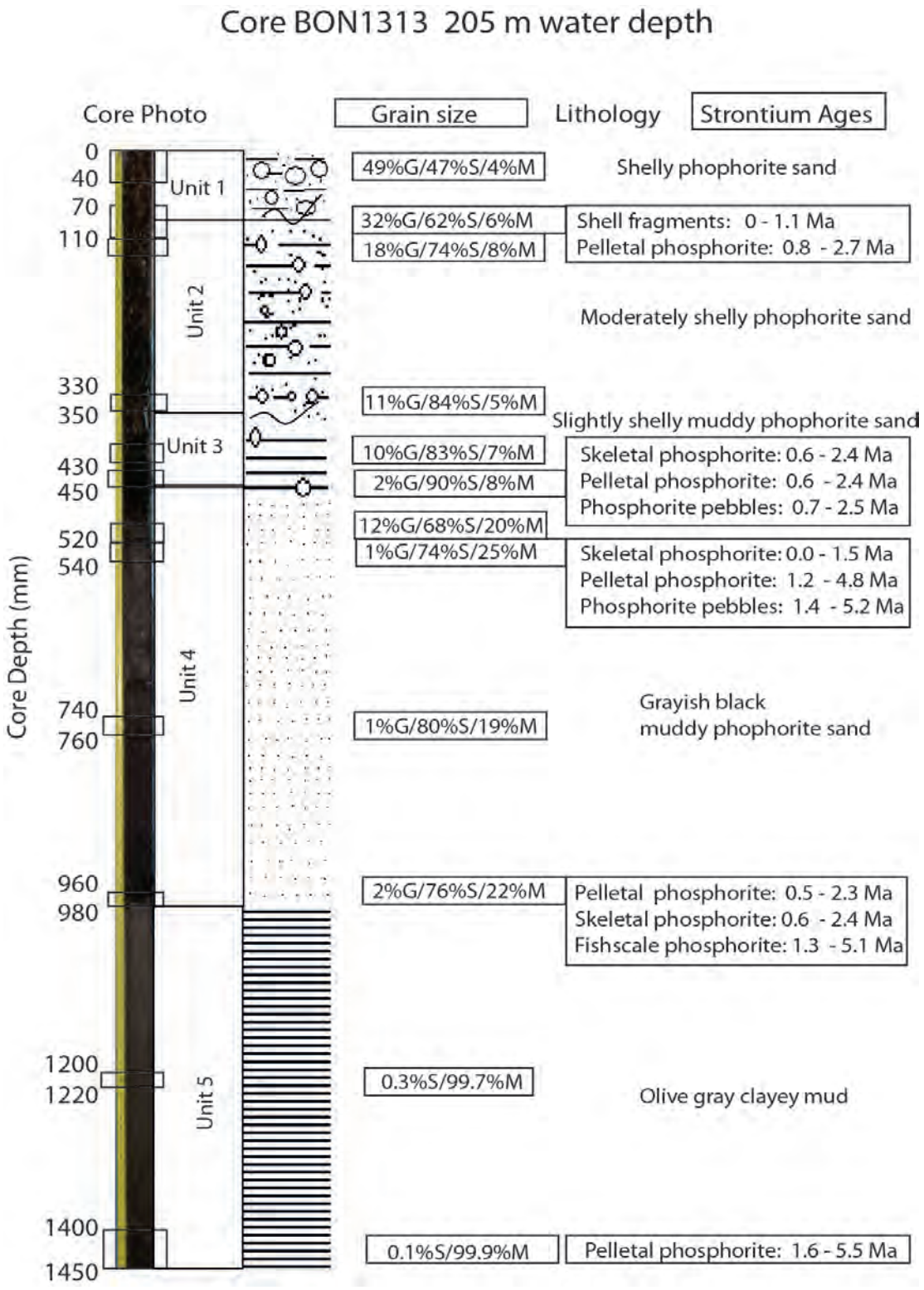


Figure 24: Stratigraphy of Core BON1313
from Bergh (2009) including Sr ages.

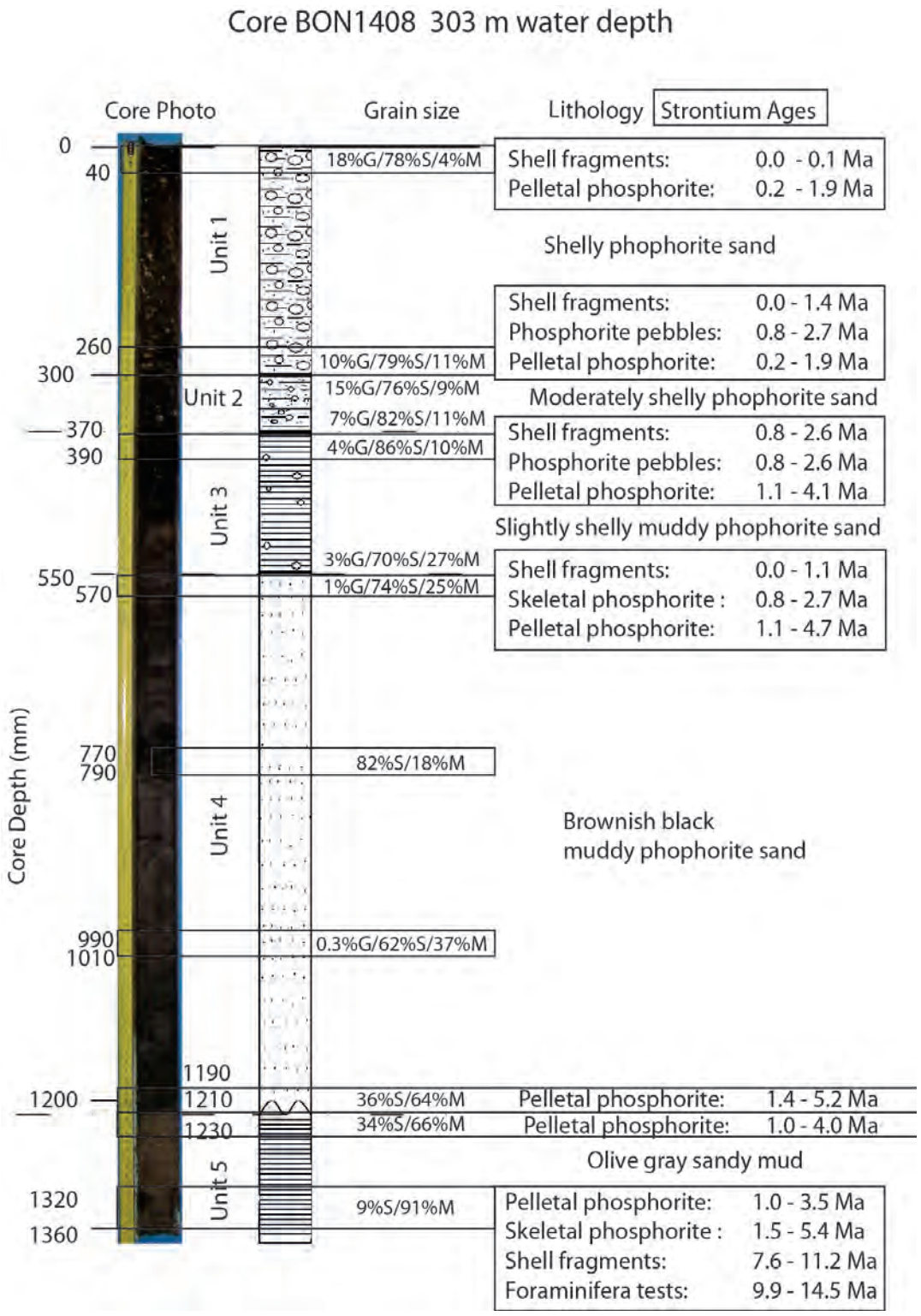


Figure 25: Stratigraphy of Core BON1408
from Bergh (2009) including Sr ages.

The stratigraphy of the three cores BON 1460-1463-1469 (Figure 26) located to the south of the Meob Bay core cluster (Figure 15) are largely similar and reflect the overall stratigraphy of the Meob Bay cores (Figs. 21 and 25). Cores BON 1460-1463-1469 did not recover Unit 5 but only penetrated into Unit 4, the base of which in all three cores was lighter in colour than the overlying Unit 4 grayish black muddy phosphorite sand (Figure 26). Only the basal lighter coloured Unit 4a of these three cores were analysed for Sr isotopes. The Sr isotope derived ages of the basal sediment recovered from the shallowest water (216 m water depth) core BON 1469 are 0-1.2 Ma for skeletal phosphorite and 0.3-2 Ma for pelletal phosphorite. The skeletal and pelletal phosphorite from the basal sediment recovered in core BON1460 at 245 m water depth are 0.4-2.2 Ma and 0.6-2.4 Ma, respectively. The Sr derived ages for the basal sediment from core BON1463 in 252 m water depth range from 0.7-2.5 Ma for skeletal phosphorite and 2.2-6 Ma for both fine (<125 um) and coarse (>500 um) pelletal phosphorite grains. The abundance of Sr-derived pelletal phosphorite ages centred on the Pleistocene is consistent with the observation of early Pleistocene foraminifera tests included within the pelletal phosphorite grains (Figure 17).

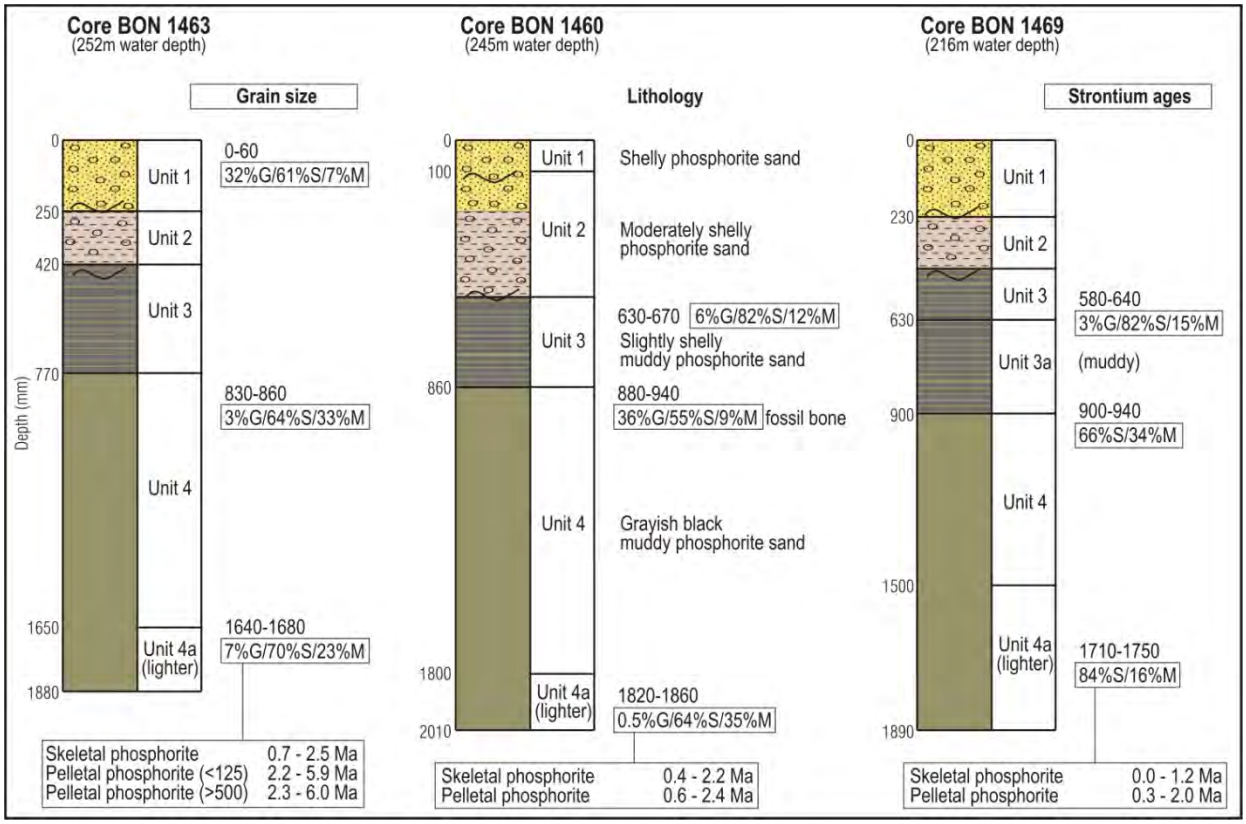


Figure 26: Stratigraphy of Cores BON1463, 1460 and 1469 including Sr ages.

© NMP 2014

12 AN IDEALISED COMPOSITE STRATIGRAPHY FOR ML 170

An idealised composite stratigraphy (Figure 27) is proposed on the basis of the stratigraphy of vibracores described from sites offshore of Conception Bay and Meob Bay (Figs. 20-21 and 24 – 26; Bergh, 2009). The proposed composite stratigraphy consists of a basal terrigenous mud (Unit 5) that is considered non economic with phosphorite sand contents generally less than 1 wt%. Unit 5 would form the hypothetical footwall of the mining area. The relatively large grain size of the few well disseminated phosphorite sand grains in Unit 5 suggest that they may be in place and not reworked. The phosphorite grains within Unit 5 have a Plio-Pleistocene Sr derived age and a likely Pliocene age consistent with the available foram biostratigraphy (Bergh, 2009). The maximum thickness of Unit 5 is uncertain but the maximum recovered is 0.5 m. Unit 5 can contain reworked middle to late Miocene biogenic grains (calcareous shells and foraminifera tests) indicating the occurrence, at least in places, of Miocene calcareous sediment (Unit 6) below the Pliocene terrigenous mud of Unit 5. Above the basal non economic mud of Unit 5 is a muddy phosphorite sand of Unit 4. The contact between units 5 and 4 is generally an abrupt increase in sand content and is interpreted to be an erosional contact. Unit 4 appears to have a maximum thickness of approximately 1 m with the lower 0.5 m having a sand content of 40 to 68 wt% composed of 64-96% pelletal phosphorite grains (Unit 4b) that grades up into an upper 0.5 m having a greater average sand content of 68 to 80 wt% composed of 82-96% pelletal phosphorite grains (Unit 4a) (Figure 27). The thickness and phosphorite sand content of the muddy phosphorite sand unit can be highly variable based on the Meob Bay cluster of cores on which it is modelled. Unit 4a would be considered economic with 19-24wt% P_2O_5, but may grade into the less economic intervals of Unit 4b down section before entering the noneconomic mud of Unit 5. The depositional age of Unit 4 is proposed to range from early Pleistocene (2.6 Ma) to between 1 and 0.63 Ma spanning the transition from the early to middle Pleistocene at 0.78 Ma.

The muddy phosphorite sand of Unit 4 can have a gradational to sharp erosional contact with the overlying shelly phosphorite sand unit. The transition is marked by an increase in the gravel content associated with the appearance of shell fragments. The shelly phosphorite sand can usually be divided into three units based on the overall coarsening upward succession as the shell content increases. Overlying Unit 4 is the only slightly gravelly Unit 3 with <10% gravel. Unit 3 grades into Unit 2 which has between 10-25% shell gravel. Unit 2 grades into Unit 1 which contains between 30-60% shell gravel. Almost all of the cores show this trend of increasing shell gravel content at the expense of sand and more or less constant mud content of 4-6%. The age of Unit 3 is considered to range from between 1 to 0.63 Ma and the age of Unit 2 from 0.63 to 0.02 Ma and Unit 1 <0.02 Ma. These ages are not well constrained but are argued based largely on the sea level record (see below). Units 1-3 are economic but generally less so than Unit 4a owing to the dilution of the phosphorite sand by carbonate shell and foram tests. The mollusc shells become less fragmented with fresh, articulated molluscs confined to the uppermost 100 to 200 mm of sediment. There is evidence in some cores of multiple erosional surfaces within the shelly phosphorite sand units 1-3 which together have a mean total thickness of between 0.3 and 0.9 m.

© NMP 2014

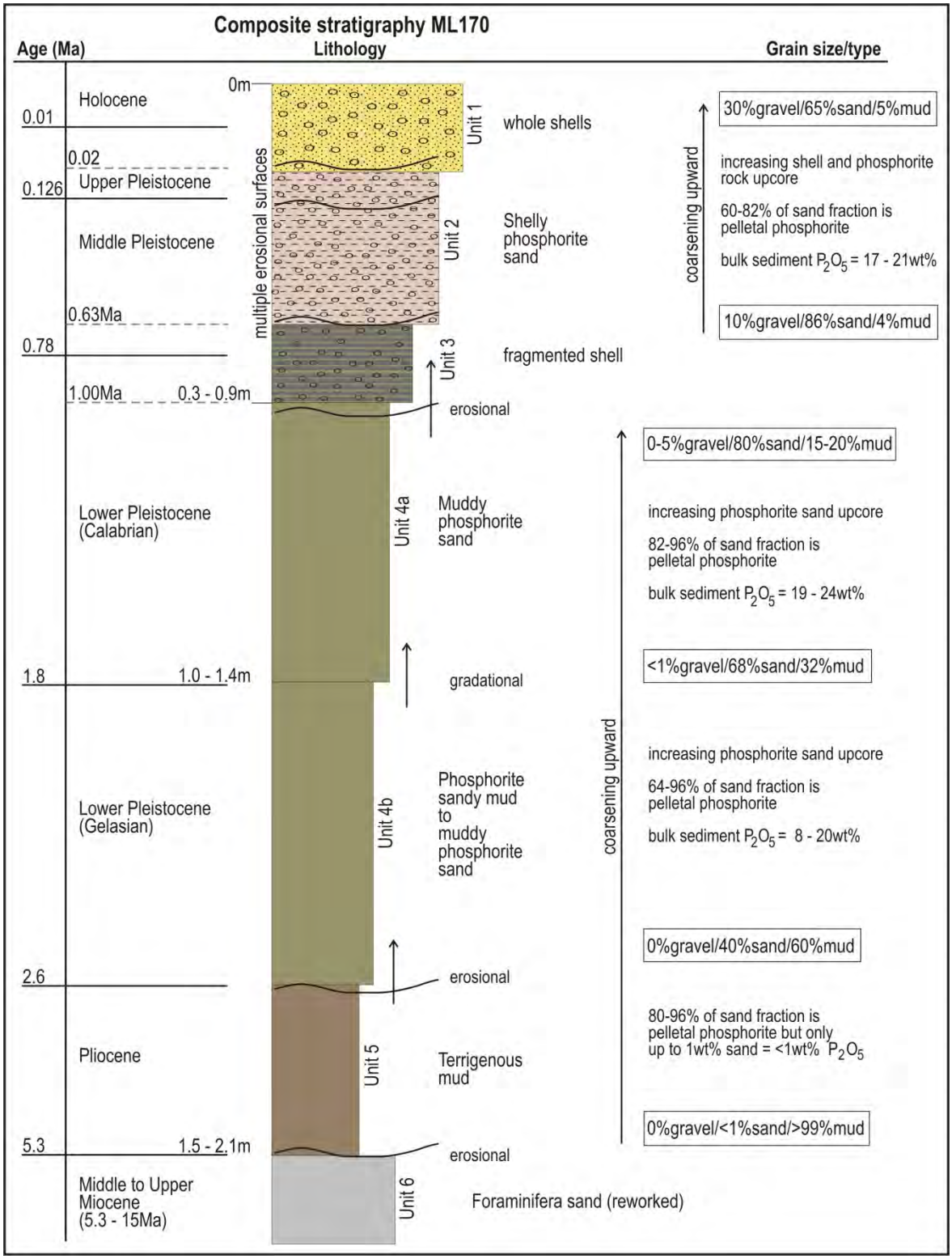


Figure 27: A proposed idealised stratigraphy for ML 170 based on the stratigraphy of cores from offshore Conception Bay and Meob Bay documented by Bergh (2009).

13 A DEPOSITIONAL AND DIAGENETIC HISTORY FOR ML 170

A depositional and diagenetic history is proposed here based on the stratigraphy, petrography and Sr-derived ages of cores recovered from ML 170. The depositional history of the Namibian shelf is argued here to largely reflect changes in sea level, both the relative height of sea level and the amplitude and frequency of sea-level fluctuations. Global, eustatic sea level is inferred primarily from the oxygen isotope composition of the deep ocean as recorded by benthic foraminifera corrected for changes in deep ocean temperatures (Miller *et al*., 2005; Bintanja *et al*., 2005; Bintanja and van der Wal, 2008). The stack of global oxygen isotope records of benthic foraminifera (Lisiecki and Raymo, 2005) reveals that Pliocene sea levels were consistently high and fluctuations were of low amplitude (Figure 28). Deposition of the terrigenous mud Unit 5 is interpreted to have occurred during this interval of relatively high Pliocene sea level, a period during which there was no major marine regressions to suspend and rework the Pliocene mud off the shelf. The Pliocene to Pleistocene boundary at 2.59 Ma is associated with the initial build up of ice sheets in the Northern Hemisphere and the onset of significant sea-level fluctuations. Sea-level fluctuations between 2.6 and 1 Ma included lowstands on the order of 60 to 80 m below present day. The phosphorite sandy mud to muddy phosphorite sand of Unit 4 is interpreted to have been deposited during the early Pleistocene between 2.6 and approximately 1 Ma. During this period, the amplitude of sea level fluctuations was sufficient to periodically suspend and rework mud off the shelf to concentrate a residual lag deposit enriched in sand sized grains. From 1 Ma the amplitude of sea-level fluctuations started to increase and reached the maximum amplitude by 0.63 Ma associated with the glacial period of Marine Isotope Stage (MIS) 16. The transition from Unit 4 with only minor amounts of gravel to Unit 3 having up to 10% shell gravel is interpreted to correspond to the transition to increased amplitude of sea-level fluctuations from 1 to 0.63 Ma. The multiple erosional surfaces and coarsening upward succession from Unit 3 to Unit 1 are interpreted to correspond to the last 0.63 Ma when large amplitude sea-level fluctuations occurred on Milankovitch 100 kyr cycles. The age of units 1-3 are difficult to assign but the presence of whole and some articulated molluscs in Unit 1 suggest that it was last reworked during the Last Glacial Maximum (MIS2) from 28 to 18 thousand years ago (28-18 ka) with deposition since 18 ka associated with the marine transgression to the Holocene interglacial highstand.

Therefore, the overall coarsening upward succession since the Pliocene can be viewed as the result of a lowering of global sea level and, more significantly, the result of increasingly large amplitude variations in sea level from the build up and wasting of ice sheets in the Northern Hemisphere. As the volume of ice held in the ice sheets increased and the maximum drop in sea level approached 130 m, energy dissipation on the shelf increased and allowed for mud to be reworked off the shelf to concentrate the coarser sediment fraction. The sand fraction of the sediment was largely made up of pelletal phosphorite grains which were retained and concentrated on the middle to outer shelf to form the phosphorite rich deposits observed today.

© NMP 2014

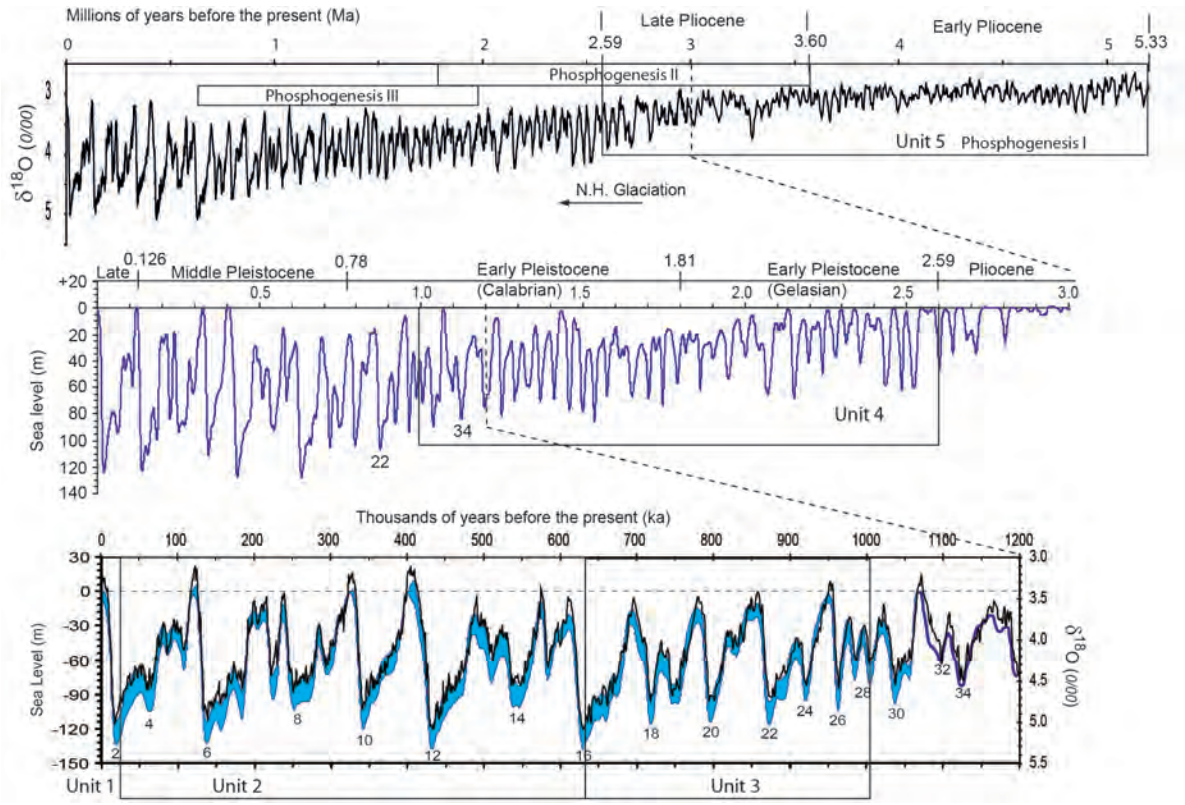


Figure 28: Relation of deposition and phosphogenesis in ML 170 to sea level since the Pliocene (top figure of the oxygen isotope composition of benthic forams stack from Lisiecki and Raymo, 2005; sea level curve for the last 3 Myr (middle) from Bintanja and van der Wal, 2008 and for the last 1.2 Myr (bottom) from Bintanja *et al*., 2005). Even numbers refer to glacial periods of maximum ice volume and minimum sea level.

The pelletal phosphorite grains are proposed to have formed during relative highstands of the sea in organic-rich mud deposited on the inner to middle shelf by analogy to the phosphorite documented to be forming in the present day, interglacial highstand (Holocene) diatomaceous mud belt (Baturin, 2000). In the transition from interglacial to glacial periods and for the duration of glacial maxima, the organic rich mud deposits of the inner to middle shelf were physically reworked, suspended in the water column and removed from the shelf by bottom currents. Suspension and dispersal of the organic-rich mud will preferentially remove mud sized material in the deposit and leave behind only sand sized phosphorite grains, glauconite sand grains, detrital quartz sand grains and calcareous shell and phosphate skeletal material to accumulate and become concentrated on the seafloor. Some of the phosphorite may have been transported out of the inner shelf and some may have originally formed on the middle to outer shelf where it has accumulated from repeated sediment reworking by wave base energy, shelf break internal wave dissipation and bottom currents (Monteiro *et al*., 2005; Inthorn *et al*., 2006; Compton and Wiltshire, 2009). When glacial periods terminated and sea level rose rapidly the reworked pelletal phosphorite sands were bypassed or overlain by the next highstand organic-rich mud deposits and phosphorite formation was renewed either as new phosphorite grains or as a new layer on concentrically banded pelletal phosphorite grains (Figs. 18 and 22). If such sea-level cycles are repeated over a long enough period of time, then an economic phosphorite deposit may form and this is the most likely model for understanding how the phosphorite deposits have accumulated on the middle to outer Namibian shelf.

© NMP 2014

Initiation of phosphorite formation on the margin appears to coincide with the establishment of coastal upwelling along the Namibian shelf extending as far north as the Walvis Ridge (Figure 3). The onset of cold water upwelling is documented to have occurred during the Plio/Pleistocene transition and the organic carbon content, diatom abundance and sea surface temperature records all indicate a particularly large increase in upwelling from the Pliocene into the Pleistocene from 2.6 Ma, the onset of Northern Hemisphere glaciation and large-scale sea-level fluctuations (Figure 29) (Wefer *et al*., 1998; Lange, 1999; Marlow *et al*., 2000). The much expanded Pliocene to Recent record recovered on the upper slope at Site 1084 indicates the transition from Pliocene calcareous nannofossil ooze to increasingly diatomaceous ooze having high organic carbon content in the Pleistocene (Figure 29) (Wefer *et al*., 1998). Much of the organic matter, diatoms and terrigenous clay at Site 1084 may have been derived from suspension and reworking of mud off the shelf resulting in the highly condensed 2 m thick succession on the outer shelf compared to the 600 m thick succession on the upper slope (Figure 30). The Pliocene deposits on the shelf are interpreted to have consisted of a mixture of carbonate foraminiferal sands and terrigenous muds similar to what is observed today (Bremner, 1977), but upwelling intensity was relatively weak and phosphorite formation was limited in extent with only 2 out of the 29 phosphorite samples having a Pliocene age (Phosphogenesis episode I; Figure 28). With the onset of Northern Hemisphere glaciation, the global climatic cycles and upwelling along the Namibian margin intensified; an event marked in the cores by the erosional contact between only slightly phosphatic (<1 wt% phosphorite) terrigenous Pliocene mud of Unit 5 and increasingly phosphatic early Pleistocene sandy mud of Unit 4. Upwelling appears to have continued to have intensified throughout the Pleistocene based on the increase in organic carbon and diatom content (Figure 29) as well as more phosphorite grains (Phosphogenesis episodes II and III; Figure 28). The Pleistocene sediment record in ML 170 on the outer shelf from 2.6 to 0.6 is a variable mixture of clay-rich and sand-rich units and perhaps reflects variation in the extent of reworking during the Pleistocene related to sea-level fluctuations.

The coarsening upward trend in mollusc gravel and sand content appears to coincide with the onset of large-amplitude sea-level fluctuations from around 900 to 600 ka. The multiple erosional cycles in the uppermost gravel unit and the concentric banding of the pelletal phosphorite grains are interpreted to reflect this high frequency (every 100 kyr) and high amplitude (130 m) fluctuations in sea level well established by 700 to 600 ka with the MIS16 glacial lowstand. The overall lowering of global, eustatic sea level since the Pliocene with the onset of Northern Hemisphere glaciation circa 2.7 million years ago has resulted in an erosional shelf environment which has allowed for the concentration of older phosphorite grains in younger reworked deposits. The Pleistocene is characterized by 9 major sea level cycles over the last 900,000 years (Figure 28) and these appear to have been very effective in generating the natural beneficiation process necessary to end up with the phosphorite-rich deposits on the Namibian shelf.

© NMP 2014

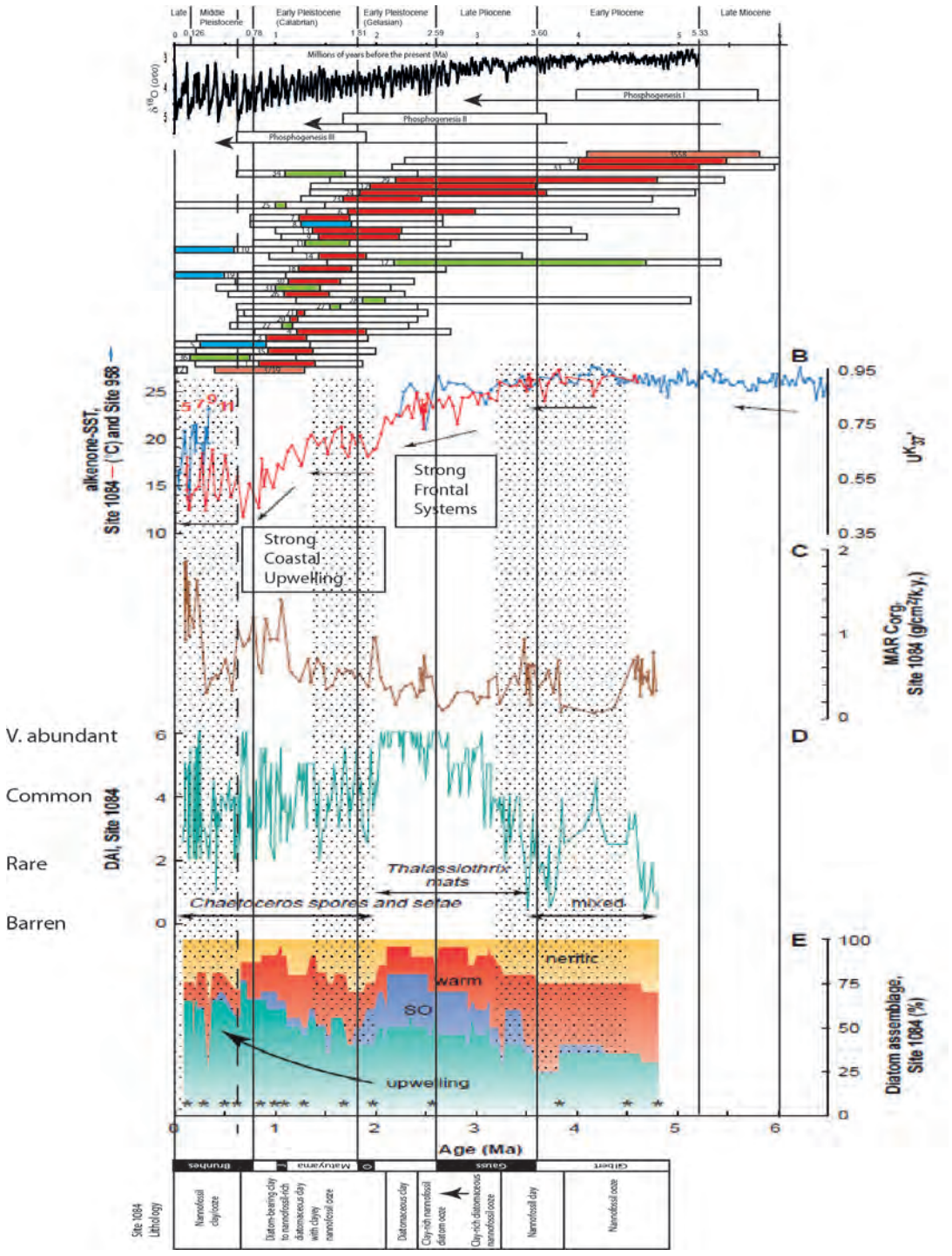


Figure 29: A comparison of the Sr-derived ages of phosphorite and calcareous shell. Pelletal phosphorite (red), skeletal phosphorite (green) and calcareous shell (blue) samples from ML 170 to the sea level record (oxygen isotope proxy sea level record, the sea surface temperature (SST) record based on alkenones, the mass accumulation rate (MAR) of total organic carbon, the Diatom Abundance Index (DAI) and the diatom assemblage all from ODP Site 1084 (Marlow *et al.*, 2000) as well as the lithology and magnetostratigraphy of Site 1084 (Wefer *et al.*, 1998).

© NMP 2014

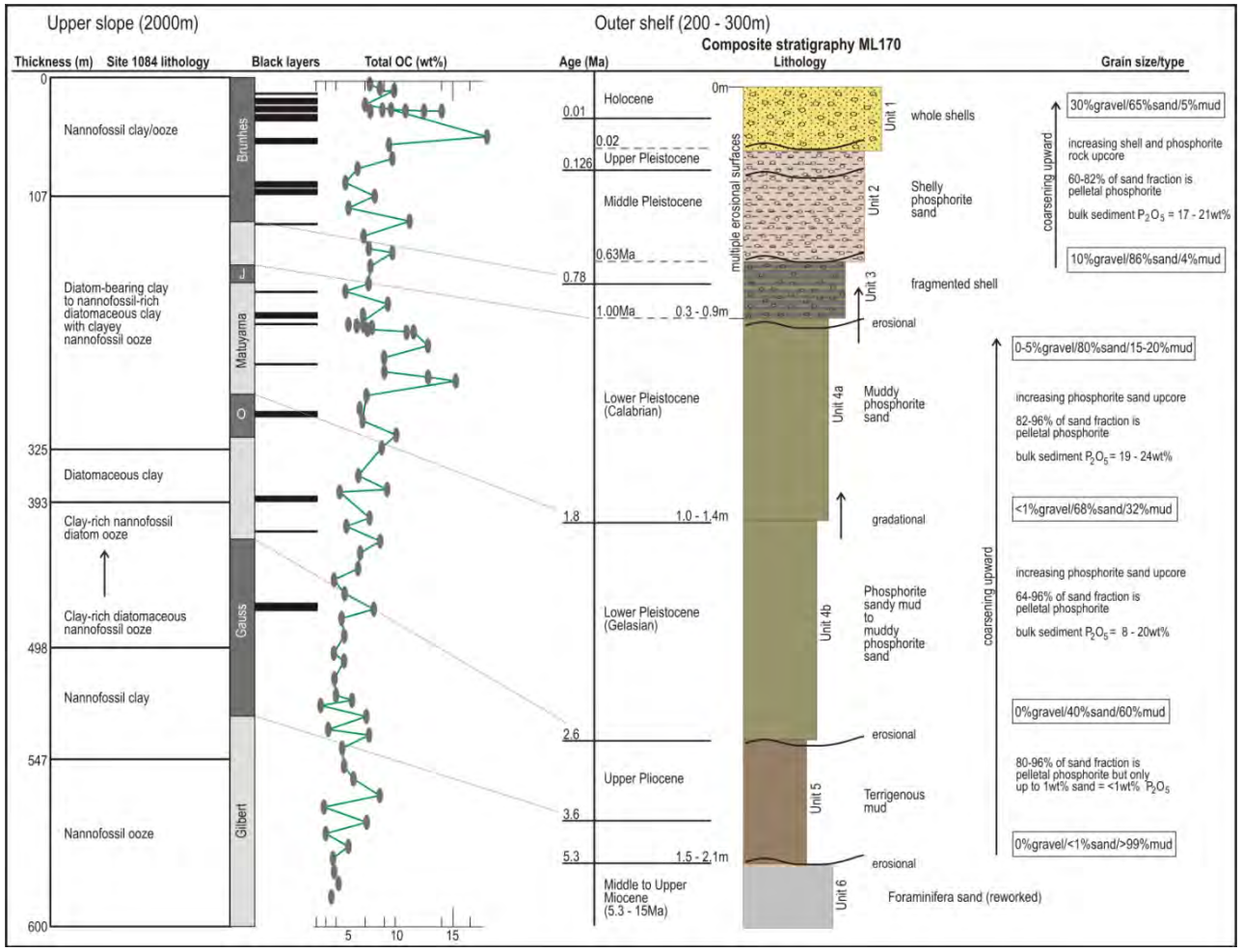


Figure 30: Comparison of the Pliocene to Pleistocene 600 m thick succession.
Recovered from the upper slope at ODP Site 1084 (Wefer *et al.*, 1998) to the 2 m thick equivalent composite succession on the Namibian outer shelf (200-300 m water depth).

Outside of the basal reworked middle to late Miocene bioclastic grains in core BON1408, the pelletal phosphorite grains are as old or older than the associated skeletal phosphorite and bioclastic grains. This is consistent with the reworking of the pelletal phosphorite grains into younger deposits. The bulk of the phosphorite grains (17 out of 29) are between 2.6 and 0.6 Ma and suggest that the major period of phosphogenesis occurred in the early Pleistocene (Phosphogenesis episode III; Figure 28). This interpretation is supported by the early Pleistocene increased coastal upwelling, abundance and type of diatoms present and the mass accumulation rate of organic carbon at Site 1084 on the upper slope offshore of ML 170 (Figure 29) (Wefer *et al*., 1998; Lange, 1999; Marlow *et al*., 2000). It seems odd that there are not more phosphorite grains younger than the early Miocene (<0.78 Ma) given that concretionary phosphorite is well documented from the modern diatom mud belt on the inner shelf. The samples analysed for Sr isotopes included several dozen individual pelletal phosphorite grains (refer to the Appendix) some of which have concentric layering (Figs. 18 and 22).

Therefore, the Sr ages represent a mean age of all the grains within the sample. Concentric banding of phosphorite on some grains clearly indicates multiple generations of phosphorite formation and it remains unclear how different in age these layers are from one another as well as the difference in age among individual grains from the same sample. For example, phosphorite pebbles from the shelf off the Orange River were found to have late Miocene aged cores and Pleistocene aged outer rims (Compton *et al*., 2002). Hence, the ages obtained here may represent an averaging of phosphorite formation from the early to late Pleistocene. To help resolve this issue, the Sr dating technique will need to be applied to individual grains and to different internal grain structures to determine what the true time span of phosphogenesis was on the Namibian shelf. Such fine scale dating should be possible with the use of laser ablation techniques made possible by the relatively high Sr content of the phosphorite grains.

The age of phosphorite from the Namibian shelf is markedly different from the phosphorite from the South African shelf. Most of the phosphorite on the South African shelf from Cape Columbine to the Orange River is late Oligocene to late Miocene in age (26 to 6 Ma) and the majority of the phosphorite is late Oligocene to early Miocene in age (26 to 21 Ma) (Compton *et al*., 2002; 2004). This age distribution pattern suggests that upwelling and phosphorite formation shifted from the south to the north, starting in the south in the latest Oligocene and continuing through the late Miocene but then shifting to the Namibian shelf by the Pliocene and intensifying during the early Pleistocene to the present day. The Namibian shelf is particularly suitable for economic phosphorite deposition from the combination of intense upwelling conditions to support primary production and low coarse sediment influx with most mud easily suspended and removed during the high energy dissipation on the margin during sea level lowstands. The shelf is starved of detrital quartz sand as the rivers are minor and ephemeral. The only time significant detrital sand is delivered to the inner shelf is when it is exposed during sea-level lowstands and the Namib Desert dunes extend over the present day inner shelf. These sands are transported by longshore drift to the north of the Orange River and are wind blown onto land. The majority of these dune sands would be reworked and recycled back onto land as sea level rose during marine transgressions but some would be bypassed and retained on the inner shelf. For example, the modern day diatomaceous mud belt is interpreted to rest upon relict lowstand dune sands off Walvis Bay (Bremner, 1977). The result has been a large phosphorite production naturally beneficiated by the dynamics of sediment reworking and concentration of the phosphorite in highly condensed surficial deposits on the seabed ideally suited for mining.

© NMP 2014

14 CONCLUSIONS

The phosphorite deposits on the middle to outer shelf of Namibia represent truly impressive reserves of phosphorus, an essential element for plant productivity and much needed as a fertilizer to increase agricultural yields to feed a rapidly growing global population. The surficial extent of phosphorite-rich seabed sediment was mapped out early on in the 1960s and 1970s, but it has only been with the recovery of sediment cores that the true extent and nature of the phosphorite deposit has been revealed. Clusters of cores recovered from offshore Conception Bay and Meob Bay on the middle to outer shelf (150-350 m water depth) within Namibian Marine Phosphate's Mining Licence 170 indicate a highly condensed, 1-2 m thick fairly uniform Plio/Pleistocene sediment succession containing between 17 and 24 wt% P_2O_5. The application of Strontium Isotope Stratigraphy in combination with existing biostratigraphy has allowed a preliminary depositional and diagenetic model to be developed for the phosphorite deposit of ML 170. The age resolution possible using Sr isotopes is limited during the Plio/Pleistocene, but it does provide new insights into the age of these deposits and can be improved in future with more detailed individual grain analysis.

The major event that led to the formation of the phosphorite deposit was an increase in coastal upwelling along the Namibian margin which was initiated as early as the Mio/Pliocene but intensified during the Pleistocene in response to global climate change. Increased coastal upwelling delivered nutrients such as phosphorus to the surface where primary productivity captured it as organic matter to initiate the northern Benguela Upwelling System. Burial of the organic remains of diatomaceous and nannofossil algal blooms in shelf sediments resulted in the microbial degradation of the organic matter, release of the phosphorus to the pore waters and precipitation of the phosphorus-bearing mineral carbonate fluorapatite as concretionary and small pelletal phosphorite grains. These relatively hard sand to fine pebble sized phosphorite grains formed during early diagenesis as disseminated grains in the organic rich mud, which then became concentrated as a lag deposit during lowered sea levels when energy dispersion on the shelf increased and preferentially suspended and removed the organic-rich mud off the shelf. The repeated cycle of sea level fluctuations resulted in the alternate formation and then reworking of the shelf phosphorite deposits to result in the natural benefaction of the phosphorite into an economic deposit. Pelletal phosphorite grains as old as Pliocene as well as Plio/Pleistocene occur but the vast majority of phosphorite appears to have formed during the early Pleistocene between 2.6 and 0.63 Ma, a period marked by the onset of cold water upwelling off Namibia and increasing amplitude of sea-level fluctuations with the onset of Northern Hemisphere glaciation.

The highest grade phosphorite deposits are associated with Unit 4 whose bulk muddy phosphorite sands contain an average of between 19-24 wt% P_2O_5. However, the phosphorite content is variable within Unit 4 and can decrease to between 8-20 wt% P_2O_5 before its basal erosional contact with underlying Pliocene terrigenous mud or middle to late Miocene calcareous sediment containing <1wt% P_2O_5. The muddy phosphorite sand of Unit 4 varies between 0.3 and 1 m in thickness before it grades into the overlying shelly phosphorite sand of Units 1-3. Units 1-3 contain less phosphorite from the increasing carbonate shell fragment content with bulk sediment containing on average 17-21 wt% P_2O_5. The coarsening upward succession can be understood in terms of the overall lowering of global sea level and the increasing amplitude of sea-level fluctuations particularly over the last 1 Ma.

© NMP 2014

15 REFERENCES

Baturin, G. N. 1969. Authigenic phosphate concentrations in Recent sediments of the South West African shelf. *Dokl. Earth Sci. Sect. English Transl.* **189**: 227-230.

Baturin, G.N. 2000. Formation and evolution of phosphorite grains and nodules on the Namibian shelf, from Recent to Pleistocene. *Marine Authigenesis: From Global to Microbial, SEPM Special Publication,* **66:** 185-199.

Baturin, G.N. 2002. Nodular Fraction of Phosphatic Sand from the Namibia Shelf. *Lithology and Mineral Resources*, **37(**1)1–17.

Bergh, E., 2009. Stratigraphy of potentially economic late Cenozoic pelletal phosphorite sediments from the Namibian outer shelf between Lüderitz and Walvis Bay. Unpublished Honours thesis, Department of Geological Sciences, University of Cape Town, 127pp.

Bintanja, R., van de Wal, R.S.W., Oerlemans, J., 2005, Modelled atmospheric temperatures and global sea levels over the past million years. *Nature* **437:** 125-128.

Bintanja, R., van de Wal, R.S.W., 2008. North American ice-sheet dynamics and the onset of 100,000-year glacial cycles. *Nature* **454:** 869-872.

Birch, G.F., 1975. Sediments on the continental margin off the West Coast of South Africa. Unpubl PhD. thesis, University of Cape Town.

Birch, G.F., 1979. The nature and origin of mixed apatite/glauconite pellets from the continental shelf off South Africa. *Marine Geology* **29:** 313-334.

Birch, G. F. 1990. Phosphate deposits on the South African continental margin and coastal terrace. In W.C. Burnett and S.R. Riggs, Eds., *Phosphate Deposits of the World, vol. 3: Neogene to Recent Phosphorites*. Cambridge: Cambridge University Press, pp. 153-158.

Birch, G. F., Thomson, J., McArthur, J.M. and Burnett, W.C. 1983. Pleistocene phosphorites off the west coast of South Africa. *Nature* **302:** 601-603.

Bremner, J. M. 1977. Sediments on the continental margin off South West Africa between Sylvia Hill and the Kunene River. Unpubl PhD. thesis, University of Cape Town.

Bremner, J. M. 1980. Concretionary phosphorite from S.W. Africa. *J. Geol. Soc. Lond.* **137**: 773-786.

Bremner, J. M. 1981. Shelf morphology and surficial sediment off central and northern South West Africa. *Geo-Marine Letters* **1**: 91-96.

Bremner, J. M. 1992. Brief description of a West Coast Phosphatic Deposit. Marine Geoscience Unit internal report.

Bremner, J.M. and Rogers, J., 1990. Phosphorite Deposits on the Namibian Continental Shelf. In W.C. Burnett and S.R. Riggs, Eds., *Phosphate Deposits of the World, vol. 3: Neogene to Recent Phosphorites*. Cambridge: Cambridge University Press, pp. 143–152.

Carr, M-E., 2002. Estimation of potential productivity in Eastern Boundary Currents using remote sensing. *Deep-Sea Res. Part II* **49:** 59-80.

Carr, M.-E., and E.J. Kearns, 2003. Production regimes in four Eastern Boundary Current systems. *Deep-Sea Res. Part II* **50:** 3199-3221.

© NMP 2014

Coles, S. K. P., Wright, C. I., Sinclair, D. A. and Van den Bossche, P. 2002. The potential for environmentally sound development of marine deposits of potassic and phosphatic minerals offshore, southern Africa. *Marine Georesources & Geotechnology*, **20(**2): 87-110.

Compton, J.S., Mallinson, D., Glenn, C.R., Filippelli, G., Follmi, K., Shields, G. and Zanin, Y. 2000. Variations in the global phosphorus cycle. . *Marine Authigenesis: From Global to Microbial, SEPM Special Publication,* **66:** 1-11.

Compton, J.S., Harris, C., and Thompson, S., 2001. Pleistocene dolomite from the Namibian shelf: High 87Sr/86Sr and 18O values indicate an evaporative, mixed-water origin. *Journal of Sedimentary Research* **71:** 800-808.

Compton, J.S., Mulabisana, J., McMillan, I.K., 2002. Origin and age of phosphorite from the Last Glacial Maximum to Holocene trangressive succession off the Orange River, South Africa. *Marine Geology* **186:** 243-261.

Compton, J.S., Wigley, R. and McMillan, I. 2004. Late Cenozoic phosphogenesis on the western shelf of South Africa in the vicinity of the Cape Canyon. *Marine Geology* **206:** 19-40.

Compton, J.S. and Wiltshire, J.G., 2009. Terrigenous sediment export from the western margin of South Africa on glacial/interglacial cycles. *Marine Geology* **266:** 212-222.

Dingle, R.V., 1974. Agulhas Bank phosphorites: a review of 100 years of investigation. *Trans. Geol. Soc. S. Afr.* **77:** 261-264.

Dingle, R.V., Bremner, J.M., Giraudeau, J., and Buhmann, D., 1996. Modern and Paleo-Oceanographic Environment under Benguela Upwelling Cells Off Southern Namibia, *Palaeogeogr., Palaeoclimatol., Palaeoecol.* **123** (1–4): 85–105.

Eckardt F. D. and Kuring, N., 2005. SeaWiFS identifies dust sources in the Namib Desert. *International Journal of Remote Sensing* **26**: 4159–4167.

Hendey, Q.B. and Dingle, R.V., 1989. Onshore sedimentary phosphate deposits in southwestern Africa. In A.J.G. Notholt, R.P. Sheldon and D.F. Davidson, Eds., *Phosphate Deposits of the World, vol. 2: Phosphate rock resources*. Cambridge: Cambridge University Press, 200–206.

Hikumuah, M., 2008. A Comparative Study of Pelletal Phosphorite in the Outer Shelf off Namibia with Pelletal Phosphorite at Langebaanweg, South Africa. Unpublished Honours thesis, Department of Geological Sciences, University of Cape Town, 105 pp.

Inthorn, M., 2006. Lateral particle transport in nepheloid layers – a key factor for organic matter distribution and quality in the Benguela high-productivity area. Berichte, Fachbereich Geowissenschaften, Universität Bremen, No. 244, 124 pages, Bremen.

Inthorn, M., Wagner, T., Scheeder, G., Zabel, M., 2006. Lateral transport controls distribution, quality, and burial of organic matter along continental slopes in high-productivity areas. *Geology* **34:** 205-208.

Jarvis, I., Burnett, W.C., Nathan, Y., *et al.*, 1994. Phosphorite Geochemistry: State of the Art and Environmental Concerns, *Eclogae Geol. Helv.* **87**(3): 643–700.

Lange, C.B., Berger, W.H., Lin, H.-L., Wefer, G., and Shipboard Scientific Party Leg 175, 1999. The early Matuyama Diatom Maximum off SW Africa, Benguela. *Marine Geology* **161:** 93–114.

Lisiecki, L. E., Raymo, M. E., 2005. A Pliocene-Pleistocene stack of 57 globally distributed benthic ^{18}O records. Paleoceanography 20, PA1003, doi:10.1029/2004PA001071.

© NMP 2014

Mallinson D. and Compton, JS. 1998. The influence of iron sulfide oxidation on the sulfur isotope analysis of Miocene phosphorites from Florida, USA. *Geochimica et Cosmochimica Acta* **62:** 3689-3694.

Marlow,J.R., Lange, C.B., Wefer, G., and Rosell-Mele, A., 2000. Upwelling intensification as

part of the Pliocene-Pleistocene climate transition. *Science* **290:** 2288-2291.

McArthur, J.M., Benmore, R.A., Coleman, M.L., Soldi, C., Yeh, H.W. and O'Brien, B.W., 1986. Stable isotopic characterisation of francolite formation. *Earth and Planetary Science Letters* **77:** 20-34.

McArthur J. M., Sahami, A. R., Thirlwall, M., Hamilton, P. J. and Osborn, A. O. 1990. Dating phosphogenesis with strontium isotopes. *Geochimica et Cosmochimica Acta* **54:** 1343-1351.

McArthur J. M., Howarth, R. J. and Bailey, T. R. 2001. Strontium Isotope Stratigraphy: LOWESS Version 3: Best Fit to the Marine Sr-Isotope Curve for 0–509 Ma and Accompanying Look-up Table for Deriving Numerical Age. *The Journal of Geology* **109:** 155–170.

Miller, K.G., Kominz, M.A., Browning, J.V., Wright, J.D., Mountain, G.S., Katz, M.E., Sugarman, P.J., Cramer, B.S., Christie-Blick, N., Pekar, S.F. 2005. The Phanerozoic Record of Global Sea-Level Change. *Science* **310:** 1293-1298.

Monteiro, P.M.S., Nelson, G., van der Plas, A., Mabille, E., Bailey, G.W., Klingelhoeffer, E., 2005. Internal tide – shelf topography interactions as a forcing factor governing the large-scale distribution and burial fluxes of particulate organic matter (POM) in the Benguela upwelling system. *Continental Shelf Research* **25:** 1864-1876.

Murray, J., and Renard, A. F., 1891. Report on the deep sea deposits based on specimens collected during the voyage of the HMS *Challenger: Report on the scientific results of the exploring voyage of HMS* Challenger *1873-1876*, pp. 391-400 London: Her Majesty's Stationary Office. (http://www.19thcenturyscience.org/HMSC/HMSC-Reports/1891-DeepSeaDeposits/htm/doc.html)

Nelson, G., 1989. Poleward motion in the Benguela area. In: Neshbya, A.J, Mooers, C.N.K., Smith, R.L., Barber, R.T. (Eds.), *Poleward Flows along Eastern Ocean Boundaries, Coastal and Estuarine Studies*. Springer-Verlag, New York **34:** 110-130.

Roberts, L., 2011. Population: Special Report. *Science* **333:** 540-543.

Rogers, J., 1977. Sedimentation on the continental margin off the Orange River and the Namib Desert. Unpubl PhD. thesis, University of Cape Town.

Rogers, J., and Bremner, J.M., 1991. The Benguela Ecosystem. Part VII. Marine-geological aspects. In M. Barnes (Ed.) *Oceanography and Marine Biology Annual Reviews*, **29:** 1-85.

Rossouw, J., 1984. Review of existing wave data, wave climate and design waves for South African snd South West African (Namibian) coastal waters. Report CSIR Stellenbosch, T/SEA 8401, 1-66.

Roux, E.H., De Jager, D.H., Du Plooy, J.H., Nicotra, A., Van der Linde, G.J. and De Waal, P., 1989. Phosphate in South Africa. *J. South African Inst. Min. Metall.*, **89:** 129-139.

Senin, Yu.M., 1970. Phosphorus in Bottom Sediments on the Shelf of Southwestern Africa, *Litol. Polezn. Iskop.*, **1**: 11–27.

Shannon, L.V., Nelson, G., 1996. The Benguela: Large scale features and processes and system variability. In: G. Wefer, W.H. Berger, G. Siedler and D.J. Webb, Eds, *The South Atlantic: Present and Past Circulation*. Springer-Verlag, Berlin Heidelberg, pp. 163-210.

© NMP 2014

Siesser, W.G., 1980. Late Miocene origin of the Benguela Upwelling System off northern Namibia. *Science* **208:** 283-285.

Summerhayes, C.P., Birch, G.F., Rogers, J. And Dingle, R.V. 1973. Phosphate in sediments off South-western Africa. *Nature* **243:** 509-511.

Thomson, J., Calvert, S.E., Mukherjee, S., Burnett, W.C. and Bremner, J.M., 1984. Further studies of the nature, composition and ages of contemporary phosphorite from the Namibian Shelf. *Earth and Planetary Science Letters* **69:** 341-353.

Watson, A.C. 1930. The Guano Islands of Southwestern Africa. *Geographical Review* **20**: 631-641.

Wefer, G., Berger, W.H., Richter, C., *et al*., 1998. *Proc. ODP, Init. Repts.,* 175: College Station, TX (Ocean Drilling Program), 12. Site 1084, 339-384.

Wigley, R.A., 2005. Sedimentary facies from the head of the Cape Canyon: insights into the Cenozoic evolution of the western margin of South Africa. Unpublished PhD thesis, Department of Geological Sciences, University of Cape Town, 289 p.

Wigley, R.A., Compton, J.S., 2006. Late Cenozoic evolution of the outer continental shelf at the Head of the Cape Canyon, South Africa. *Marine Geology* **226:** 1-23.

Wigley, R., Compton, J.S., 2007. Oligocene to Holocene glauconite-phosphorite grains from the Head of the Cape Canyon on the western margin of South Africa. *Deep-Sea Research Part II* (**54**): 1375-1395.

© NMP 2014

Annexure: 1. Summary of SR analyses of Samples discussed in this Report

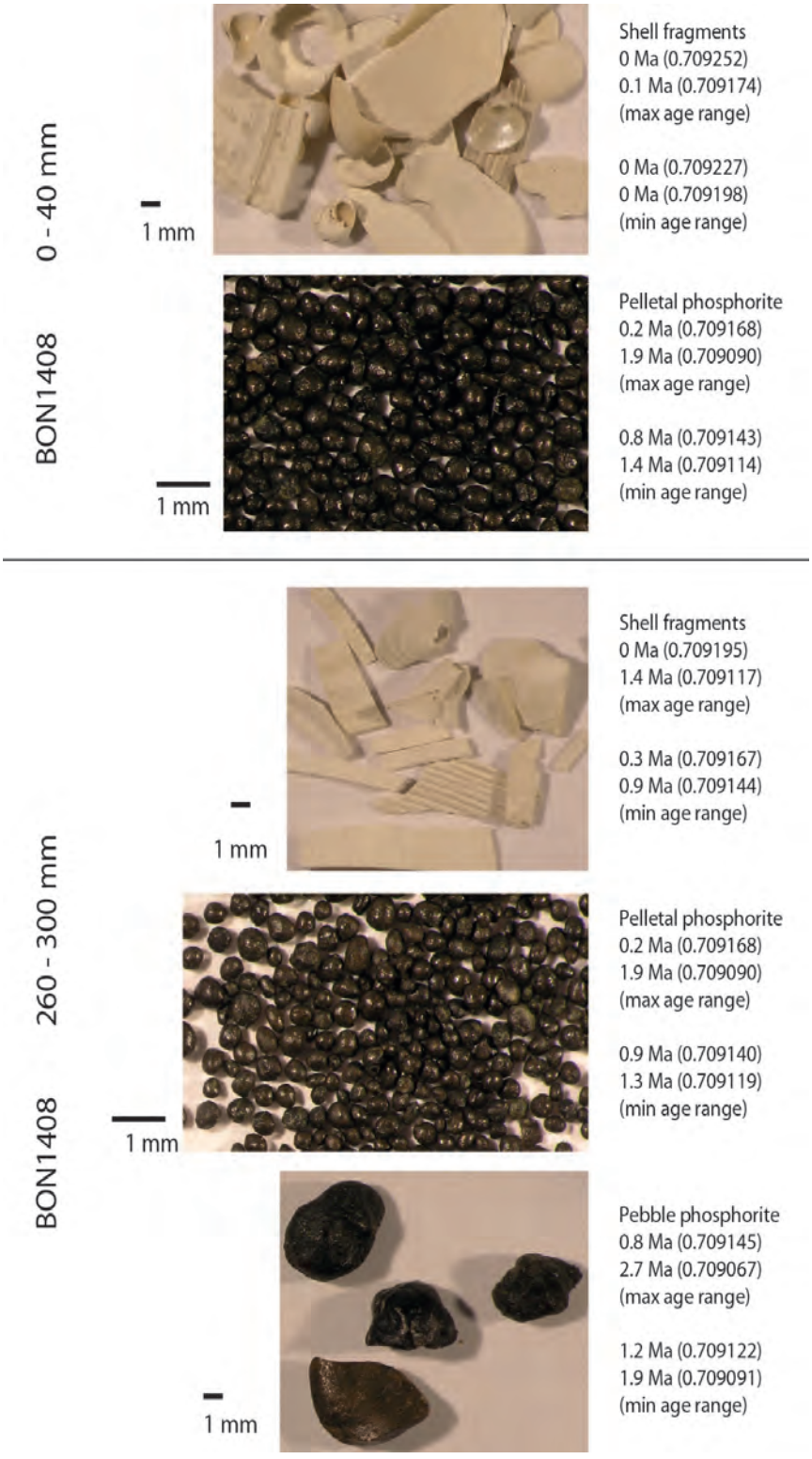
No.	Core	Sample (mm)	Sample description	Photo #	mass (mg)	87/86 Sr	2sigma	87/86 adj NIST987	87/86 min	87/86 max	Age min (Ma)	Age max (Ma)	87/86 min	87/86 max	Age min (Ma)	Age max (Ma)
	Meob Bay North Cluster															
1	Bon1408	0-40	Pelletal phosphorite (>250)	417/8	25	0.709136	14	0.709129	0.709114	0.709143	0.84	1.39	0.709090	0.709168	0.23	1.90
2	Bon1408	0-40	Shell fragments (fresh)	419/20	22	0.709220	14	0.709213	0.709198	0.709227	0.00	0.00	0.709174	0.709252	0.00	0.13
3	Bon1408	260-300	Pelletal phosphorite (>250)	421/2	33	0.709136	10	0.709129	0.709119	0.709140	0.91	1.32	0.709090	0.709168	0.23	1.92
4	Bon1408	260-300	4 Large grain phoshorite (3mm max)	423/4	35	0.709113	15	0.709106	0.709091	0.709122	1.21	1.89	0.709067	0.709145	0.79	2.74
5	Bon1408	260-300	Shell fragments	425/6	25	0.709163	12	0.709156	0.709144	0.709167	0.26	0.93	0.709117	0.709195	0.00	1.35
6	Bon1408	370-390	Pelletal phosphorite (>250)	427/8	24	0.709084	13	0.709077	0.709064	0.709090	1.74	2.99	0.709038	0.709116	1.29	5.01
7	Bon1408	370-390	8 Large grain phoshorite (3.5 mm max)	429/30	8	0.709115	12	0.709108	0.709096	0.709120	1.24	1.74	0.709069	0.709147	0.75	2.64
8	Bon1408	370-390	Shell fragments	431/2	24	0.709115	10	0.709108	0.709098	0.709118	1.26	1.70	0.709069	0.709147	0.75	2.64
9	Bon1408	550-570	Pelletal phosphorite (>250)	433/4	21	0.709101	13	0.709094	0.709081	0.709106	1.43	2.23	0.709055	0.709133	1.05	4.09
10	Bon1408	550-570	Shell fragments	435/6	16	0.709177	11	0.709170	0.709159	0.709180	0.00	0.59	0.709131	0.709209	0.00	1.16
11	Bon1408	550-570	Skeletal (amber)	437/8	12	0.709113	9	0.709106	0.709096	0.709115	1.30	1.74	0.709067	0.709145	0.79	2.74
12	Bon1408	1190-1210	Pelletal phosphorite (>250)	439/40	25	0.709079	13	0.709072	0.709059	0.709084	1.94	3.58	0.709033	0.709111	1.35	5.17
13	Bon1408	1210-1230	Pelletal phosphorite (>250)	441/2	39	0.709102	15	0.709095	0.709080	0.709110	1.37	2.26	0.709056	0.709134	1.03	3.95
14	Bon1408	1320-1360	Pelletal phosphorite (>250)	443/4	19	0.709106	8	0.709099	0.709091	0.709106	1.43	1.89	0.709060	0.709138	0.96	3.46
15	Bon1408	1320-1360	Shell fragments (weathered)	445/6	30	0.708902	15	0.708895	0.708880	0.708910	9.00	10.40	0.708856	0.708934	7.57	11.23
16	Bon1408	1320-1360	Forams (benthic/planktic mix)	447/8	21	0.708850	13	0.708843	0.708830	0.708857	10.72	12.59	0.708804	0.708882	9.93	14.46
17	Bon1408	1320-1360	Skeletal (amber vertebra)	449/50	16	0.709069	15	0.709062	0.709047	0.709077	2.18	4.68	0.709023	0.709101	1.52	5.40

© NMP 2014

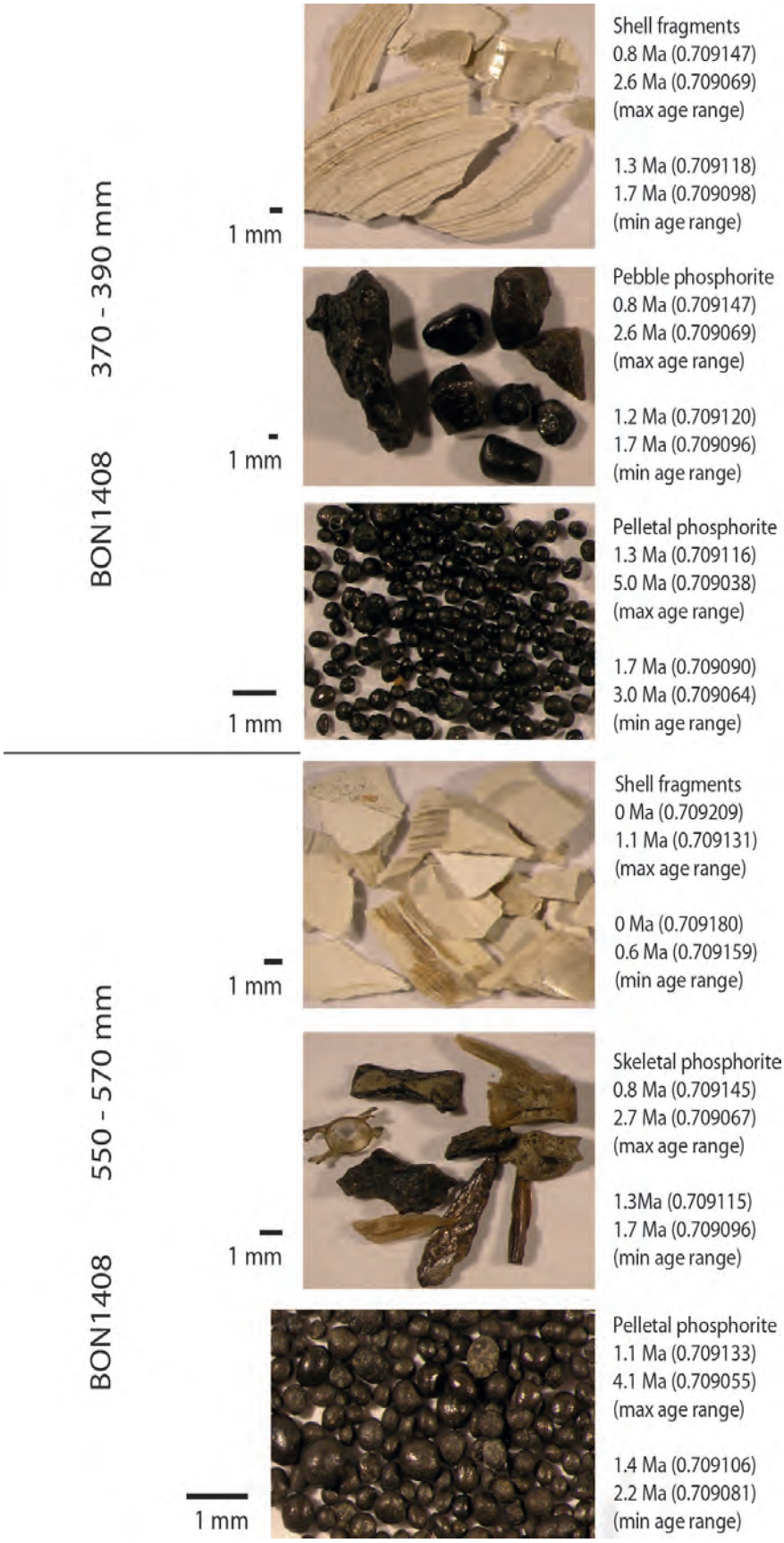
	Conception Bay Cluster															
18	BON1313	70-110	Pelletal phosphorite (>250)	451/2	27	0.709114	14	0.709107	0.709094	0.709121	1.22	1.79	0.709068	0.709146	0.77	2.69
19	BON1313	70-110	Shell fragments	453/4	27	0.709180	11	0.709173	0.709162	0.709185	0.00	0.51	0.709134	0.709212	0.00	1.11
20	BON1313	430-450	Pelletal phosphorite (>250)	455/6	27	0.709121	13	0.709114	0.709101	0.709127	1.14	1.22	0.709075	0.709153	0.63	2.42
21	BON1313	430-450	6 Large grain phoshorite (2.5 mm max)	457/8	40	0.709118	11	0.709111	0.709100	0.709122	1.21	1.28	0.709072	0.709150	0.69	2.52
22	BON1313	430-450	Skeletal (7 mm max)	459/60	27	0.709122	13	0.709115	0.709103	0.709128	1.12	1.20	0.709076	0.709154	0.61	2.38
23	BON1313	520-540	Pelletal phosphorite (>250)	461/2	25	0.709091	10	0.709084	0.709074	0.709093	1.67	2.45	0.709045	0.709123	1.19	4.77
24	BON1313	520-540	6 Large grain phoshorite (2 mm max)	463/4	14	0.709079	15	0.709072	0.709058	0.709087	1.83	3.69	0.709033	0.709111	1.35	5.17
25	BON1313	520-540	Skeletal (3.5 mm max)	465/6	12	0.709155	12	0.709148	0.709136	0.709160	1.00	1.08	0.709109	0.709187	0.00	1.48
26	BON1313	960-980	Pelletal phosphorite (>250)	467/8	28	0.709125	12	0.709118	0.709106	0.709130	1.09	1.53	0.709079	0.709157	0.54	2.29
27	BON1313	960-980	Skeletal (4 mm max)	469/70	21	0.709121	13	0.709114	0.709101	0.709127	1.52	1.63	0.709075	0.709153	0.63	2.42
28	BON1313	960-980	Fish scales (3.5 mm max)	471/2	27	0.709081	12	0.709074	0.709063	0.709086	1.87	2.08	0.709035	0.709113	1.33	5.11
29	BON1313	1400-1450	Pelletal phosphorite (fine to med)	473/4	6	0.709067	16	0.709060	0.709044	0.709076	2.21	4.80	0.709021	0.709099	1.56	5.45
	Moeb Bay South Cluster															
30	BON1460	1820-1860	Pelletal phosphorite (>250) etched	475/6	45	0.709122	14	0.709115	0.709101	0.709128	1.12	1.63	0.709076	0.709154	0.61	2.38
31	BON1460	1820-1860	Skeletal (4 mm max)	477/8	26	0.709130	12	0.709123	0.709112	0.709135	1.02	1.43	0.709084	0.709162	0.41	2.15
	Moeb Bay South Cluster															
32	BON1463	1640-1680	Pelletal phosphorite (>500)	479/80	42	0.709042	15	0.709035	0.709021	0.709050	4.04	5.45	0.708996	0.709074	2.28	6.00
33	BON1463	1640-1680	Pelletal phosphorite (<125)	481/2	42	0.709046	10	0.709039	0.709029	0.709050	4.04	5.30	0.709000	0.709078	2.15	5.94
34	BON1463	1640-1680	Skeletal (bone, 6 mm max)	483/4	128	0.709120	15	0.709113	0.709098	0.709127	1.14	1.70	0.709074	0.709152	0.65	2.45
	Moeb Bay South Cluster															
35	BON1469	1710-1750	Pelletal phosphorite (>250)	485/6	64	0.709134	12	0.709127	0.709115	0.709139	0.94	1.38	0.709088	0.709166	0.28	2.00
36	BON1469	1710-1750	Skeletal (amber vertebra, 5 mm max)	487/8	35	0.709168	10	0.709161	0.709151	0.709171	0.15	0.76	0.709122	0.709200	0.00	1.21

© NMP 2014

Annexure 2: Photomicrographs of Samples analysed for SR isotopes in this Study



© NMP 2014


BON1408
370 - 390 mm
1 mm
Shell fragments
0.8 Ma (0.709147)
2.6 Ma (0.709069)
(max age range)
1.3 Ma (0.709118)
1.7 Ma (0.709098)
(min age range)
1 mm
Pebble phosphorite
0.8 Ma (0.709147)
2.6 Ma (0.709069)
(max age range)
1.2 Ma (0.709120)
1.7 Ma (0.709096)
(min age range)
1 mm
Pelletal phosphorite
1.3 Ma (0.709116)
5.0 Ma (0.709038)
(max age range)
1.7 Ma (0.709090)
3.0 Ma (0.709064)
(min age range)
BON1408
550 - 570 mm
1 mm
Shell fragments
0 Ma (0.709209)
1.1 Ma (0.709131)
(max age range)
0 Ma (0.709180)
0.6 Ma (0.709159)
(min age range)
1 mm
Skeletal phosphorite
0.8 Ma (0.709145)
2.7 Ma (0.709067)
(max age range)
1.3Ma (0.709115)
1.7 Ma (0.709096)
(min age range)
1 mm
Pelletal phosphorite
1.1 Ma (0.709133)
4.1 Ma (0.709055)
(max age range)
1.4 Ma (0.709106)
2.2 Ma (0.709081)
(min age range)

© NMP 2014

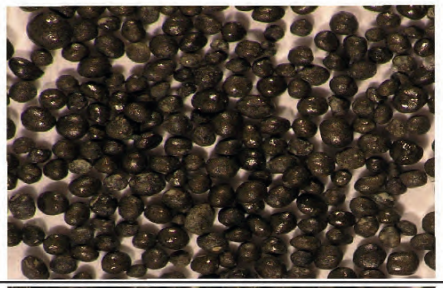
BON1408
1190-1210 mm



Pelletal phosphorite
1.4 Ma (0.709111)
5.2 Ma (0.709033)
(max age range)

1.9 Ma (0.709084)
3.6 Ma (0.709059)
(min age range)

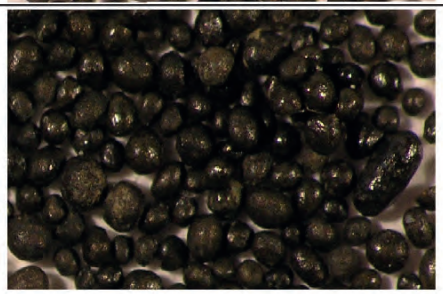
BON1408
1210-1230 mm



Pelletal phosphorite
1.0 Ma (0.709134)
4.0 Ma (0.709056)
(max age range)

1.4 Ma (0.709110)
2.3 Ma (0.709080)
(min age range)

BON1408 1320 - 1360 mm



Pelletal phosphorite
1.0 Ma (0.709138)
3.5 Ma (0.709060)
(max age range)

1.4 Ma (0.709106)
1.9 Ma (0.709091)
(min age range)



Skeletal phosphorite
1.5 Ma (0.709101)
5.4 Ma (0.709023)
(max age range)

2.2 Ma (0.709077)
4.7 Ma (0.709047)
(min age range)



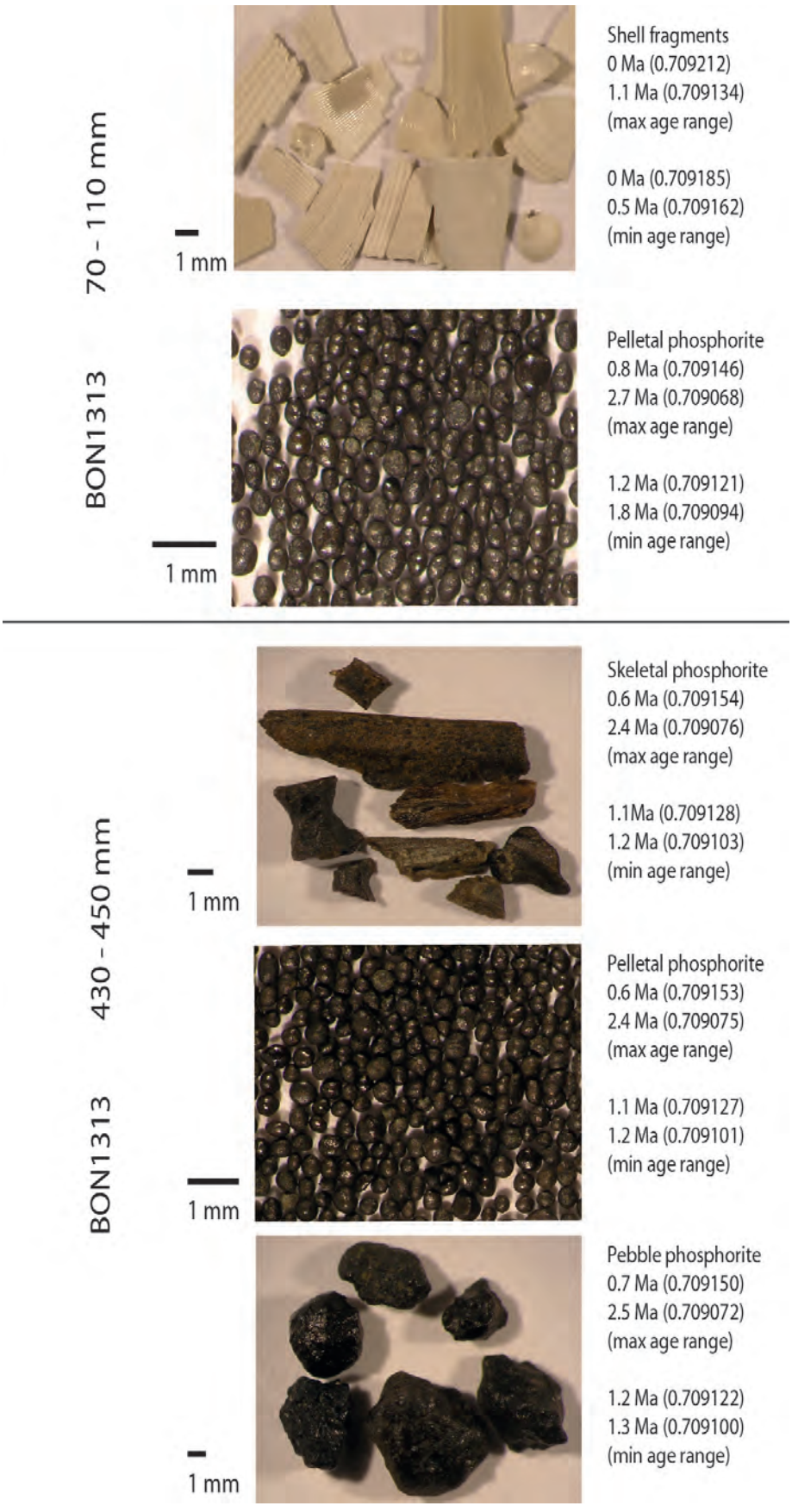
Shell fragments
7.7 Ma (0.708934)
11.2 Ma (0.708856)
(max age range)

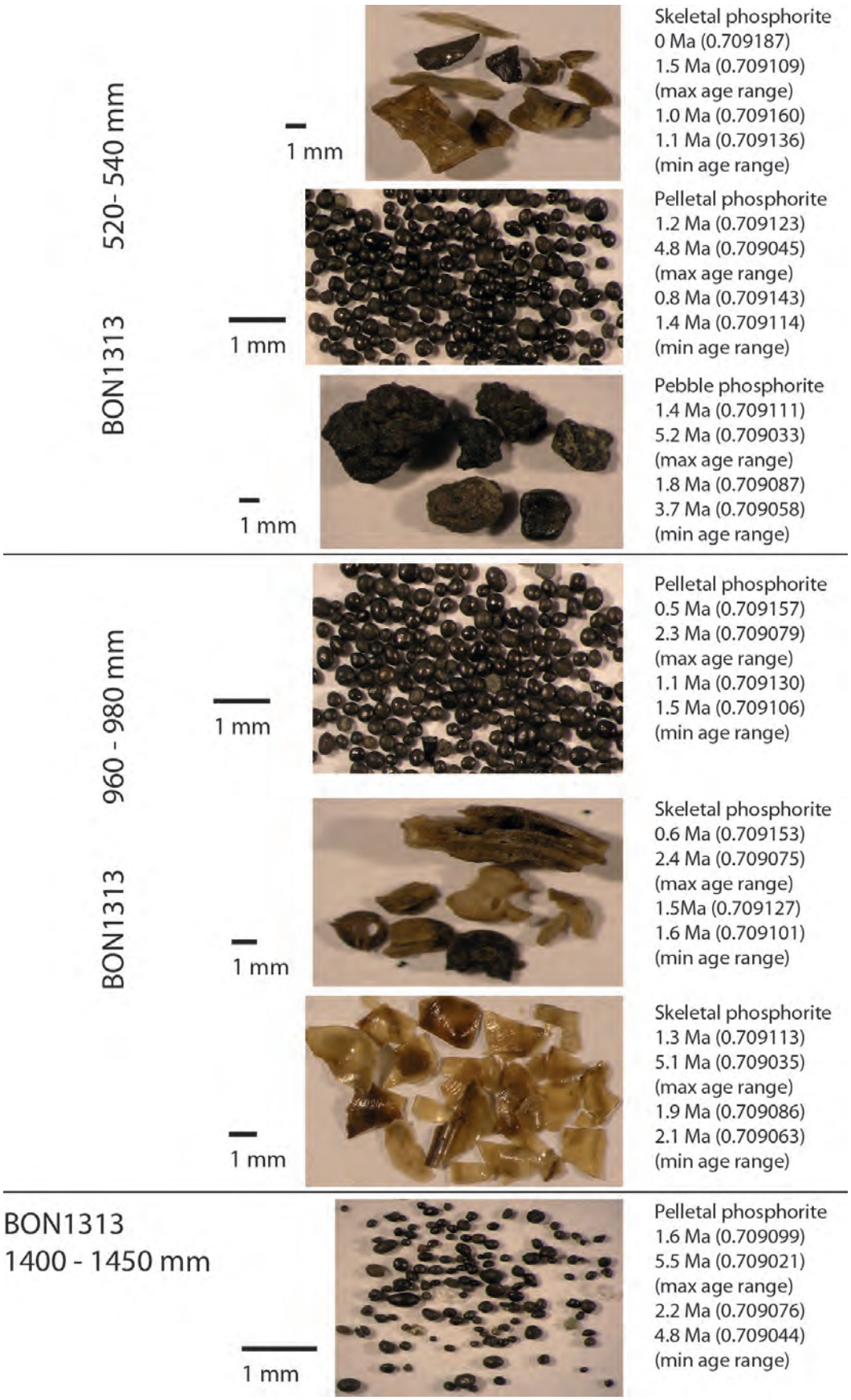
9.0 Ma (0.708910)
10.4 Ma (0.708880)
(min age range)



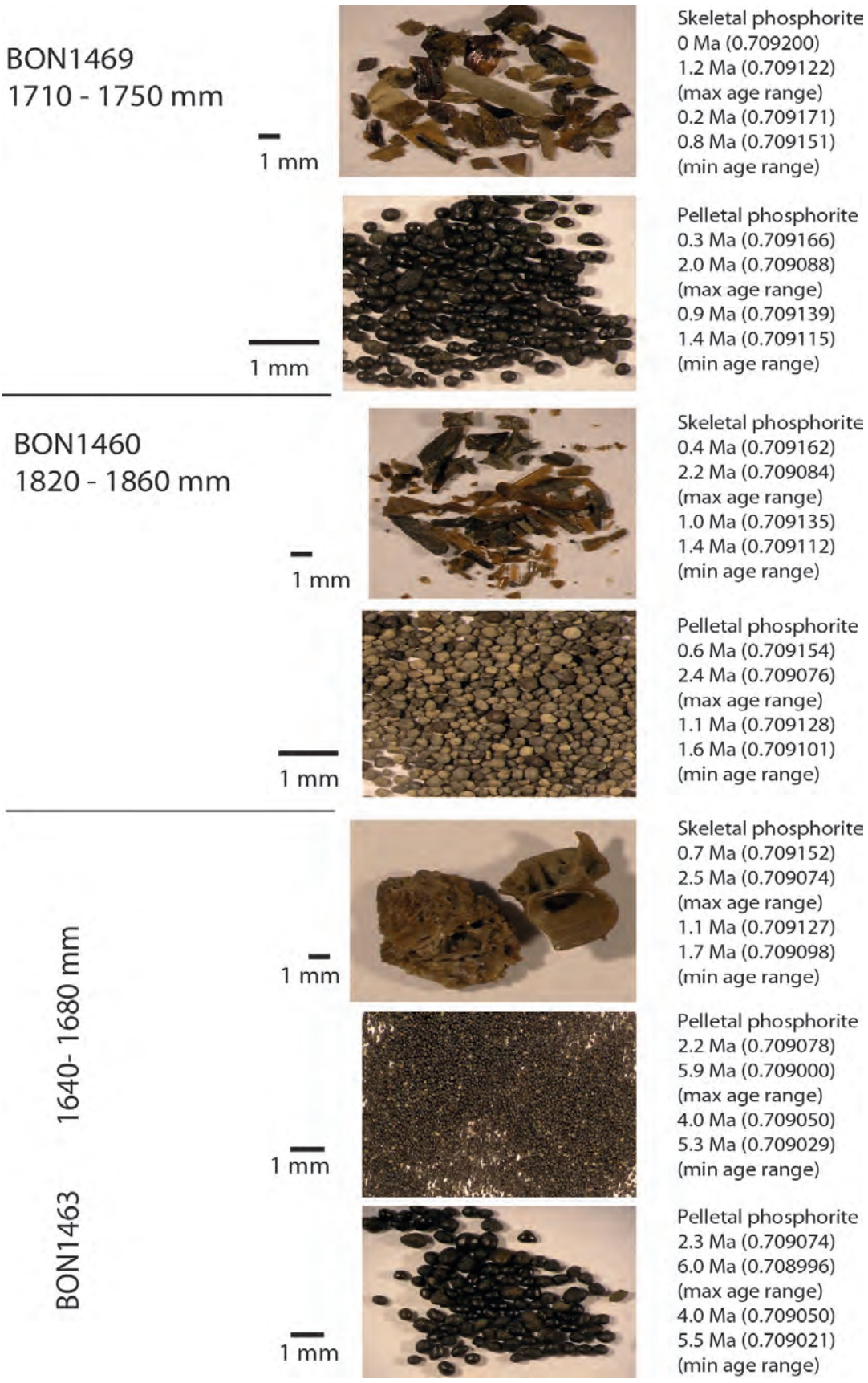
Foraminifera tests
9.9 Ma (0.708882)
14.5 Ma (0.708804)
(max age range)

10.7 Ma (0.708857)
12.6 Ma (0.708830)
(min age range)


70 - 110 mm
1 mm
Shell fragments
0 Ma (0.709212)
1.1 Ma (0.709134)
(max age range)
0 Ma (0.709185)
0.5 Ma (0.709162)
(min age range)
BON1313
1 mm
Pelletal phosphorite
0.8 Ma (0.709146)
2.7 Ma (0.709068)
(max age range)
1.2 Ma (0.709121)
1.8 Ma (0.709094)
(min age range)
430 - 450 mm
1 mm
Skeletal phosphorite
0.6 Ma (0.709154)
2.4 Ma (0.709076)
(max age range)
1.1Ma (0.709128)
1.2 Ma (0.709103)
(min age range)
BON1313
1 mm
Pelletal phosphorite
0.6 Ma (0.709153)
2.4 Ma (0.709075)
(max age range)
1.1 Ma (0.709127)
1.2 Ma (0.709101)
(min age range)
1 mm
Pebble phosphorite
0.7 Ma (0.709150)
2.5 Ma (0.709072)
(max age range)
1.2 Ma (0.709122)
1.3 Ma (0.709100)
(min age range)


BON1313
520- 540 mm
1 mm
Skeletal phosphorite
0 Ma (0.709187)
1.5 Ma (0.709109)
(max age range)
1.0 Ma (0.709160)
1.1 Ma (0.709136)
(min age range)
1 mm
Pelletal phosphorite
1.2 Ma (0.709123)
4.8 Ma (0.709045)
(max age range)
0.8 Ma (0.709143)
1.4 Ma (0.709114)
(min age range)
1 mm
Pebble phosphorite
1.4 Ma (0.709111)
5.2 Ma (0.709033)
(max age range)
1.8 Ma (0.709087)
3.7 Ma (0.709058)
(min age range)
BON1313
960 - 980 mm
1 mm
Pelletal phosphorite
0.5 Ma (0.709157)
2.3 Ma (0.709079)
(max age range)
1.1 Ma (0.709130)
1.5 Ma (0.709106)
(min age range)
1 mm
Skeletal phosphorite
0.6 Ma (0.709153)
2.4 Ma (0.709075)
(max age range)
1.5Ma (0.709127)
1.6 Ma (0.709101)
(min age range)
1 mm
Skeletal phosphorite
1.3 Ma (0.709113)
5.1 Ma (0.709035)
(max age range)
1.9 Ma (0.709086)
2.1 Ma (0.709063)
(min age range)
BON1313
1400 - 1450 mm
1 mm
Pelletal phosphorite
1.6 Ma (0.709099)
5.5 Ma (0.709021)
(max age range)
2.2 Ma (0.709076)
4.8 Ma (0.709044)
(min age range)

© NMP 2014


BON1469
1710 - 1750 mm
1 mm
Skeletal phosphorite
0 Ma (0.709200)
1.2 Ma (0.709122)
(max age range)
0.2 Ma (0.709171)
0.8 Ma (0.709151)
(min age range)
1 mm
Pelletal phosphorite
0.3 Ma (0.709166)
2.0 Ma (0.709088)
(max age range)
0.9 Ma (0.709139)
1.4 Ma (0.709115)
(min age range)
BON1460
1820 - 1860 mm
1 mm
Skeletal phosphorite
0.4 Ma (0.709162)
2.2 Ma (0.709084)
(max age range)
1.0 Ma (0.709135)
1.4 Ma (0.709112)
(min age range)
1 mm
Pelletal phosphorite
0.6 Ma (0.709154)
2.4 Ma (0.709076)
(max age range)
1.1 Ma (0.709128)
1.6 Ma (0.709101)
(min age range)
1640- 1680 mm
1 mm
Skeletal phosphorite
0.7 Ma (0.709152)
2.5 Ma (0.709074)
(max age range)
1.1 Ma (0.709127)
1.7 Ma (0.709098)
(min age range)
1 mm
Pelletal phosphorite
2.2 Ma (0.709078)
5.9 Ma (0.709000)
(max age range)
4.0 Ma (0.709050)
5.3 Ma (0.709029)
(min age range)
BON1463
1 mm
Pelletal phosphorite
2.3 Ma (0.709074)
6.0 Ma (0.708996)
(max age range)
4.0 Ma (0.709050)
5.5 Ma (0.709021)
(min age range)

© NMP 2014

SANDPIPER PROJECT

Verification Programme Report: Mining Licence Area No. 170

SECTION C : SPECIALIST STUDIES

Section C.2

Water Column and Sedimentary Environment

C2.1: Water column and sediments
C2.2: Sediment plume
C2.3: Thiobacteria
C2.4: Meiofauna
C2.5: Macrobenthos
C2.6: Epifauna
C2.7: Plankton

SPECIALIST STUDIES – SECTION C

C2.1 Water Column and Sediments

NAMIBIAN MARINE PHOSPHATE

WATER COLUMN AND SEDIMENTS

Prepared for:
Namibian Marine Phosphate (Pty) Ltd.

Prepared by:
Lwandle Technologies (Pty) Ltd.
Report compiled by Robin Carter and Kate Munnik

October 2014

Job no: LT 149 Version 03

LWANDLE TECHNOLOGIES (PTY) LTD
The Old Warehouse, Black River Park, Fir Road, Observatory 7925, South Africa
Directors: C.P. Matthysen, B.J. Spolander
Co Reg. No. 2003/015524/07

MARINE SPECIALIST TEAM:

Dr. Robin Carter – Lwandle Technologies
Kate Munnik – Lwandle Technologies

Marine Team
Andrew Russell – Lwandle Technologies
Tim McClurg – Lwandle Technologies
Henry Gilham – Lwandle Technologies
Sannette Gildenhuys – Met-ocean Services International
Jeremy Midgley – Client Representative
Bill Ludick – Client Representative

Date	Version	Revised	Reviewed
10/04/2014	0.1	Kate Munnik	Dr. Robin Carter
30/04/2014	1.0	Kate Munnik	Dr. Robin Carter
4/07/2014	2.0	Kate Munnik	Dr. Robin Carter
14/10/2014	3.0	Dr Robin Carter	

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed “Attention: Administration Manager,” at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

SUMMARY

Namibian Marine Phosphate (NMP) proposes to recover pelletal phosphate from an ore body situated in Mining Licence Area (MLA) 170, offshore of Namibia. The project involves the recovery of marine sediment by dredging and the subsequent processing of this sediment at an onshore facility. An Environmental Impact Assessment (EIA) for the marine component of this project was submitted in 2012. A central conclusion in this EIA was that the risks associated with the project were expected to be largely physical as opposed to biogeochemical in nature. This conclusion was based on regional data and physical sediment properties reported from within the target mine area. As this conclusion was pivotal in the risk evaluation, NMP initiated a verification survey to obtain empirical data on sediment properties, currents and the characteristics of the water column in the mine area, the findings of which are detailed here. This report should be read in conjunction with the original marine ecology specialist report to the NMP EIA.

The verification survey gathered empirical data in the target mine area on currents, water column characteristics and sediment properties including benthic macro- and meiofauna and the thiobacteria assemblage present in the area. The analyses of these data showed that:

- Currents were as expected for the region displaying uniform north westward flow at the surface and varying poleward and equatorward flow in the bottom of the water column. Near seabed current velocities averaged 18 cm/s for poleward flow and 9 cm/s for equatorward flow. Peak flows recorded were ~30 cm/s.
- The dominant water mass present in the area during the survey period was South Atlantic Central Water with origins in the Cape Basin and the Angolan continental shelf. The former was relatively oxic and the latter severely hypoxic.
- The upper mixed layer in the water column ranged in depth from 20 m to 30 m and was oxic. Below the relatively weakly developed thermocline oxygen concentrations declined with depth to very low (severe hypoxia) levels near the seafloor.
- Upper water column turbidity was low at <1 NTU. Mean turbidity near the seafloor was <3.5 NTU but episodically exceeded 350 NTU. The data indicate that these short term turbidity events were generated outside of the survey area and were being advected through it.
- Dissolved heavy metal concentrations in the water column were close to the analytical detection levels. Nutrient concentrations agreed with those reported for the region and nitrogen/phosphorus ratios were close to Redfield (17.7 vs 16.0).
- Surficial sediments in the survey area were silty sand and the underlying sediments primarily silt. Average POM concentrations were 7.4% and molar C:N ratios 11.4 – 19.8. These indicate that the POM was relatively refractory compared with that reported for the nearer shore diatomaceous mud belt sediments (<9).
- Inorganic nutrient concentrations in the sediment pore waters average 156 µg/ℓ for nitrogen (ammonia + nitrite + nitrate-nitrogen) and 209 µg/ℓ for phosphorus. This shows a considerable departure from the Redfield ratio and is attributed to phosphorus enrichment from the pelletal phosphorus ore. Sediment water content was low leading to minimal risk of modifications to the overlying water column nutrient distributions.

© NMP 2014

- The range of measurements indicative of the oxidative state of the sediments showed that they were hypoxic. The presence of nitrate-nitrogen in the sediment pore water supports this as it converts to ammonia in anoxic conditions. AVS was below detection levels in the surficial sediments and averaged <2 mMol/kg in the subsurface layers. The absence of AVS is consistent with hypoxia as free sulphide is oxidized over time to sulphate (SO_4^{2-}) in the presence of oxygen. This implies that POM mediated sulphide fluxes would be low.
- The potential for the dissolution (release) of sulphide from iron pyrites (FeS_2) in the target dredge sediment body was evaluated on the basis of sediment particle size distributions, measured AVS-S concentrations in the sediments, and published information linking pyrites dissolution rates with sediment particle size and AVS-S/FeS_2-S concentration ratios. Dissolution rates in sediments larger than 1 µm are slow, 0.08 – 0.34%/day, but more rapid, 3-20%/day, in sediments <1 µm. The proportion of sediments in the <1 µm size category in the surveyed area is low (<8% by mass), as is the estimated mean FeS_2-S concentration in the bulk sediment (0.64 mM S/kg). The mass of Fe_2-S available for dissolution is calculated as 0.05 mM/kg (= 1.64 mg S/kg). If oxidized to sulphate (SO_4^{2-}) this would require 3.2 mg of oxygen/kg of sediment. However, the end point of the oxidation is most probably elemental sulphur and not sulphate with little consequence for dissolved oxygen concentrations.
- Surficial and subsurface sediments supported relatively high concentrations of the heavy metals arsenic, cadmium, chromium, copper and nickel. The bioavailability of these heavy metals was investigated by elutriation tests and negligible proportions entered the dissolved phase. This is possibly due to their precipitation as insoluble sulphides as, although there was low AVS in the tested (subsurface) sediments, it was present well in excess of the simultaneously extracted metal (SEM) fraction. Iron was abundant in both of the sediment layers and scavenging of the metals from the dissolved phase by iron hydroxides and organic complexes is another possible sink.

The low release of the metals into the dissolved phase indicates that although their natural concentrations exceeded the sediment quality guidelines for the region they do not represent a toxicity risk in this phase either *in situ* or following physical disturbance.

An alternative toxicity pathway of the heavy metals is via complexing with organic particles and then ingestion by deposit and filter feeders. Toxicity effects are linked to gut absorption efficiencies and excretion rates and the affected organism's ability to detoxify absorbed heavy metals by isolation in insoluble granules or metallothioneins. A range of factors control this but it is apparent that there can be accumulation of metals such as cadmium in the livers of demersal fish inhabiting areas with naturally high authigenic concentrations. Assessments of trophic transfers of heavy metal contaminants indicate that, in pelagic food webs, these are generally attenuated at the primary consumer level, dominated by copepods, with low transfer efficiencies to fish. In benthic food webs with carnivorous molluscan whelks as top predators appreciable bio-magnification can occur as whelks sequester and store metals derived from their prey. However the proposed mining operations in the survey area are not expected to increase exposures of benthic fauna to heavy metals such as cadmium over and above that which occurs naturally in the region.

This supports the assessment of toxicity risks in the EIA.

- The investigations into benthic meiofauna and macrofauna in the surficial sediments in the survey area showed that fauna were abundant in both size classes. This is consistent with a

© NMP 2014

mainly hypoxic sediment environment and inconsistent with sulphidic sediments. The relative abundance of benthic macrofauna in the >1 000 µm size class indicates that this condition is persistent as (*Para*)*Prionospio*, which formed a large proportion of the fauna, has a life cycle of 1-2 years (http://www.genustraithandbook.org.uk) and the *Diopatra* sp. may be as long-lived (Steffani 2014). This is consistent with a stable sedimentary environment even though the overlying water body may undergo seasonal changes in terms of its oxygen content with varying contributions of Cape Basin and Tropical Atlantic Central Water.

- The investigation into sulphur bacteria indicated that, at the time of sampling, sulphide fluxes were probably low as the large sulphate bacteria, namely from the genera *Thiomargarita*, *Beggiatoa* and *Thioploca*, which play a significant roles in the oxidisation of H_2S, were absent from the bacterial assemblage. Smaller forms including *Thiobacillus* spp. with relatively lower growth yields were present; however, indicating that although estimated to be low (hydrogen) sulphide was present in the sediments.

The main findings of the EIA are supported by the data gathered and analysed during this verification study. As a result, the level of confidence with which a number of the impacts are assessed has been increased. The major findings of the verification survey confirmed that the majority of the impacts associated with the project are expected to be physical rather than biogeochemical as was described in the EIA.

© NMP 2014

contents

SUMMARY ii

1 INTRODUCTION 1

2 SCOPE 2

3 METHODS 4

3.1 CURRENT FLOWS AND WATER PROPERTIES TIME SERIES MEASUREMENTS 7
3.2 WATER COLUMN FEATURES 8
3.3 SEDIMENT PROPERTIES 8
3.4 BENTHOS 12
3.5 THIOBACTERIA 12

4 RESULTS 13

4.1 WATER COLUMN DYNAMICS AND PROPERTIES 13
4.1.1 Currents 13
4.1.2 Water Column Properties 19
4.1.2.1 Water Masses 19
4.1.2.2 Temperature and Dissolved Oxygen 23
4.1.2.3 Turbidity 25
4.1.2.4 Nutrients 27
4.1.2.5 Phytoplankton Biomass 27
4.1.2.6 Heavy Metals 28

4.2 SEDIMENTS 28
4.2.1 Sediment particle size 28
4.2.2 Sediment organic content and associated properties 34
4.2.3 Heavy metal concentrations 35

4.3 BENTHOS 39
4.4 MEIOFAUNA 39
4.4.1 Macrofauna 40
4.4.2 Thiobacteria 41

5 DISCUSSION 42

6 CONCLUSIONS 54

7 REFERENCES 56

Annexure 1: Synthesis of observations to test the hypothesis that the Namibian Marine Phosphate (ML 170) area is biogeochemically similar to the mud-belt 59

© NMP 2014

figures

Figure 1: NMP's Mining Licence area ML 170 and mineral resource areas on the continental shelf offshore of Namibia. 5
Figure 2: Verification sampling sites in the SP-1 Mine Area. 6
Figure 3: Configuration of the oceanographic instrumentation mooring deployed during the verification survey. The upward looking ADCP measured currents in the upper 100 m water column. 7
Figure 4: Map of the verification sampling regime highlighting the six water sampling stations, indicated here with blue circles. 9
Figure 5: Map of the gravity cores (blue squares) collected as part of the verification survey. 10
Figure 6: A frozen core sample collected using a gravity core. 11
Figure 7: Sub-sampling and analysis procedure for gravity core samples carried out at the CSIR. 12
Figure 8: Summary plots of current speed and directions during deployments P1 and P2. 14
Figure 9: Near seabed Aquadopp current meter data from P1 15
Figure 10: Near seabed Aquadopp current meter data from P2 showing current velocity and varying poleward and equatorward flows. 16
Figure 11: Cross-shelf (U) velocity spectra recorded at 50 m and 5 m depth during P1 17
Figure 12: Cross-shelf (U) velocity spectra as recorded in P2 at 50 m and 5 m depth 18
Figure 13: Alongshore velocity (V) spectra for P1 recorded at 50 m and 5 m water depth 18
Figure 14: Alongshore velocity (V) spectra for P2 at 50 m and 5 m depth 19
Figure 15: T/S diagram showing the results from the CTD profile data collected during the verification survey. 20
Figure 16: P1 near seabed RBR CTD data. 21
Figure 17: P2 near seabed RBR CTD data. 22
Figure 18: Cross-shelf (U) velocity and temperature record from P1 showing a possible soliton event on 17th July 2013. 23
Figure 19: Temperature (upper panel) and salinity (lower panel) profiles measured in the survey area. 24
Figure 20: Oxygen profiles measured in the survey area. 25
Figure 21: Turbidity profiles measured in the survey area (X-axis units are NTU). 26
Figure 22: Chlorophyll fluorescence profiles measured in the survey area (x-axis units are chlorophyll *a* equivalents in µg/ℓ). 28
Figure 23: Ternary diagram showing surficial sediment texture classification (Day grab samples) 29
Figure 24: Ternary diagram showing subsurface sediment texture (Gravity core samples) 30
Figure 25: Particle size distribution plot for Day grab samples of surficial sediments in the survey area 31
Figure 26: Particle size distribution plot for gravity core samples of subsurface sediments in the survey area 31
Figure 27: Box/whisker plot showing medians, inter-quartile ranges and outliers of sediment particle size D_{50} values for gravity core and grab sample sediments in the survey area. 32
Figure 28: Grab sample photographs showing the shelly (top panel) and sandy silt (bottom panel) nature of the Day grab samples collected during the verification survey. 33
Figure 29: Distribution of surficial sediment (Day grab samples) median particle size (D_{50}) across the survey area. 34
Figure 30: Scatterplots showing the relationships between selected heavy metals and aluminium 38
Figure 31: Namibian cross-shelf POM distributions (from Bremner 1978) and the locations of the 22° S station transect (redrawn from van der Plas *et al.* 2007) 43
Figure 32: Relationship between POM C:N ratios and a) ammonium (NH_4) and b) hydrogen sulphide (H_2S) concentrations in the benthic boundary layer (van der Plas *et al.* 2007). 44
Figure 33: Thermodynamics of stepwise oxidation reactions for O_2 oxidation with H_2S for both one and two-electron transfer reactions. At zero electrons transferred, ΔG° is the sum of the standard state ΔG° values before a reaction occurs. 47
Figure 34: The mechanism explaining the indirect role of oxygen and the catalytic role of adsorbed Fe(II) in the oxidation of pyrite (from Figure 8 in Moses and Herman, 1991) 48

© NMP 2014

tables

Table 1: Mean dissolved nitrogen and phosphorus concentrations and the resultant Redfield ratios associated with water samples collected during the verification survey. 27

Table 2: Surficial sediment properties in the survey area (Day grab samples). Note that acid volatile sulphide (AVS) was below the concentration threshold (0.2 mMol/kg) of the analytical procedure employed. 35

Table 3: Subsurface sediment properties in the survey area (gravity core samples). Note that nitrate and phosphate were measured in pore water extracts 35

Table 4: Median heavy metal concentrations (mg/kg), AVS and SEM (mM/kg) for Day grab (surficial sediments) and gravity core (subsurface sediments) samples in the survey area 36

Table 5: Proportions (% of mass in sediment) of selected heavy metals released from gravity core samples subjected to elutriation tests. 39

Table 6: Benthic boundary layer properties across the Namibian continental shelf (from Brüchert *et al.* 2003). 43

Table 7: Summary table of the re-gradings of the 7 impact assessments in marine ecology component of the EIA (NMP 2012) for which the information gained in the verification surveys is relevant. 55

© NMP 2014

1 INTRODUCTION

Namibian Marine Phosphate (NMP) is investigating the possibility of extracting pelletal marine phosphate from the seabed on the continental shelf offshore of Namibia. In order to assess the potential impacts associated with this project on the local and regional marine environment, an Environmental Impact Assessment (EIA) was carried out (NMP 2012). This assessment was based primarily on available scientific literature from the region and measurements of the physical properties within the target mining area. To strengthen the available empirical data and to provide further information sources to support impact evaluations NMP initiated a focused study of the important features and processes in the dredge area. The suite of investigations focused on were current flows, water column features and water quality and sediment properties, benthos (macrofauna and meiofauna), thiobacteria, plankton and fish. The results of these investigations are detailed in this report. Following submission of the draft report a specialist review workshop focussed on the full scope of work undertaken in the verification programme was held by NMP. Comments from the reviewers have been used to refine and improve this submission. Findings from the studies also address concerns raised by independent reviewers of the EIA and have been used to update the relevant impact assessment tables from the original EIA.

The marine ecology specialist report in the environmental impact assessment conducted for NMP's proposed mining operations offshore of Namibia concluded that the environmental effects of dredging would be primarily linked to the sediment properties in the mining areas (Lwandle 2012).

The information supporting the EIA is considered to be scientifically and practically robust as it is drawn from the seminal work conducted by Bremner (1978), direct surveys of sediment properties across one of the mine areas by Rogers (2008) and because it is consistent with adduced distributions of turbulent energy across the shelf which control sediment texture distributions (Monteiro *et al*. 2005). All of this indicates that the sediments in the target mining area are predominantly of muddy sand texture[1]. Hydrogen sulphide, methane and other chemical flux rate measurements conducted by, *inter alia*, Namibian and South African marine scientists indicate that these are low, as particulate organic matter (POM) (which sediments from the pelagic zone) does not accumulate on these sediments (van der Plas *et al*. 2007). Further, the phosphate ore body is considered to be derived initially from concentration of phosphorus in marine algae and thereafter the transfer of this organic form to the mineral carbonate fluorapatite and francolite as pelletal (sand) grains in the Pleistocene (2.6—1.0 MA, Compton 2012). Therefore any organic material incorporated in the ore body would be refractory compared with freshly sedimenting organic matter. This implies that the predominant sources of sulphur in the ore body itself would be pyrites which have low dissolution rates, and therefore sulphide would not be readily available for formation into, e.g., hydrogen sulphide.

On the basis of the above, the water quality and associated environmental risks associated with the marine mining ore recovery process, i.e. dredging, were considered to be predominantly physical as opposed to biogeochemical. Consequently the conclusions on sediment textures in the Mining Licence Area (ML 170) are of pivotal importance in the environmental assessment.

[1] Throughout this document mud is used as a generic descriptor of all sediment particles smaller than 62.5 µm equivalent spherical diameter (ESD). This is effectively the combination of the silt (4-62.5 µm) and clay (<4 µm) fractions of the sediment as defined in the Wentworth Scale.

© NMP 2014

It was clear from comments received from interested parties, in Namibia especially, that this is a contentious issue as, although no data or analyses (peer reviewed or not) have been presented in support of alternative views, there is a persistent concern that muddy (i.e. sediment dominated by the <62.5 µm size fraction) sulphidic sediments will be exposed during dredging with important consequences for water quality. The verification survey described here was conducted to obtain empirical data and information on the proposed mining site in order to determine actual as opposed to predicted sediment properties and oceanographic conditions to evaluate the predictions and conclusions on marine ecology in the specialist study on the water column (Lwandle 2012 in NMP EIA 2012). The verification survey also sought to provide clarity on key concerns raised by NatMIRC and other external reviewers of the EIA (NMP 2012) as distilled below:

- The currents and circulation information in the EIA studies were primarily taken from regional scale circulation modelling and other published sources. There is uncertainty on the applicability of this to the proposed mining area.
- Similarly, important features of the water column were generalised from regional and possibly outdated information; this needs to be focused on the mining area.
- Sediment characteristics vary zonally and longitudinally on the Namibian continental shelf, extrapolation from measurements to the north and south of the proposed mining area may not be sufficiently reliable leading to uncertainty on whether:
    - The adduced sediment particle size and sediment texture apply;
    - The sediment bed is resistant to suspension (sediment water content/porosity and presence/absence of armouring);
    - The *in situ* organic content (POM) and molar carbon/nitrogen (C/N) ratios are as predicted;
    - Sediment pore water departs from Redfield ratios, specifically in terms of inorganic nitrogen and phosphate ratios;
    - Sediment heavy metal contents are within the published guidelines for the region and whether those that are not are likely to be biologically available, and
    - The sediments are sulphidic or likely to release hydrogen sulphide (H_2S) during dredging.
- The available ancillary biological data presented (sediment meiofauna, macrofauna and presence/absence of thiobacteria and (thio)bacterial mats required refinement to add confidence to the impact assessments.

The report is presented as a fully referenced scientific document, where a detailed scope and method statement is provided, followed by the presentation of the key results of the study and then the discussion of these results in light of their verification of the findings of the existing EIA. The main themes of the report are presented in the following order: current flows and water masses; water column characteristics; sediment characteristics; and synopses of the associated benthos and thiobacteria investigations.

2 SCOPE

The measurements listed below were carried out to determine the validity of previously published baseline environmental information in the EIA (NMP 2012). The survey was also designed to address the reviewer's and NatMIRC's comments as summarised above. The following measurements were

© NMP 2014

undertaken within the mining licence area (MLA), specifically SP-1 the 20-year target mining site (Figure 1) as part of the verification survey and the linked gravity coring survey (Figure 2):

- Investigation into the physical and chemical characteristics of the water column:
  - Vertical profiles of the distributions of temperature, conductivity, dissolved oxygen (DO), chlorophyll fluorescence (Chl) and turbidity measured by a multi-probe internal logging CTD extending from the sea surface to within 5 m of the sea bed;
  - Water samples collected at various depths concurrent with the CTD profiles for calibrations and water quality assessments;
  - Near sea bed temperature, conductivity, DO and turbidity time series measurements (measured using a moored internal logging multi-parameter CTD) to elucidate background concentrations and possible variations linkable to internal tide generated turbulence (Figure 3);
  - Near sea bed high frequency current measurements (measured using a moored Aquadopp current meter – see Figure 3) to determine turbulence and the presence of sediment resuspension events linkable to internal tide generated turbulence, complementary to the DO and turbidity time series, and
  - Currents and indirect measurements (beam attenuation) of suspended sediments (equivalent to turbidity) through the upper water column (<100 m depth) measured by a moored, upward looking ADCP current meter (Figure 3).

- Investigation into the physical and chemical nature of marine sediments:
  - Surficial sediment particle size and texture distribution investigations (measured on samples recovered by Day grab[2]), to determine whether sediments in (and surrounding) the proposed mining areas are mainly fine and medium sands with minimal mud (as stated in the NMP EIA, 2012). Also the companion measurements on sediment properties that are made (below) can only be properly understood in terms of the host sediment environment;

[2] A Day Grab was deployed for surficial sediment sampling in this survey as multiple field trials at the site with the box core demonstrated that it could not penetrate the sediment sufficiently to provide the sample volumes required. This is attributed to the dense shell layers present across the survey area. A multi-corer was not considered to be a suitable alternative either in this case, as it would have 'bounced' of the sediment surface.

© NMP 2014

- Subsurface sediment particle size and texture distributions to ~2.5 m depth (depth of phosphate resource) measured from samples recovered by gravity core;
- Surficial and deep sediment organic content, POC and PON concentrations;
- Surficial and deep sediment heavy metal, acid volatile sulphide (AVS) and simultaneously extracted metals (SEM) concentrations;
- Surficial and deep sediment heavy metal elutriation measurements to determine the proportion of each metal that may be released into the water column (dissolved phase) through the dredging process and thereby become bioavailable, and
- Sediment pore water inorganic nutrient (nitrogen and phosphorus) concentrations to demonstrate potential risks of departures from Redfield ratios when pore water is translocated to the upper water column, as water is released in discharge from the dredge hopper during dredging.

3 METHODS

The verification survey was carried out in the SP-1 area within the ML 170 licence area, offshore of Namibia (Figure 1) as this is the stated target area for the first 20 years of mining. Areas SP-2 and SP-3 are only expected to be mined in the distant future and were excluded from this survey as any field surveys in these areas should be undertaken closer to the time of mining.

The verification survey comprised ship borne measurements covering the water column and sediments (surficial and profile measurements) as well as the deployment of an oceanographic instrumented mooring focused on currents, temperature, salinity, dissolved oxygen and turbidity time series measurements. Figure 2 shows the layout of the stations occupied in the survey. The mooring was deployed by Metocean Services International (MSI) and data were recorded over two consecutive measurement periods P1 (8 June to 26 July 2013) and P2 (2 August to 13 September 2013), totalling 90 days of measurements. Surficial sediment and water column profiling and sampling were carried out from the service vessel MV *DP Star* over the period 24th July to 4th August 2013, while the sediment core sampling was carried out from the MV *Snowgoose* between the 8th and 11th of August 2013.

Figure 1/...

© NMP 2014

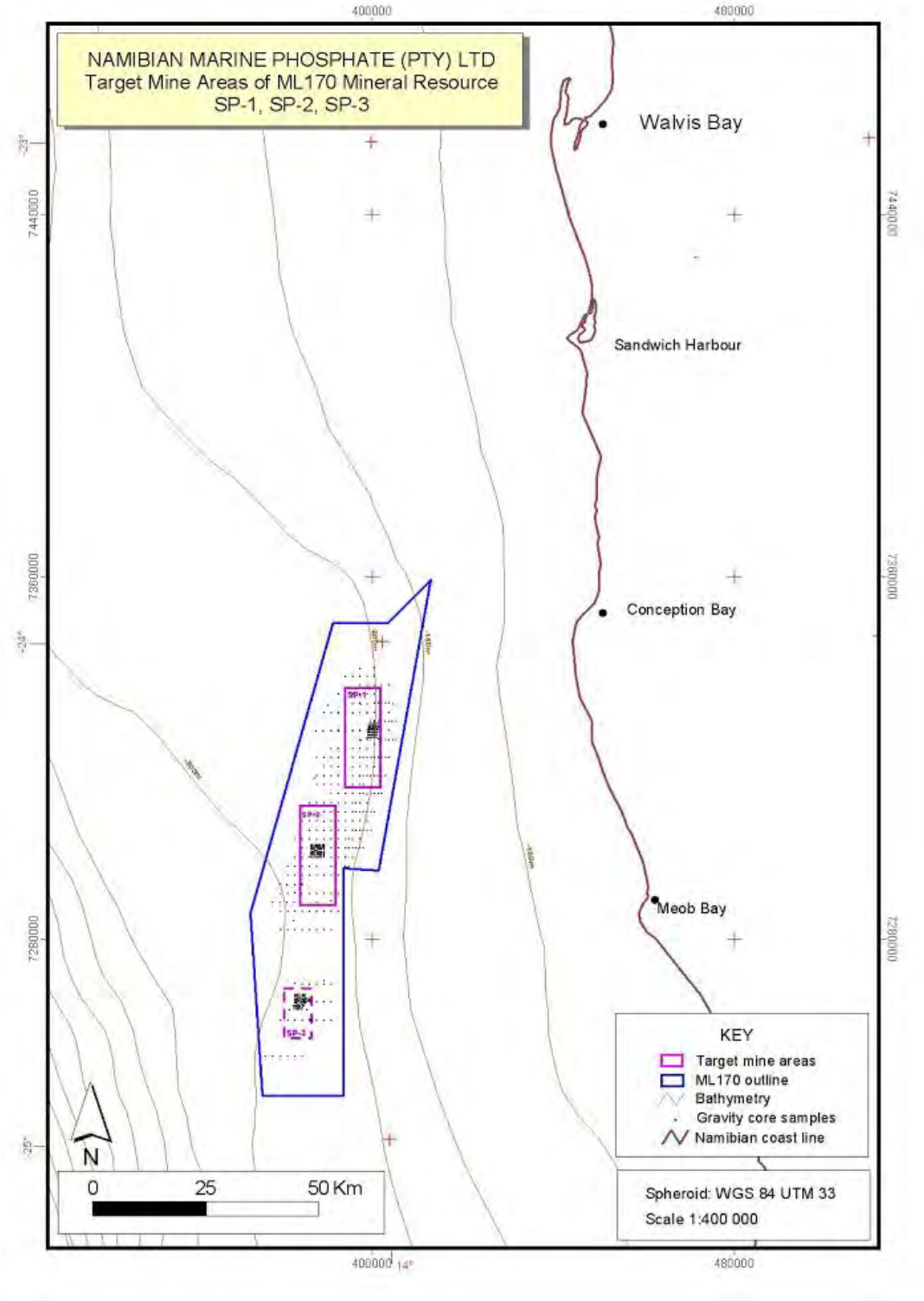


Figure 1: NMP's Mining Licence area ML 170 and mineral resource areas on the continental shelf offshore of Namibia.
The mining target areas within the Licence area are indicated as SP-1, SP-2 and SP-3. The verification survey was carried out in target area SP-1.

© NMP 2014

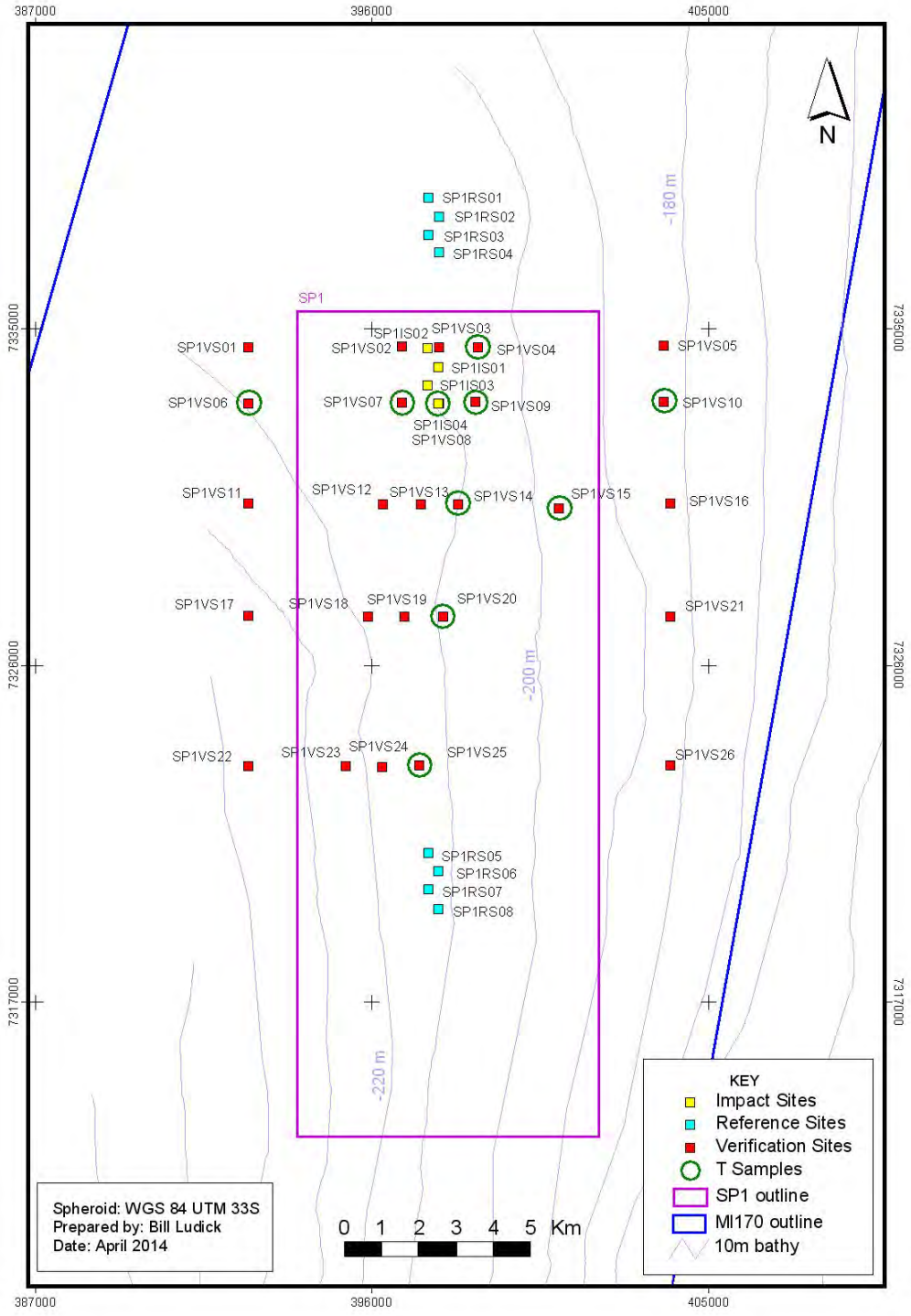


Figure 2: Verification sampling sites in the SP-1 Mine Area.
Note that the verification survey sites are represented by red squares. Location of the oceanographic mooring is at SP1VS15. Yellow and light blue squares show the locations of the benthic macrofauna sample sites. Isobaths are at 10 m intervals.

© NMP 2014

3.1 CURRENT FLOWS AND WATER PROPERTIES TIME SERIES MEASUREMENTS

Local oceanographic processes were assessed during a 90 day deployment of a fixed mooring fitted with an upward looking ADCP, two Aquadopp current metres as well as a RBR CTD fitted with turbidity and dissolved oxygen sensors (Figure 3). The 90 day period was selected, in part, to detect effects of internal tides with a ~14 day (lunar) periodicity shown by Monteiro *et al*. (2005) to be important features controlling fine sediment distributions on the central Namibian continental shelf. The 90 day period would be able to capture 5-6 of these events, should they be detectable at the measurement site. A further consideration influencing the measurement period was the requirement to obtain a sufficiently long time series of data to show whether currents and the other measured variables at the mooring site were typical of those measured in and/or predicted for the region.

The mooring was deployed on the 8th June 2013 at site SP1VS15, 24° 08' 18.96" S and 14° 01' 32.88" E, in a water depth of ~193 m (Figure 2). Recorded data were collected from the mooring during a service visit at day 45 and after the final recovery of the mooring on 13th September 2013 (day 90). These data were quality checked and processed using WAVESMON and MATLAB software suites. Further details regarding data processing procedures are available in the MSI reports (MSI 2013a & 2013b).

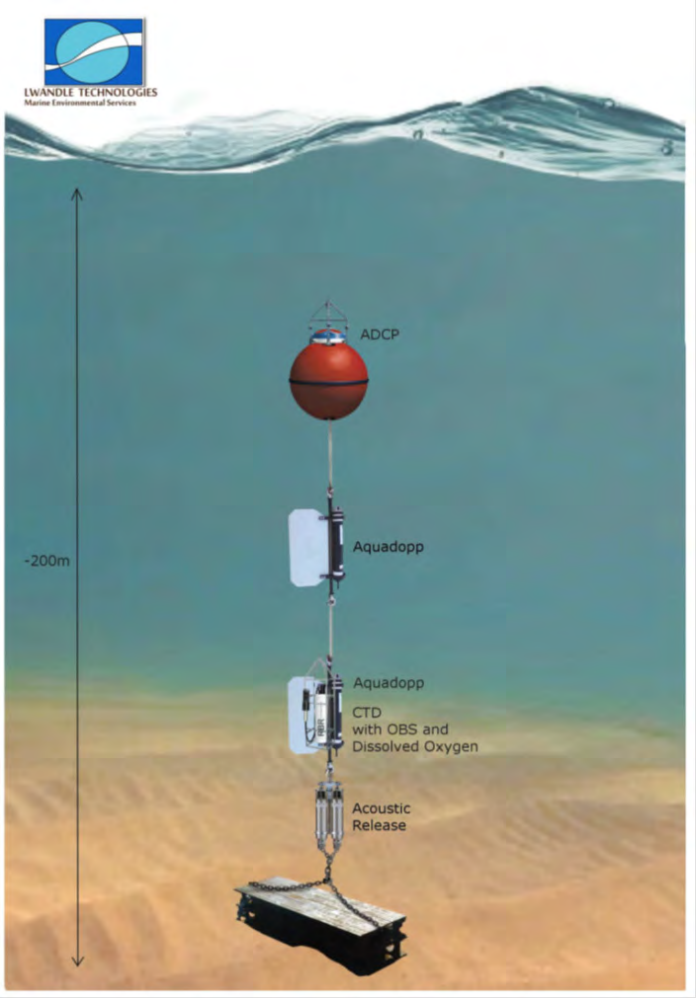


Figure 3: Configuration of the oceanographic instrumentation mooring deployed during the verification survey. The upward looking ADCP measured currents in the upper 100 m water column.

3.2 WATER COLUMN FEATURES

During the MV *DP Star* verification cruise (July – August 2013) CTD profiles and water samples were collected at six stations (SP1VS04, SP1VS09, SP1VS14, SP1VS15, SP1VS20 and SP1VS25) within the survey area (Figure 4). At these stations water samples were collected at six depths (-1 m, - 10 m, -20 m, -50 m, -100 m, and 5 m from the sea floor) for analyses of TSS, heavy metal, inorganic nutrients and DOC concentrations and profiles of conductivity, temperature, chlorophyll fluorescence, dissolved oxygen, and turbidity against depth through the water column.

3.3 SEDIMENT PROPERTIES

The verification sediment sampling regime covered a total of 26 stations, which extended across SP-1 (Figure 2 and Figure 5). Surficial sediment samples were collected by Day grab (MV *DP Star*) and the underlying sediments by gravity corer (MV *Snowgoose*). The sub-samples collected from the cores and grabs were then analysed at the CSIR's SANAS accredited chemical analysis laboratories in Stellenbosch, South Africa.

From each Day grab sample, sediment sub-samples were collected for physical and chemical analysis. Analyses included sediment particle size (laser diffraction spectroscopy) and texture distributions, heavy metal, acid volatile sulphides (AVS), and simultaneously extracted metals (SEM) concentrations, oxidation-reduction potential (ORP), organic content and organic carbon and total nitrogen concentrations.

Sediment cores ranging in length from 0.90 – 2.90 m depth were collected at the 26 sites (Figure 5) within two weeks of the completion of the Day grab sampling. Following recovery, each core was sectioned into 1 m lengths (Figure 6), capped, sealed and frozen at -18° C before transfer to shore based analytical facilities in South Africa. Analysis of the core sections followed the scheme shown in Figure 7a and 7b. The priority samples (Figure 5) were subjected to a full suite of analyses at eight set lengths of the core (Figure 7b). The remaining cores were analysed according to Figure 7a, where analyses were carried out at five set lengths. The suite of analyses carried out on each subsection included test for: particle size analysis, %moisture, %loss on ignition, organic carbon, total nitrogen, heavy metals, AVS, SEM, and pore water ORP, nitrate and phosphate concentrations.

Elutriation tests on heavy metal solubilisation were carried out on the priority cores with two elutriations per core, one using sediment collected from the top half/section of the core and the other from the bottom half/section (Figure 7b).

© NMP 2014

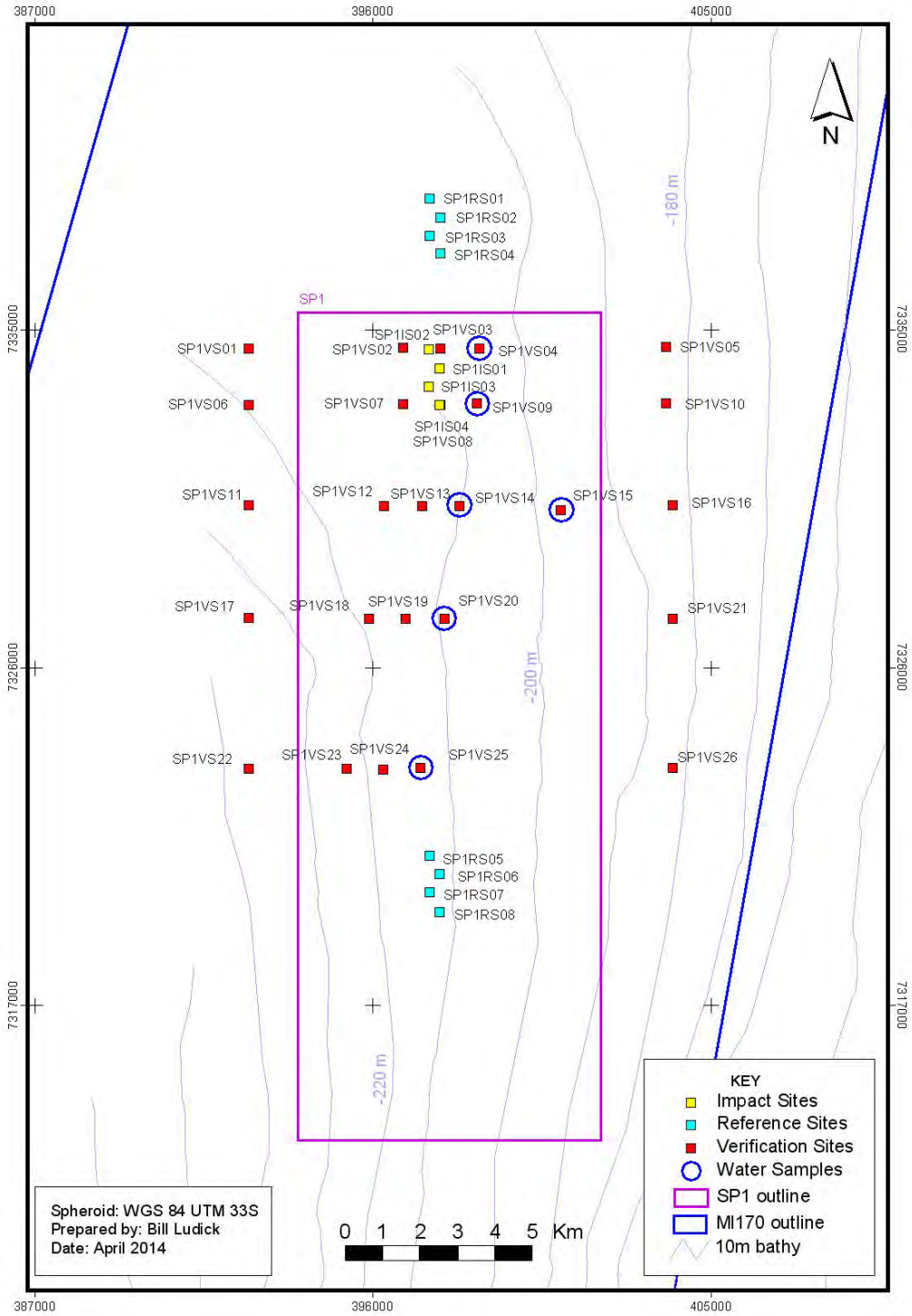


Figure 4: Map of the verification sampling regime highlighting the six water sampling stations, indicated here with blue circles.

© NMP 2014

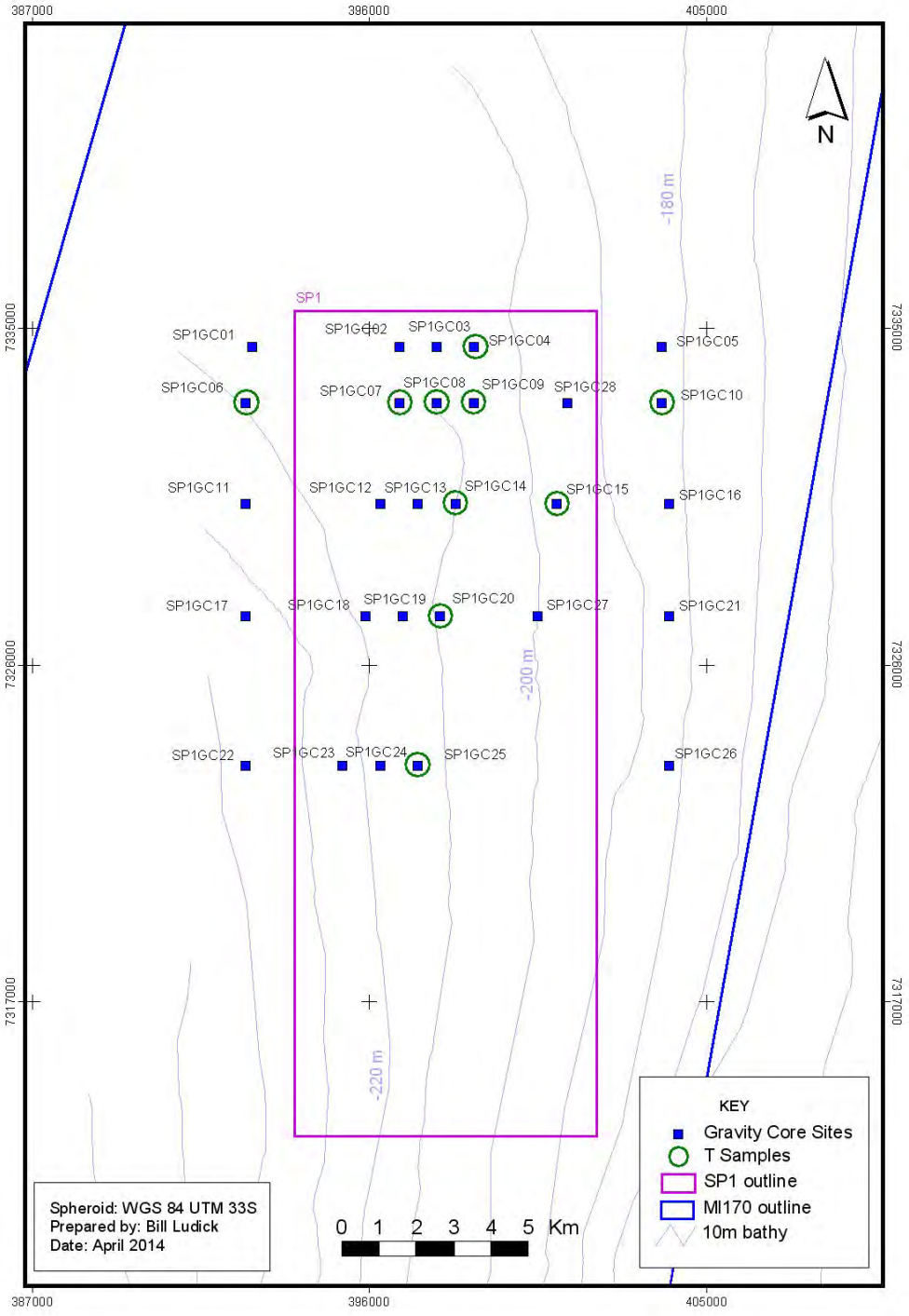


Figure 5: Map of the gravity cores (blue squares) collected as part of the verification survey. The sites highlighted by green circles were selected as priority samples for analyses but all data from all of the collected cores is discussed here. Sites SP1GC10 and SP1GC21 were failed cores (high shell density preventing penetration) and therefore two extra samples were collected at SP1GC27 and SP1GC28.

© NMP 2014



Figure 6: A frozen core sample collected using a gravity core.
a) Depicts the full core, before separation into two lengths, b) shows the core sections once separated and capped and c) depicts the frozen sediment sample after removal from the plastic core lining.

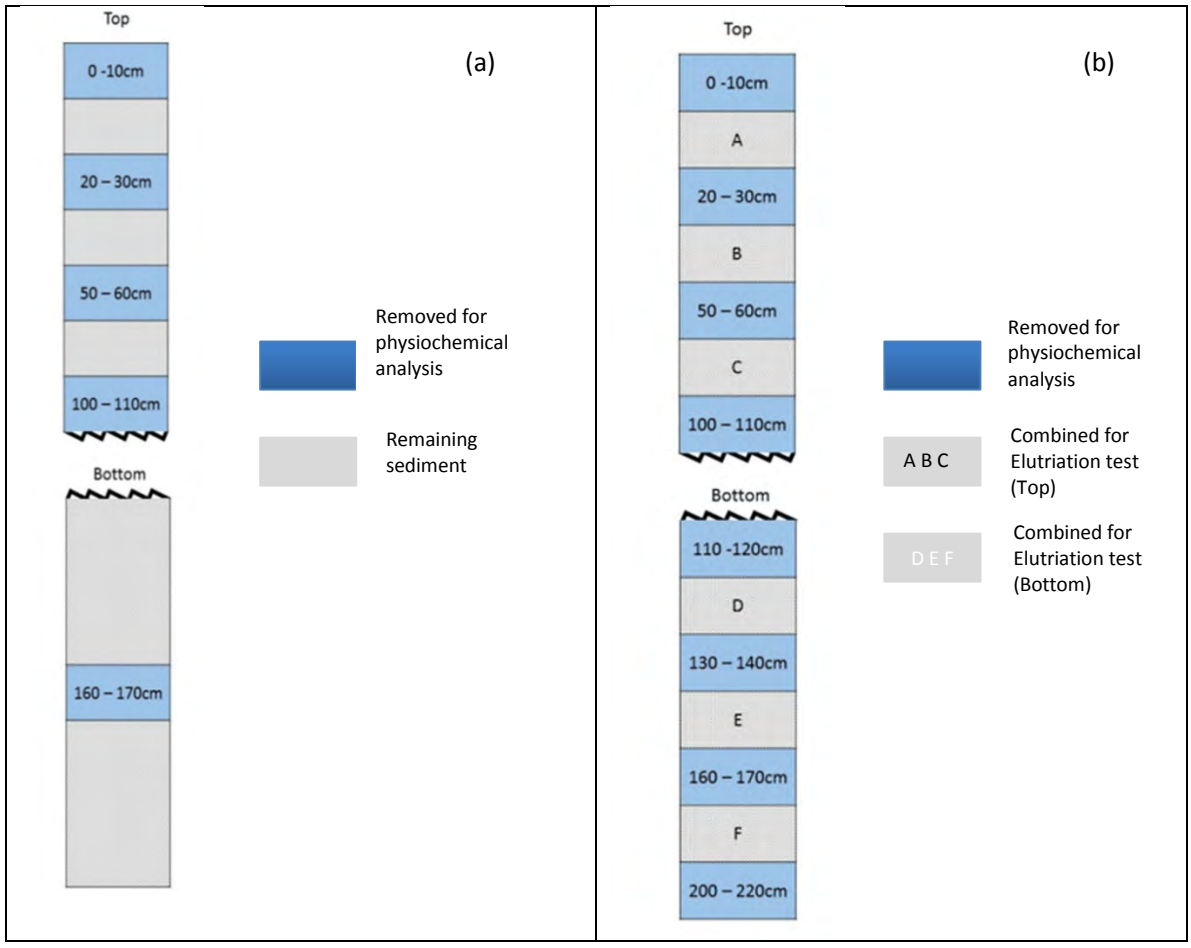


Figure 7: Sub-sampling and analysis procedure for gravity core samples carried out at the CSIR. a) Shows the sub sampling requirements for all gravity cores, while b) depicts the sampling regime for the priority samples identified in Figure 5.

3.4 BENTHOS

During the cruise on the MV *DP Star* benthic macrofauna and meiofauna samples were collected from each of the Day grab samples (Figure 2). The samples collected for benthic macrofauna were sieved through 300, 500 and 1 000 µm sieves. These, and the bulk samples for meiofauna, were preserved with ~4% buffered formalin and stored for later identification and counts which were carried out by Dr Nina Steffani of Steffani Marine Environmental Consultant (macrofauna), and Dr Simon Forster, Physalia Applied Sciences UK (meiofauna).

3.5 THIOBACTERIA

In a separate survey sulphur oxidising and reducing bacteria samples were obtained within the NMP mining licence (ML 170) area. Gravity core samples were retrieved from 10 sites and four subsamples of the surficial layers within the core were withdrawn for “quantitative Polymerase Chain Reaction” (qPCR) analysis in order to distinguish the sulphur bacteria species present.

© NMP 2014

4 RESULTS

The results of the various surveys and measurements that have been conducted under the verification 'umbrella' are compartmentalised into the broad groupings of

- Water column dynamics and properties and,
- Sediment characteristics.

This is purely for convenience and does not signify or imply that there is no dynamic link between the two.

4.1 WATER COLUMN DYNAMICS AND PROPERTIES

4.1.1 Currents

The full results of the measurements obtained from the moored oceanographic instrumentation are presented in the data reports for the two observation periods (MSI 2013a & 2013b). Summary plots of the data are shown in Figure 8, Figure 9 and Figure 10 below. From these it is evident that the prevailing near surface (<10 m) flow in both Period 1 (P1, 8 June to 26 July 2013) and Period 2 (P2, 2 August to 13 September 2013) was in a north-north westerly direction, consistent with that typical of the Benguela Current regime (Shannon, 1985). Subsurface currents alternated between northward and southward flows in both periods whilst near the seafloor the current direction was dominated by a south-south westerly flow in P1, typical of the poleward undercurrent (PUC). In P2 however, the near seafloor flow was more variable, oscillating between poleward and equatorward flows consistent with the flow pattern at the midwater depth. The PUC was thus more clearly defined in P1 than in P2.

Current velocities decreased with depth through the upper water column from a mean of 17 cm/s (P1 & P2) near the surface (<10 m depth) to 10 cm/s (P1) and 9 cm/s (P2) at mid-depth (~140 m). A marked increase in speed was however observed near the seafloor in P1 where a mean speed of 18 cm/s was recorded at 193 m depth in the predominantly poleward flow. Mean velocity in this depth zone in P2 was lower at 9 cm/s.

Figure 8 shows elevated current velocities attaining ~30 cm/s occurred around 22nd June, immediately following a reversal in flow direction from equatorward to poleward. For the remainder of both measurement periods flow velocities were relatively uniform even though, as noted above, P1 experienced higher mean velocities than P2.

© NMP 2014

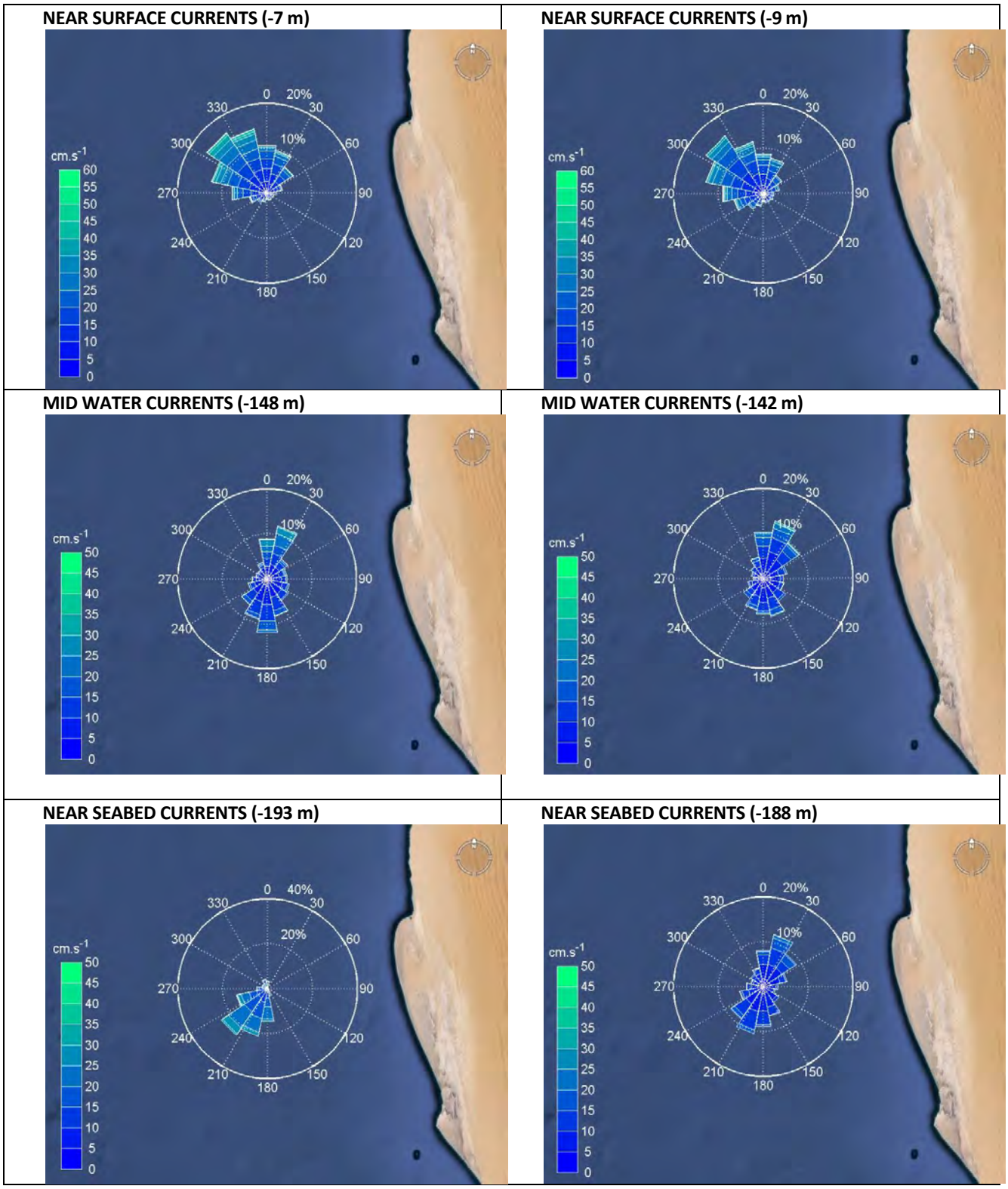


Figure 8: Summary plots of current speed and directions during deployments P1 and P2.
P1: 8 June – 26 July 2013 (left panel) and P2: 2 August – 13 September 2013 (right panel) at the near surface, mid water and near the seabed, collected from the oceanographic mooring located at 24° 08' 18.96" S, 14° 01' 32.88" E. Note the different scale in the lower left panel.

© NMP 2014

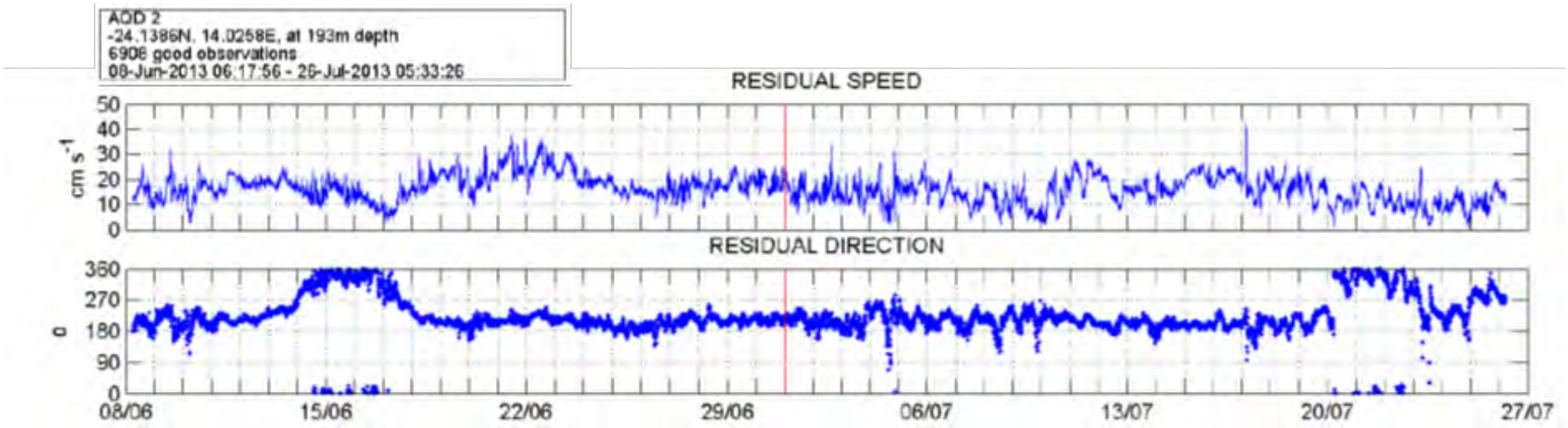


Figure 9: Near seabed Aquadopp current meter data from P1
Figure shows current velocity and predominant southward flow (flowing towards 180-270°) but with equatorward flows (360°) around the 15th of June and 22nd July.

© NMP 2014

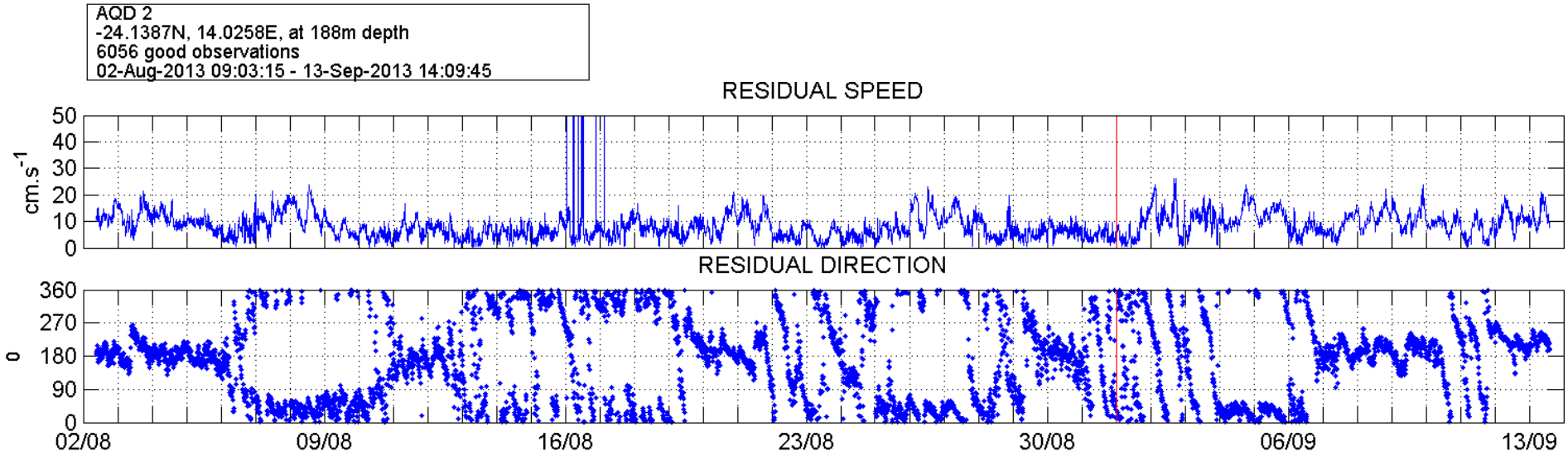


Figure 10: Near seabed Aquadopp current meter data from P2 showing current velocity and varying poleward and equatorward flows.

© NMP 2014

The recorded currents are consistent with those derived for the region from measurements (e.g. Shannon 1985), and regional scale hydrodynamic modelling (Shillington *et al*. 2006). Frequency analyses of the current data resolved into long- (V) and cross-shore (U) components show energy peaks at diurnal and 3 day intervals (Figure 11, Figure 12, Figure 13, Figure 14). The presence of an internal tide event or a tidal wave breaking at the shelf edge (*sensu* Monteiro *et al*. 2005) identified in the EIA as a possible sediment re-suspension mechanism was not evident in the 90 day dataset analysed here. However, bottom shear stress is estimated at 0.2-0.3 Pa, above the threshold settling velocity (0.05 Pa) (P. Monteiro, CSIR, pers. comm.), implying that sediment would remain in suspension at the observed higher velocity near seabed current velocities (20-30 cm/s, Figure 9 and Figure 10). This is supported by the classical Hjulstrom curve (e.g. http://imnh.isu.edu/digitalatlas/hydr/concepts/gwater/hjulstrm.htm) which shows that unconsolidated clay and silt sized particles, with specific gravities >1.8, will remain in suspension at current velocities higher than 20 cm/s. POM typically has a lower specific gravity (~1.1 to 1.4, Parsons *et al*. 1977), and will be less likely to deposit in the observed current velocities. Therefore, over the period of measurement, current conditions were such that accumulation of sedimenting particulate organic matter such as phytoplankton detritus and zooplankton faecal pellets, from upper water column plankton communities would not have occurred.

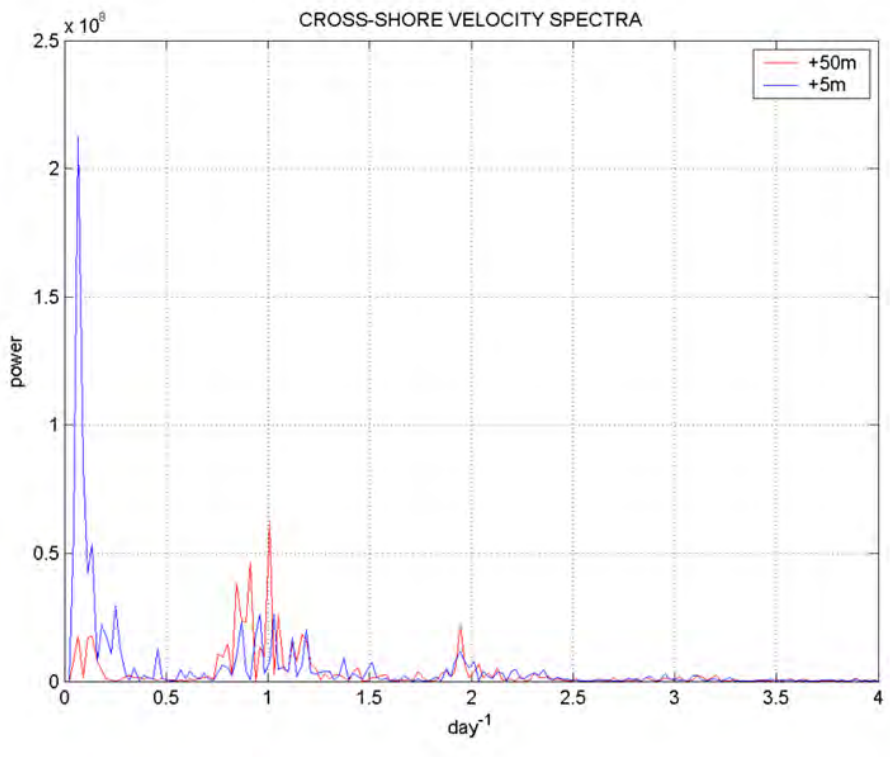


Figure 11: Cross-shelf (U) velocity spectra recorded at 50 m and 5 m depth during P1
These spectra show most variability is ascribed to long period (>3 days) fluctuations, daily motions possibly indicative of inertial cycles are the next most important. Motions occurring twice per day were only the third most important explanations of cross shelf variability.

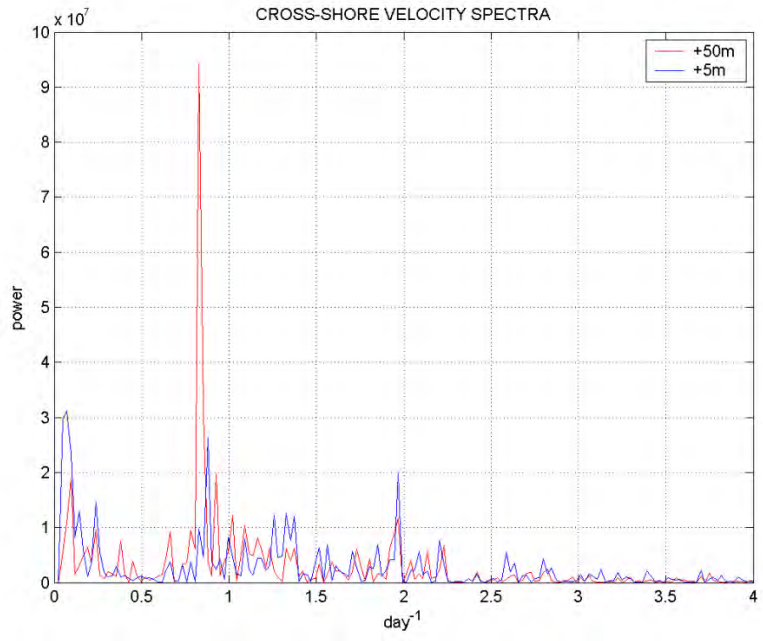


Figure 12: Cross-shelf (U) velocity spectra as recorded in P2 at 50 m and 5 m depth
Inertial frequencies account for the majority of variability at 50 m, with a secondary peak close to the M2 tide as well as longer period (>3 days) fluctuations. 5 m variability in Uis highest at longer period fluctuations followed by inertial and twice daily fluctuations.

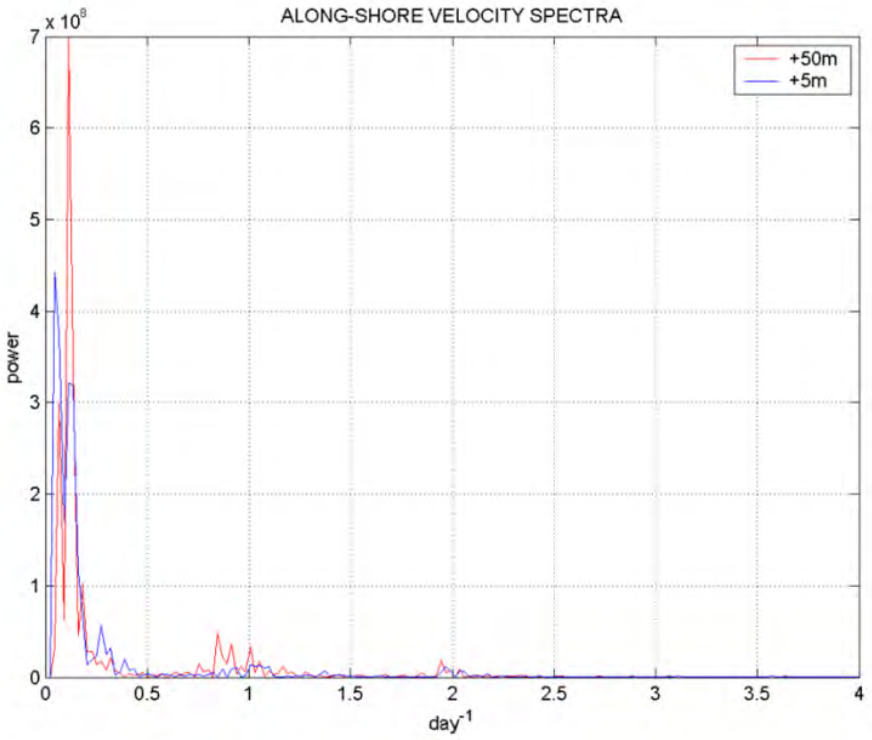


Figure 13: Alongshore velocity (V) spectra for P1 recorded at 50 m and 5 m water depth
These spectra show the dominance of long period fluctuations (>3 days), the secondary importance of daily motions (including inertial cycles) and then the third most important fluctuations occurred twice daily.

© NMP 2014

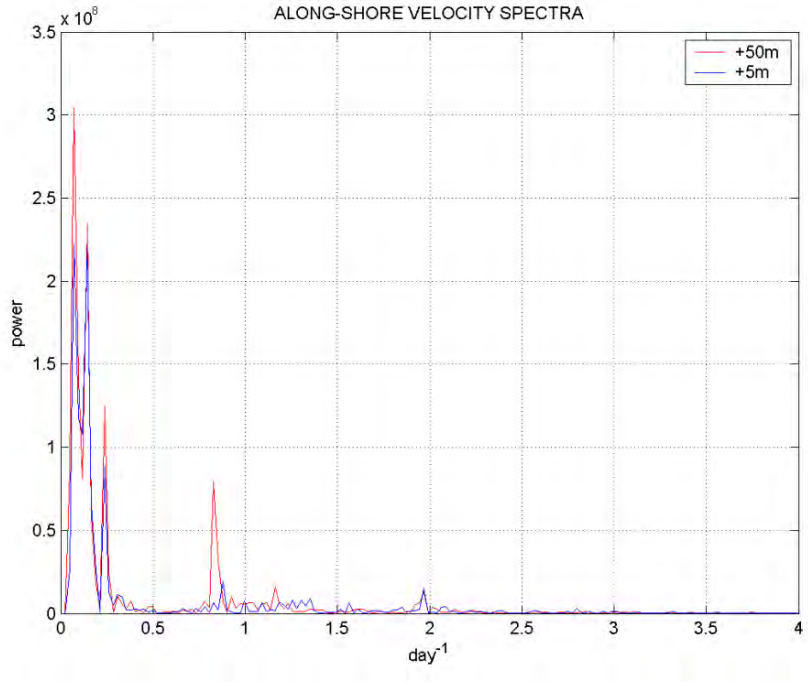


Figure 14: Alongshore velocity (V) spectra for P2 at 50 m and 5 m depth
The spectra show a clear peak in longer period (>3 day) fluctuations, the daily fluctuations were the next most important source of variability (especially at 50 m depth) , followed by the twice daily tidal fluctuations.

4.1.2 Water Column Properties

4.1.2.1 Water Masses

The temperature/salinity (T/S) characteristics of the water mass present in the survey area during the survey period are shown in the context of historical data for the region in Figure 15. There is close alignment between the two data sets although the verification period survey measurements lie towards the cooler side of the historical data. This notwithstanding, the water mass is clearly characteristic of South-Atlantic Central Water (SACW).

Inspection of the temperature, salinity and oxygen time series data from the first measurement period of the oceanographic mooring (P1, Figure 16) indicates that there are two sources of SACW present, one from the Cape Basin (fresh, cool and relatively well oxygenated) and the other which originates in the tropics (salty, warmer and oxygen deficient). The dissolved oxygen concentrations and salinity measurements for the first period of the mooring data show that the northward flowing water is associated with ventilation events (e.g. 13-20 June in Figure 16) where predominantly fresher and more oxygenated water flows into the region from the Cape Basin while southward flow is associated with SACW from a tropical source, this is consistent with Monteiro *et al*. (2006). During P2 southward flow was more common and the tropical source of SACW is reflected in the temperature and salinity time series data (oxygen data for P2 were not available due to equipment malfunction) (Figure 17).

© NMP 2014

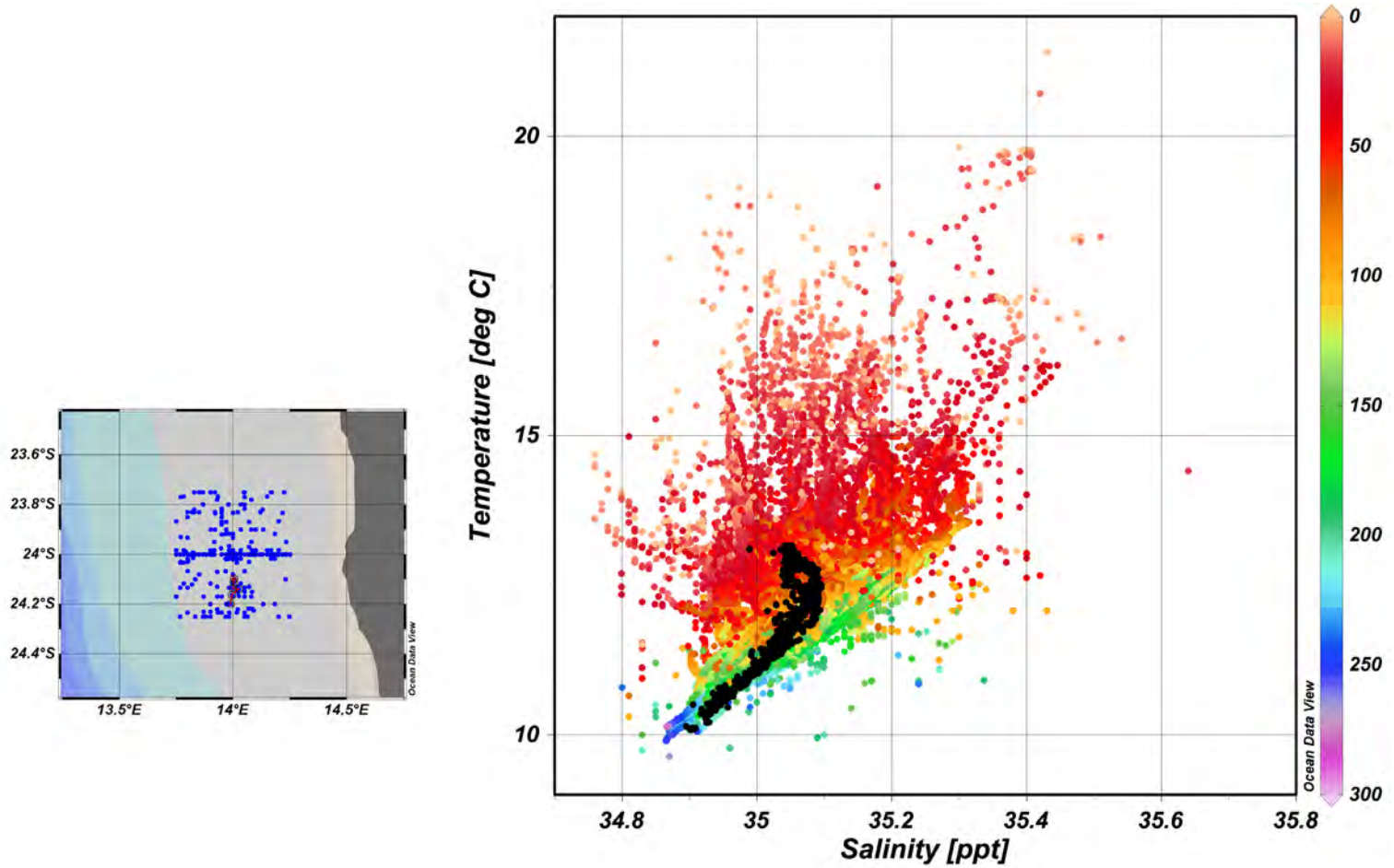


Figure 15: T/S diagram showing the results from the CTD profile data collected during the verification survey.
The survey data (black dots) are plotted against the regional T/S data as available from the SADCO database (Data courtesy of Louise Watt, CSIR): imagery plotted in ODV (Ocean Data Viewer). The colour scale is representative of water depth in metres. [n=71379]

© NMP 2014

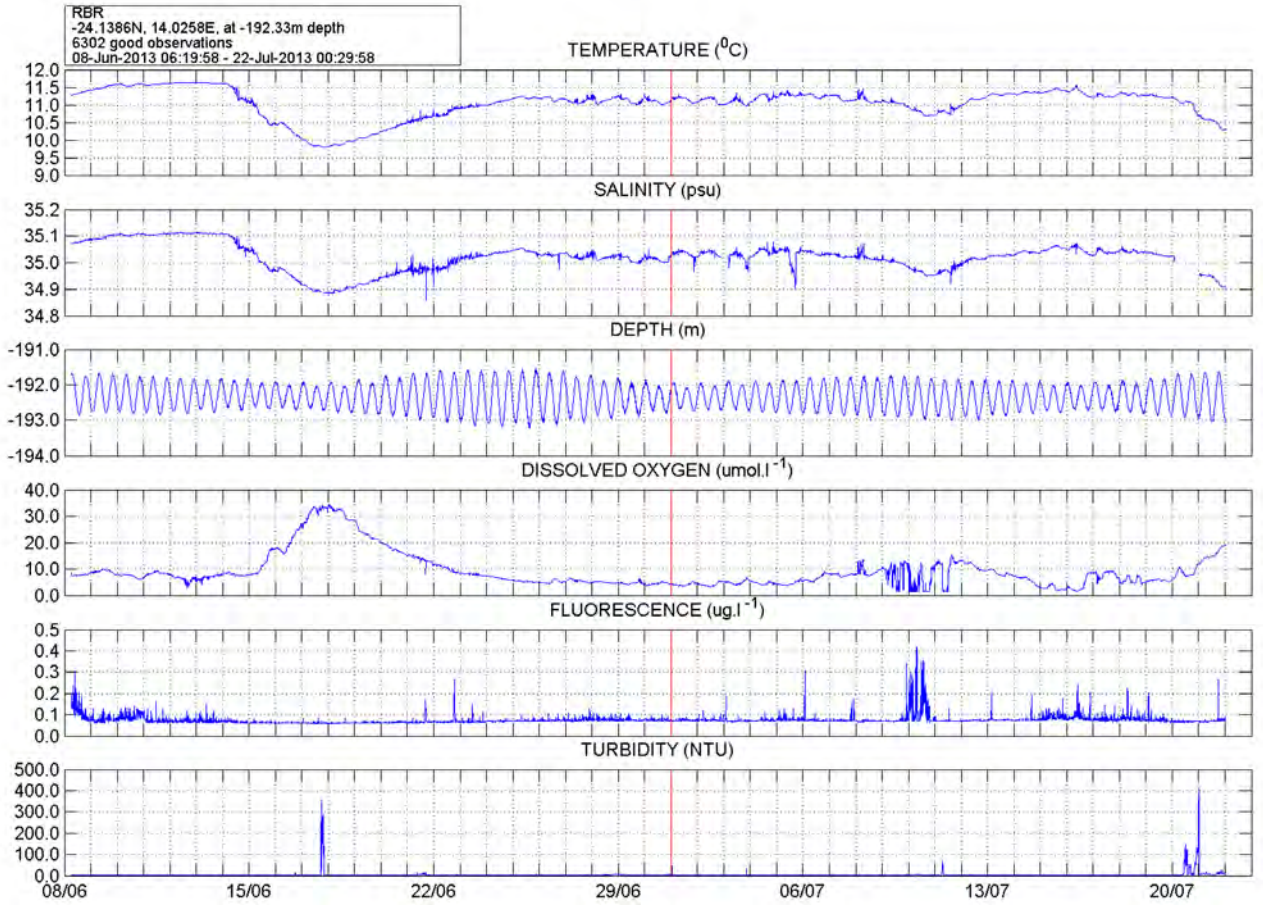


Figure 16: P1 near seabed RBR CTD data.
The data show the relationship between temperature, salinity and oxygen indicating the different sources of SACW water and isolated turbidity events.

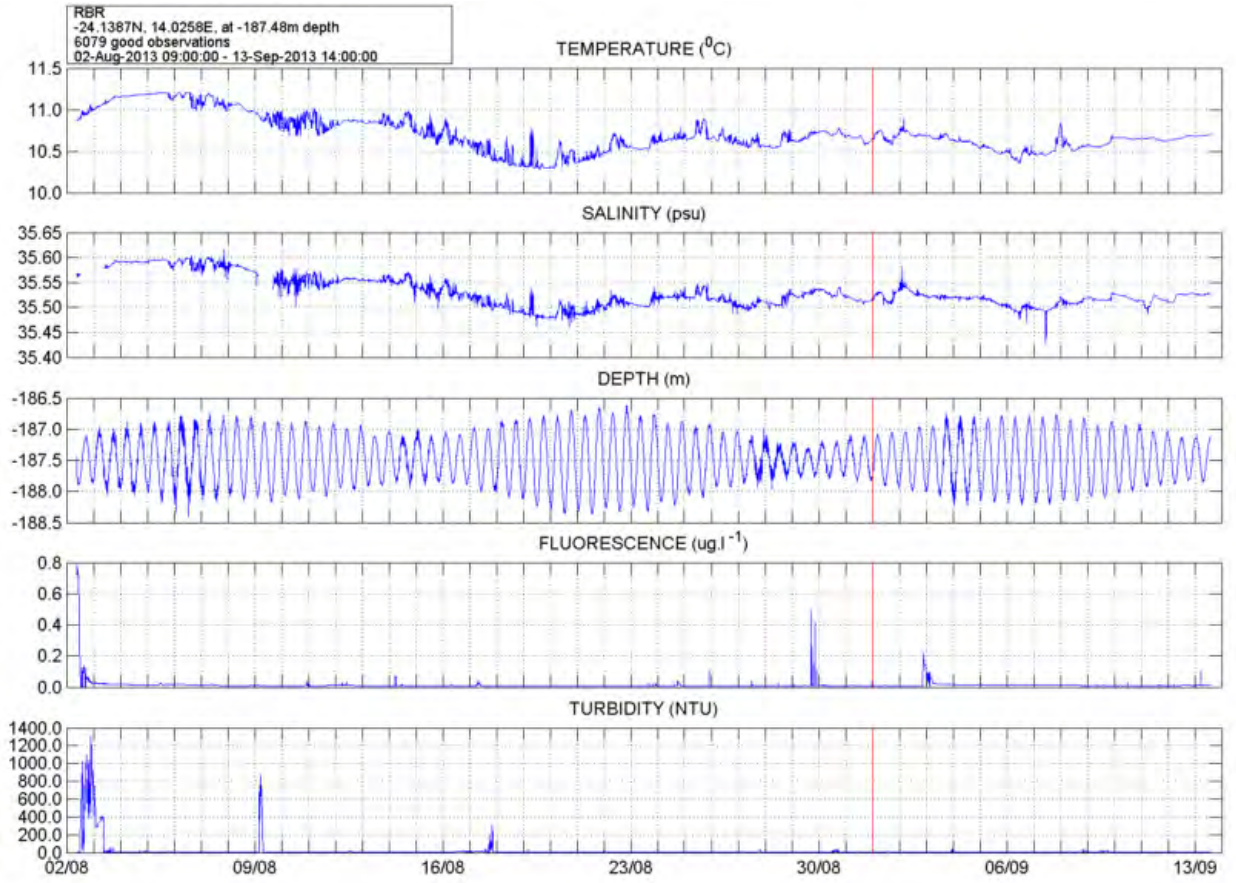


Figure 17: P2 near seabed RBR CTD data.
The data show the limited number of turbidity events, as well as the relationship between temperature and salinity.

© NMP 2014

In terms of system variability, a possible soliton event (where current speed and direction are found to change rapidly over a very short period of time (few hours)), was recorded on 17th July 2013 (P1). Such events may have implications for the engineering design of the mining equipment. The event was evident in temperature, current speed and direction, DO and salinity readings from the moored instrumentation where it was associated with cooler, fresher, more oxygenated water (Figure 18). The possible soliton event did not appear to result in a significant increase in turbidity at the mooring site.

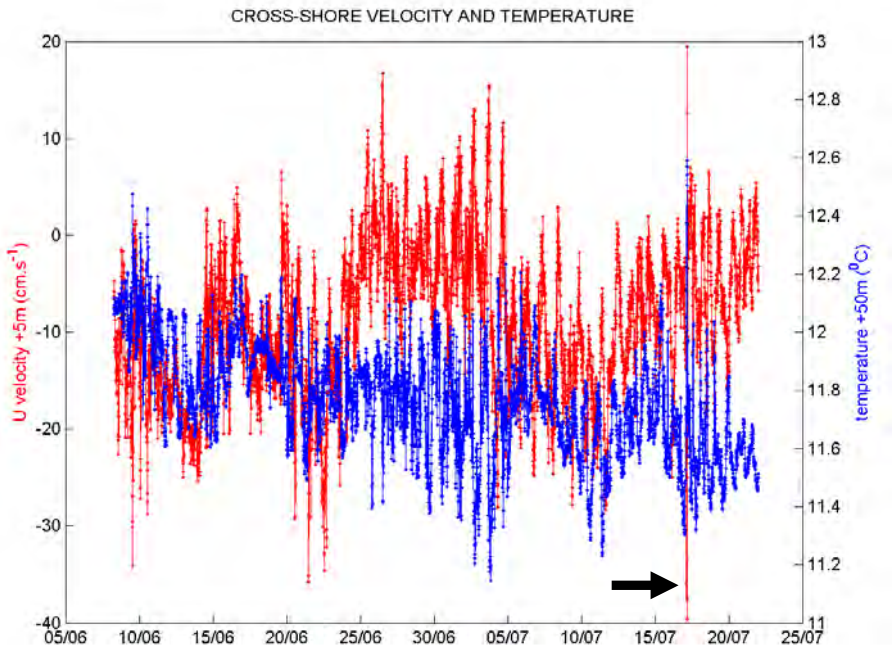


Figure 18: Cross-shelf (U) velocity and temperature record from P1
showing a possible soliton event on 17th July 2013.
This event involved an atypical change in speed and direction of the velocity field as well as the temperature over a very short period of time (few hours).

4.1.2.2 Temperature and Dissolved Oxygen

The temperature and dissolved oxygen profiles collected during the MV *DP Star* survey suggest that the depth of the upper mixed layer (UML) varied during the survey period. This UML, depicted by uniform temperature and high oxygen values (Figure 19), extended to a depth of between 20 and 30 m in the water column. As the measurements were made at six stations over a five day period (between 26th and 30th June 2013) these changes in UML depth indicate short term variability in the system. Below the normoxic (DO > 2.8 mg/ℓ[3]) UML thermocline temperature decreased and oxygen values fell to hypoxic values (<2.8 mg/ℓ) at approximately 120 m depth, declining further to severe hypoxia ,<0.5 mg/ℓ, near the seafloor (e.g. Stn VS14, Figure 20). The time series data from the moored instrumentation showed that near sea floor oxygen concentrations were persistently in the

[3] The terminology established by Diaz and Rosenberg (1995) is used here where normoxia = 11.2 – 14.0 mg/ℓ to 2.8 mg/ℓ, hypoxia = 2.8 mg/ℓ to zero and anoxia is zero oxygen.

© NMP 2014

severe hypoxia range (mean = 0.3 mg/ℓ) but increased to hypoxic levels (~1.10 mg/ℓ, 35 µM/l) during the ventilation event on 17-20 June (Figure 16).

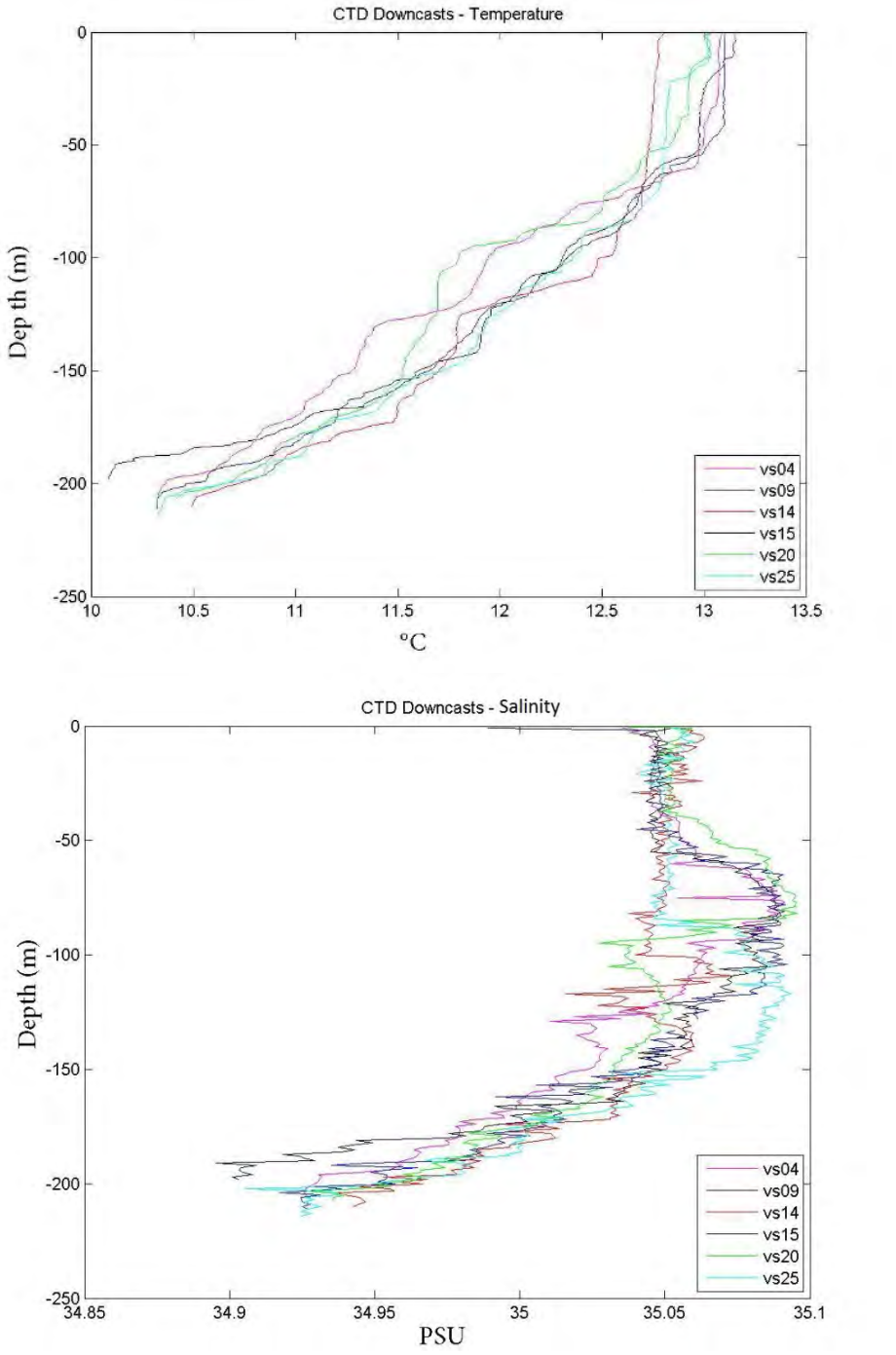


Figure 19: Temperature (upper panel) and salinity (lower panel) profiles measured in the survey area.

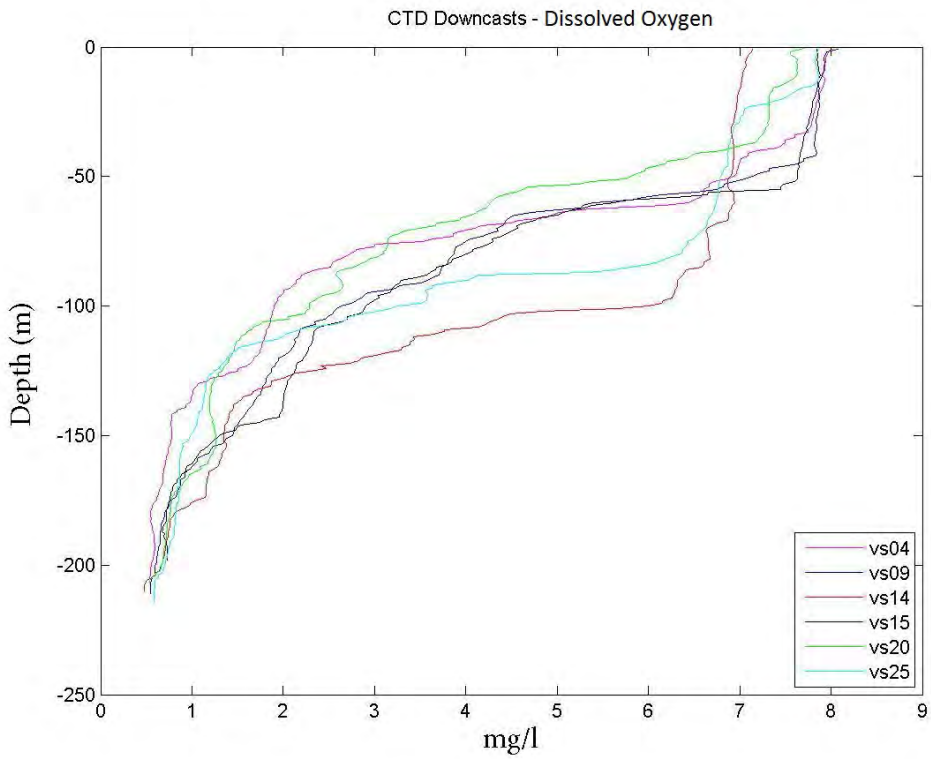


Figure 20: Oxygen profiles measured in the survey area.

4.1.2.3 Turbidity

Turbidity levels were generally low (<1 NTU) throughout both mooring measurement periods (Figure 16 and Figure 17) as well as through the water column (Figure 21). Slight elevations in surface and seafloor turbidity readings from the CTD profiles may be linked to the capture of dust particles at the surface and possibly low level turbidity in the benthic boundary layer due to elevated suspended sediments (e.g. Inthorn *et al*. 2006).

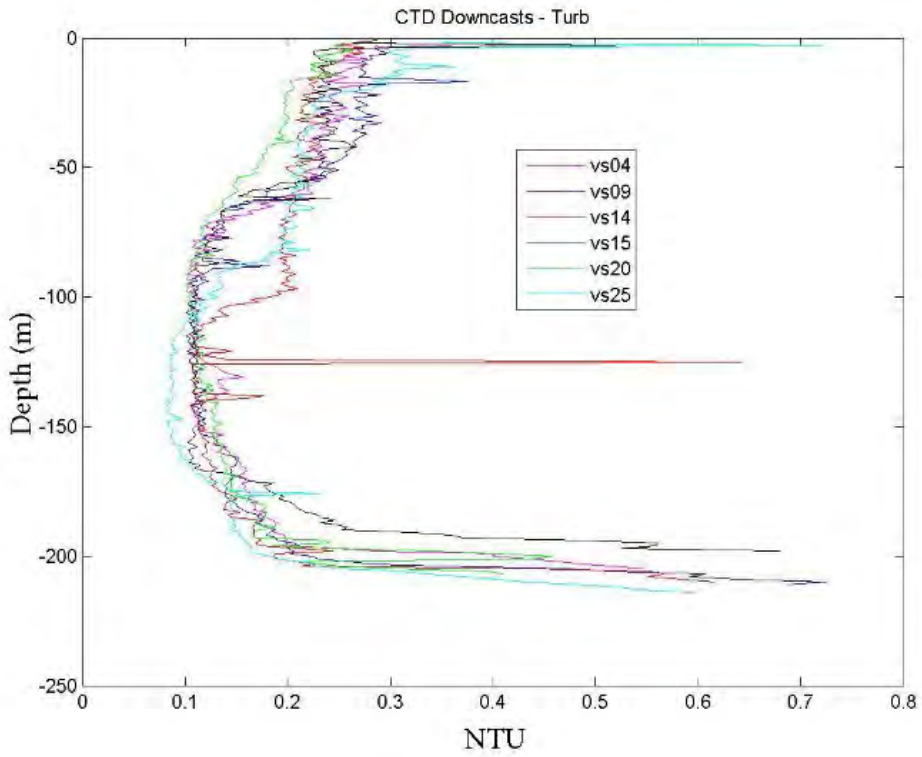


Figure 21: Turbidity profiles measured in the survey area (X-axis units are NTU).

Isolated elevations in turbidity were recorded near the seabed during the P1 and P2 current measuring periods. The period median value for P1 was 1.01 NTU, however two occasions of elevated turbidity were noted, where readings in excess of 350 NTU were recorded. The first of these occurred on the 17th of June and lasted for a few hours, while the second extended across 20th and 21st July, and was associated with turbidity >100 NTU increasing to a peak of ~400 NTU close to midnight on the 20th July (Figure 16). During P2 the median turbidity value was 3.51 NTU with increases in excess of 200 NTU noted on three occasions (Figure 17). These included a prolonged period of increased turbidity at the beginning of the measurement period (extending over 2nd and 3rd August) with a maximum value exceeding 1 300 NTU. Elevated NTU levels peaking at over 800 NTU were also evident for a few hours on the 9th August, and then on the 17th August turbidity levels rose steadily over a few hours to peak at ~ 300 NTU.

No clear trend between current speed and direction (acceleration or switching events) and turbidity levels was identified throughout the current measurement period (although the two events identified in P1 did coincide with changing current direction) similar to Inthorn *et al*. (2006). It appears that the recorded elevated turbidity events were generated further afield and then advected across the survey area (Figure 9, Figure 10, Figure 16, and Figure 17). Particles associated with these apparently farfield generated events (as well as those suspended from any events originating within the survey area) are not expected to settle on the seafloor of the survey area, as the bed shear stress was 0.2-0.3 Pa (Dr P. Monteiro, CSIR, *pers. comm.*), which is greater than the 0.05 Pa required to re-suspend the particle sizes that were encountered in this study (see Section 4.2).

© NMP 2014

4.1.2.4 Nutrients

The measures of inorganic nutrient concentrations collected from water samples at the various depths in the water column are summarised in Table 1.

Table 1: Mean dissolved nitrogen and phosphorus concentrations and the resultant Redfield ratios associated with water samples collected during the verification survey.

Sample depth (m)	NH_3-N	NO_3+NO_2-N	Phosphate	Redfield Ratio
	µg/ℓ	µg/ℓ	µg/ℓ	
1	28.00	179.33	20.67	21.75
10	28.00	154.50	21.33	18.48
20	25.00	145.67	20.33	18.10
50	24.67	200.67	28.50	17.22
100	20.00	273.33	40.00	16.18
Bottom Bin (185-200 m)	25.50	314.33	44.17	16.98
Survey Mean	**25.19**	**211.31**	**29.17**	**17.71**

As expected nitrate-nitrogen and phosphate-phosphorus increased with depth, attaining highest concentrations near the base of the water column. Redfield ratios, calculated as moles ammonia and nitrate-nitrogen/moles phosphate phosphorus, ranged from 16 to 22 with a water column average of 17.7. The upper water column ratios (20 m and above) indicate a slight elevation from the classical value of 16:1 implying that phosphorus may be marginally reduced. The data are limited in space and time and cannot be generalised to the region or longer time periods (e.g. months or seasons).

4.1.2.5 Phytoplankton Biomass

Fluorescence levels are elevated in the UML, as is expected in post upwelling conditions (Figure 22). The six CTD profiles indicate variability in the depth of the phytoplankton biomass maximum which could be linked to changes in phytoplankton buoyancy. The fluorescence levels decrease below 100 m.

© NMP 2014

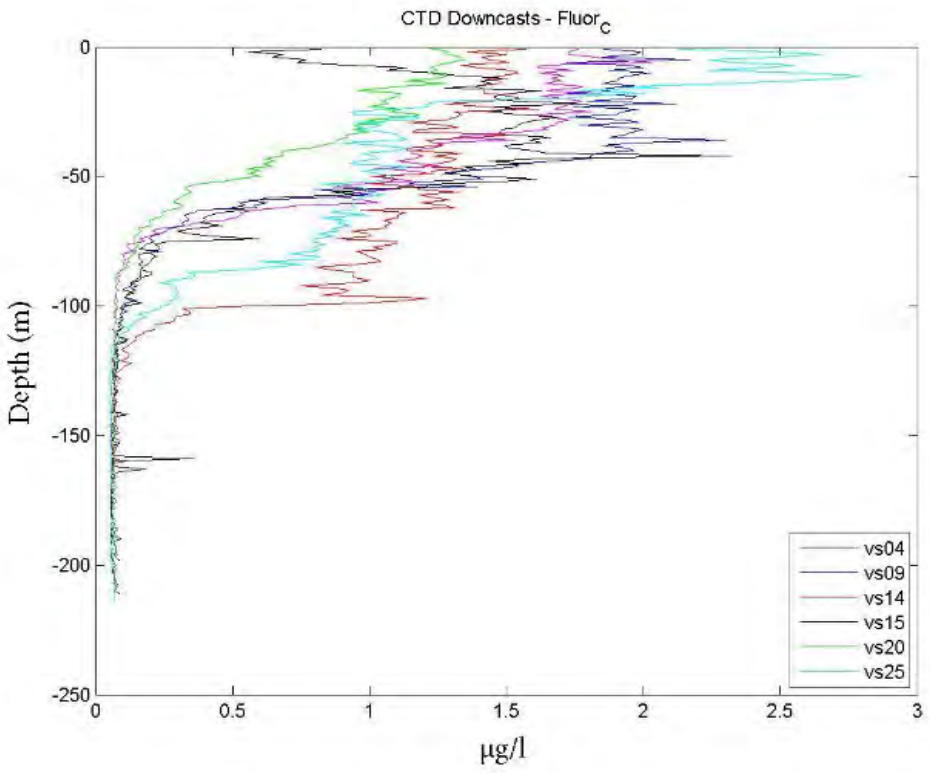


Figure 22: Chlorophyll fluorescence profiles measured in the survey area (x-axis units are chlorophyll *a* equivalents in µg/ℓ).

4.1.2.6 Heavy Metals

Heavy metal concentrations in the water samples collected at various depths in the water column during the verification survey were uniformly low. Aluminium, cadmium, chromium, copper, lead, mercury, manganese and nickel were all present at concentrations below the detection limits (Detection limits: 0.5 µg/ℓ (cadmium, chromium, lead, manganese, nickel), 1 µg/ℓ (mercury, copper), 5 µg/ℓ (aluminium)) and none of the measured metal concentrations exceeded the BCLME water quality guideline threshold values available for the region (CSIR 2006).

4.2 SEDIMENTS

4.2.1 Sediment particle size

The textural classification of the surficial sediments sampled by Day grab and the underlying sediments sampled by gravity core at the 26 sample sites are shown in Figure 23 and Figure 24, respectively (GRADISTAT v.8 (Blot 2010))[4].

[4] Note: In this study sediment particle sizes were measured by laser diffractometry. The algorithms used for image processing required that sediment particle sizes >2 000 µm ESD were excluded from analysis. Consequently gravel sized particles, mainly the larger shell debris, have not been estimated.

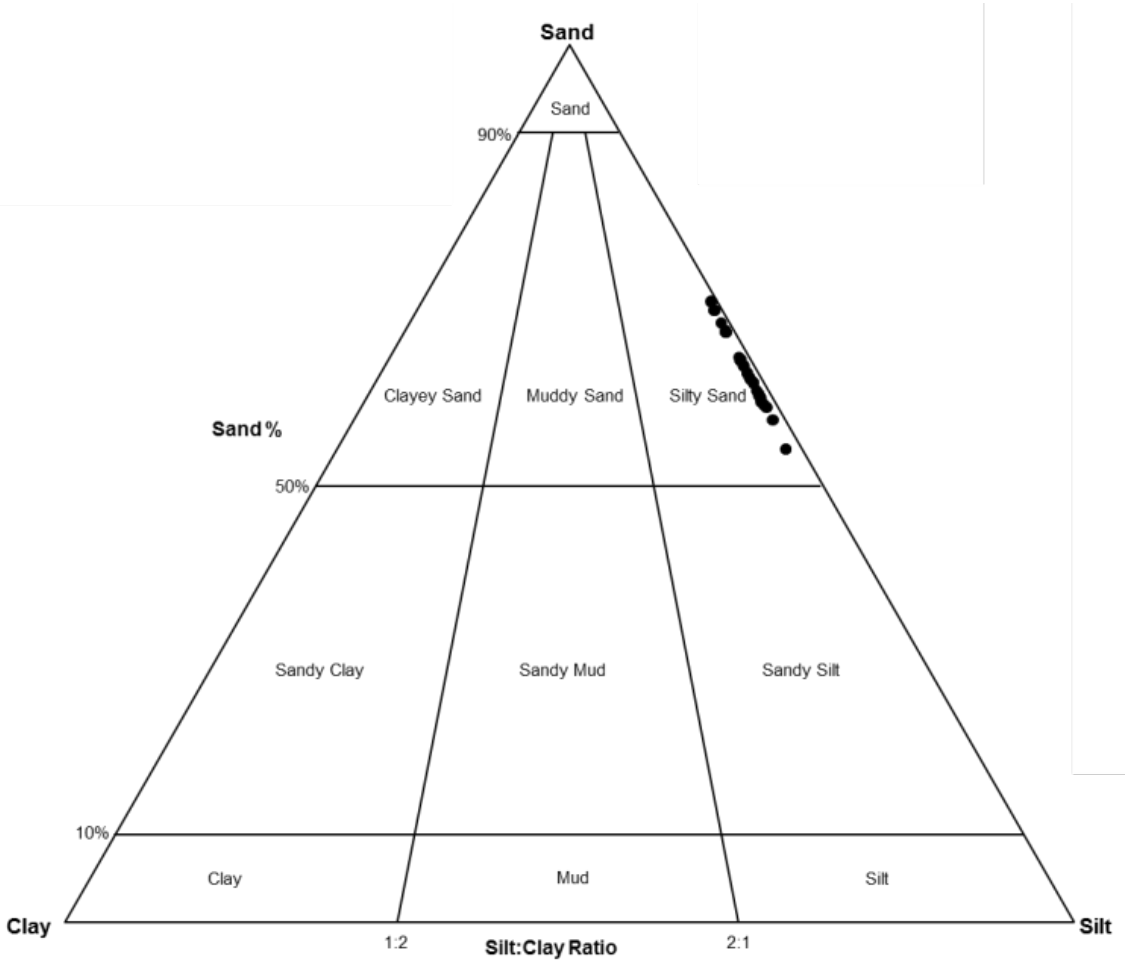


Figure 23: Ternary diagram showing surficial sediment texture classification (Day grab samples)

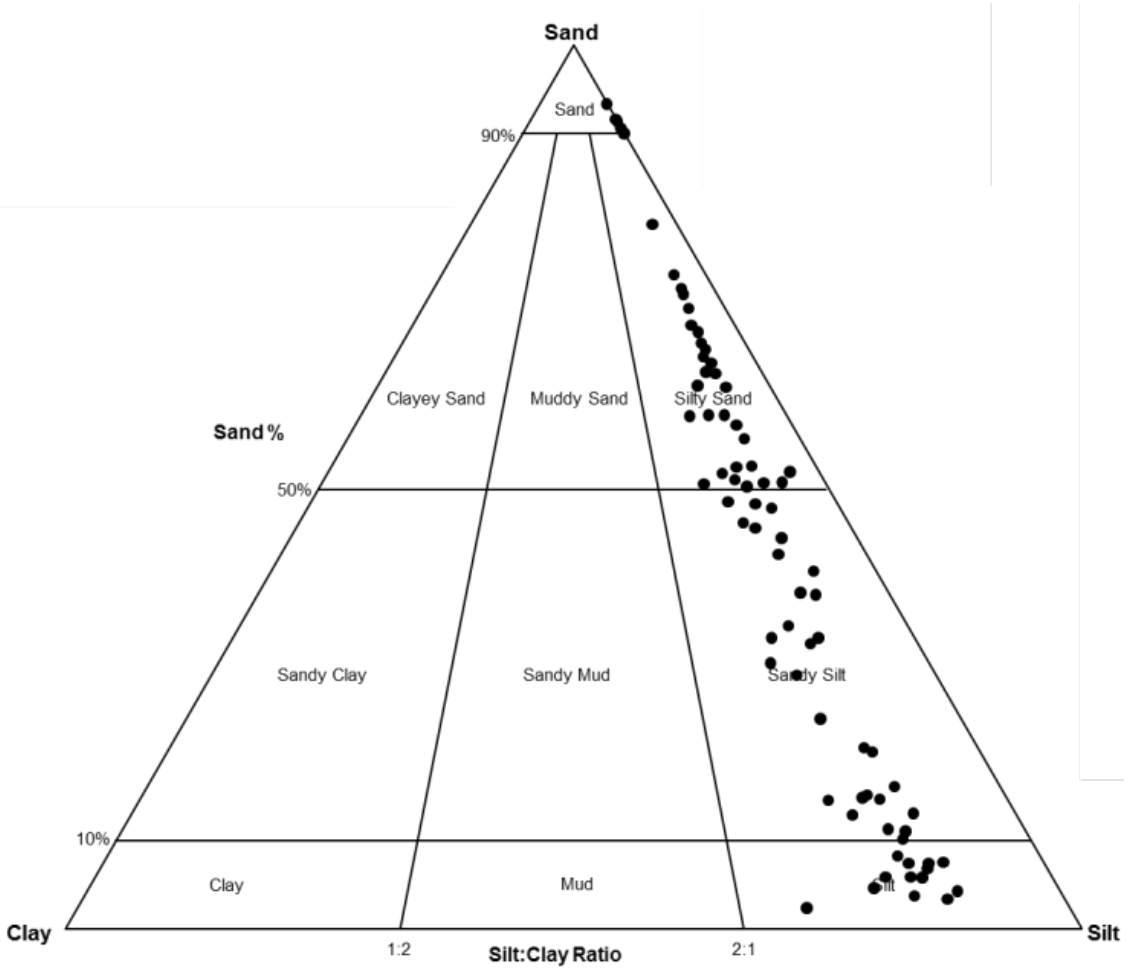


Figure 24: Ternary diagram showing subsurface sediment texture (Gravity core samples)

Surficial sediments textures are classed as silty sand and the underlying material falls into the silty sand to silt range.

These differences are reflected in particle size distribution plots (Figure 25 and Figure 26), which show that although the modal size is higher in core samples there is a stronger contribution of sediments of <10 µm particle size. This is confirmed in the box and whisker plot comparing the median (D_{50}) sediment particle sizes between the subsurface core samples and the surficial layer grab samples (Figure 27). In both cases the distributions are skewed towards the smaller particle size ranges but this is more dramatically so in the core samples than is evident in the Day grab samples of the surficial sediments.

© NMP 2014

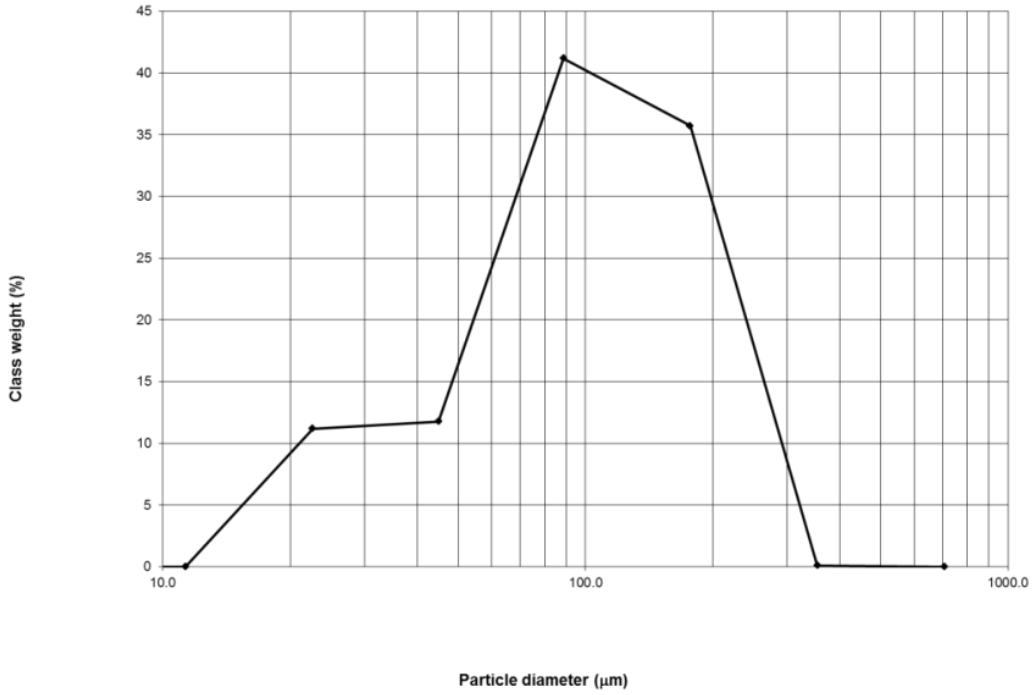


Figure 25: Particle size distribution plot for Day grab samples of surficial sediments in the survey area

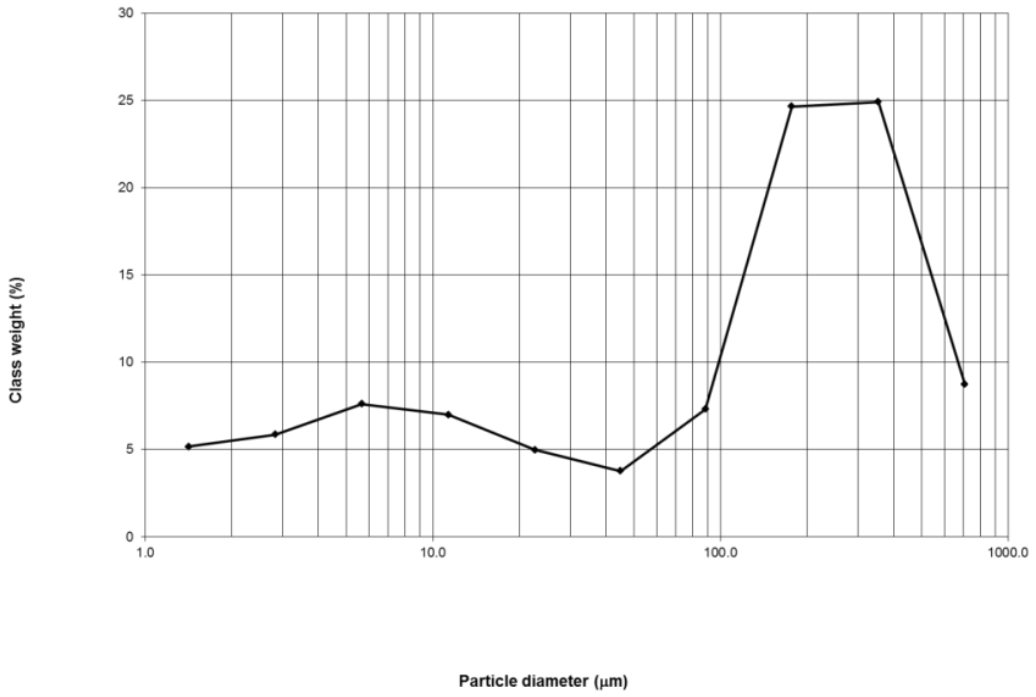


Figure 26: Particle size distribution plot for gravity core samples of subsurface sediments in the survey area

© NMP 2014

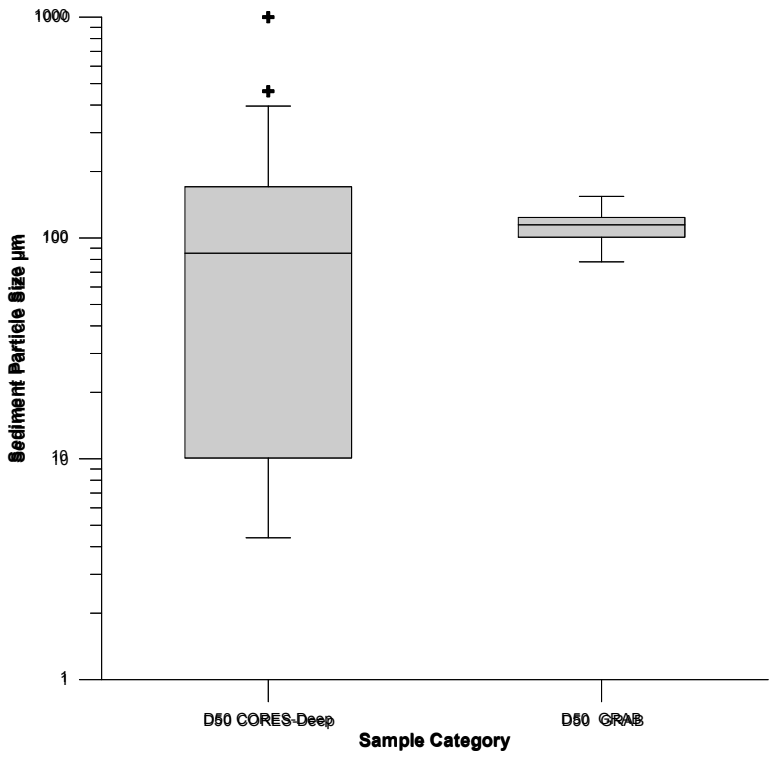


Figure 27: Box/whisker plot showing medians, inter-quartile ranges and outliers of sediment particle size D_{50} values for gravity core and grab sample sediments in the survey area.

Day grab and gravity core deployments showed that surficial sediment layers frequently included dense shell layers, to the point that repeat deployment attempts had to be made to obtain the required samples. Figure 28 shows an example of this (Grab sample #SP1VS23) in contrast to a less shell loaded silty sand sample (Grab sample #SP1VS20).

© NMP 2014

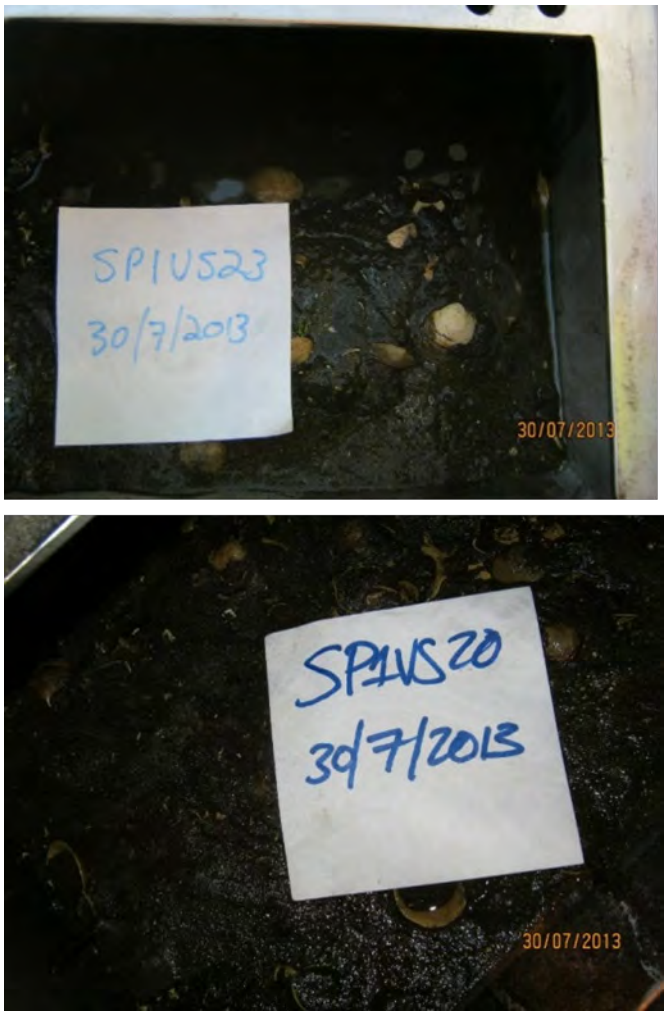


Figure 28: Grab sample photographs showing the shelly (top panel) and sandy silt (bottom panel) nature of the Day grab samples collected during the verification survey.

Gravity core deployments indicate that shell was denser on the eastern boundary of the survey area than sample sites further to the west. However, this is not apparent in the horizontal distributions of surficial sediment D_{50} values (median particle sizes) which indicate a less systematic pattern (Figure 29). Given the scale of the survey area relative to that of the processes controlling sediment distributions in mid- to outer-continental shelf areas this result is to be expected.

© NMP 2014

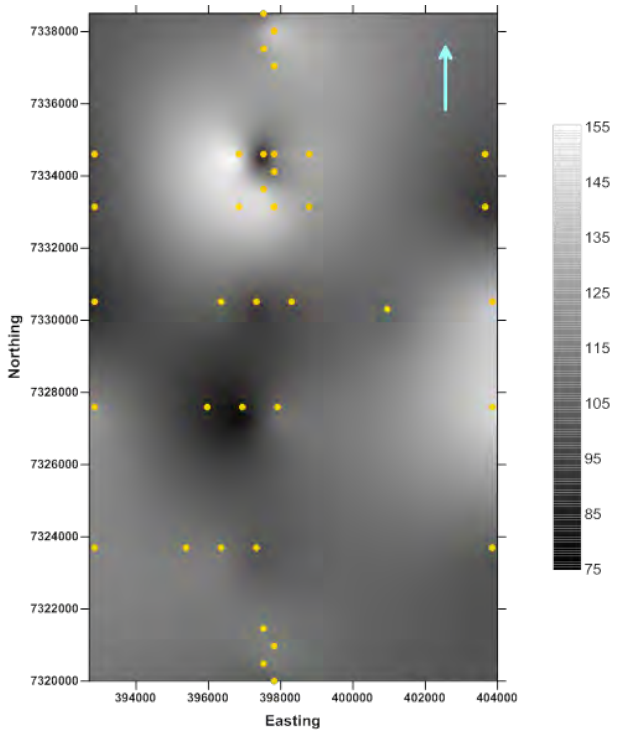


Figure 29: Distribution of surficial sediment (Day grab samples) median particle size (D_{50}) across the survey area.
The sample sites are shown by filled yellow circles (note that these include the macrofauna test and reference sites (n = 12); the blue arrow shows north.

4.2.2 Sediment organic content and associated properties

The sediment particulate organic matter (POM) content and the related metrics of organic carbon (POC) and total nitrogen (PON) concentrations, oxidation/reduction potential (ORP)[5] and acid volatile sulphide (AVS) concentrations measured across the target mining depth in the survey area are listed in Table 2 and Table 3.

[5] Core samples only

© NMP 2014

Table 2: Surficial sediment properties in the survey area (Day grab samples). Note that acid volatile sulphide (AVS) was below the concentration threshold (0.2 mMol/kg) of the analytical procedure employed.

Metric	Moisture	POM	POC	PON	C:N	AVS
	%	%	%	%		mM/kg
Mean	39.66	7.41	7.43	0.81	11.39	nd
SD	4.78	1.74	3.03	0.35	3.73	nd
n	26	26	26	26	26	26

Table 3: Subsurface sediment properties in the survey area (gravity core samples). Note that nitrate and phosphate were measured in pore water extracts

Metric	Moisture	POM	POC	PON	C:N	ORP	AVS	Nitrate	Phosphate
	%	%	%	%		mV	mM/kg	µg/ℓ	µg/l
Mean	35.85	7.46	6.62	0.44	19.85	70.80	1.67	155.87	209.19
SD	15.07	3.06	2.48	0.19	12.75	24.18	1.06	97.70	362.49
n	137	54	137	137	137	137	53	137	39

The mean moisture content, POM and POC concentrations were similar between the two sediment layers. Total nitrogen (PON) was elevated in the surficial sediments but AVS was below the analytical detection limit. AVS, although detectable in the subsurface sediments, was low. Molar C:N ratios in both sediment layers were high, indicative of relatively refractory organic matter. This metric was higher in the subsurface sediments consistent with a longer burial period as would be expected from the origin of the ore body (Compton 2012).

In the subsurface sediments (Table 3) the redox potential (ORP) measurements indicate that the sediment body is hypoxic (dissolved oxygen levels within the sediment body are less than 2.8 mg/ℓ but greater than zero) (e.g. Palmeri *et al*. 2014). However, bottom waters were characterised by severe hypoxia (DO <0.5 mg/ℓ) over most of the measurement period and it would be expected that pore waters would be similarly low in oxygen. Given this, it is possible, but considered to be unlikely, that the core sediment samples were exposed to the atmosphere during the ORP measurement process and linked oxygen flux into the sediment produced the elevated redox potential measurements. The presence of nitrate-nitrogen in the sediment pore waters from cores collected to a depth of over 2 m indicates that, even if severely hypoxic the sediments were not sulphidic as nitrate-nitrogen and hydrogen sulphide do not coexist (Brüchert *et al*. 2003). This is further supported by the observed low AVS concentrations.

The subsurface sediment pore water contained moderate nitrate-nitrogen concentrations but high phosphate-phosphorus concentrations (Table 3). The latter is to be expected as the sediments sampled are part of a pelletal phosphate ore body. A consequence of this phosphorus enrichment is that the pore waters show a considerable departure from the water column Redfield ratio observed in the survey area (8.2 vs 17.7, Table 1). The moisture content of the sediment is low, however, indicating that the affected pore water volume is also low (~35 litres/m^3 sediment).

4.2.3 Heavy metal concentrations

The heavy metal concentrations measured in the surficial sediment layer (Day grab samples) and in the underlying sediments (gravity core samples) across the target mining depth are summarised and compared against BCLME sediment quality guideline concentrations (BCLME 2006) in Table 4. This

© NMP 2014

table shows that for all elements, except for manganese and mercury, concentrations in the subsurface layers were higher than those in the surficial sediments. This is partly ascribed to the dilution effects of dense shell aggregations on heavy metal concentrations in the surficial layers. The median concentrations of five of the metals measured in the sediment body exceeded the toxicity effect concentration thresholds for the region as defined in BCLME (2006). Chromium and copper were higher than the recommended guideline level (equivalent to the threshold effect level, TEL, above which toxicity effects may occur) while arsenic, cadmium and nickel exceeded the probable effect level (PEL). Although the concentration values of many heavy metals exceeded TELs, the actual bioavailabilty of these was found to be very low (Table 5). Additionally, similar to the metals AVS was undetectable in the surficial sediments but occurred at measurable concentrations in the subsurface sediments and was in exceedance of the simultaneously extracted metal (SEM) levels.

Table 4: Median heavy metal concentrations (mg/kg), AVS and SEM[6] (mM/kg) for Day grab (surficial sediments) and gravity core (subsurface sediments) samples in the survey area

The heavy metal concentrations are compared with the BCLME regional sediment quality guideline concentrations (mg/kg). Elements in bold type exceed recommended guideline (BCLME RGL) concentrations whilst those in bold red type exceed probable effects level threshold concentrations (BCLME PEL).

Metal / Property	Day Grab Samples (n = 26)	Gravity Core Samples (n = 136)	BCLME RGL (= TEL)	BCLME PEL
Al	5106.00	14855.00	-	-
As	**46.88**	**51.65**	7.24	41.60
Ba	39.34	61.99	-	-
Cd	**13.85**	**21.40**	0.68	4.21
Co	3.21	5.53	-	-
Cr	**120.60**	**155.12**	52.30	160.00
Cu	**21.89**	**35.50**	18.70	108.00
Fe	9516.22	18460.00	-	-
Mn	30.35	14.25	-	-
Hg	0.10	0.07	0.13	0.70
Ni	**46.99**	**77.63**	15.90	42.80
Pb	7.90	23.35	30.20	112.00
V	29.58	50.21	-	-
Zn	26.51	53.67	124.00	271.00
AVS	-	1.97		
SEM (Divalents)	0.14	0.15		
SEM/AVS	-	0.09		

Heavy metals in the surficial sediments co-vary with aluminium with most of their variability being explained to varying extents by the distribution of this proxy for clay minerals (Figure 30). Clay minerals would be imported into the area via atmospheric dust fallout and fluvial input. Hence it is probable that the heavy metals have a terrigenous origin. Cadmium does not conform to this model as its relationship with aluminium is weak. Borchers *et al*. (2005) attribute high cadmium

[6] SEM is calculated as the sum of the concentrations of the divalent metals Cd, Cu, Ni, Pb and Zn extracted in the acid fraction along with AVS (Di Toro *et al*. 1992)

concentrations in Namibian continental shelf sediments to cycles of H_2S outgassing and sulphidation of the lower water column. This triggers precipitation of cadmium (as CdS) and sedimentation along with POM from phytoplankton. Similar non-conformity has been reported for cadmium in the biologically productive Saldanha and St. Helena Bays on the South African west coast (CSIR 2010); here sequestration in the sediments may be mediated via sedimenting senescent phytoplankton as opposed to precipitation as a sulphide.

Despite their apparent natural, as opposed to anthropogenic origin, the heavy metals that exceed the established sediment quality guidelines for the region (BCLME 2006) represent an apparent toxicity risk. This risk is primarily linked to whether or not the metals are bioavailable to marine organisms; exposures being either through the aqueous (dissolved) phase, or direct ingestion of heavy metals bound to POM (Wang, 2002). Dissolution can occur when metals are mobilised from the particulate into the dissolved form (e.g. Di Toro *et al*. 1992 and others) through, e.g., disturbances to the seabed resulting from natural processes such as methane ebullition or through direct disturbances such as those caused by dredging and demersal trawling. Metal dissolution (especially that of divalent metals) is affected by the presence of free sulphides as these bind readily with the metals causing rapid re-precipitation as insoluble metal-sulphides. The availability of other metal binding sites such as iron and manganese hydroxides, and particulate organic matter either individually or (more frequently) in metal-organic complexes also affects metal dissolution.

The potential for the heavy metals that exceed the BCLME sediment quality guideline concentrations to become bioavailable, by entering and persisting in the dissolved phase, was measured by elutriation tests on gravity core samples (surface to over 2 m depth in the sediment body). There was insufficient sediment volume in most of the Day grab samples to run these tests on the surficial sediments, hence their exclusion from this measurement. The results summarised in Table 5 indicate that negligible proportions of the metals solubilised and that the concentrations of the bioavailable fraction of the metals were well within the BCLME (2006) threshold effect (TEL) guideline concentrations. Factors limiting the dissolution of metals would have been the presence of AVS as, although present at low concentrations, it was in excess of the SEM fraction (Table 4), as described above. Additionally other metal binding complexes such as iron and manganese hydroxides and particulate organic matter, would have prevented the dissolution of metals. Hence, no toxicity effects of the identified heavy metals, including bioaccumulation and trophic transfers in the marine food chain, either *in situ* or following redistribution by the mining process are expected from increased concentrations in the dissolved phase.

© NMP 2014

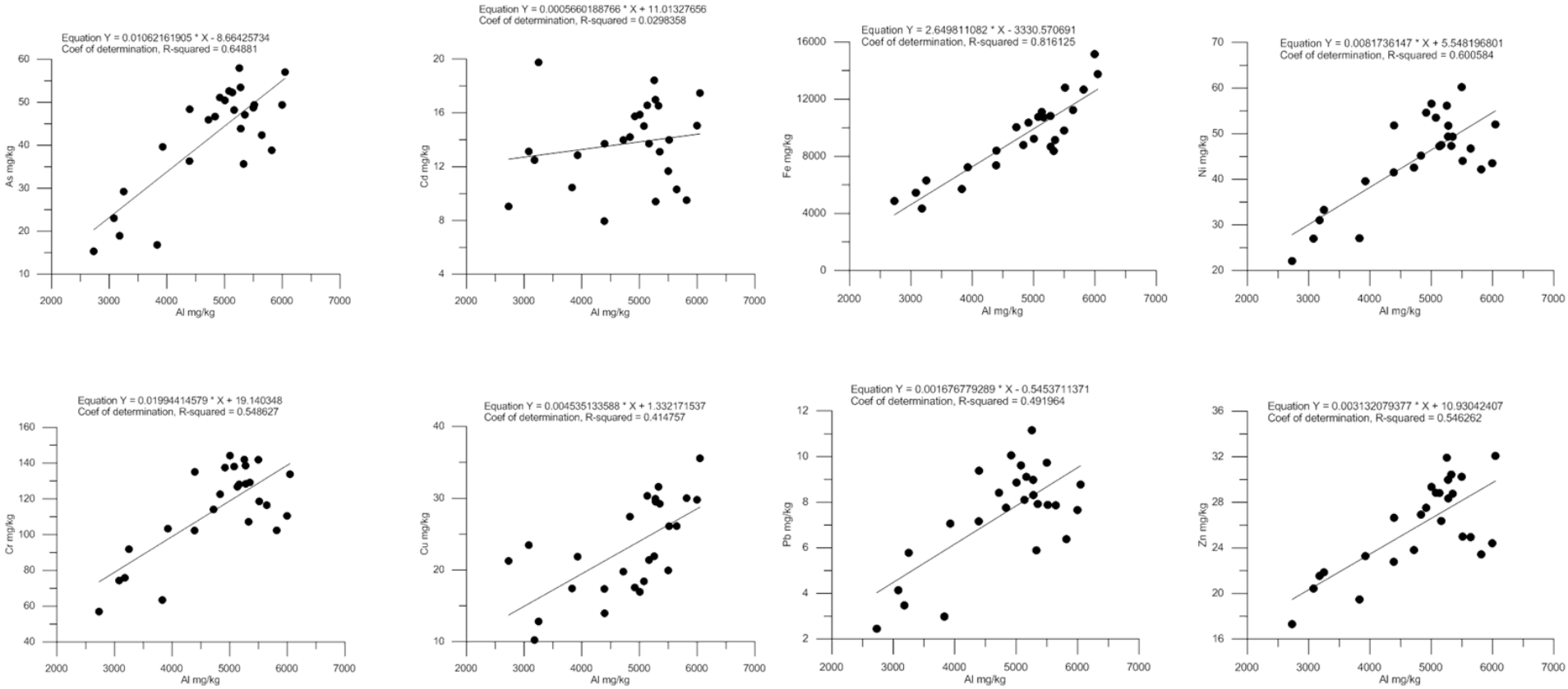


Figure 30: Scatterplots showing the relationships between selected heavy metals and aluminium a proxy for terrigenous clay minerals, in the surficial sediments sampled from the survey area (Day grab samples).

Table 5: Proportions (% of mass in sediment) of selected heavy metals released from gravity core samples subjected to elutriation tests.

Core #	% As	% Cd	% Cr	% Cu	% Ni	% Pb
2878	0.125	0.013	0.002	0.004	0.004	0.031
2880	0.447	0.041	0.001	0.01	0.008	0.033
2880	0.373	0.021	0.001	0.006	0.006	0.023
2881	0.305	0.012	0.001	0.006	0.004	0.025
2882	0.231	0.049	0.001	0.011	0.003	0.035
2882	0.401	0.016	0.001	0.006	0.004	0.023
2883	0.378	0.093	0.001	0.01	0.006	0.032
2883	0.162	0.109	0.001	0.005	0.02	0.042
2884	1.387	0.154	0.001	0.005	0.004	0.047
2884	1.75	0.011	0.001	0.006	0.002	0.036
2888	1.55	0.177	0.001	0.013	0.006	0.04
2894	0.485	0.054	0.002	0.013	0.005	0.034
2894	2.339	0.052	0.001	0.012	0.005	0.038
Mean	**0.76**	**0.06**	**0.00**	**0.01**	**0.01**	**0.03**
Bioavailable Fraction mg/kg	0.36	0.03	0.00	0.00	0.00	0.01
BCLME TEL	7.24	0.68	52.30	18.70	15.90	30.20

Toxicity effects mediated through take-up of heavy metals in the particulate phase by primarily by deposit and filter feeders requires adsorption to or association with organic particles, generally detritus. The potential for this is unknown in the survey area. However, effects appear to be constrained as trophic transfers in pelagic food chains probably attenuate at the primary consumer level (copepods, Wang and Fisher, 1998, Wang 2002).

4.3 BENTHOS

Benthic faunal distributions were investigated in the meiofauna and macrofauna size categories. These investigations were conducted respectively by Dr Simon Forster of Physalia Applied Sciences, UK (Physalia) and Dr Nina Steffani of Steffani Marine Environment Consultant and are the subject of independent reports presented as part of the verification programme (Physalia 2014, Steffani 2014). For completeness, summaries of these investigations are presented below.

4.4 MEIOFAUNA

A total of 135 nematode and 36 harpacticoid copepod taxa was identified from meiofauna samples collected at the 26 verification sites. Nematode species richness values of up to 42 species per sample were recorded and densities of up to 30,400 nematodes per litre of sediment were present. These data are comparable to other offshore seabed sites recorded at similar water depth. Analyses of community structure identified six robust, coherent clusters of communities comprising structurally-related species assemblages. The community clusters were consistent with the presence of an environmental gradient along the west-east axis of the sampling sites. It is apparent that this gradient in sediment granulometry, with finer sediments and silts occurring to the west of the survey area and coarser sediments to the east, was the principal determinant of meiofaunal community

© NMP 2014

structures during the verification survey. The sediment particle size analysis results, described earlier, support this view although when plotting the median particle size value for each site (determined from the surface grabs) (Figure 29), the trend in particle size is more complex than suggested in the meiofauna report.

The detailed Physalia report is presented in Section C, Chapter C2.4 (Physalia 2014).

4.4.1 Macrofauna

The distributions of benthic macrofauna across the verification survey area were investigated in three size fraction, >1 000 µm, 500-1 000 µm and 300-500 µm to show the relative distributions of taxa and biomass. The >1000 µm fraction was clearly characterised by macrofauna, which contributed 93% to the benthos while meiofauna was sparse (7%). The smaller fractions, on the other hand, were dominated by meiofauna with 73% and 83% in the 500-1000 µm and 300-500 µm sections, respectively. A total of 26 macrofauna species/taxa was encountered in the >1000 µm fraction. The addition of the 500-1000 µm section increased the number of species to 30, with the additional species being two polychaetes, , a cephalocarid and an ectoprocta species The addition of the 300-500 µm section, however, did not add any further taxa to the macrofauna list. Macrofauna was most abundant in the >1 000 µm fraction contributing >90% to the overall abundance, while the relative abundance of meiofauna increased drastically in the 500 µm fraction and even more so in the 300 µm fraction to 83% relative abundance. The addition of the 500 µm size fraction increased the total number of species encountered from 27 to 33 (increase of 18%), but the 300 µm fraction did not add any more species. In the >500 µm size fraction a total of 3919 specimen belonging to 36 taxa was recorded at the 15 survey sites in SP-1. Polychaetes were dominant, being represented by 25 taxa, followed by crustaceans and cnidarians (three taxa each) and single taxa for molluscs, echinoderms, nemertines, ectoprocta and oligochaetes. The most common species was an oligochaete Tubificidae spp., which contributed on average 32.6% to the total abundance per site, closely followed by the polychaete *Paraprionospio pinnata* (31.3%). Other common animals included the polychaetes *Aphelochaeta* sp. 1 (11.7%), *Lumbrineris meteroana* (6.6%), *Diopatra monroi* (4.6%), and *Syllidia armata* (3%). The most common non-annelid taxon was a seapen Veretellidae sp. (<1%). Crustaceans were represented by the sandprawn *Callianassa australis* (8 specimens in total or 0.2% on average), an amphipod *Grandidierella* sp. 1 (two specimens at one site), and one cephalocarid specimen of the family Hutchinsoniellidae sp. 1. Nemertines and anemones were represented by five and three specimens, respectively, while all other phyla had one specimen only.

While *P. pinnata* and Tubificidae spp. characterised the macrofauna communities in terms of abundance, biomass was strongly dominated by the presence of the large polychaete *Diopatra monroi* that contributed on average 54.5% to the total biomass per site. It is endemic to southern West Africa, where it can occur in dense concentrations of >500/m^2. The second most important biomass-contributor was the also relatively large *P. pinnata* contributing 20.5%, followed by the seapen (12%) and the sandprawn *C. australis* (4.6%). All other taxa contributed insignificantly to the biomass (<1% per taxa). This shows that more than 90% of the macrofaunal biomass consisted of five species only.

The benthos assemblage recorded in the verification survey was similar to that observed in the area in the initial surveys conducted there (Steffani 2010). These communities are apparently shaped by hypoxic conditions that are characteristic of the area as exemplified by the dominance of *P. pinnata* as it typifies oxygen-constrained environments worldwide. The low crustacean abundance is another feature of such environments. In contrast there were some large forms present that appear to

© NMP 2014

require more oxic environments or, at least, episodic exposures to these, e.g. the abundance of a variety of large species (e.g. *D. monroi*) that clearly dominate the biomass and abundance/biomass distributions that indicate mostly undisturbed environment. Further, the presence of large polychaetes such as *D. monroi* may be an indicator as to whether anoxia or toxic H_2S levels occur. Such large animals can have appreciable life spans, e.g. another brooding species of the genus, *D. marocensis*, is considered to have a life span of at least two years. The presence of this species and possibly the congeneric *D. monroi* thus suggest that at least in the >6 month period prior to the verification survey, conditions had not become anoxic or sulphidic to the extent that lethal effects would have been generated on the benthos in general or these species in particular.

4.4.2 Thiobacteria

Sulphur bacteria distributions in the MLA 170 licence area were investigated by Bronwyn Kirby, Next Generation Sequencing Facility Department of Biotechnology, University of Stellenbosch and are the subject of a separate specialist report commissioned as part of the verification process. For completeness a summary of the main findings of this investigation is presented below.

Bacterial genera involved in both sulphur-oxidisation and sulphur-reduction were found to be present in the samples obtained from the proposed mining area. The numbers of sulphur-oxidising bacteria were lower than the numbers of sulphur-reducing bacteria. Sulphur-oxidising bacteria utilise H_2S as fuel, oxidising it into sulphate. This keeps the H_2S within the sediment, and prevents it from being released into the water column. In contrast to this process, sulphur-reducing bacteria reduce sulphate, through respiratory processes, into H_2S, and so are characteristic of sediments where higher concentrations of H_2S are present (Jorgensen 1977). The presence of the sulphur-utilising groups of bacteria corroborates the presence of the hypoxic sediments within the mining licence block, as both groups are associated with low oxygen conditions (Jorgensen 1977).

The bacterial genera involved in sulphur reduction identified in the samples obtained included *Desulfobacteralis*, *Desulfovibrionales*, *Syntropobacterialis*, *Desulfoto-maculum*, *Desulfosporomusa* and *Desulfosporosinus*. The bacterial species involved in sulphur oxidisation included *Thiobacillus thiooxidans*, *Thiobacillus ferrooxidans*, *Thiobacillus denitrificans* and *Acidothiobacillus* spp. In general, *Thiobacillus* species have a low growth yield (Jorgensen & Nelson 2004), which explains the lower concentrations of sulphur-oxidising bacteria in comparison to sulphur-reducing bacteria within the study region. Because of these low growth yields and less efficient oxidising capabilities, *Thiobacillus* spp. are of less significance in the oxidisation of H_2S, compared with the large sulphur bacteria, that have been found in the Namibian continental shelf region (Jorgensen & Nelson 2004, Brüchert *et al*. 2003) . None of the large sulphate bacteria, namely from the genera *Thiomargarita*, *Beggiatoa* and *Thioploca*, which have developed more specialised modes of sulphur oxidisation and that play a more significant role in the oxidisation of H_2S, were found in the samples from the mining licence area (MLA 170).

The sediment properties analysed in this verification survey indicate that there are low acid volatile sulphide (AVS) concentrations in the sediment. AVS is used as a proxy for H_2S production and sulphate reduction. The apparent low levels of H_2S production and sulphate reduction occurring within sediments in the mining area corroborate the absence of large sulphur bacteria within the samples and would suggest that the levels of H_2S flux within the area are too low to support large populations of these bacteria. Instead less conspicuous sulphur-oxidising bacteria, such as *Thiobacillus* spp. are active.

© NMP 2014

5 DISCUSSION

The purpose of the survey described in this report was to examine and verify, or contradict, the main conclusions of the NMP Marine Phosphate Mining EIA specialist study (Lwandle 2012 in NMP 2012). The pivotal issue and expressed uncertainty by the various reviewers of the specialist study was the nature of the seabed in the proposed mining area, especially in terms of whether it supported an appreciable sulphide flux and linked environmental processes. This aspect is addressed through the discussion of the above findings in conjunction with assessments provided to this study by Dr. P. Monteiro, CSIR, South Africa (*in Litt*.) The balance of the issues raised during review of the original specialist report to the EIA are also summarised.

Monteiro (*in litt.*) evaluated the potential releases of sulphide from the sediments from two sources; that linked to organic loading to the sediments and from oxidation of iron pyrites (FeS_2) in suspended sediment (turbidity plumes) in the water column.

In the first instance Monteiro examined the core hypothesis that the area surveyed in the verification study has characteristics typical of the inner continental shelf biogenic particulate matter enriched mud belts, hereafter referred to generically as mud, extending north of 24° S and an alternate hypothesis that sulphate reduction, an important characteristic of the mud belt, is minimal because turbulence in the benthic boundary layer limits accumulation of pelagically produced particulate matter (POM) and associated particulate organic carbon and nitrogen. Data and information used were those summarised in this report and the peer reviewed published investigations on the Namibian continental shelf mud belts (Monteiro *et al*., 2005, 2006; van der Plas *et al*. 2007 and Brüchert *et al*. 2003).

The Namibian cross shelf %POM and bathymetry characteristics as well as the positions of the 22°S line of stations investigated by van der Plas *et al*. (2006) are shown in Figure 31. This study showed that the inshore mud belt sediments were characterized by elevated POM (>15%) and molar C:N ratios <9. These are indicative of a high flux of relatively fresh phytoplankton into the sediments of the mud belt. In contrast, sediments offshore of the mud belt support lower POM (<10%) and higher C:N ratios (>9), implying a lower supply, or less retention, of pelagically produced organic carbon and that this is older, refractory material. Further, AVS, a proxy for hydrogen sulphide (HS^-) production (sulphate (SO_4) reduction) is low (<5 mMol/kg) in low POM environments but elevated to 8-22 mMol/kg in high POM sediments.

© NMP 2014

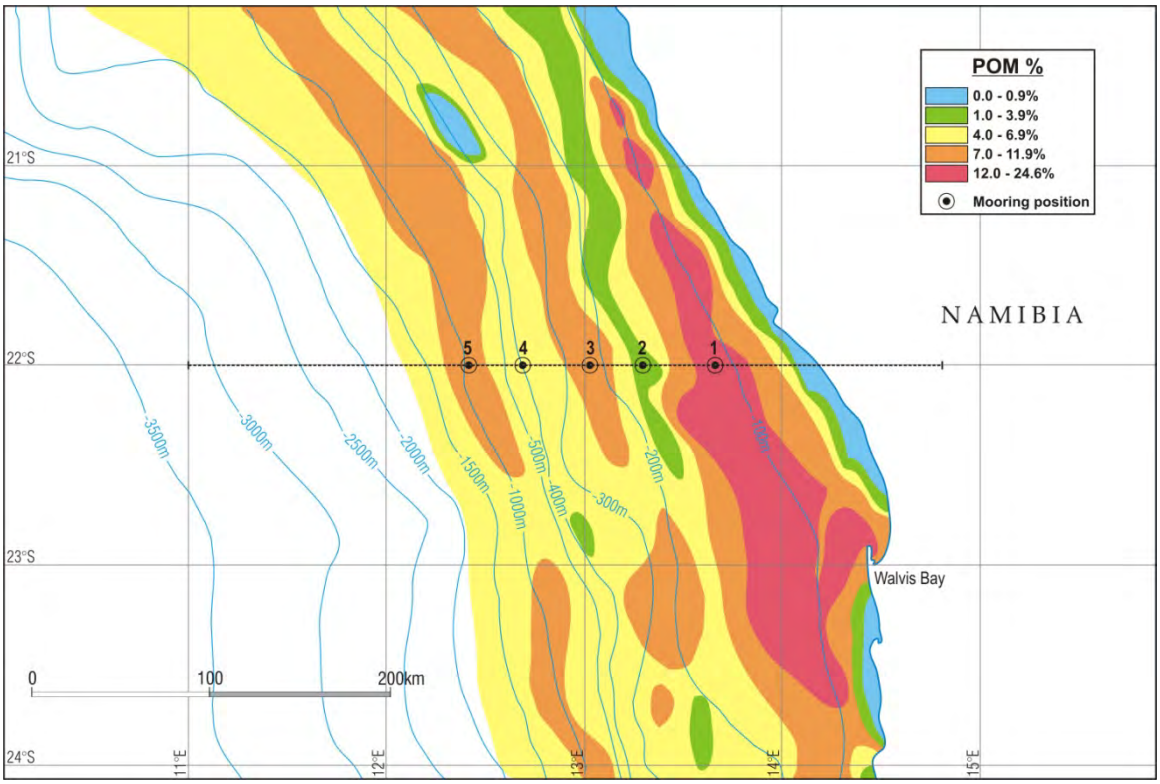


Figure 31: Namibian cross-shelf POM distributions (from Bremner 1978) and the locations of the 22° S station transect (redrawn from van der Plas *et al*. 2007)

Brüchert *et al*. (2003) measured SO_4 reduction and pore water HS^- concentrations on a transect across the continental shelf between 22° S and 23° S. Their results showed that SO_4 reduction rates were very high at 300-3 000 nMol/cm^3/day in the upper 10 cm of the mud belt sediments but outside of this declined sharply to 2-10 nMol. Correspondingly pore water HS^- concentrations were ~10 mMol/l in the mud belt sediments but an order of magnitude less offshore of the mud belt.

The Brüchert *et al*. (2003) investigation also showed that the transition between mud belt conditions and the lower POC concentration offshore was sharp as summarised in Table 6**.** This leads to the general statement that, when water depth is >150 m and nitrate-nitrogen concentrations rise above zero, HS^- in the benthic boundary layer is zero.

Table 6: Benthic boundary layer properties across the Namibian continental shelf (from Brüchert *et al*. 2003).

Station #	Latitude S	Longitude E	Water Depth (m)	O_2 (µM)	Sulphide (µM)	$NO_3^- + NO_2^-$ (µM)
1	22·51.9’	14·28.9’	25	0.0	26.6	0.0
2	22·48.9’	14·26.9’	40	0.0	30.1	0.0
3	22·38.5’	14·17.5’	75	0.0	40.7	0.0
4	22·24.9’	14·03.1’	100	0.0	28.7	1.2
5	22·41.0’	13·56.2’	125	0.0	7.0	0.0
6	23·01.9’	13·44.8’	150	3.3	0.0	1.4
7	23·10.0’	13·31.8’	200	3.0	0.0	22.7

© NMP 2014

In addition to the presence of dissolved oxygen and nitrates, POM C:N ratios also affect HS^- fluxes into the benthic boundary layer in that where C:N is <9 HS^- is present but not so when C:N is >9 (Figure 32).

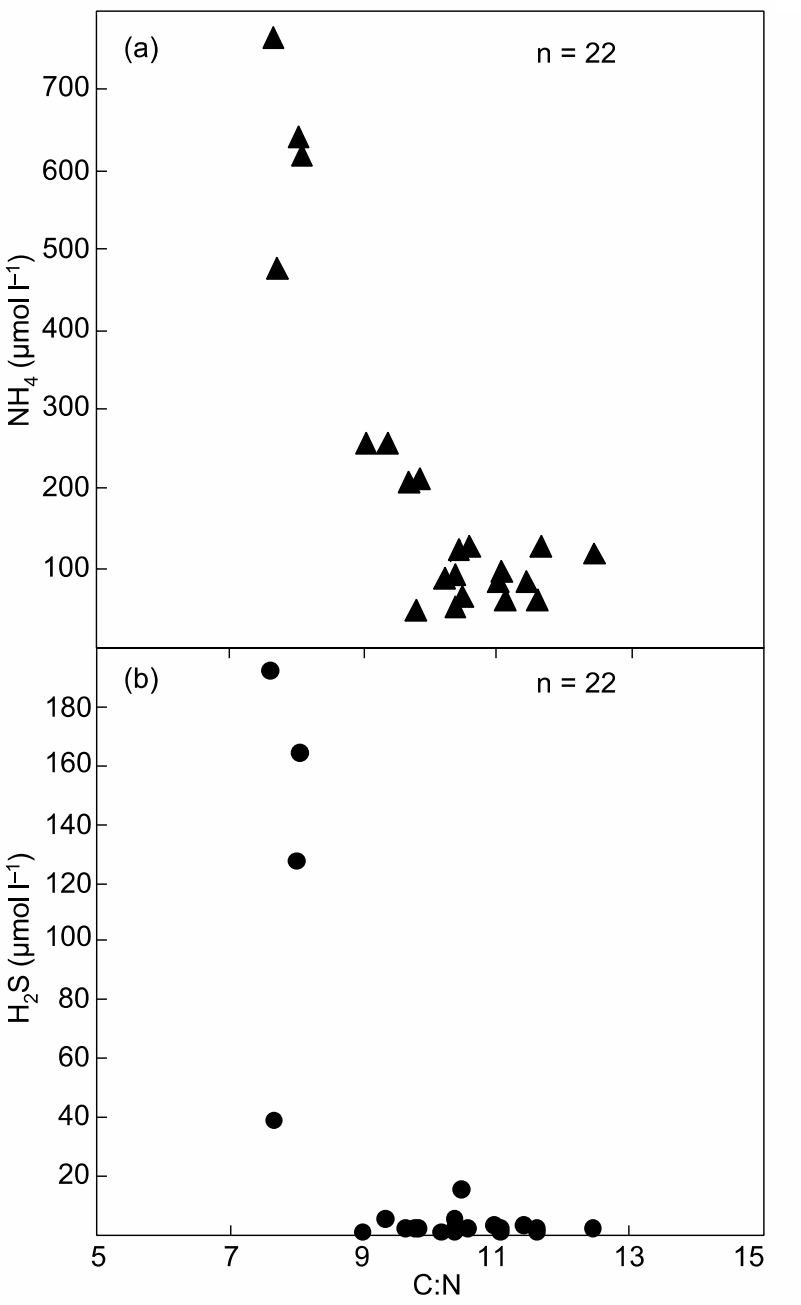


Figure 32: Relationship between POM C:N ratios and a) ammonium (NH_4) and b) hydrogen sulphide (H_2S) concentrations in the benthic boundary layer (van der Plas *et al*. 2007).

In summary the following is apparent from the research synthesised above:

- The organic rich mud belt has a unique set of biogeochemical indicators:
  - Low C:N ratio (<9)
  - Elevated HS^- production (100 – 1000 nMol/cm^3/day)
  - Elevated HS^- concentrations in the benthic boundary layer (> 100 µMol/l)
  - Elevated AVS > 5mMol (5 – 25) in the sediments
- The refractive offshore belt is characterized by:
  - Higher C:N > 9
  - HS^- production < 1nMol/cm^3/d
  - HS^- concentrations in the benthic boundary layer < 1µMol/l
  - Low AVS < (0 – 5mMol) in the sediments

These features validate the employment of AVS as an order of magnitude indicator of proxy for HS^- fluxes from Namibian continental shelf sediments.

The verification survey of sediment properties (both surficial and sub-surface) in the proposed pelletal phosphorus mining area where water depths are 190 m-210 m has demonstrated the following:

- High C:N ratios in the sediments indicative of refractory POM
- Very low AVS concentrations and, from the above, predicted low to zero flux of HS^- into the benthic boundary layer, and
- Elevated nitrate concentrations at the base of the water column and in the sediment pore water supporting the contention that HS^- flux is zero as the two compounds do not coexist (Brüchert *et al*. 2003).

A process contributing to this condition is the measured high shear stress at the seafloor, this being two orders of magnitude higher than that required to erode sedimenting POM. Consequently even if fresh, labile low C:N ratio POM was to reach the seabed in this area it is unlikely, if the measured current conditions persist over time, that it would remain there or accumulate sufficiently to materially alter the location's biogeochemical conditions.

From the above it is concluded that the proposed mine area (SP-1/ML 170) does not show the characteristics of the mud belt and the SO_4 reduction and therefore HS^- flux from the sediments would be minimal; i.e. the core hypothesis is rejected and the alternative applies. This supports the conclusion of the EIA specialist study that environmental risks of mining by dredging would be physical as opposed to biogeochemical.

Monteiro (*in litt*) raises the caveat that his conclusions are based on conditions measured at the proposed mining site in winter and may be different especially in late summer when dissolved oxygen advection into the area (ventilation) may be reduced due to the dominance of poleward flows of SACW from the Angola region. Whether there would be markedly different fluxes is moot however as the main controlling factor for POM deposition is current velocity and regional data indicate that these would be mostly higher than 10 cm/s. These are sufficient to maintain even coarse silt sized particles with specific gravities >1.8 in suspension.

With respect to oxidation of iron pyrite in sediment resuspended during mining (dredging) Monteiro examined the implicit assumption apparent in the Lwandle (2012) assessment that this compound is stable over time scales that are much larger than the mining and re-sedimentation time scales. The

© NMP 2014

potential oxidation was evaluated under aerobic conditions, as would occur with sediment discharged from the dredger as part of the lean water generating turbidity plumes in the upper mixed layer of the water column, and hypoxic/anaerobic conditions at the base of the water column.

Oxidation of iron pyrite under aerobic conditions

There are two questions central to aerobic oxidation of iron pyrite, which are important because they constrain the rate at which pyrite oxidation impacts on dissolved oxygen:

1. what determines the rate?
2. What is the geochemical fate of the sulphur fraction of the pyrite?

Geochemical experimental studies on the oxidation of pyrite under aerobic conditions indicate that the key factor that determines the rate is the mineral particle size in the sediment (Morse, 1991). The oxidation rate was shown to be sensitive to the surface-area : volume ratio (A/V) µm. Broadly, small particles (<1 µm) oxidized on time scales of hours to days (3 – 20%/d) and larger particles (>1 µm) oxidized on time scales of months to years (0.08 – 0.34%/d).

Overall, the rate (R) expression is summarized as:

$$R \text{ (mol/hour/pyrite-grain)} = \boldsymbol{\alpha} * k_s * r^2$$

Where:
$\boldsymbol{\alpha}$= 9.23 mol/m^3 (Oxygen saturation)

k_s= rate constant (3.07×10^{-6} mol/h), and

r – radius (m)

This expression has been used experimentally to determine the mean ratio of the pyrite particles in the sediment. The main outcome from this study that is relevant to the NMP study is that the upper boundary of pyrite that is expected to oxidize within time scales that are meaningful for the mining activity (< 10 – 30 days) is small probably ~ 10% of the pyrite load in the sediments – this needs to be constrained from samples.

The biogeochemical fate of sulphur is important because of the impact that it has on oxygen demand. In this respect it is not appropriate to assume thermodynamic equilibrium to link the fate of sulphur to oxygen demand in a natural seawater system. This is the case because of the kinetic activation barrier related to the stability of the intermediate products for oxygen (O_2^- superoxide) and sulphur (HS^- - radical) (Ma *et al*. 2006; Luther *et al*. 2010). Under aerobic conditions the main product of sulphur oxidation is S(0) or elemental sulphur rather than SO_4^{2-} (Ma *et al*. 2006).

The two possible reaction pathways are:

$$O_2 + HS^- \rightarrow O_2^- + HS^- \qquad \text{Equation 1}$$
$$O_2 + HS^- \rightarrow S(0) + H2O_2 \qquad \text{Equation 2}$$

In the Eq. 1 reaction, as described earlier, the two unfavourable intermediate products resulting from a single electron transfer to form O_2^- impose a kinetic control of the reaction. The main reason is the

electron structure of oxygen where two singly occupied (pi*) anti-bonding molecular orbitals exist (Luther *et al*. 2010). The main difference between the two reactions is that the unfavourable one involves a single electron transfer whereas the second is a two-electron transfer (Luther *et al*. 2010).

The thermodynamics of the one and two electron transfers are depicted in Figure 33, reproduced from Figure 3 in Luther *et al*. 2010. It shows how the 2-electron transfers are associated with favourable negative Gibbs free energy compared to the positive shift for the single electron transfer via the super-oxide pathway. The two-electron transfer is thermodynamically more viable but kinetically slow because of the electron spin pairing problem.

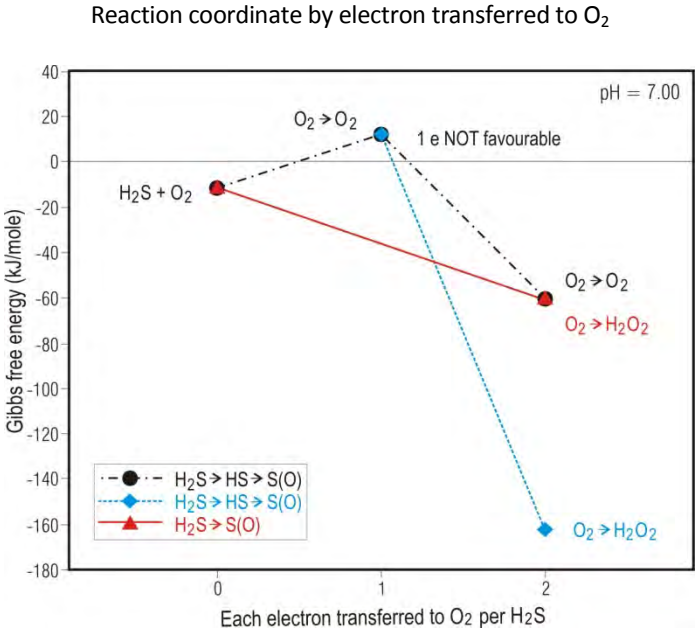
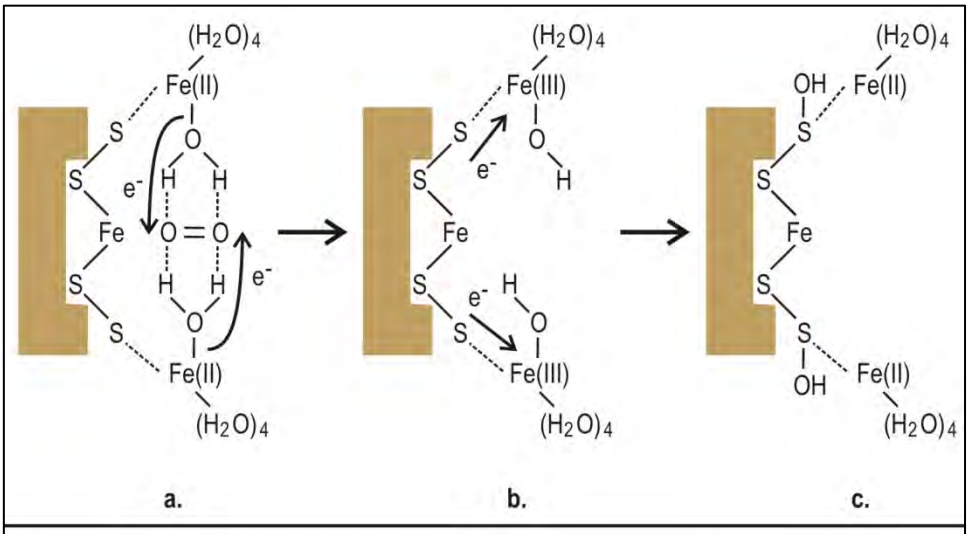


Figure 33: Thermodynamics of stepwise oxidation reactions for O_2 oxidation with H_2S for both one and two-electron transfer reactions. At zero electrons transferred, ΔG° is the sum of the standard state ΔG° values before a reaction occurs.
(Reproduced from Luther *et al*. (2010))

The reason why the two-electron transfer explanation is important is that it highlights why oxygen in the water does not directly oxidize FeS_2. Rather it requires the mediation of adsorbed Fe(II) on the pyrite (Moses and Herman, 1991). This is depicted in the reaction mechanism scheme shown in Figure 34, reproduced from Figure 8 in Moses and Herman, 1991).

© NMP 2014



Schematic sequence of reaction steps for the oxidation of pyrite sulfur.

(a) Adsorbed Fe(II) (preferred over Fe(III) as an adsorbate) forms a hydrogen-bonded termolecular complex with DO, and electrons are transferred from Fe(II) to DO. The product of DO reduction is not shown (see Moses and Herman, 1989). One of the 6 waters of hydration on the aquo-Fe complex has been lost to accommodate the bond for the Lewis acid-base surface complex.

(b) Electrons are transferred rapidly from pyrite to the adsorbed Fe(III) that results from step (a). The adsorbed Fe(III) is unstable both with respect to reduction by pyrite and with respect to displacement by a softer Lewis acid, such as Fe(II), but its reduction is so rapid that displacement is an unlikely fate.

(c) An OH group has been transferred from the adsorbed aquo-Fe(III) in response to the electron transfer shown in step (b). The adsorbed Fe species is now Fe(II), which is the more stable adsorbate but is unstable with respect to oxidation by DO. After rehydration, the Fe(II) in step (c) can be oxidized again as in step (a), and so on.

Figure 34**:** The mechanism explaining the indirect role of oxygen and the catalytic role of adsorbed Fe(II) in the oxidation of pyrite (from Figure 8 in Moses and Herman, 1991)

Figure 34 shows that in the first step dissolved oxygen (O=O) is involved in a two electron transfer from two adjacent Fe(II) ions adsorbed onto the FeS_2 (pyrite surface). The product of this step is the oxidation of Fe(II) to Fe(III) from the electron transfer and the release of H_2O_2 as a reaction product (not shown) which dissociates into H_2O and O_2 (Moses and Herman, 1991; Luther *et al*. 2010). The subsequent transfer of an electron from S to Fe(III) results in the formation of a partially oxidized S-OH and the concomitant regeneration of the reduced Fe(II). In this way the adsorbed Fe(II) plays a catalytic role which is self-generating (Moses and Herman, 1991; Ma *et al*. 2006).

These reaction models are simplifications of the more complex and biologically mediated natural systems but they indicate that, whether the oxidation is mediated by Fe catalysis or biologically, the challenge is to overcome the electron spin-pairing problem of the oxygen molecule. The contrast between these two mechanisms is highlighted by the rates:

© NMP 2014

- Fe catalysis: k: 1 – 50 µMol/d
- Bio-mediation (chemolithotrophic): k: $5x10^3$ – $5x10^4$ µMol/d

In summary, FeS_2 oxidation is kinetically controlled and oxidation is via water-derived oxygen rather than direct chemical interaction with dissolved oxygen. The overall rate and extent of the reaction under aerobic conditions is governed by the A/V ratio, which together with the percentage particle size distribution will govern the overall rates of oxidation and its extent.

Oxidation of iron pyrite under anaerobic conditions

Under sub-oxic and anaerobic conditions the adsorption of Fe(II) onto the pyrite surfaces blocks the reaction sites to any further oxidation action from all electron acceptors beyond oxygen (Moses and Herman, 1991; Ma *et al*. 2006; Luther *et al*. 2010). No significant pyrite oxidation is viable under these conditions even if biologically mediated (Schippers and Jorgensen, 2002).

To summarize we pose two questions which connect pyrite fluxes to a possible risk to water column dissolved oxygen:

1. What happens to FeS_2 when it is disturbed by mining / dredging in the sea-bed but remains at the hypoxic / anoxic sea-bed or within the benthic boundary layer?

No significant geochemical changes are predicted within the benthic boundary layer beyond the contribution that these particles make to turbidity.

2. What happens to the FeS_2 when it is discharged overboard as part of the "fines" effluent from the dredger?

The extent and rates of FeS_2 oxidation during the discharge and dispersion of the FeS_2 fines at the surface will depend largely on the fine particle size distribution, particularly the fraction that contains the FeS_2 pyrite mineral phases. The most likely outcome, should this oxidation be measurable, is an increase in Fe(III) and S(0) in the plume. S(0) will intensify the reflectivity (albedo) of the plume in a way that is analogous to the milky colouration of surface waters following methane eruptions where similar kinetically controlled oxidation of HS^- to S(0) also occurs (Weeks *et al*.).

Monteiro (*in litt.*) recommends that it will be important to quantify the fraction of the sediment fines, which have FeS_2 particles < 1 µm as this will give a more accurate estimate of the rates and extent of oxidation rates during the discharge of fines in mining operations. The smallest size fraction measured in the sediment particle size analyses of either the grab or gravity core samples obtained in the verification survey was <2 µm. In the core samples, representative of the bulk of sediments to be dredged, this fraction comprises ~8% of the overall mass of the sediment. Following the conservative assumption that all of the <2 µm fraction behaves as predicted for <1 µm sized particles in terms of FeS_2 oxidation rates and that pyrite is uniformly distributed across all sediment size fractions indicates that ~8% of the total mass of this compound may oxidise. Rickard and Morse (2005) summarise AVS-S and FeS_2-S ratios for marine sediments. From their data for 50-300 m depth sediments coupled with the median AVS concentration for the verification survey gravity core data an estimate for FeS_2-S of 0.6432 mMol/kg of sediment is derived. This indicates that the amount of sulphide that may be oxidised from the <2 µm size fraction, assuming that rates determined for the <1 µm fraction apply, is 0.05 mMol S/kg which is equivalent to 1.64 mg S/kg. Oxidation to sulphate (SO_4^{2-}) would demand ~6.4 mg O_2/kg. However, as the probable end product of any oxidation of

pyrite is sulphur (S(0)) and only a (presently unknown) proportion of the pyrite in the <2 µm particle size range is predicted to oxidise within realistically short time scales (days), effects on ambient dissolved oxygen concentrations are predicted to be minor.

The evidence gained from the verification survey on the balance of the issues of concern and queries raised by the reviewer's and addressable by the results of the verification survey is summarised below in bullet format.

- The measured currents reflected consistent NW (equatorward) flow in the near surface depths, switching between NW and S (poleward) flow at mid-depth and near the seabed a period of sustained poleward flow followed by switching between poleward and equatorward flows. The near surface and seabed currents are consistent with those predicted in the EIA. Time series measurements at mid-depth were not available to the EIA and the verification measurements represent new detail for the region.

  Current flow velocities were variable temporally and with depth. In general surface flows averaged 17 cm/s, mid-depth flows ~10 cm/s and near seabed flows 18 cm/s for poleward flow but were lower at 9 cm/s in oscillating pole/equatorward flows. These are in general agreement with the information in the EIA. Seabed current velocities are higher than the <10 cm/s predicted by Shillington *et al* (2006) as quoted in the EIA. In the short term velocities ~30 cm/s were recorded at the mooring implying considerable turbulence at the seafloor.

  Spectral analysis of the current velocity data show that most of the variability resided in longer period (>3 day) fluctuations with inertial and tidal periods also being important. Shelf waves at longer periods (e.g. 10 day) and lunar (~14 day periods, (*cf* Monteiro *et al*. 2006) were not identified in the data set. The lunar tide specifically was invoked as the probable mechanism that prevented accumulation of pelagically produced POM in mid-shelf sediments immediately offshore of the nearer shore biogenic mud belt. Even in the absence of such a mechanism, however, the ambient current velocities measured were sufficient to exert bottom shear stress forces well in excess of those required to suspend finer sedimenting particles such as POM, preventing its accumulation in the survey area (above). Thus although the mechanism that was invoked in the EIA was not demonstrated here, the consequences remain and coincide with the conclusions in that analysis.

- The characteristics of the water masses present in the survey area over the period of measurement are those of the oxygen depleted, saline SACW flowing south in the poleward undercurrent from the Angola gyre, and the less saline, relatively oxic ESACW from the Cape Basin. The influence of the latter on ventilation of bottom water in the area is clearly evident from the temperature, salinity and dissolved oxygen time series measurements that were made. This is consistent with the findings in the EIA.
- The upper mixed layer (UML) depths measured during the survey ranged between 20 m and 30 m. In general the UML was weakly developed over the short period of measurement. The recorded depths are consistent with those quoted in the EIA.
- Dissolved oxygen distributions measured during the survey showed that the UML was normoxic and that in the sub-thermocline water oxygen concentrations decreased with depth to ~0.5 mg/ℓ. At the seafloor dissolved oxygen concentrations were generally below this (demonstrating periods of severe hypoxia but, as stated above, increased during ventilation events (to ~1.10 mg/ℓ). This is consistent with the data reviewed in the EIA.

© NMP 2014

- Turbidity both in the water column and at the seabed in the presumed benthic boundary layer near the seabed was typically low (~1 NTU) throughout the survey period. Episodic short term elevations in turbidity were recorded at the base of the water column during both of the moored instrumentation measurement periods. During the first period (P1) the median value was 1.01 NTU but there were two occasions where values in excess of 350 NTU were recorded, both of which had short durations (hours). In the second period of measurement (P2) the median turbidity level was higher at 3.51 NTU compared to P1 and there were three occasions when turbidity exceeded 200 NTU. Again these were short duration events (hours to <2 days).

  There was no clear association between the recorded turbidity events and current speed and direction (accelerations or switching events). The measurements support the conclusions of Inthorn *et al* (2006), invoked in the EIA, that the observed turbidity events are derived from the farfield, e.g. the nearer shore biogenic mud belt, and are advected past the survey area to the outer continental shelf and slope.

- Dissolved heavy metal concentrations in the water column were close to or below the detection limits of the analytical procedures used. This is expected for the survey area which is distant from any industrial sources of such metals. Nutrient concentrations that were measured were within those recorded for the region and Redfield ratios (Molar N/P) averaged 17.71. This is marginally higher than the classical 16:1 and may be attributable to minor nitrate-nitrogen enrichment. Both of these findings support the general contention of the EIA that water quality in the region of the survey area is at or close to its natural state.
- The textural classification of the survey area sediments show that the surficial sediments were a silty sand whilst the underlying sediments were primarily silt. Clay sized material was present but at low proportions (<8%) and this in the deeper sediments only. This is consistent with the results presented in the EIA.

  Important aspects of the sediments were low porosity implying a firmly packed sediment with low pore water volumes and, especially in the eastern segments of the survey area, abundant shell material in the surficial and upper layers of the sediment. Both features would make the sediment body resistant to resuspension and reinforce the conclusions drawn in the EIA that local turbidity generation is probably a rare event.

- Average particulate organic matter (POM) concentrations in the survey area sediments were 7.4%, marginally higher than the upper level of 6.9% quoted in the EIA. C:N ratios in the POM were 11.4 in the surficial layers and higher at 19.8 in the underlying sediments. These ratios are indicative of refractory organic matter and are consistent with the predictions made in the EIA. The gradient between the sediment layers is attributed to deposition and incorporation of minor amounts of fresher POM on the sediment surface, diluting the 'base' aged, refractory material, but due to limited sediment turnover this effect does not extend into the subsurface layers.
- Inorganic nutrient concentrations in the sediment pore waters averaged 156 µg/ℓ for nitrogen (ammonia + nitrite + nitrate-nitrogen) and 209 µg/ℓ for phosphorus. The latter is considerably enriched compared with the overlying water column and there is a considerable departure from the classical Redfield ratio of 16 and that measured in the overlying water column (17.7). The phosphorus enrichment is attributed to enrichment from the pelletal phosphate ore body. Pore water volumes are low, due to the low sediment porosity, and therefore significant

© NMP 2014

modifications to upper water column Redfield ratios through translocation of pore water to the surface are not expected to occur.

- The range of measurements indicative of the oxidative state of the sediments included ORP, nitrate-nitrogen and AVS. ORP was moderately high (>0-+100 mv) throughout all of the sediment core samples implying that they were hypoxic (but note the caveats on this variable above). The presence of nitrate-nitrogen in the sediment pore water supports this as it converts to ammonia in anoxic conditions. AVS was below detection levels in the surficial sediments and averaged <2 mMol/kg in the subsurface layers. The absence of AVS is consistent with hypoxia as free sulphide is oxidized to sulphate ($SO4^{2-}$) in the presence of oxygen. This implies that the surficial sediments were hypoxic during the period of measurement and that this may have extended to the deeper layers but this is equivocal to an extent due to the presence of low levels of AVS. These support the conclusion on sediment properties in the EIA, i.e. sediments in the proposed mining area were probably hypoxic and would have low sulphide fluxes associated with them.
- Heavy metal concentrations in both surficial and subsurface sediments support relatively high concentrations of arsenic, cadmium, chromium, copper and nickel. High concentrations of cadmium and nickel were predicted in the EIA. The bioavailability of these heavy metals in the dissolved phase was investigated by elutriation tests and negligible proportions were released. This is possibly due to their precipitation as insoluble sulphides as, although concentrations in the tested (subsurface) sediments were low, AVS was present at levels well in excess of the simultaneously extracted metal (SEM) fraction. Iron was abundant in both of the sediment layers and scavenging of the metals from the dissolved phase by iron hydroxides and organic complexes is another possible sink.

  The low release of the metals into the dissolved phase indicates that although their natural concentrations exceeded the sediment quality guidelines for the region (BCLME 2006), they do not represent a toxicity risk either *in situ* or following physical disturbance in this phase.

  Transfers into deposit feeding biota via particle ingestion and assimilation of heavy metals possibly associated with POM represent another trajectory of toxicity risk. For example Wang and Fisher (1998) showed that while uptake of cadmium by a planktonic copepod was mostly via the dissolved phase more than 50% of the zinc body burden was obtained from ingested food. Lee *et al*. (2000) found a link between cadmium body burdens in benthic molluscs and polychaetes and concentrations of this metal in sediments. In this case there was an excess of AVS present implying that even in the apparently stable sulphide state cadmium was available to these fauna. These results are a prelude to Rouleau *et al*. (2006) who showed that demersal fish inhabiting sedimentary areas with relatively high authigenic cadmium had elevated concentrations of cadmium in their livers compared to the same species from areas with lower authigenic cadmium levels. These authors concluded that take-up was via predation on benthic invertebrates.

  Trophic transfers of heavy metals in pelagic food chains, phytoplankton/zooplankton (mainly copepods)/fish, show bio-diminution, as opposed to bio-magnification, due to the efflux of metals by copepods and low assimilation efficiencies in fish (Wang 2002). In contrast benthic food chains comprising deposit feeders and predatory whelks show bio-magnification of metal concentrations primarily due to effective sequestration of dietary metals by whelks (Wang 2002).

© NMP 2014

Namibian continental shelf sediments are characterised by elevated cadmium concentrations (Chapman and Shannon 1985) and, although no empirical data could be sourced for this, it is probable that resident demersal fish such as hake and monkfish would naturally have elevated cadmium concentrations in their livers and that the observations of Wang (2002) would apply to the benthic food chain. If present these patterns would extend across the region and the proposed NMP mining operations would not affect them. Trophic transfers of heavy metals associated with sediment plumes generated in the water column by the proposed mining would include ingestion/take-up by planktonic copepods and be interrupted at this stage. Note that the diminution would be partly due to rates of digestion of food particles being longer than gut passage leading to loss of metals in faecal pellets (Wang and Fisher 1998). Sinking rates of these are high and metals would be returned rapidly (hours to days) to the seafloor.

In general these evaluations support the assessment of toxicity risks in the EIA.

- The investigations into benthic meiofauna and macrofauna in the surficial sediments in the survey area showed that fauna were abundant in both size classes. This is consistent with a mainly hypoxic sediment environment and inconsistent with sulphidic sediments. The relative abundance of benthic macrofauna in the >1 000 µm size class indicates that this condition is persistent as (*Para*)*Prionospio*, which formed a large proportion of the fauna, has a life cycle of 1-2 years (http://www.genustraithandbook.org.uk) and the *Diopatra* sp. may be as long-lived (Steffani 2014). This is consistent with a stable sedimentary environment even though the overlying water body may undergo seasonal changes in terms of its oxygen content with varying contributions of Cape Basin and Tropical Atlantic Central Water.
- The investigation into sulphur bacteria indicated that, at the time of sampling, sulphide fluxes were probably low as the large sulphate bacteria, namely from the genera *Thiomargarita*, *Beggiatoa* and *Thioploca*, which play a significant roles in the oxidisation of H_2S, were absent from the bacterial assemblage. Smaller forms including *Thiobacillus* spp. with relatively lower growth yields were present; however, indicating that although estimated to be low (hydrogen) sulphide was present in the sediments.

© NMP 2014

6 CONCLUSIONS

This verification survey was carried out in order to verify the marine ecology specialist report that was previously submitted as part of the Namibian Marine Phosphate EIA. The survey comprised time series measurements of currents and water column features, synoptic scale water column profiling and surficial and deeper layer sediment sampling and analyses along with benthic meiofauna, macrofauna and sulphur bacteria distribution studies. The survey results were examined to support or contradict important conclusions that formed the base of the EIA assessment.

In general the data and information gathered through the verification survey support the environmental description in the EIA and lend credence to the associated environmental risk assessments. Further, the survey has obtained new and detailed information on the Namibian central continental shelf and the dynamic processes affecting it. Based on the findings discussed in this report, the confidence interval of each of the relevant impacts investigated in the original marine ecology report for the EIA (NMP 2012) can be re-rated to HIGH as the empirical data supporting has now been obtained. The re-ratings are summarised in Table 7.

© NMP 2014

Table 7: Summary table of the re-gradings of the 7 impact assessments in marine ecology component of the EIA (NMP 2012) for which the information gained in the verification surveys is relevant.

NMP (2012) Table No.	4-6	4-8	4-9	4-10	4-11	4-12	4-13
Risk Area	**Overspill discharge**			**Seabed dredging**			
Impact	**H_2S toxicity at surface**	**Nutrients added at surface**	**Trace/heavy-metal toxicity at surface**	**Trace-metal toxicity on seabed**	**H_2S toxicity on seabed**	**Lowered oxygen levels on seabed**	**Increase of H_2S flux.**
Extent	Dredge area	Dredge area	Dredge area	Annual Mining Area	Dredge area	Annual Mining Area	Dredge area
Duration	Short term	Short term	Short term	Short term	Medium term	Medium term	Medium term.
Intensity	Minor effects	No lasting effect	Minor effects	Minor effects	Minor effects	Minor effects	Minor effects
Probability	Possible	Possible	Possible	Possible	Possible	Possible	Improbable
Status	Negative	Neutral	Negative	Negative	Negative	Negative	Negative
Significance (no mitigation)	Low	None	Low	Low	Low	Low	Low
Mitigation	None possible	None possible	None possible	None possible	None possible	Not possible	n/a
Significance (with mitigation)	Low	None	Low	Low	Low	Low	Low
Confidence level	Medium	Medium	Medium	Medium	Medium	High	Medium
Re-Rated Confidence Level	High	High	High	High	High	High	High
Reason	Mine site sediment property data indicate low H_2S presence, pyrite sulphide will have low solubility	Mine site sediment pore water volumes are low	Mine area Heavy metals have low solubility and bioavailability, trophic transfers are attenuated at primary consumer level	Mine area Heavy metals have low solubility and bioavailability, dredging should not increase exposures	Mine site sediment property data indicate low H_2S presence	POM in sediments is relatively refractory	Mine site sediment property data indicate low H_2S presence and release from iron pyrites should be low.

© NMP 2014

7 REFERENCES

BCLME 2006 - The development of a common set of water and sediment quality guidelines for the coastal zone of the BCLME. CSIR Report No. CSIR/NRE/ECO/ER/2006/0011/C.

BREMNER, J. M. 1978 - Sediments on the continental margin off South West Africa between latitudes 17° and 25° S. PhD thesis, University of Cape Town, South Africa.

BORCHERS, S., SCHNETGER, B., BÖNING, P. and BRUMSACK, H. 2005 - Geochemical signatures of the Namibian diatom belt: perennial upwelling and intermittent anoxia. *Geochem. Geophys. Geosyst.* **6**: 20.

BRUCHERT, V, JORGENSEN, B. B, NEUMANN, K, RIECHMANN, D, SCHLOSSER, M, SCHULZ, M. 2003 - Regulation of bacterial sulfate reduction and hydrogen sulfide fluxes in the central Namibian coastal upwelling zone. *Geochimica et Cosmochimica Acta.* Vol. 67, **23**: 4505-4518.

CHAPMAN P and LV SHANNON 1985. The Benguela Ecosystem. Part II. Chemistry and related processes. *Oceanogr. Mar. Biol. Ann. Rev.* **23:** 183-251.

COMPTON, J. S. 2012 - A review of offshore phosphorite deposits on the Namibian margin and a preliminary model for the origin, age and deposition of phosphorite in ML 170. Specialist Study for Namibian Marine Phosphate (Pty) Limited.

CSIR 2010. Review and update of South Africa's National Action List for the screening of dredged sediment proposed for marine disposal. CSIR Report CSIR/NRE/CO/ER/2010/ 94pp.

DI TORO, MAHONY, J. D. HANSEN, D. J., SCOTT, K. J., CARLSON, A. R., and ANKLEY, G. T. 1992 - Acid Volatile sulfide predicts the acute toxicity of cadmium and nickel in sediments. *Environ. Sci. Technol.* **26**: 96 – 101.

INTHORN, M., MOHRHOLZ, V., and MATTHIAS, Z. 2006 - Nepheloid layer distribution in the Benguela upwelling area offshore Namibia. *Deep Sea Research* I. **53**: 1423

JORGENSEN B.B. 1977. The sulphur cycle of a coastal marine sediment (Limfjorden, Denmark).*Limnology and Oceanography* **22**(5): 814- 832.

JORGENSEN B.B., Nelson D.C. 2004. Sulfide oxidation in marine sediments: Geochemistry meets microbiology. *Geological Society of America*: Special Paper 379.

KIRBY, B. 2014 – Next Generation Sequencing Facility Department of Biotechnology Analytical report. University of Stellenbosch. 9 pp.

LEE BG, SB GRISCOM, JS LEE, HJ CHOI, CH KOH, SN LUOMA and NS FISHER 2000. Influences of dietary uptake and reactive sulphides on metal bioavailability from aquatic sediments. *Science,* **287:** 282-284.

LUTHER, G.W. III, 2010. The role of one and two electron transfer reactions in forming thermodynamically unstable intermediates as barriers in multi-electron redox reactions. *Aquatic Geochemistry* 16:395–420, http://dx.doi.org/10.1007/s10498-009-9082-3.

© NMP 2014

LWANDLE. 2012 - The Dredging of Marine Phosphate Enriched Sediments From Mining Licence Area No. 170. Sandpaper Phosphate Project, Specialist Study 1B: *Assessment of Potential Impacts on Marine Life Arising From Changes to Marine Water Quality.*

MA et al 2006. Removal of H2S via an iron catalytic cycle and iron sulphide precipitation in the water column of dead end tributaries. *Est. Coast. Shelf Sci.*, **70:** 461-472.

MONTEIRO, P. M. S. and VAN DER PLAS, A. K. 2006 - Low Oxygen Water (LOW) variability in the Benguela System: key processes and forcing scales relevant to forecasting. In V. Shannon; G. Hempel; P. Malanotte-Rizzoli; C. Moloney; & J. Woods (Eds.). Benguela: Predicting a Large Marine Ecosystem. *Large Marine Ecosystems*, Elsevier. **14**: 71-90.

MONTEIRO, P. M. S, NELSON, G., VAN DER PLAS, A. K., MABILLE, E., BAILEY, G. W. and KLINGELHOEFFER, E. 2005 - Internal-tide shelf topography interactions as a forcing factor governing the large scale distribution and burial fluxes of particulate organic matter (POM) in the Benguela upwelling system. *Continental Shelf Research*. **25**: 1864 -1876.

MORSE JW 1991. Oxidation kinetics of sedimentary pyrite in seawater. *Geochimica et Cosmochimica Acta* **55**: 3665-3667.

MOSES CO AND JS HERMAN 1991. Pyrite oxidation at circumneutral pH. *Geochimica et Cosmochimica Acta* **55**: 471-482.

MSI 2013a – Draft Data Report. Prepared for Namibian Marine Phosphates by Metocean Services International. MSI PROJECT 267. 76pp.

MSI 2013b - Draft P2 Data Report. Prepared for Namibian Marine Phosphates by Metocean Services International. MSI PROJECT 267. 79pp.

NMP 2012 – Environmental Impact Assessment for the proposed dredging of phosphate enriched sediments from Marine Licence Area No. 170. Namibian Marine Phosphates, Ltd. Namibia.

PHYSALIA. 2013 - Meiofaunal Analyses of Namibian Offshore Sediment forming part of Verification Surveys for proposed Benthic Mining Operations, Baseline Surveys.

RICKARD D and JW MORSE 2005. Acid volatile sulfide (AVS). *Marine Chemistry* **97**:141–197.

ROGERS, J. 2008 - Report on unconsolidated seafloor sediments from the shelf off NAMIBIA for Bonaparte Diamond Mining. Department of Geological Sciences, University of Cape Town. 19.

ROLEAU C, C GOBEIL and H TJALVE 2006. Cadmium accumulation in coastal demersal fish. *Mar. Ecol. Prog. Ser.*, **311:** 131-143.

SCHIPPERS A. and BB JORGENSEN 2002. Biogeochemistry of pyrite and iron sulphide oxidation in marine sediments. *Geochimica et Cosmochimica Acta* **66** (1): 85-92.

SHANNON, L. V. 1985 - The Benguela Ecosystem. Part 1. Evolution and physical oceanography. *Oceanogr. Mar. Biol. Ann. Rev.* **23:** 1-182.

© NMP 2014

SHILLINGTON, F. A., Reason, C. J. C., DUNCOMBE RAE, C. M., FLORENCHIE, P. and PENVEN, P.. 2006 - Large scale physical variability of the Benguela Current Large Marine Ecosystem (BCLME). In V. Shannon, G. Hempel, P. Malanotte-Rizzoli, C. Moloney, & J. Woods (Eds.), *Benguela: Predicting a Large Marine Ecosystem*. Large Marine Ecosystems, Elsevier. **14**. 49-70.

STEFFANI, N. 2014 - Benthic macrofauna in the sandpiper SP – 1 target area. *Steffani Marine Environmental Consultant.*

VAN DER PLAS, A. K., Monteiro, P. M. S. and Pascall, A. 2007 - Cross-shelf biogeochemical characteristics of sediments in the central Benguela and their relationship to overlying water column hypoxia. *African Journal of Marine Science,* **29**(1): 37-47.

WANG WX 2002. Interactions of trace metals and different marine food chains. *Mar. Ecol. Prog Ser.*, **243:** 295-309.

WANG WX and NS FISHER 1998. Accumulation of trace elements in a marine copepod. *Limnol. Oceanogr.*, **43**(2): 273-283.

© NMP 2014

Annexure 1: Synthesis of observations to test the hypothesis that the Namibian Marine Phosphate (ML 170) area is biogeochemically similar to the mud-belt

© NMP 2014

Synthesis of observations to test the hypothesis that the Namibian Marine Phosphate (ML 170) area is biogeochemically similar to the mud-belt

Dr Pedro M.S. Monteiro

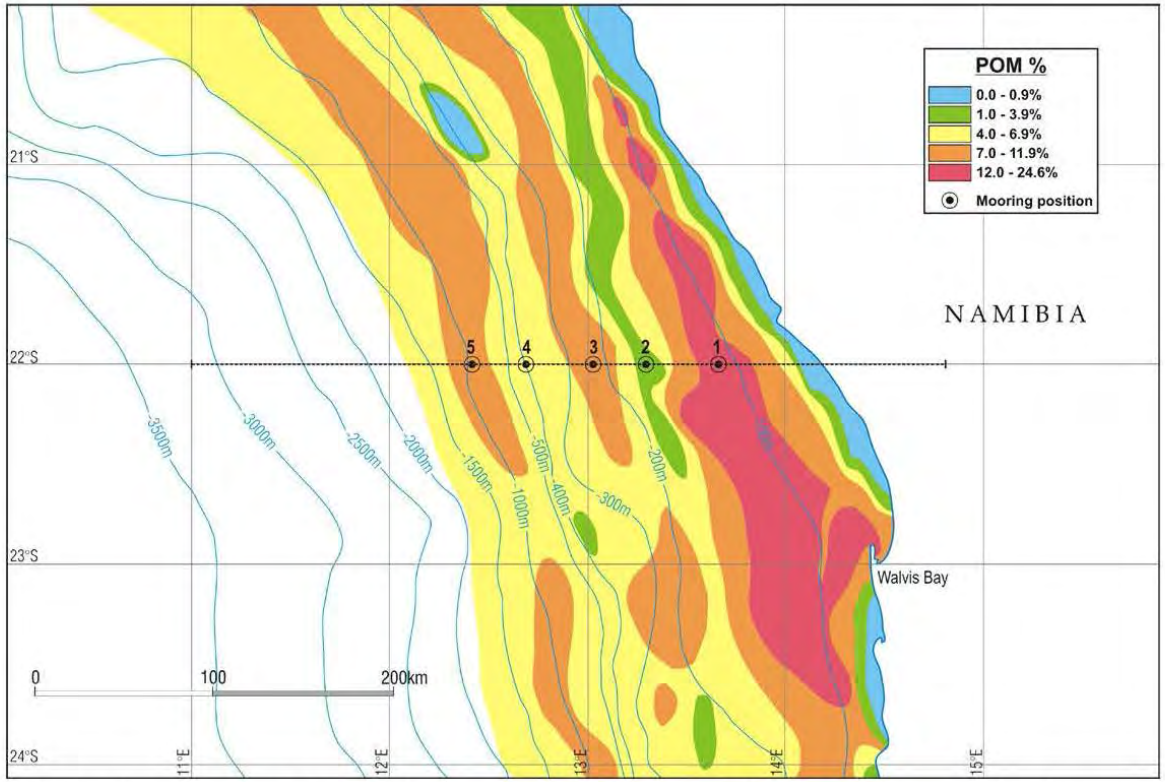
© NMP 2014

Core Hypothesis

- The dredging area (MLA 170: SP-1) is part of the organic rich anoxic and sulphide rich mud belt.

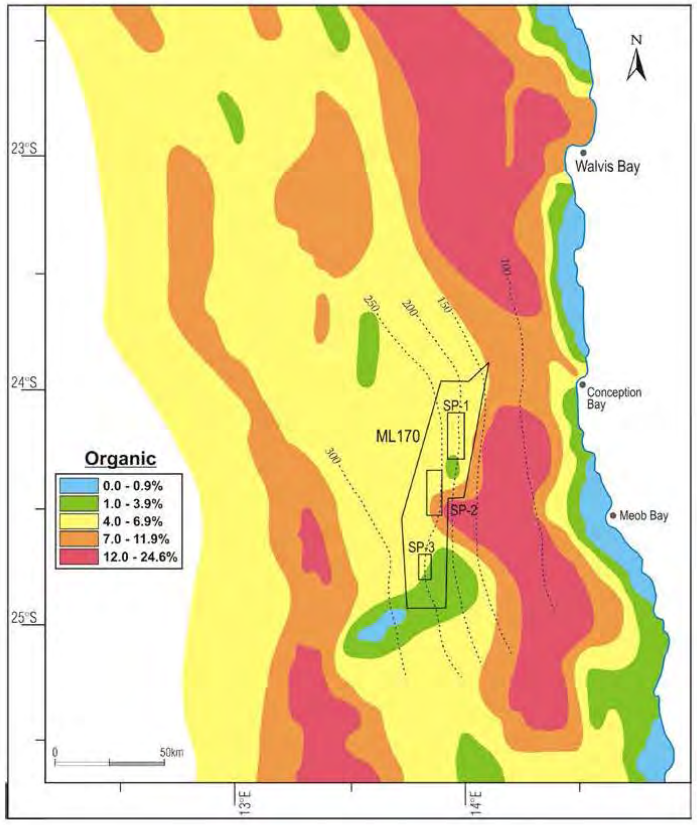
- The alternate hypothesis is that sulphate reduction is minimal because the elevated benthic boundary layer limits accumulation of pelagic POC/PON.

© NMP 2014

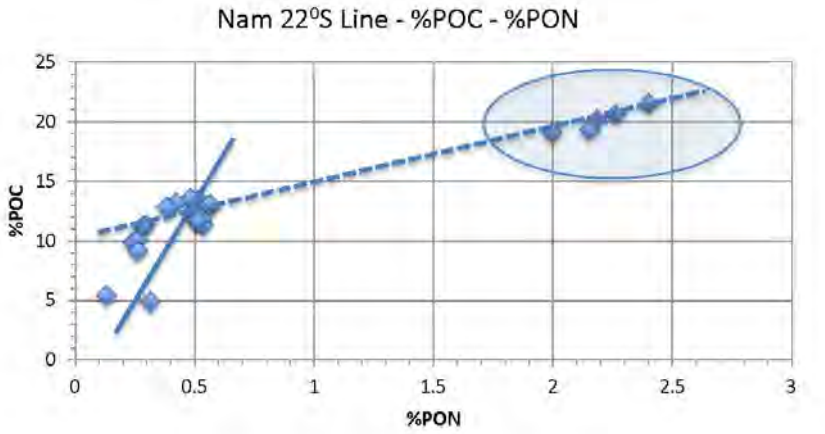


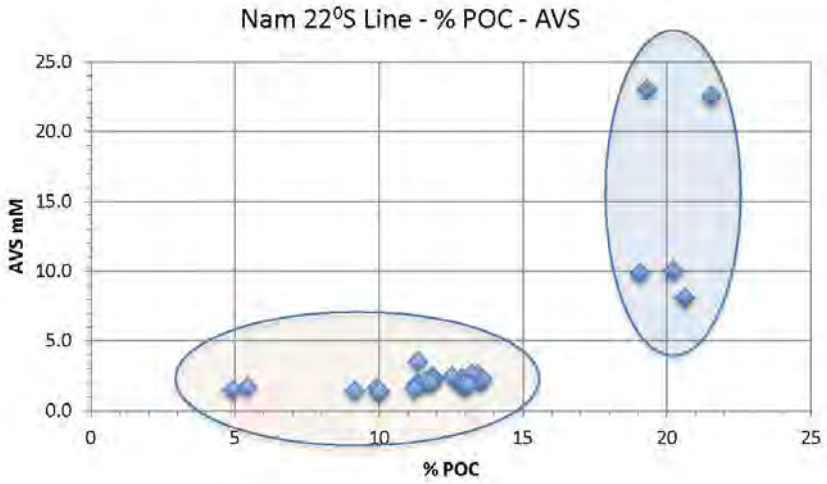
The Namibian cross shelf %POM and bathymetry characteristics as well as the positions of the 22^{0}S line

Reproduced from Monteiro et al., 2005



The Namibian cross shelf %POC and bathymetry characteristics, with MLA 170 overlay. Adapted from Monteiro *et al.*, 2005

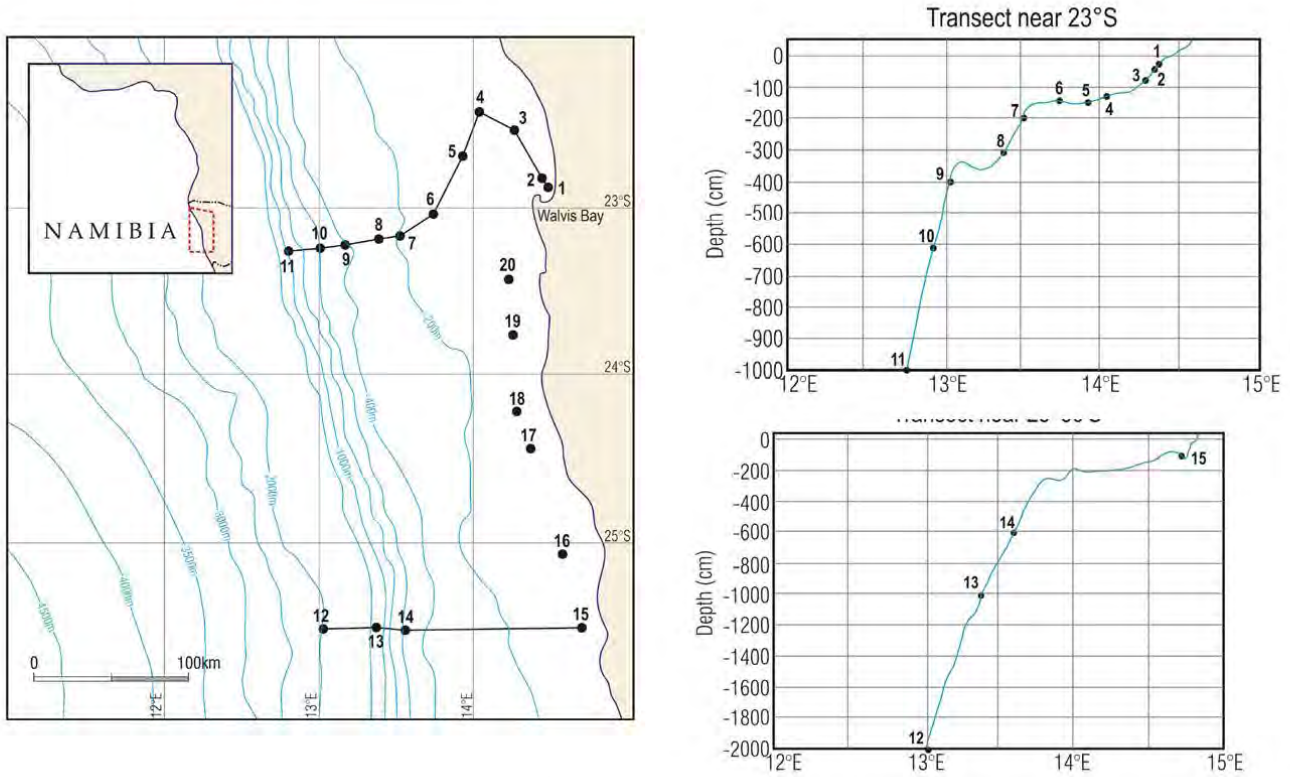




- The main cross-shelf sediment data set (NatMIRC – CSIR) sampled along 22°S shows that the Namibian sediments can be divided into two main "biogeochemical modes": an inshore mud-belt mode dominated by elevated POC > 15% and relatively low C:N ratios < 9.
- In the plots (left), the mud-belt mode is highlighted in the shaded area.
- The key point here is that AVS is used as a proxy for HS^- production (SO_4 reduction) i.e.: AVS is a "memory" of HS^- production.
- The basis for this link is made using the Bruchert *et al*, 2003 study which has a comparable cross shelf section of sulphate reduction and pore water HS^- concentration profile.
- Next figure.....

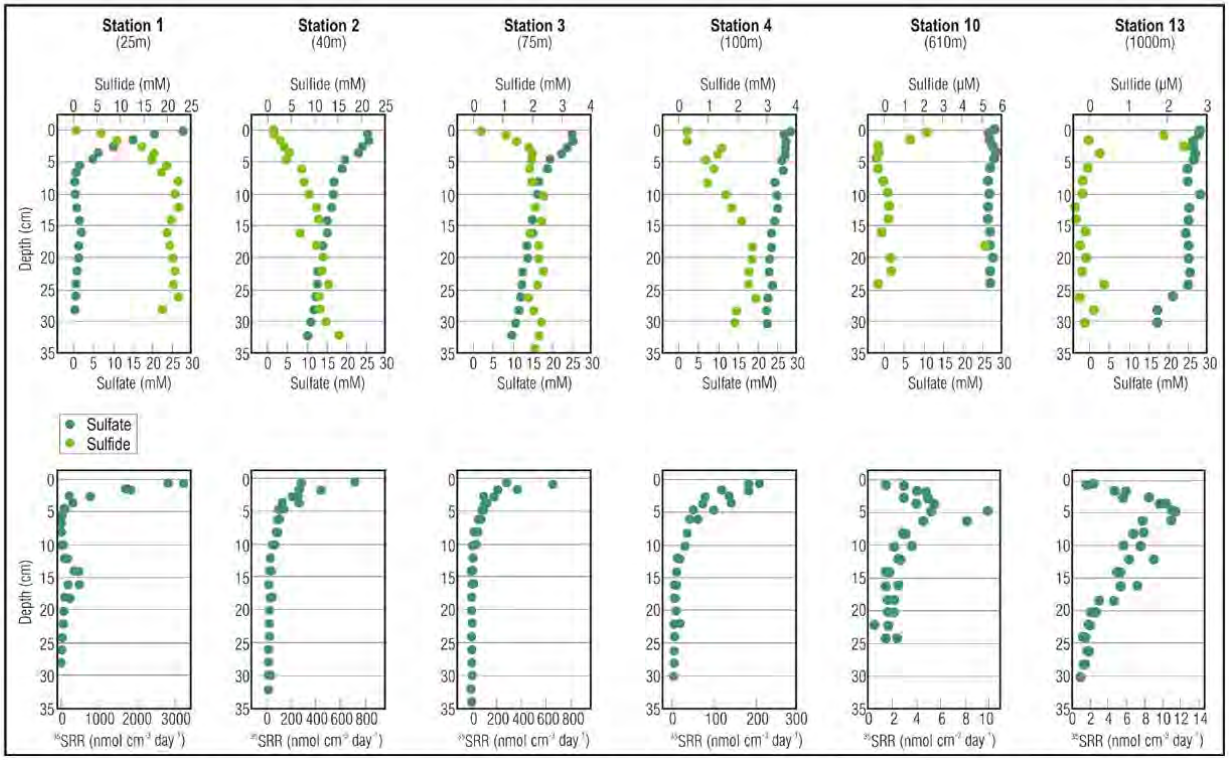
CSIR – NatMIRC data, 2000

© NMP 2014



- Shows the positions of the Bruchert 2003 stations in the 22 – 23^{0}S zone offshore from Walvis Bay. Stations 1 – 4 are in the mud-belt and comparable to station 1 on 22^{0}S line. The core of mud belt has a mean offshore extent to 150 m. Stations 5 – 6 are in the same long shore zone as station 2 along 22^{0}S
- The central hypothesis is that the dredge area is in the sulphide rich mud belt which means having characteristics comparable to Stations 1 – 4 (Bruchert 2003) and Station 1 along 22S
- Next slide…..

Brüchert *et al.*, 2003



- Sediment pore water profiles of Sulphate Reduction Rates (SRR) show a strong gradient from Station 1 to 4 in the mud belt. SRR ranges from > 3000nmoll^{-1} d^{-1} at Station 1, to < 300 at Station 4.
- The pore water SRR and HS^- profiles outside the mud belt station 10 and 13 show that SRR rates are 2 to 3 orders of magnitude lower than in mud belt. (even though station 10 and 13 are deeper than 200 m the sediment biogeochemistry is comparable to the 150 – 200 m low POC band. HS^- < 1 cf. > 10mM in mud belt (note the change in scale for [HS^-])
- Most SRR occurs in the upper 10cm
- Next slide…….

© NMP 2014

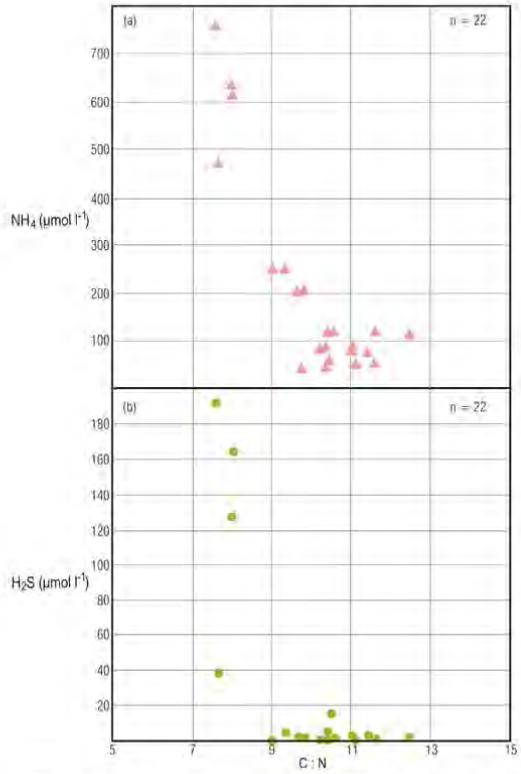
Brüchert *et al*., 2003 Figure 3. Porewater profiles and sulfate reduction rate profiles for shelf stations 1 to 4

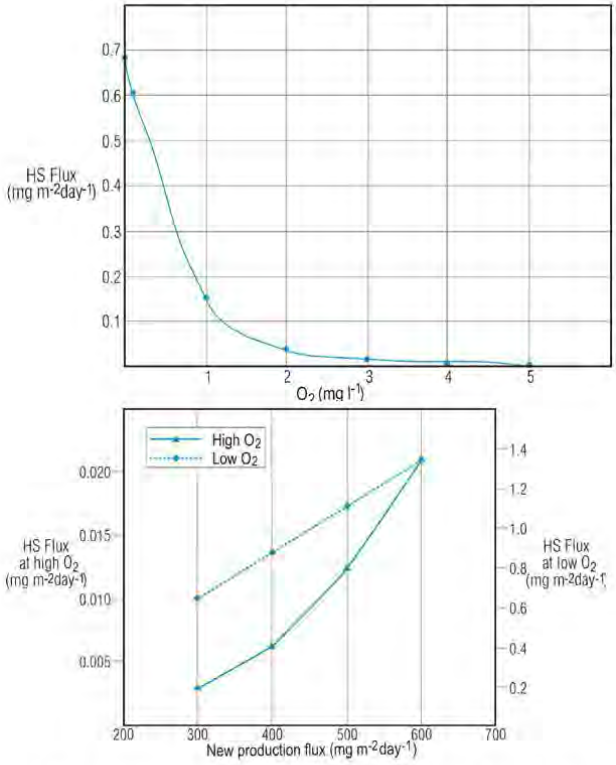
Table 1. Station locations and water column chemistry.

Station #	Position	Position	Water depth (m)	Bottom water O_2 (µM)	Bottom water Sulfide (µM)	Bottom water $NO_3^- + NO_2^-$ (µM)
1	22° 51.9'S	14° 28.9'E	25	0.0	26.6	0.0
2	22° 48.9'S	14° 26.9'E	40	0.0	30.1	0.0
3	22° 38.5'S	14° 17.5'E	75	0.0	40.7	0.0
4	22° 24.9'S	14° 03.1'E	100	0.0	28.7	1.2
5	22° 41.0'S	13° 56.2'E	125	0.0	7.0	0.0
6	23° 01.9'S	13° 44.8'E	150	3.3	0.0	1.4
7	23° 10.0'S	13° 31.8'E	200	3.0	0.0	22.7

- Highlights the sharp transition from anoxic mud belt to hypoxic off shore sediments in the depth (z) > 150 m band
- HS^- in the BBL is 0 when Z > 150 m and $NO_3 > 0$

© NMP 2014





- The sharp transition between the POC rich mud belt and HS^- production is highlighted again by biogeochemical indicators.
- HS^- concentrations are close to detection limits when C:N > 9 reflecting elevated but refractive POM. HS^- production increases exponentially when C:N in the range 7 – 9
- These data are from the same sampling survey as those in Figure. 1 which also supports the sharp transition between high POM continuously re-supplied with fresh low C:N ratio POM, and the elevated but refractive POM in the 150 to 200 m zone.
- The model outputs on RHS reflect the sensitivity of the HS^- production to both the POC/PON flux as well as the BBL oxygen concentration. HS^- production is an order of magnitude higher under low O_2 < 1mll^{-1} compared to when O_2 > 1 mll^{-1}. Points to a strong seasonality in the H^- production (high in summer and lower in winter) (van der Plas *et al.,* 2007)

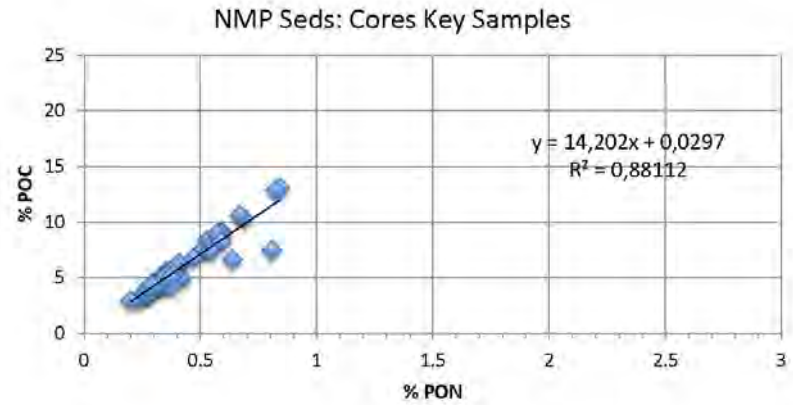
© NMP 2014

Characterization of the indicators for the mud belt and non mud belt environments

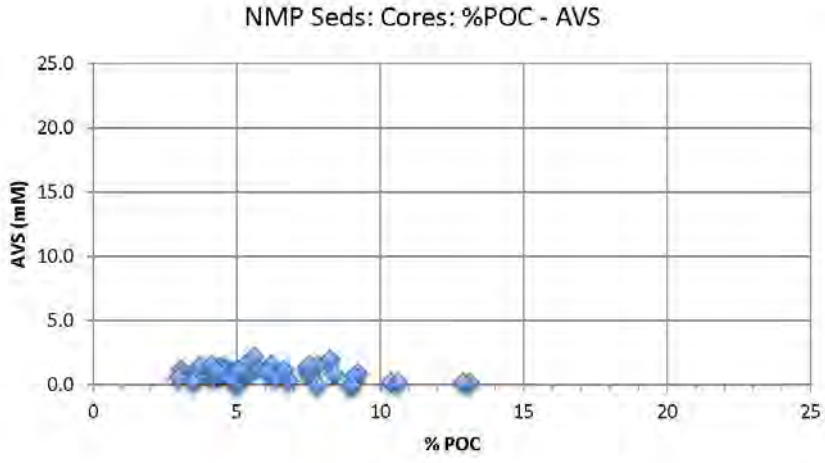
- The organic rich mud belt has unique set of biogeochemical indicators
  - Low C:N ratio
  - Elevated HS^- production (100 – 1000nmolml-1d-1)
  - Elevated HS^- concentrations (> 100µmoll-1)
  - Elevated AVS > 5mM (5 – 25)
- Refractive offshore belt
  - Higher C:N > 9
  - HS^- production < 1nmolml-1d-1
  - $[HS^-]$ < 1µmoll-1
  - Low AVS < (0 – 5mM)

- These data provide the link between HS^- production / $[HS^-]$ and AVS – supports the plausibility of AVS as a proxy / memory of HS production levels on order of magnitude levels
- These data provide thresholds for the transition between the mud belt and the non mud belt domains

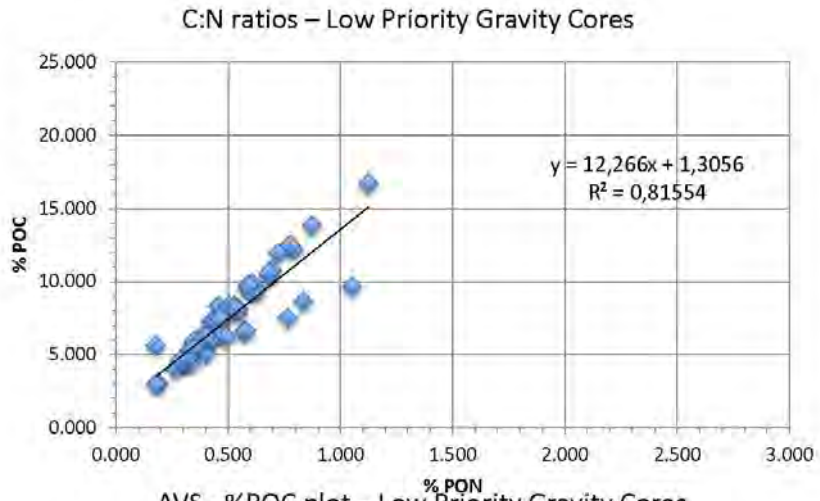
© NMP 2014

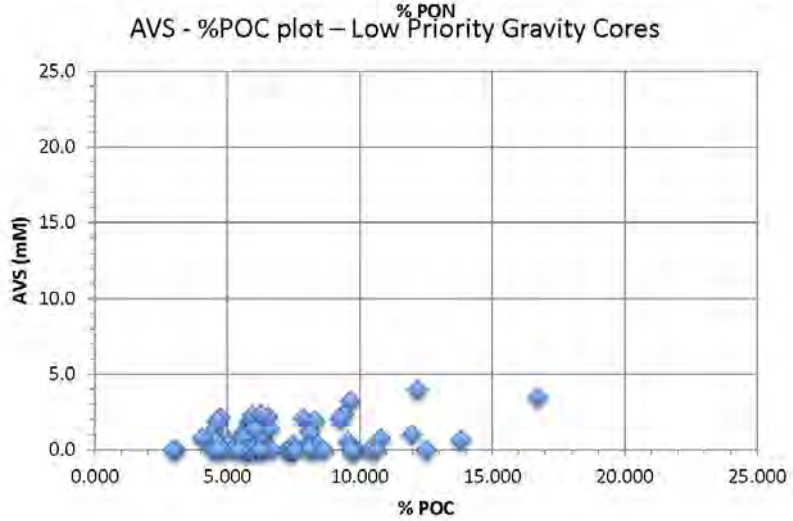


- What are the characteristics of the NMP sediments
- C:N ~ 10 – 14
- AVS concentrations < 3mM even if POC is in the range 5 to 15%

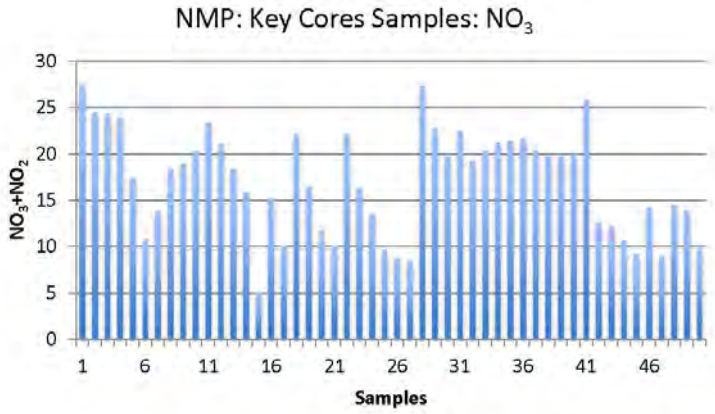


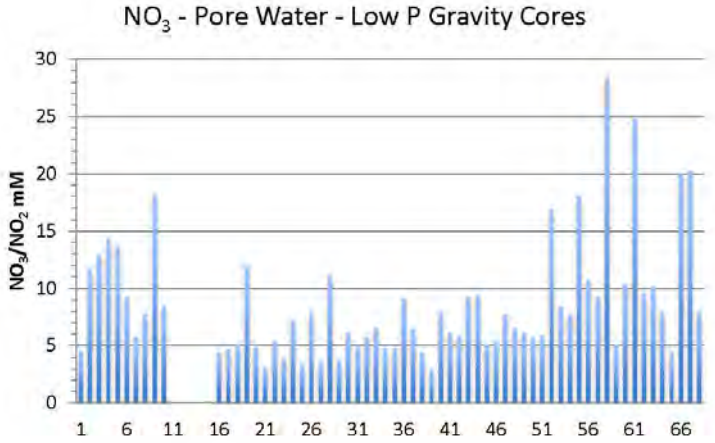
Lwandle data, 2013 : Section C 2.1





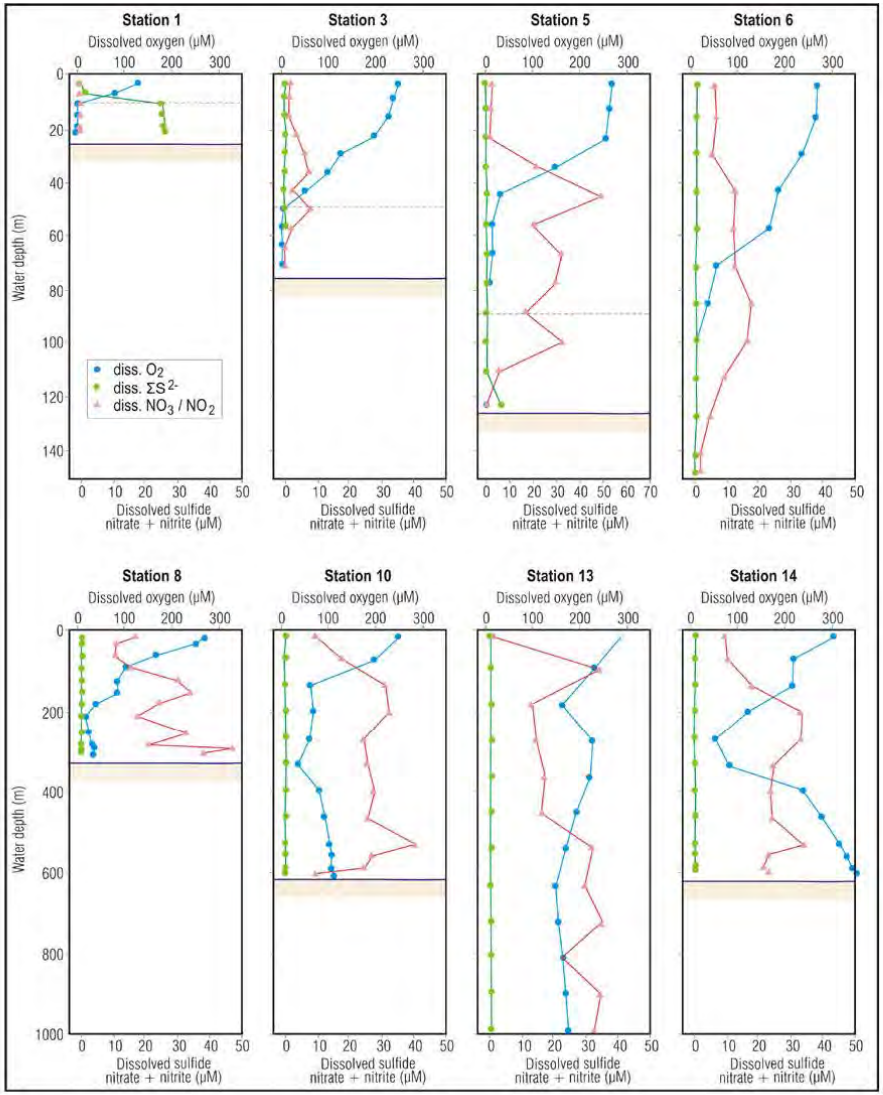
CSIR – NatMIRC data, 2000





- NO_3 concentrations in the pore water from the sediment cores also supports that previous slide data which points to the dredging area sediment not being in the mud belt domain
- NO_3: 5 to 25umoll^{-1}

Lwandle data, 2013 : Section C 2.1



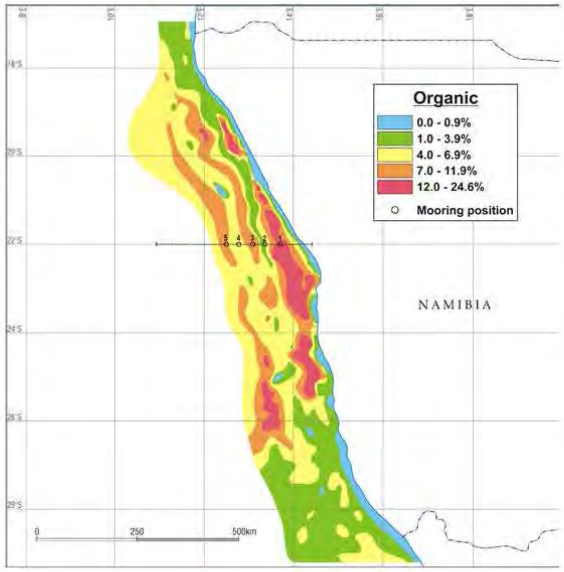
Brüchert et al., 2003

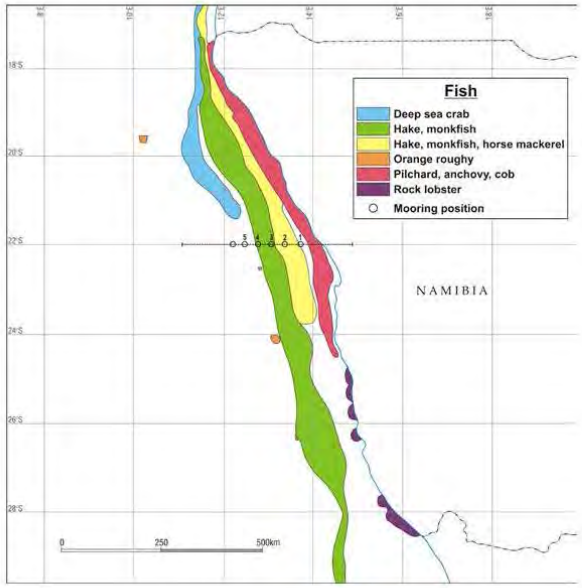
Dredging Area: Biogeochemical character

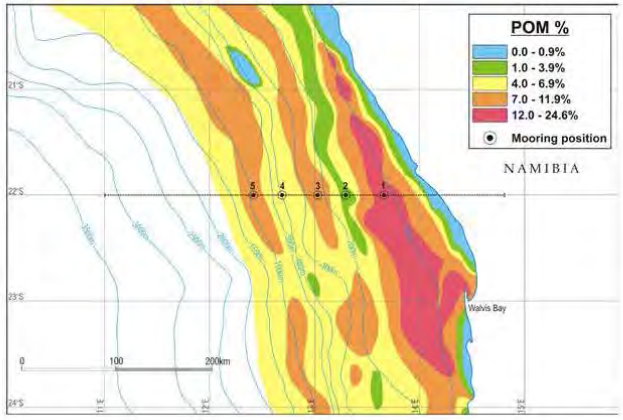
- The dredging area demonstrates:
  - High C:N (refractive POM)
  - Very low AVS (low HS^-)
  - Elevated NO_3
- It indicates that the dredging area is outside of the mud belt environment

A word of caution here is that because the mining area was sampled in winter it could present a bias in terms of the HS^- & O_2 relationship shown earlier. It indicates that there is a need for a summer study in February to eliminate this possible uncertainty

© NMP 2014







(Reproduced from) Monteiro et al., 2005; re-suspension dynamics CSS > 0.05 Pa

Vbbl ~0.2ms^{-1} == Bottom shear stress ~0.25Pa
Vbbl ~ 0.3ms^{-1} == Bottom shear stress ~0.30Pa

Shift from Tidal to Inertial forcing of mixing in the BBL

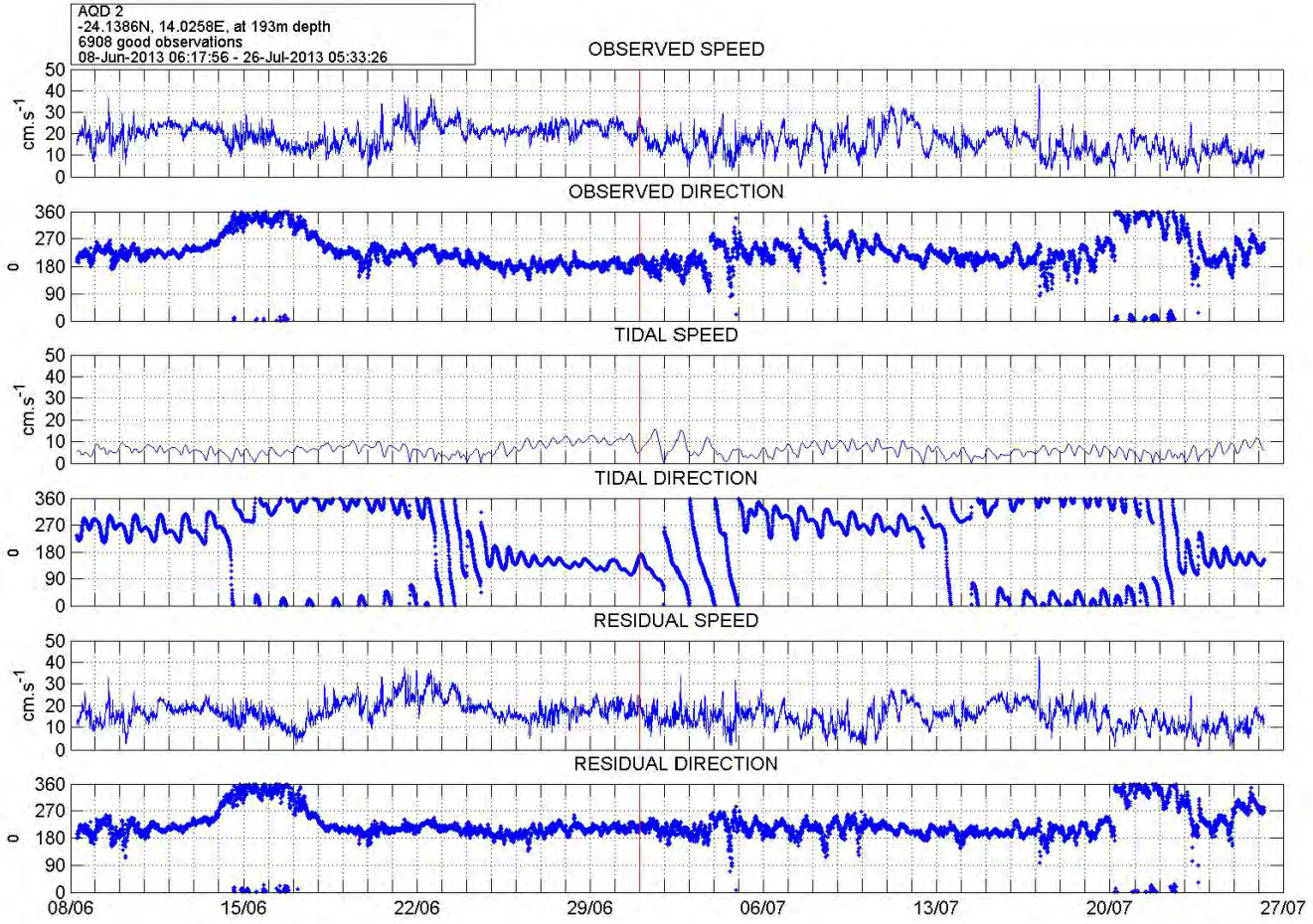
Inthorn et al., 2006; nepheloid layer flows

© NMP 2014

The images of the next two sides display a time series plot which consists of:

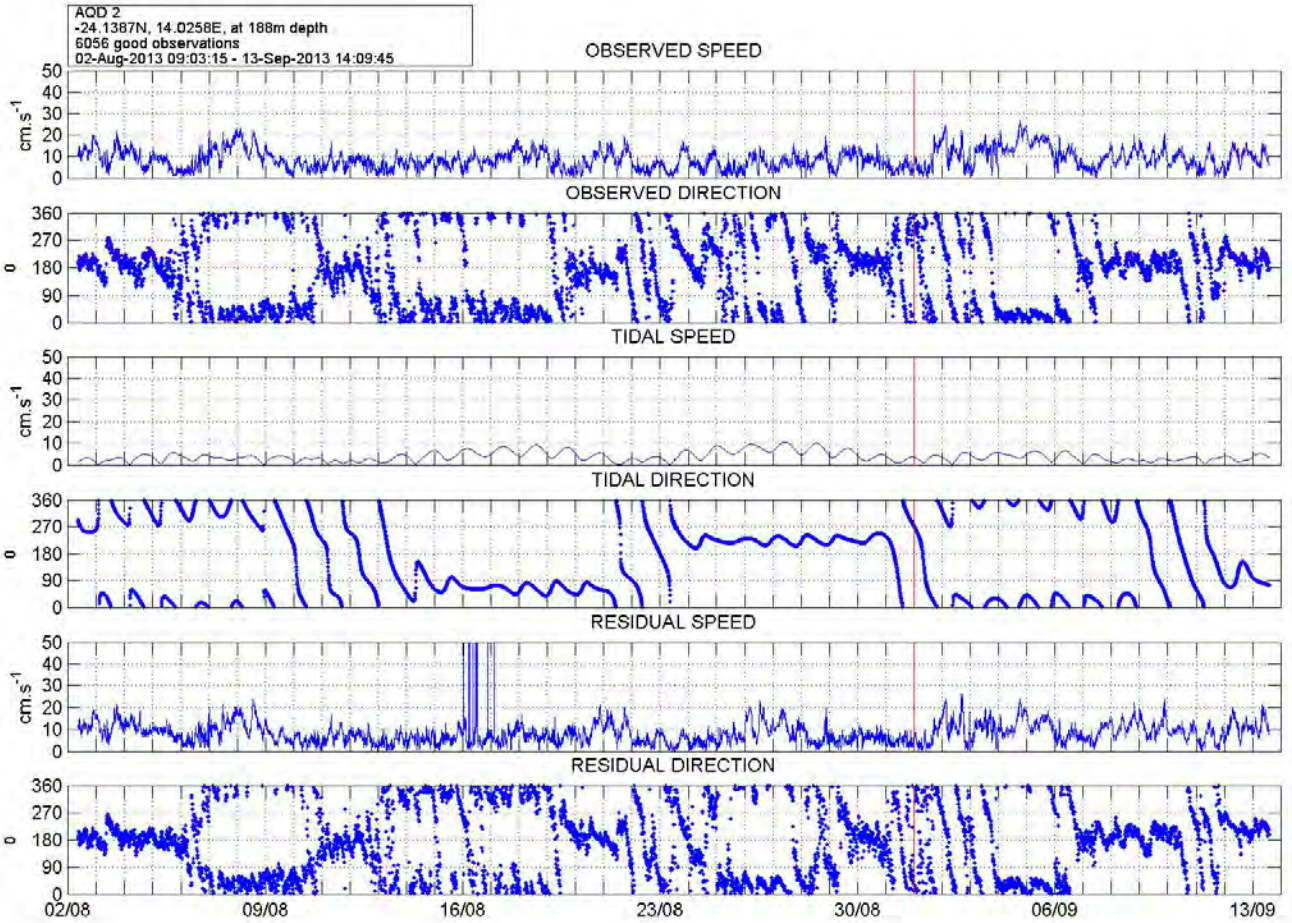
1. The first (upper) panel is of the observed current speed against time.
2. The second panel is of the observed current direction against time.
3. The third panel is of the tidal current speed, calculated from the observed current speed and direction, against time.
4. The fourth panel is of the tidal current direction, against time.
5. The fifth panel is of the residual current speed against time. The residual has been calculated as north and east components (residual component = observed component – tidal component), which have then been converted into residual speed and direction.
6. The sixth panel is of the residual current direction against time, calculated as above.

© NMP 2014



MSI Section D 1.8 & 1.9 – Lwandle, 2013 – Section C 2.1

© NMP 2014



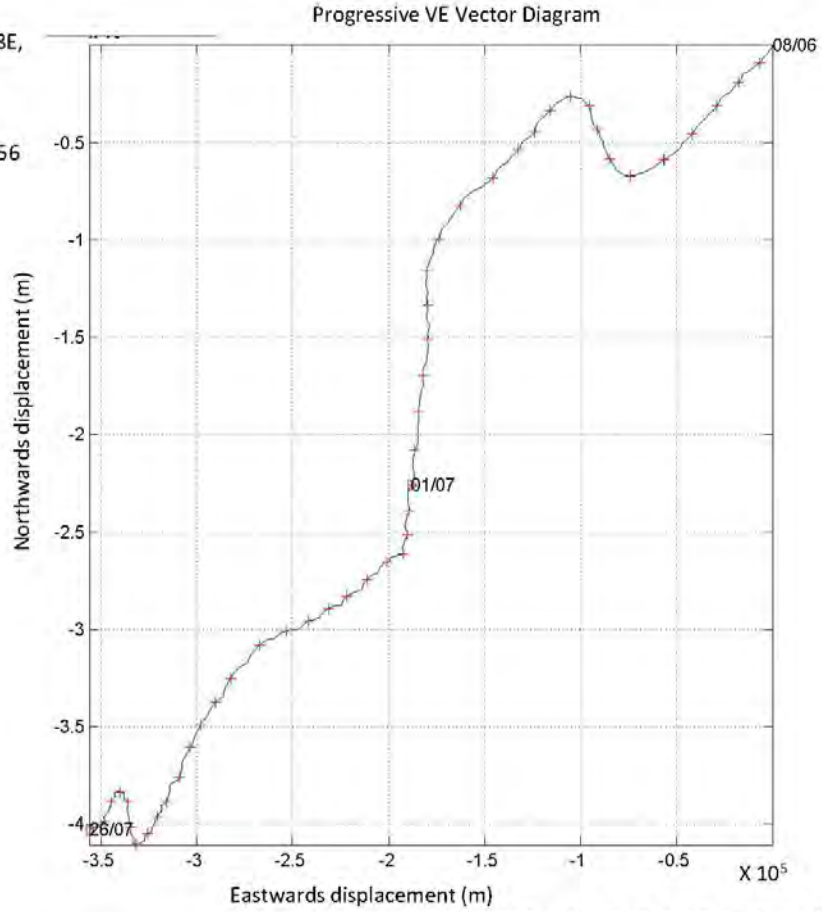
MSI Section D 1.8 & 1.9 – Lwandle, 2013 – Section C 2.1

© NMP 2014

AQD 2
-24.1386N, 14.0258E,
at 193 m depth
6908 good
observations
08-Jun-2013 06:17:56
to 26-Jul-2013
05:33;26

The Plot shows:

- The solid line represents the displacement that a particle of water would undergo when subject to the currents that were observed.
- The start and end points of the observations are labelled.
- Each day is represented by a red cross.



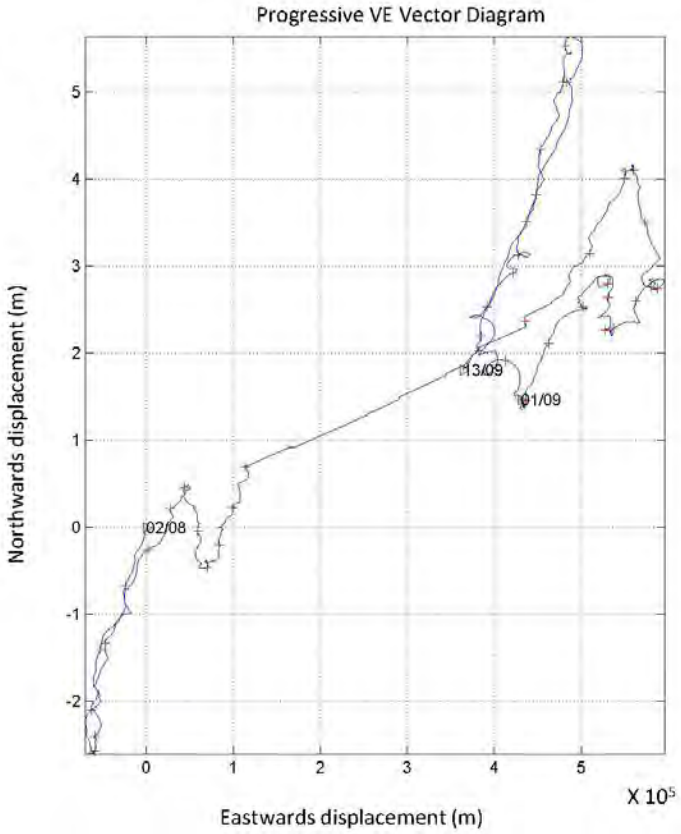
MSI Section D 1.8 & 1.9 – Lwandle, 2013 – Section C 2.1

© NMP 2014

AQD 2
-24.1386N, 14.0258E,
at 188 m depth
6056 good
observations
02-Aug-2013 09:03:15
to 13-Sep-2013
14:09:45

The Plot shows:

- The solid line represents the displacement that a particle of water would undergo when subject to the currents that were observed.
- The start and end points of the observations are labelled.
- Each day is represented by a red cross.



MSI Section D 1.8 & 1.9 – Lwandle, 2013 – Section C 2.1

© NMP 2014

Namibian Shelf Biogeochemistry and BBL physics

- Shift from tidal 22^{0}S to inertial dynamics 24^{0}S
  - Possible reasons:
    - Shelf structure change
    - Stratification (stronger buoyancy forcing from Luderitz)
    - Seasonal differences in water column stratification
- Even though there is change in the mechanism driving BBL turbulence the net effect is identical and if anything the persistent inertial periods will be stronger.
  - Verified by the AaDOP – VBBL ~ 0.2 – 0.3ms-1 which corresponds to a bed shear stress of 0.2 – 0.3Pa >> CSS ~0.05Pa for accumulation of fine sediments and organics.

© NMP 2014

Synthesis

- Core hypothesis was not supported by observations: Therefore, the dredging area is not in the mud belt – hypoxic but not anoxic, and characterized by:
  - High C:N
  - High NO_3
  - Low AVS (memory of SR)
  - Elevated BBL turbulence (SS) > 0.3Pa >> 0.05Pa CSS required to re-suspend fine particles

© NMP 2014

References

- Brüchert, V. *et al.*, 2003 Regulation of bacterial sulfate reduction and hydrogen sulfide fluxes in the central Namibian coastal upwelling zone. Geochimica et Cosmochimica Acta, **67**: 4505–4518.
- Inthorn M, Wagner T, Scheeder G and Zabel M 2006 Lateral transport controls distribution, quality, and burial of organic matter along continental slopes in high-productivity areas *Geology* **34:** 205–8.
- Monteiro, P.M.S., Nelson, G., van der Plas, A., Mabille, E., Bailey G.W., Klingelhoeffer E., (2005). Internal tide - shelf topography interactions as a potential forcing factor governing the large scale sedimentation and burial fluxes of particulate organic matter (POM) in the Benguela upwelling system. *Continental Shelf Research* **25**: 1864 - 1876.
- van der Plas, A., Monteiro, P.M.S. and Pascall, A. [2007] Cross-shelf biogeochemical characteristics of sediments in the central Benguela and their relationship to overlying water column hypoxia. African Journal of Marine Science. **29**(1): 37 - 47
- CSIR-NatMIRC data 2002 SADCO database.

© NMP 2014

SPECIALIST STUDIES – SECTION C

C2.2 The utility of hydrodynamic and biogeochemical numerical modelling to better inform the assessment of potential water column and benthic impacts of proposed dredging of marine phosphates in Mining Licence Area ML 170, Namibia

Prepared for:
Namibian Marine Phosphate (Pty) Ltd.

Prepared by:
CSIR, Natural Resources and the Environment
Report compiled by Roy van Ballegooyen



October 2014

CSIR/NRE/CO/ER/2014/0064/B

CSIR, Natural Resources and the Environment
PO Box 320, Stellenbosch 7599, South Africa
Tel: + 27 21 888 2574
Fax: + 27 21 888 2693
Email: rvballeg@csir.co.za

Published and issued by:

CSIR
P O Box 320
STELLENBOSCH 7599
South Africa
Tel: + 27 21 888-2400
Fax: + 27 21 888-2693
Email: rvballeg@csir.co.za

The report should be cited as:

van Ballegooyen, R.C. (2014) Review: The utility of hydrodynamic and biogeochemical numerical modelling to better inform potential water column and benthic impacts of proposed dredging of marine phosphates in Mining Licence Area ML 170, Namibia, CSIR Report, CSIR/NRE/ECO/ER/2014/0064/B.

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed “Attention: Administration Manager,” at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

SUMMARY

Background

The Mining Licence Area (ML 170) proposed to be mined by Namibian Marine Phosphate (Pty) Ltd is located on the Namibian continental shelf approximately 60 km off the coast of Conception Bay. The area of the mining lease area covers 2 233 km^2 within which there are three areas identified for exploitation: Sandpiper-1 (SP-1), Sandpiper-2 (SP-2) and Sandpiper-3 (SP-3). It is proposed to exploit each area systematically over time starting in SP-1. The mining licence would be granted for 20 years and the company proposes to mine an area of approximately 3 km^2 annually, i.e. an area of 60 km^2 over the period licenced.

The Ministry of Fisheries and Marine Resources in its evaluation of the specialist assessment of possible negative impacts in the water column and sediments, determined that that plume modelling should be undertaken. The purpose of this modelling would be to provide a more robust assessment of the nature and scale of potential impacts. This request was further emphasised during a peer review exercise by Dr M. O'Toole, who recommended that a preliminary numerical model be assembled using the data gathered by the project to date (the 90 day instrument mooring deployment). However it is considered by Dr Robin Carter that the value of the insights gained from interpretation of prior assessments, along with a robust understanding of plume dynamics, will far out-weigh the value provided by any newly commissioned modelling study.

Purpose of the Review

The purpose of this review is to provide an opinion on:

- the utility of a plume modelling study in reducing any existing residual uncertainties in the specialist assessments of potential water column and benthic impacts associated with the proposed NMP Sandpiper dredging project to the extent that the reviewing authorities confidently would be able to make the relevant environmental decisions around the proposed project, and
- provide a recommendation on the best approach going forward.

The initial impact assessment (Lwandle in 2012 EIA) and subsequent verification study (Lwandle, 2014) suggest that the majority of the impacts associated with the project are expected to be physical (e.g. water column turbidity and possibly smothering of benthos[1]) rather than biogeochemical. This was confirmed by subsequent reviews of these studies, suggesting that the only residual uncertainty remaining being the behaviour, extent and duration of the sediment discharge charge plumes. This is the focus of this review.

This review indicates that it is *possible (but not certain) that the actual plume dimensions may exceed the dimensions assumed in the Lwandle (2012 EIA) assessment* (i.e. plume dimensions may be up to 2 to 5 times larger than indicated). However, the implication of these potentially increased plume dimensions for the overall impact assessment and subsequent environmental decision-making is limited. Should the plume dimensions exceed those originally estimated in the Lwandle (2012 EIA) study, the extent of the plume reported in the impact assessment tables of that study may increase from being limited to the

[1] Smothering implies a sediment deposition rate exceeding a level beyond which benthic organisms would be unable to process through normal bioturbation activities.

"Immediate Dredge Area" (per vessel cycle) to affecting possibly the "Annual Mining Area (3 km^2)". It is not anticipated that this change in the extent of the impact would be such that it affected the "Specific Mining Site" (SP-1). Therefore it is not expected that these possible, but modest, changes in the impacted area will materially affect the environmental decision-making for this project.

Two possible modelling approaches have been assessed in terms of providing greater certainty on the behaviour, extent and duration of the sediment discharge plumes. The first approach, comprising large-scale modelling with a nested high resolution modelling domain, is not considered viable due to the time that will be required to undertake such a modelling study, the likely high costs of such an exercise and the very real risk that such an approach may not manage to further constrain any of the key uncertainties in the existing environmental impact assessment specialist studies.

An alternate approach comprising high resolution modelling of a limited area with the open boundary conditions being provided by existing measurements (i.e. the 90 days of existing current and water quality data), is considered viable in terms of cost, duration of the study and likely outcomes. Such modelling indeed will help to constrain some of the residual uncertainties in the assessments around plume extent and duration, e.g. associated with uncertainties in sediment loads, sediment characteristics, settling rates, etc. It will also better characterise the sensitivity of the impact assessments to possible changes in the rates of dredging and nature of material being dredged. However, as indicated above, any changes in the estimated extent of the impacted area indicated by such modelling are expected to be modest and unlikely to affect substantially the environmental decision-making surrounding this project. This modelling will provide a more explicit means (than the existing assessments) of constraining the uncertainties (listed above) and providing greater confidence in the assessed impacts based on the plume behaviour extents and duration. Should this be a priority, such a limited area, high resolution modelling study should be undertaken, despite the fact that the outcomes of such modelling are unlikely to change the significance of assessed impacts materially.

The measurements required to support the above modelling studies are similar to those required to assess plume dynamics and resultant impacts should it be chosen to make these assessments based on measurements alone. Specific requirements for the modelling study will include:

- Initial sediment concentrations and discharge parameters such as discharge volumes, flow rates, grain size distributions
- Initial concentrations of biogeochemical parameters of concern;
- Current meter measurements for the proposed simulation periods.
- Wind and atmospheric flux data (which can be obtained from global data sets such as National Centre for Environmental Protection (NCEP) data should it not be able to measure these using an offshore weather station);
- Water column structure measurements and water quality data: however should such data not be available, seasonal profiles based on historical data will need to be used.

Finally, should such modelling not be undertaken prior to the commencement of dredging operations, it is recommended that modelling form a key part of the verification and impact monitoring studies proposed for the early stages of the proposed dredging operations (e.g. by helping to inform the design of monitoring activities and in the interpretation of the resultant measurements). An appropriate model-based predictive capability is likely to prove invaluable should environmental constraints (over and above those already anticipated) need to be placed on dredging operations. Furthermore the development of a well-calibrated and validated model-based predictive capability is likely to prove invaluable for future environmental impacts assessments of a similar nature or should it become necessary in the future to assess potential cumulative impacts of marine dredging in these waters.

© NMP 2014

SCOPE OF WORK

The Mining Licence Area (ML 170) proposed to be mined by Namibian Marine Phosphate (Pty) Ltd is located on the Namibian continental shelf approximately 60 km off the coast of Conception Bay. The area of the mining licence covers 2 233 km^2 within which there are three areas identified for exploitation: Sandpiper-1 (SP-1), Sandpiper-2 (SP-2) and Sandpiper-3 (SP-3). It is proposed to exploit each area systematically over time starting in SP-1. The mining licence would be granted for 20 years and the company proposes to mine an area of approximately 3 km^2 annually, i.e. an area of 60 km^2 over the period licenced.

The Ministry of Fisheries and Marine Resources, in its evaluation of the specialist assessment of possible negative impacts in the water column and sediments (undertaken by Dr Robin Carter – Lwandle, 2012), determined that that plume modelling should be undertaken. The purpose of this modelling would be to provide a more robust assessment of the nature and scale of potential impacts. This request was further emphasised during a peer review exercise by Dr M. O'Toole, who recommended that a preliminary numerical model be assembled using the data gathered by the project to date (the 90 day instrument mooring deployment). It is considered by Dr Robin Carter that the value of the insights gained from interpretation of prior assessments undertaken by Dr Trevor Probyn and the CSIR (2006) for DeBeers Marine along with a robust understanding of plume dynamics, will far out-weigh the value provided by any new modelling study. The De Beers mining project was located to the south of the NMP MLA in water depths of 90 to 130 m. The modelling study was project-specific and validated with *in-situ* observations.

Given the conflicting views of Dr Robin Carter and those of Dr M. O'Toole, together with the views of MFMR, Namibian Marine Phosphate (Pty) Ltd requires a position statement from an independent, qualified and respected scientist that provides clarity on what would be the best approach going forward. Consequently this review was commission by Namibian Marine Phosphate (Pty) Ltd that has the objective of obtaining an independent professional opinion on:

- the utility of such plume modelling in better informing the assessment of potential impacts on the water column and benthic environment associated with dredging in ML 170 and consequently;
- provide a recommendation on the best approach to an additional assessment of potential dredging plumes, ranging from an expert opinion (based on a qualitative interpretation of existing data) to a comprehensive modelling study.

The purpose of such an additional assessment (model-based or otherwise) would be to ***reduce any existing uncertainties in the specialist assessments to the extent that the reviewing authorities confidently would be able to make the relevant environmental decisions around the proposed project.*** Specifically the additional information generated should be sufficient to allow the authorities to confidently provide support the project and issue the relevant environmental authorisations as appropriate.

The specific terms of reference for this study therefore are as follows. The independent scientist (modeller) should by independent assessment:

- provide a definitive statement on the optimum approach to be taken to deal with residual uncertainties in the project;
- indicate the relative merits of the proposed approaches (ranging from the existing expert opinion based on a qualitative interpretation of existing data and information to a comprehensive modelling study or some combination thereof) in providing an optimal outcome in terms of the scientific information generated to better inform environmental decision-making around the

© NMP 2014

proposed project (*i.e*. provide an understanding of the nature and likely extent of potential impacts and the reduction of existing uncertainties in this regard);

- provide an assessment of monitoring data and measurements that would be required by each of the approaches considered (e.g. for calibration, validation or the set-up of modelling scenarios so that this can be included in ongoing environmental management practices and monitoring required for the project).

If the assessment undertaken here determines that an approach comprising more than an expert opinion based on a qualitative interpretation of existing data and information (i.e. a model-based approach as suggested by Dr M. O' Toole and MFMR) is likely to add sufficient value, then a clear indication must be provided of which aspects of the assessment(s) will be significantly improved and the likely extent in the reduction of uncertainty around these aspects of the assessments(s) that is expected from such a modelling study. Furthermore should such a modelling study be indicated, the likely duration and cost of such a modelling study is to be provided.



Roy van Ballegooyen

Coastal Systems Research Group
Natural Resources and the Environment CSIR
Stellenbosch, South Africa

October 2014

© NMP 2014

contents

SUMMARY ii
SCOPE OF WORK iv

1 INTRODUCTION 1
1.1 BACKGROUND 1
1.2 SCOPE OF WORK 2
1.3 REVIEW APPROACH 3
2 KEY FINDINGS OF THE RELEVANT EIA SPECIALIST STUDIES 4
3 KEY ASPECTS OF UNCERTAINTY TO BE RESOLVED 9
4 HYDRODYNAMIC AND WATER QUALITY MODELLING 19
4.1 APPROACHES TO THE HYDRODYNAMIC AND WATER QUALITY MODELLING 19
4.1.1 Modelling Approach 1: Large-scale model with nested high resolution domain 19
4.1.2 Modelling Approach 2: High resolution model using measured data at the open boundaries 20
4.2 MEASUREMENTS REQUIRED TO SUPPORT MODELLING STUDIES 29
5 CONCLUSIONS AND RECOMMENDATIONS 30
5.1 CONCLUSION 30
5.2 RECOMMENDATIONS 30
6 REFERENCES 31

figures

Figure 1.1: The Mining Licence Area (ML 170) and the three areas that are proposed to be mined within the mining licence area. 1
Figure 2.1: Risks to water quality from operation of a Trailer Suction Hopper Dredger at sea (adapted from Lwandle, 2012). 5
Figure 3.1: Summary plots of current speed and directions during P1: 8 June – 26 July 2013 (left panel) and P2: 2 August – 13 September 2013 (right panel) at the near surface, mid water and near the seabed, collected from the oceanographic mooring located at 24° 08' 18.96" S, 14° 01' 32.88" E. Note the different scale in the lower left panel 15
Figure 3.2: Current roses for data measured at 28.6192S; 16.1028E in 110 m water depth (from the CSIR (2006) study). 16
Figure 4.1: High resolution drill cuttings disposal simulation offshore of KwaZulu-Natal using Modelling Approach 2 21

© NMP 2014

Figure 4.2: Sample of outputs (high resolution drill cuttings disposal simulation offshore of KwaZulu-Natal) from a modelling study using Modelling Approach 2 23

tables

Table 3.1: Impact Assessment summary table (Lwandle 2012 EIA) 12
Table 3.2: Re-rated impact assessment table after the verification studies (Lwandle 2014) 13
Table 3.3: Impact criteria used to assess extent and duration (Lwandle, 2012 EIA). 19
Table 4.1: Comparative assessment of required information and model functionality for the two proposed modelling approaches. 24

© NMP 2014

1 INTRODUCTION

1.1 BACKGROUND

The Mining Licence Area (ML 170) proposed to be mined by Namibian Marine Phosphate (Pty) Ltd is located on the Namibian continental shelf approximately 60 km off the coast of Conception Bay. The area of the mining lease area (Figure 1.1) covers 2 233 km^2 within which there are three areas identified for exploitation: Sandpiper-1 (SP-1), Sandpiper-2 (SP-2) and Sandpiper-3 (SP-3). It is proposed to exploit each area systematically over time starting in SP-1. The mining licence would be granted for 20 years and the company proposes to mine an area of approximately 3 km^2 annually, which will lead to dredging an area of 60 km^2 over the period licenced.

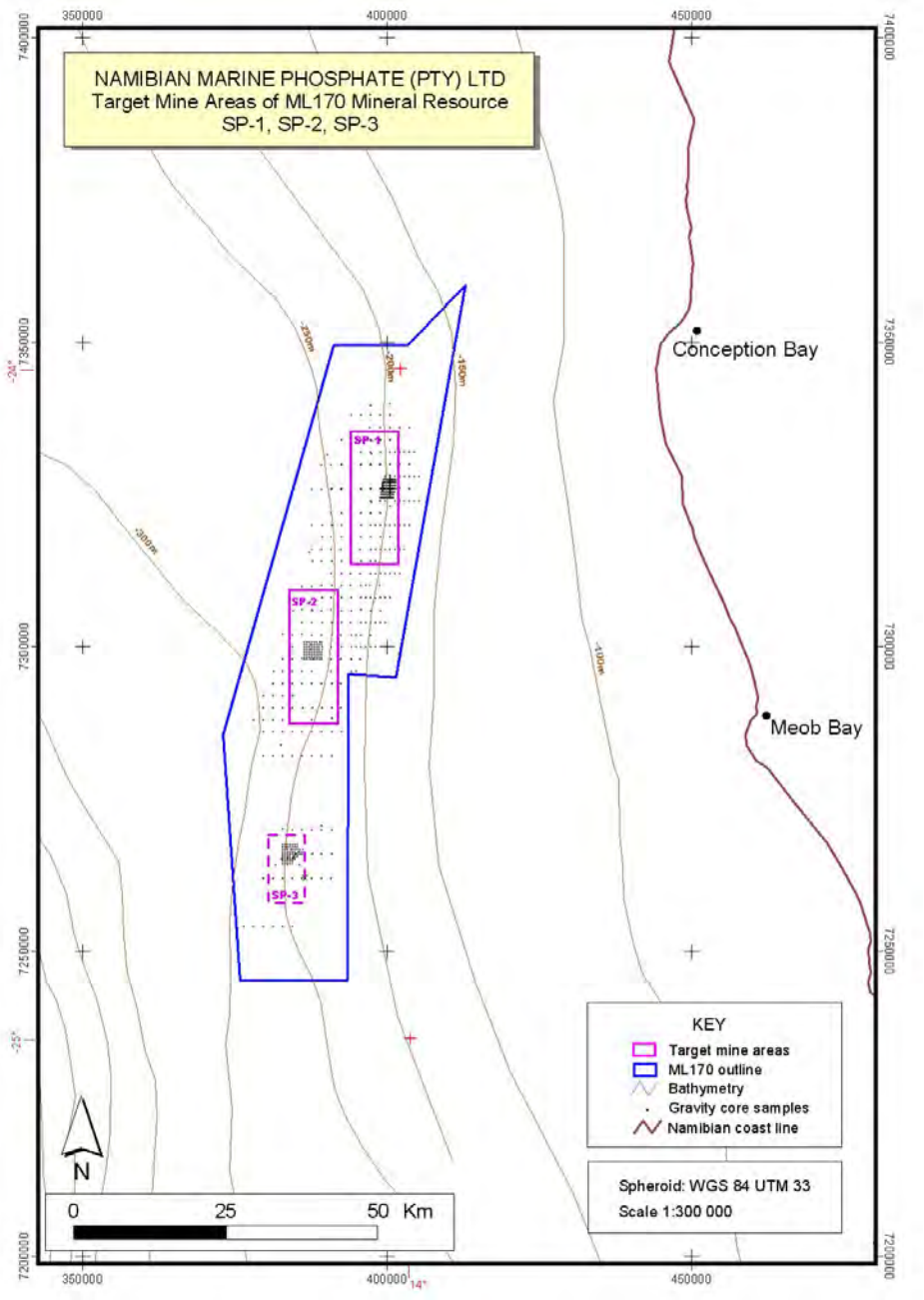


Figure 1.1: The Mining Licence Area (ML 170) and the three areas that are proposed to be mined within the mining licence area.

The Ministry of Fisheries and Marine Resources, in its evaluation of the specialist assessment of possible negative impacts in the water column and sediments (undertaken by Dr Robin Carter – Lwandle, 2012), determined that that plume modelling should be undertaken. The purposes of this modelling would be to provide a more robust assessment of the nature and scale of potential impacts. This request was further emphasised during a peer review exercise by Dr M. O'Toole, who recommended that a preliminary numerical model be assembled using the data gathered by the project to date (the 90 day instrument mooring deployment). It is considered by Carter (Lwandle, 2012) that the value of the insights gained from interpretation of prior assessments undertaken by Dr Trevor Probyn and the CSIR (2006) for DeBeers Marine along with a robust understanding of plume dynamics, will far out-weigh the value provided by any new modelling study. The De Beers mining project was located to the south of the NMP MLA in water depths of 90 to 130 m. The modelling study was project-specific and validated with *in-situ* observations.

1.2 SCOPE OF WORK

Given the conflicting views of Dr Robin Carter and those of Dr M. O'Toole, together with the views of MFMR, Namibian Marine Phosphate (Pty) Ltd requires a position statement from an independent, qualified/competent and respected scientist that provides clarity on what would be the best approach going forward. Consequently Namibian Marine Phosphate (Pty) Ltd commissioned this review that has the objective of obtaining an independent professional opinion on:

- the *utility of such plume modelling in better informing the assessment of potential impact on the water column and benthic environment associated with dredging in ML 170*, and consequently;
- a recommendation on the best approach which could comprise an additional assessment of potential dredging plumes ranging from the *existing expert opinion (based on a qualitative interpretation of existing data and information)* to a comprehensive modelling study.

The purpose of such an additional assessment (model-based or otherwise) *would be to reduce any existing uncertainties in the specialist environmental impact assessments to the extent that the reviewing authorities would be able to confidently make the relevant environmental decisions around the proposed project*. Specifically the additional information generated should be sufficient to allow the authorities to confidently provide support for the project and issue the relevant environmental authorisations as appropriate.

The specific terms of reference for this review therefore are as follows. The independent scientist (modeller) should by independent assessment:

- provide a *definitive statement on the optimum approach to be taken to deal with residual uncertainties* in the project;
- indicate the *relative merits of the proposed approaches* (the existing expert opinion based on a qualitative interpretation of existing data and information to a comprehensive modelling study or some combination thereof) in providing an optimal outcome in terms of the scientific information generated to better inform environmental decision-making around the proposed project (*i.e*. provide the requisite understanding of the nature and likely extent of potential impacts and the reduction of existing uncertainties in this regard);
- provide an assessment of *monitoring data and measurements* that would be required by each of the approaches considered (e.g. for calibration, validation or the set-up of modelling scenarios

© NMP 2014

so that this can be included in ongoing environmental management practices and monitoring required for the project).

If this assessment undertaken here determines that an approach *comprising more than an expert opinion based on a qualitative interpretation of existing data and information* (i.e. a model-based approach as suggested by Dr M. O' Toole and MFMR) is likely to add sufficient value, then a clear indication must be provided of *which aspects of the assessment(s) will be significantly improved and the likely extent in the reduction of uncertainty around these aspects of the assessments(s) that can be expected from such a modelling study*. Furthermore should such a modelling study be indicated, the likely duration and cost of such a modelling study is to be provided.

1.3 REVIEW APPROACH

The approach taken in this review is first to summarise the key findings of the existing impact assessment studies and assess the uncertainties that remain with respect to each of the key findings (Section 2). An evaluation of those aspects of the assessments of plume behaviour, extent and duration assessments (i.e. physical and biogeochemical processes) needed to resolve the residual uncertainties in the environmental impact assessments, is given in Section 3. Here the robustness of the existing impact assessments is reviewed. A clear indication is given of the sources of uncertainty in the existing assessments and the uncertainties that will remain should these not be fully resolved in a modelling study.

In Section 4 a brief summary of existing modelling platforms and modelling expertise available for making the relevant assessments is provided. Given the *inherent capabilities* of the models and *existing data* to support such modelling activities, an assessment is made whether the proposed approaches to the modelling studies will be able to reduce significantly the residual uncertainties of concern in the existing specialist assessments. Two potential modelling approaches will be considered and their relative merits assessed in terms of their ability to reduce residual uncertainties in the assessments and their likely cost and duration.

Should the review indicate that such modelling studies are required and that the data available to undertake such modelling studies are insufficient to warrant a modelling study at this time, recommendations are made as to the nature of model that should be set up and the likely data requirements to support such modelling. An assessment of monitoring data and measurements that would be required for each of the proposed modelling approaches in terms of model calibration, validation and the setting up of modelling scenarios is included in Section 5. This information is required so that the relevant measurement activities can be included into ongoing environmental management programmes.

© NMP 2014

2 KEY FINDINGS OF THE RELEVANT EIA SPECIALIST STUDIES

The proposed dredging method will:

- Directly modify the seafloor in the dredged area;
- Redistribute fine sediments to the adjacent seabed;
- Modify benthic community structure in the mined area;
- Affect seawater quality through re-suspension of sediments at the dredge head and discharge of lean water from the dredger's hoppers, possibly modifying dissolved oxygen distribution through either relocating hypoxic water in the water column or exposing anoxic pore water in the sediments. This can also apply to methane, hydrogen sulphide and contaminants that may be held within the dredge area sediments;
- Import alien and/or noxious organisms into the region via ballast water discharges from the dredger on first entry to the project area;
- Possibly affect fish and fisheries;
- Possibly disturb marine mammals and seabirds; and
- Possibly compromise other ecological services such as eco-tourism etc.

The focus here is on potential water quality effects of dredging and risks associated with ballast water discharges (bullets 4 and 5 above) and to a lesser extent benthic impacts (bullets 1 to 3).

Water column impacts

The initial specialist report on potential water column impacts (Lwandle, 2012) comprised a desktop study that considered a number of potential impacts on the water column from the dredging activities. The eleven potential impacts considered were:

- Pollution from discharged vessel wastes;
- Ecosystem disruption by alien species discharged with ballast water;
- Organisms adversely affected by suspended sediments in the water column;
- Toxicity from released hydrogen sulphide in the water column;
- Reduction in dissolved oxygen in the upper water column from introduced anoxic bottom waters;
- Increased nutrients promote phytoplankton growth and ultimately reduce dissolved oxygen concentrations;
- Trace metals (cadmium and nickel) discharged with the overspill affect organisms in the water column;
- Benthic organisms are exposed to remobilised cadmium and nickel in the dredge areas on the seabed;
- Benthic and/or demersal organisms are exposed to an increased flux of dissolved H_2S into the lower water column;
- Benthic and/or demersal organisms are exposed to anoxic sediments and lowered oxygen levels on the seabed; and
- Removal of thiobacteria mats by dredging increases the flux of H_2S to the lower water column.

This assessment on the likely utility of plume modelling in reducing uncertainty in the assessed impacts, is limited to the impacts in the highlighted text box above. Plume modelling will not be able to improve assessment of the potential impacts listed in bullets 1 and 2 above. The impacts assessed in this review are summarised in Figure 2.1 below (adapted from Lwandle, 2012).

© NMP 2014

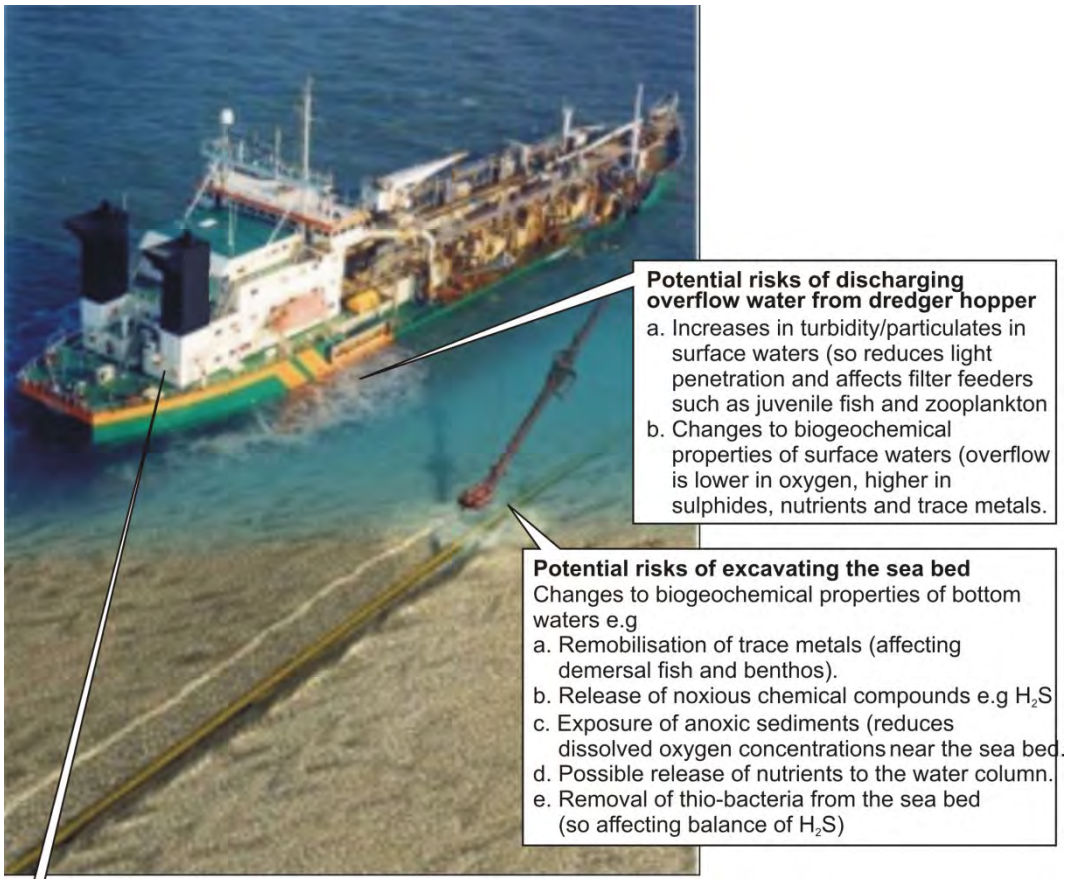


Figure 2.1: Risks to water quality from operation of a Trailer Suction Hopper Dredger at sea (adapted from Lwandle, 2012).

The water quality impact assessment (desktop) study concluded that, apart from the risk of ecosystem impacts from the introduction of alien species, all the others were of low significance or not of significance. A verification study was undertaken to reduce residual uncertainties in the initial impact assessments (Lwandle, 2014). Acknowledged limitations of the initial study are:

- while the impacts of the proposed dredging were assessed, it is not be possible to assess cumulative or additive effects of the dredging operations and other activities such as industrial fishing (demersal trawling), until the effect of these other activities are similarly quantified.
- the confidence levels awarded to the impact assessments show that there is some uncertainty about the biogeochemical properties of the sediments in the proposed dredging areas. This should be resolved by investigations specific to the dredging areas either prior to commencement of dredging or in its early/initial stages. Of particular relevance are the overspill plume characteristics and behaviour. Should investigations show that the impacts are more severe than predicted, then real-time controls on, for example, exceeding established thresholds for turbidity, dissolved oxygen, H_2S, etc. would need to be used to manage the dredging operations.

© NMP 2014

The scope of the verification survey undertaken was based on key concerns raised by NatMIRC and other external reviewers of the NMP EIA report (2012) as abstracted below (Lwandle, 2014):

- The currents and circulation information in the EIA studies were primarily taken from regional scale circulation modelling and other published sources. There is uncertainty on the applicability of this to the proposed dredging area.
- Similarly, important features of the water column were generalised from regional and possibly outdated information; this needs to be focused on the dredging area.
- Sediment characteristics vary zonally and longitudinally on the Namibian continental shelf, *extrapolation from measurements to the north and south of the proposed dredging area may not be safe leading to uncertainty* on whether:
  - the adduced sediment particle size and sediment texture apply;
  - the sediment bed is resistant to suspension (sediment water content/porosity and presence/absence of armouring);
  - the *in situ* organic content (POM) and molar carbon/nitrogen (C/N) ratios are as predicted;
  - sediment pore water departs from Redfield ratios, specifically in terms of inorganic nitrogen and phosphate ratios;
  - sediment heavy metal contents are within the published guidelines for the region and whether those that are not are likely to be biologically available, and
  - the sediments are sulphidic or likely to release hydrogen sulphide (H_2S) during dredging?
- The available ancillary biological data presented (sediment meiofauna, macrofauna and presence/absence of thiobacteria and (thio) bacterial mats required refinement to add confidence to the impact assessments.

The verification study (Lwandle, 2014) was required to address the above issues, particularly:

- the characterisation of the prevailing currents and water column structure, and;
- the characterisation of the sediments in terms of the parameters listed above.

The characterisation of the prevailing currents and water column structure is important in determining the transport and fate (dispersion) of suspended sediments and other biogeochemical or potentially toxic components of concern, while the characterisation of the sediments largely is required to determine the initial loading of biogeochemical or potentially toxic components of concern (low oxygen water, H_2S, trace metals, etc.). The characterisation of the sediments and the nature of the initial loading of biogeochemical or potentially toxic components of concern also have relevance in terms of transformation processes that may affect the transport and fate assessments (i.e. provide insight into the non-conservative behaviour of the constituents of concern when undertaking the plume modelling transport and fate assessments).

The results of the verification study (Lwandle, 2014) are summarised below.

- Currents measured during two mooring periods (MSI, 2014 a,b) were as expected for the region displaying uniform north westward flow at the surface and varying poleward and equatorward flow in the bottom of the water column. Near seabed current velocities averaged 18 cm/s for poleward flow and 9 cm/s for equatorward flow. Peak flows recorded were approximately 30 cm/s. Profiling of the water column indicated a reasonably strong variability over 5 days in the upper mixed layer and thermocline depths. Clearly evident in these data were the effects of

local wind mixing as well as advection of water masses into the region[2]. *Also reported were a general decrease in velocities with depth except for near the seabed where flows were relatively large. In this respect these data differ from those measured by the CSIR (2006) which indicated a general decrease in velocities with depth.* Similar to the currents reported in CSIR (2006), the flows at depth often opposed those nearer the sea surface. The two measurement periods reported in the verification study also indicated quite different current regimes near the seabed, the earlier mooring indicating persistent southwards flow at depth (MSI, 2014 a) and the later mooring data more variable flow both northwards and southwards (MSI, 2014 b).

- The dominant water mass present in the area during the survey period was South Atlantic Central Water with origins in the Cape Basin and the Angolan continental shelf. The former was relatively oxic and the latter severely hypoxic. The upper mixed layer in the water column ranged in depth from 20 m to 30 m and was oxic. Below the relatively weakly developed thermocline oxygen concentrations declined with depth to very low (severe hypoxia) levels near the seafloor. The southwards flows near the seabed were associated with low dissolved oxygen concentrations while the northward flows at depth constituted "ventilation" events, suggesting that the dissolved oxygen concentrations at depth were generally higher in the second period when bottom flows were more variable with a much higher occurrence of northerly flows than the first period.
- Upper water column turbidity was low at <1 NTU. Mean turbidity near the seafloor was <3.5 NTU but episodically exceeded 350 NTU. The data indicate that these short term turbidity events were generated outside of the survey area and were being advected through it.
- The characteristics of the sediments may be summarized from Lwandle (2014) as follows:
    - Dissolved heavy metal concentrations in the water column were close to the analytical detection levels and nutrient concentrations agreed with those reported for the region. Nitrogen/phosphorus ratios were close to Redfield (17.7 vs 16.0).
    - Surficial sediments in the survey area were silty sand and the underlying sediments primarily silt. Average POM concentrations were 7.4% and molar C:N ratios 11.4 – 19.8. These indicate that the POM was refractory.
    - Inorganic nutrient concentrations in the sediment pore waters average 156 µg/l for nitrogen (ammonia + nitrite + nitrate-nitrogen) and 209 µg/l for phosphorus. This shows a considerable departure from the Redfield ratio and is attributed to phosphorus enrichment from the pelletal phosphorus ore. Sediment water content was low leading to minimal risk of modifications to the overlying water column nutrient distributions.
    - The range of measurements indicative of the oxidative state of the sediments showed that they were hypoxic. The presence of nitrate-nitrogen in the sediment pore water supports this as it converts to ammonia in anoxic conditions. AVS was below detection levels in the surficial sediments and averaged <2 mMol/kg in the subsurface layers. The absence of AVS is consistent with hypoxia as free sulphide is oxidized to sulphate (SO_4^{2-}) in the presence of oxygen. This implies that sulphide fluxes would be low.
    - Surficial and subsurface sediments supported relatively high concentrations of the heavy metals arsenic, cadmium, chromium, copper and nickel. The bioavailability of these heavy metals was investigated by elutriation tests and negligible proportions

[2] The implication of this observation is that any detailed plume modelling would need to take into account both the wind-mixing as well as the effects of the advection of water masses into the area of interest.

© NMP 2014

entered the dissolved phase[3]. The low release of the metals into the dissolved phase indicates that although their natural concentrations exceeded the sediment quality guidelines for the region they do not represent a toxicity risk either *in situ* or following physical disturbance. This supports the assessment of toxicity risks in the EIA.

- The investigations into benthic meiofauna and macrofauna in the surficial sediments in the survey area showed that fauna were abundant in both size classes, consistent with a mainly hypoxic sediment environment and inconsistent with sulphidic sediments. The relative abundance of benthic macrofauna in the >1 000 µm size class is consistent with a stable sedimentary environment even though the overlying water body may undergo seasonal changes in terms of its oxygen content with varying contributions of Cape Basin and Tropical Atlantic Central Water.
- The investigation into sulphur bacteria indicated that sulphide fluxes were probably low as the large sulphate bacteria, namely from the genera *Thiomargarita*, *Beggiatoa* and *Thioploca*, which play a significant roles in the oxidisation of H_2S, were absent from the bacterial assemblage. Smaller forms including *Thiobacillus* spp. with relatively lower growth rates were present; however, indicating that although estimated to be low (hydrogen) sulphide was present in the sediments.

The conclusion of the study was that the main findings of the initial impact assessment (Lwandle, 2012) are supported by the data gathered and analysed during this verification study. As a result, the level of confidence with which a number of the impacts are assessed has been increased. *The major findings of the verification survey confirmed that the majority of the impacts associated with the project are expected to be physical rather than biogeochemical as was described in the original assessment* (Lwandle, 2014). Specifically the characteristics of the sediments dredged were such that impacts associated with potential elevation in nutrients, the introduction of low dissolved oxygen waters and H_2S into the water column and the effects of the bioavailable component of trace metals released into the water are expected to be limited, particularly given the predictions that the extent of the plumes containing these constituents will be relatively constrained.

Subsequent more detailed reviews of these impact assessments (i.e. Lwandle, 2012 EIA, 2014) raised a number of potential residual uncertainties that needed to be resolved. The key aspects of these reviews are outlined in Section3 of this report.

[3] This is possibly due to their precipitation as insoluble sulphides as, although there was low AVS in the tested (subsurface) sediments, it was present well in excess of the simultaneously extracted metal (SEM) fraction. Iron was abundant in both of the sediment layers and scavenging of the metals from the dissolved phase by iron hydroxides and organic complexes is another possible sink

3 KEY ASPECTS OF UNCERTAINTY TO BE RESOLVED

The key impacts assessed as part of the Lwandle (2012 EIA) specialist study are listed in Table 3.1. The severity of the impacts is based on the intensity (e.g. concentration levels of the constituents of concern), the extent (plume dimensions) and the duration (occurrence and longevity of plumes) of the potential impacts being assessed. Also of relevance is the probability of the envisaged impact occurring. Clearly listed in the table are the confidence levels for the various impacts assessed. Added to the table are the likely aspects of uncertainty underlying the lower confidence levels where indicated. It is these uncertainties that needed either to be addressed in the verification studies, or additional modelling studies as suggested by MFMR, and one of the reviewers (Dr M. O' Toole). Upon completion of the verification studies (Lwandle, 2014) there was a re-rating of the impacts based on the findings of the verification study. These re-rated risks are listed in Table 3.2, which also contains the key residual uncertainties that remained after the verification study.

An early concern raised was the potential for large-scale systemic impacts. This particular issue has been addressed in a separate review (Cochrane, 2014). The conclusion from that review is that given the combination of the high uncertainty typically associated with projections by ecosystem models and the small area that will be impacted by the proposed dredging, it is unlikely that ecosystem modelling would expose any unexpected, highly significant threats that have not already been considered in the specialist studies. A caveat to this was that this conclusion may, however, not apply if the area to be impacted by the mining is of particular importance in the ecosystem or in the life cycle of one or more key species. It was, therefore, important that the nature and likely ecological role of the benthic substrate and biota be adequately understood. Based on the above, it is highly unlikely that ecosystem modelling would better inform decisions around the environmental approval of the proposed NMP mining project.

Similarly additional hydrodynamic or biogeochemical modelling suggested by reviewers of the EIA report is only indicated if it significantly reduces the uncertainty in these key aspects of the potential impact(s) under consideration. The key aspects of uncertainty in the assessments are:

- uncertainty in the initial loadings (i.e. bioavailability of trace metals, oxygen demand, etc);
- the transport and fate of the constituents of concern (i.e. plume dynamics and fate of constituents of concern contained within the plume). The transport and fate of the constituents of concern are determined by transformation processes (i.e. non-conservative behaviour of the various plume constituents of concern) and the advection and dispersion of these constituents (that are largely determined by horizontal flows and vertical mixing in the water column). Here the purpose is to provide a quantification of the extent and duration of the plumes containing constituent concentrations exceeding levels of concern in the environment;
- a quantification of the negative effects of the various vectors of impact.

The focus of this review is therefore on the transport and fate of the constituents of concern (*i.e*. the nature, extent and duration of the expected plumes associated with the proposed mining operations).

A review by Roychoudhury (2014) states that whether the biogeochemical dynamics and their impact to a large extent becomes significant, depends on the behaviour of the sediment plume generated during the dredging activity. *Should the plume be larger than anticipated, in addition to impacting the wider area, prolonged sustenance of the plume will make biogeochemical processes important within*

the water column by modifying the redox status and mobilization of trace metals. For example, sulphide dynamics may become important under these conditions and will require a better understanding of oxygen consumption by the chemically reduced sediment reservoir. The sensitivity of biogeochemical processes and resultant potential impacts to an increased plume extent and duration (i.e. greater than assessed in Lwandle (2012 EIA, 2014)), is uncertain.

While all indications are that the initial loadings are such that they are unlikely to result in significant impacts (e.g. the volume of low oxygen waters, potential oxygen demand and bioavailable trace metals concentrations), the review by Professor Roychoudhury suggests that there exists a potential sensitivity that remains to be resolved should the plume extent be significantly different to that originally assessed (Lwandle, 2012 EIA, 2014). Consequently this review focusses on the likely plume extents and duration and whether these have been assessed correctly and/or could be better informed by additional modelling studies[4].

Should these initial or discharge concentrations (including initial non-conservative behaviour of the various biogeochemical parameters) be adequately determined, the most significant contribution of additional modelling studies will be a reduction in uncertainty due to a better characterisation on the extent and duration of the impacts, i.e. plume behaviour characterised in terms of its likely extent and the duration of its presence at concentrations of concern. Should the assertion that the only potential residual impacts of concern relate only to the physical impacts of dredge discharge plumes (*i.e*. turbidity effects in the water column and smothering at the seabed) then any proposed modelling study need only focus on the sediment plume behaviour, extent and durations.

As noted above, for an assessment of the plume dynamics to be robust:

- the *initial loadings* in terms of sediments and any associated potentially toxic or biogeochemical parameters/constituents of concern need to be adequately constrained. This includes the physical characterisation of the sediments being discharged, as well as the rate and duration of the discharge. This requires an adequate knowledge of the sediments being dredged (grain size, organic content, etc.). The nature of the sediments (proportion of fines) and the quantity being discharged (or the concentration of the discharge) may significantly affect *the initial (near-field) behaviour of the discharge plume*, resulting in a number of behaviours that may significantly affect the plume extent and duration.
- the assessment of the plume extent and duration (*i.e*. assessment of the advection and dispersion of constituents of concern) require that a number of processes are adequately resolved in either the available measurements or the hydrodynamic and/or water quality models used in the assessment. The most basic requirement is that the *currents distributions (both horizontal and vertical distributions)* are accurately measured or simulated in the models. In the NMP area this implies that tidal and wind-driven currents need to be measured or sufficiently accurately simulated in the available models. Given the offshore location and water depth at the proposed dredging sites, it is highly likely that the currents will be strongly influenced by large-scale flow features such as the upwelling fronts that occur in this region. Secondly, vertical mixing dynamics need to be known. These affect the vertical mixing of constituents of concern and also affect the settling rates of sediments, particularly in the upper

[4] Should the biogeochemical processes prove to be important in determining the ”initial loadings” or result in non-conservative behaviour of relevance to the plume modelling, such non-conservative behaviour and biogeochemical processes, in principle, could be included in the plume (i.e. transport and fate) modelling undertaken.

mixed layer. These vertical mixing dynamics are difficult to measure and are either i) inferred from observations of concentrations of the constituents in the plume being assessed or ii) need to be sufficiently accurately simulated in the hydrodynamic and water quality models used for the assessments. These vertical mixing dynamics depend on turbulence introduced into the water column as well as the existing water column structure (i.e. stratification). The implication is that *the processes driving vertical mixing (*e.g. *the introduction of turbulence due winds, tides and waves)*, as well as *horizontal inflows and/or atmospheric fluxes affecting water column structure* will need to be specified or sufficiently accurately simulated in any modelling study undertaken.

- Where *non-conservative behaviour of constituents* of concern is significant, this will need to be included in the assessment whether based on measurements of more detailed modelling of these biogeochemical processes.

Whether the environmental impacts assessments to date meet these requirements or whether additional modelling studies are required, is assessed below based on prevailing perceived residual uncertainties in the assessments (see Table 3.2). The residual uncertainties that may need to be resolved by modelling largely relate to the behaviour, extent and duration of sediment plumes (i.e. the near-field behaviour and far-field behaviour of the discharge plumes).

The assessment of risks in the water column (Lwandle, 2012 EIA) is based on an interpretation of previous modelling results for similar dredging scenarios, however for variable but significantly larger discharges and in shallower water depths (90 m to 130 m). It is important to note that the interpretation of the measurements and modelling outputs of the study (CSIR, 2006) used to reach the assessments in Lwandle (2012 EIA) made a few key assumptions, these being:

- that the flows in the CSIR (2006) study were accurately simulated and that these flows are representative of those prevailing at the deeper 200 m to 225 m ML 170 sites.
- the physical properties (grain size distributions, flocculated or unflocculated settling rates, etc.) of the material that was dredged was similar to that which will be dredged at the NMP operations site;
- the quantities being discharged (particularly the fines component) by the NMP dredging operations will be less than that assessed in the CSIR (2006) study. The fact that the overall sediment discharge rates for the CSIR (2006) study were approximately 4 times those anticipated for the NMP dredging suggest that this will remain true even if there is a significantly increased fines component in the NMP dredging discharges;
- The assumed initial plume behaviours in the CSIR (2006) study were correct and correctly accounted for in the modelling undertaken as part of that study;
- That these initial plume behaviours reported in the CSIR (2006) study are also applicable for the assessment of the proposed NMP dredging discharges

The desktop assessment of the proposed NMP dredging discharges (Lwandle, 2012 EIA) needed to interpret correctly and adapt the CSIR (2006) study outcomes to ensure a sufficiently robust assessment. This was largely achieved, however some minor issues may not have been fully resolved (see below). The robustness of the initial CSIR (2006) study as well as its interpretation to provide the Lwandle (2012 EIA) assessment of the proposed NMP dredging operations, is discussed below.

© NMP 2014

Table 3.1: Impact Assessment summary table (Lwandle 2012 EIA)

Impact	1	2	3	4	5	6	7	8	9
Risk Area	**Overspill discharge**					**Seabed dredging**			
Nature of the impact	**Turbid plume**	**H_2S toxicity at surface**	**Oxygen deficient water at surface**	**Nutrients added at surface**	**Trace-metal toxicity at surface**	**Trace-metal toxicity on seabed**	**H_2S toxicity on seabed**	**Lowered oxygen levels on seabed**	**Increase of H_2S flux.**
Extent	Dredge area	Dredge area	Dredge area	Dredge area	Dredge area	Annual Mining Area	Dredge area	Annual Mining Area	Dredge area
Duration	Very short term	Short term	Very short term	Short term	Short term	Short term	Medium term	Medium term	Long term.
Intensity	No lasting effect	Minor effects	No lasting effect	No lasting effect	Minor effects	Minor effects	Moderate effects	Minor effects	Minor effects
Probability	Possible	Possible	Improbable	Possible	Possible	Possible	Possible	Possible	Improbable
Status	Negative	Negative	Negative	Neutral	Negative	Negative	Negative	Negative	Negative
Significance (no mitigation)	Low	Low	None	None	Low	Low	Low	Low	None
Mitigation	Built-in	None possible	n/a	None possible	None possible	None possible	None possible	Not possible	n/a
Significance (with mitigation)	Low	Low	None	None	Low	Low	Low	Low	None
Confidence level	High	Medium	High	Medium	Medium	Medium	Medium	High	Medium
Source(s) of residual uncertainty	Near-field behaviour (initial density/grain-sizes, settling rates) and far-field behaviour (currents, thermocline and mixing behaviour)	Initial H_2S concentrations and subsequent dynamics, dispersion (near-field behaviour, far-field behaviour (currents, thermocline and mixing))	Initial dissolved oxygen concentration & evolution of oxygen demand upon release, dispersion (near-field behaviour, far-field behaviour (currents, thermocline and mixing behaviour)	Initial nutrient concentrations & consequences of elevated nutrients, (near-field behaviour, far-field behaviour (currents, thermocline and mixing behaviour)	Initial trace metal concentrations (near-field behaviour & far-field behaviour (currents, thermocline and mixing behaviour)	Initial trace metal concentrations and bio-availability, far-field behaviour (currents and mixing behaviour)	Initial H_2S concentrations at source & far-field behaviour (currents and mixing behaviour)	Initial trace metal concentrations and their bio-availability & far-field behaviour (currents and mixing behaviour)	Time taken for Thio-bacterial mats to re-establish

© NMP 2014

Table 3.2: Re-rated impact assessment table after the verification studies (Lwandle 2014)

Impact	1	2	3	4	5	6	7	8	9
Risk Area	**Overspill discharge**					**Seabed dredging**			
Nature of the impact	**Turbid plume**	**H_2S toxicity at surface**	**Oxygen deficient water at surface**	**Nutrients added at surface**	**Trace-metal toxicity at surface**	**Trace-metal toxicity on seabed**	**H_2S toxicity on seabed**	**Lowered oxygen levels on seabed**	**Increase of H_2S flux.**
Extent	Dredge area	Dredge area	Dredge area	Dredge area	Dredge area	Annual Mining Area	Dredge area	Annual Mining Area	Dredge area
Duration	Very short term	Short term	Very short term	Short term	Short term	Short term	Medium term	Medium term	Medium term
Intensity	No lasting effect	Minor effects	No lasting effect	No lasting effect	Minor effects	Minor effects	Minor effects	Minor effects	Minor effects
Probability	Possible	Possible	Improbable	Possible	Possible	Possible	Possible	Possible	Improbable
Status	Negative	Negative	Negative	Neutral	Negative	Negative	Negative	Negative	Negative
Significance (no mitigation)	Low	Low	None	None	Low	Low	Low	Low	Low
Mitigation	Built-in	None possible	n/a	None possible	None possible	None possible	None possible	Not possible	n/a
Significance (with mitigation)	Low	Low	None	None	Low	Low	Low	Low	Low
Re-Rated Confidence level	High	High	High	High	High	High	High	High	High
Reason for re-rating		Mine site sediment property data indicate low H_2S presence, pyrite sulphide will have low solubility		Mine site sediment pore water volumes are low	Mine area Heavy metals have low solubility and bioavailability, trophic transfers are attenuated at primary consumer level	Mine area Heavy metals have low solubility and bioavailability, dredging should not increase exposures	Mine site sediment property data indicate low H_2S presence	POM in sediments is refractory	Mine site sediment property data indicate low H_2S presence and release from iron pyrites should be low.

© NMP 2014

Seemingly the modelling studies undertaken in the CSIR (2006) study were sufficiently calibrated and validated for the purpose of assessing the dredge plumes from the dredging activities being assessed. The calibration and validation of the modelling results in Figure 9.4 of the CSIR (2006) study confirm that this is the case for the near-bottom currents (for ADCP currents measured at depths of 72 m and 85 m in an approximate 101 m water depth). However, the ADCP current measurements reported in the study (albeit for a very short time period - 8 March 2006 to 14 March 2006) indicate that there exists significant vertical shear in the measured currents with the deeper currents (> 35 m water depth) often opposing those measured higher up in the water column and near the sea surface. While the calibration and verification of the model is assumed to be correct, the CSIR (2006) study provides no evidence that these vertical shears in current flows indeed were adequately simulated in the model.

Given that the currents measured in the CSIR (2006) study:

- were measured in a *ca*. 110 m water depth as opposed to those for the NMP verification study (MSI, 2014a, 2014b) that were measured in a water depth exceeding 190 m, and;
- were measured in a different season from those measured for the NMP verification study, i.e. a late summer to autumn period (8 Mar 2006 to 4 May 2006) as opposed to the currents measured for the NMP verification study that were measured in winter to early spring (8 June to 26 July 2013 and 2 August to 13 September 2013);
- the two data sets are surprisingly similar in that both have northward or north-westerly surface flows and southerly or south-easterly flows at depth. This is perhaps not unsurprising and modelling studies in the region indicate that the poleward undercurrent, to a greater or lesser extent, is likely to be present at both of these locations (Veitch, 2010). The surface flows in the data measured by the CSIR in an approximately 110 m water depth (Figure 3.1) are slightly larger than those measured in the NMP verification study (Figure 3.2) while the flows near the seabed are slightly weaker for the current measured in a 110 m water depth.

The Lwandle (2012 EIA) assessment estimates the initial concentration of muddy sand mixture of sediments discharged will be of the order of 18 g/l, suggesting that the near-field behaviour in at intermediate concentrations in the overspill are expected to behave in ‘transition mode’; as defined by Winterwerp (2002) where the discharged plume is subject to both density currents and mixing. This *initial near-field behaviour is important in determining the initial plume dynamics and the spread and persistence of sediment, particularly in the upper mixed layer*. The lower these initial sediment concentrations the greater the proportion of the sediments discharged that will mix into upper mixed layer. However the lower these initial concentrations, the lower will be this loading of the water column. Provided that the CSIR (2006) study consistently took into account the range of possible initial discharge or near-field behaviours for the various initial discharge concentrations (which it claims to do), the interpretation of the results of the CSIR will remain relevant to the assessment of the plume dynamics reported in Lwandle (2014).

© NMP 2014

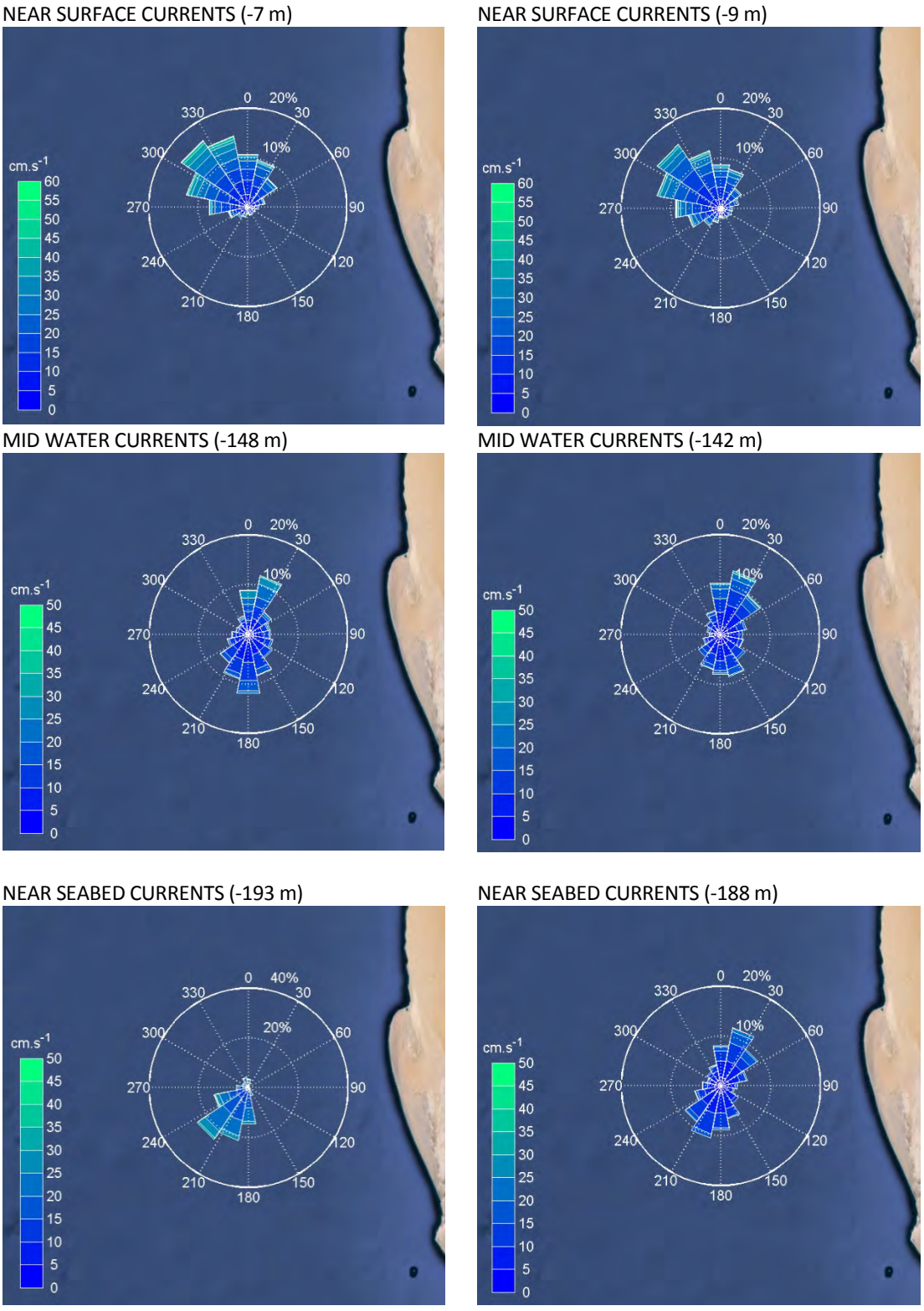
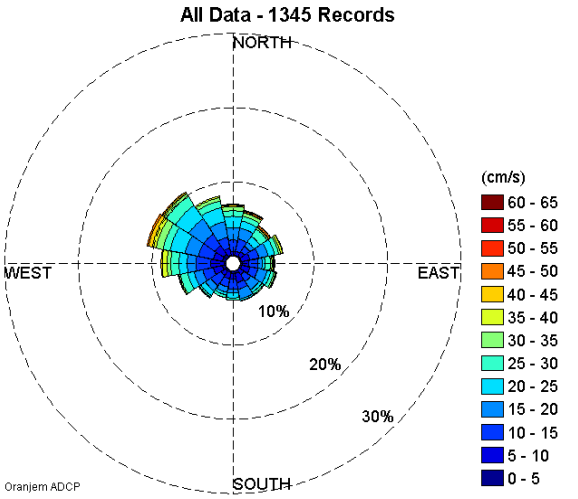
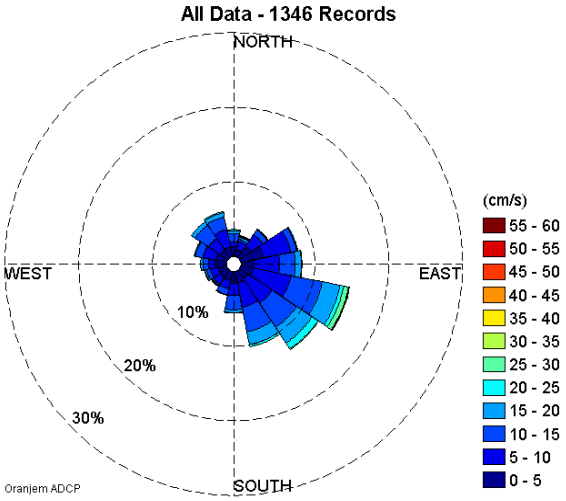


Figure 3.1: Summary plots of current speed and directions during P1: 8 June – 26 July 2013 (left panel) and P2: 2 August – 13 September 2013 (right panel) at the near surface, mid water and near the seabed, collected from the oceanographic mooring located at 24° 08' 18.96" S, 14° 01' 32.88" E. Note the different scale in the lower left panel

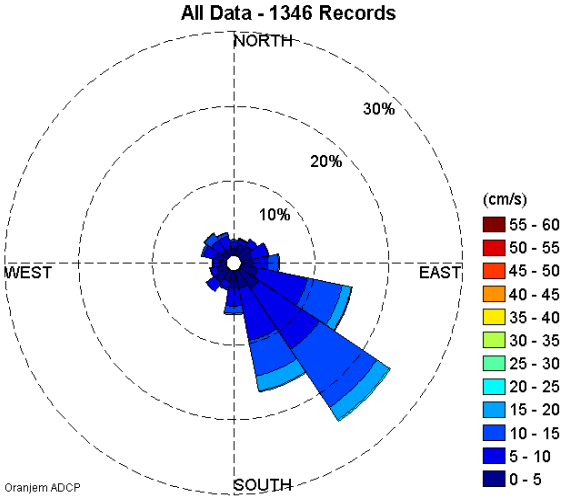
(Source: Lwandle, 2014)



Near surface: 20 m



Midwater: 50 m



Near seabed: 104 m

Figure 3.2: Current roses for data measured at 28.6192S; 16.1028E in 110 m water depth (from the CSIR (2006) study).

The sediment loadings used in the CSIR (2006) study were highly variable, nevertheless the estimated plume dimensions used in the Lwandle (2012 EIA) assessment (a plume dimension of 1 500 m long by 800 m wide with suspended sediment concentrations within this plume ranging between >20 mg/ℓ but <100 mg/ℓ) were based on plume dimensions reported in CSIR (2006) for mining operations in southern Namibia having a overspill discharge rate approximately 4 times higher than that estimated for the proposed NMP dredging project. While the sediment grain sizes are likely to differ between the two projects, the differences in initial loadings are such that the estimates of plume dimensions from the CSIR (2006) are likely to remain conservative *in terms of the initial sediment loadings*.

While the current speed distributions near the surface and near the seabed are similar for the CSIR (2006) data measured in a 110 m water depth and data measured in an approximate water depth of 200 m in ML 170, the *difference in water depths will significantly change the time taken for sediments to reach the seabed at these two sites*. The discharges for the proposed NMP dredging will take place in water depths of 200 m to 225 m. The implication is that the plumes from the proposed NMP dredging activities will take approximately twice as long to reach the seabed than estimated for the CSIR (2006) study. This does not however imply that the plume dimensions will be twice as large as those reported in the CSIR (2006) study. The *actual dimensions of the plume depend on the concentration contour(s) selected to represent the outer dimensions of the plume, which in turn depends on the initial loadings from the waters being discharged to the marine environment*.

A further uncertainty when assessing sediment plume extent and duration is *the accurate specification of the settling rate of the various sediment fractions being discharged*. Assumed settling rates affect significantly the estimates of plume dimension, particularly in modelling studies. The Lwandle (2012 EIA) assessment suggest that all things being equal (to the CSIR (2006) study) that the sediments discharged at the deeper ML 170 dredging site will settle within approximately 2 hours. This implies a settling rate of approximately 20 mm/s which seems very high. A significant factor in this seemingly high settling rate most probably is the initial behaviour of the discharged material which may have acted as a negatively buoyant plume and rapidly flowed directly downwards in convective descent through the receiving water column. This assumed behaviour I.e. rapid descent of the plume) is predicated on an initially high concentration of sediment in the discharge, particularly fines, which may not necessarily be the case for the NMP dredging project.

For the assessment of dredger plumes generated in the proposed Sandpiper Project dredging area (Lwandle, 2012 EIA) a lower sedimentation rate of 1.6 mm/s was applied. (This lower sedimentation rate is based on average settling rates reported in the CSIR (2006) study.) The use of this sedimentation rate suggested a duration of approximately 3 hours being required for the settling sediments to transit the upper mixed layer and approximately 33 hours to sink to the base of the water column. Assuming uni-directional current magnitudes of approximately 0.1 m/s, the sediments will travel some 10 to 12 km before reaching the seabed. Consistent with the measurements and hydrodynamic modelling in the CSIR (2006) study, sediment concentrations within the plumes in the Lwandle (2012 EIA) assessment were predicted to be <100 mg/ℓ. It should be noted that in the CSIR (2006) study concentrations of 100 mg/ℓ were predicted to extend as far as 10 km from the dredge area, however exceedances for >50% of the time were limited to within 2 km of dredging. Concentrations >20 mg/ℓ could extend over an area of approximately 10 km^2. While the assumed low settling rates of 1.6 mm/s would suggest more extensive plume dimension than the assumed plume dimensions (of 1 500 m long by 800 m wide with suspended sediment concentrations in the plume ranging between >20 mg/ℓ but <100 mg/ℓ) in the Lwandle (2012 EIA)

study, these assumed dimensions presumably were based on the median exceedances of 100 mg/ℓ not exceeding a distance of 2 km from the discharges.

Based on the above observations, it is *possible that the actual plume dimensions may exceed the dimensions assumed in the Lwandle (2012 EIA) assessment*. It should also be noted that, in the Lwandle (2012 EIA) assessment, the plume dimensions were based on the expected total suspended solids (TSS) concentration in the water column. These concentrations, because of the settling of sediments over time, are likely to be lower in the plume for sediments than for a conservative tracer or toxic constituent that is dissolved in the water column. However none of the constituents of concern (dissolved oxygen, H_2S or trace metals) are likely to display truly conservative behaviour and are likely to show some degree of decay (e.g. uptake of Cd by phytoplankton, oxygenation of upper mixed layer waters, etc.). This suggests that the plume dimensions determined from the distribution of a conservative tracer also are likely to overestimate the true situation. Finally, it should also be noted that the waters containing the dissolved toxic components or changed biogeochemical components of concern are likely to show similar near-field behaviour as sediment-laden waters being discharged from the dredger, suggesting a similar (at least initially) plume behaviour (and dimension) to that of the sediment laden water being discharged.

In summary, the two key metrics of relevance in terms of plume dynamics are the extent of the plume and the persistence (or duration) of the plume. The duration of the plume potentially has implications for biogeochemical transformation processes that may result in ecological impacts (e.g. oxygen demand and/or toxicity in the upper water column).

Based on this review of the initial impact assessment (Lwandle, 2012 EIA) and subsequent verification study (Lwandle, 2014) it is *possible that the actual plume dimensions may exceed dimensions assumed in the Lwandle (2012 EIA) assessment* (*i.e*. plume dimensions may be up to 2 to 5 times larger than indicated). However, the implication of these potentially increased plume dimensions for the overall impact assessment and subsequent environmental decision-making is limited. It is not certain that the plume dimensions will exceed those indicated in the Lwandle (2012 EIA) study, however should this be the case, the extent of the plumes reported in the impact assessment tables may increase from being limited to the" Immediate Dredge Area" to affecting possibly the "Annual Mining Area". It is not expected that the extent of the impact would increase to such an extent that is affects the "Specific Mining Site" (see Table 3.3 below for the definition of the impact extents and durations.

Should the potential biogeochemical impacts be limited in their intensity as is indicated by the studies to date and the reviews of these studies, it is only the turbidity and possibly the sediment deposition on the seabed that remain impacts of potential concern. It also should be noted that for a given sediment discharge, an increased plume extent necessarily implies lower turbidity levels over a larger area. *Given that the plume extent is typically defined in terms of turbidity or TSS values exceeding a given threshold, more widespread dispersion of TSS may not significantly change the dimensions of a turbidity plume s defined in terms of TSS values exceeding thresholds of concern.*

© NMP 2014

Table 3.3: Impact criteria used to assess extent and duration (Lwandle, 2012 EIA).

Impact Criteria:						
Extent	**Dredge Area** Per vessel immediate cycle i.e. approximately 66,000m^2 or 6.6 ha	**Annual Mining Area** Up to 3 km^2	**Specific Mine Site** (SP1 or SP2) each is 22x8 km or 176 km^2	**Local** 25-50 km or 2,000km^2- 8,000 km^2	**Regional** 50-100 km or 8,000km^2 – 30,000 km^2	**National** 100 km to EEZ (200 nautical miles)[5] 100 to 370 km, or >30,000 km^2

Duration	**Very Short Term** 3 days	**Short term** 3 days – 1 year	**Medium term** 1 - 5 years	**Long term** 5 – 20 years	**Permanent** > 20 years (life of mine)

4 HYDRODYNAMIC AND WATER QUALITY MODELLING

For a stand-alone modelling study to reduce uncertainties associated with the existing assessments based on measurements and the interpretation thereof or prior modelling results in the region, certain pre-conditions need to be met in terms of available data and the functionality of the model(s) to be used. These uncertainties and requirements are listed in Table 4.1 below.

4.1 APPROACHES TO THE HYDRODYNAMIC AND WATER QUALITY MODELLING

Two modelling approaches may be used to address residual uncertainties, most of which is related to the plume dimension and duration. The first comprises a comprehensive modelling study with an interior high-resolution nested domain relying on the larger-scale model to provide the conditions at the boundary of the nested model. The second is a high resolution model only, with the conditions at the open boundary provided by measurements. The advantages and pitfalls of the two modelling approaches are discussed in detail below.

4.1.1 Modelling Approach 1: Large-scale model with nested high resolution domain

In this approach a large-scale model will be used to generate the requisite open boundary conditions for a high resolution nested domain used to simulate plume dynamics, extent and duration. The nested model domain, in turn, would be used to provide high resolution simulations of the dredge plumes. The advantages of such an approach is that it is unlikely to be constrained by the need for on-going availability of measured data to specify the boundary conditions for the nested high resolution model. This approach also allows for a better understanding of the regional ocean dynamics which may be of use for similar or more extensive modelling assessments in the region. However there are considerable disadvantages to such an approach. It is likely to be computationally very expensive, and likely to take 8 to 12 months to complete. Furthermore there is a significant

[5] 1 nautical mile = 1,85 kilometres

likelihood that the large-scale model, while able to simulate key features in the region (e.g. Veitch *et al*., 2010), will not be able to produce representative boundary conditions on the spatial and temporal scales required for the nested high-resolution model being used to assess plume behaviour, extents and durations. *Such a modelling study is not recommended due to the time that will be required to complete it, the probable high costs of such an exercise and the very real risk that such an approach that it may not manage to further constrain any of the key uncertainties in the existing environmental impact assessment specialist studies.* However should extensive verification studies of the impacts of the dredging be undertaken, it would be beneficial to attempt such a modelling study as it will provide a greater understanding of the hydrodynamic and biogeochemical dynamics in the region and also provide a platform for undertaking other high resolution assessments of one or more similar projects in the region.

4.1.2 Modelling Approach 2: High resolution model using measured data at the open boundaries

This comprises a more simple modelling approach and mirrors that used to assess the consequences of drill cuttings disposal on the Natal Bight offshore of KwaZulu-Natal, South Africa (Morant *et al*., 1998). This approach was taken to overcome similar constraints to those likely to be experienced when undertaking a modelling assessment of the NMP dredging operations, namely that presently no predictive modelling platform exists that can reliably predict the hydrodynamic flows and water column parameters required to specify the open boundary conditions for a high resolution plume modelling study in the proposed dredging area. The approach proposed is to utilise the measured data to specify the requisite open boundary conditions for such a high resolution model (see Figures 4.1 and 4.2). The data required to run such a model include current measurements (presently available for a 90 day period), representative offshore wind data (ideally weather buoy measurements however NCEP data or a similar wind product are likely to be adequate), atmospheric fluxes (which can mostly be derived from NCEP data fields) and water column profile data. The latter may be difficult to obtain and therefore may need to be specified as a seasonal profile to which the interior domain of the model is relaxed over a period of time. Fortunately such data only serve to constrain mostly the vertical mixing in the model and only have a more limited effect on the current distributions in a model set up in this manner.

© NMP 2014

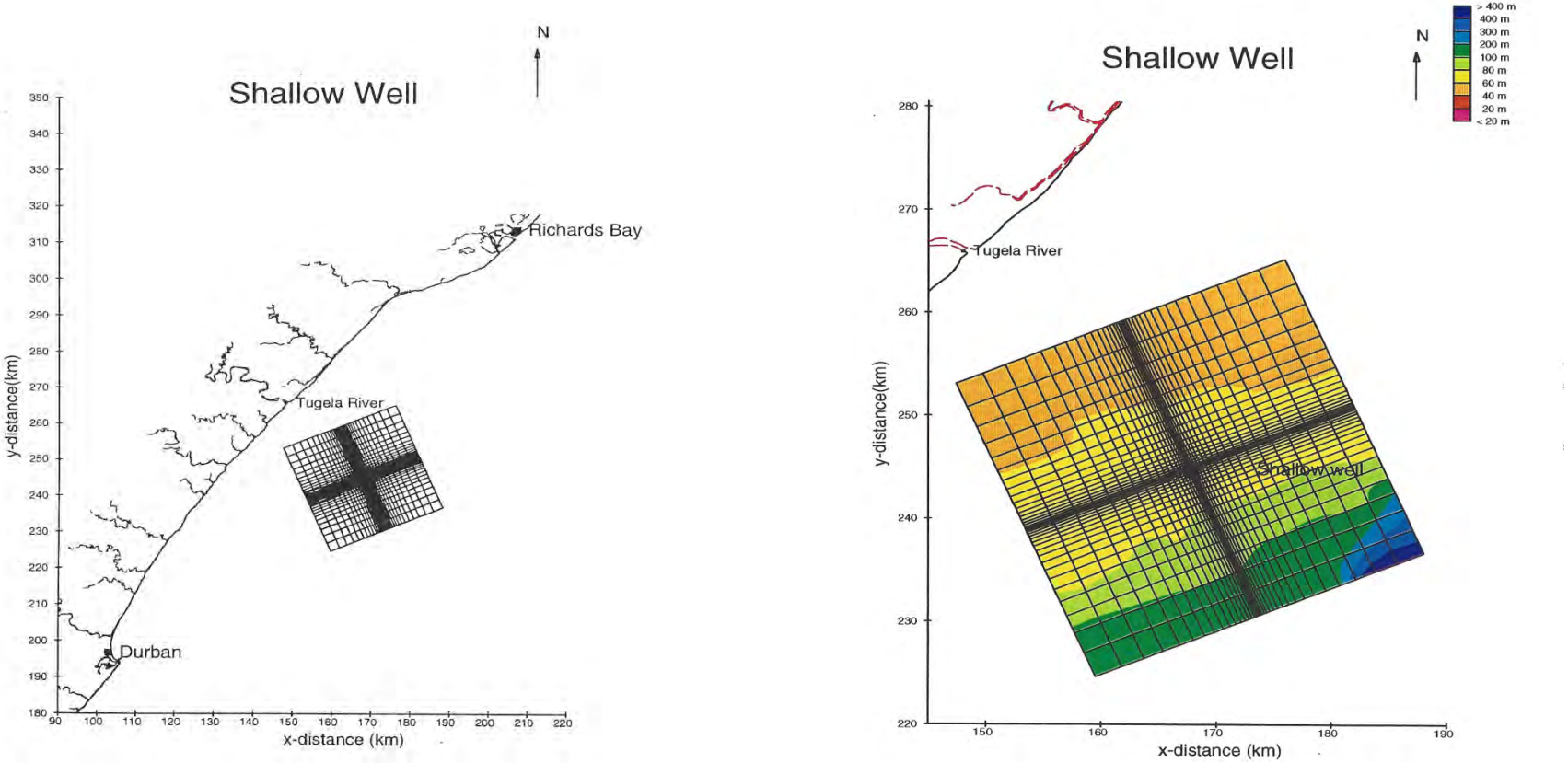


Figure 4.1: High resolution drill cuttings disposal simulation offshore of KwaZulu-Natal using Modelling Approach 2

(Source: Morant *et al*., 1998).

A constraint of this more simple approach is that the model simulations will not include significant horizontal shears in flows and that the plume dynamics and information on their extent will be constrained by the size of the high resolution model domain (likely to be limited to an approximate 15 km x 15 km domain). **Perhaps the biggest potential constraint is that the model simulation periods constrained by the availability of measured data** (i.e. current and to a lesser extent water column structure measurements for the full periods that the model simulations are undertaken). However the advantages of such a modelling approach is that is cost-effective, can be executed within a reasonable time-frame of 3 months or less and **the simulated environment in the high resolution model domain will certainly will be representative of environmental conditions prevailing at the dredging location** (thus removing a significant source of uncertainty in the predicted plume behaviour, extent and duration).

This modelling approach, in principle, will be able to better constrain the estimates of the plume dimension and duration. Should it be of interest, estimates of the deposition patterns of the discharged sediments on the seabed also can be produced by the model (see Figure 4.2). Certainly this type of modelling will allow one to explore explicitly the sensitivity of the plume predictions to uncertainties in initial loadings, plume dynamics and effective settling rates of the sediments, as well as possible changes in the rates of dredging and nature of material being dredged.

Should there be uncertainties in biogeochemical processes in the plume, it is possible to extend the modelling to include such processes, however this will required that these biogeochemical processes are adequately parameterised and included in the modelling platforms. There will also then be al requirement for additional measurements such as ambient concentrations of dissolved oxygen as well as other relevant biogeochemical parameters. Presently the indication is that the biogeochemical effects of concern are sufficiently constrained and that such biogeochemical modelling will not be required.

© NMP 2014

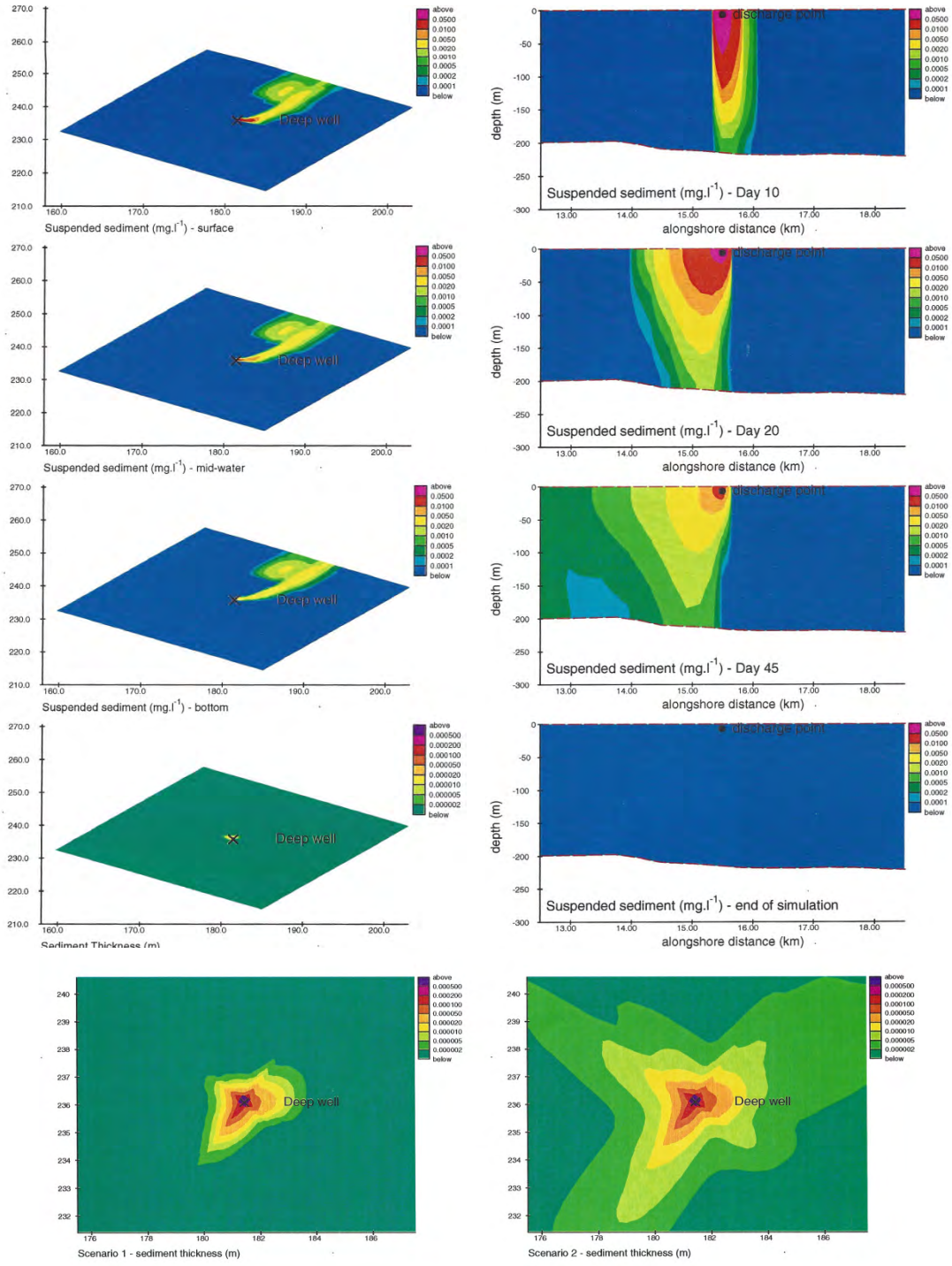


Figure 4.2: Sample of outputs (high resolution drill cuttings disposal simulation offshore of KwaZulu-Natal) from a modelling study using Modelling Approach 2

(Source: Morant *et al.*, 1998).

Table 4.1: Comparative assessment of required information and model functionality for the two proposed modelling approaches.

Source of Uncertainty	Required information/ model functionality	Modelling Option 1 Large-scale model with nested high resolution domain	Modelling Option 2 High resolution model using measured data at the open boundaries	Comment
Initial discharge sediment concentrations	Adequate information on the material to be dredged in terms of grain size distribution, dredging rates. etc.	This is not a modelling issue *per se*. It just requires an adequate specification of the material to be dredged (that presently exists) and an adequate description of proposed dredging operations (technology, nature of overspill, dredging rates, etc.)		If this information in not available or inadequate this will negate the value of modelling in providing quantitative estimates of plume behaviour and characteristics
Initial behaviour of the discharge plume (e.g. convective descent, mixing into upper mixed layer or transitional behaviour)	Accurate assessment of initial discharge conditions (discharge velocity, depth of discharge below the sea surface, Initial discharge sediment concentrations and grain sizes)	Based on an accurate assessment of initial discharge conditions (discharge velocity, depth of discharge below the sea surface, initial discharge sediment concentrations and grain sizes), initial plume behaviours will need to be parameterised using software such as STFATE using the categorisation process contained in Winterwerp (2002).		If this initial plume behaviour is not adequately characterised and incorporated into the modelling, errors in the prediction of plume behaviour could be significant, resulting in errors of an estimated approximately 30 to 50% in the plume extent and duration in various parts of the water column.
Initial concentrations of biogeochemical parameters of concern	Adequate information on the material to be dredged in terms grain size distributions, dredging rates, etc. Adequate understanding/ quantification of relevant biogeochemical processes.	Whatever the process in obtaining the relevant information, the initial concentrations can be specified in the relevant modelling platform, e.g. Deltares Water Quality model (or similar) software	Whatever the process in obtaining the relevant information, the initial concentrations can be specified in the relevant modelling platform, e.g. Deltares Water Quality model (or similar) software.	It is not clear whether some of the larger-scale modelling platforms proposed for use in Modelling Option 1 will have the necessary functionality to model the parameters of concern. The nested domain therefore will need to comprise a modelling platform that is suited to this purpose, i.e. a platform such as the Deltares Water Quality model (or similar) software has the necessary functionality.

© NMP 2014

Source of Uncertainty	Required information/ model functionality	Modelling Option 1 Large-scale model with nested high resolution domain	Modelling Option 2 High resolution model using measured data at the open boundaries	Comment
Advection and dispersion of constituents of relevance	Adequate specification of currents (both horizontal and vertical) variability through the water column This requires that large-scale flows (upwelling fronts, under-currents, etc.), wind-driven, tidally and wave-driven flows be adequately simulated. This also will require that water column structure is accurately simulated.	The large-scale model with need to simulate the large-scale flows required at the open boundary of the nested high resolution model. The large-scale model simulations will require appropriate input time series such as winds and atmospheric fluxes, etc. If not undertaken as a research project some of these data may need to be purchased.	The model will require the on-going specification of current velocities profiles with depth at the open boundaries for the periods simulated. These will be provided by the existing (or future) measurements. Given that the model is dependent on the ongoing specification of open boundary conditions, it will not be possible to run model simulations when such data are not measured.	The flows and water column structure simulated in the large-scale model may not adequately represent the actual situation at the open boundaries of the nested model and therefore would not be adequate for specifying times series of relevance at the nested model boundaries. Of particular concern would be that the large-scale modelling does not adequately represent the location of upwelling fronts and the spatial characteristics of poleward undercurrent which is likely to lead to currents and water column parameters being specified at the nested model that are not representative of conditions that prevail in the area of interest.
	Quantification of vertical mixing processes that depend on turbulence introduced into the water column (by wind waves and tides) as well as the existing water column structure (i.e. stratification) that in turn requires accurate simulation or specification of (large-scale) horizontal inflows	The large-scale model with need to simulate the water column structure and large-scale flows (affecting water column structure in the nested model) required at the open boundary of the nested high resolution model. The large-scale model simulations will require appropriate input	The model will require the on-going specification of wind, waves, tides, atmospheric fluxes and profiles of water column structure profiles with depth at the open boundaries for the periods simulated. These will be provided by the existing (or future) measurements. Given that	see comment above

Source of Uncertainty	Required information/ model functionality	Modelling Option 1 Large-scale model with nested high resolution domain	Modelling Option 2 High resolution model using measured data at the open boundaries	Comment
	and/or atmospheric fluxes affecting water column structure.	time series such as winds and atmospheric fluxes, etc. If not undertaken as a research project some of these data may need to be purchased.	the model is dependent on the on-going specification of open boundary conditions, it will not be possible to run model simulations when such data are not measured.	
Changes in sediment concentrations due to the settling of sediments through the water column.	Accurate specification of settling rates. This requires a good understanding of sediment grain size distributions, likely flocculation behaviour and to a lesser extent water column parameters such as salinity and temperature.	The settling rates specified in the model will be based on theoretical considerations and/or published data for the sediment being discharged.		This remains a key uncertainty in the modelling studies. The approach generally undertaken to address this key uncertainty is to undertake a number of simulations to determine the model sensitivity to these model parameterisations. This necessarily will result in a range of plume extents and durations that will need to be included in the assessments.
Changes in concentrations of biogeochemical parameters and toxic constituents of concern (e.g. low oxygen water, oxygen demand, changes in trace metal bioavailability, etc.) due to biogeochemical transformations.	Sufficient understanding of biogeochemical processes and the incorporation of this (process) knowledge into the modelling platform.	Where relevant the process models determining the evolution of the relevant parameters will need to be included in the relevant modelling platform, e.g. Deltares Water Quality model (or similar) software. It is anticipated that most, if not all of these process models will be able to be included in the Deltares Water Quality software considered to be	Where relevant the process models determining the evolution of the relevant parameters will need to be included in the modelling platform, e.g. Deltares Water Quality model (or similar) software. It is anticipated that most, if not all, of these process models will be able to be included in the Deltares Water Quality software considered to be most	While it is envisaged that the Deltares Water Quality software or similar DHI software considered for use in the high resolution domain will have the necessary functionality, this is unlikely to be the case for the large-scale modelling platforms likely to be used for this modelling study (e.g. ROMS). The implications for the coupling of the large-scale modelling platforms to the nested domains is uncertain, however it is likely that any limitations in this regard can be

Source of Uncertainty	Required information/ model functionality	Modelling Option 1 Large-scale model with nested high resolution domain	Modelling Option 2 High resolution model using measured data at the open boundaries	Comment
		most suitable for the proposed study. It is however not clear that the large-scale modelling platforms likely to be used for this modelling study (e.g. ROMS) presently have the necessary functionality to address the biogeochemical process modelling required here	suitable for the proposed study.	overcome given sufficient time.
Availability of data to calibrate and validate the models	Requirement for model calibration/verification data	This approach will require large scale calibration data such a satellite temperature fields and hydrographic data (historical) and well as a degree of expert opinion to calibrate and validate the large-scale model. Specifically the model would need to represent the known large-scale oceanographic features of the region such as the offshore location of upwelling fronts and the poleward undercurrent. For the nested model this approach requires current profiles to calibrate the hydrodynamic parameters. Additional data	This approach requires current profiles to calibrate the hydrodynamic parameters. Additional data on the water column structure will help to constrain/calibrate the mixing dynamics in the model.	The Modelling Option 2 will require a number of large-scale data sets as well as some expert opinion to ensure that the model is generating the relevant hydrodynamics fields and mixing dynamics. In a strict sense, the data used to calibrate the nested high-resolution model (or the model envisaged for Modelling Option 1) should provide adequate data for the model calibrations as it is only the large-scale model outputs utilised at the boundary of the nested model that are of relevance. However the larger-scale calibration data would help to diagnose/understand the model limitations should the data generated for the nested model boundaries not

© NMP 2014

Source of Uncertainty	Required information/ model functionality	Modelling Option 1 Large-scale model with nested high resolution domain	Modelling Option 2 High resolution model using measured data at the open boundaries	Comment
		on the water column structure will help to constrain/calibrate the mixing dynamics in the model.		adequately represent the measured calibration data.
Availability of data time series required to run the models	Requirement for on-going time series to run the models.	The large-scale model simulations will require appropriate input time series such as winds and atmospheric fluxes, etc. However the nested model will not require the specification of flows and water column structure as these will be available from the large-scale model.	This approach requires current profiles, wind & atmospheric flux time series and specification of water column structure at the model boundaries. The latter may be difficult to obtain and therefore may need to be specified as a seasonal profile to which the interior domain of the model is relaxed over a period of time.	The benefit of Modelling Option 2 is that the data required to run the large-scale model is likely to be available in the long-term (*i.e*. from global products) thus avoiding the limitation of Modelling Approach 1 where the model simulations can only take place is the requisite time series measurements are made specifically for the modelling study.

© NMP 2014

4.2 MEASUREMENTS REQUIRED TO SUPPORT MODELLING STUDIES

The measurements required to support the modelling studies are similar to those that will be required to assess plume dynamics and resultant impacts should it be chosen to make these assessments on measurements alone.

Specific requirements will include:

- Initial sediment concentrations and discharge parameters such as discharge volumes, flow rates, grain size distributions
- Initial concentrations of biogeochemical parameters of concern;
- Current meter measurements for the proposed simulation periods.
- Wind and atmospheric flux data (which can be obtained from global data sets such a s NCEP data should it not be able to measure these using an offshore weather station);
- Water column structure measurements and water quality data, however should such data not be available, seasonal profiles based on historical data will be used.

© NMP 2014

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSION

Based on this review of the initial impact assessment (Lwandle, 2012 EIA) and subsequent verification study (Lwandle, 2014) it is *possible (but not certain) that the actual plume dimensions may exceed the dimensions assumed in the Lwandle (2012 EIA) assessment* (*i.e*. plume dimensions may be up to 2 to 5 times larger than indicated). However, the implication of these potentially increased plume dimensions for the overall impact assessment and subsequent environmental decision-making is limited. Should the plume dimensions exceed those estimated in the Lwandle (2012 EIA) study, the extent of the plume reported in the impact assessment tables of this study may increase from being limited to the "Immediate Dredge Area" to affecting possibly the "Annual Mining Area". It is not expected that this change in the extent of the impact would be such that it affected the "Specific Mining Site". Therefore it is not expected that these possible, but modest, changes in the impacted area will materially affect the environmental decision-making surrounding this project.

5.2 RECOMMENDATIONS

The proposed Modelling approach 2 is viable in terms of cost, duration of the study and likely outcomes. Such modelling indeed will constrain some of the uncertainties remaining in the assessments around plume extents and durations (e.g. associated with uncertainties in sediments loads, sediment characteristics, settling rates, etc.) and also better characterise the sensitivity of the impact assessments to possible changes in the rates of dredging and nature of material being dredged. However, as indicated above, any changes in the estimated extent of the impacted area indicated by the modelling, are expected to be modest and unlikely to affect substantially the environmental decision-making surrounding this project.

The modelling will provide a more explicit means (than the existing assessments) of constraining the uncertainties (listed above) and providing greater confidence in the assessed impacts based on the plume behaviour extents and duration. . Should this be a priority, a modelling study should be undertaken using Modelling Approach 2, despite the fact that the outcomes of such modelling are unlikely to materially change the significance of assessed impacts.

Should such modelling not be undertaken prior to the commencement of dredging operations, it is recommended that modelling form a key part of the verification and impact monitoring studies proposed for the early stages of the proposed dredging operations (e.g. by helping to inform the design of monitoring activities and in the interpretation of the resultant measurements). . An appropriate model-based predictive capability is likely to prove invaluable should environmental constraints (over and above those already anticipated) need to be placed on dredging operations.

Furthermore the development of a well-calibrated and validated model-based predictive capability is likely to prove invaluable for future environmental impact assessments of a similar nature or should it become necessary in the future to assess potential cumulative impacts of marine dredging in these waters.

© NMP 2014

6 REFERENCES

Cochrane, K. (2013) Opinion on the ecosystem impact related to mining of phosphates offshore

Deltares (2011a) Delft3D-WAVE: Simulation of short-crested waves with SWAN – User Manual, Version 3.04 (Revision 15779), 206pp.

Deltares (2011b) Delft3D-FLOW: Simulation of multi-dimensional hydrodynamic flows and transport phenomena, including sediments, Version3.15 (Revision18392), 672pp.

Lwandle (2012) The Dredging of Marine Phosphate Enriched Sediments From Mining Licence Area No. 170. Sandpaper Phosphate Project, Specialist Study 1B: *Assessment of Potential Impacts on Marine Life Arising From Changes to Marine Water Quality*.

Lwandle (2014) Namibian Marine Phosphate Verification Report, Lwandle Report (project 149),

MSI (2014a) Namibian Marine Phosphate (Pty) Ltd: Sandpiper project environmental data report – Day 0 to 45, Project 267, 76pp.

MSI (2014b) Namibian Marine Phosphate (Pty) Ltd: Sandpiper project environmental data report – Day 45 to 90, Project 267, 76pp.

Morant, P.D., R.A. Carter, M.L. Grundlingh, M.L., R.C. van Ballegooyen, M. Rossouw, A.D. Connell, V.M. Peddemors, R.P. van der Elst, M.H. Schleyer, A. Govender, S.T. Fennesey and B. Tomalin (1998) Environmental impact assessment for the proposed exploration drilling in petroleum exploration lease Block 17/18 on the continental shelf of KwaZulu-Natal, South Africa: Main report, CSIR report ENV/S-C 98045.

Shillington FA, Reason CJC, Duncombe Rae CM, Florenchie P and Penven P. (2006). Large scale physical variability of the Benguela Current Large Marine Ecosystem (BCLME). In *V. Shannon, G. Hempel, P. Malanotte-Rizzoli, C. Moloney, & J. Woods (Eds.), Benguela: Predicting a Large Marine Ecosystem. Large Marine Ecosystems*, **Series 14**. Elsevier, 49-70.

Veitch, J., P. Penven and F. Shillington (2010). Modeling equilibrium dynamics in the Benguela Current System, *Journal of Physical Oceanography*, **40**, 1943-1964.

© NMP 2014

SPECIALIST STUDIES – SECTION C

C2.3 Thiobacteria

Prepared for:
Namibian Marine Phosphate (Pty) Ltd.

Prepared by:
Next Generation Sequencing Facility
Department of Biotechnology
University of the Western Cape





Report compiled by Dr Bronwyn Kirby

October 2014

	ANALYTICAL REPORT
Report to	Lwandle Technologies (PTY) Ltd
Project ID	Namibian Marine Phosphate_RT_Thio
Version	1
Status	Final
Date	10th May 2014
Author	Dr Bronwyn Kirby (Facility Manager)
Data generated by	Dr Bronwyn Kirby
Reviewed by Summary	Lonnie Van Zyl (Senior Research Officer) Dr R Carter

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed "Attention: Administration Manager," at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

SUMMARY

Sulphur bacteria distribution in the MLA 170 mine licence area were investigated by Bronwyn Kirby, Next Generation Sequencing Facility Department of Biotechnology, University of the Western Cape

Bacterial genera involved in both sulphur-oxidisation and sulphur-reduction were found to be present in the samples obtained from the proposed mining area. The numbers of sulphur-oxidising bacteria were lower than the numbers of sulphur-reducing bacteria. Sulphur-oxidising bacteria utilise H_2S as fuel, oxidising it into sulphate. This keeps the H_2S within the sediment, and prevents it from being released into the water column. In contrast to this process, sulphur-reducing bacteria reduce sulphate, through respiratory processes, into H_2S, and so are characteristic of sediments where higher concentrations of H_2S are present (Jorgensen 1977). The presence of the sulphur-utilising groups of bacteria corroborates the presence of hypoxic sediments within the mining licence block, as both groups are associated with low oxygen conditions (Jorgensen 1977).

The bacterial genera involved in sulphur reduction identified in the samples obtained included *Desulfobacteralis*, *Desulfovibrionales*, *Syntropobacterialis*, *Desulfoto-maculum*, *Desulfosporomusa* and *Desulfosporosinus*. The bacterial species involved in sulphur oxidisation included *Thiobacillus thiooxidans*, *Thiobacillus ferrooxidans*, *Thiobacillus denitrificans* and *Acidothiobacillus* spp. In general, *Thiobacillus* species have a low growth yield (Jorgensen and Nelson 2004), which explains the lower concentrations of sulphur-oxidising bacteria in comparison to sulphur-reducing bacteria within the study region. Because of these low growth yields and less efficient oxidising capabilities, *Thiobacillus* spp. are of less significance in the oxidisation process of H_2S, compared with the large sulphur bacteria, that have been found in the Namibian continental shelf region (Jorgensen and Nelson 2004, Brüchert *et al*. 2003). None of the large sulphate bacteria, namely from the genera *Thiomargarita*, *Beggiatoa* and *Thioploca*, which have developed more specialised modes of sulphur oxidisation and that play a more significant role in the oxidisation of H_2S, was found in the samples from the mining licence area (MLA 170).

The sediment properties analysed in this verification survey indicate that there are low acid volatile sulphide (AVS) concentrations in the sediment. AVS is used as a proxy for H_2S production and sulphate reduction. The apparent low levels of H_2S production and sulphate reduction occurring within sediments in the mining area corroborate the absence of large sulphur bacteria within the samples and would suggest that the levels of H_2S flux within the area are too low to support large populations of these bacteria. Instead less conspicuous sulphur-oxidising bacteria, such as *Thiobacillus* spp. are active.

© NMP 2014

contents

SUMMARY ii

1 SAMPLE INFORMATION 1

2 METHODOLOGY 2

2.1.1 Extraction of metagenomic DNA 2
2.1.2 Extraction of metagenomic RNA 2
2.1.3 cDNA conversion 3
2.1.4 Primer design 3
2.1.5 Quantitative PCR (qPCR) 3

3 DATA ANALYSIS 4

3.1.1 QC of nucleic acid extractions 4
3.1.2 Quantitative Polymerase Chain Reaction (qPCR) analysis 5

4 REFERENCES 7

tables

Table 1: Samples used for qPCR analysis 1
Table 2: Primers designed for qPCR analysis for detection of sulphur utilizing bacteria. 3
Table 3: Concentration of nucleic acid extracted for each sample. 4
Table 4: Estimated number of sulphur utilizing bacteria based on qPCR analysis. Each experiment was performed in triplicate and the average is reported. 6

© NMP 2014

1 SAMPLE INFORMATION

Samples were delivered by Lwandle Technologies in March 2014 in a -20°C freezer (Appendix 1.3 and 1.4). 1 g aliquots were immediately prepared which were stored at -80°C until analysis. Samples were collected in sterile Nalgene bottles. Four separate samples were collected at each sampling time; two samples were used for DNA extraction while two samples were treated with RNAlater (Sigma) for RNA extraction.

Table 1: Samples used for qPCR analysis

Identification on collection bottle	Sample ID	Sample description
To:01 Non1 12:13 26/02/2014	Sample LB1	Sediment/shell mix, course sand. Extraction no metallic layer
To:02 Non1 02:28 26/02/2014	Sample LB2	Sediment/shell mix, course sand. Extraction no metallic layer
To:03 Non1 03:05 26/02/2014	Sample LB3	Sediment/shell mix, course sand. Extraction no metallic layer
To:04 Non1 04:02 26/02/2014	Sample LB4	Soil/seawater Extraction had slight metallic layer
To:05 Non1 05:05 26/02/2014	Sample LB5	Sediment/shell mix, course sand. Extraction had slight metallic layer
To:06 Non1 07:00 26/02/2014	Sample LB6	Medium-Dark brown fine sediment Extraction had slight metallic layer
To:07 Non1 07:15 26/02/2014	Sample LB7	Medium-Dark brown fine sediment Extraction had slight metallic layer
To:08 Non1 07:50 26/02/2014	Sample LB8	Medium-Dark brown fine sediment Extraction had thick metallic layer
To:09 Non1 08:50 26/02/2014	Sample LB9	Dark brown, very fine sediment Extraction had thick metallic layer
To:10 Non1 09:40 26/02/2014	Sample LB10	Dark brown, very fine sediment Extraction had thick metallic layer

*During DNA extraction after the first centrifugation step several samples had a gold/yellow metallic layer floating on the top of the sample. As metals can inhibit the enzymes used for DNA/RNA amplification this layer was removed.

© NMP 2014

2 METHODOLOGY

Different nucleic acid extraction methods preferentially extract nucleic acids from particular microbial taxa. Therefore, in order to overcome this bias two different extraction methods were employed for both RNA and DNA extraction. The two separated nucleic acid extractions for each sample were pooled in equimolar ratios prior to analysis [DNA analysis – MoBio kit sample and Wang method sample; RNA analysis – RNeasy and $LiCl_2$ method sample].

2.1.1 Extraction of metagenomic DNA

Genomic DNA was extracted using a modified version of the method described by Wang *et al.* (1996). Sediment samples were thawed on ice and approximately 1 g of sediment was used per extraction. Samples were resuspended in 2-3 ml lysis buffer (25 mM Tris-HCl pH 8; 50 mM glucose; 10 mM EDTA; 25 mg lysozyme per ml) and 0.5 g quartz sand (Sigma S-9887) was added to each tube. Microbial cells were lysed by both mechanical and chemical methods. Mechanical shearing involved three cycles of vortexing at maximum speed for 1 min followed by rapid cooling on ice for 2 min. After vortexing the samples were incubated in lysis buffer overnight at 37°C. SDS was added to a final concentration of 1% and the samples were incubated at 65°C for 30 min. Nucleic acids were extracted twice with 1 vol equilibrated phenol (pH 7.6), followed by extraction with 1 vol chloroform:iso-amyl alcohol (24:1, vol/vol). Nucleic acid was precipitated with 1 vol ice-cold isopropanol at room temperature for 30 min and harvested by centrifugation at 14 000 X g for 5 min. The resulting pellet was resuspended in 50 µl 10 mM Tris-HCl; 1 mM EDTA (TE) buffer pH 7.8.

DNA was also extracted using the Ultra PowerSoil kit (MoBio) according to the manufacturer's instructions. Two separate extractions using 500 mg of sediment were performed per sample and the nucleic acid was pooled in the final steps.

2.1.2 Extraction of metagenomic RNA

Total cellular RNA was extracted using the CTAB lysis buffer method adapted from Griffiths *et al*., 2000. Sediment samples stored in RNAlater were thawed at room temperature. In order to remove the RNAlater, samples were vortexed briefly and centrifuged at 4000 x g for 3 min. The RNAlater was removed and the sediment was resuspended in 3 ml DEPC-treated phosphate buffered saline (PBS) and centrifuged as above. After the removal of the PBS, 2 ml CTAB buffer (100 mM Tris-HCl pH 8, 1.4 M NaCl, 20 mM EDTA pH 8, 2% CTAB (wt/vol), 1% polyvinylpyrollidone, 0.4% β-mercaptoethanol (vol/vol), prepared in DEPC-treated H_2O) and 0.5 g each chilled 0.1 mm glass and 0.5 mm silica beads. Lysis was achieved by three cycles of vortexing the samples for 30 s followed by rapid chilling on ice for 1 min. After the addition of 0.8 ml chloroform:isoamylalcohol (24:1, vol/vol), samples were shaken at room temperature for 15 min. Samples were centrifuged for 15 min at 4°C at 15000 x g. Total nucleic acids were precipitated by the addition of 5 M NaCl and 1 vol ice-cold isopropanol. Samples were incubated at -80°C for 30 min. Nucleic acids were harvested by centrifugation at 15000 x g for 15 min at 4°C. The pellet was washed in ice cold 70% ethanol, dried for 15 min and resuspended in 20 µl DEPC-treated water.

In addition, RNA was extracted using the RNeasy kit (Qiagen) according to the manufacturer's instructions.

© NMP 2014

2.1.3 cDNA conversion

In order to remove genomic DNA, 0.4U shrimp nuclease (ThermoScientific) was added to a 5 µl aliquot of the RNA extraction and incubated at 25°C for 30 min. RNA was extracted with 8 mM $LiCl_2$, harvested by centrifugation at 14000 x g for 30 min at 4°C and the resulting pellet was resuspended in 15 µl DEPC-treated water. The concentration and the purity of the RNA was determined using a NanoDrop ND-100 spectrophotometer and samples were stored at -80°C. 1 µg of total RNA was used as the template in the synthesis of cDNA using Transcriptor First Strand cDNA Synthesis Kit (Roche) according to the manufacturer's instructions and stored at -20°C. cDNA was quantified using the Nanodrop. To determine RNA integrity the ratio of 23S to 16S rRNA gene was assessed by gel electrophoresis.

2.1.4 Primer design

Primers for quantitative PCR (qPCR) analysis were adapted from published primers used for detection of bacteria in environmental samples. Primers for detecting bacterial genera involved in sulphur reduction detected both the phylum Delta Proteobacteria (the genera *Desulfobacterales, Desulfovibrionales* and *Syntropobacterales*) and members of the phylum Firmicutes (the genera *Desulfotomaculum, Desulfosporomusa* and *Desulfosporosinus*). Primers for the detection of sulphur oxidising bacteria, detected several bacterial species including *Thiobacillus thioooxidans, Thiobacillus ferrooxidans, Thiobacillus denitrificans* cluster and several *Acidothiobacillus* species.

Table 2: Primers designed for qPCR analysis for detection of sulphur utilizing bacteria.

Detection	Primer name	Primer sequence (5' to 3')	Reference
Sulphur reducing bacteria	Delta-13200F	AGGAATWTTGCGCAATGG	Scheid & Stubner, 2001
	Delta-00432R	AGTTAGCCGGTGCTTCCT	Lűcker *et al.*, 2007
Sulphur oxidising bacteria	Thio3-615F	TGGGAATGGCGGTGGAAAC	Kyselkova*et al.,* 2009
	Thio820-810R	CACCAAACATCTAGTATTCATCG	Pecci*et al.,* 2000

2.1.5 Quantitative PCR (qPCR)

qPCR was performed using SYBR Green Master Mix (Roche) according to the manufacturer's instructions. cDNA was diluted 1/5 in sterile water and 5µl was used per PCR reaction. qPCR analysis was performed on a Roche LC480 and Cycling conditions for qRCR were as follows: Detla-13200F/Delta-00432R primers – denaturation 95°C for 2 min, followed by 45 amplification cycles of 95°C for 10 sec, annealing at 51°C for 10 sec and elongation at 72°C for 10 sec. Thio3-615F/Thio820-810R primers denaturation 95°C for 2 min, followed by 40 amplification cycles of 95°C for 10 sec, annealing at 56°C for 20 sec and elongation at 72°C for 25 sec. Absolute quantification was performed using a dilution series of the resulting amplicons (range 100 copies to 10^6 copies per reaction). In order to determine the number of bacteria per gram of soil, the number of copies of the 16S rRNA gene detected per reaction (5µl cDNA used) was multiplied by 15.

© NMP 2014

3 DATA ANALYSIS

3.1.1 QC of nucleic acid extractions

For metagenomic DNA extracted from sediment an A260/280 ratio of greater than 1.60 is acceptable due to the presence of contaminating humic and/or organic compounds (Table 3). The DNA extracted from all samples was considered to be of reasonably good quality (ratio great than 1.6 and non-degraded). Samples 1, 2, 3, 5 and 10 contained a large amount of PCR inhibitors and required additional clean up steps. DNA and RNA extraction was repeated on sample LB10 three times, but this sample consistently failed to amplify.

Table 3: Concentration of nucleic acid extracted for each sample.

Sample	Extraction method	DNA concentration (ng/µl)	A260/A280	Extraction method	RNA concentration (µg/µl)	A260/A280
LB1	Wang method MoBio Kit	30.9 24.6	1.75 1.72	$LiCl_2$ method RNeasy kit	2.1 1.8	1.92 1.94
LB2	Wang method MoBio Kit	87.1 91.4	1.69 1.71	$LiCl_2$ method RNeasy kit	3.2 4.4	1.88 1.92
LB3	Wang method MoBio Kit	32.2 39.0	1.86 1.82	$LiCl_2$ method RNeasy kit	2.5 2.8	2.10 2.08
LB4	Wang method MoBio Kit	105.5 74.2	1.62 1.65	$LiCl_2$ method RNeasy kit	7.9 6.4	1.94 1.98
LB5	Wang method MoBio Kit	37.5 42.7	1.68 1.72	$LiCl_2$ method RNeasy kit	2.2 1.9	1.97 1.91
LB6	Wang method MoBio Kit	59.7 53.8	1.77 1.61	$LiCl_2$ method RNeasy kit	3.1 3.6	2.03 2.07
LB7	Wang method MoBio Kit	76.4 136.1	1.83 1.67	$LiCl_2$ method RNeasy kit	4.2 5.9	1.93 1.95
LB8	Wang method MoBio Kit	187.4 173.0	1.71 1.71	$LiCl_2$ method RNeasy kit	7.8 6.3	2.04 1.99
LB9	Wang method MoBio Kit	41.1 25.3	1.75 1.80	$LiCl_2$ method RNeasy kit	2.8 3.1	1.94 2.03
LB10	Wang method MoBio Kit	146.6 103.2	2.70 2.43	$LiCl_2$ method RNeasy kit	1.4 1.6	1.85 1.88

The total RNA extracted was of high quality, particularly the RNA extracted with lithium chloride ($LiCl_2$). In addition, the integrity of the RNA was further assessed by gel electrophoresis to ensure ratio of the 23S rRNA to 16S rRNA gene was great than 2. All the sediment samples passed the required QC standards required for qPCR analysis.

© NMP 2014

3.1.2 Quantitative Polymerase Chain Reaction (qPCR) analysis

The total number of bacteria detected was within the expected range for marine sediments, which are reported to range from 10^4 bacteria per gram to 10^8 bacteria per gram.

It is estimated that the number of sulphur reducing bacteria per gram of soil ranges from less than 3000 (sample LB1) to 7.2x10^6 (sample LB3). In general, samples with a higher total bacteria number also appeared to have a higher number of sulphur reducing bacteria.

It is estimated that the number of sulphur oxidising bacteria per gram of soil ranges from less than 3800 (samples LB1 and LB6) to 8.9x10^5 (sample LB6). The numbers of sulphur oxidising bacteria present appear to be lower than the number of sulphur reducing bacteria. To ensure that this difference is not due to the primers used in the analysis, three different primer combinations were tested for detection of sulphur utilizing bacteria. All primer combinations gave comparable results (data not shown), and it is therefore probable that the difference in bacterial number are not due to primer efficiency. If additional studies are conducted it is proposed that specific genes involved in sulphur oxidation such as the *soxB* gene (Friedrich *et al*., 2001) also be included in the analysis.

© NMP 2014

Table 4: Estimated number of sulphur utilizing bacteria based on qPCR analysis. Each experiment was performed in triplicate and the average is reported.

Sample	Number of copies of the 16S rRNA gene detected with universal bacterial primers	Estimated total bacterial counts per gram sediment	Number of copies 16S rRNA gene specific for sulphur oxidising genera	Estimated number of sulphur oxidising bacteria per gram	Number of copies 16S rRNA gene specific for sulphur reducing genera	Estimated number of sulphur reducing bacteria per gram
LB1	2522	3.7x10^4	<250*	3.8x10^3 (<10%	<200	<3000**
LB2	13496	2.0x10^5	1080	1.6x10^4 (8%)	3172	4.8x10^4 (24%)
LB3	3816959	5.7x10^7	24098	3.6x10^5 (0.63%)	477167	7.2x10^6 (13%)
LB4	311225	4.6x10^6	59272	8.9x10^5 (19%)	5284	8.0x10^4 (1.8%)
LB5	301456	4.5x10^6	28829	4.3x10^5 (9.6%)	50536	7.6x10^5 (17%)
LB6	2522	3.7x10^4	<250*	3.8x10^3(<10%)	104	1.6x10^3 (4.3%)
LB7	810190	1.2x10^7	18447	2.8x10^5 (2.3%)	450546	6.8x10^6 (57%)
LB8	130720	2.0x10^6	30728	4.6x10^5 (23%)	16238	2.4x10^5 (12%)
LB9	229145	3.4x10^6	30532	4.6x10^5 (13.5%)	5455	8.2x10^4 (2.4%)
LB10	NA		NA		NA	

* Sample had detectible amplification but it was below the range to accurately determine the copy number for this primer set (range would be between 50 and 250 copies)
** Sample had detectible amplification but it was below the range to accurately determine the copy number for this primer set (range would be between 50 and 200 copies)

© NMP 2014

4 REFERENCES

Friedrich C.G., Rother D., Bardischewsky F., Quentmeier A., Fischer J. (2001) Oxidation of reduced inorganic sulphur compounds by bacteria: Emergence of a common mechanism. *Appl Environ Microbiol* **67**: 2873-2882.

Jorgensen B.B. 1977. The sulphur cycle of a coastal marine sediment (Limfjorden, Denmark).*Limnology and Oceanography* **22**(5): 814- 832.

Jorgensen B.B., Nelson D.C. 2004. Sulfide oxidation in marine sediments: Geochemistry meets microbiology. *Geological Society of America*: Special Paper 379.

Kyselkova M., Kopecky J., Frapolli M., Defago G., Sagova-Mareckova M., Grundmann G.L., Moënne-Loccoz Y. (2009) Comparison of rhizobacterial community composition in soil suppressive or conducive to tobacco black root rot disease. *ISME Journal* **3**: 1127-1138.

Lűcker S., Steger D., Kjeldsen K.U., MacGregor B.J., Wagner M., Loy A. (2007) Improved 16S rRNA-targeted probe set for analysis of sulphate-reducing bacteria by fluorescence in situ hybridization. *J Microbiol Methods* **69**: 523-528

Peccia J., Marchand E.A., Silverstein J., Hernandez M. (2000) Development and Application of Small-Subunit rRNA Probes for Assessment of Selected *Thiobacillus* Species and Members of the Genus *Acidiphilium*. *Appl Environ Microbiol* **66**: 3065-3072.

Scheid, D., Stubner S. (2001) Structure and diversity of Gram-negative sulfate-reducing bacteria on rice roots. *FEMS Microbiol Ecol* **36**: 175–183.

© NMP 2014

SPECIALIST STUDIES – SECTION C

C2.4 Meiofaunal Analysis of Namibian Offshore Sediments forming part of Verification Surveys for proposed marine dredging operations in ML 170

MEIOFAUNAL ANALYSIS OF NAMIBIAN OFFSHORE SEDIMENTS FORMING PART OF VERIFICATION SURVEYS FOR PROPOSED MARINE DREDGING OPERATIONS IN ML 170

BASELINE SURVEY

Prepared for:
Namibian Marine Phosphate (Pty) Ltd.

Prepared by:
Dr Simon Forster

July – August 2013

Physalia Ltd
Little Pook Hill, Heathfield Road, Burwash Weald, Etchingham, East Sussex, United Kingdom
Simon.forster@physalia.co.uk

Tel: + 44 (0) 1582 764 304

This report to be cited as:
Physalia (2013). Meiofaunal Analyses of Namibian Offshore Sediments forming part of Verification Surveys for proposed Benthic Mining Operations. Baseline Surveys, July - August 2013. A factual, baseline survey report prepared for Lwandle Technologies (Pty) Ltd, Cape Town, by Physalia Ltd, Consultant & Forensic Ecologists, Harpenden, UK.

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed “Attention: Administration Manager,” at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

SUMMARY

- Physalia was approached by Lwandle Technologies (Pty) Ltd on behalf of their client Namibian Marine Phosphate to undertake analyses of the benthic meiofaunal communities present in sediment samples collected in the vicinity of a proposed offshore dredging operation. The survey site is situated on the Namibian continental shelf in approximately 200 metres of water.
- The survey area examined here, comprised 26 sampling stations. Sediments present in this area were predominantly fine to very fine silty sands with, in places, significant proportions of mollusc and/or brachiopod shell fragments.
- Of the meiofaunal groups present, the Nematoda (free-living roundworms) and harpacticoid Copepoda (microscopic, shrimp-like crustaceans) were processed and analysed quantitatively to species-level. The resulting data matrices were examined using a range of uni - and multivariate analytical techniques to describe and document patterns in the structures of their communities.
- Specialised, multivariate correlation analyses were then used to identify and describe quantitatively the relationships between the community structures and the measured sediment physico-chemical parameters.
- A total of 135 nematode and 36 harpacticoid copepod taxa was documented. With nematode species richness values of up to 42 species per sample and densities of up to 30,400 nematodes per litre sediment, these data are comparable to other offshore seabed sites recorded at similar water depths.
- Univariate distribution plots of nematode and harpacticoid copepod community data within the survey area were prepared and are presented and described.
- Multivariate analyses of the meiofaunal nematode communities revealed six robust, coherent clusters of communities comprising structurally-related species assemblages. Distributions of the multivariate clusters of these communities within the survey area were consistent with the presence of an environmental gradient oriented along an east - west axis. This is described.
- The correlation analyses identified the majority of elevated metal concentrations and finer sediment fractions as statistically significantly correlated with the largest nematode cluster located to the west of the survey area. The proportions of the coarsest sediment fraction (1,000 - 2,000 µm) correlated positively with a separate cluster of nematode communities. These were located along the eastern boundary of the sampling area. The authors conclude that sediment granulometry was the principal determinant of meiofaunal community structures in the 2013 verification survey.
- This verification survey has demonstrated that the meiofaunal assemblages will provide a robust means of assessing and tracking any changes in the seabed habitats that are associated with the proposed dredging operations and enable these to be placed into context with any changes in background conditions. Similarly, the same approach will enable recovery of mined areas to be documented.

© NMP 2014

contents

SUMMARY ii

1 INTRODUCTION 1

2 MATERIALS AND METHODS 2

2.1 MEIOFAUNA ANALYSES 2
2.1.1 Meiofaunal Sample Collection 2
2.1.2 Meiofaunal Sample Processing and Examination 2
2.2 ANALYSES OF DATA MATRICES 3
2.2.1 Standard Univariate Analyses 3
2.2.2 Multivariate Methods (Including ARESC Analyses) 3

3 RESULTS AND DISCUSSION 9

3.1 NOTES ON TAXONOMY 9
3.2 COMMUNITY STRUCTURES AND SPATIAL DISTRIBUTIONS 9
3.2.1 Univariate Community Data Distributions 11
3.2.2 Multivariate Analyses of Meiofaunal Community Data 11
3.3 MULTIVARIATE CORRELATION (ARESC) ANALYSES 13
3.4 OTHER MEIOFAUNAL GROUPS 15

4 SUMMARY AND CONCLUDING COMMENTS 16

4.1 THE SURVEY AREA MEIOFAUNAL COMMUNITIES 16
4.2 SUITABILITY OF MEIOFAUNAL ANALYSES FOR MONITORING PURPOSES 17

5 REFERENCES 18

Annexure A: Taxonomic Lists of Invertebrate Species and their Identification Codes 20
Annexure B: Meiobenthic Community Data Tables 27
Annexure C: Unvariate Distribution Plots for Key Meiobenthic Community Parameters 31
Annexure D: Multivariate Analyses of the Meiobenthic Nematode Community Structures 38
Annexure E: ARESC Analyses Identifying Relationships Between Community Structures and Measured Seabed Environmental Parameters 43

© NMP 2014

figures

Figure C1: Numbers of meiofaunal nematode species recorded at each of the off shore Namibian verification survey sites during the survey. 32
Figure C2: Total densities of meiofaunal nematode species recorded at the offshore Namibian verification survey sites. 32
Figure C3: Diversity indices (Simpson's *D*) for the meiofaunal nematode communities recorded at the onshore Namibian verification survey sites, July/August 2013. 33
Figure C4: Dominance (% abundance) recorded in the meiofaunal nematode communities present at the onshore Namibian verification survey sites, July/August 2013. 33
Figure C5: Co-dominance (%) for the meiofaunal nematode communities recorded at the offshore Namibian verification survey sites, July/August 2013. 34
Figure C6: Meiofaunal nematode community 1B/2A feeding type ratios recorded at the offshore Namibian verification sites, July/August 2013. 34
Figure C7: Total number of meiofaunal harpacticoid copepod species recorded in the sediments at the offshore Namibian verification survey sites, July/August 2013. 35
Figure C8: Densities of meiofaunal harpacticoid copepod communities represented in sediments at the offshore Namibian verification survey sites. July/August 2013. 35
Figure C9: Diversity indices (Simpson's *D*) for meiofaunal harpacticoid copepod communities recorded at the offshore Namibian verification sites, July/August 2013. 36
Figure C10: Dominance, the percentage abundance of the most abundant meiofaunal harpacticoid copepod species, recorded at the offshore Namibian verification survey sites, July/August 2013. 36
Figure C11: K-dominance plots for the July / August 2013 Namibian meiofaunal nematode communities. 37
Figure D1: Interpretation of Physalia Multivariate Analyses 38
Figure D2: Two-way classification analyses 39
Figure D3: Multivarient ordination analyses 40
Figure D4: Distributions of structurally – related meiofaunal nematode communities 41
Figure E1: ARESC plot showing mathematical relationship between meiofaunal communities and the sediment physico-chemical environment. 44

tables

Table 2.1: Standard and more specialised community parameters for which spatial distribution plots have been prepared (see maps in Annexure C). 5
Table 3.1**:** Comparison of meiofaunal nematode community data for the Namibian verification survey with those from an offshore North Sea survey undertaken in 2013 at 200 metres depth 10
Table A1: Table presenting the full taxonomic list of meiofaunal Nematoda 20
Table A2: Table presenting the full taxonomic list of meiofaunal harpacticoid Copepoda (Biramia) 25
Table B1: Site-by-site results table for the communities of meiofaunal Nematoda 27
Table B2: Site-by-site results table for the harpacticoid Copepoda communities 30
Table D1: List of the indicator species 42
Table E1: The formal ARESC analysis table 45

© NMP 2014

1 INTRODUCTION

Namibian Marine Phosphate (Pty) Ltd is currently undertaking a verification assessment following on from the environmental impact assessment (EIA 2102) for the proposed marine dredging operation that would centre on a site on the Namibian continental shelf, Mining Licence Area ML 170. The mineral material of interest is pelletal phosphorite and would involve dredging in approximately 200 metres of water. The consolidated verification survey will include assessments of the biological, chemical and physical conditions of the water column and benthic (seabed) habitats, as well as temporal studies of the prevailing water current regime designed to inform modelling of potential suspended sediment dispersion plumes.

Physalia Ltd. was contracted to undertake analyses of the communities of benthic meiofauna and to provide baseline and subsequent monitoring information relating to the effects of the proposed dredging activities on the benthic environment. Staff members at Physalia have been undertaking similar meiofaunal assessments and surveys at locations throughout the world since the mid-1980s and have produced numerous scientific papers/technical publications on the subject of meiofaunal ecology, eco-physiology and on the use of meiofauna as bio-indicators of environmental conditions.

The meiofauna comprises animals that live within sediments and are typically within the size range 50 µm and 1 mm in length (although some species with larger individuals exist). The benefits of meiofaunal analyses when assessing baseline conditions of a site and where monitoring, and documenting subsequent changes in conditions is required, can be summarised as follows:

- In a given habitat, meiofauna are usually an order of magnitude more abundant and more diverse than other invertebrate faunal groups. The high numerical abundance of individuals belonging to meiofaunal groups, such as the nematodes, means that the collection of scientifically robust, statistically valid samples is a simple, cost-effective process, minimising disturbance of existing habitats and maximising on information content.
- Meiofauna communities include species that occur throughout the entire spectrum of prevailing environmental conditions. These range from grossly polluted sites through to pristine habitats. They include tolerant, resistant species that are amongst the last to disappear as conditions deteriorate and are the first to reappear as conditions improve. Conversely, other more sensitive species are amongst the first to disappear as stresses increase and conditions begin to deteriorate. Analyses of meiofaunal communities can therefore be used to assess changes over the entire range of habitat conditions.
- Meiofaunal life-cycle times range less than 10 days (“egg-to-egg”) up to several years. This means that the structures of meiofaunal communities can respond rapidly to short-term changes in conditions as well as integrating the effects of, and providing information on, prevailing conditions over longer periods of time.
- Located nearer to the base of foodwebs than larger animal groups, populations of many meiofaunal species respond directly to any stresses that affect the nature and quality of their food supply (e.g. protozoans and ciliates (“microbes”) as well as algae, including diatoms). This means that changes in conditions are more rapidly expressed as changes in the relative abundances of these more sensitive meiofaunal species than in most other faunal groups.
- Living in the spaces between sediment particles and with relatively low mobility, meiofaunal animals are continuously subjected to the constraints of any materials that enter their

© NMP 2014

environment (e.g. contaminants or materials that lead to altered habitat conditions). The same is true of physical perturbations (e.g. sediment disturbance and smothering). As a result, analyses of meiofaunal communities provide greater spatial resolution of effects resulting from site-specific changes in habitat conditions than can be achieved by analysing more mobile and more patchily distributed animal groups.

Further details of the use of meiofaunal species as bio-indicators and their applications in industrial and other situations are given in Trett *et al.* (2009).

This report presents the results of the analyses of meiofaunal samples collected by Lwandle staff from 26 sites during the marine survey undertaken in July and August 2013. Site-by-site physico-chemical data provided by the Lwandle team enable a full suite of univariate and multivariate statistical analyses to be undertaken in parallel with the analyses of the meiofaunal assemblages. The data analyses employed in the present report also include ARESC analyses[1]. These permit the key factors that shape the biological communities to be identified and ranked in order of statistical (and biological) significance.

2 MATERIALS AND METHODS

2.1 MEIOFAUNA ANALYSES

2.1.1 Meiofaunal Sample Collection

Sediment samples were collected from the Namibian continental shelf pelletal phosphorite dredging site Sandpiper-1 (SP-1) over the period 26th July to 3rd August 2013 using a box corer. Sub-samples for subsequent meiofaunal analyses were taken by inserting a hand corer into the sediment retained in the box corer. Samples were preserved in formalin (ca. 4% formaldehyde). A total of 27 samples from 26 sites was supplied to Physalia for analyses.

2.1.2 Meiofaunal Sample Processing and Examination

a Sample Separation

Standardised laboratory protocols developed and refined by staff at Physalia over the past 30 years were used for the extraction of the meiofauna from the preserved sediment samples. After re-coding, the volume of sediment in each sample was measured. The samples were homogenised in approximately 800 ml water. Initial separation was carried out using a modified, multiple Boisseau apparatus to elutriate the microscopic organisms from the bulk of the inorganic matrix. The first ("light") and subsequent ("heavy") meiofaunal fractions were collected on 50 µm mesh sieves immersed in flowing tap water (Flegg and Hooper, 1970).

[1] ARESC analyses - Technically the Assessment and Ranking of Ecologically Significant Contaminants. However, these analyses include assessments of correlations between the community structures *natural* physico-chemical parameters as well

Pooled meiofauna/silt fractions for each sample were further concentrated by a polymer density separation technique with centrifugation and the meiofauna re-collected onto 38 µm mesh sieves. The density separation technique was repeated and the separation efficiency estimated.

b Meiofaunal Harpacticoid Copepoda

Harpacticoid copepod shrimps were removed from the samples by hand using mounted 000-gauge needles (or single, mounted eyelashes; after David Hooper, Rothamsted Experimental Station, Harpenden). For microscopy, specimens were then mounted in Berlese's thin formulation medium prepared using the technique described by Humason (1979) or polyvinyl lactophenol (PVLP; Physalia in-house formulation). The addition of a small quantity of lignin pink to the mountant aided location of the specimens on the slides. After clearing (approximately 3 days at room temperature), specimens were identified by means of 5th limb setotaxy (Lang, 1948) using Zeiss and Nikon differential interference microscopes, enumerated as numbers of individuals per species (or per "operational taxonomic unit" (= OTU)), and recorded as numbers per species per litre sediment per site.

c Meiofaunal Nematoda

Modified nematological techniques based on those of Bührer (1949), Baker (1953) and Cairns and Tarjan (1955) were used to process, handle and examine the remaining meiofauna, (primarily Nematoda - free-living roundworms). Specimens were processed to glycerol using a modified Seinhorst method (Seinhorst, 1959) in Syracuse watch glasses at 40 °C in a drying oven. Taxonomic microscope slides were then prepared for identification and enumeration. All microscopic examination was carried out using Zeiss Nomarski and Nikon differential interference contrast (DIC) microscopes. For the highly abundant nematodes, the first 100 specimens encountered were identified and counted. Remaining nematode specimens were then counted to allow the total densities of each species in each sample to be calculated and then recorded as numbers per species per litre sediment per sampling site.

2.2 ANALYSES OF DATA MATRICES

2.2.1 Standard Univariate Analyses

Table 2.1 below summarises and describes the standard univariate community parameters examined for the nematode and harpacticoid copepod communities. Maps and plots using scaled symbols for these parameters at each sampling site were prepared to enable spatial patterns and trends to be detected and examined (e.g. depression of species numbers or elevations of dominance values in the vicinity of the proposed dredging area).

To aid interpretation, the univariate data outlined in Table 2.1 below were superimposed onto survey maps and the values indicated by scaled symbols.

2.2.2 Multivariate Methods (Including ARESC Analyses)

With complex physico-chemical and faunal data matrices, multivariate analyses offer a practical means of screening and identifying/mapping spatial (and temporal) patterns of variation in the data. These analyses are used to recognise and describe the patterns of similarities in community

© NMP 2014

structures that develop wherever similar prevailing conditions act on diverse assemblages of species in marine systems. The techniques group structurally similar communities into "clusters" of assemblages. If these clusters are mapped back onto the survey area their distributions can then be examined. This enables the identification of sites at which different environmental conditions exist (e.g. effects of different sediment types, natural differences in sediment chemistry and any anthropogenic contaminants that may be present).

Two fundamentally different multivariate methods were used in the present study; a **classification technique** that "weighs" each community mathematically[2] and then groups them together to form clusters (hence its generic name cluster analysis) and an **ordination technique** that awards scores to each community and distributes them along different axes of variation[3]. The former produce results in the form of dendrograms whilst the latter produces graphs with communities grouped together in mathematical space. Distribution maps were prepared for the clusters identified in each set of multivariate analyses. These enable rapid assessment of the spatial patterns of groups of structurally-related species assemblages on the seabed in the 2013 verification survey area.

To aid ecological interpretation, an analysis based on **Monte Carlo permutation tests** (MCPTs; Sokal and Rohlf, 1995) was used to identify "indicator species" and to test the statistical significance of the relationships between these and the clusters of communities identified by the multivariate analyses (Dufrêne and Legendre, 1997).

[2] Based on Sørensen's distance method and flexible ß-linkage technique (Lance & Williams, 1967 & 1968) for both the inter- and subtidal survey data sets

[3] Non-metric multidimensional scaling after Kruskal (1964a and 1964b) as modified by Mahler (1976)

Table 2.1: Standard and more specialised community parameters for which spatial distribution plots have been prepared (see maps in Annexure C).

Parameter	Description
Densities	Total numbers of animals per litre sediment
Species richness	Numbers of species per animal group per sampling site
Dominance	The percentage abundance of the most abundant species; a measure of stress-selection for tolerant, resistant species
Diversity indices	Simpson's index[4] integrating densities, dominance and numbers of species. This index is preferred as it gives more even weighting to abundant and rare species than other measures of diversity; see Peet, 1974 and Forster, 1998
Feeding type ratio	Nematodes only; the ratio of densities of non-selective deposit feeding species (e.g. detritus-feeders) to more sensitive specialist feeding types (e.g. diatom feeder and epigrowth feeders). Shows changes in the trophic (feeding) structure of nematode communities.
Selected features	Specific plots prepared to illustrate an ecological feature (e.g. changes in communities of species with particular physiological characteristics)

As its name suggests, Monte Carlo tests works by generating **large** numbers of random combinations, in this case of species (see Manly, 1997). From this it is possible to calculate the probability that the observed (real) patterns of relationships between each species and their clusters could have occurred by chance. By default, the robustness of the observed combinations can be determined. These results permit a more rigorous interpretation as the biologies, sensitivities, feeding requirements, physiologies and habitat requirements of indicator species can be used to corroborate the findings of correlation analyses described below.

To determine the statistical relationships between the community structures and the measured environmental parameters, **multivariate correlation analyses** (MCAs) have been employed. A modification of these analyses, termed ARESC analyses[5], was developed by Dr. Beatriz Calvo Urbano (see Calvo Urbano in Trett *et al*., 2000 and summarised in Trett *et al*., 2009). These are based on ordination analyses of the community structures[6]. For present purposes, plots of the correlation lines

[4] Simpson's diversity index *D* calculated as:

$$D = \frac{1}{\sum_{i=1}^{S} P_i^2}$$

Where: S is the number of species and P_i is the proportion of individuals of the *i*th species in the sample

[5] ARESC = Assessment and Ranking of Ecologically Significant Contaminants. However, it also assesses and ranks natural factors such as the proportions of individual sediment particle size categories or the concentrations of total organic carbon.

[6] Over 50 different random starting configurations of the real data were used in the multivariate correlation analyses. A 50-cycle Monte Carlo permutation test showed that the probability of achieving a similar low stress configuration of the data from a random combination of the variables was less than 0.05 and indicated that a three-dimensional analysis was the most appropriate for a given community data set. When completed, analyses showed that the minimum proportion of the variance present in the data sets explained by the axes (i.e. the coefficients of determination), was 0.814 (= 81.4% for the meiofaunal assemblages 3-dimensional solution). The environmental parameters were then correlated with the

© NMP 2014

for the environmental determinands have been prepared and are presented in Annexure E. The significance data were used to rank the environmental determinands (metal concentrations, proportions of sediment particle size fractions and total organic carbon contents) which can be used to indicate the importance of each parameter in the structuring of the faunal communities.

In the case of the ARESC analyses that were used to identify relationships between the meiofauna nematode community structures and the sediment physico-chemical parameters that were measured, the data were corrected to overcome the statistical issues that arise where multiple comparisons are made. These apply a mathematical correction to the results to prevent a false rejection of the null hypothesis that would lead to the identification of statistical significance where none exists. The differences can be seen in the ARESC summary table (Table E1; Annexure E) which presents the raw probability data (standard *p*-values) and the results from two different correction methods, the Benjamini and Hochberg (1995) technique ("BH") and the rather more draconian Benjamini and Yekutieli (2001) method ("BY"). In each case, the correlation coefficient values that are statistically significantly associated with the meiofaunal nematode community structures are identified in bold enabling the differences to be seen.

nematode community axes to provide information on the ecological (and statistical) significance of the physico-chemical parameters.

© NMP 2014

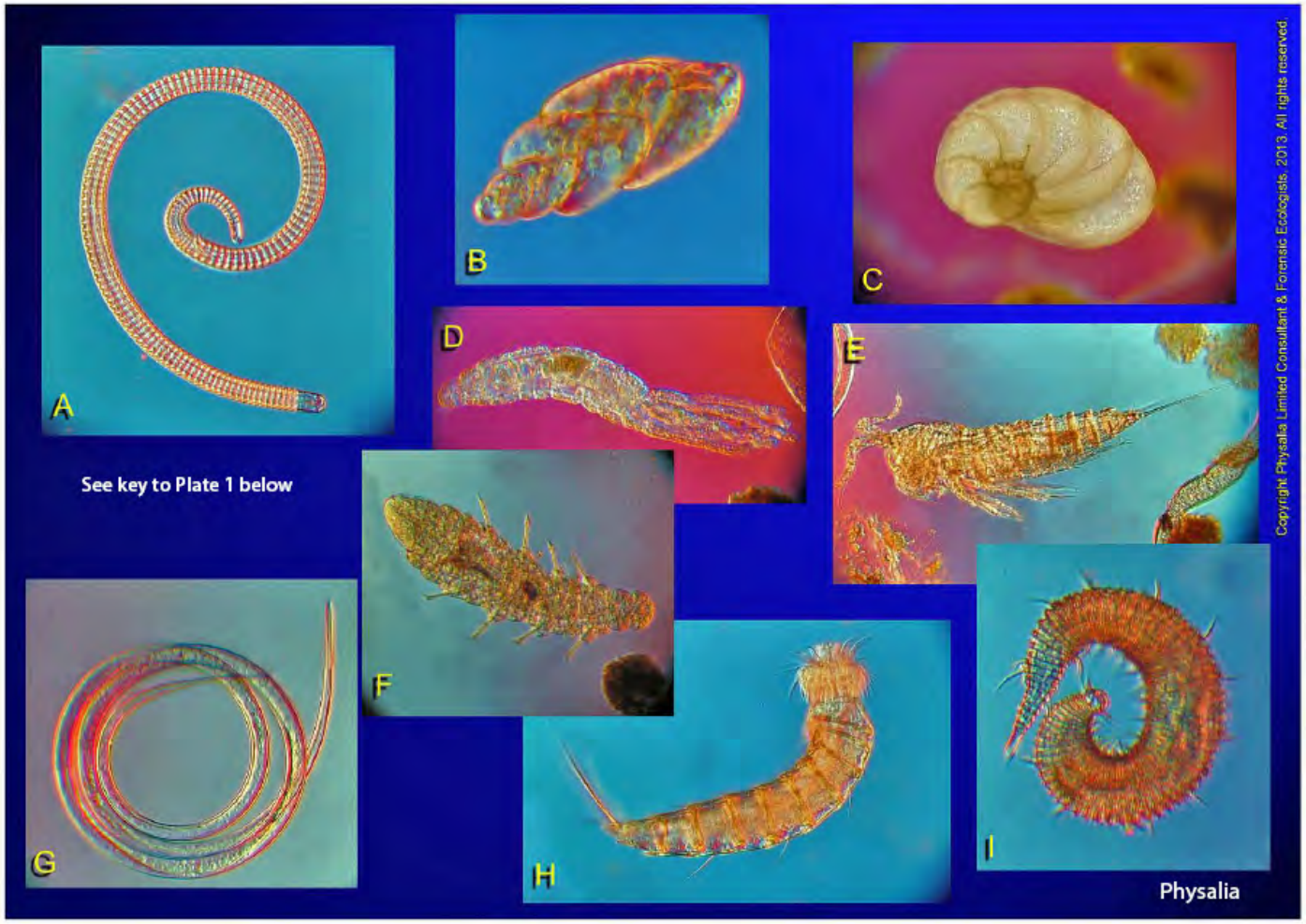


Plate 1: Meiofauna

Key to Plate 1:

A Members of the nematode family Ceramonematidae are easily recognized by their "chain mail" formed by overlapping circular plates. This species of *Ceremonema* was found at 12 of the 26 verification sites.

B Foraminifera were ubiquitous throughout the verification survey with specimens. A number of structural types were recorded including the Bolivinitid type shown here, as well as C, the planospiral "hyaline" species belonging to the family Elphidiidae

D and F Juvenile/neochaete polychaete annelid worms were recorded in all meiofaunal samples examined. These are temporary or ransient meiofauna and, as such, do not provide suitably robust data for inclusion meiofaunal biomonitoring. In the present survey, the mature poly-chaetes were studied as part of the larger macrofauna.

E A total of 36 harpacticoid copepod species was recorded in the verification survey with densities of up to 687 animals per litre. Due to the high fine silt content of the sediment, the majority of the copepods were large epibenthic species.

G Nematodes (free-living roundworms) were the most abundant meiofaunal group recorded. Densities >30,000 nematodes per litre sediment were recorded in the verification samples and included members of 135 species. This is a microbivorous *Halalaimus* species (probably *H. isaitshikovi*).

H The Phylum Kinorhyncha is considered exclusively meiobenthic, although kinorhynchs can occur in sediment associated with algal holdfasts. These animals were not abundant in the verification survey meiofauna samples and were observed at 3 sites only.

I This species of *Quadricoma* represented one of three genera within the family Desmoscolecidae. The family is characterized by the presence of cuticles annulated with desmen (thick rings of secretions and attached debris) that extend from the head to the tail.

© NMP 2014

3 RESULTS AND DISCUSSION

3.1 NOTES ON TAXONOMY

A total of 135 discernable nematode taxa was recorded during the present meiofaunal analyses, including representatives of 23 families. The taxonomic classification of these taxa is presented in Table A1, Annexure A.

Taxonomic descriptions of the nematode assemblages of West African offshore benthic habitats are poor and no comprehensive taxonomic lists and descriptions of nematode species are available for use as guides. Given the lack of meiobenthic studies in these habitats, it is highly likely that *a significant proportion of the nematode species in the verification survey area are "new to science"*. In order to determine which species has been described and which is currently un-described it would be necessary to review all of the current species description within the genera present. Such investigations were neither practical nor pragmatic. The purpose of the present study was to characterise the baseline, pre-dredging, conditions of the survey area and provide robust biological information against which post-dredging conditions can be compared. To this end, as with other sites that we have examined and monitored around the World, we have drawn and described each species encountered to create a set of site-specific observed taxonomic units (= OTU). In nearly all cases these have been ascribed to family and genus level based on the existing generic level definitions.

Beyond this, species level differences, based solely on the combination of standard taxonomic (= morphological) features present, have been used to define the individual OTUs and to ensure that valid comparisons are made between the sampling sites examined in the present survey. In each case full taxonomic drawings and descriptions have been prepared for the species encountered in the 2013 survey area to ensure consistency both within the current survey and with future surveys of this area. The same procedure was adopted for the meiofaunal harpacticoid copepod shrimp species. Tables A1 and A2 (Annexure A) list the taxonomic species for these meiofauna.

3.2 COMMUNITY STRUCTURES AND SPATIAL DISTRIBUTIONS

Table 3.1 below provides a summary of the status of the assemblages of meiofaunal nematode and harpacticoid copepod communities recorded in the 2013 verification survey area. In each case key, descriptive community parameters are presented. These include numbers of families and species per invertebrate group, ranges and means for total densities, species richness values and the diversity indices (descriptive indices that are based on a combination of the numbers of species present per sampling station, their densities and the distributions of these densities amongst the species present). In the case of the meiofaunal Nematoda, feeding type ratios have also been included. These descriptors allow changes in different nematode groups ("guilds") to be examined and compared and serve here to provide a baseline against which changes in sediment physico-chemistry can be assessed[7].

[7] Prevailing conditions within sediments exert differential effects on nematode species with differing feeding preferences. For example, chemical stresses often militate against specialist feeders that exploit microbial epigrowth whilst populations of non-selective deposit feeders may be relatively unaffected. This is detected in the nematode feeding-type ratios (FTRs) as well as in the multivariate analyses feeding

© NMP 2014

In the present survey, total densities, species groups, species richness values and diversity indices for the nematode assemblages were comparable with those recorded in other offshore benthic sediments that we have examined in similar depths of water. Examples include parallels with species assemblages recorded in a recent Physalia survey in the North Sea offshore of Scotland in 200 metres water[8]. The data are compared in Table 3.2 below. Whilst nematode densities in the present survey were lower overall, the species richness and diversity values were remarkably similar.

Table 3.1**:** Comparison of meiofaunal nematode community data for the Namibian verification survey with those from an offshore North Sea survey undertaken in 2013 at 200 metres depth

Parameter	Offshore Namibia	Offshore North Sea
Mean Density (no.litre^{-1})	11,949	17,688
Max Density (no.litre^{-1})	30,400	36,800
Min Density(no.litre^{-1})	1,746	4,407
Mean Species Richness	29.77	30.25
Max Species Richness	42	44
Min Species Richness	14	18
Mean Diversity	11.30	12.18
Max Diversity	24.83	24.31
Min Diversity	4.47	2.06
Mean 1B/2A ratio	0.383	3.798
Max 1B/2A ratio	3.200	15.400
Min 1B/2A ratio	0.082	0.516

Interestingly, marked differences can be seen in the mean and ranges of the 1B/2A feeding type ratios between the two survey sites, with the present survey area yielding lower values than those for the North Sea study. As outlined in Table 2.1 above, this index is based on the density ratios of type 1B species (nematode species characterised by large, un-armed buccal cavities presumed to be associated with detritus feeders), and type 2A species (species with small buccal cavities armed with teeth, presumed to be selective epigrowth browsers and diatomivorous species). The assumptions relating to the feeding preferences of the nematode species are based on solely morphological features and several exceptions have been documented (see, for example, Moens and Vincx, 1997). One of the most common species recorded in the present (verification) survey was a *Paracomesoma* species (coded species 4). The elevated abundance of this species contributed strongly to the low 1B/2A ratios. This nematode has a deep but narrow, cuticularised buccal cavity with fine teeth at the anterior end. In nearly all studies this species has been classified as a type 2A nematode. Given its abundance in the Namibian sediments with elevated silt contents, it is quite likely that this *Paracomesoma* species does not feed selectively and should not be included in the type 2A category.

[8] Survey of the meiofaunal communities of the Scanner and Braemar SAC sites, undertaken by Physalia for the UK governmental body Centre for Environment, Fisheries and Aquaculture Science (CEFAS)

© NMP 2014

Further consideration will be given to this, along with the feeding type classifications of other taxa, before the interpretation of the mining monitoring surveys is undertaken.

3.2.1 Univariate Community Data Distributions

A selection of descriptive, site-by-site univariate parameters for the meiofaunal nematode and harpacticoid copepod assemblages recorded in the 2013 survey are displayed as spatial plots with scaled symbols in Figures B1 to B10 (Annexure B). The distribution plots enable visual assessments of natural variation in each community parameter to be made and comparisons to be drawn between values in the proposed mining area and those at sites beyond. The degree of spatial variation ("patchiness") that can be seen in the plots appears to relate primarily to differences in the sediment granulometry. Although individual plots have not been prepared for the individual granulometric fractions, the results of the ARESC analyses, that assess correlations between community structures, provide strong supporting evidence for this (see Section 3.3 below).

From the *nematode* community parameter plots, several "textbook" examples of relationships can be seen between the different sets of ecological (community) descriptors. Note the inverse relationships between total nematode densities and species richness values (Figures C1 and C2) and again between nematode diversity and the community dominance/co-dominance values (Figure C3 and Figures C4/C5). In the case of the meiofaunal harpacticoid copepod communities, the parallel patterns were not observed (see Figures C7 to C10). This reflected the pre-dominance of active, mobile, epibenthic species. These larger harpacticoid species are typified by the Diosaccidae which migrate across the sediments in search of decomposing detrital materials and/or diatoms that have settled onto the seabed.

Figure C11 (Annexure C) presents cumulative species abundance curves for the July/August 2013 nematode assemblages. Also known as *k*-dominance curves, these provide a valuable means of visualising the dominance/diversity characteristics of the assemblages. Each assemblage (sample community) is represented by a plot of the species rank (*x*-axis; $\log_{10}$ scale) against their cumulative percentage abundance (*y*-axis). Typically, the assemblage with highest species richness and highest evenness value, in this case the nematode community present in the sample from Site VS2, is represented by a sigmoid curve that is displaced down towards the bottom right of the plot. The community curves that lie in this area of the dominance-diversity "space" include the most diverse, species-rich assemblages present in the survey area.

In contrast, where selection pressures arising from prevailing environmental conditions within the sediments lead to a more restricted number of tolerant/resistant species, the low evenness/high dominance communities are displaced towards the top left of the dominance - diversity plot. In this instance, examples included the nematode assemblages present at sites VS5 and VS26.

During the subsequent mining monitoring program, the examination of *k*-dominance curves will provide a useful means to assess and visualise changes in the dominance/diversity characteristics of the meiofaunal communities associated with the mining activities.

3.2.2 Multivariate Analyses of Meiofaunal Community Data

Studies undertaken at sites around the world over the last 30 years have shown that, under similar prevailing conditions in contiguous habitats, meiofaunal nematode communities develop structurally

© NMP 2014

similar assemblages of species (see Trett *et al.,* 2000 and 2009). This observation is important and forms the basis for two powerful analytical/diagnostic tools. These are:

a) The use of meiofaunal nematode assemblages to map sites that are subject to different prevailing environmental conditions and to identify and track changes in the physico-chemical parameters that shape the communities over time and

b) Using advanced mathematical techniques, to rank and track the ecological importance of the measured environmental parameters that are responsible for shaping the meiofaunal nematode assemblages.

The former relies on the use of two fundamentally different sets multivariate techniques (outlined in Section 2.4.2 above) to identify patterns in the communities based on the species present at each site and their abundances (densities). The latter is achieved using multivariate correlation analyses to assess the strength of the relationships between the species assemblages and the measured environmental parameters. A brief guide to the interpretation of the classification and ordination analyses used to identify structurally-related related communities that are then mapped onto the survey area is presented in Figure D1 (Annexure D).

The results of the classification analyses are presented in Figure D2 in the form of a *two-way dendrogram*. The smaller, vertical dendrogram located on the left-hand side of the plot displays the relationships between the sample sites' nematode assemblages *and* identifies the *clusters* of the structurally-related communities (Clusters A to F; Figure D2). The larger, horizontal dendrogram represents the similarity linkages between the nematode species identified in the present survey based on *the samples in which they occurred and their densities in these samples.* This is summarised in the large density distribution matrix that depicts the densities of each species in each sample (colour coded from dark blue for the highest densities through to white for the lowest).
Note that Cluster E (light blue; Figure D2) comprises solely the meiofaunal assemblage present at Site 4 (S4). Although it exhibited similarities with the communities present in Clusters D and F, the sediments at Site 4 supported several species that were unique to this site (see species matrix in Figure D2 and indicator species analyses below).

The multivariate ordination studies (i.e. the non-metric multi-dimensional scaling (NMMDS) analyses), that were run in parallel to the classification analyses, confirmed the relationships between the meiofaunal nematode communities described above (see Figure D3; Annexure D). Note that the clusters were coherent and non-overlapping in the three-dimensional ordination space indicating structurally distinctive assemblages in each of the clusters. Taken together, the three community axes explained over 80% of the total statistical variation present in the nematode community data matrices. A minor difference between the two sets of multivariate analyses was the degree to which ordination analysis isolated Cluster F communities from their closest "relatives" i.e. the communities present in Clusters D and E.

Table C1 (Annexure D) presents the results of the mathematical indicator species analyses (ISAs). Based on Monte Carlo permutation tests, these identify species whose density distributions within the survey area show statistically significant correlations with the clusters of sample site communities identified in the multivariate analyses. Aside from characterising the ecology of the communities present in these clusters, the results provide a robust basis for the assessment of changes in the communities that occur as result of any natural/seasonal processes *and* those associated with the

© NMP 2014

effects arising from operational activities once these commence. Note that indicator species could not be identified for Cluster E as this comprised the single sampling site S4.

The clusters of structurally-related nematode assemblages identified by the classification analyses and corroborated by the ordination studies have been transposed onto the survey area chart (see Figure D4). This reveals a nematode community distribution pattern *that is consistent with the presence of an environmental gradient*. The closely-related Cluster D, E and F meiofaunal assemblages were present at sites located on the eastern side of the verification survey area. Amongst these, the Cluster F communities were confined to the five sampling stations that extended along the eastern side of the grid. The remaining nematode assemblages, i.e. those belonging to Clusters A, B and C, were identified at sites located in the western half of the survey area (Figure D4).

To determine the driver(s) for this pattern of community distributions we can turn to the results of the ARESC analyses described in the following section.

3.3 MULTIVARIATE CORRELATION (ARESC) ANALYSES

The results of the ARESC analyses that are used to assess the inter-relationships between structures of the seabed communities and the measured environmental parameters are presented in Figure D1 and Table D1 (Annexure E). From the ARESC plot (Figure E1) it is clear that the majority of the elevated sediment metal concentrations recorded in the 2013 verification survey was associated with the finer sediment fractions. Note the orientation and lengths of the correlation lines for these sediment parameters. The direction of these lines indicates the communities with which the parameters are associated (in the present case, primarily with the group of communities belonging to Cluster A). The length of the individual correlation lines is a function of the strength of the associations and Table E1 identifies those correlations that are statistically significant once corrections have been made for potential “false positives” arising from multiple comparisons[9].

Figure E1 shows a similar orientation of correlation lines for the majority of the metals and the finer sediment fractions. This is consistent with binding of metals by the surface charges present on fine, alumino-silicate (silt-clay) sediment particles. The concentrations of sediment vanadium and cadmium are interesting exceptions and elevated values were associated with sediments characterised by coarser particle size fractions (500 - 1,000+ µm; Figure E1). The reason for this is unknown. However, whilst these metals may be of background, geological origin, there is a body of scientific information that details accumulation of vanadium and cadmium in some benthic invertebrates such as polychaete annelids and molluscs (see for example Fattorini *et al*., 2010, Fattorini and Regoli 2012 and Erk *et al*., 2005).

[9] In statistical analyses, *multiple comparisons,* such as those that arise when considering which measured physico-chemical parameters are associated with the structures of the bio-indicator communities, can lead to serious problems. Put simply, the greater the numbers of measured parameters that are compared with the community axes, the greater the chance of rejecting the null hypothesis and, as a result, identifying a statistically significant association where none exists. To overcome this, compensatory techniques have been developed that require a stronger body of evidence for an individual comparison to be deemed "significant", based on the numbers of inferences being made. Table E1 (Annexure E) provides uncorrected (raw) comparisons (standard *p*-values) for the relationships between sediment physico-chemical parameters and the community axes as well as the results of two different correction methods; the Benjamini and Hochberg technique - a standard, “moderate” approach and the Benjamini and Yekutieli technique - considered by some as rigorous and by others as over zealous.

© NMP 2014

In Section 3.2.2 above, it was noted that the spatial distribution of the clusters of the meiofaunal nematode assemblages within the 2013 survey grid was consistent with the presence of an environmental gradient. Cluster A, B and C communities were located at sites on the western side of the sampling area whilst the species assemblages in Custer D, E and F were present at sites on eastern side. In the latter case, the Cluster F communities were confined to 5 sites located along the eastern edge of the survey area. Reference to Figure E1 indicates that the environmental gradient was primarily granulometric with the finest sediments located to the west and the coarsest sediments located to the east. It is noted that fine sediments correlated spatially with elevated concentrations of a range of sediment metals. This is consistent with alumino-silicate metal binding to the finest sediment fractions.

Table E1 (Annexure E) presents the statistical data for the relationships between the measured physico-chemical parameters and the three main axes of variance derived from the multivariate analyses of the meiofaunal nematode communities. Note that Axis 1 accounted for ("explained") the highest proportion of the statistical variance in the meiofaunal nematode community structures (41.4%). Once corrections had been made for multiple comparisons 9 below), it was clear that sediment granulometry and the concentrations of several sediment metals were important determinants of the meiofaunal community structures.
Reference to Axis 1 shows that the proportions of finer particle size fractions (i.e. ≤ 63 µm) were all statistically significantly correlated with the nematode communities in July/August 2013 (Benjamini and Hochberg correction; Table E1). Of these, both sets of correlation values corrected for multiple comparisons ("BH" and "BY" methods) identified the proportions of the 16 - 32 µm sediment fractions as the most important *granulometric* factor with respect to which species occurred where and at what densities. Note that the uncorrected data (headed *p*-value for Axis 1) also identified a relationship between coarser sediment fractions (125 - 500 µm and 1,000 - 2,000 µm) and ARESC Axes 1 and 2. With some meiofaunal species with life-cycles as short as 10-20 days, these might still be important factors in the shaping of the offshore meiobenthic communities over longer periods of time.

Although important, the strongest correlations between the meiofaunal nematode community structures and the quantified environmental parameters were not the sediment particle size fractions. Instead, these related to several of the chemical analytes. Structural variance in the nematode communities showed correlations with sediment concentrations of aluminium, arsenic, barium, cobalt, chromium, manganese, mercury, nickel and lead. The same elements were also identified in the uncorrected data with the single addition of zinc which was not found to be correlated with the nematode community structures when allowance was made for multiple comparisons (Table E1).

Note that neither the "BH" nor the "BY" sets of corrected data indicated statistically significant correlations between the sediment metal concentrations and the structures of the meiofaunal nematode communities for ARESC Axes 2 and 3. However, the uncorrected ("raw" *p*-value) correlation data indicated that cadmium and vanadium were associated with ARESC Axis 3 and that total organic carbon was associated with ARESC Axis 2 (Table E1). This implies that the nematode communities differed in their responses to these parameters when compared to the other (Axis 1) environmental parameters.

Examining these data, it appears likely that the distributions and concentrations of sediment TOC, cadmium and vanadium were not solely related to the sediments and that other localised

© NMP 2014

"processes" may have been involved. Sediment cadmium and vanadium may have been associated with patchy colonies of invertebrates (e.g. beds of polychaete worms, crustaceans and molluscs). As already noted in references cited above, the colonial species may have accumulated these elements in their tissues, shells and cuticles. In the case of organic carbon, elevated sediment values would have reflected the presence of biological tissues wherever beds of macroinvertebrate species had become established. Several published studies show that the stabilising effect of macrofaunal colonies results in accretion of organic/detrital materials that then become incorporated into the seabed. Similarly, the production of faeces and, in some cases, the secretion of mucus materials, that further serve to trap fine organic matter and bind it into sediments, would increase the net organic carbon contents, whilst fuelling microbial populations and increasing biomass still further (see, for example, Hughes and Gerdol, 1994).

Taken together, we believe that these could explain the differential nature of the relationships exhibited between the nematode communities and sediment cadmium, vanadium and total organic carbon contents when compared to other measured sediment physico-chemical determinands in the verification survey area.

3.4 OTHER MEIOFAUNAL GROUPS

The variety and abundance of meiofaunal groups other than nematodes and harpacticoid copepods observed during the taxonomic studies was surprisingly poor. However, polychaete annelid worms and foraminiferans (cased Protista) were found to be present in all samples examined. Most polychaete species present in the meiofaunal size fractions are temporary or transient meiofauna, and are usually represented by juveniles, rendering their taxonomy difficult. Assessment of the polychaete populations is, therefore, best undertaken on mature (adult) specimens present in the macrofaunal fractions (> 500 µm).

Amongst the Foraminifera a variety of test ("shell") forms was observed during the meiofaunal sample analyses. It would therefore be possible in future surveys to undertake an assessment of the distribution of foraminiferan taxa based on structures of the tests. However, the persistence of tests in the sediment after the animals have died is an issue. Whilst viable tests are generally "glassy" in appearance and non-viable tests appear dull as a result of abrasion, the difference is not always clear and the success of such a study would rely on consistent interpretation of "live" and "dead" frustule appearance.

Occasional ostracods ("seed shrimps"), kinorhynchs ("spiney-crown worms"), ciliates and halacarid mites were also recorded during the taxonomic analyses of the nematode. However, these groups were present at low densities only and, based on the verification survey results, would not provide sufficiently robust data suitable for the assessment and monitoring of changes in benthic habitat conditions.

© NMP 2014

4 SUMMARY AND CONCLUDING COMMENTS

4.1 THE SURVEY AREA MEIOFAUNAL COMMUNITIES

The meiofauna analyses of the 26 verification sites demonstrated that abundant and diverse/species-rich nematode assemblages occurred in the benthic sediments at and within the vicinity of the proposed mining site. A total of 135 nematode taxa was documented with species richness values of up to 42 species per sample and densities of up to 30,400 nematodes per litre sediment. These data are comparable to other offshore seabed sites collected from similar depths of water.

The harpacticoid copepod assemblages were less diverse and abundant than the nematodes and a total of 36 taxa/species was recorded in the 26 verification samples, with up to 15 taxa documented in a single sample. Respectable densities of up to 687 harpacticoid copepods per litre sediment were recorded. Due to the high fine silt fraction contents of the sediments, the majority of the copepod species comprised larger, epibenthic species rather than the small, often vermiform, interstitial species that are usually more abundant in silt-free, "clean" sands.

The use of different multivariate analyses to examine the nematode communities revealed robust, coherent clusters of communities comprising structurally-related species assemblages. When these clusters were plotted onto the survey sampling site plan, distinctive zones of similar nematode communities were identified (see Section 3.2.2). In general, changes in the nematode community structures were orientated along an east-west, with Clusters A, B and C being located to the west of the survey area and Clusters D, E and F being located to the east.

The structural variation in the nematode communities correlated with the distribution of the measured physico-chemical parameters that were identified by the ARESC analytical techniques. The ARESC diagram (Figure E1) indicated a positive correlation between a suite of sediment metals, the finer silt fraction (< 63 μm) and the nematode communities within cluster A and a negative correlation with cluster F.

The statistical significance of the correlations between the nematode community structures and the physico-chemical parameters were calculated and are presented in Table E1. Of these correlations, the most statistically significant related to a suite of sediment metal concentrations. Statistically significant correlations between the fine silt (< 63 μm) fractions and the nematode community structures were also identified.

Given that the nematode communities present in Cluster A exhibited the highest diversity values recorded during the survey (and, hence, can be considered to the least "stressed"), it is likely that the main driver influencing the nematode community structures was sediment particle size characteristics rather than sediment metal concentrations. The majority of the measured sediment metals will adsorb readily to the charges present on the alumino-silicates of the fine silt fractions and will, therefore, be present at higher concentrations wherever fine silts occur. It is likely, in this case, that the significant correlation between the sediment metals and the nematode community structures is coincidental (due the metals' associations with the fine sediments) rather than causal. This is supported by the highest correlation values identified by the analyses for sediment aluminium.

© NMP 2014

4.2 SUITABILITY OF MEIOFAUNAL ANALYSES FOR MONITORING PURPOSES

The verification survey reported here provides firm evidence that the benthic meiofaunal communities present in the vicinity of the proposed pelletal phosphorite mining site are appropriate bioindicators for monitoring and assessment of any operational impacts that might arise. The diversity and abundance of the principal meiofaunal groups, namely the Nematoda and harpacticoid Copepoda, will provide scientifically robust data enabling statistically valid ecological assessments. These will enable pre-mining baseline conditions to be established and described, the extent of the effects of the mining activities to be determined and, as operations move to new sites, the monitoring and documentation of the subsequent recovery of the formerly disturbed benthic habitats.

© NMP 2014

5 REFERENCES

This report to be cited as:
Physalia (2013). Meiofaunal Analyses of Namibian Offshore Sediments forming part of Verification Surveys for proposed Benthic Mining Operations. Baseline Surveys, July - August 2013. A factual, baseline survey report prepared for Lwandle Technologies (Pty) Ltd, Cape Town, by Physalia Ltd, Consultant & Forensic Ecologists, Harpenden, UK.

Baker, A.D. (1953). Rapid method for mounting nematodes in glycerine. *Canadian Entomology*, **85:** 77-78.

Benjamini, Y. and Hochberg, Y. (1995). Controlling the False Discovery Rate: A Practical and Powerful Approach to Multiple Testing. *Journal of the Royal Statistical Society*, **57**(1): 289-300

Benjamini, Y. and Yekutieli, D. (2001). The control of the false discovery rate in multiple testing under dependency. *Annals of Statistics*, **29**(4): 1165 – 1188.

Bouisseau, J.-P. (1957). Techniques pour l'étude quantitative de la faune interstitielle des sables. *Comptès Rendus du Congres des Sociétés Savantes des Paris et des Départements,* 1957, 117-119.

Bührer, E.M. (1949). Technique for beheading and *en face* examination of nematodes and similar animal types. *Proceedings of the Helminthological Society of Washington,* **16:** 3-6.

Cairns, E.J. and Tarjan, A.C. (1955). Methylcellulose for the rapid preparation of temporary nematode head mounts. *Proceedings of the Helminthological Society of Washington,* **22:** 32.

Cobb, N.A. (1917). Notes on nemas. *Contr. Sci. Nematol.*, **5**: 117-128.

Dufrêne, M. and Legendre, P. (1997). Species assemblages and indicator species; the need for a flexible asymmetric approach. *Ecological Monographs*, **67:** 345-366.

Erk, M., Ruus, A., Ingerbrigtsen, K. and Hylland, K. (2005). Cadmium accumulation and Cd-binding proteins in marine invertebrates; A radiotracer study. *Chemosphere,* **61:** 1651-1664.

Fattorini, D., Notti, A., Nigro, M. and Regoli, F. (2010). Hyperaccumulation of vanadium in the Antarctic polychaete *Perkinsiana littoralis* as a natural chemical defence against predation. *Environmental Science and Pollution Research*, **17(1):** 220-228.

Fattorini, D. and Regoli, F. (2012). Hyperaccumulation of vanadium in Polychaetes. In *Vanadium - Biochemical and Molecular Biological Approaches.* Pages 73-92. Springer, Netherlands.

Forster, S.J. (1998a). *Aspects of the Ecology of Free-living Nematodes in a Temperate Intertidal Mudflat.* Ph.D. Thesis, University of London.

Flegg, J.J.M. and Hooper, D.J. (1970). Extraction of free-living stages from soil. In *Laboratory Methods for Work with Plant and Soil Nematodes.* Ed. Southey, J.F. Ministry of Agriculture, Fisheries and Food, Technical Bulletin No. 2, H.M.S.O.: London. 148 pp.

© NMP 2014

Gerdol, V. and Hughes, R. G. (1994). Effects of *Corphium volutator* on the abundance of benthic diatoms, bacteria and sediment stability in two estuaries in south eastern England. *Marine Ecology Progress Series,* **114:** 109 - 115.

Humason, G.L. (1979). *Animal Tissue Techniques*. 4th. Edition. Freeman and Co., San Francisco.

Kruskal, J.B. (1964a). Multidimensional scaling by optimising goodness of fit to a non-metric hypothesis. *Psychometrika,* **29:** 1-27

Kruskal, J.B. (1964b). Non-metric multidimensional scaling; a numerical method. *Psychometrika,* **29:** 115-129

Lance, G.N. and Williams, W.T. (1967). A general theory of classification sorting strategies. I. Hierarchical systems. *Computer Journal,* **9:** 373-380

Lance, G.N. and Williams, W.T. (1968). A general theory of classification sorting strategies. II. Clustering systems. *Computer Journal,* **10:** 271-277

Lang, K. (1948). *Monographie der Harpacticoiden.* Naturhistorisches Reichsmuseum, Stockholm, pp. 1683.

Manly, B.F.J. (1997). *Randomisation, Bootstrap and Monte Carlo Methods in Biology.* Second edition. Texts in Statistical Science. Chapman and Hall, London. 399 pp.

Moens, T., and Vincx M. (1997). Observations on the feeding ecology of estuarine nematodes. *Journal of the Marine Biological Association of the United Kingdom*, **77**, 211-227.

Peet, R.K. (1974). The measurement of species diversity. *Annual Review of Ecological Systems,* **5:** 285-307.

Sokal, R.R. and Rohlf, F.J. (1995). *Biometry*. Third edition. Freeman and Co. Ltd. New York. 889 pp.

Trett, M.W., Calvo Urbano, B., Forster, S.J., Hutchinson, J.D., Feil, R.L., Trett., S.P. and Best, J.G. (2000). Terrestrial Meiofauna and Contaminated Land Assessment. *Environmental Science and Technology*, **34:** 1594 -1602.

Trett, M.W., Calvo Urbano, B., Forster, S.J. and Trett, S.P. (2009). Commercial Aspects of the Use of Nematodes as Bioindicators. Chapter 12 in *Nematodes as Environmental Indicators* eds. M.J. Wilson and T. Kakouli-Duarte, CAB International, Cambridge, pp. 275 - 326.

Seinhorst, J.W. (1959). A rapid method for the transfer of nematodes from fixative to anhydrous glycerin. *Nematologica*: **4**: 67-69.

© NMP 2014

Annexure A: Taxonomic Lists of Invertebrate Species and their Identification Codes

Table A1: Table presenting the full taxonomic list of meiofaunal Nematoda recorded by taxonomist team at Physalia in the July 2013 verification survey area sediments. The numbers shown beside each species are the unique identifier codes (UICs) ascribed by Physalia to Nematode taxa present in each survey region worldwide. These relate to specimens in the faunal reference collections and/or description maintained at Physalia. The UICs are essential for the multivariate (mathematical) analyses of the communities and appear in the site-by-site results tables (see Table B1; Annexure B).

Class Adenophorea; Sub-class Enoplia
Order Enoplida; Sub-order Enoplina

Family Thoracostomopsidae
- 130 *Epacanthion* species
- 118 *Paramesacanthion* species (? P. marei)

Sub-order Trefusiina

Family Trefusiidae
- 102 *Halanonchus* species
- 95 Trefusiid species (? *Rhabdocoma*)

Sub-order Oncholaimina

Family Enchelidiidae
- 1 *Bathyeurystomina* species

Family Oncholaimidae
- 105 *Oncholaimus* species
- 3 *Viscosia* species (? *V. elegans*)
- 31 *Viscosia* species
- 99 *Viscosia* species

Sub-order Ironina

Family Oxystominidae
- 12 *Halalaimus* species 1 (? *H. isaitshikovi*)
- 26 *Halalaimus* species 2 (? *H. capitulatus*)
- 43 *Halalaimus* species 3
- 45 *Halalaimus* species 4
- 94 *Halalaimus* species 5
- 25 *Nemanema* species 1
- 112 *Nemanema* species 2
- 6 *Oxystomina* species 1 (?*H. asetosa*)
- 70 *Oxystomina* species 2 (? H. *elongata)*
- 90 *Thalassoalaimus* species 1
- 131 *Oxystominidae* species (? *Nemanema*)

© NMP 2014

Class Chromadorea;
Sub-class Chromadoria
Order Chromadorida;
Sub-order Chromadorina

Family Chromadoridae
66 *Acantholaimus* species
14 *Actinonema* species 1
104 *Actinonema* species 2
29 *Innocuonema* species 1
98 *Innocuonema* species 2
16 *Prochromadorella* species (? *P. septempapillata*)
72 *Spiliphera* species

Family Cyatholaimidae
9 *Pomponema* species 1
20 *Pomponema* species 2
57 *Pomponema* species 3
71 *Pomponema* species 4
129 *Pomponema* species 5
36 Cyatholaimidae species 1

Family Ethmolaimidae
47 *Comesa* species (? *C. warwicki*)
63 *Filitonchus* species (? *F. ewensis*)

Family Selachinematidae
60 *Cheironchus* species
2 *Gammarus* species 1 (? *G. conicauda*)
38 *Gammarus* species 2
113 *Synonchiella* species
122 Selachinomatidae species

Order Desmodorida;

Sub-order Desmodorina

Family Desmodoridae
121 *Catanema* species
32 *Chromaspirina* species (? *C. multipapillata*)
19 *Desmodora* species 1
64 *Desmodora* species 2
103 *Sigmophoranema* species
11 *Spirinia* species 1 (? S. parasitifera)
27 *Spirinia* species 2 (? S. laevis)
21 Desmodoridae species 1
23 Desmodoridae species 2
128 Desmodoridae species 3 (? *Chromaspirina*)

Family Microlaimidae
22 *Aponema* species 1

© NMP 2014

56 *Aponema* species 2
15 *Calomicrolaimus* species
35 *Microlaimus* species 1
73 *Microlaimus* species 2
80 *Microlaimus* species 3
92 *Microlaimus* species 4
132 *Microlaimus* species 5

Family Paramicrolaimidae
59 *Paramicrolaimus* species 1
84 *Paramicrolaimus* species 2

Order Desmoscolecida

Family Desmoscolecidae
34 *Quadricoma* species
96 *Tricoma* species

Order Monhysterida;
Sub-order Monhysterina

Family Monhysteridae
17 *Monhystera* species 1 (? *M. vulgaris*)
37 *Monhystera* species 2
52 *Monhystera* species 3
119 *Monhystera* species 4
74 Monhysterid species

Family Xyalidae
135 *Cobbia* species
7 *Daptonema* species 1
13 *Daptonema* species 2
30 *Daptonema* species 3 (? *D. psammoides*)
61 *Daptonema* species 4
85 *Daptonema* species 5
88 *Daptonema* species 6 (? *D. hirsutum*)
106 *Metadesmolaimus* species
33 *Theristus* species (? *T. ensifer*)
81 Xyalid species
115 Xyalid species

Sub-order Linhomoeina

Family Linhomoeidae
127 *Linhomoeus* species 2
44 *Metalinhomoeus* species 1
48 *Metalinhomoeus* species 2
49 *Metalinhomoeus* species 3
69 *Metalinhomoeus* species 4
93 *Metalinhomoeus* species 5
125 *Metalinhomoeus* species 6
10 *Paralinhomoeus* species 1
42 *Paralinhomoeus* species 2

© NMP 2014

54 *Paralinhomoeus* species 3
55 *Paralinhomoeus* species 4
101 *Terschellingia* species 1
28 Linhomoeidae species 1
51 Linhomoeidae species 2
39 Linhomoeidae species 3
77 Linhomoeidae species 4
107 Linhomoeidae species 5
117 Linhomoeidae species 6
120 Linhomoeidae species 7
123 Linhomoeidae species 8

Family Siphonolaimidae
89 *Siphonolaimus* species

Order Araeolaimida

Family Axonolaimidae
53 *Odontophora* species 1
78 *Odontophora* species 2
75 *Parodontophora* species

Family Comesomatidae
4 *Paracomesoma* species 1
50 *Paracomesoma* species 2
40 *Sabatieria* species (? *S. punctata*)

Family Diplopeltidae
100 *Campylaimus* species
82 Diplopeltidae species 1 (? *Morlaixia*)
83 Diplopeltidae species 2

Order Plectida

Family Aegialoalaimidae
97 *Aegialoalaimus* (? *A. elegans*)
5 *Cyartonema* species 1 (? *C. elegans*)
76 *Cyartonema* species 2
109 Diplopeltoides species
8 *Southernia* species
110 *Southernia* species (? S. zosterae)
67 Aegialoalaimidae species (? *Cyartonema*)
116 Aegialoalaimidae species
124 Aegialoalaimidae species

Family Ceramonematidae
18 *Ceramonema* species 1
114 *Ceramonema* species 2
79 *Dasynemoides* species 1
91 *Dasynemoides* species 2
133 *Pselionema* species 1
68 *Pselionema* species 2

© NMP 2014

111 *Pselionema* species 3
126 *Pselionema* species 4

Family Leptolaimidae
58 *Deontolaimus* species
62 *Leptolaimus* species 1 (? *L. elegans*)
46 *Leptolaimus* species 2
24 *Leptolaimidae* species

Class Indet.; Sub-class Indet.
Order Indet.

Family Indet.
86 NAM.13.A (? *Cyatholaimidae*)
87 NAM.13.B
108 NAM.13.C

© NMP 2014

Table A2: Table presenting the full taxonomic list of meiofaunal harpacticoid Copepoda (Biramia) recorded by taxonomist team at Physalia in the July 2013 verification survey area sediments. The numbers shown beside each species are the unique identifier codes (UICs) ascribed by Physalia to harpacticoid copepod taxa present in each survey region worldwide. These relate to specimens in the faunal reference collections and/or description maintained at Physalia. The UICs are essential for the multivariate (mathematical) analyses of the communities and appear in the site-by-site results tables (see Table B2; Annexure B).

Phylum Biramia ("*Crustacea*")

Class Maxillopoda; Sub-class Copepoda

Order Harpacticoida; Sub-order Oligoarthra

Family Ameiridae

5	Ameirid sp. 1
14	Ameirid sp. 2 (?*Nitocra*)
20	Ameirid sp. 3
33	Ameirid sp. 4
34	Ameirid sp. 5

Family Cletodidae

1	*Enhydrosoma* species 1
2	Cletodid sp. 1
22	Cletodid sp. 2
23	Cletodid sp. 3
28	Cletodid sp. 4

Family Diosaccidae

31	Diosaccid sp. 2 (?*Stenhelia*)
35	*Stenhelia* sp. 3
3	*Typhlamphiascus* sp. 1
7	Diosaccid sp. (?*Bulbamphiascus*)
4	Diosaccid sp. 1 (?*Amphiascella*)
29	Diosaccid sp. 1 (?*Amphiascus*)
30	Diosaccid sp. 1 (?*Stenhelia*)
8	Diosaccid sp. 1
12	Diosaccid sp. 2 (?*Typhlamphiascus*)
10	Diosaccid sp. 2
15	Diosaccid sp. 3
24	Diosaccid sp. 4

Family Ectinosomatidae

13	*Ectinosoma* (*Ectin*.) sp. 1 (?*Ectinosoma*)
27	Ectinosomatidae sp.

Family Harpacticidae

36	Harpacticid sp. (?*Harpacticus*)
6	Harpacticid sp. 1

Family Laophontidae

9	Laophontid sp. 1
11	Laophontid sp. 2

© NMP 2014

17	Laophontid sp. 3

Family Thalestridae

21	Thalestrid sp. 1 (?*Thalestris*)
26	Thalestrid sp. 3 (?*Idomene*)

Family Unknown

19	NAM.7.13A
25	NAM.7.13B
32	NAM.7.13C (?Thalestridae)
16	NAM.7.13D (Miraciidae sp.)
37	NAM.7.13E (Miraciidae sp. 2)

© NMP 2014

Annexure B: Meiobenthic Community Data Tables

Table B1: Site-by-site results table for the communities of meiofaunal Nematoda present in the July 2013 verification survey area sediment samples. Species codes (in brackets) are followed by the numbers of animals belonging to that species recorded per litre sediment. The key to the species codes used is presented in Table A1 (Annexure A).

Site	Species Identification Code and Numbers per Litre Sediment	Species Richness	Densities	Feeding Type Ratios
VS 1	(1)135; (2)271; (3)406; (4)271; (5)813; (12)677; (14)542; (15)135; (16)135; (22)406; (27)1625; (28)135; (34)542; (35)542; (37)677; (40)813; (42)135; (43)135; (47)135; (52)135; (56)135; (57)406; (60)135; (62)1083; (66)135; (70)135; (72)406; (80)271; (95)135; (96)135; (97)406; (98)135; (99)271; (100)135; (101)135; (102)135; (103)271; (104)135; (105)135; (106)135; (107)135; (121)135	42	13804	0.37
VS 2	(1)123; (2)123; (3)123; (4)246; (5)676; (12)123; (13)123; (14)184; (18)123; (19)184; (22)492; (27)184; (32)61; (34)123; (35)246; (36)61; (37)184; (47)184; (50)123; (57)184; (60)61; (61)123; (62)369; (66)184; (69)61; (70)123; (79)123; (80)123; (91)61; (92)61; (97)61; (107)61; (108)246; (109)123; (110)61; (111)61; (112)61; (113)61; (114)123; (115)61; (133)61	41	6139	0.18
VS 3	(4)1583; (5)905; (11)226; (12)226; (18)226; (19)302; (20)226; (22)377; (25)151; (26)75; (27)151; (30)75; (32)75; (33)75; (35)151; (37)226; (46)75; (48)75; (50)528; (57)151; (62)302; (66)151; (70)151; (72)75; (75)75; (76)75; (83)151; (87)75; (108)226; (109)75; (116)151; (117)75; (118)75	33	7536	0.08
VS 4	(1)300; (2)600; (3)450; (4)2551; (5)1501; (6)300; (7)300; (8)150; (9)300; (10)600; (11)600; (12)600; (13)1201; (14)300; (15)600; (16)600; (17)150; (18)300; (19)450; (20)1201; (21)300; (22)1351; (23)150; (24)150; (25)750; (26)300; (27)150; (28)300; (29)150; (30)150; (31)150; (32)150; (33)150; (34)150	34	17405	0.34
VS 5	(4)3061; (5)106; (11)1161; (13)739; (14)106; (19)211; (20)1583; (25)633; (32)317; (33)1478; (45)106; (56)739; (62)106; (66)211	14	10557	0.36
VS 6	(2)239; (4)1317; (5)1556; (9)479; (11)120; (15)120; (19)359; (20)479; (24)120; (27)1077; (28)120; (32)120; (34)120; (35)239; (36)1077; (37)838; (38)120; (39)120; (40)1436; (42)479; (43)359; (44)120; (45)120; (46)120; (47)120; (48)120; (49)120; (50)120; (66)239	29	11973	0.54
VS 7	(2)47; (3)47; (4)608; (5)842; (9)234; (15)47; (16)47; (18)47; (20)187; (22)140; (25)47; (27)47; (29)47; (32)47; (35)47; (36)94; (37)187; (39)47; (40)94; (42)140; (47)94; (50)94; (51)47; (52)234; (53)94; (54)187; (55)94; (56)47; (57)94; (58)94; (59)47; (60)47; (61)94; (62)47; (63)47; (64)47; (66)47; (67)140; (68)47; (75)94	40	4779	0.35
VS 8	(4)4561; (5)1320; (11)240; (12)120; (19)120; (20)240; (22)1680; (25)120; (27)240; (30)120; (33)240; (34)120; (37)360; (42)120; (50)600; (56)240; (57)360; (61)120; (62)600; (69)240; (70)120; (71)120; (72)120	23	12121	0.10

© NMP 2014

Site	Species Identification Code and Numbers per Litre Sediment	Species Richness	Densities	Feeding Type Ratios
VS 9	(2)161; (3)161; (4)5647; (5)1613; (10)484; (11)645; (13)161; (15)161; (18)161; (19)161; (20)807; (22)645; (23)161; (25)484; (27)323; (28)161; (30)161; (33)323; (35)161; (37)807; (42)161; (47)323; (50)323; (55)161; (57)645; (62)161; (66)161; (69)161; (71)161; (73)161; (74)161; (75)161; (76)161	33	16289	0.19
VS 10	(2)485; (4)9216; (5)1455; (10)485; (11)2183; (12)243; (15)243; (16)243; (18)243; (20)1455; (25)728; (30)728; (33)970; (40)243; (42)243; (43)243; (50)243; (56)1455; (57)243; (70)485; (72)1698; (75)243; (77)243; (78)243	24	24259	0.20
VS 11	(3)112; (4)1791; (5)896; (12)560; (19)224; (22)672; (25)336; (27)1232; (29)112; (30)112; (34)112; (35)448; (37)224; (40)1120; (43)112; (47)336; (60)112; (61)672; (62)672; (63)112; (76)224; (80)112; (85)112; (87)112; (96)112; (97)672; (99)112; (113)112; (116)112; (118)112; (121)112; (135)224	32	12095	0.57
VS 12	(3)78; (4)1947; (5)857; (6)78; (11)78; (12)78; (14)156; (18)78; (19)78; (20)78; (22)545; (25)234; (26)156; (27)234; (30)78; (34)78; (37)156; (47)467; (57)78; (61)234; (62)389; (63)234; (69)234; (70)156; (75)78; (80)78; (81)78; (82)156; (87)78; (97)78; (107)78; (119)78; (120)78; (121)78; (122)234	35	7871	0.21
VS 13	(2)86; (4)242; (5)225; (12)17; (16)17; (20)35; (22)52; (25)35; (27)17; (34)17; (35)17; (37)86; (50)35; (56)35; (61)52; (62)35; (70)35; (75)17; (81)104; (83)69; (87)69; (89)17; (98)35; (101)17; (120)17; (121)17; (123)52; (124)121; (125)156; (135)17	30	1746	0.85
VS 14	(1)91; (4)3282; (5)1003; (10)182; (11)274; (13)91; (18)91; (20)91; (22)638; (25)274; (27)182; (30)91; (32)91; (33)182; (35)91; (42)274; (50)274; (57)91; (62)547; (66)91; (70)274; (72)365; (76)91; (79)91; (80)182; (81)91; (82)182; (83)91	28	9298	0.18
VS 15	(1)120; (3)120; (4)3007; (5)962; (6)120; (10)120; (11)962; (12)601; (13)120; (19)120; (20)962; (22)361; (25)241; (27)120; (30)842; (32)241; (33)120; (42)241; (43)481; (46)120; (47)120; (50)361; (56)120; (57)481; (61)241; (62)241; (72)120; (80)120; (92)120; (93)120; (94)120	31	12145	0.29
VS 16	(2)894; (4)2235; (5)1564; (9)224; (11)3352; (12)1341; (13)1118; (16)224; (19)224; (20)3576; (25)447; (33)224; (40)224; (50)447; (53)224; (56)2011; (57)670; (62)447; (66)447; (72)894; (74)670; (79)224; (90)224; (98)447	24	22352	0.14
VS 17	(2)144; (4)144; (5)402; (6)29; (11)29; (12)29; (18)29; (20)57; (22)172; (27)287; (30)29; (32)29; (34)172; (35)287; (37)29; (40)172; (42)57; (47)115; (52)29; (61)29; (62)115; (66)29; (80)29; (81)29; (96)29; (101)29; (108)29; (110)29; (119)29; (121)29; (126)29; (127)29; (128)115; (129)29; (130)29	35	2877	3.20
VS 18	(2)644; (4)176; (5)526; (9)176; (14)58; (19)58; (22)58; (25)58; (27)58; (32)117; (34)58; (37)468; (40)58; (42)176; (45)58; (49)58; (50)58; (55)58; (56)292; (57)58; (61)58; (62)117; (66)117; (71)1638; (72)58; (81)58; (83)58; (121)176; (127)58; (131)234	30	5843	0.18

© NMP 2014

Site	Species Identification Code and Numbers per Litre Sediment	Species Richness	Densities	Feeding Type Ratios
VS 19	(1)58; (2)115; (3)115; (4)2362; (5)518; (12)58; (19)58; (20)58; (22)58; (26)58; (27)173; (30)115; (33)115; (35)58; (37)461; (38)115; (40)115; (42)58; (47)58; (49)58; (50)173; (52)58; (53)58; (56)58; (76)58; (81)115; (83)230; (105)58; (119)58; (120)58; (121)58	31	5766	0.22
VS 20	(2)95; (3)95; (4)4474; (5)571; (12)190; (14)95; (16)95; (18)95; (19)190; (20)190; (22)666; (25)190; (27)571; (30)381; (33)190; (34)190; (35)190; (37)286; (38)95; (44)95; (50)381; (62)190; (70)190; (86)95; (87)95	25	9895	0.10
VS 21	(2)347; (4)2340; (11)1560; (12)347; (13)173; (16)173; (19)173; (20)520; (22)87; (25)87; (33)433; (40)173; (42)173; (50)87; (56)693; (57)260; (62)87; (66)173; (74)780; (87)87	20	8753	0.21
VS 22	(4)1028; (5)571; (11)114; (12)685; (14)343; (18)114; (19)114; (22)343; (25)114; (27)1028; (30)457; (34)914; (35)1942; (40)685; (43)228; (47)571; (50)114; (57)228; (61)114; (62)914; (66)114; (80)114; (90)114; (96)228; (97)228; (98)114; (109)114; (119)114; (132)114	29	11875	0.24
VS 23	(2)873; (4)7855; (5)2327; (12)1745; (13)1455; (14)291; (16)582; (18)291; (19)582; (20)1164; (22)2327; (25)291; (27)873; (33)291; (34)1164; (35)873; (37)291; (38)291; (39)291; (47)873; (61)291; (62)1164; (66)582; (70)291; (80)291; (83)873; (121)291; (124)291	28	28804	0.15
VS 24	(4)1181; (5)246; (10)49; (13)295; (16)49; (19)148; (22)295; (25)148; (27)295; (30)98; (37)98; (38)148; (40)98; (47)49; (50)148; (55)49; (56)98; (57)49; (61)49; (62)246; (68)49; (70)148; (83)98; (90)98; (91)49; (97)49; (107)148; (112)148; (119)98; (120)49; (121)49; (124)49; (128)49	33	4917	0.40
VS 25	(3)335; (4)2906; (5)1006; (7)112; (11)447; (12)335; (13)112; (16)112; (20)224; (22)1341; (25)335; (29)112; (30)112; (37)112; (38)112; (42)335; (46)447; (47)112; (50)559; (57)335; (62)559; (66)112; (69)112; (70)112; (72)112; (76)112; (79)112; (88)112; (89)112; (90)112; (91)112	31	11180	0.18
VS 26	(4)6992; (5)608; (6)304; (11)5776; (12)1216; (20)6384; (25)1520; (26)608; (27)608; (32)304; (33)2128; (50)304; (53)304; (56)912; (57)912; (62)608; (72)304; (75)304; (98)304	19	30400	0.13
July/August 2013 Survey				

Table B2: Site-by-site results table for the harpacticoid Copepoda communities present in the July 2013 verification survey area sediment samples. Species codes (in brackets) are followed by the numbers of animals belonging to that species recorded per litre sediment. The key to the species codes used is given in Table A2 in Annexure A.

Site	Identification Code and Number per Litre	No. Species	Density
VS 1	(6)14; (13)14; (27)14; (28)14; (29)14; (30)14; (31)43	7	127
VS 2	(4)18; (7)18; (10)18; (14)18; (16)18; (28)18; (29)18	7	126
VS 3	(32)4	1	4
VS 4	(1)9; (2)37; (3)37; (4)37; (5)19; (6)28; (7)102; (8)167; (9)93; (10)19; (11)19; (12)83; (13)19; (14)9; (15)9	15	687
VS 5	(3)18; (16)175; (33)18; (34)35	4	246
VS 6	(16)10	1	10
VS 7	(7)5; (13)5; (16)10	3	20
VS 8	(17)12	1	12
VS 9	(3)14; (4)14; (7)14; (8)70; (9)14; (10)28; (11)14; (17)42	8	210
VS 10	(7)19; (16)112; (19)112; (20)56	4	299
VS 11	(4)45; (17)45; (35)89	3	179
VS 12	(1)9; (36)17	2	26
VS 13	(1)38	1	38
VS 14	(7)5; (8)20; (10)10; (21)5; (22)5; (23)5	6	50
VS 15	(3)8; (6)8; (8)40; (17)16; (21)16; (24)8; (25)16	7	112
VS 16	(3)10; (5)10; (16)97	3	117
VS 17	(3)12	1	12
VS 18	(16)42; (37)8	2	50
VS 20	(5)21; (6)21; (8)42; (9)42; (17)21; (25)21; (26)104	7	272
VS 21	(16)147; (19)29	2	176
VS 22	(4)81; (9)40; (25)40; (30)81; (31)81	5	323
VS 23	(16)10	1	10
VS 24	(14)6	1	6
VS 25	(6)19; (8)134; (14)38; (16)19; (21)19; (24)19	6	248
VS 26	(7)4; (16)8	2	12

© NMP 2014

Annexure C: Unvariate Distribution Plots for Key Meiobenthic Community Parameters

© NMP 2014

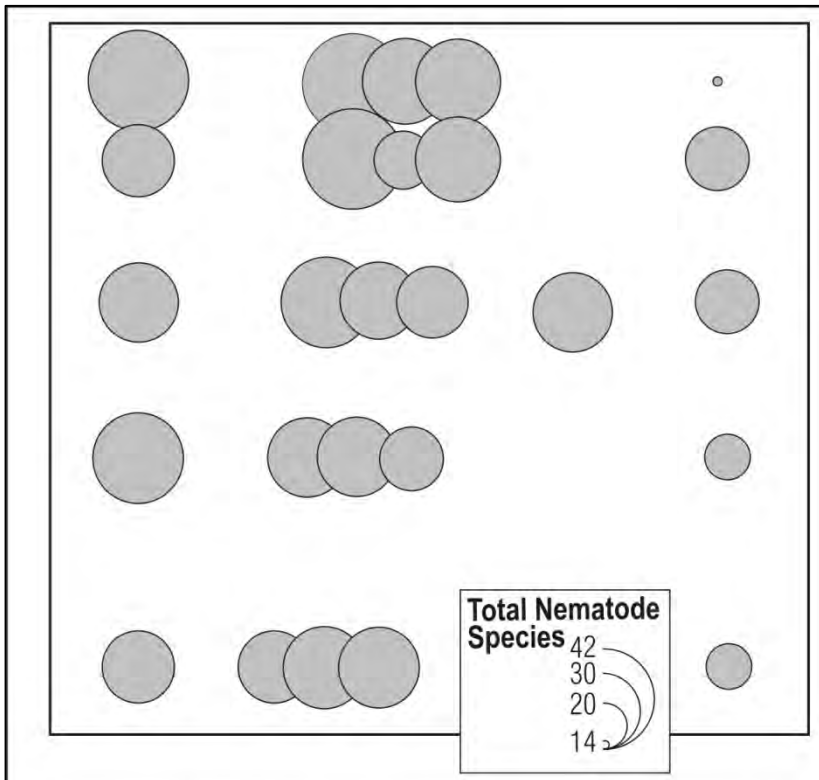


Figure C1: Numbers of meiofaunal nematode species recorded at each of the off shore Namibian verification survey sites during the survey undertaken in July/August 2013.

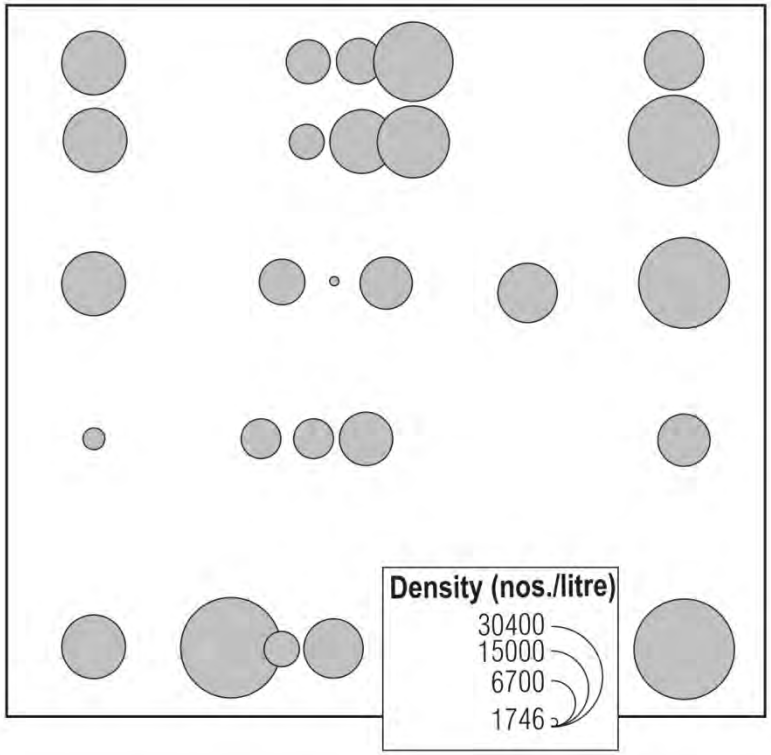


Figure C2: Total densities of meiofaunal nematode species recorded at the offshore Namibian verification survey sites, July/August 2013.

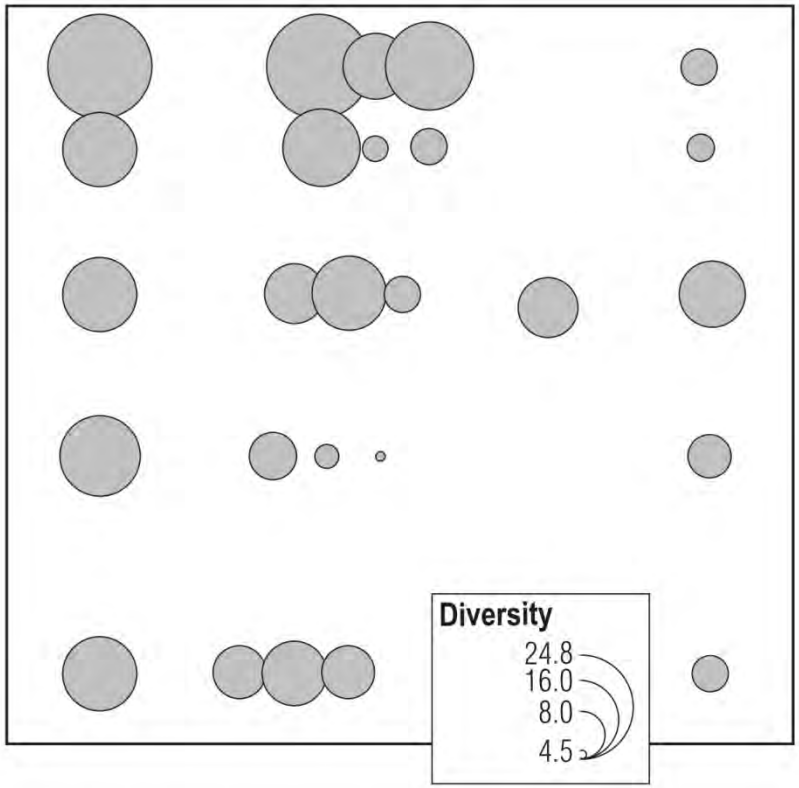


Figure C3: Diversity indices (Simpson's *D*) for the meiofaunal nematode communities recorded at the onshore Namibian verification survey sites, July/August 2013.

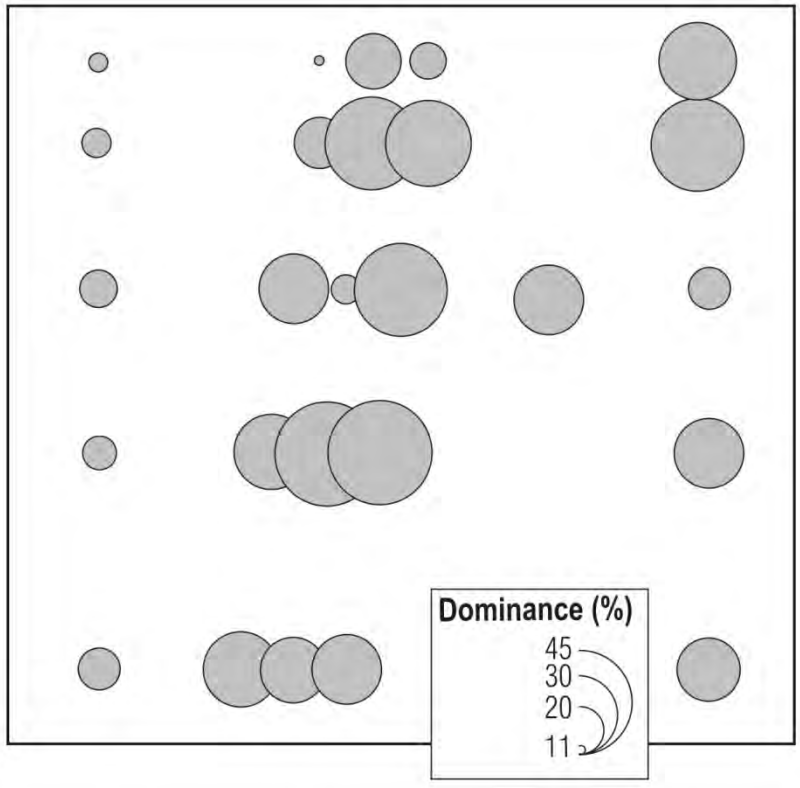


Figure C4: Dominance (% abundance) recorded in the meiofaunal nematode communities present at the onshore Namibian verification survey sites, July/August 2013.

© NMP 2014

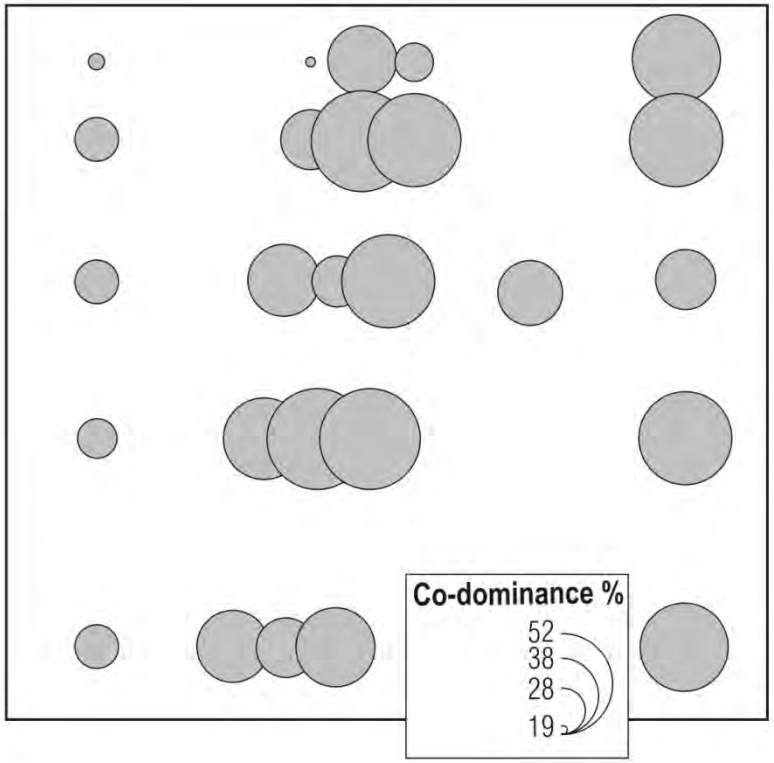


Figure C5: Co-dominance (%) for the meiofaunal nematode communities recorded at the offshore Namibian verification survey sites, July/August 2013.

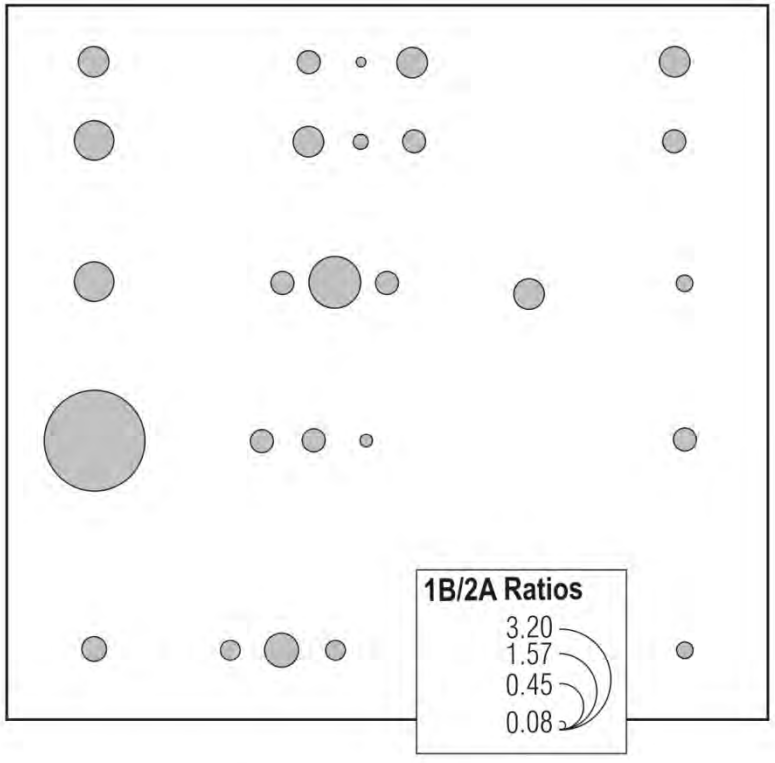


Figure C6: Meiofaunal nematode community 1B/2A feeding type ratios recorded at the offshore Namibian verification sites, July/August 2013.

© NMP 2014

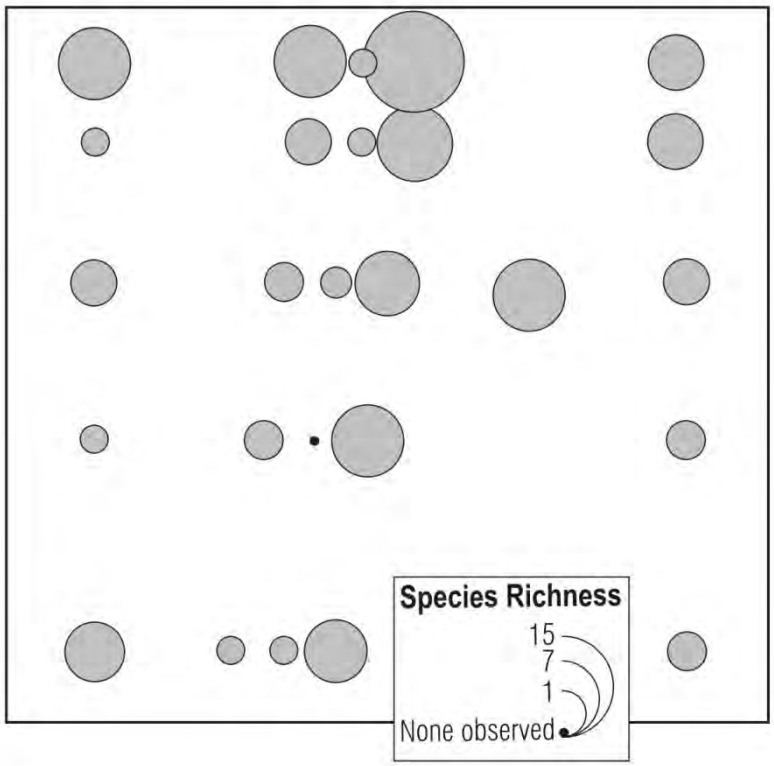


Figure C7: Total number of meiofaunal harpacticoid copepod species recorded in the sediments at the offshore Namibian verification survey sites, July/August 2013.

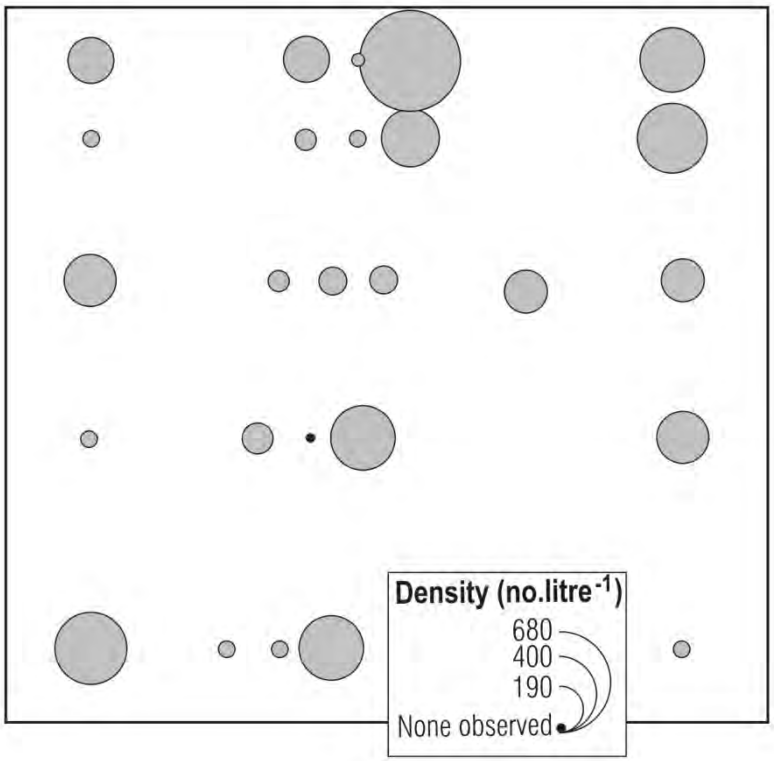


Figure C8: Densities of meiofaunal harpacticoid copepod communities represented in sediments at the offshore Namibian verification survey sites. July/August 2013.

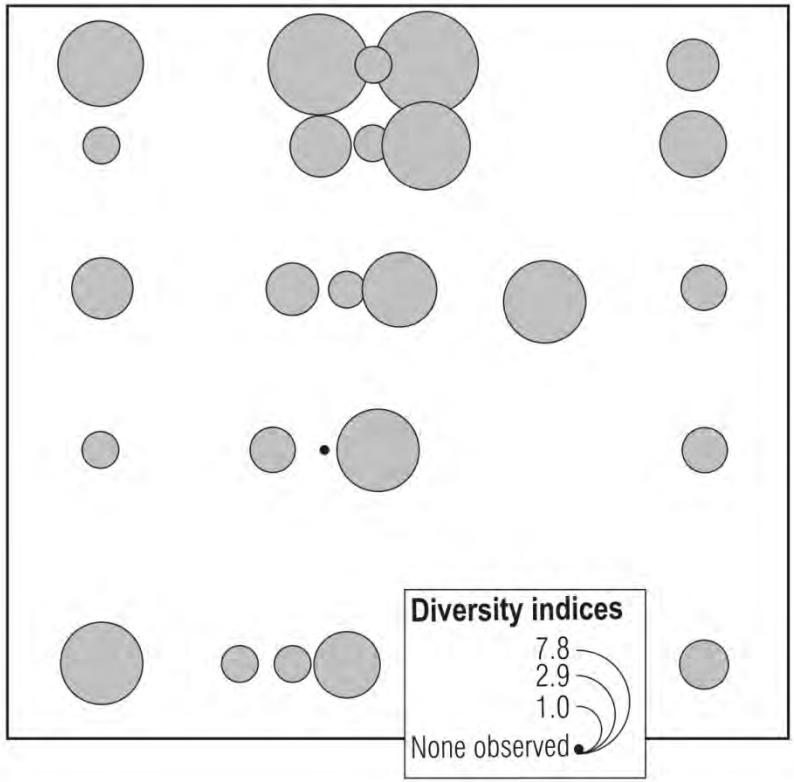


Figure C9: Diversity indices (Simpson's *D*) for meiofaunal harpacticoid copepod communities recorded at the offshore Namibian verification sites, July/August 2013.

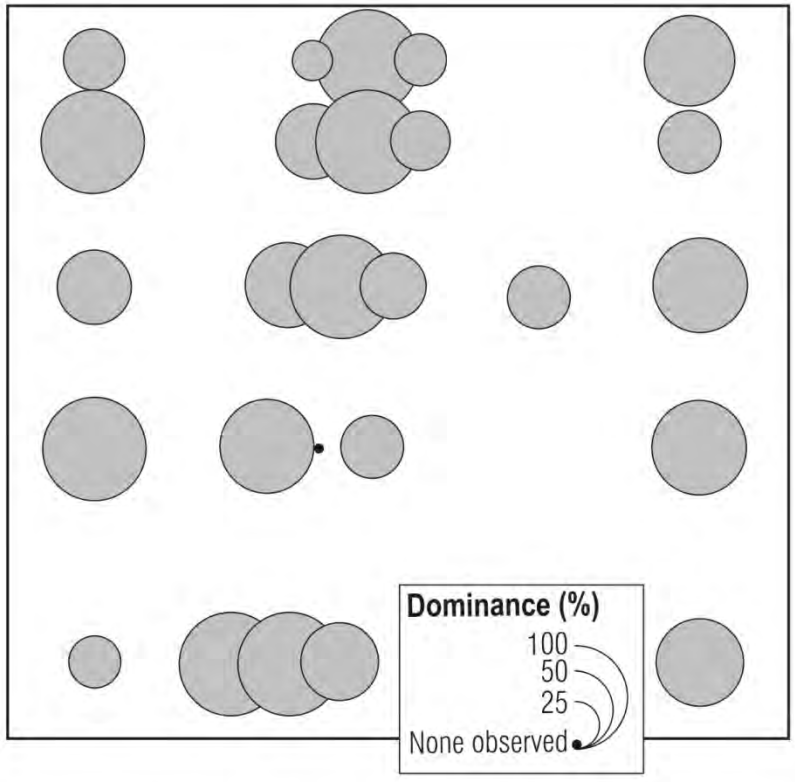


Figure C10: Dominance, the percentage abundance of the most abundant meiofaunal harpacticoid copepod species, recorded at the offshore Namibian verification survey sites, July/August 2013.

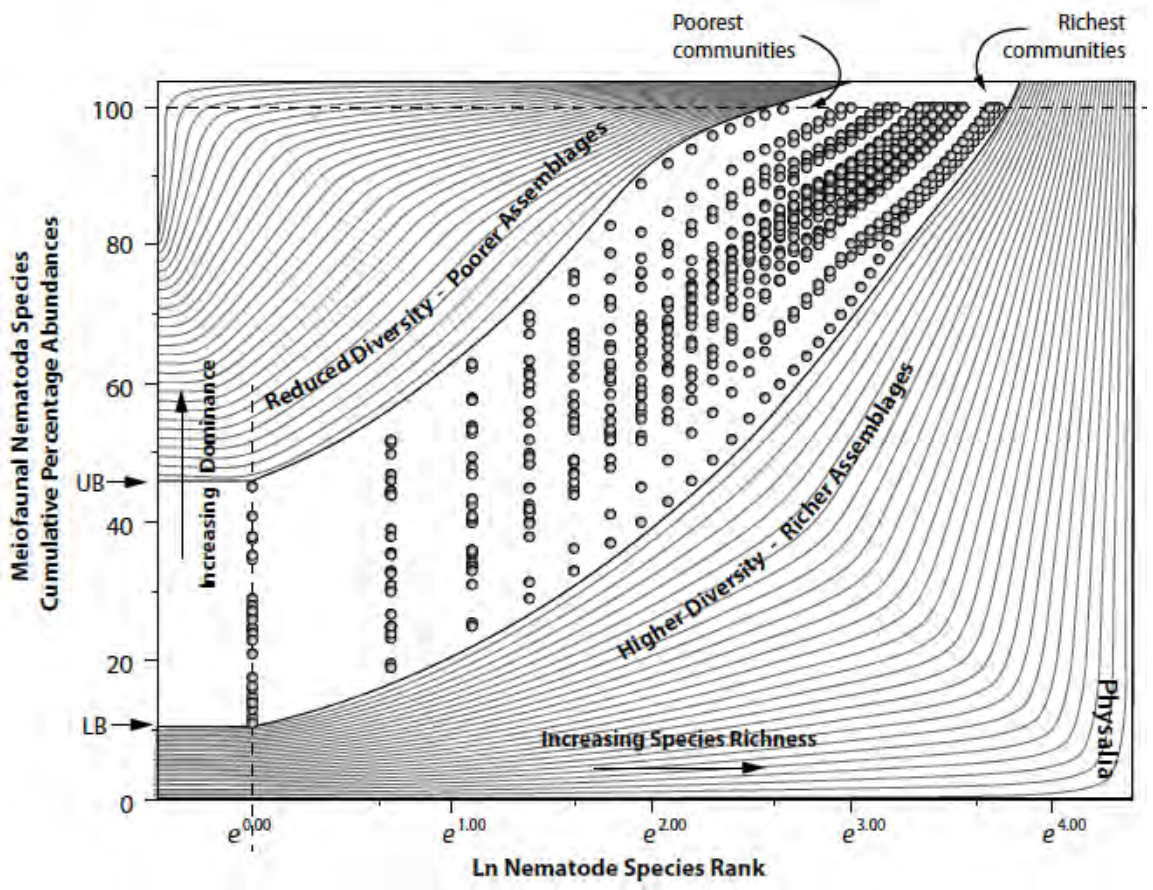


Figure C11: K-dominance plots for the July / August 2013 Namibian meiofaunal nematode communities. These comprise combined dominance: diversity curves for each of the nematode assemblages described by Physalia in the verification survey which forms part of the baseline assessment for proposed dredging operations. UB = upper dominance – diversity boundary (most 'stressed' of modified assemblage); LB = lower dominance – diversity boundary (least 'stressed' / most species rich assemblage).

Annexure D: Multivariate Analyses of the Meiobenthic Nematode Community Structures

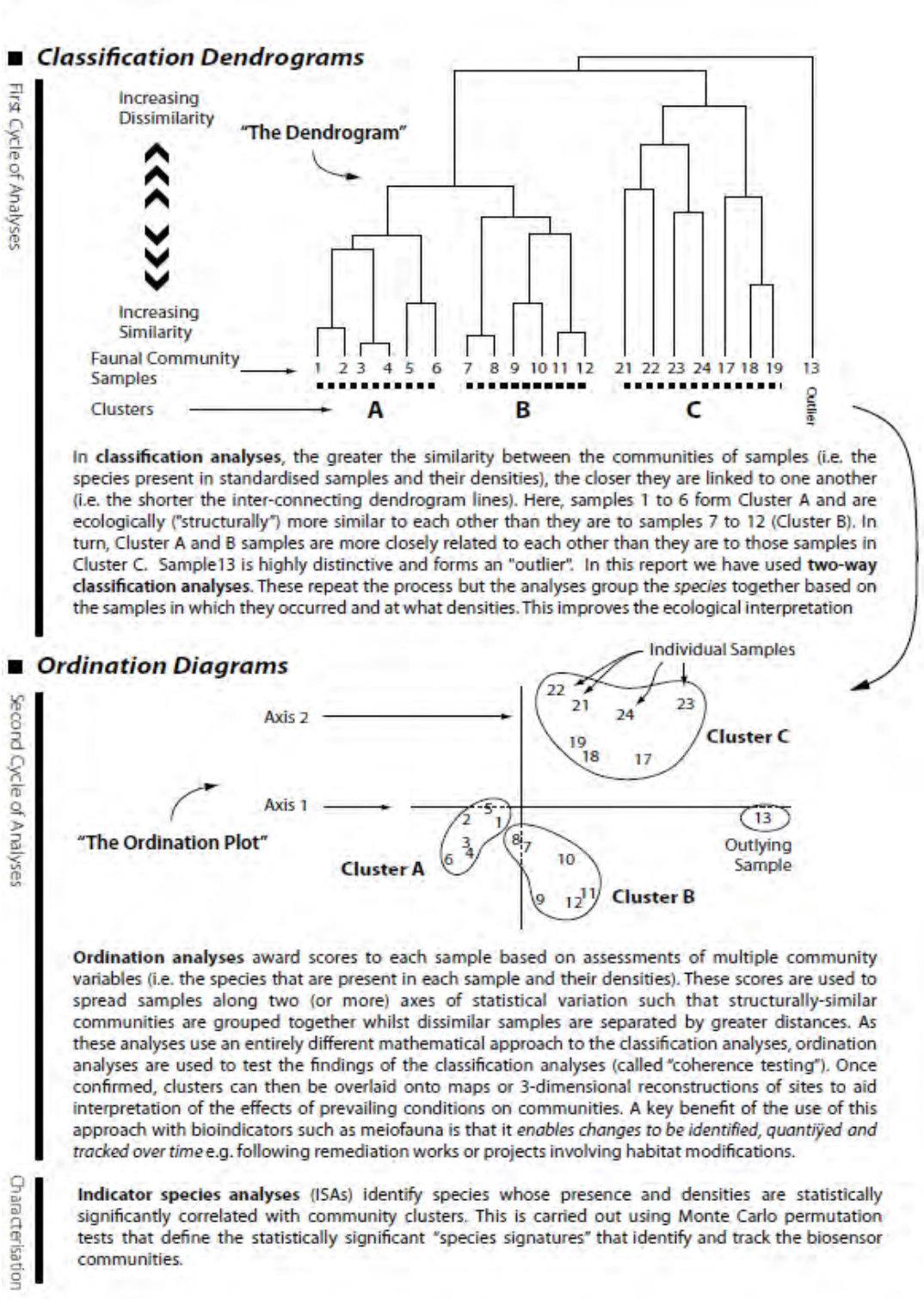


Figure D1: Interpretation of Physalia Multivariate Analyses

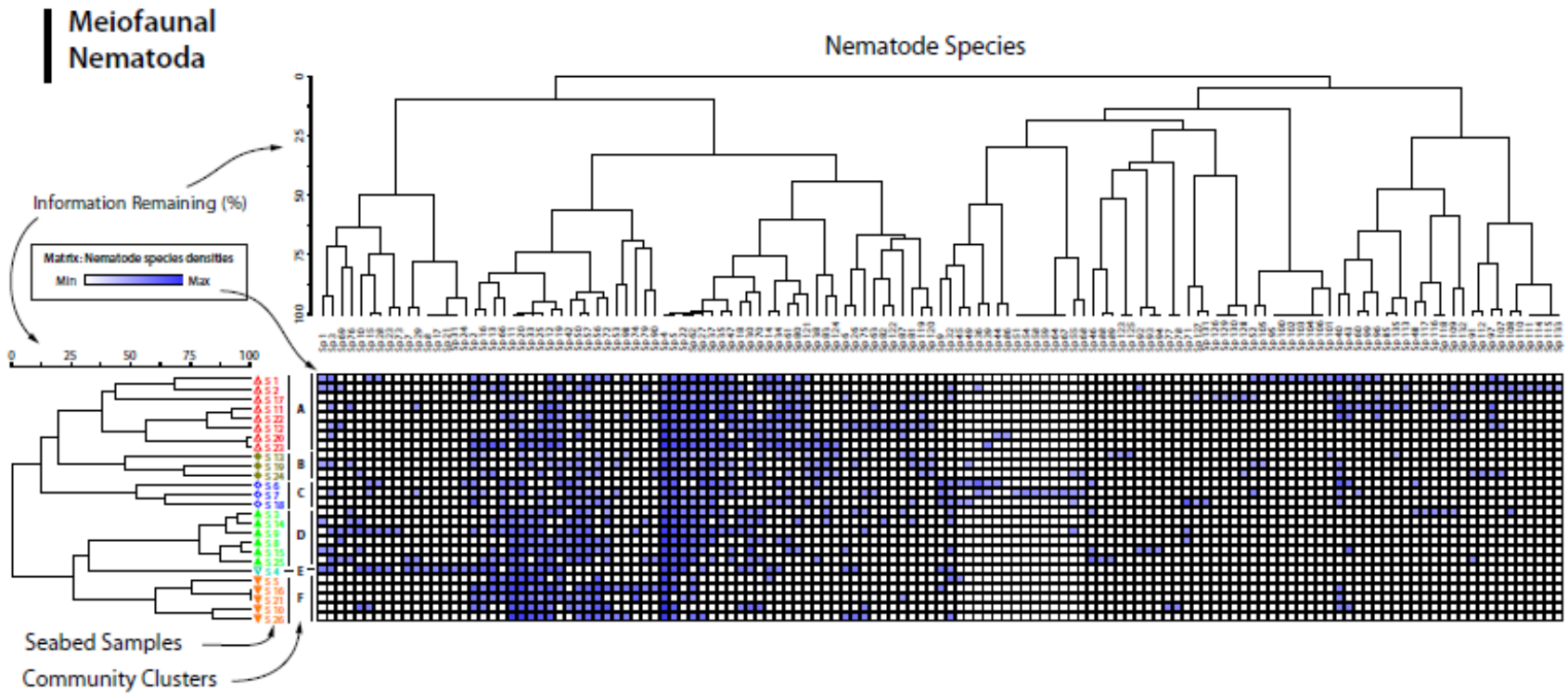


Figure D2: Two-way classification analyses
(Sorensen's distance + flexible β – cluster analyses) identifying structural relationships between the communities of meiofaunal nematode worms (species / individuals > 38µm) that were present in the 2013 verification survey area). See Figure D3 for the parallel NMMDS analyses used to corroborate the relationships described here. See Annexure A for key to nematode species.

© NMP 2014

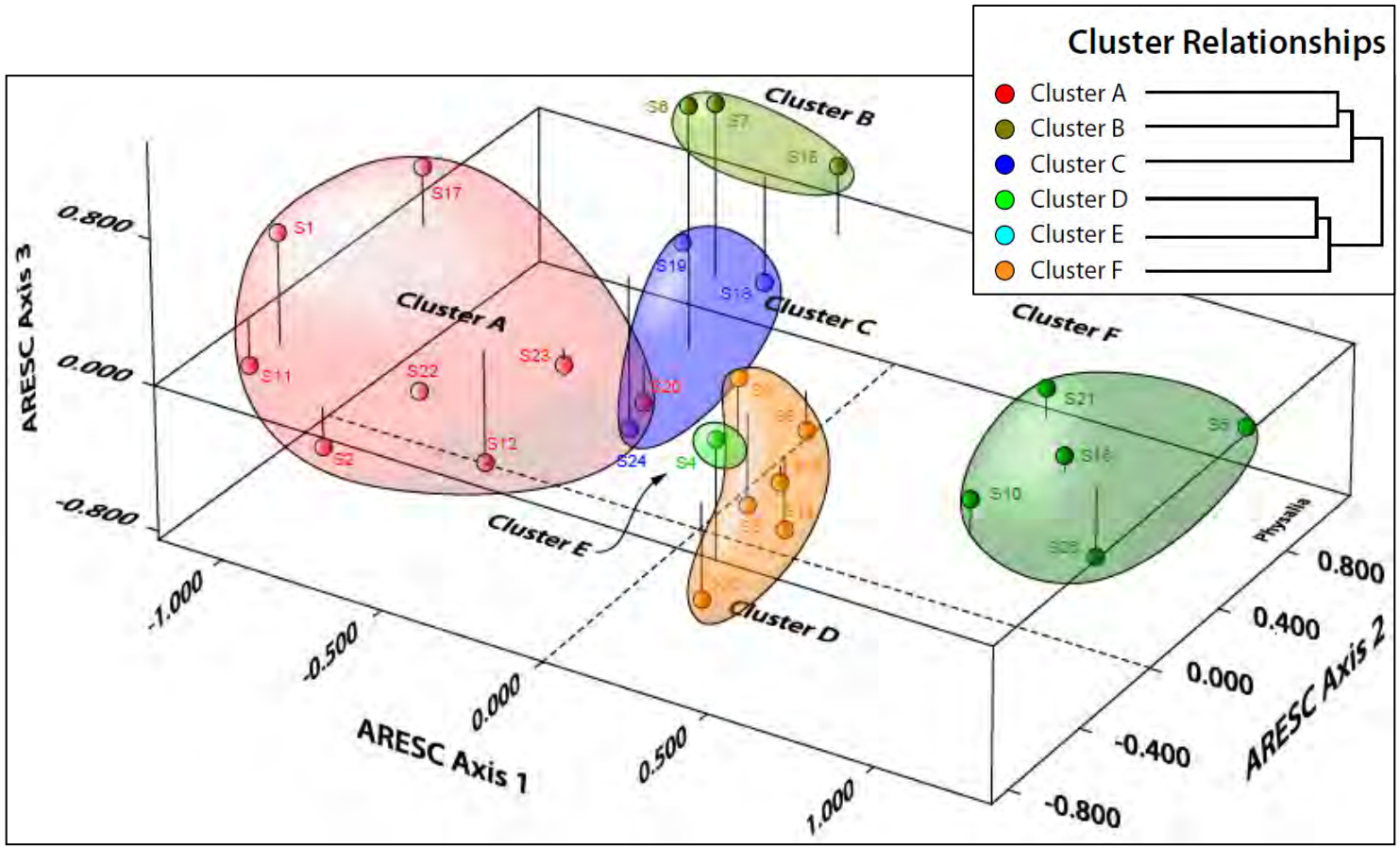


Figure D3: Multivarient ordination analyses
(non-metric multi dimensional scaling) of the 2013 meiofaunal nematode communities (individuals > 38 38µm) present in the Namibian seabed survey area. Three axes shown here accounted for 81.4% of the total variation recorded in the communities

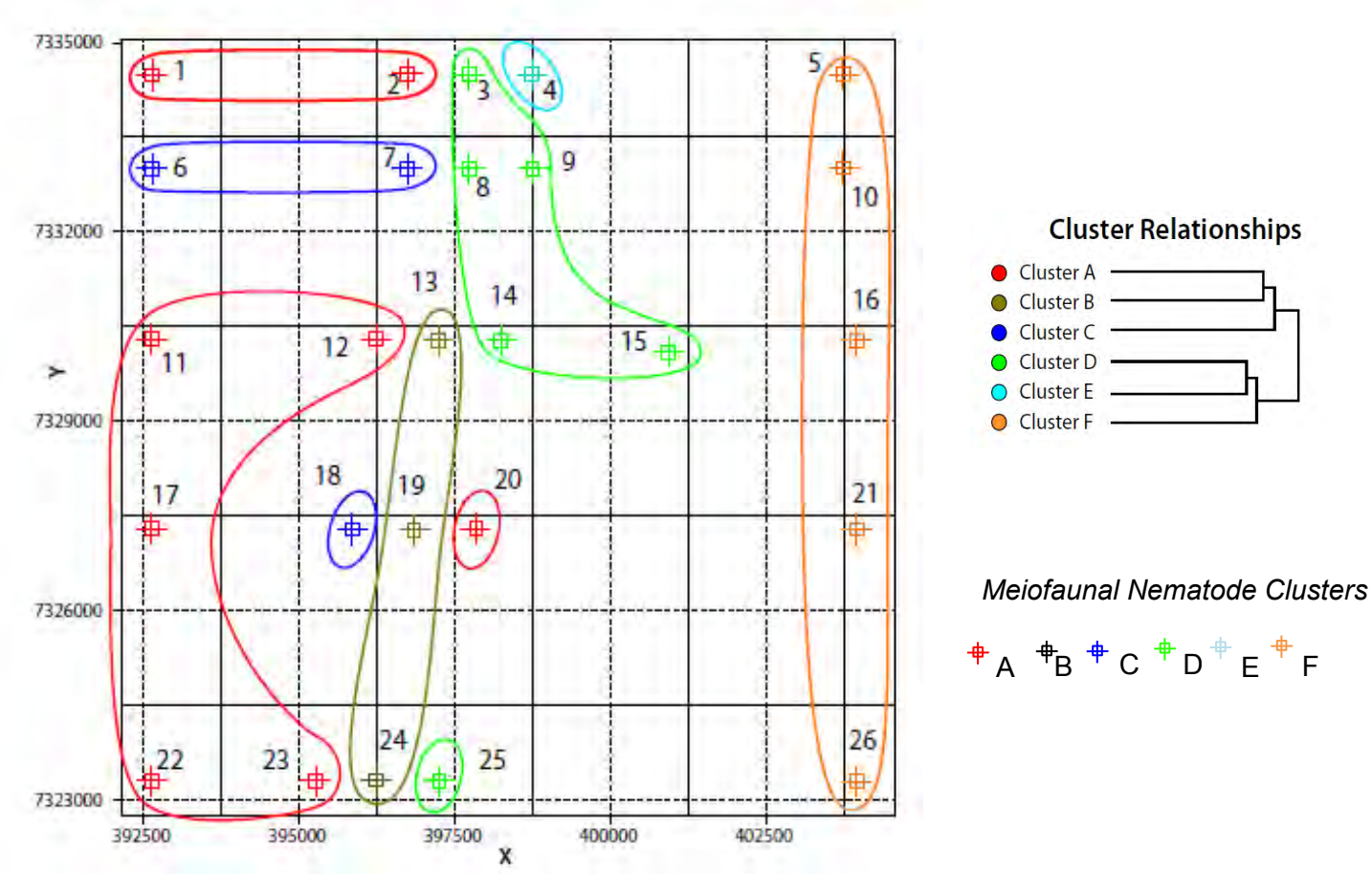


Figure D4: Distributions of structurally – related meiofaunal nematode communities recorded in the sediments offshore of Namibian in the July /August baseline survey

Table D1: List of the indicator species

MVA Cluster	Species Code	Indicator Value	Mean	St. Dev.	*p*-Value*	Indicator Species/Taxon/OTU
A	12	33.3	26.5	4.13	0.0270	*Halalaimus* species 1 cf. *H. isaitshikovi*
	14	48.0	23.4	10.07	0.0468	*Actinonema* species 1
	27	29.5	25.7	2.43	0.0408	*Spirinia* species 2
	34	54.1	25.3	8.38	0.0006	*Quadricoma* species
	62	27.6	24.2	1.31	0.0040	*Leptolaimus* species 1 cf. *L. elegans*
	80	62.5	24.1	8.96	0.0006	*Microlaimus* species 3
	96	50.0	20.2	11.11	0.0138	*Tricoma* species
	97	44.8	22.0	11.51	0.0304	*Aegialoalaimus* species cf. *A. elegans*
B	83	55.6	22.7	10.85	0.0218	Diplopeltidae species 2
	119	43.3	21.1	11.82	0.0236	*Monhystera* species 4
	120	86.9	20.6	11.64	0.0024	Linhomoeidae species 7
	124	53.6	20.4	11.25	0.0354	Aegialoalaimidae species
C	9	83.8	20.4	11.61	0.0032	*Pomponema* species 1
	36	58.8	20.2	11.1	0.0118	Cyatholaimidae species 1
	39	53.5	20.2	11.16	0.0382	Linhomoeidae species 3
	45	50.7	20.0	10.76	0.0478	*Halalaimus* species 4
D	22	30.8	25.6	2.29	0.0068	*Aponema* species 1
	30	40.1	25.8	7.42	0.0156	*Daptonema* species 3 (cf. *D. psammoides*)
	76	40.3	21.7	11.82	0.0390	*Cyartonema* species 2
E	←	*Single community cluster; not possible to identify individual cluster-speciÿc, statistically signiÿcant nematode indicator species could be identiÿed by the analyses for this cluster*				
F	11	45.9	26.2	6.78	0.0004	*Spirinia* species 1 (cf. *S. parasitifera*)
	20	34.0	26.2	3.41	0.0048	*Pomponema* species 2
	25	30.1	25.6	2.15	0.0112	*Nemanema* species 1
	33	48.0	25.1	7.96	0.0014	*Theristus* species (ascribed to *T. ensifer*)
	56	42.1	25.5	7.91	0.0220	*Aponema* species 2

Table D1. List of the indicator species that exhibited statistically significant correlations with the clusters of the meiofaunal nematode communities described in the 2013 seabed survey area off the Namibian coast. Data derived from Monte Carlo permutation test-based indicator species analyses. **p*-values relate to correlations between species and their respective clusters.

Physalia

Annexure E: ARESC Analyses Identifying Relationships Between Community Structures and Measured Seabed Environmental Parameters

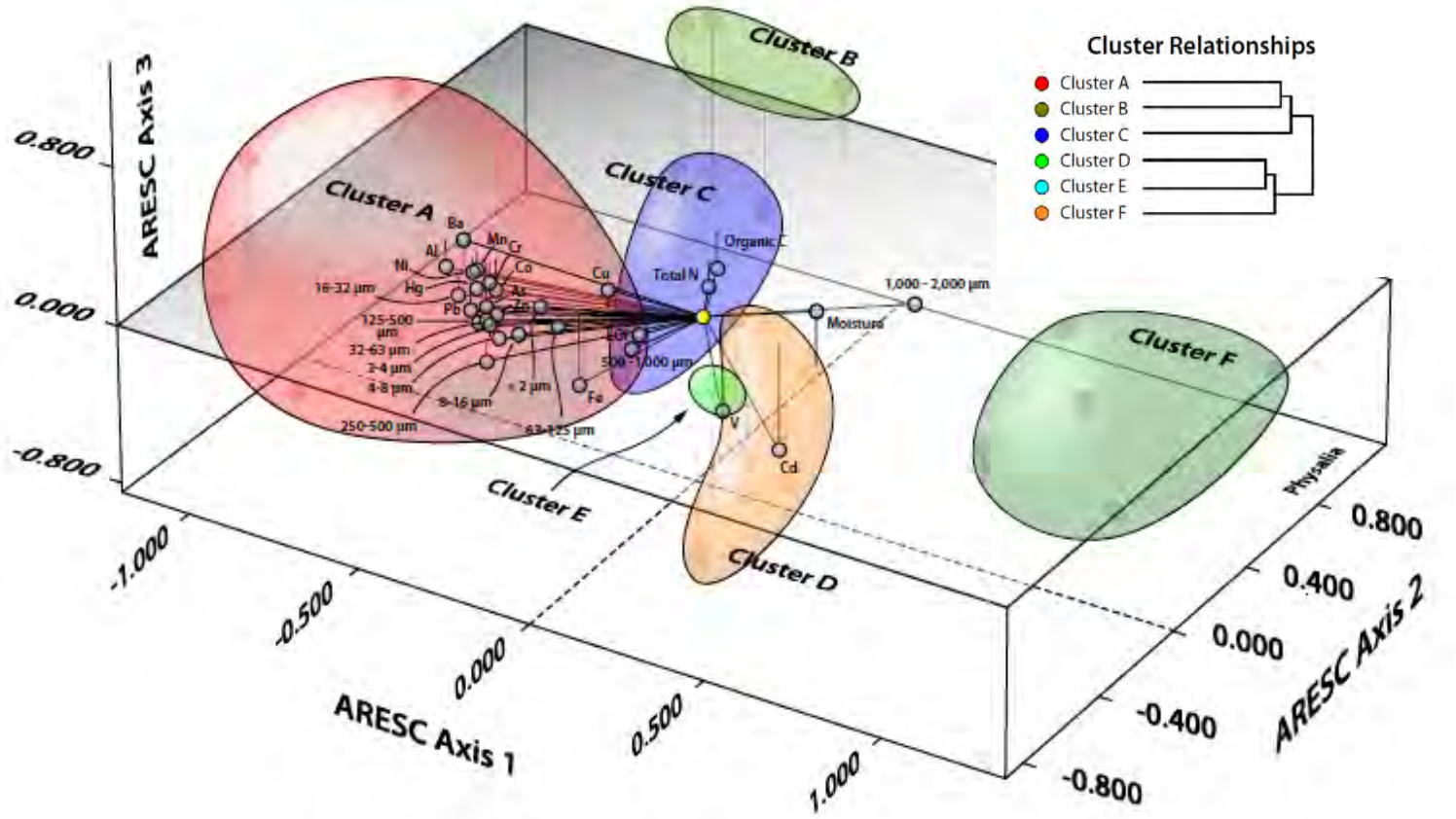


Figure E1: ARESC plot showing mathematical relationship between meiofaunal communities and the sediment physico-chemical environment.
Note 1: higher metal concentrations with finer sediments (silt-binding): Cluster A communities (offshore) associated with non-selective deposit feeders, detritivores and microbivorous species. Note 2: High vanadium, cadmium, Total N and organic C found in coarser sediments

© NMP 2014

Table E1: The formal ARESC analysis table

Sediment Determinands	**Axis1** (41.4% of total variance)			**Axis2** (19.1% of total variance)			**Axis3** (20.9% of total variance)		
	***p*-Value**	**BH**	**BY**	***p*-Value**	**BH**	**BY**	***p*-Value**	**BH**	**BY**
Al	**8.760E-06**	**2.540E-04**	**1.006E-03**	9.771E-01	9.771E-01	1.000E+00	4.922E-01	9.693E-01	1.000E+00
As	**1.408E-03**	**4.538E-03**	**1.798E-02**	7.439E-01	9.318E-01	1.000E+00	2.681E-01	9.693E-01	1.000E+00
Ba	**4.164E-04**	**3.019E-03**	**1.196E-02**	5.986E-01	9.136E-01	1.000E+00	5.140E-01	9.693E-01	1.000E+00
Cd	2.504E-01	3.157E-01	1.000E+00	9.108E-01	9.665E-01	1.000E+00	**5.121E-03**	1.214E-01	4.808E-01
Co	**1.156E-03**	**4.538E-03**	**1.798E-02**	8.640E-01	9.637E-01	1.000E+00	4.401E-01	9.693E-01	1.000E+00
Cr	**1.344E-03**	**4.538E-03**	**1.798E-02**	7.851E-01	9.318E-01	1.000E+00	6.254E-01	9.693E-01	1.000E+00
Cu	2.657E-01	3.211E-01	1.000E+00	6.718E-01	9.318E-01	1.000E+00	6.892E-01	9.693E-01	1.000E+00
Fe	1.847E-01	2.551E-01	1.000E+00	4.248E-01	8.021E-01	1.000E+00	6.560E-02	6.342E-01	1.000E+00
Mn	**2.826E-04**	**3.019E-03**	**1.196E-02**	9.332E-01	9.665E-01	1.000E+00	6.342E-01	9.693E-01	1.000E+00
Hg	**5.971E-04**	**3.463E-03**	**1.372E-02**	4.410E-01	8.021E-01	1.000E+00	6.123E-01	9.693E-01	1.000E+00
Ni	**3.823E-04**	**3.019E-03**	**1.196E-02**	7.790E-01	9.318E-01	1.000E+00	7.356E-01	9.693E-01	1.000E+00
Pb	**9.893E-04**	**4.538E-03**	**1.798E-02**	5.230E-01	8.427E-01	1.000E+00	3.531E-01	9.693E-01	1.000E+00
V	8.912E-01	8.912E-01	1.000E+00	8.032E-01	9.318E-01	1.000E+00	**8.370E-03**	1.214E-01	4.808E-01
Zn	**4.364E-02**	7.176E-02	2.843E-01	5.065E-01	8.427E-01	1.000E+00	7.800E-01	9.693E-01	1.000E+00
Moisture	6.852E-02	1.046E-01	4.143E-01	7.602E-01	9.318E-01	1.000E+00	1.816E-01	9.693E-01	1.000E+00
TOC	3.294E-01	3.821E-01	1.000E+00	**2.971E-02**	4.413E-01	1.000E+00	3.636E-01	9.693E-01	1.000E+00
Total N	5.283E-01	5.892E-01	1.000E+00	1.674E-01	4.413E-01	1.000E+00	5.081E-01	9.693E-01	1.000E+00
LOI	7.760E-01	8.335E-01	1.000E+00	2.703E-01	6.030E-01	1.000E+00	8.037E-01	9.693E-01	1.000E+00
1,000-2,000 µm	**3.633E-02**	6.584E-02	2.608E-01	6.471E-02	4.413E-01	1.000E+00	9.943E-01	9.943E-01	1.000E+00
500-1,000 µm	8.475E-01	8.778E-01	1.000E+00	1.411E-01	4.413E-01	1.000E+00	8.314E-01	9.693E-01	1.000E+00
250-500 µm	1.139E-01	1.652E-01	6.544E-01	**4.993E-02**	4.413E-01	1.000E+00	9.411E-01	9.747E-01	1.000E+00
125-250 µm	**4.454E-02**	7.176E-02	2.843E-01	**4.663E-02**	4.413E-01	1.000E+00	8.046E-01	9.693E-01	1.000E+00
63-125 µm	2.045E-01	2.696E-01	1.000E+00	1.482E-01	4.413E-01	1.000E+00	9.006E-01	9.693E-01	1.000E+00
32-63 µm	**1.824E-02**	**4.281E-02**	1.696E-01	1.271E-01	4.413E-01	1.000E+00	9.025E-01	9.693E-01	1.000E+00
16-32 µm	**2.162E-03**	**6.271E-03**	**2.484E-02**	4.425E-01	8.021E-01	1.000E+00	8.385E-01	9.693E-01	1.000E+00
8-16 µm	**2.409E-02**	**4.657E-02**	1.845E-01	1.548E-01	4.413E-01	1.000E+00	6.323E-01	9.693E-01	1.000E+00
4-8 µm	**2.067E-02**	**4.281E-02**	1.696E-01	1.362E-01	4.413E-01	1.000E+00	6.712E-01	9.693E-01	1.000E+00
2-4 µm	**1.279E-02**	**3.373E-02**	1.336E-01	1.248E-01	4.413E-01	1.000E+00	8.141E-01	9.693E-01	1.000E+00
< 2 µm	**1.934E-02**	**4.281E-02**	1.696E-01	2.022E-01	4.886E-01	1.000E+00	8.697E-01	9.693E-01	1.000E+00

Table E1. The formal ARESC analysis table showing the relationships beween measured physico-chemical parameters and the structures of the meiofaunal nematode communities in the 2013 marine survey area. Identification of statistically significant correlations is based on Pearson's correlation analyses for which the *p*-values have been corrected for multiple comparisons for each of the axes using the correction methods of Benjamini and Hochberg (1995) = "BH" and Benjamini and Yekutieli (2001) = "BY". Statistically significant raw and corrected *p*-values are highlighted as bold, underscored text for each of the nematode community axes to which they relate. *Total structural variance in the 2013 nematode communities explained by analyses* = ***81.4%***

© NMP 2014

SPECIALIST STUDIES – SECTION C

C2.5 Benthic Macrofauna in the Sandpiper SP-1 Target Dredge Area

BENTHIC MACROFAUNA IN THE SANDPIPER SP-1 TARGET DREDGE AREA

VERIFICATION SURVEY

Prepared for:
Namibian Marine Phosphate (Pty) Ltd.

Prepared by:
Dr Nina Steffani
Steffani Marine Environmental Consultant

June 2014

Steffani Marine Environmental Consultant
Email: nina@steffanienviro.co.za

Date	Version	Revised	Reviewed
30 May 2014	Draft 1	N Steffani	P Morant
18 June 2014	Final	N Steffani	P Morant

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed "Attention: Administration Manager," at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

SUMMARY

Namibian Marine Phosphate (Pty) Ltd (NMP) has been awarded a 20-year mining licence (ML170 or Sandpiper licence), which is located on the Namibian continental shelf offshore Conception Bay in water depths ranging from 180 to 300 m. Three target areas have been identified in the licence area, *i.e.* Sandpiper-1 (SP-1), 2 (SP-2), and 3 (SP-3). NMP is proposing to dredge the uppermost 1 to 2.5 m (possibly up to 3 m) of the seafloor in these target areas to recover phosphate rich material for use as fertilizer. The northern centre portion of SP-1, with water depth ranging from ~200-225 m, has been identified as the initial target area with a 20-year mine plan for the issued mining licence. With respect to the proposed project, an Environmental Impact Assessment (EIA) was undertaken, and key environmental issues addressed in a series of Marine Specialist Studies including a report on benthic fauna. This study recommended a 'verification' survey to confirm the impact assessments as these were based on assumptions that were largely arrived at from data from areas outside the Sandpiper licence area, with the exception of a macrofauna baseline survey conducted in SP-1 in 2010. The verification survey was undertaken by Lwandle Technologies in July/August 2013 and includes the collection of benthic macrofauna, meiofauna, and sulphur-utilising bacteria samples as well as data on sediment texture, organic matter, heavy metal distributions, near bottom dissolved oxygen concentration, oxidative state of the sediments, and water column characteristics. NMP has appointed Steffani Marine Environmental Consultant to conduct the identification and analysis of the benthic macrofauna communities and to report on the results.

METHODS

The survey design consisted of 15 macrofauna samples arranged in a grid pattern across the mining target area in depth of 209-227 m. The samples were collected with a Day grab, and the sediments in the grabs subsampled using 75-mm diameter plastic tubes. Eight cores were retrieved per grab and pooled, sampling a surface area of 0.035 m^2, and sieved initially through a 300-µm mesh sieve. The samples were later separated into the three distinct size fractions >1000 µm, 500-1000 µm, and 300-500 µm. For seven of the sites, all fractions were analysed while only the two larger fractions were analysed for the remaining samples. For each fraction, specimens were identified to the lowest taxon possible, counted and their wet biomass estimated. Meiofauna taxa were counted but excluded from analyses. Statistical analyses of the macrofauna data involved computation of univariate diversity measures, as well as multivariate analyses including hierarchical cluster analysis, multi-dimensional scaling (MDS), Principal Coordinates Analysis (PCO), Distance Based Linear Model (DistLM), SIMPER, and Abundance/Biomass Comparison (ABC) curves. The samples were analysed A) by comparing the three size fractions of the first seven samples to determine their relative importance and to provide recommendations on future mesh-size use, B) to establish macrofauna distribution patterns at the verification survey sites and their relation to environmental variables based on the >500 µm size fraction (500-1000 µm and >1000 µm pooled), and C) by comparing the verification survey results (>1000 µm only) to the data from the 2010 SP-1 baseline survey (Steffani 2010a).

RESULTS

The results can be summarized as follows:

A) The comparison of the three size fractions has shown that the >1000 µm fraction was highly dominated by macrofauna while the two smaller fractions were primarily characterised by meiofauna. The addition of the 500-1000 µm fraction to the >1000 µm fraction increased the macrofauna species list by a small number of species (26 species in the >1000 µm fraction plus 4 additional species in the 500-1000 µm fraction), and contributed somewhat to the overall abundance but very little to the biomass. While most of the macrofauna species recorded in the

© NMP 2014

samples have generally relatively large adult body sizes, few of the smaller but relatively common species may be underrepresented when sampling the >1000 µm fraction only. The 300-500 µm fraction, on the other hand, contributed no new macrofauna species, and contained overall a very low macrofauna abundance and negligible biomass. It is recommended to use the size range >500 µm for future surveys.

B) *i)* The 500-1000 µm and >1000 µm fractions were combined for the study of macrofauna distribution at the 15 verification survey sites. 69% of the taxa were polychaetes, while all other phyla including crustaceans were poorly represented both in terms of number of taxa as well as abundance per taxa. The most abundant species was an oligochaete Tubificidae spp. (32.6%) closely followed by the polychaete *Paraprionospio pinnata* (31.3%). Biomass, however, was strongly dominated by the large polychaete *Diopatra monroi* (54.5%).

ii) With the exception of one site, sediment particle size distributions were relatively similar at the sites being dominated by medium and fine sand with a steady decline towards the smaller grain sizes.

iii) Multivariate analyses on macrofauna abundances show a very high similarity among all sites (73%). At the 70% similarity level two groups emerge but with only a minimal increase in similarity level each group splits into smaller groups or individual sites, rendering the significance of this grouping questionable. Although the DistLM test determined a model solution of 13 environmental variables to best explain the macrofauna distribution pattern, only copper was statistically significant but its contribution to the macrofauna variation was very marginal (15.9%). It is suggested that because there is little variation in macrofauna distribution and little variation in the environmental conditions, a causal relationship between the two cannot be readily shown. This does not suggest that trace metals and/or sediment properties are not shaping the macrobenthic communities; just that this would only become evident when the verification survey sites are being compared to sites with different macrofauna distribution patterns.

iv) SP-1 lies at the southern offshore fringe of the Namibian shelf oxygen minimum zone. Measurements on the oxidative state of the sediments indicate that during the survey period the sediments were hypoxic but not anoxic nor were there significant amounts of HS^- fluxes from the sediments (Lwandle 2014). Bottom water conditions were mostly hypoxic (<0.5 O_2 mg/ℓ) with ventilation events (>1 O_2 mg/ℓ) (Lwandle 2014). The extremely low abundance of crustaceans and the dominance of *P. pinnata* are indicative of a low-oxygen environment. However, while low oxygen conditions are probably an essential factor, the macrobenthos has also some elements that are not typical for permanent low-oxygen environments such as the presence of a variety of large species that clearly dominate the biomass (e.g. *D. monroi*) and result in the communities being classified as undisturbed (according to the ABC curves). This suggests that while low oxygen conditions influence macrofauna distribution in SP-1, other factors such as organic matter quantity and quality and/or sediment texture may play an equally or even a more important role.

C) The 2010 SP-1 macrofauna baseline survey consisted of three transects traversing SP-1 in an east-west direction, whereby each transect had six stations covering a depth range of 175-240 m. The northern and middle transects are in the same section of SP-1 as the verification survey sites, whereas the southern transect is ~7 km to the south. The 2010 study reported a marked gradient of the samples according to depth as well as a distinct separation of the samples from the northern transect to those from the middle and southern transects. For comparison purposes with the 2010 baseline survey, the >1000 µm fractions of the verification survey sites were scaled to 0.2 m^2. Almost all the species found at the verification survey sites had also been recorded

© NMP 2014

from the baseline survey. The verification survey sites group with the northern 2010 transect at the 40% similarity level while the samples from the middle and southern transects separate into two other groups, parted by depth. At a higher similarity level of 60%, most of the verification survey sites split from the samples of the northern transect, but from the ordination plot it is evident that they group along the vertical axis with the 2010 samples from the same water depth. In general, the results of the diversity-measure comparison and the SIMPER analysis agree with the benthic distribution pattern observed from the multivariate analyses confirming the grouping of the verification survey sites with the samples from the northern transect, specifically those from similar depth, and the separation to the middle and southern transects.

CONCLUSION

The EIA benthos specialist study identified impacts on the benthic communities that can be expected from the proposed Sandpiper Phosphate Project, and assessed their significance. A total of nine negative impacts were identified in the original assessment study with one impact having medium significance, one low to medium, and seven low significance. The confidence levels for many impact assessments were only medium due to lack of data directly from the target area. The verification survey was designed to verify whether the assessments will remain in view of the newly acquired empirical data. In sum, all changes to the original assessments centre on the level of confidence, increasing the level from medium to high as the verification survey largely confirmed the assumptions on which the assessments were based. This applied to five of the impact assessments while four remained unchanged.

MONITORING RECOMMENDATIONS

A macrofauna monitoring programme was established, whose principle objective is to study the rate of recovery of disturbed macrofaunal communities once the mining activity has ceased in a mine block. For operations in SP-1, four impact stations and four associated reference sites to the north and four to the south (each with five replicates) of the 20-year mining areas were selected and a baseline survey conducted in 2013 utilising the same method as for the verification survey. Analysis of the samples is underway. Following commencement of mining, sampling of both impact and reference sites should be undertaken at regular intervals after completion of dredging to determine the (functional) recovery rates of the benthic communities.

© NMP 2014

contents

SUMMARY ii

1 INTRODUCTION 1

2 METHOD 3

2.1.1 Sampling Stations and Sample Collection 3
2.1.2 Environmental Data 4
2.1.3 Biological Data 5

2.2 RESULTS AND DISCUSSION 9

2.2.1 Comparison of the Three Macrofauna Size Fractions 9
2.2.2 Macrofauna Distribution Pattern at the Verification Survey Sites 12
2.2.3 Comparison with the 2010 Baseline Data 25

3 CONCLUSIONS AND MONITORING RECOMMENDATIONS 32

3.1.1 Monitoring Recommendations 32

4 REFERENCES 35

Annexure 1a: Macrofauna abundances (no/0.035m^2) in the >1000 µm fraction at the 15 verification survey sites in 2013. 39
Annexure 1b: Macrofauna abundances (no/0.035m^2) in the 500-1000 µm fraction at the 15 verification survey sites in 2013. 41
Annexure 1c: Macrofauna abundances (no/0.035m^2) in the 300-500 µm fraction at the seven of the verification survey sites in 2013. 43
Annexure 1d: Macrofauna wet biomass (g/0.035m^2) in the >1000 µm fraction at the verification survey sites in 2013. 44
Annexure 1e: Macrofauna wet biomass (g/0.035m^2) in the 500-1000 µm fraction at the verification survey sites in 2013. 46
Annexure 1f: Macrofauna wet biomass (no/0.035m^2) in the 300-500 µm fraction at the seven of verification survey sites in 2013. 48

© NMP 2014

figures

Figure 1: Location of the Sandpiper Mining Licence and the macrofauna survey verification sites 2
Figure 2: Average (±SE) relative abundance (%) of meio- to macrofauna 10
Figure 3: Macrofauna species accumulation curve for seven sampling sites in SP-1 10
Figure 4: Photo of the polychaete *Paraprionospio pinnata* 11
Figure 5: Photographic gallery of macrofauna taxa at the verification survey sites. 13
Figure 6: Macrofauna species number, abundance (no/0.035m^2), wet biomass (g/0.035m^2), richness, evenness 15
Figure 7: Dendrogram (top), MDS ordination (bottom left) and PCO (bottom right) plots of macrofauna abundances at the verification survey sites. 16
Figure 8: Sample groups as identified by the dendrogram, MDS and PCO plots overlain on the macrofauna survey verification sites (green squares) in SP-1. 17
Figure 9: Sediment grain size distribution at the verification survey sites. 18
Figure 10: PCO plot of the sediment grain size fractions at the verification survey sites. 19
Figure 11: Abundance/Biomass Comparison (ABC) curves of the verification survey sites. 23
Figure 12: Location of the verification survey sites 26
Figure 13: Dendrogram of macrofauna abundances at the verification survey (VS) sites and the baseline sites sampled in 2010 (81-98, water depth in brackets). 27
Figure 14: MDS ordination of macrofauna abundances at the verification survey (VS) sites and the baseline sites sampled in 2010 28
Figure 15: Diversity indices at the verification survey sites from 2013 30

tables

Table 1: Positions and water depths of the verification survey sites in SP-1. 3
Table 2: Sediment grain size fractions and associated heavy metal concentrations at the 15 verification survey sites. 7
Table 3: Total species number (no/0.035m^2), and mean species number (no/0.035m^2), abundance (no/0.035m^2), and biomass (g/0.035m^2) in the three size fractions at seven sampling sites in SP-1. 11
Table 4: DistLM sequential test for macrofauna abundances 21
Table 5: Results of the SIMPER tests 31

© NMP 2014

1 INTRODUCTION

Namibian Marine Phosphate (Pty) Ltd (NMP) has been awarded a 20-year mining licence (ML170), which is located on the Namibian continental shelf offshore Conception Bay in water depths ranging from 180 to 300 m covering a total area of 2233 km^2 (Figure 1). Within the mineralized resource zones of the licence area, also named Sandpiper licence area, three target areas have been identified, *i.e.* Sandpiper-1 (SP-1), 2 (SP-2), and 3 (SP-3). NMP is proposing to dredge the uppermost 1 to 2.5 m (possibly up to 3 m) of the seafloor in these target areas to recover phosphate rich material for use as fertilizer. SP-1 in the north of ML170 is the initial target area, whereby the northern centre portion of SP-1, with water depth ranging from 200-225 m, has been identified as the 20-year mining zone. Within this zone, smaller target blocks have been designated for the mining years 1-5, 6-10, and 11-20, respectively (Figure 1).

With respect to this proposed project, an Environmental Impact Assessment (EIA) was undertaken (Midgley 2012), and key environmental issues addressed in a series of Marine Specialist Studies including a report on benthic fauna (Steffani 2012). The impact assessments discussed in the Benthic Specialist Study were based on an initial macrofauna baseline data set collected in the SP-1 in 2010 (Steffani 2010a), supported by extrapolations that were arrived from publicly available data from the general region but outside the Sandpiper licence area. The assumptions drawn from these data are deemed robust, but nonetheless it was recommended to conduct a 'verification' survey to confirm these. Concerns voiced by interested parties and reviewers about the lack of empirical data from the actual target zones in the licence area reinforced the need for this verification survey. The verification survey included the collection of benthic faunal samples (both meio- and macrofauna) as well as the gathering of primary data on sediment properties and characteristics in the mine area including sediment texture and associated hydrogen sulphide fluxes, heavy metal distributions, and water column characteristics. The macrofauna component of the verification survey focussed on the 20-year mining zone with 15 sampling stations spread across the zone in a grid pattern (Figure 1). The verification survey was undertaken by Lwandle Technologies (Ltd) (Lwandle) in July/August 2013. On advice from its independent environmental advisors CSIR and J Midgley & Associates, NMP has appointed Steffani Marine Environmental Consultant to conduct the analysis of the benthic macrofauna samples and to report on the results.

© NMP 2014

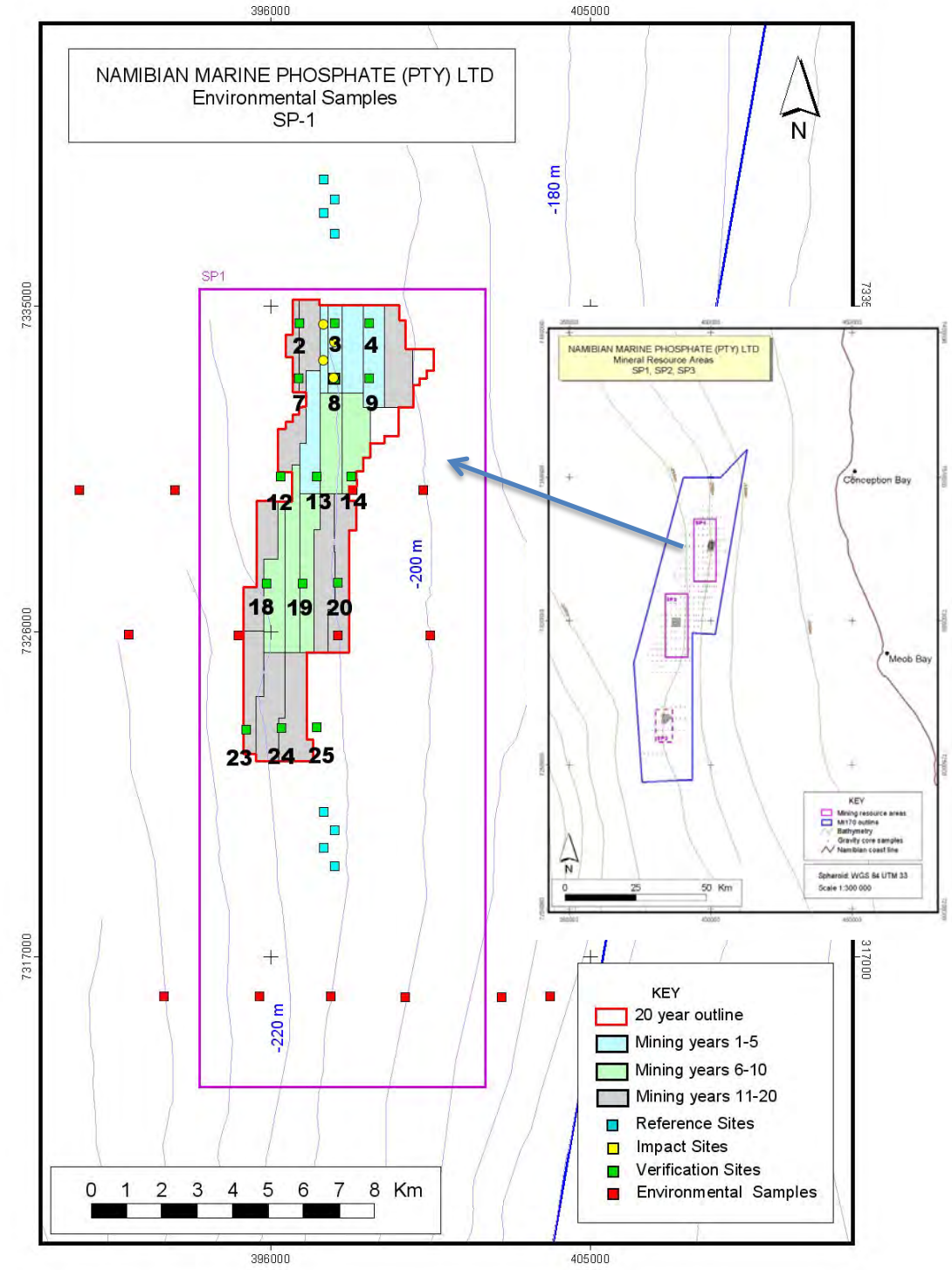


Figure 1: Location of the Sandpiper Mining Licence and the macrofauna survey verification sites (inset) (green squares) in SP-1. The red squares show the sampling stations of the 2010 macrofauna baseline survey, and the blue and yellow squares denote the sampling positions of the impact and reference sites for the planned monitoring survey.

© NMP 2014

2 METHOD

2.1.1 Sampling Stations and Sample Collection

The positions of the verification survey stations are shown in Figure 1 and geographical positions and water depths are provided in Table 1. The sites are in relatively similar depths ranging from 209-227 m.

Table 1: Positions and water depths of the verification survey sites in SP-1.

Site	Longitude WGS84	Latitude WGS84	Depth (m)
SP1VS02	-24 05 54.66095	13 59 40.05835	218
SP1VS03	-24 05 54.89280	14 00 15.47432	214
SP1VS04	-24 05 54.89280	14 00 15.47432	209
SP1VS07	-24 06 43.19281	13 59 04.25792	217
SP1VS08	-24 06 43.42709	13 59 39.67750	213
SP1VS09	-24 06 43.65909	14 00 15.09720	209
SP1VS12	-24 09 48.76097	13 59 41.77107	220
SP1VS13	-24 11 58.18695	13 58 08.59876	216
SP1VS14	-24 08 11.32233	13 59 56.70444	211
SP1VS18	-24 09 48.28947	13 58 30.90366	225
SP1VS19	-24 09 48.52636	13 59 06.33730	220
SP1VS20	-24 09 48.76097	13 59 41.77107	214
SP1VS23	-24 11 58.18695	13 58 08.59876	227
SP1VS24	-24 11 58.42562	13 58 44.04230	223
SP1VS25	-24 11 58.66200	13 59 19.48596	217

Sample collection was carried out by Lwandle and the macrofauna sampling method is described in the Cruise Summary Report (Lwandle 2013). In summary, macrofauna samples were collected with a Day grab[1], whereby grabs that were <40% full were regarded as failed and repeated. The sediment in the grab was subsampled using plastic tubes with a 75-mm diameter. This method ensured that a controlled representative sample of the surface and the deeper layers of the sediment was collected. Eight cores were retrieved per grab and pooled, resulting in approximately 5 litre of sediment and sampling a surface area of 0.035 m^2. The sample was then placed into the Wilsons autosiever. The autosiever had two tiers of sieves, which were placed above the incoming seawater jets. The top sieve had an aperture of 3 mm and the bottom sieve had an aperture of 300 µm. A hand held hosepipe was used to wash the sediment from above. Shell fragments and larger grains that were retained on the 3 mm sieve were carefully washed, and any fauna retained on the sieve handpicked from the mesh and added to the sample. Macrofauna samples were then fixed with 4-5% neutralised formalin. To separate the macrofauna from the sediment, the samples were washed

[1] A Day Grab was deployed for surficial sediment sampling in this survey as field trials at the site with the box core available showed that it could not penetrate the sediment sufficiently to provide the sample volumes required. This is attributed to the dense shell layers present across the survey area. Furthermore it was acknowledged that a multicore unit would have had similar difficulty penetrating such sediments in a consistent manner.

© NMP 2014

with freshwater through a three-tiered set of sieves. The top sieve had a mesh size of 1000 µm, the second one of 500 µm, and the lowest one of 300 µm. This separated the samples into three distinct size fractions, >1000 µm, 500-1000 µm, and 300-500 µm. Each size fraction was hand-sorted separately, the fauna extracted and transferred to 1% phenoxatol (ethylenglycolmonophenyl-ether). The size fractions 300-500 µm and 500-1000 µm were sorted under a stereo-binocular microscope. The samples were stained with Rose Bengal to aid in the sorting. Specimens were identified to the lowest taxon possible, counted and densities expressed as no/0.035m^2. Wet biomass was estimated by blot-drying the specimens on absorbent tissue for a standard period of time and weights recorded per species per sample as g/0.035m^2. Abundance and biomass data per fraction are provided in the appendix. For seven of the samples, all three size fractions were analysed to obtain an overview of the relative importance of the three fractions across the evaluation area. The remaining samples were analysed down to the >1000 µm and 500-1000 µm fractions. Taxa that traditionally are considered to be meiofauna (e.g. nematodes, copepods, ostracods and foraminifera) were counted, but biomass measurements were not obtained nor were these taxa included in subsequent analyses. This is in line with other studies using 300 µm sieves for macrofauna collection (e.g. Levin *et al.* 2000, Gallardo *et al.* 2004).

2.1.2 Environmental Data

The concentrations of a range of heavy metals in the sediment, the sediment grain size distribution, the moisture and organic carbon content, as well as %total nitrogen were determined for each of the 15 sample sites by sub-sampling the sediment contained in the Day grab (Table 2). The sediment properties were analysed according to the Wentworth scale resulting in eleven size fractions ranging from very coarse sand to clay (note that gravel (>2mm in diameter) was not recorded in the sediments analysis)[2]. In addition, the verification survey comprised the deployment of an oceanographic instrumented mooring that focused on currents, temperature, salinity, dissolved oxygen and turbidity time series measurements throughout the water column and at the seabed. Data from the mooring were recorded over two consecutive measurement periods P1 (8 June to 26 July 2013) and P2 (2 August to 13 September 2013), totalling 90 days of measurements. The results are discussed in detail in the Verification Survey Report on Sediment Properties (Lwandle 2014). The environmental data are here applied to explain patterns observed in the macrofauna distribution. Draftsman plots of environmental variables were used to investigate the level of transformation needed. Sediment fractions were arcsine transformed, iron log transformed, and all data normalised prior to analysis. The Draftsman plots further showed that nickel was highly correlated with cobalt and chromium (>0.95), and many sediment fractions, especially the silt fractions, were also highly inter-correlated. The suggested 'cut-off' point for exclusion of variables due to correlation is Pearson r >0.95 (see Clarke & Gorley 2006). Nickel, as well as medium sand, very fine sand, very coarse silt, medium silt, fine silt, and very fine silt, are therefore excluded for certain analyses, which is noted in the appropriate result sections. Patterns of sediment composition were investigated with Principal Coordinates Analysis (PCO) based on Euclidean distances (see below).

[2] Note: In this study sediment particle sizes were measured by laser diffractometry. The algorithms used for image processing required that sediment particle sizes >2 000 µm ESD were excluded from analysis. Consequently gravel sized particles, mainly the larger shell debris, have not been estimated

© NMP 2014

2.1.3 Biological Data

Diversity indices (e.g. number of species, abundance, and biomass per 0.035m^2, as well as species richness, evenness, and Shannon-Wiener diversity (log_e)) were computed (PRIMER v6, Clarke & Warwick 2001). Shannon-Wiener diversity index is a measurement of biodiversity taking into account the number of species and the evenness of the species (evenness expresses how evenly the individuals are distributed among the different species, in other words whether a community is dominated by individuals of one or few species (low evenness) or whether all species contribute evenly to the abundance (high evenness)). The unit-less index is increased either by having additional unique species, or by having a greater species-evenness.

The computer package PRIMER 6 & PERMANOVA+ was used to analyse the benthic data (*i.e.* all species except meiofauna species) following the multivariate analysis procedures described by Clarke & Warwick (2001), Clarke & Gorley (2006), and Anderson *et al.* (2008, and other references therein). All data were 4th-root transformed, and a Bray-Curtis resemblance matrix computed. This was followed by hierarchical cluster analysis and multi-dimensional scaling (MDS), which is an ordination 'map' in two dimensions, where the distances between the samples represent their dissimilarity - *i.e.* the closer the samples are depicted in the MDS, the more similar they are. In addition, Principal Coordinates Analysis (PCO) was employed, which is a routine for performing principal coordinates analysis on the basis of a resemblance matrix (Bray-Curtis similarity). PCO places the samples onto Euclidean axes whereby the eigenvalues associated with each axis provide information on how much of the variability inherent in the resemblance matrix is explained by each successive axis (expressed as a percentage of the total). In contrast to MDS, which works on the ranks of resemblance measures, PCO provides a direct projection of the points in the space defined by the actual dissimilarities themselves (Anderson *et al.* 2008). Both routines are used to visualise patterns in the dataset in a small number of dimensions (usually two dimensions) and the adequacy of the representation of the points in this reduced dimensions needs to be ascertained. For the MDS plots, the stress value gives a measure of how well the two-dimensional picture may represent the sample relationship, whereby stress values >0.25 indicate that a higher dimensional projection may be more appropriate. The adequacy of the two-dimensional PCO routine may be determined by how much of the total variation in the system is explained by the first two axes that are drawn. There is no clear cut-off point but it is suggested that ~70% or more would be expected to provide a reasonable representation of the general overall structure (Anderson *et al.* 2008). MDS and PCO were performed on both abundance and biomass data, but for the sake of brevity only abundance data are presented here. In general, both abundance and biomass datasets gave very similar results.

The relationship between biotic (abundance) assemblage data and abiotic data (e.g. heavy metals and sediment grain size fractions) was investigated using a Distance Based Linear Model (DistLM) (Anderson *et al.* 2008). DistLM is a routine for analysing and modelling the relationship between a multivariate data cloud and one or more predictor (environmental) variables. At first, DistLM conducts a marginal test, which determines the proportion of the variance in the macrofaunal distribution pattern that can be explained by each predictor variable. DistLM then partitions the variation in data distribution according to a multiple regression model (based on predictor variables), as selected by the user, (e.g. forward, stepwise, best fit), which provides a best solution for a combination of available sediment fractions and/or heavy metal concentrations. The 'step-wise' procedure and Adjusted R^2 criteria options were used in this study. *P*-values for testing the null hypothesis of no relationship are obtained using appropriate permutation methods.

© NMP 2014

Distributional analysis (Abundance/Biomass Comparison (ABC)) curves are used to represent patterns of species abundance and biomass in a sample. The underlying assumption for the interpretation of the ABC curves is that when communities are undisturbed, the biomass is dominated by individuals of a few species, which grow to a large size. The biomass curve for the community therefore lies above the abundance curve on the ABC plot. Where sites have undergone moderate disturbance, the larger, longer-lived species may be eliminated, reducing the difference between the abundance and biomass curves. The curves may therefore lie close to one another on the graph, and may cross each other one or more times. At severely disturbed sites, an abundance of opportunistic, small, short-lived species dominates the sample, and the abundance curve lies above the biomass curve. The difference in area under the abundance and biomass curves is summarised by the *W*-statistic. *W* tends towards +1 when the abundance is even across species but the biomass is dominated by a single species (undisturbed), and *W* tends towards -1 in disturbed communities (although neither limit is likely to be attained in practice). *W* around 0 indicates moderately disturbed communities.

© NMP 2014

Table 2: Sediment grain size fractions and associated heavy metal concentrations at the 15 verification survey sites.
Heavy metal concentrations are dry weight in mg/kg except for mercury measured in µg/kg. Sediment grain fractions are given as percentages. Data extracted from Lwandle (2014).

	Variables	SP1VS02	SP1VS03	SP1VS04	SP1VS07	SP1VS08	SP1VS09	SP1VS12	SP1VS13	SP1VS14	SP1VS18	SP1VS19	SP1VS20	SP1VS23	SP1VS24	SP1VS25
Heavy Metals	Aluminum (Al)	5165	4720	3927	5351	4835	5276	5514	5997	5135	4395	5006	6048	5078	4919	5256
	Arsenic (As)	48.2	45.9	39.6	47.1	46.7	53.5	49.4	49.4	52.3	48.4	50.4	57.0	52.62	51.1	58.0
	Barium (Ba)	41.5	36.4	31.7	40.3	38.9	39.1	37.5	33.6	37.5	42.1	45.3	39.6	41.8	39.8	42.2
	Cadmium (Cd)	13.7	14.0	12.9	13.1	14.2	17.0	14.0	15.1	16.6	13.7	15.9	17.5	15.0	15.7	18.4
	Cobalt (Co)	3.4	3.1	2.8	3.4	3.2	3.6	3.2	3.2	3.4	3.7	4.0	3.7	3.9	3.9	4.2
	Chromium (Cr)	128.1	114.1	103.3	129.2	122.6	138.6	118.6	110.5	126.8	135.1	144.2	133.8	138.1	137.5	142.0
	Copper (Cu)	21.4	19.8	21.9	29.2	27.4	29.9	26.1	29.8	30.3	14.0	17.0	35.6	18.4	17.6	21.9
	Iron (Fe)	10731	10039	7235	9142	8787	10823	12804	15154	11107	8396	9227	13757	10752	10357	32523
	Manganese (Mn)	33	29	26	34	31	33	29.7	30.1	31	32.1	37.1	34	33.3	32.5	35.6
	Mercury (Hg)	116	116	100	98	92	108	99	92	102	105	107	116	100	105	116
	Nickel (Ni)	48	43	39.6	49.3	45.2	49.4	44.0	43.5	47.2	51.8	56.6	52.0	53.5	54.6	56.1
	Lead (Pb)	9.1	8.4	7.1	7.9	7.8	9.0	7.9	7.7	8.1	9.4	8.9	8.8	9.6	10.1	11.2
	Vanadium (V)	30.4	30.7	23.9	29.3	27.6	32.3	29.8	31.5	30.7	29.8	34.4	34.0	32.9	33.2	35.6
	Zinc (Zn)	26.4	23.8	23.3	28.8	26.9	30.0	25.0	24.4	28.8	26.7	29.4	32.1	28.8	27.5	31.9
Organics	% Moisture	38.7	37.1	41	40	38	37	35.8	38.7	36	33.3	36.6	39	34.1	35.1	35
	% Organic Carbon	5.828	4.415	4.699	5.392	4.473	4.846	9.723	13.150	5.028	6.275	8.614	4.193	7.599	9.705	4.298
	% Total Nitrogen	0.448	0.563	0.793	0.544	0.887	0.538	0.948	1.439	0.470	0.342	0.940	0.662	0.927	0.956	0.552
Sediment Fractions	Very Coarse Sand	0.01	0.28	0.52	0.35	0.69	0.07	0.03	0.03	0.03	71.9	0.46	0.30	0.01	2.29	0.11
	Coarse Sand	5.30	4.99	6.64	7.31	6.91	5.86	3.85	4.57	4.97	0.0	4.50	5.55	4.23	5.78	5.49
	Medium Sand	25.18	19.58	21.13	22.52	21.88	21.29	18.79	17.11	18.48	0.1	14.76	19.32	19.58	17.20	18.60
	Fine Sand	27.70	23.62	22.41	24.25	24.15	22.31	23.40	20.76	21.10	7.1	18.38	21.88	23.99	22.53	20.59
	Very Fine Sand	13.85	16.03	14.85	15.14	15.08	15.14	15.57	17.26	16.27	9.8	16.79	15.50	15.43	15.22	16.50
	Very Coarse Silt	10.40	13.12	12.75	11.69	11.56	12.71	13.41	15.30	14.22	4.0	15.77	13.57	13.09	12.91	14.84
	Coarse Silt	7.74	9.64	9.51	8.24	8.53	9.53	10.61	10.98	10.57	7.2	12.25	10.36	10.19	10.32	10.43

© NMP 2014

	Variables	SP1VS02	SP1VS03	SP1VS04	SP1VS07	SP1VS08	SP1VS09	SP1VS12	SP1VS13	SP1VS14	SP1VS18	SP1VS19	SP1VS20	SP1VS23	SP1VS24	SP1VS25
	Medium Silt	4.86	6.19	6.01	5.11	5.49	6.42	6.99	6.84	7.03	<	8.25	6.65	6.58	6.78	6.50
	Fine Silt	2.63	3.30	3.08	2.71	2.91	3.42	3.70	3.58	3.70	<	4.32	3.47	3.45	3.52	3.44
	Very Fine Silt	1.29	1.65	1.54	1.39	1.46	1.67	1.87	1.79	1.82	<	2.18	1.72	1.73	1.74	1.75
	Clay	0.59	1.05	1.01	0.82	0.85	1.05	1.20	1.15	1.21	<	1.66	1.09	1.15	1.13	1.14

© NMP 2014

2.2 RESULTS AND DISCUSSION

2.2.1 Comparison of the Three Macrofauna Size Fractions

The original macrofauna baseline survey in SP-1 (Steffani 2010a) used a 1-mm sieve to separate the macrofauna from the sediment as presently all published scientific work on Namibian macrofauna (e.g. Savage 1996, Savage *et al.* 2001, Zettler *et al.* 2009, 2013, Atkinson *et al.* 2011) as well as grey-literature reports (Field *et al.* 1996, Parkins & Field 1998, Pulfrich & Penney 1999, Steffani & Pulfrich 2007, Steffani 2007, 2010b, among others) have used this sieve size, which allows comparison with these studies. However, as the study area is in deeper waters at the offshore fringe of the Namibian shelf Oxygen Minimum Zone (OMZ), this was criticised as many studies on macrofaunal abundance in OMZs often use smaller sieve sizes in anticipation that many macrofauna species will be generally smaller to better deal with the low oxygen environment (e.g. Gallardo *et al.* 2004, Gooday *et al.* 2009, Levin *et al.* 2009). Sieve sizes used in OMZ studies vary between 300 µm (e.g. Gallardo *et al.* 2004, Gooday *et al.* 2009, Levin *et al.* 2000, 2009), 500 µm (e.g. Sahling *et al.* 2002, Gutiérrez *et al.* 2000, Palma *et al.* 2005), and 1 mm (e.g. Rosenberg *et al.* 1983, Zettler *et al.* 2009, 2013, see also Levin & Gage 1997 for references on studies using sieve sizes ranging from 0.3 to 1.0 mm). To determine the relative importance of the various size fractions and to give recommendations as to the best way forward, seven of the samples (SP1VS04, SP1VS07, SP1VS08, SP1VS09, SAP1VS14, SP1VS20, SP1VS25) were separated into the fractions 300-500 µm, 500-1000 µm, and >1000 µm, and each size fraction analysed separately.

Classical meiofauna taxa, such as Nematoda and Harpacticoida, were not further considered in this study but were nonetheless counted to provide an indication of the relative meio- to macrofauna abundance in the three fractions. The >1000 µm fraction was clearly characterised by macrofauna, which contributed 93% to the benthos while meiofauna was sparse (7%) (Figure 2). The smaller fractions, on the other hand, were dominated by meiofauna amounting to 73% and 83% in the 500-1000 µm and 300-500 µm sections, respectively. Macrofauna contributed only 27% and 17% in the 500-1000 µm and 300-500 µm sections, respectively.

The species accumulation curve shows that a total of 26 macrofauna species/taxa were encountered in the >1000 µm fraction of the seven samples (Figure 3). The addition of the 500-1000 µm section increased the number of species to 30, with the additional species being two polychaetes, Dorvilleidae sp.1 and *Prionospio* sp. 1, a cephalocarid Hutchinsoniellidae sp. 1, and an entoproct Loxosomatidae sp. 1. These species were represented by one single specimen each, except for two specimens of *Prionospio* sp. 1. The addition of the 300-500 µm section, however, did not add any further taxa to the macrofauna list.

© NMP 2014

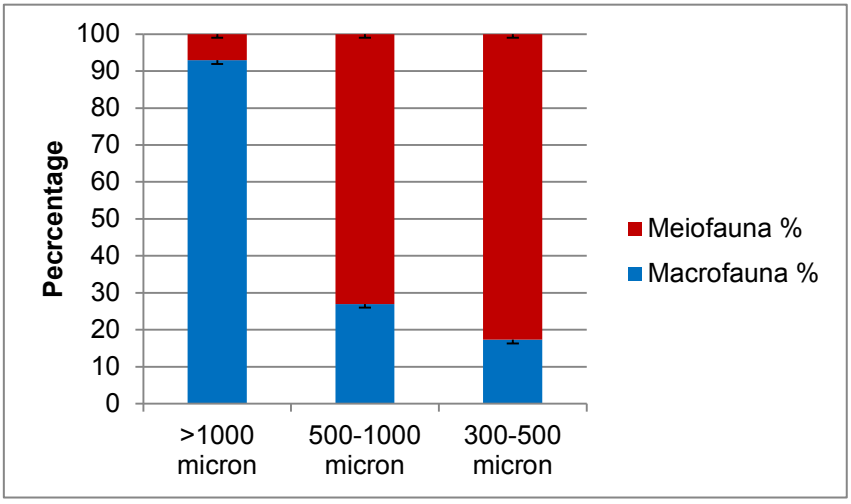


Figure 2: Average (±SE) relative abundance (%) of meio- to macrofauna
in the three size fractions >1000 µm, 500-1000 µm, and 300-500 µm of seven sampling sites.

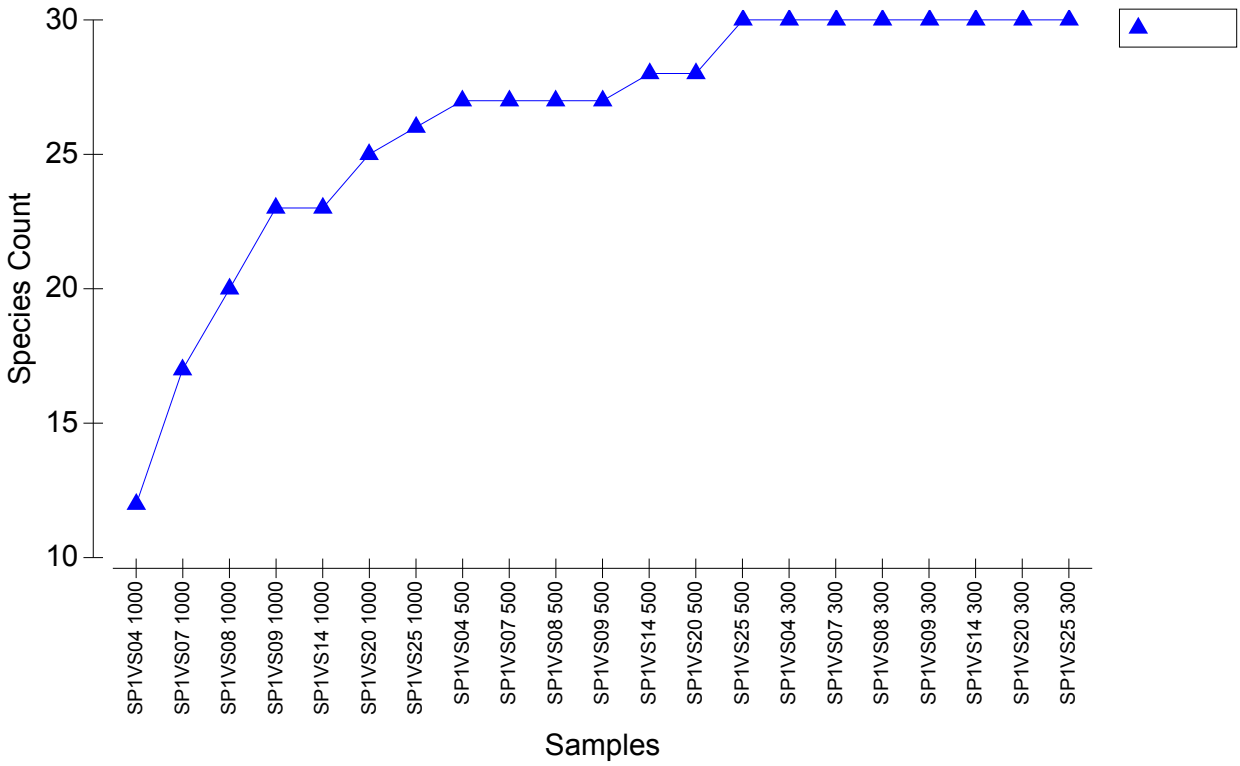


Figure 3: Macrofauna species accumulation curve for seven sampling sites in SP-1
ordering the fractions in sequence from >1000 µm (left on the x-axis) to 300 µm (right on the x-axis).

Total macrofauna species number and average species number, as well as average abundance and biomass were all highest in the >1000 µm fraction and lowest in the 300-500 µm fraction (Table 3). This is, however, not surprising as the 500-1000 µm and 300-500 µm fractions are constrained at

© NMP 2014

both their lower and upper grain size range whereas the >1000 µm is only constrained towards its lower range, *i.e.* the sample size of the >1000 µm is considerably larger than that of the smaller-sized fractions.

Table 3: Total species number (no/0.035m^2), and mean species number (no/0.035m^2), abundance (no/0.035m^2), and biomass (g/0.035m^2) in the three size fractions at seven sampling sites in SP-1.

Fraction	Total Species Number	Average Species Number	Average Abundance	Average Biomass
>1000 µm	26	14	163	4.07
500-1000 µm	19	9.4	91.1	0.87
300-500 µm	9	5	27.9	0.002

The most common species in the >1000 µm fraction was the polychaete *Paraprionospio pinnata* (total of 451 specimens), followed by an oligochaete Tubificidae spp. (259 specimens). Other common polychaetes were the large *Diopatra monroi* (69 specimens) and the smaller *Lumbrineris meteroana* (62) and *Aphelochaeta* sp. 1. (60). The most common animals in the 500-1000 µm fraction were Tubificidae spp. (353) and *Aphelochaeta* sp. 1 (138) followed by juveniles of *P. pinnata* (97). Species that were more abundant in the 500-1000 µm than in the >1000 µm fraction include Tubificidae spp. and *Aphelochaeta* sp. 1, and the small polychaetes *Jasmineira* ? *elegans* and *Syllidia armata* (6 and 33, respectively, in the >1000 µm; 20 and 41, respectively, in the 500-1000 µm fraction). Species in the 300-500 µm fraction include Tubificidae spp., *Aphelochaeta* sp. 1, and some *P. pinnata* juveniles. In all fractions, Crustaceans were very sparse and other phyla such as Echinodermata and Cnidaria were only present in the >1000 µm fraction. It was further noted that a large proportion of the organic material in the smaller fractions consisted of broken-off appendages from larger macrofauna specimens, particularly the gills and palps of the polychaete *P. pinnata* (Figure 4).



Figure 4: Photo of the polychaete *Paraprionospio pinnata*
showing the gills and palps that can easily break off and were found in great abundance in the smaller sample-size fractions 300-500 µm and 500-1000 µm.

© NMP 2014

The comparison of the three size fractions has shown that the addition of the 500-1000 µm fraction has added a small number of additional species to the macrofauna species list, and contributed somewhat to the overall abundance but very little to the biomass (primarily related to the smaller size range of the fraction). Not too much attention should be given to the addition of the four macrofauna taxa as the number of samples investigated in this comparison study is very small (N = 7) and the presence of a taxa represented by a single specimen in one but not the other fraction could easily be just by chance. An increase in sample size would most likely show that all or most of these taxa can also be found in the >1000 µm fraction. However, while most of the macrofauna species found in the SP-1 samples have generally relatively large adult body sizes (e.g. polychaetes *P. pinnata*, *D. monroi*, *Sigambra parva*, *Brada villosa capensis*, *Nephtys hombergii*, sandprawn *Callianassa australis,* and seapen Veretellidae *spp.*), it is apparent that few of the smaller but relatively common species, such as the polychaetes *Aphelochaeta* sp. 1 and *Jasmineira* ? *elegans*, as well as oligochaetes, are somewhat underrepresented when sampling the >1000 µm fraction only. The 300-500 µm fraction, on the other hand, contributed no additional macrofauna species, and contained overall a very low macrofauna abundance and negligible biomass and, therefore, does not add any critical information to the macrofauna distribution pattern. Although the >1000 µm fraction on its own would probably satisfy the requirements for monitoring studies, it is recommended to use the size range >500 µm for future surveys.

2.2.2 Macrofauna Distribution Pattern at the Verification Survey Sites

Following on from the above analysis, the >500 µm size range (*i.e.* the 500-1000 µm and >1000 µm size fractions pooled) was used for the study of the macrofauna distribution pattern at the 15 verification survey sites in SP-1.

A total of 3919 specimens belonging to 36 taxa were recorded. The vast majority (69%) were polychaetes with 25 taxa. Crustaceans and cnidarians were represented by three taxa each, followed by one mollusc, one echinoderm, one nemertine (Nemertea were not identified to lower taxonomic levels), one entoprocta, and one oligochaete. Oligochaetes were identified to family level but the condition of most of the animals in addition to the strong staining hindered a satisfactory identification to lower levels, and it is thus possible that this taxa group contains more than one species. The most common species was an oligochaete Tubificidae spp. (gut-containing), which contributed on average 32.6% to the total abundance per site, closely followed by the polychaete *Paraprionospio pinnata* (31.3%) (Figure 5). Other common animals included the polychaetes *Aphelochaeta* sp. 1 (11.7%), *Lumbrineris meteroana* (6.6%), *Diopatra monroi* (4.6%), and *Syllidia armata* (3%) (Figure 4). Other phyla were very sparsely present. The most common non-annelid taxon was a seapen Veretellidae sp. (<1%) (Figure 5). Crustaceans were represented by the sandprawn *Callianassa australis* (8 specimens in total or 0.2% on average), an amphipod *Grandidierella* sp. 1 (two specimens at one site), and one cephalocarid specimen of the family Hutchinsoniellidae sp. 1 (Figure 5). Nemertines and anemones were represented by five and three specimens, respectively, while all other phyla had one specimen only.

© NMP 2014



Figure 5: Photographic gallery of macrofauna taxa at the verification survey sites.
From top left to bottom right: *Paraprionospio pinnata*, Tubificidae spp., *Lumbrineris meteroana*, *Aphelochaeta* sp. 1, *Diopatra monroi*, *Syllidia armata*, Verellidae sp., *Callianassa australis*, Hutchinsoniellidae sp. 1.

© NMP 2014

While *P. pinnata* and Tubificidae spp. characterised the macrofauna communities in terms of abundance, biomass was strongly dominated by the presence of the large polychaete *Diopatra monroi* that contributed on average 54.5% to the total biomass per site. This carnivorous polychaete can reach up to 150 mm in length and lives in a tube composed of hardened mud without shell fragments (Day 1967a). It is endemic to southern West Africa, where it can occur in dense concentrations of >500/m^2. The second most important biomass-contributor was the also relatively large *P. pinnata* (up to 60 mm, Day 1967b) contributing 20.5%, followed by the seapen (12%) and the sandprawn *C. australis* (4.6%). All other taxa contributed insignificantly to the biomass (<1% per taxa). This shows that more than 90% of the macrofaunal biomass consisted of five species only.

Species number ranged from 13 to 19 with highest numbers at SP1VS09 and SP1VS18 (Figure 6). Abundances varied from 126/0.035 m^2 at SP1VS07 to 464/0.035 m^2 at SP1VS20. The high abundance at the latter site was not due to any particular species being more dominant but rather all of the generally common species had higher densities there. Biomass ranged from as little as 0.6 g/0.035 m^2 at SP1VS04 to 9.3 g/0.035m^2 at SP1VS02. Species richness ranged from 2.1 to 3.3 and was highest at SP1VS09 and SP1VS02. Evenness and Shannon-Wiener diversity varied relatively little with both being highest at SP1VS03.

© NMP 2014

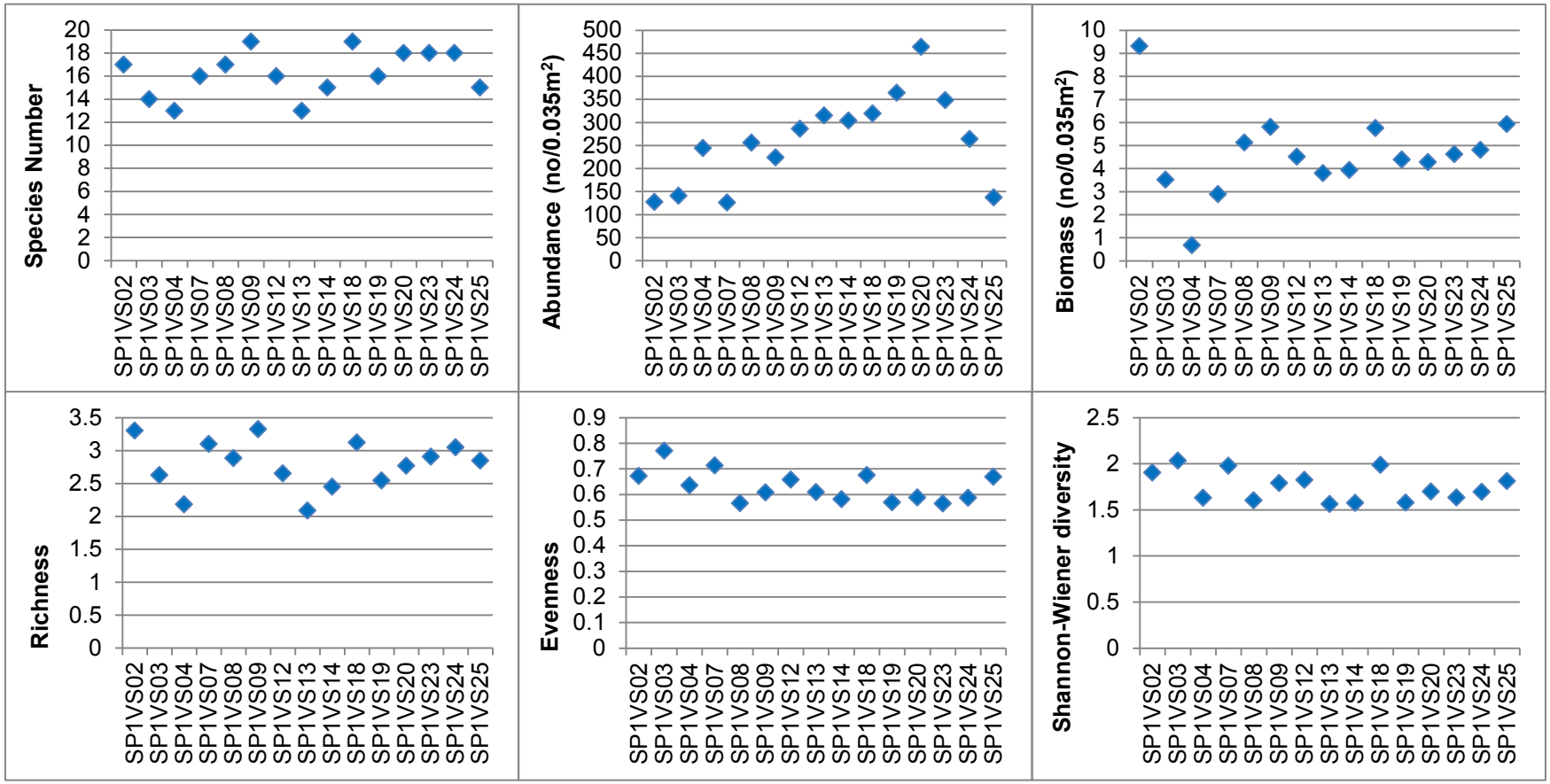


Figure 6: Macrofauna species number, abundance (no/0.035m^2), wet biomass (g/0.035m^2), richness, evenness and Shannon-Wiener diversity index at the verification survey sites.

© NMP 2014

The dendrogram on macrofauna abundances shows a very high similarity among all sites (average similarity 73%) (Figure 7). At the 70% similarity level, a clustering into two groups is noticeable, which is confirmed by both the MDS and PCO plots (Figure 7).

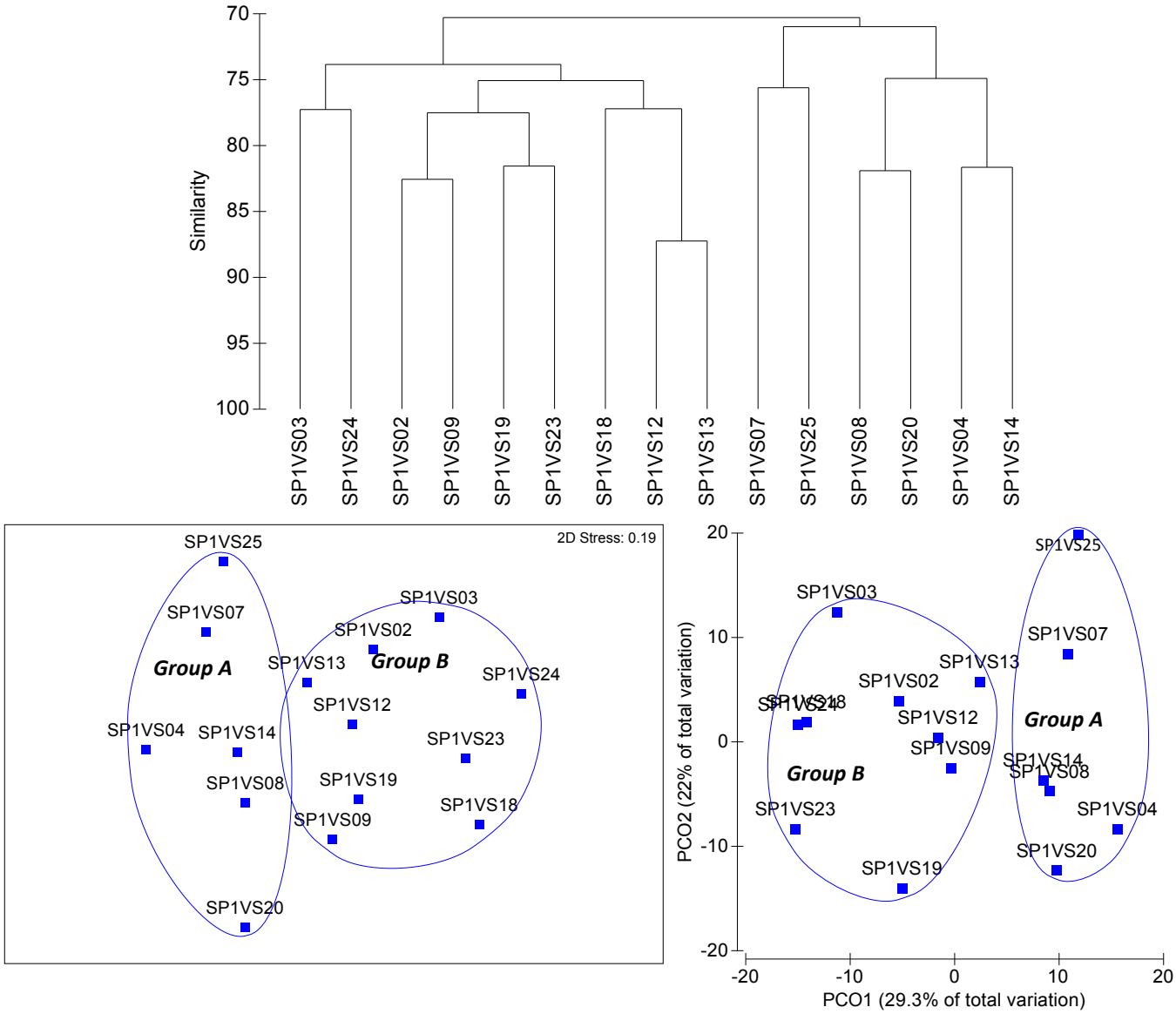


Figure 7: Dendrogram (top), MDS ordination (bottom left) and PCO (bottom right) plots of macrofauna abundances at the verification survey sites.
The circles in the MDS and PCO plots group sites at 70% similarity level. Stress value of the MDS plot is 0.19 and total variation explained by the first two axes in the PCO is 51.3%.

Figure 8 illustrates the sample clusters overlain onto the map of the verification survey sites, showing that Group A contains mostly the slightly shallower sites in the east of the survey grid with the exception of site SP1VS09. Sites SP1VS07 and SP1VS08 also fall into this group. Group B encompasses the western sites and SP1VS09. However, with only a minimal increase in similarity level (*i.e.* 75%) each group splits into smaller groups or individual sites, rendering the significance of this grouping questionable. Highest similarity of any two sites is between SP1VS12 and SP1VS13 at 87%. Not surprisingly, the species that contributed most to the similarity among the samples are *P. pinnata* (15%) and Tubificidae spp. (14%). This is followed by *Aphelochaeta* sp. 1 (11%), *Lumbrineris meteroana* (10%), *Diopatra monroi* (9%), and *Syllidia armata* (8%).

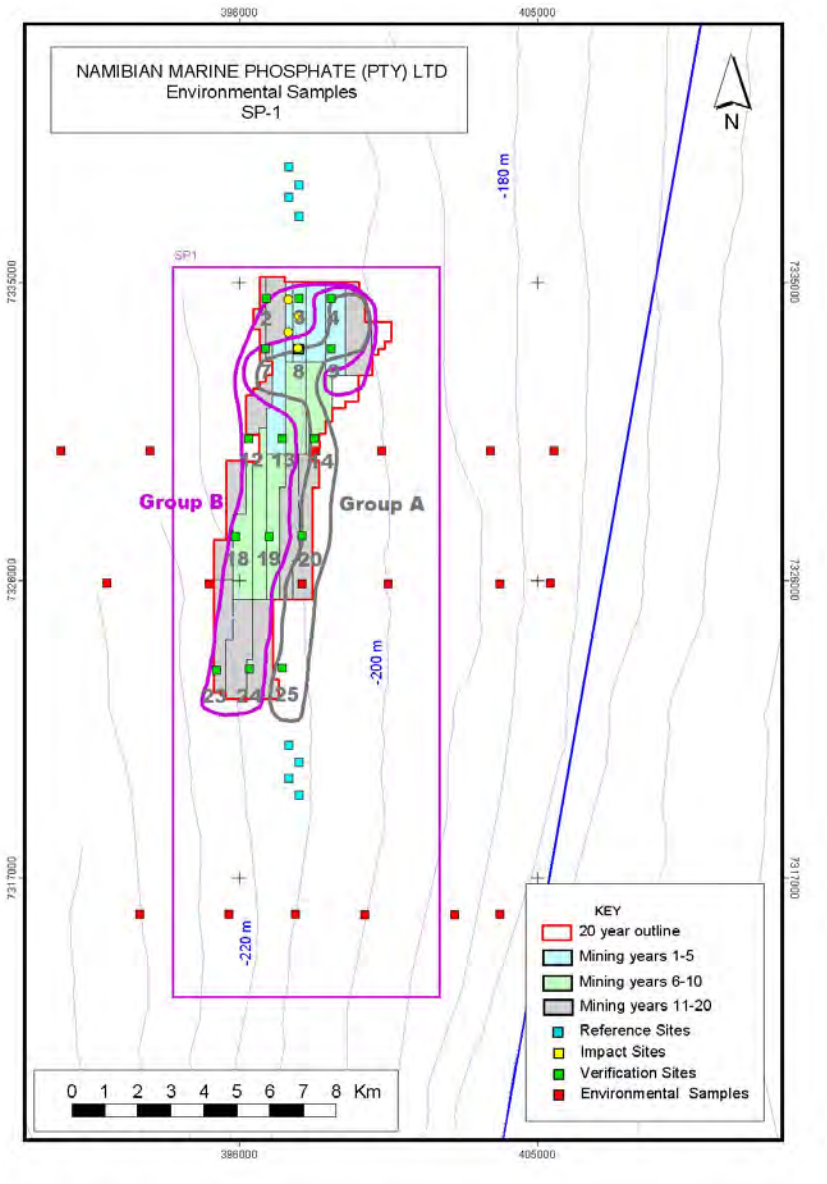


Figure 8: Sample groups as identified by the dendrogram, MDS and PCO plots overlain on the macrofauna survey verification sites (green squares) in SP-1.

Sediment characteristics and associated heavy metal concentrations are discussed in detail in the Verification Survey Report on Sediment Properties (Lwandle 2014). Here only a short description of the sedimentary environment is provided. Surficial sediments in SP-1 can generally be classed as silty sand with an average median (D_{50}) sediment particle size of 114.39 µm and low porosity implying a firmly packed sediment with low pore water volumes. Surficial sediment layers frequently included dense shell layers, which were denser on the eastern boundary of the survey area than further to the west (Lwandle 2014). With the exception of SP1VS18, the measured particle size distributions were relatively similar at the sites being dominated by medium and fine sand with a steady decline towards the smaller grain sizes (Figure 9).

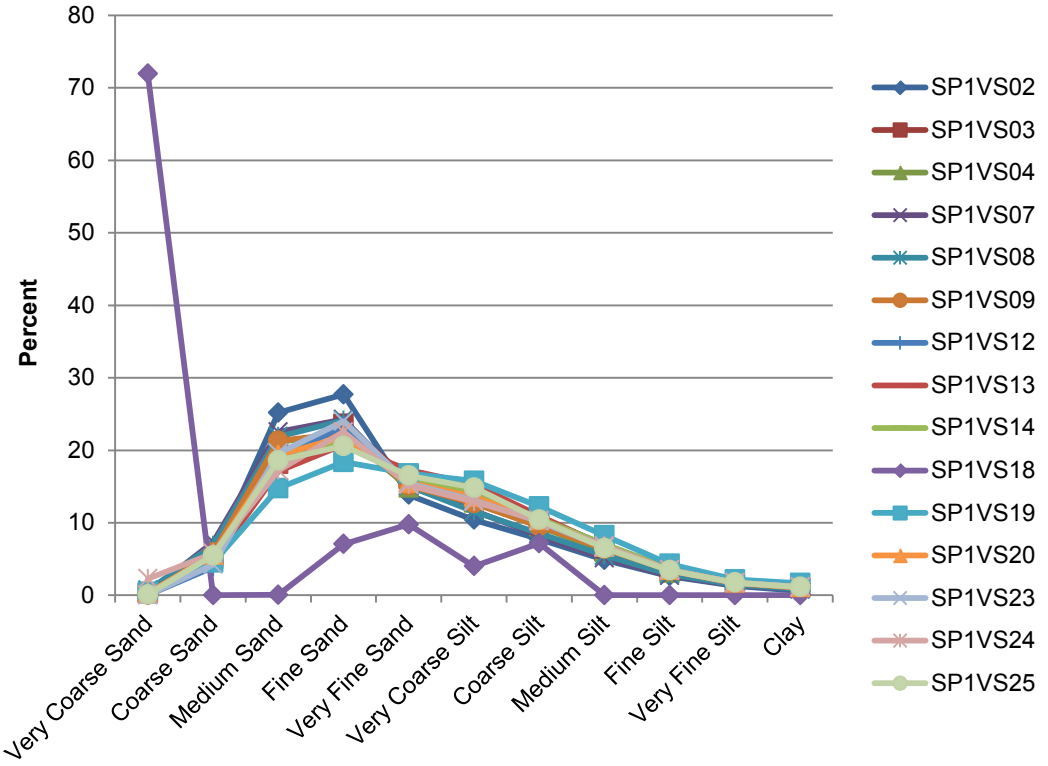


Figure 9: Sediment grain size distribution at the verification survey sites.

The combined fractions of <63 micron, *i.e.* the mud fraction, yielded around 30% while clay generally contributed <2%. In contrast to all other sites, SP1VS18 was highly dominated by very coarse sand (>70%). The PCO plot on sediment properties confirms the outlying position of SP1VS18, which is illustrated by the PCO1 axis explaining 86.2% of the total variation (Figure 10). Along the second axis PCO2, there is a gradual shift apparent from the northern sites (SP1VS02 – SP1VS09) that are slightly more dominated by fine, medium and coarse sands to two sites in the centre of the survey grid, SP1VS13 and SP1VS19, which have higher proportions of coarse silt. The southern sites are positioned in the middle of this gradient. However, PCO2 only adds 11.8% in explaining the variation in the sediment pattern.

© NMP 2014

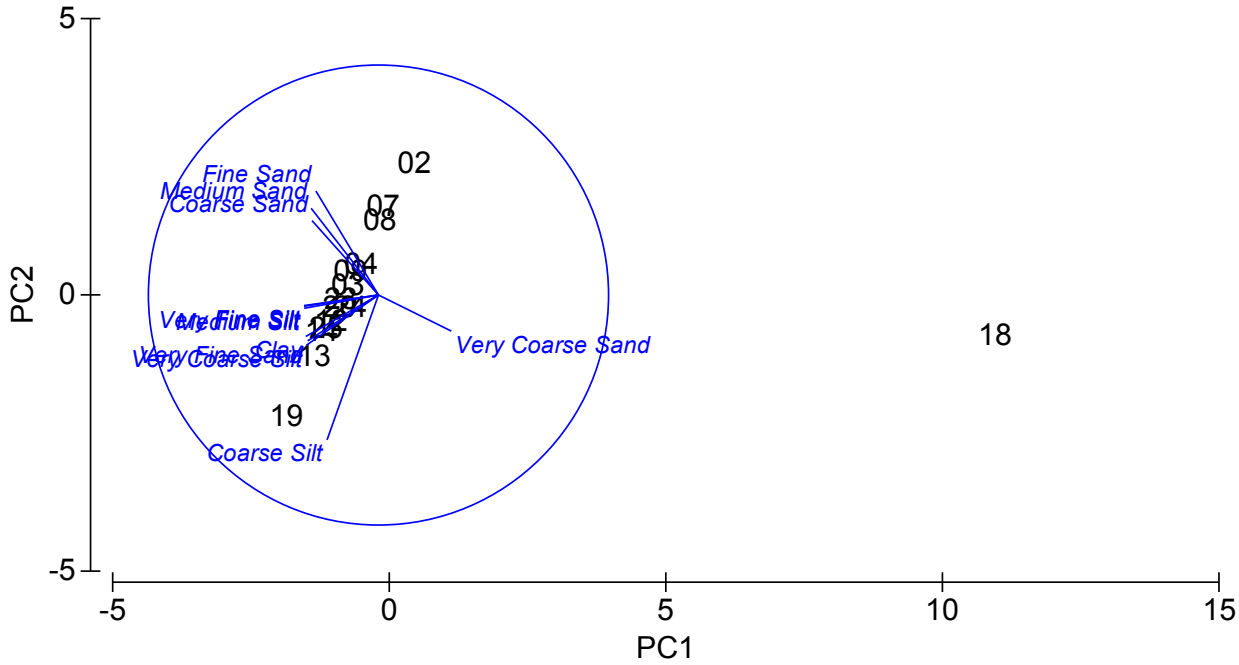


Figure 10: PCO plot of the sediment grain size fractions at the verification survey sites.
The first two axes explain 98% of the variation in the sediment pattern. The blue lines are vectors that correspond to the Pearson correlations of individual variables with the PCO axes. Note that to enhance visual clarity the site names are abbreviated to the numbers only.

Organic matter content in the sediments was on average 6.6% (see Table 2). Molar C:N ratios were high (average of 11.39), which is indicative of very refractory organic matter (Lwandle 2014). With the exception of manganese and mercury, heavy metal concentrations in the surficial sediment layers were generally lower compared to the underlying sediments (concentration values in the underlying sediments are provided in Lwandle 2014). Five of the heavy metal concentrations exceeded the toxicity effect concentration thresholds for the region as defined in the BCLME sediment quality guideline (BCLME 2006); however, as explained below it is considered that these levels do not necessarily represent the bioavailability levels of heavy metals in the sediment (Lwandle 2014). Chromium and copper were higher than the recommended guideline level (equivalent to the threshold effect level (TEL) above which toxicity effects may occur) while arsenic, cadmium and nickel exceeded the probable effect level (PEL). The toxicity risk of these metals is primarily linked to whether the metals can be mobilised from the particulate into the dissolved form. Elutriation tests (simulating physical disturbance such as dredging) and simultaneously extracted metal (SEM)[3] tests both yielded low solubilisation values indicating low bioavailability of the heavy metals (Lwandle

[3] SEM is the amount of the simultaneously extracted divalent metals Cd, Cu, Ni, Pb and Zn extracted in the acid fraction along with AVS.

© NMP 2014

2014). Acid volatile sulphide (AVS)[4] was undetectable in the surficial sediments (*i.e.* below the detection limit of 0.2 mmol/kg) and at low concentrations (average of 1.67 mmol/kg) in the underlying sediments. The low or unmeasurable AVS concentrations in conjunction with the very low SEM values (0.14 and 0.15 mmol/kg for the surficial and underlying sediments, respectively) indicate that during the verification survey period hydrogen sulphide concentrations both in the surficial sediments as well as in the underlying sediments were very low if present at all (Lwandle 2014). The presence of nitrate-nitrogen in the subsurface sediment pore waters further suggests that the sediments were not sulphidic as nitrate-nitrogen and hydrogen sulphide do not coexist. Processes held responsible for this condition are the ambient seafloor current velocities (mean of 18 cm/s and 9 cm/s during the first and second period, respectively), which are more than sufficient to exert bottom shear stress forces that prevent accumulation of sedimenting particulate organic matter such as phytoplankton cells and zooplankton faecal pellets, from upper water column plankton communities (Lwandle 2014).

The DistLM test analyses the relationship between the macrofauna abundances pattern and the environmental predictor variables heavy metals, sediment fractions, organic matter and nitrogen. The sequential test provides a list of 13 environmental variables that best explain the distribution pattern of the benthic macrofauna communities (Table 4). At the top of the list is copper followed by a mixture of other heavy metals and some of the sediment fractions. Although the combined list of these environmental variables would explain close to 98% of the macrofauna distribution, only the contribution of the first variable copper is significant (p <0.05, highlighted in bold in the table). This indicates that only copper provides some significance to the macrofauna pattern, which is with only 15.9% relatively marginal.

[4] The acid volatile sulphide (AVS) in a sediment sample is the amount of sulphide, which is convertible to hydrogen sulphide (H_2S) and the amount that was present in the sediment as H_2S by acidification with HCL at room temperature. This represents the amount of free sulphide in the sediments *i.e.* sulphide that is not strongly combined with metals such as in iron pyrites.

© NMP 2014

Table 4: DistLM sequential test for macrofauna abundances at the verification survey sites with heavy metal concentrations, organic carbon, total nitrogen, and sediment fractions as predictor variables using step-wise procedure and adjusted R^2. Marginal tests are not shown. Nickel, medium sand, very fine sand, very coarse silt, medium silt, fine silt, and very fine silt are inter-correlated with other environmental data and are therefore excluded from analysis. Significant *p*-values are highlighted in bold.

Variable	Adjusted R^2	SS(trace)	Pseudo-F	*P*-value	Pro-portion	Cumulative %	Residual df
Copper (Cu)	0.093817	864.72	2.4494	0.0133	15.9	15.9	13
Coarse Sand	0.14969	614.24	1.8543	0.073	11.3	27.1	12
Log Iron (Fe)	0.18323	474.98	1.4927	0.1691	8.7	35.8	11
Arsenic (As)	0.2491	574.8	1.9649	0.0616	10.5	46.4	10
Zinc (Zn)	0.32056	543.12	2.0519	0.0592	9.9	56.3	9
Coarse Silt	0.39091	483.94	2.0395	0.0885	8.9	65.2	8
Vanadium (V)	0.45814	420.61	1.9925	0.0882	7.7	72.9	7
Very Coarse Sand	0.51891	353.17	1.8844	0.1353	6.5	79.4	6
Cobalt (Co)	0.55168	251.25	1.4386	0.2443	4.6	84.0	5
%Total Nitrogen	0.62332	286.29	1.9509	0.1266	5.3	89.2	4
Chromium (Cr)	0.663	193.12	1.4709	0.2739	3.6	92.8	3
Mercury (Hg)	0.6834	147.18	1.1933	0.3809	2.7	95.5	2
Cadmium (Cd)	0.70958	133.54	1.1803	0.4539	2.5	97.9	1

This apparent low relationship between the macrofauna pattern and environmental condition is most likely due to the facts that, firstly, the 15 verification survey sites are very similar in their macrofauna communities and, secondly, the environmental conditions also do not vary greatly among the sites (see Table 2, Figures 9 and 10). In other words, the 20-year mine zone of SP-1 has a generally uniform environment both benthic and oceanographic, which is not surprising given its small scale. As there is little variation in macrofauna distribution and little variation in the environmental variables, there is no ground (nor need) to evoke a causal relationship between the two. This does not mean that heavy metals and/or sediment characteristics are not influencing the macrobenthic communities at the verification survey sites, just that this can only be explored when these sites are being compared to sites with different macrofauna distribution patterns (and then presumably different environmental conditions).

As stated above, the biomass was strongly dominated by one species, the large polychaete *D. monroi*. This strong single-species dominance is exemplified by the Abundance/Biomass curves where the biomass curves lie clearly above the abundance curves in most plots and barely touching at SP1VS13, SP1VS14, SP1VS19 and SP1VS20 with $W = 0.098$, $W = 0.082$, $W = 0.074$, and $W = 0.066$, respectively (Figure 11). According to the principle of the ABC plots, this indicates that the macrofauna communities at the verification survey sites are largely undisturbed.

The central Namibian shelf is characterised by the occurrence of persistent natural shelf hypoxia, which is referred to as the oxygen minimum zone (OMZ). OMZs are defined as regions where oxygen concentrations are permanently <0.5 ml/ℓ (or about 7.5% saturation; ~0.7 mg/ℓ). On the Walvis Bay margin, there are two shelf breaks at about 150 m and 300-400 m depths, which effectively divide the shelf into an inner and outer shelf. A significant feature of the inner shelf is an extensive mud belt comprising organically rich diatomaceous oozes originating from planktonic detritus, which extends over 700 km in an N-S direction in approximately 50-150 m water depth and is the core of the OMZ. The licence area is located on the outer shelf beyond the inner shelf break, and thus

© NMP 2014

offshore of the diatomaceous mud belt. The baseline survey and benthic specialist study have described that the target area SP-1 lies at the southern offshore fringe of the OMZ (Steffani 2010a, 2012). Based on extrapolations from data from the surrounding region, the studies further deduced that the area is probably affected by low dissolved oxygen levels (<0.5 ml/ℓ) at the bottom but typically not anoxic conditions or the presence of critical H_2S levels. This is now confirmed by empirical data collected directly from SP-1. The time series measurements of near sea floor oxygen concentrations during the two verification survey periods in June and August 2013 were for most of the time highly hypoxic <0.5 mg/ℓ (mean = 0.3 mg/ℓ) but increased to ~1.10 mg/ℓ during a ventilation event and the combined results from the AVS and SEM tests negate the presence of significant H_2S levels (Lwandle 2014).

The macrofauna communities in the SP-1 are shaped by these low oxygen conditions in the area, which is exemplified by the dominance of *P. pinnata*. This spionid polychaete typifies oxygen-constrained environments worldwide (e.g. Gutiérrez *et al.* 2000, Gallardo *et al.* 2004, Lim *et al.* 2006, Zettler *et al.* 2009) and is classified as resistant to severe hypoxia (Diaz & Rosenberg 1995). The extremely low abundance of crustaceans is also in common with other low oxygen environments around the world (e.g. Gutiérrez *et al.* 2000, Levin *et al.* 2000, 2009, Gallardo *et al.* 2004, Lim *et al.* 2006, Gooday *et al.* 2009). This was also described in the original baseline study (Steffani 2010a). However, the macrobenthos has also some elements that are not typical for permanent low oxygen habitats or OMZs such as the abundance of a variety of large species (e.g. *D. monroi*) that clearly dominate the biomass and the results from the ABC plots indicating a mostly undisturbed environment. The verification survey has shown that during the survey period, extreme hypoxic conditions were not permanent but that ventilation processes periodically increased oxygen concentrations to almost oxic levels (oxic defined as >1.43 mg O_2/ℓ or 1 ml O_2/ℓ as per dissolved oxygen concentration nomenclature adopted in Levin (2003)). This suggests that while low oxygen conditions are likely to be an important factor influencing macrofauna distribution in SP-1, other factors such as organic matter quantity and quality and/or sediment texture may play an equally or even a more important role. For example, for the Pakistan margin oxygen thresholds were found at around 0.12-0.20 ml/ℓ (~0.17-0.29 mg/ℓ), below which most animals were excluded through physiological intolerance to hypoxia, but above which most taxa were present in fully bioturbated sediments whereby oxygen levels interacted with organic matter to generate faunal transitions (Levin *et al.* 2009). The availability of both oxygen and organic carbon seem to determine the richness of macrofaunal species in low oxygen environments until the oxygen content rises to about 0.45 ml/ℓ; above that level, oxygen is much less important (Levin & Gage 1998).

© NMP 2014

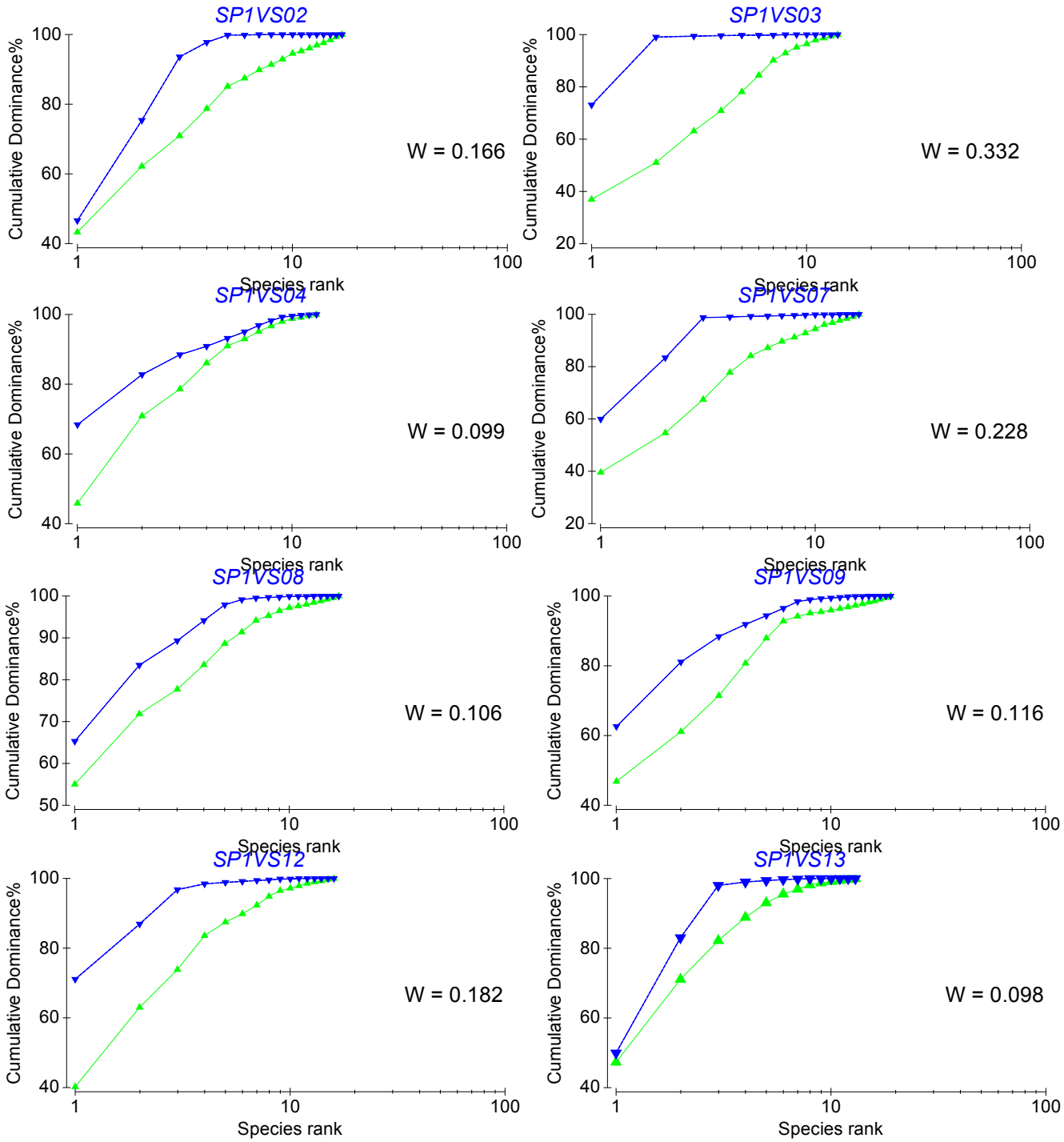


Figure 11: Abundance/Biomass Comparison (ABC) curves of the verification survey sites.
▼ = Biomass, ▲ = Abundance.

© NMP 2014

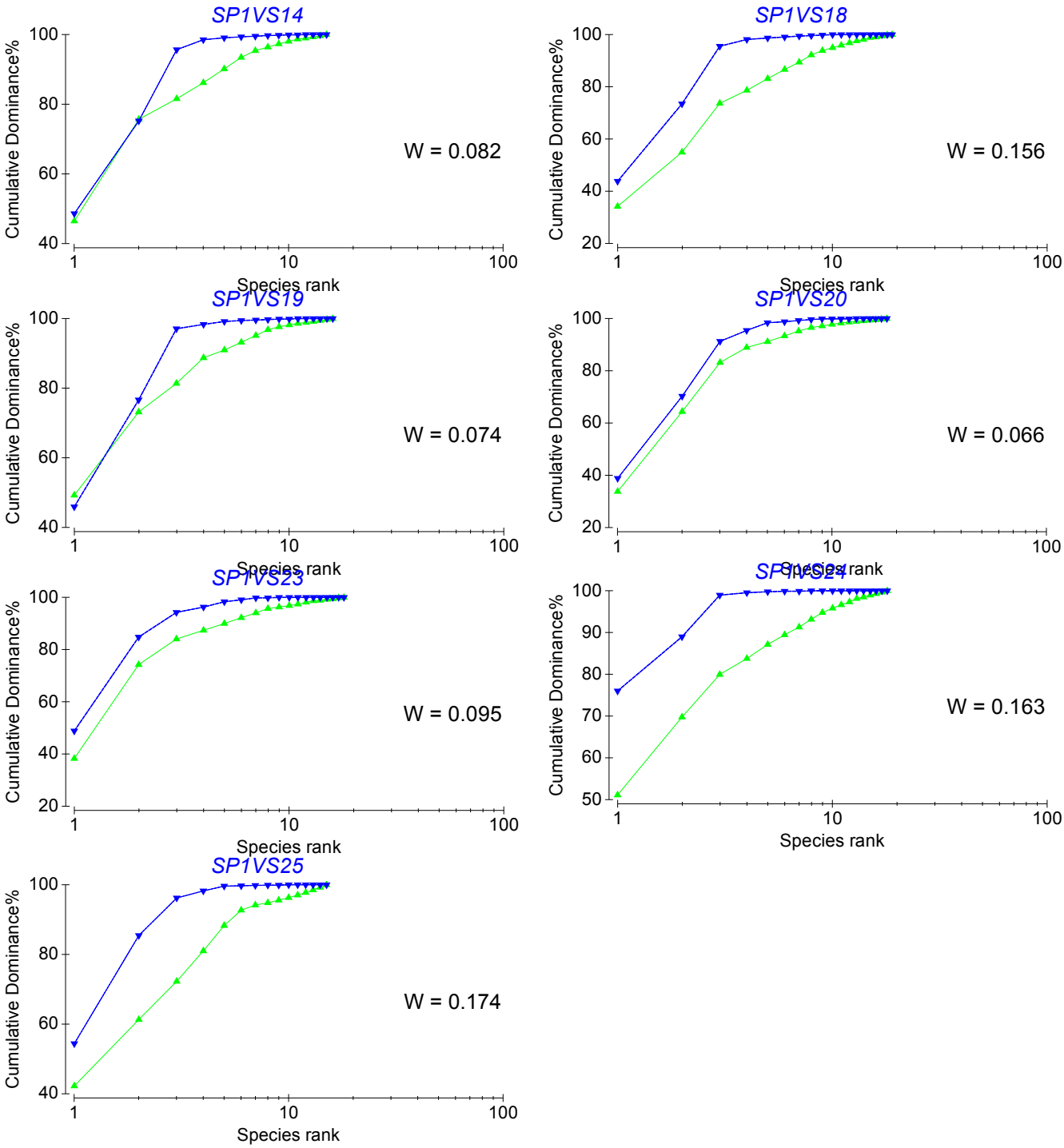


Figure 11: continued.

While the verification survey shows that HS^- flux from the sediments in SP-1 would be minimal this conclusion is based on conditions measured in the austral winter (July/August), and it has to be kept in mind that this could change in mid to late summer when low oxygen conditions are generally more pervasive on the Namibian central continental shelf (Monteiro 2014 in Lwandle 2014). However, as noted in Lwandle (2014) the main factors controlling the development of sulphidic sediments in the region are deposition and retention of fresh pelagically produced particulate organic matter. This is strongly influenced by the near seabed currents and the regional data cited in Lwandle (2014) indicate these are sufficient to prevent such deposition and thus the potential for the development of strong sulphide fluxes is considered to be low. Further, the presence of large polychaetes such as *D. monroi* may be an indicator whether conditions deteriorate to such an extent during the summer months that anoxia and/or toxic H_2S levels occur. Members of the genus *Diopatra* produce relatively large eggs and most species including *D. monroi*, deposit the eggs inside the parental tube where they undergo direct development until the young are large enough to leave the tube. In fact, many of the specimens collected in this survey had larvae in their tubes (pers. obs.). No information could be found on the life span of *D. monroi* but another brooding species of the genus, *D. marocensis*, is for example reported to have a life span of at least two years (Arias *et al.* 2013). The presence of large mature adults of this polychaete may thus suggest that in the summer prior to the verification survey, conditions had not gone below its oxygen threshold limit, *i.e.* gone anoxic or H_2S toxic. Adult *D. monroi* were also recorded from the 2010 baseline survey (Steffani 2010a).

2.2.3 Comparison with the 2010 Baseline Data

Figure 12 illustrates the location of the verification survey sites in relation to the three cross transects that were sampled during the macrofauna baseline survey in 2010. The northern and middle transects are in the same section of SP-1 as the verification survey sites, whereas the southern transect is approximately 7 km to the south. Each transect comprised of six sites along a depth gradient from 175 m in the east to 240 m in the west whereby each site was sampled with five replicates (N = 6 per transect, N = 5 per site). The verification survey sites, on the other hand, were sampled without replication (N = 1 per site). As the 2010 baseline survey was sampled with a 1000-µm sieve, only the >1000 µm fraction of the verification survey sites are used for comparison purposes. These >1000 µm fractions were further scaled up to 0.2 m^2, which is the sample size of the 2010 data that were taken with a Van Veen grab.

As previously reported on in the baseline study (Steffani 2010a) and illustrated by both the dendrogram (Figure 13) and the MDS plot (Figure 14) in this report, there is a marked gradient of the 2010 samples according to depth as well as a distinct separation of the samples from the northern transect (green symbols) to those from the middle and southern transects (red and blue symbols). The grouping according to depth was related to accompanying changes in sediment composition but differences in sediment properties could not explain differences in macrofauna composition between the northern and the two more southern transects. It was suggested that this grouping difference may have been related to differences in oxygen and/or hydrogen sulphide concentrations as a H_2S smell was noted from the shallower stations of the latter two transects, especially from the southernmost transect. However, no measurements had been taken and this could thus not be corroborated. It has to be kept in mind that a H2S smell is not conclusive as humans are very sensitive to hydrogen sulphide gas and can smell it at concentrations as little as <1 µmol.
Almost all the species found at the verification survey sites had also been recorded from the baseline survey sites with the exception of five polychaetes, namely *Syllidia armata*, *Paracabira capensis, Paradoneis* ? sp. 1, *Hesiospina* sp, and *Prionospio* sp. On the other hand, a total of 23 species that were encountered at the baseline sites had not been recorded from the verification survey sites. This

is clearly due to the smaller number of samples of the verification survey (N = 15) compared to that of the baseline survey (N = 87).

At the 40% similarity level, the verification survey sites clearly group with the northern most 2010 transect, while the samples from the middle and southern transects separate into two other groups, parted by depth (Figures 13 and 14). At a higher similarity level of 60%, most of the verification survey sites split from the samples of the northern transect, but from the two-dimensional MDS plot (Figure 14) it is apparent that the verification survey sites, with water depths from 209-227 m, group along the vertical axis with the 2010 samples from 215-230 m depth.

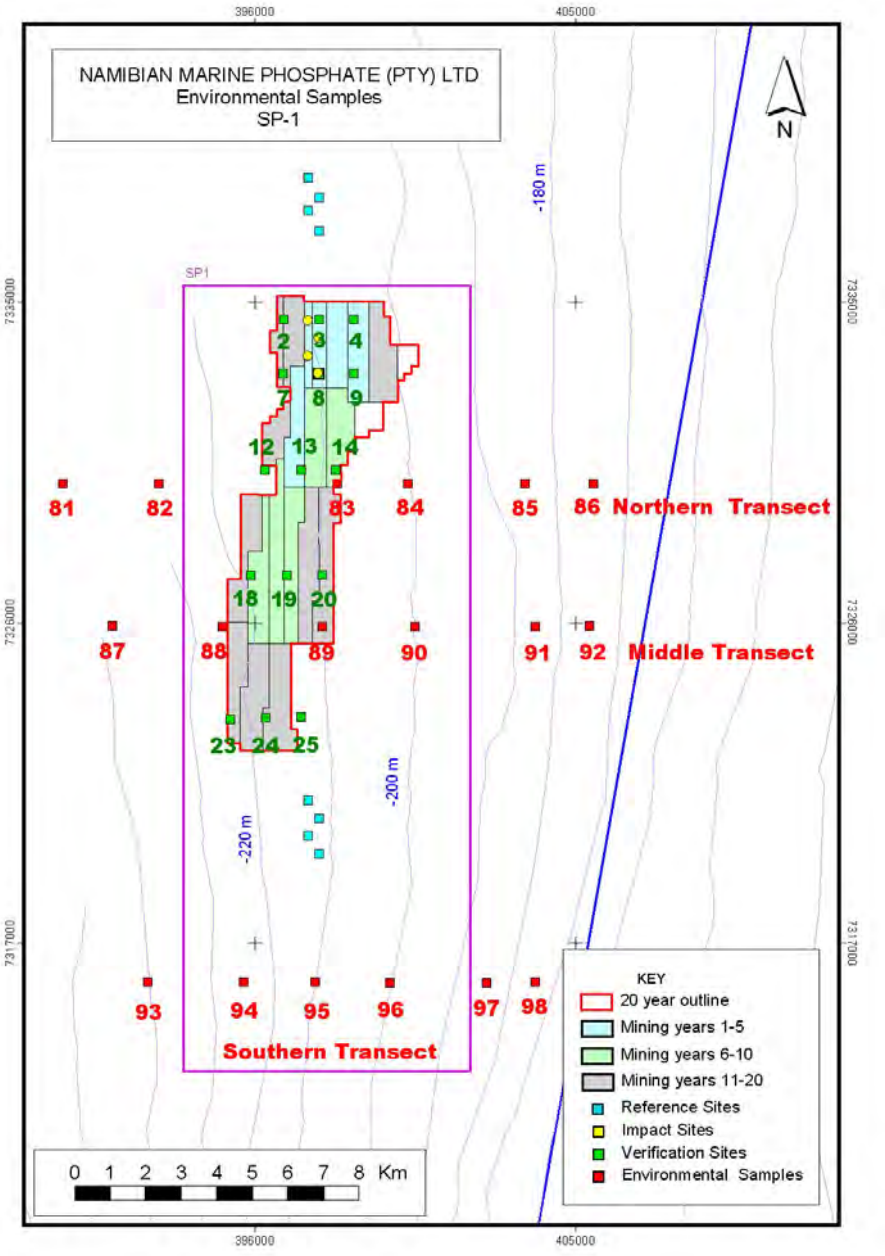


Figure 12: Location of the verification survey sites (green squares and labelled in green) in relation to the three 2010 macrofauna baseline survey sampling transects with six stations each (red squares and labelled in red).

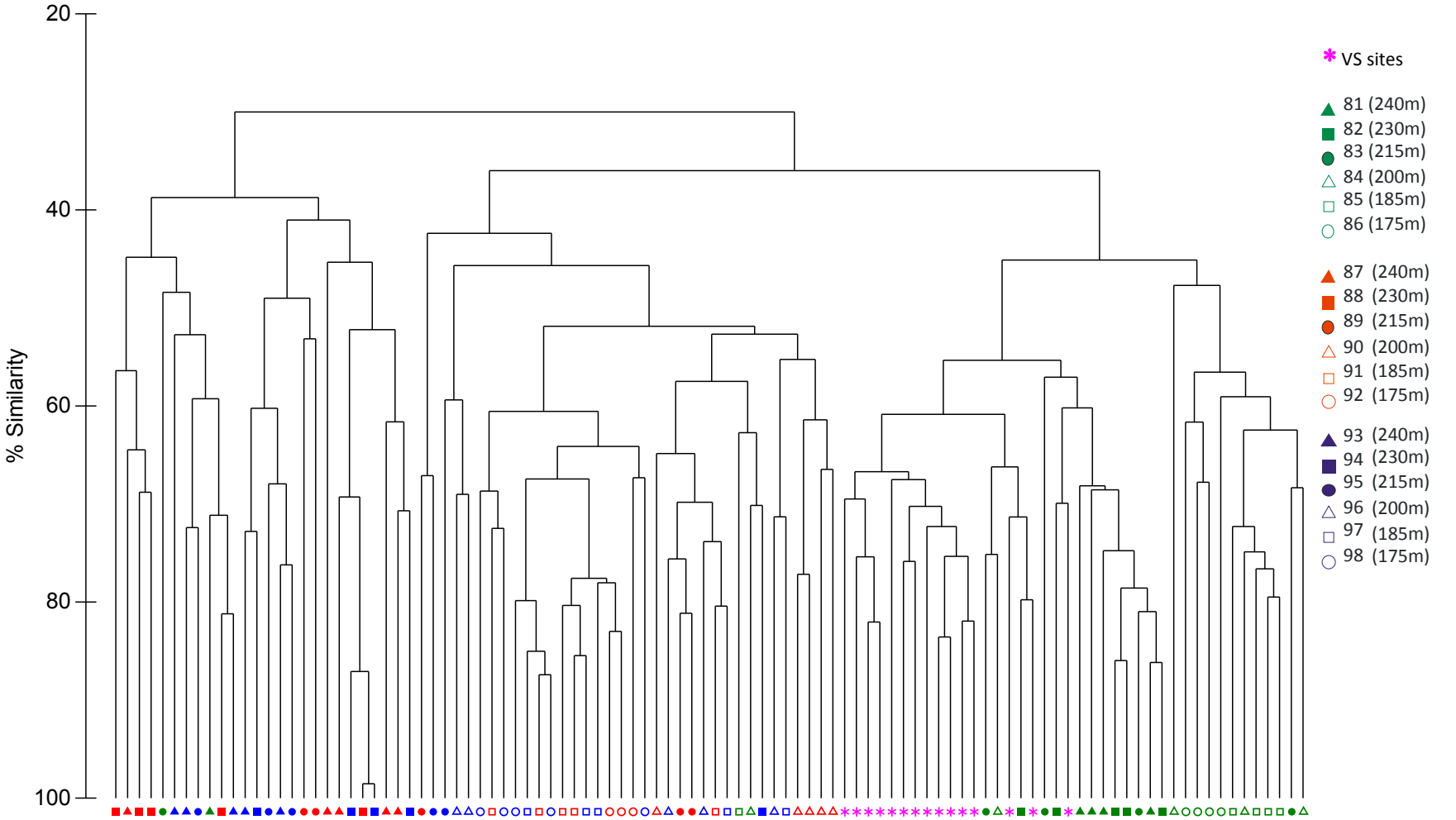


Figure 13: Dendrogram of macrofauna abundances at the verification survey (VS) sites and the baseline sites sampled in 2010 (81-98, water depth in brackets).

© NMP 2014

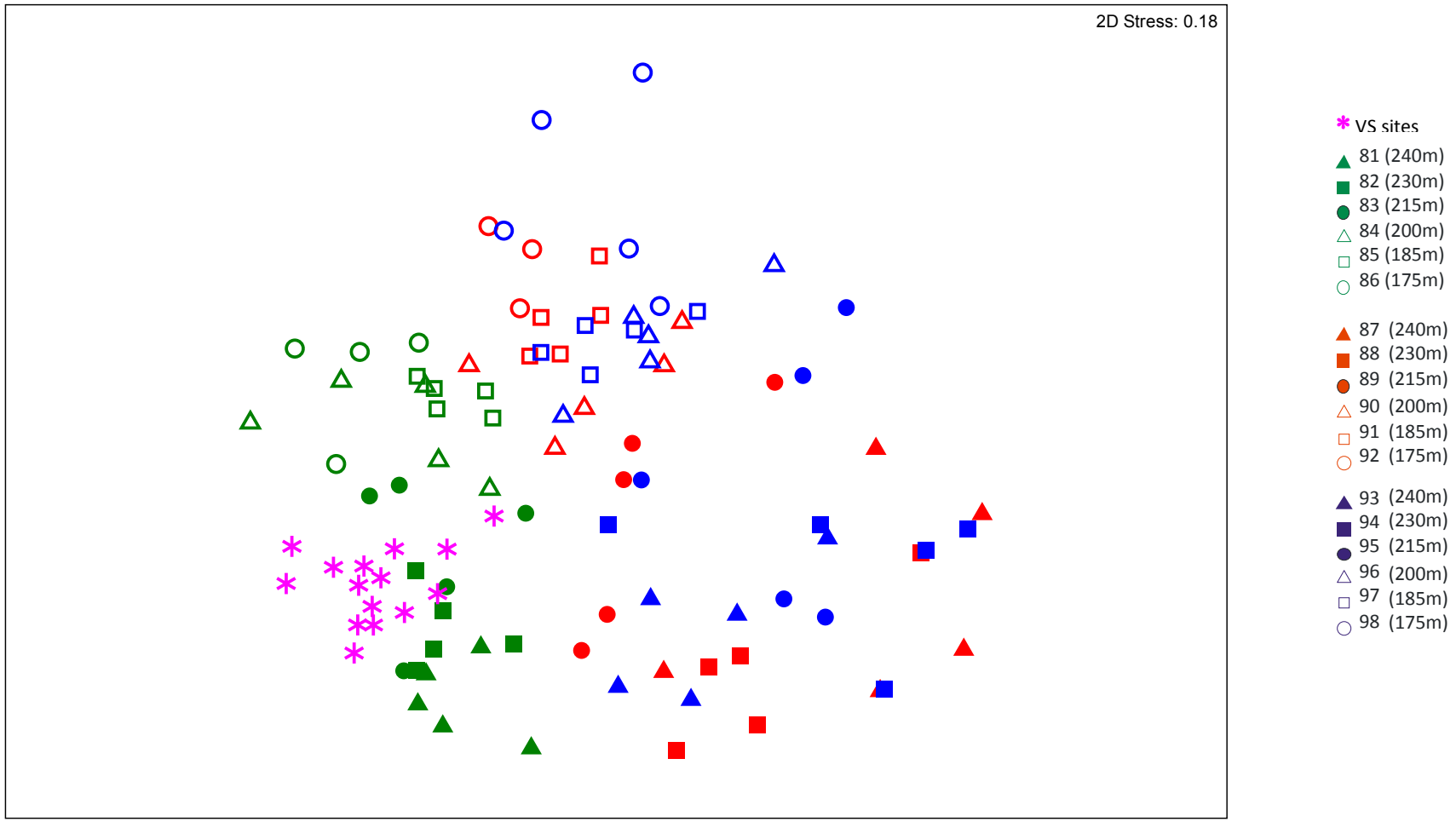


Figure 14: MDS ordination of macrofauna abundances at the verification survey (VS) sites and the baseline sites sampled in 2010 (81-98, water depth in brackets).

© NMP 2014

Comparing the population diversity measures shows that the verification survey sites have very similar species numbers, biomass, richness, evenness and Shannon-Wiener diversity values to those from the northern 2010 transect (Figure 15). The biomass outliers at sites 84 and 90 are due to the presence of a single large starfish (Asteroidea) each per one replicate sample. Abundances at the verification survey sites and along the northern transect are somewhat more varied with highest average abundances at the verification survey sites. In contrast, the middle and southern transects differed in their diversity values, being generally lower than at the verification survey sites or the northern transect with the exception of evenness.

The SIMPER analysis determines which taxa/species are primarily responsible for dissimilarities between the verification survey sites and the three cross transects from the baseline survey (Table 5). The dissimilarity between the verification survey sites and samples from the northern transect was only 36.9%, and is primarily related to higher abundances of Tubificidae spp. at the verification sites, the absence of the polychaete *Syllidia armata* from the northern transect, but the absence of two other polychaetes and the bivalve *Tellina gilchristi* from the verification sites. In contrast, dissimilarities between the verification sites and the middle and southern transects was higher with 52.4% and 50.0%, respectively. The dissimilarities between these transects and the verification sites are largely due to the same suite of species. Again Tubificidae spp. were more abundant at the verification sites, *Syllidia armata* absent from the transect samples, and *Tellina gilchristi* absent from the verification sites. Furthermore, *P. pinnata* and *D. monroi* were more abundant at the verification sites than at the transect sites.

In general, the results of the diversity-measure comparison and the SIMPER analysis agree with the benthic distribution pattern observed from the hierarchical cluster dendrogram and the MDS plot (see Figures 13 and 14) confirming the grouping of the verification survey sites with the samples from the northern transect, specifically those from similar depth, and the separation to the middle and southern transects.

© NMP 2014

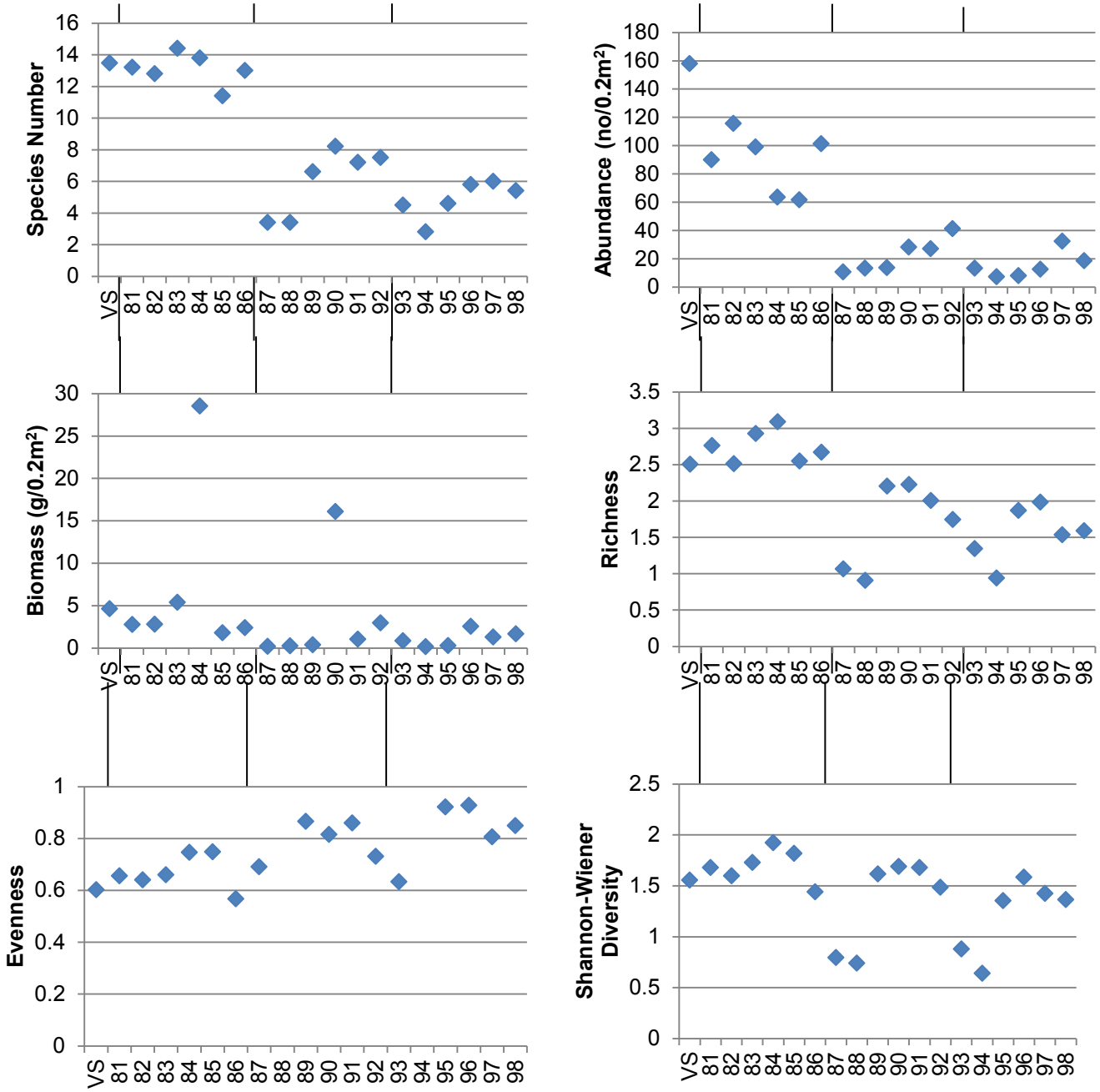


Figure 15: Diversity indices at the verification survey sites from 2013 (average of the 15 sites) and the 2010 baseline survey sites (average of five replicates per site). The vertical lines separate the verification survey (VS) sites from the northern (81-86), middle (87-92), and southern (93-98) transects.

© NMP 2014

Table 5: Results of the SIMPER tests
showing the first five species responsible for the dissimilarities between the verification survey sites (VS) and baseline survey sites from the Northern Transect (NT) (Table A), the Middle Transect (MT) (Table B), and the Southern Transect (ST) (Table C) from 2010. Tests were done on 4th-root transformed data.

Table A	**Average Abundance NT**	**Average Abundance VS**	**Contribution %**	**Cumulative contribution %**
Tubificidae	1.22	2.66	5.42	5.42
Syllidia armata	0.00	1.34	5.04	10.46
Ampharete sp.	1.33	0.00	4.99	15.45
Tellina gilchristi	1.10	0.00	4.14	19.59
Spiophanes soederstromi	1.05	0.00	3.93	23.52

Table B	**Average Abundance MT**	**Average Abundance VS**	**Contribution %**	**Cumulative contribution %**
Tubificidae	0.65	2.66	7.34	7.34
Syllidia armata	0.00	1.34	4.90	12.25
Paraprionospio pinnata	1.68	2.84	4.23	16.47
Tellina gilchristi	1.12	0.00	4.08	20.56
Diopatra monroi	0.75	1.78	3.74	24.30

Table C	**Average Abundance ST**	**Average Abundance VS**	**Contribution %**	**Cumulative contribution %**
Tubificidae	0.70	2.66	7.88	7.88
Syllidia armata	0.00	1.34	5.38	13.26
Paraprionospio pinnata	1.62	2.84	4.86	18.11
Diopatra monroi	0.74	1.78	4.16	22.27
Tellina gilchristi	1.01	0.00	4.04	26.30

© NMP 2014

3 CONCLUSIONS AND MONITORING RECOMMENDATIONS

The Benthos Specialist Study (Steffani 2012) conducted within the framework of the EIA (Midgley 2012) identified impacts on the benthic communities that can be expected from the proposed Sandpiper Phosphate Project, and assessed their significance. For many of these impact assessments, the confidence levels were only medium as data directly from the target area were lacking. The verification survey was specifically designed to tackle this issue, and to verify whether the assessments will remain in view of the newly acquired empirical data. These data were primarily of biogeochemical nature and are dealt with in the Verification Survey Report on Sediment Properties (Lwandle 2014). Below follows a list of the impacts as they were assessed in the original benthic impact study (Steffani 2012). Any changes in the assessments due to the verification survey results are ***highlighted in blue*** in the appropriate tables.

A total of nine negative impacts were identified in the original assessment study with one impact having medium significance, one low to medium, and seven low significance. In sum, all changes to the original assessments centre on the level of confidence, increasing the level from medium to high as the verification survey largely confirmed the assumptions on which the assessments were based. This applied to five of the impact assessments while four remained unchanged.

3.1.1 Monitoring Recommendations

A macrofauna monitoring programme needs to be established, whose principle objective is to study the rate of recovery of disturbed macrofaunal communities once the mining activity has ceased in a particular mine block. Recovery has been shown to be both spatially and temporally variable, and to confidently measure the ecological recovery rate of mined areas, it is therefore necessary to develop a benthic monitoring plan that is not only appropriate in the medium-term (~5 years), but has the flexibility and potential to be extended into the long-term.

The key questions for the *monitoring programme* are the following:

- What is the rate of recovery of the physical environment e.g. in-filling of mined-out areas with unconsolidated sediments?
- What is the process of the recovery of the benthic macrofauna?
- How long after the disturbance does it take for the benthic community to recover to at least an ecologically functional community?
- How does the physical environment (e.g. sediment particle size, organic matter, dissolved oxygen) influence the recovery rate?

In identifying and assessing the impacts of phosphate mining on the macrobenthic communities, it is important to recognize that the marine environment can be very variable both in space and time. An impact should not therefore be characterized as being the difference in some measure at a particular site before and after a disturbance, but should be distinguished as being the relative difference between changes at a disturbed/impact site compared with changes that have occurred in a similar undisturbed reference site (Underwood 1992, 1993, 1994). In other words there must be some change from before to after a disturbance and such change must be significantly different from what occurred in undisturbed reference areas. Community parameters, however, vary both spatially as well as with time, fluctuating in response to natural variations in the environment (these may be monthly, seasonal or annual variations). Without adequate indices of natural variability, it will be

inherently difficult to place mining-related impacts in context. It is therefore important to have a number of impacts sites in association with a number of reference sites that are in a similar environment (e.g. depth and sediment texture) but will remain undisturbed over the period of the monitoring programme.

Figure 1 in the introduction chapter of this report illustrates the position of the monitoring sampling stations. For operations in SP-1, four impact stations and four associated reference sites to the north and four to the south of the 20-year mining areas were selected. The reference sites to the north are located outside of SP-1 and >2 km from any proposed mining activities but some concern was voiced that the sites could still be affected by sediment plumes generated during mining. Therefore four reference site were also selected downstream of the mining areas in the south of SP-1. Although they are located in SP-1, mining will focus on the north of SP-1 and the reference sites will thus not be affected by the activities. The pre-mining baseline survey was undertaken in July/August 2013, coinciding with the verification survey and utilising the same macrobenthos collection method as described in this report. At each site, five replicate samples were taken. Included in the sampling procedure was sampling for sediment properties (*i.e.* grain size analysis) as well as near-bottom dissolved oxygen concentrations and organic matter content. The impact sites have been selected according to the currently proposed mine schedule to fall into the mine blocks that will be mined in Year 1 and Year 2 of the schedule (see Figure 1). This ensures that any information on recovery process can be collected as early as possible to inform the Environmental Management Programme.

Following commencement of mining, sampling of both impact and reference sites should be undertaken at regular intervals after completion of dredging to determine the (functional) recovery rates of the benthic communities. One of the basic assumptions of developing a benthic monitoring program is that recovery of disturbed macrofaunal communities does in fact occur. The process and time of recovery is, however, strongly dependent on the rate of the in-filling of sediment in the mined-out areas, and the type of sediment. A wide range of recorded recovery rates highlight the inherent difficulties in the application of general impact/recovery predictions to sites with varying environmental characteristics (Robinson *et al.* 2005). It is recommended that high resolution geophysical surveys (e.g. side scan sonar) are conducted immediately after dredging, and 2-3 years post-dredging (and potentially at later years depending on the results) to determine the depth of the dredged trenches and the sediment infilling-rates. Depending on the geophysical survey results, it is assumed that the first post-dredging survey can be conducted 2-3 years after cessation of dredging (three years for Target Block 1 and two years for Target Block 2 of the SP-1 resource). The subsequent sampling interval can best be determined after the first post-dredging sampling campaign, but an appropriate interval may be every 2-3 years. Periodically reviewing the monitoring plan as new data are collected and analysed will ensure that the monitoring plan and associated sampling schedule remains a dynamic process.

Traditionally, the ecological recovery of the disturbed seafloor has been defined as the establishment of a successional community of species, which progresses towards a community that is similar in species composition, population density and biomass to that previously present. Measures used to assess recovery typically include biodiversity analysis such as the numbers of species and/or individuals in an assemblage. However, this approach presents a number of challenges, especially when the physical characteristics of the sediment have been altered to such an extent that it can no longer accommodate its original assemblage. Recovery in the sense of the above definition may thus not be achieved (only when the sediment properties revert to their original state). For this reason, it may be more sensible to consider the functional capacity (or health) of the ecosystem rather than simply the range and proportion of species present. Some ecosystem functions can be undertaken

© NMP 2014

by a variety of different organisms, leading to the notion of possible functional redundancy, whereby the loss of a particular species may not affect the basic functioning of an ecosystem as long as the function performed by that species is taken up by another species from the same functional group. To address this issue, many studies have recently focussed on functional diversity to assess macrofaunal recovery following anthropogenic perturbations by incorporating biological differences among species showing that function- or trait-based diversity metrics (based on functional traits such as feeding mode, mobility, attachment, adult habitat, larval type, relative adult size, etc.) may represent appropriate additional methods for assessing changes in ecosystem function (e.g. Borja *et al.* 2003, 2010, Bremner *et al.* 2006, Josefson *et al.* 2009, Cooper *et al.* 2008, Hussin *et al.* 2012). In terms of dredging impact on functional diversity, communities of macrofaunal organisms inhabiting an area of dredged seabed may possibly differ in composition or diversity from the pre-dredged state, but may develop similar functional capacity through the recovery process (functional recovery). Therefore, system recovery may not require similar biomass, biodiversity or community composition. It is thus proposed to utilise a variety of analyses including biodiversity measures, multivariate approaches as well as functional traits analyses to describe the macrofaunal colonization process after the dredging impact.

© NMP 2014

4 REFERENCES

Anderson MJ, Gorley RN, Clarke KR (2008) PERMANOVA+ for PRIMER: Guide to Software and Statistical Methods. PRIMER-E: Plymouth, UK.

Arias A, Richter A, Anadon N, Paxton H (2013) Evidence of simultaneous hermaphroditism in the brooding Diopatra marocensis (Annelida: Onuphidae) from northern Spain. Journal of the Marine Biological Association of the United Kingdom: 1-10.

Atkinson LJ, Field JG, Hutchings L (2011) Effects of demersal trawling along the west coast of southern Africa: multivariate analysis of benthic assemblages. *Mar Ecol Prog Ser* **430**:241-255.

BCLME (2006) The development of a common set of water and sediment quality guidelines for the coastal zone of the BCLME. Prepared by the CSIR and compiled by Susan Taljaard. CSIR Report No CSIR/NRE/ECO/ER/2006/0011/C.

Borja Á, Dauer DM, Elliott M, Simenstad CA (2010) Medium- and long-term recovery of estuarine and coastal ecosystems: patterns, rates and restoration effectiveness. *Estuaries and Coasts* **33**:1249-1260.

Borja A, Muxika I, Franco J (2003) The application of a Marine Biotic Index to different impact sources affecting soft-bottom benthic communities along European coasts. *Marine Pollution Bulletin* **46**:835-845.

Bremner J, Rogers SI, Frid CLJ (2006) Matching biological traits to environmental conditions in marine benthic ecosystems. *Journal of Marine Systems* **60**:302-316.

Clarke KR, Gorley RN (2006) PRIMER v6: User Manual/Tutorial. PRIMER-E: Plymouth, Plymouth. pp. 190.

Clarke KR, Warwick RM (2001) Change in marine communities: an approach to statistical analysis and interpretation, 2nd edition. PRIMER-E: Plymouth.

Cooper KM, Barrio Froján CRS, Defew E, Curtis M, Fleddum A, Brooks L, Paterson DM (2008) Assessment of ecosystem function following marine aggregate dredging. J*ournal of Experimental Marine Biology and Ecology* **366**:82-91.

Day JH (1967a) A monograph on the polychaeta of southern Africa - Part I: Errantia. Eyre and Spottiswoode Limited, Grosvenor Press, Portsmouth.

Day JH (1967b) A monograph on the polychaeta of southern Africa - Part II: Sedentaria. Eyre and Spottiswoode Limited, Grosvenor Press, Portsmouth.

Diaz RJ, Rosenberg R (1995) Marine benthic hypoxia: A review of its ecological effects and the behavioural responses of benthic macrofauna. O*ceanography and Marine Biology: an Annual Review* 33:**245**-303.

Field, J.G., Parkins, C.A., Winckler, H., Savage, C. and K. van der Merwe. 1996. Specialist study #9: Impact on benthic communities. In: Impacts of Deep Sea Diamond Mining, in the Atlantic 1 Mining Licence Area in Namibia, on the Natural Systems of the Marine Environment. Environmental Evaluation Unit Report No. 11/96/158, University of Cape Town. Prepared for De Beers Marine (Pty) Ltd.: 370 pp.

Gallardo VA, Palma M, Carrasco FD, Gutiérrez D, Levin LA, Cañete JI (2004) Macrobenthic zonation caused by the oxygen minimum zone on the shelf and slope off central Chile. *Deep-Sea Research* II **51**:2475-2490.

Gooday AJ, Levin LA, Silva AAd, Bett BJ, Cowie GL, Dissard D, Gage JD, Hughes DJ, Jeffreys R, Lamont PA, Larkin KE, Murty SJ, Schumacher S, Whitcraft C, Woulds C (2009) Faunal responses to oxygen gradients on the Pakistan margin: A comparison of foraminiferans, macrofauna and megafauna. *Deep-Sea Research* II **56**:488-502.

Goosen AJJ, Gibbons MJ, McMillan IK, Dale DC, Wickens PA (2000) Benthic biological study of the Marshall Fork and Elephant Basin areas off Lüderitz, Prepared by De Beers Marine (Pty) Ltd. for Diamond Fields Namibia (Confidential).

Gutiérrez D, Gallardo VA, Mayor S, Neira C, Vásquez C, Sellanes J, Rivas M, Soto A, Carrasco F, Baltazar M (2000) Effects of dissolved oxygen and fresh organic matter on the bioturbation potential of macrofauna in sublittoral sediments off Central Chile during the 1997/1998 El Niño. *Mar Ecol Prog Ser* **202**:81-99.

Hussin WMRW, Cooper KM, Froján CRSB, Emma C. Defew, Paterson DM (2012) Impacts of physical disturbance on the recovery of a macrofaunal community: A comparative analysis using traditional and novel approaches. *Ecological Indicators* **12**:37-45.

Josefson AB, Blomqvist M, Hansen JLS, Rosenberg R, Rygg B (2009) Assessment of marine benthic quality change in gradients of disturbance: Comparison of different Scandinavian multi-metric indices. *Marine Pollution Bulletin* **58**:1263-1277.

Levin L, Gage JD (1998) Relationships between oxygen, organic matter and the diversity of bathyal macrofauna. *Deep-Sea Research* II **45**:129-163.

Levin LA (2002) Deep-ocean life where oxygen is scarce. American Scientist **90**:436-444.

Levin LA (2003) Oxygen minimum zone benthos: adaptation and community response to hypoxia. *Oceanography and Marine Biology: an Annual Review* **41**:1-45.

Levin LA, Gage JD, Martin C, Lamont PA (2000) Macrobenthic community structure within and beneath the oxygen minimum zone, NW Arabian Sea. Deep-Sea Research II **47** 47:189-226

Levin LA, Whitcraft CR, Mendoza GF, Gonzalez JP, Cowie G (2009) Oxygen and organic matter thresholds for benthic faunal activity on the Pakistan margin oxygen minimum zone (700 - 1100 m). *Deep-Sea Research* II **56**:449-471.

Lim H-S, Diaz RJ, Hong J-S, Schaffner LC (2006) Hypoxia and benthic community recovery in Korean coastal waters. *Marine Pollution Bulletin* **52**:1517-1526.

Lwandle (2013) Namibian Marine Phosphate Verification Survey: Cruise Summary Report. Prepared for Namibian Marine Phosphate by Lwandle Technologies (Pty) Ltd. Job No. 149.

Lwandle (2014) Namibian Marine Phosphate: Verification Survey Report. Prepared for Namibian Marine Phosphate by Lwandle Technologies (Pty) Ltd. Job No. 149.

Midgley J (2012) Environmental Impact Assessment for the proposed dredging of phosphate enriched sediments from Marine Licence Area No. 170. Prepared for Namibian Marine Phosphate (Pty) Ltd. Prepared by J Midgley &Associates in association with EnviroDymanics and CSIR.

Palma M, Quiroga E, Gallardo VA, Arntz W, Gerdes D, Schneider W, Hebbeln D (2005) Macrobenthic animal assemblages of the continental margin of Chile (228 to 428S). J *Mar Biol Ass UK* **85**:233-245.

Parkins, C.A. and J.G. Field. 1998. The effects of deep sea diamond mining on the benthic community structure of the Atlantic 1 Mining Licence Area. Annual Monitoring Report – 1997. Unpublished Report to De Beers Marine, April 1998, pp 44. (Confidential).

© NMP 2014

Pulfrich, A. and A.J. Penney. 1999. The effects of deep-sea diamond mining on the benthic community structure of the Atlantic 1 Mining Licence Area. Annual Monitoring Report – 1998. Prepared for De Beers Marine (Pty) Ltd by Marine Biology Research Institute, Zoology Department, University of Cape Town and Pisces Research and Management Consultants CC. pp 49. (Confidential).

Robinson J.E., Newell R.C., Seiderer L.J., and N.M. Simpson, 2005. Impacts of aggregate dredging on sediment composition and associated benthic fauna at an offshore dredge site in the southern North Sea. *Marine Environmental Research,* **60**:51-68.

Rosenberg R, Arntz WE, Flores ECd, Flores LA, Carbajal G, Finger I, Tarazona J (1983) Benthos biomass and oxygen deficiency in the upwelling system off Peru. *Journal of Marine Research* **41**:263-279.

Sahling H, Rickert D, Lee RW, Linke P, Suess E (2002) Macrofaunal community structure and sulfide flux at gas hydrate deposits from the Cascadia convergent margin, NE Pacific. *Mar Ecol Prog Ser* **231**:121-138.

Savage C, Field JG, Warwick RM (2001) Comparative meta-analysis of the impact of offshore marine mining on macrobenthic communities versus organic pollution studies. *Mar Ecol Prog Ser* **221**:265-275.

Savage, C. 1996. Multivariate Analysis of the Impact of Offshore Marine Mining on the Benthic Macrofauna off the West Coast of Southern Africa. Msc Thesis, Department of Zoology, University of Cape Town, 190 pp.

Steffani N (2007) Biological Monitoring Survey of the Macrofaunal Communities in the Atlantic 1 Mining Licence Area and the Inshore Area between Kerbe Huk and Bogenfels-2005 Survey. Report prepared for De Beers Marine Namibia. pp. 51 + Appendices. (Confidential).

Steffani N (2010a) Biological Baseline Survey of the Benthic Macrofauna Communities in the Phosphate Licence Blocks EPL 3415 and EPL 3233 in the Sandpiper/Meob JV Project Area. Prepared for Namibian Marine Phosphate. May 2010. pp28 + Appendices (confidential).

Steffani N (2010b) Biological Monitoring Surveys of the Benthic Macrofaunal Communities in the Atlantic 1 Mining Licence Area - 2008. Prepared for De Beers Marine Namibia, pp. 40 + Appendices. (Confidential).

Steffani N (2012) Marine Benthic Specialist Study for a Proposed Development of Phosphate Deposits in the Sandpiper Phosphate Licence Area off the Coast of Central Namibia. Appendix 1C in: Midgley J (2012) Environmental Impact Assessment for the proposed dredging of phosphate enriched sediments from Marine Licence Area No. 170.

Steffani N, Pulfrich A (2007) Biological Survey of the Macrofaunal Communities in the Atlantic 1 Mining Licence Area and the Inshore Area between Kerbehuk and Lüderitz. 2001- 2004 Surveys. Prepared for De Beers Marine Namibia (Pty) Ltd. March 2007. pp 273 + Appendices. (Confidential).

Underwood, A.J., 1992. Beyond BACI: the detection of environmental impact on populations in the real but variable world. *Journal of Experimental Marine Biology and Ecology*, **161**: 145-178.

Underwood, A.J., 1993. The mechanics of spatially replicated sampling programmes to detect environmental impacts in a variable world. *Australian Journal of Ecology*, **18**: 99 - 116.

Underwood, A.J., 1994. On beyond BACI: sampling designs that might reliably detect environmental disturbances. *Ecological Applications*, **4**: 3-15.

© NMP 2014

Zettler M, Bochert R, Pollehne F (2013) Macrozoobenthic biodiversity patterns in the northern province of the Benguela upwelling system. *African Journal of Marine Science* **35**:283-290.

Zettler ML, Borchert R, Pollehne F (2009) Macrozoobenthos diversity in an oxygen minimum zone off northern Namibia. *Marine Biology* **156**:1949-1961.

Annexure 1a: Macrofauna abundances (no/0.035m^2) in the >1000 µm fraction at the 15 verification survey sites in 2013.

Species	SP1VS02	SP1VS03	SP1VS04	SP1VS07	SP1VS08	SP1VS09	SP1VS12	SP1VS13	SP1VS14	SP1VS18	SP1VS19	SP1VS20	SP1VS23	SP1VS24	SP1VS25
POLYCHAETA															
Amphicteis gunneri	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Brada villosa capensis	1	0	4	1	2	0	1	1	1	0	0	0	0	0	1
Cossura coasta	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Aphelochaeta spp.	5	4	6	6	4	18	9	24	1	1	6	24	10	6	1
Diopatra monroi	10	11	2	8	13	11	11	13	14	14	6	9	6	10	12
Eulalia sp.	0	1	0	0	1	0	0	0	0	0	1	1	0	0	0
Eteone ? spp.	0	0	1	1	3	0	0	0	0	0	0	0	0	0	0
Glycinde kameruniana	0	0	0	0	0	0	1	0	0	2	0	1	0	0	0
*Gyptis (*or *Podarkeopsis ?* sp.*)*	1	0	0	0	0	1	2	1	0	1	0	0	1	0	0
Hesiospina spp.	0	0	0	2	0	0	0	0	0	0	0	1	0	0	0
Jasmineira elegans ?	0	0	1	0	3	1	0	1	1	0	3	0	2	0	0
Johnstonia knysna	0	0	1	0	1	1	0	0	1	0	0	1	0	0	1
Lumbrineris meteroana	1	2	10	12	6	12	15	19	3	6	11	15	7	4	4
Mediomastus capensis	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0
Nephtys hombergii	1	0	1	1	0	1	0	0	0	0	1	0	2	0	0
Prionospio spp.	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0
Leodamas sp.	2	1	0	1	0	1	7	1	2	4	1	0	8	2	1
Paracabira capensis	0	0	0	0	0	0	0	0	0	2	0	0	1	1	0
Paradoneis ? spp	0	0	0	3	0	0	0	2	0	0	0	1	1	0	0
Paraprionospio pinnata	48	36	38	41	26	92	51	66	77	86	79	132	110	46	45
Sigambra parva	2	2	2	1	0	1	5	6	2	1	2	8	1	1	2
Syllidia armata	0	0	3	2	3	16	4	2	5	6	2	4	1	1	0
Terebellidae	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
CRUSTACEA															
Callianassa australis	1	0	0	0	1	1	0	0	1	0	1	1	1	1	0

© NMP 2014

Species	SP1VS02	SP1VS03	SP1VS04	SP1VS07	SP1VS08	SP1VS09	SP1VS12	SP1VS13	SP1VS14	SP1VS18	SP1VS19	SP1VS20	SP1VS23	SP1VS24	SP1VS25
Aoridae (Grandidierella? spp.)	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
CNIDARIA															
Anemone A	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0
Veretillidae	0	0	0	1	3	1	1	4	3	3	0	6	0	0	1
Virgularia schultzei	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
NEMERTEA															
Nemertea	1	0	0	0	0	1	1	0	0	1	1	0	0	0	0
ECHINODERMATA															
Holothuroidea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
OLIGOCHAETA															
Tubificidae	5	4	33	17	67	6	74	129	56	22	105	61	78	78	19
MOLLUSCA															
Bivalvia A	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
MEIOFAUNA															
Nematoda	0	1	2	6	33	6	12	70	15	3	30	28	5	10	3
Copepoda	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0

© NMP 2014

Annexure 1b: Macrofauna abundances (no/0.035m^2) in the 500-1000 µm fraction at the 15 verification survey sites in 2013.

Species	SP1VS02	SP1VS03	SP1VS04	SP1VS07	SP1VS08	SP1VS09	SP1VS12	SP1VS13	SP1VS14	SP1VS18	SP1VS19	SP1VS20	SP1VS23	SP1VS24	SP1VS25
POLYCHAETA															
Brada villosa capensis	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Aphelochaeta spp.	19	16	12	7	11	14	22	11	17	59	24	63	24	21	14
Diopatra monroi	0	0	1	0	0	0	0	0	0	0	1	1	0	0	0
Dorvilleidae	0	0	0	0	0	0	0	0	1	0	0	0	0	5	0
Eulalia sp.	2	0	0	0	0	1	0	0	0	4	1	2	1	0	0
Eteone ? spp.	0	0	1	1	0	0	0	0	0	0	1	1	0	0	0
Glycinde kameruniana	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Gyptis (or *Podarkeopsis ?* sp.)	0	2	0	0	1	0	0	0	0	0	2	0	0	1	0
Jasmineira elegans ?	3	10	4	2	4	2	7	0	5	9	5	3	6	5	0
Prionospio spp.	0	0	1	0	0	0	2	0	1	0	4	0	2	1	0
Leodamas sp.	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0
Lumbrineris meteroana	7	6	9	4	9	9	13	2	7	10	16	12	5	2	6
Mediomastus capensis	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
Paracabira capensis	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Paradoneis ? spp	1	4	0	0	1	1	2	2	0	9	0	0	5	3	1
Paraprionospio pinnata	7	16	23	9	17	13	14	9	12	23	8	10	15	3	13
Syllidia armata	2	3	9	2	4	7	1	0	7	5	4	6	1	3	6
Sigambra parva	0	0	3	1	1	1	2	2	1	1	1	1	1	1	0
Syllides spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
CRUSTACEA															
Hutchinsoniellidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Aoridae (Grandidierella ? spp.)	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0

Species	SP1VS02	SP1VS03	SP1VS04	SP1VS07	SP1VS08	SP1VS09	SP1VS12	SP1VS13	SP1VS14	SP1VS18	SP1VS19	SP1VS20	SP1VS23	SP1VS24	SP1VS25
ENTOPROCTA															
Loxosomatidae sp. 1	0	9	0	0	0	0	0	0	0	1	0	0	0	9	1
OLIGOCHAETA															
Tubificidae	6	13	79	2	74	10	41	20	85	44	74	96	55	57	7
MEIOFAUNA															
Nematoda	65	174	350	17	900	100	850	1000	1000	750	600	850	500	400	130
Copepoda	0	0	1	0	0	5	0	1	0	0	0	4	1	3	1

© NMP 2014

Annexure 1c: Macrofauna abundances (no/0.035m^2) in the 300-500 µm fraction at the seven of the verification survey sites in 2013.

Sites	SP1VS04	SP1VS07	SP1VS08	SP1VS09	SP1VS14	SP1VS20	SP1VS25
POLYCHAETA							
Aphelochaeta sp. 1	0	2	6	3	5	22	6
Eulalia sp.	0	0	0	0	0	0	1
Jasmineira elegans ?	1	2	1	0	1	3	3
Lumbrineris meteroana	3	0	1	0	1	3	2
Paraprionospio pinnata	4	1	9	0	1	1	2
Syllidia armata	0	0	0	0	0	0	1
Sigambra parva	0	0	0	0	0	1	0
ENTOPROCTA							
Loxosomatidae sp. 1	0	0	0	0	0	6	1
OLIGOCHAETA							
Tubificidae spp.	5	6	50	5	14	20	2
MEIOFAUNA							
Nematoda	110	27	450	30	264	270	45
Copepoda	16	1	6	6	6	5	1

© NMP 2014

Annexure 1d: Macrofauna wet biomass (g/0.035m^2) in the >1000 µm fraction at the verification survey sites in 2013.

Species	SP1VS02	SP1VS03	SP1VS04	SP1VS07	SP1VS08	SP1VS09	SP1VS12	SP1VS13	SP1VS14	SP1VS18	SP1VS19	SP1VS20	SP1VS23	SP1VS24	SP1VS25
POLYCHAETA															
Amphicteis gunneri	0	0	0	0	0	0	0	0	0	0.03	0	0	0	0	0
Brada villosa capensis	0.0002	0	0.0156	0.0011	0.005	0	0.001	0.0021	0.0019	0	0	0	0	0	0.0006
Cossura coasta	0.0001	0	0	0.0004	0	0	0	0	0	0	0	0	0	0	0
Aphelochaeta spp.	0.0009	0.002	0.003	0.003	0.0042	0.0096	0.0033	0.0087	0.0002	0.0006	0.0031	0.0109	0.003	0.0029	0.0002
Diopatra monroi	2.6721	2.575	0.4636	1.7317	3.3554	3.64	3.215	1.9031	1.9114	2.5185	2.0205	0.8962	2.2562	3.65	3.223
Eulalia sp.	0	0.0008	0	0	0.0005	0	0	0	0	0	0.001	0.0007	0	0	0
Eteone ? spp.	0	0	0.0008	0.0015	0.001	0	0	0	0	0	0	0	0	0	0
Glycinde kameruniana	0	0	0	0	0	0	0.0027	0	0	0.0066	0	0.0014	0	0	0
*Gyptis (*or *Podarkeopsis ?* sp.*)*	0.0002	0	0	0	0	0.0009	0.002	0.0003	0	0.0003	0	0	0.0002	0	0
Hesiospina spp.	0	0	0	0.0036	0	0	0	0	0	0	0	0.0009	0	0	0
Jasmineira elegans ?	0	0	0.0005	0	0.0009	0.0002	0	0.0002	0.0001	0	0.0006	0	0.0005	0	0
Johnstonia knysna	0	0	0.0098	0	0.2458	0.0135	0	0	0.1101	0	0	0.1791	0	0	0.1195
Lumbrineris meteroana	0.0001	0.0008	0.0135	0.0064	0.0035	0.0084	0.0058	0.0049	0.0024	0.0045	0.0049	0.0102	0.003	0.0016	0.004
Mediomastus capensis	0	0	0	0	0	0	0	0	0	0.0002	0	0	0.0004	0.0003	0
Nephtys hombergii	0.3875	0	0.0975	0.0048	0	0.122	0	0	0	0	0.002	0	0.4356	0	0
Prionospio spp.	0	0	0	0	0	0	0	0	0	0	0.0022	0	0	0	0
Leodamas sp.	0.0012	0.001	0	0.0055	0	0.0023	0.0131	0.0029	0.0096	0.0248	0.0032	0	0.0264	0.0087	0.0021
Paracabira capensis	0	0	0	0	0	0	0	0	0	0.0009	0	0	0.0002	0.0005	0
Paradoneis ? spp	0	0	0	0.0004	0	0	0	0.0004	0	0	0	0.0004	0.0001	0	0
Paraprionospio pinnata	4.333	0.9	0.0307	0.4384	0.297	1.0638	0.6964	0.5667	0.7985	1.2661	0.8916	1.66	1.6574	0.4798	0.6289
Sigambra parva	0.0041	0.0124	0.0118	0.0005	0	0.0072	0.0089	0.015	0.0052	0.0021	0.0093	0.0174	0.0002	0.0002	0.004
Syllidia armata	0	0	0.0005	0.0008	0.0011	0.0047	0.003	0.0006	0.0023	0.0017	0.0008	0.0009	0.0002	0.0002	0
Terebellidae	0	0	0	0	0	0.0315	0	0	0	0	0	0	0	0	0

© NMP 2014

Species	SP1VS02	SP1VS03	SP1VS04	SP1VS07	SP1VS08	SP1VS09	SP1VS12	SP1VS13	SP1VS14	SP1VS18	SP1VS19	SP1VS20	SP1VS23	SP1VS24	SP1VS25
CRUSTACEA															
Callianassa australis	1.7019	0	0	0	0.0621	0.2017	0	0	0.0015	0	1.3499	0.0004	0.0998	0.6258	0
Aoridae (Grandidierella? spp.*)*	0	0	0	0	0	0	0	0	0	0	0	0.0002	0	0	0
CNIDARIA															
Anemone A	0	0	0	0	0.1937	0.1124	0	0	0	0	0	0.1267	0	0	0
Veretillidae	0	0	0	0.6761	0.9328	0.4264	0.448	1.2588	1.0489	1.7077	0	1.3445	0	0	0.0815
Virgularia schultzei	0	0	0	0	0	0	0	0	0	0	0	0	0.0879	0	0
NEMERTEA															
Nemertea	0.1855	0	0	0	0	0.1452	0.074	0	0	0.1505	0.0568	0	0	0	0
ECHINODERMATA															
Holothuroidea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.8429
OLIGOCHAETA															
Tubificidae	0.0026	0.0007	0.0053	0.0029	0.0159	0.0016	0.0165	0.0403	0.01	0.0063	0.0319	0.0075	0.0361	0.0235	0.0036
MOLLUSCA															
Bivalvia A	0	0.004	0	0	0	0	0	0	0	0	0	0	0	0	0

© NMP 2014

Annexure 1e: Macrofauna wet biomass (g/0.035m^2) in the 500-1000 µm fraction at the verification survey sites in 2013.

Species	SP1VS02	SP1VS03	SP1VS04	SP1VS07	SP1VS08	SP1VS09	SP1VS12	SP1VS13	SP1VS14	SP1VS18	SP1VS19	SP1VS20	SP1VS23	SP1VS24	SP1VS25
POLYCHAETA															
Brada villosa capensis	0	0	0	0	0	0	0	0	0.0001	0	0	0	0	0	0
Aphelochaeta spp.	0.0047	0.0034	0.0038	0.0003	0.003	0.0057	0.0066	0.0007	0.0082	0.0214	0.0042	0	0.0052	0.0035	0.0029
Diopatra monroi	0	0	0.0001	0	0	0	0	0	0	0	0.0002	0.0002	0	0	0
Dorvilleidae	0	0	0	0	0	0	0	0	0.0001	0	0	0	0	0.0006	0
Eulalia sp.	0.0006	0	0	0	0	0.0001	0	0	0	0.0008	0.0003	0.0003	0.0002	0	0
Eteone ? spp.	0	0	0.0001	0.0004	0	0	0	0	0	0	0.0002	0.0002	0	0	0
Glycinde kameruniana	0	0	0	0	0	0	0	0	0	0	0	0.0002	0	0	0
Gyptis (or *Podarkeopsis ?* sp.)	0	0.0003	0	0	0.0002	0	0	0	0	0	0.0003	0	0	0.0002	0
Jasmineira elegans ?	0.0006	0.0016	0.0012	0.0005	0.0006	0.0004	0.0004	0	0.001	0.0008	0.0008	0.0004	0.0005	0.0007	0
Prionospio spp.	0	0	0.0005	0	0	0	0.0009	0	0.0002	0	0.0013	0	0.0002	0.0001	0
Leodamas sp.	0.0004	0	0	0	0	0	0	0	0	0.0007	0	0	0.0002	0	0
Lumbrineris meteroana	0.0042	0.0012	0.003	0.0013	0.0021	0.0025	0.0029	0.0002	0.0019	0.0034	0.0026	0.0043	0.0008	0.0004	0.0018
Mediomastus capensis	0	0	0	0	0	0	0	0	0	0.0002	0	0	0.0001	0	0
Paracabira capensis	0	0	0	0	0	0	0	0	0	0.0002	0	0	0	0	0
Paradoneis ? spp	0.0002	0.0006	0	0	0.0001	0.0003	0.0009	0.0002	0	0.0004	0	0	0.0004	0.0004	0.0002
Paraprionospio pinnata	0.01	0.0144	0.008	0.0055	0.003	0.0057	0.016	0.0015	0.0053	0.0038	0.0037	0.0038	0.0029	0.0017	0.007
Syllidia armata	0.0005	0.0004	0.0013	0.0008	0.0007	0.0009	0.0002	0	0.0006	0.0009	0.0008	0.0008	0.0003	0.0003	0.0013
Sigambra parva	0	0	0.0003	0.0003	0.0001	0.0002	0.0005	0.0003	0.0001	0.0001	0.0003	0.0003	0.0002	0.0001	0
Syllides spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0003	0
CRUSTACEA															
Hutchinsoniellidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0003
Aoridae (Grandidierella? spp.)	0	0	0	0	0	0	0	0	0	0	0	0.0001	0	0	0

© NMP 2014

Species	SP1VS02	SP1VS03	SP1VS04	SP1VS07	SP1VS08	SP1VS09	SP1VS12	SP1VS13	SP1VS14	SP1VS18	SP1VS19	SP1VS20	SP1VS23	SP1VS24	SP1VS25
ENTOPROCTA															
Loxosomatidae sp. 1	0	0.001	0	0	0	0	0	0	0	0.0001	0	0	0	0.001	0.0001
OLIGOCHAETA															
Tubificidae	0	0.0017	0.007	0.0004	0.006	0.0005	0.0031	0.0015	0.0127	0.0029	0.0054	0.0116	0.0041	0.0044	0.0007

© NMP 2014

Annexure 1f: Macrofauna wet biomass (no/0.035m2) in the 300-500 µm fraction at the seven of verification survey sites in 2013.

Sites	SP1VS04	SP1VS07	SP1VS08	SP1VS09	SP1VS14	SP1VS20	SP1VS25
POLYCHAETA							
Aphelochaeta sp. 1	0	0.0003	0.0005	0.0002	0.0008	0.001	0.0008
Eulalia sp.	0	0	0	0	0	0	0.0001
Jasmineira elegans ?	0.0001	0.0002	0.0001	0	0.0002	0.0002	0.0004
Lumbrineris meteroana	0.0005	0	0.0003	0	0.0002	0.0003	0.0003
Paraprionospio pinnata	0.0003	0.0001	0.0005	0	0.0001	0.0002	0.0002
Syllidia armata	0	0	0	0	0	0	0.0001
Sigambra parva	0	0	0	0	0	0.0002	0
ENTOPROCTA							
Loxosomatidae sp. 1.	0	0	0	0	0	0.0001	0.001
OLIGOCHAETA							
Tubificidae spp.	0.0005	0.0003	0.001	0.0003	0.0009	0.0011	0.0011

© NMP 2014

SPECIALIST STUDIES – SECTION C

C2.6 A Survey of Epifauna in the Sandpiper-1 (SP-1) Target Phosphate Dredging Area on the Central Namibian Continental Shelf

Prepared for:
Namibian Marine Phosphate (Pty) Ltd.

Prepared by:
T. P. McClurg



October 2014

T. P. McClurg
KZN Coastal Impact Consultants. P.O. Box 230, KLOOF, South Africa 3640.
mcclurgs@telkomsa.net

Date	Version	Revised	Reviewed
1 August 2014	Draft 1	T. P. McClurg	M. Smith
30 September 2014	Draft 2	T. P. McClurg	M. Smith
17 October 2014	Final	T. P. McClurg	M. Smith
APPROVED	Final	T. P. McClurg	

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed "Attention: Administration Manager," at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

SUMMARY

Trawling at 24 stations across the SP-1 target phosphate dredging area revealed a significant presence of epifaunal organisms with low diversity (14 taxa). The samples were heavily dominated by an ascidian "sea squirt" (*Molgula*) and a pennatulid "sea pen" (family Veretellidae), both of which appear to be capable of enduring periodic hypoxic events. Two crustaceans, notably a swimming crab (*Bathynectes piperitus*) and a mantis shrimp (*Pterygosquilla armata capensis*), were also prominent in the catches. Both of these are active swimmers and considered to be capable of physically avoiding hypoxic conditions. The remaining 10 taxa, which generally follow more sedentary lifestyles, were present in far fewer numbers. Similar surveys performed further south, where hypoxia is not prominent, have yielded far richer epifaunal assemblages, particularly in terms of the less mobile taxa. It appears that the epifauna in the SP-1 area is relatively impoverished and that this is due to the prevalence of episodic hypoxia. The data gathered in this survey may be used as a baseline for future impact monitoring. However, it is important that hypoxic events be concurrently monitored to enable partition of impacts between those putatively caused by dredging and those arising from the natural hypoxic episodes.

© NMP 2014

contents

SUMMARY ii

1 INTRODUCTION 1

2 MATERIALS AND METHODS 1

3 RESULTS AND DISCUSSION 4

3.1 OVERALL COMPOSITION 4
3.2 COMPOSITION OF THE EPIFAUNA 4
3.3 COMPARISONS WITH OTHER TRAWLING SURVEYS 13
3.4 ENVIRONMENTAL DRIVERS 14

4 CONCLUSION 15

5 ACKNOWLEDGEMENTS 15

6 REFERENCES 16

Annexure 1: Epifauna Counts and Weights 17

figures

Figure 1: Location of the proposed target dredging sites SP-1, SP-2 and SP-3 within the Sandpiper Phosphate licence area (ML-170). 2
Figure 2: Location of the 24 stations (trawl lanes) where the epifauna was surveyed. 3
Figure 3: Relative proportions of all epibenthic taxa recorded in the trawling survey according to numbers (top and weights (bottom). 7
Figure 4: Relative proportions of epibenthic fauna recorded in the trawling survey after removal of selected super-abundant or heavy taxa (*Molgula* and/or Veretellidae). 8
Figure 5: Trawl contents at station 20 showing high abundance of spherical *Molgula* . 9
Figure 6: Close-up view of *Molgula* displaying aggregation. 9
Figure 7: Sea Pens (*Veretellidae*). 10
Figure 8: Porifera (sponge). 10
Figure 9 : The two gastropod whelks encountered in the survey. 1 – *Fasciolaria lugubris* (dorsal); 11
Figure 10: Crustacea. 1 –Bathynectes piperitus; 2 – Solenocera africana; 12
Figure 11: Echinoderms. 1 – *Odontaster australis;* 2 – *Astropecten* (aboral view); 3 – *Astropecten* (oral view); 4 - *Pseudoncnus thandari.* 13

© NMP 2014

tables

Table 1: Composition of the epifauna expressed in terms of numbers for each taxon and their percentage contributions to the overall biomass. 5

Table 2: Composition of the epifauna expressed in terms of weights for each taxon and their percentage contributions to the overall biomass. 5

© NMP 2014

1 INTRODUCTION

The proposal to mine phosphate on the continental shelf off central Namibia has raised concern over environmental damage and consequent impact on fisheries. The project, accordingly, has been intensely scrutinised through a rigorous Environmental Impact Assessment (NMP, 2012). This has, *inter alia*, entailed detailed characterisation of the environment, and its resident faunal communities. This information is being used in making risk assessments and in formulating management plans. It will also serve as a baseline against which future impacts may be judged. The benthic environment within SP-1, where dredging is scheduled to commence (Figure 1 and Figure 2), is the particular area of focus. Studies of relevance in SP-1 include two detailed benthic fauna surveys (Steffani 2010, 2013). Project reviewers have expressed concern that these surveys, which were based on traditional grab sampling, were not fully comprehensive, in that the larger organisms inhabiting the sea bed (epifauna) were not adequately sampled. Epifaunal organisms tend to be larger, more mobile and occur in lower densities than their infaunal counterparts and may accordingly be missed in grab-based surveys. Partly in response to this criticism an additional survey, which focussed on epifauna, was performed in June 2014.

This study formed part of a wider trawling survey aimed at further elucidating the biodiversity and fishery potential of the proposed dredging area and environs. This report describes the results of the epifaunal component of the survey.

2 MATERIALS AND METHODS

Three categories of fauna, which are broadly defined by size, are commonly targeted in marine ecological assessments. First, the meiofauna, which includes microscopic organisms which, when sampled, are retained by a fine sieve (usually 0,063 mm). These organisms typically burrow near the sediment/water interface. Second, the macrofauna, which comprises the larger organisms that dwell in close association with the sea-bed and are retained by a coarser sieve (usually 0. 5 or 1 mm). Third, the epifauna (sometimes referred to as megafauna) which is the subject of this study and includes the larger, and typically more mobile, organisms that dwell above the sediment surface.

Special target sampling methods are applied for each category of fauna. Cores and grabs are usually employed for meiofauna and macrofauna, while observations via remotely operated vehicles (ROVs), together with sleds and trawls, are usually more appropriate for the collection and evaluation of epifauna. ROV observations are very expensive and tend to be more suited to qualitative, rather than quantitative, analysis. They also require clear underwater visibility, which seldom prevails in the SP-1 area due to the suspension of particulates in the water column. Additionally, the operation of sleds in deep waters may be confounded by technical problems. It was consequently determined that trawling, using the technical skills of local trawler-men, was the most appropriate route for the collection of the epifauna of this region. This epifauna survey could then be linked logistically to a broader biodiversity and fishery survey which comprises part of the verification programme.

© NMP 2014

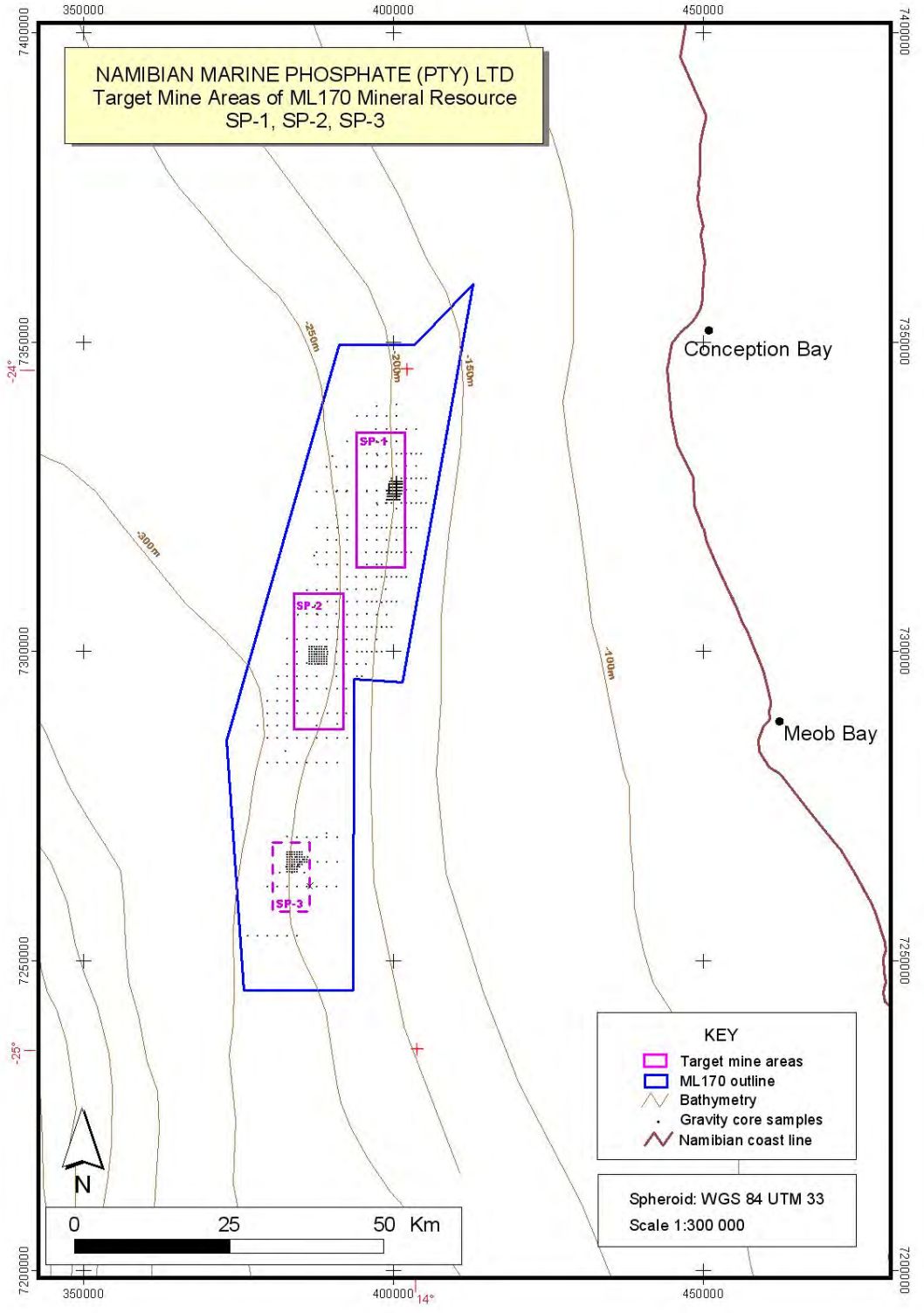


Figure 1: Location of the proposed target dredging sites SP-1, SP-2 and SP-3 within the Sandpiper Phosphate licence area (ML-170).

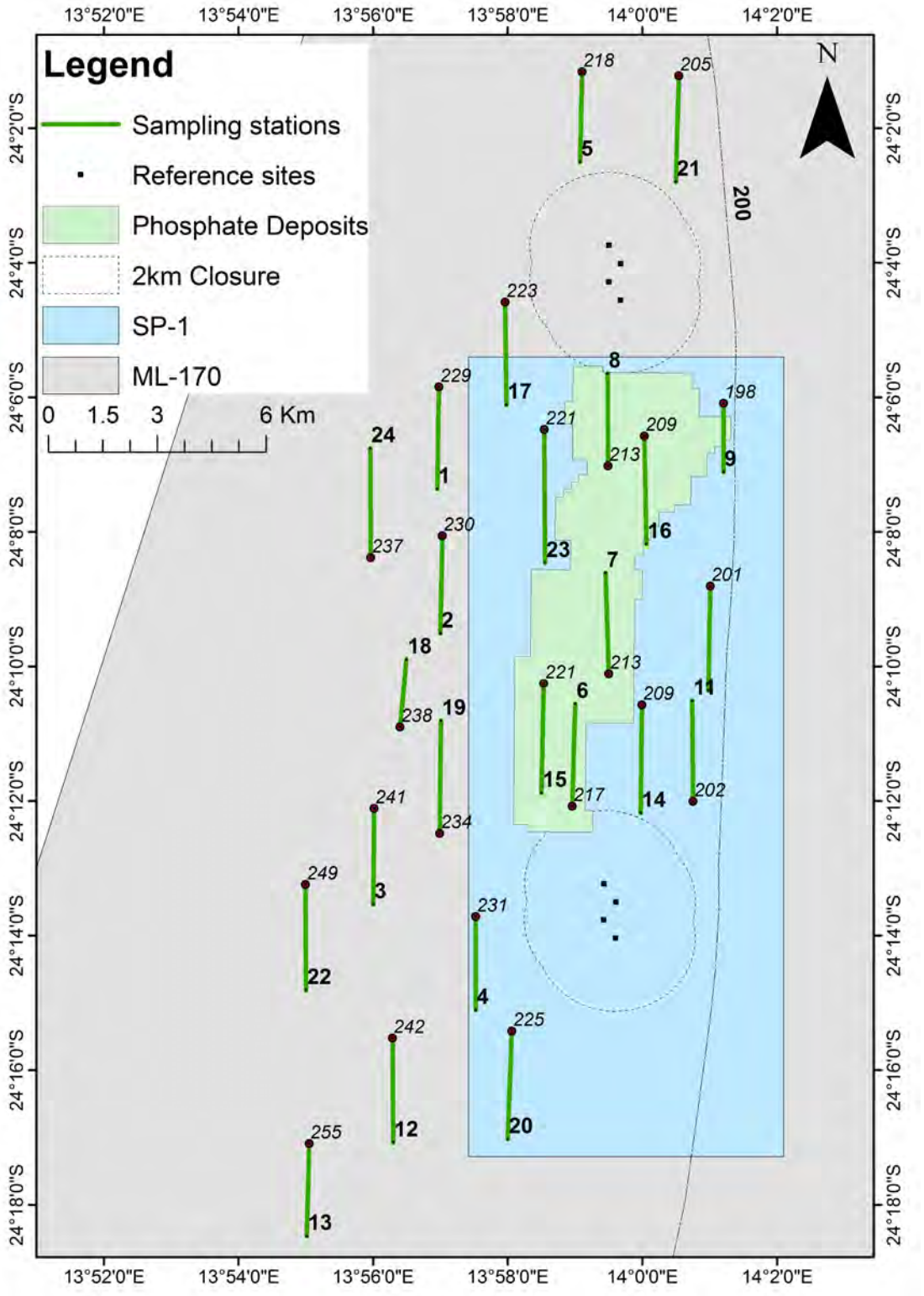


Figure 2: Location of the 24 stations (trawl lanes) where the epifauna was surveyed.

The survey took place during the latter half of June, 2014 using the Walvis Bay-based Fishing Vessel *Zeearend*. Trawling was achieved with a standard double belly monk trawl (108 metres) fitted with a tickler chain. The cod ends were lined with a 20 mm mesh net so that the smaller epibenthic

organisms would be retained. Twenty four trawls were completed, as illustrated in Figure 2. Twelve were undertaken during daylight hours (07:00 – 18:00) and twelve at night (20:00 – 05:30). The trawl distances were standardised at approximately 1.5 nautical miles. Processing of the catches was achieved through team work by all the scientists and crew. Key components of each trawl (principally fishes and jellyfish) were extracted first and the remaining material was then transferred to a sorting table where it was rigorously screened for epifauna. Counts and weights were recorded for each epifaunal taxon. Appropriate photographic records were made and samples of each taxon were preserved in 96% ethanol for future reference.

3 RESULTS AND DISCUSSION

The identities, counts and weights of all organisms collected in the trawls are listed in Annexure 1. Since the trawls were not all of equal length, it was necessary to standardise the figures so that valid statistical comparisons could be made. The standardised figures are given in Annexure 2.

3.1 OVERALL COMPOSITION

Fourteen epifauna taxa were recovered from the trawls comprising 209 185 specimens with a total mass of 5582 kg., the equivalent standardised results being 198 767 specimens and 5325 kg. Some perspective on the dimensions of the epifauna catch can be gained by making comparisons with the “fish and pelagic” component of the survey (section C 3.1) where the equivalent standardised totals were 37 885 specimens and 23124 kg. This reveals, as might be expected, a biomass dominance in the ”fish and pelagic” component and, perhaps surprisingly, a massive numerical dominance in the epifauna.

3.2 COMPOSITION OF THE EPIFAUNA

The composition of the epifauna , expressed in terms of standardised numbers and weights for each taxon, and their percentage contributions to the overall catch, is summarised in Tables 1and 2 and depicted graphically in pie charts. Figure 3, which draws on the full data set, displays massive dominance by two taxa, namely the sea squirt (*Molgula*) and the sea pen (Veretellidae). *Molgula* contributed 60% of the numbers and 85 % to the biomass, while Veretellidae contributed 37 % to the numbers. Apart from a marginal 7 % weight contribution by the sponge (Porifera) none of the other taxa had any significant presence, the vast majority contributing less than 1%.

© NMP 2014

Table 1: Composition of the epifauna expressed in terms of numbers for each taxon and their percentage contributions to the overall biomass.

Identity	Common Name	Number	% of Catch	% of Catch (excl. *Molgula* and Veretellidae)
Astropecten	Starfish (long-armed)	5	0.0025	0.089
Bathynectus piperitus	Swimming Crab	2701	1.36	48.373
Callianassa africana	Mud Prawn	1	0.0005	0.018
Fasciolaria lugubris	Whelk (tulip)	206	0.1036	3.69
Funchalia woodwardi	Prawn	6	0.0030	0.107
Molgula	Sea Squirt	116573	58.649	-
Nassarius wolffi	Whelk (dog)	7	0.0035	0.125
Odonaster australis	Starfish (cushion star)	15	0.00754	0.269
Paguridae	Hermit Crab	7	0.0035	0.125
Porifera	Sponge (brown)	1619	0.815	29.00
Pseudocnus thandari	Sea Cucumber	43	0.022	0.770
Pterygosquilla armata	Mantis Shrimp	903	0.454	16.18
Solenocera africana	Prawn	70	0.035	1.254
Veretellidae	Sea Pen	76612	38.54	-
TOTAL		**198767**	**100**	**100**

In order to better display the relative contributions of the lesser taxa, the process was repeated after removal of the very high numbers attached to *Molgula* and Veretellidae. The results (Figure 4) show the swimming crab (*Bathynectus pip*eritus) and the sponge (Porifera) to be relatively dominant. However , the remaining taxa were again very poorly represented. The epifauna in the SP-1 area is clearly skewed in favour of a few dominant taxa. A description of each epifaunal taxon (with illustrations) is given below.

Table 2: Composition of the epifauna expressed in terms of weights for each taxon and their percentage contributions to the overall biomass.

Identity	Common Name	Weight (kg)	% of Catch	% of Catch (excl. *Molgula*)
Astropecten	Starfish (long-armed)	0.03	0.00056	0.00505
Bathynectus piperitus	Swimming Crab	118.4	2.223	19.942
Callianassa africana	Mud Prawn	0.01	0.00018	0.00168
Fasciolaria lugubris	Whelk (tulip)	11.12	0.209	1.873
Funchalia woodwardi	Prawn	0.06	0.00112	0.0101
Molgula	Sea Squirt	4731.55	88.85	-
Nassarius wolffi	Whelk (dog)	0.01	0.00018	0.00168
Odonaster australis	Starfish (cushion star)	0.05	0.00093	0.00842
Paguridae	Hermit Crab	5.29	0.0993	0.8909
Porifera	Sponge (brown)	408.52	7.671	68.805
Pseudocnus thandari	Sea Cucumber	0.202	0.00379	0.03402
Pterygosquilla armata	Mantis Shrimp	21.03	0.3949	3.542
Solenocera africana	Prawn	0.21	0.00394	0.0354
Veretellidae	Sea Pen	28.8	0.5408	4.856
TOTAL		**5325.282**	**100**	**100**

© NMP 2014

Ascidiacea (sea squirts or ascidian tunicates). A single species (*Molgula*) was encountered at 21 of the 24 stations, often in large numbers (Figures 4 and 5). Ascidians are widespread and common, particularly on rocky shores and reefs (Branch *et al*., 2010). They are often overlooked and have not been well described. They have several life forms which include solitary anchored individuals, and compound colonies. The latter may form encrustations or exist as relatively loose aggregations. They can reproduce by budding. *Molgula* are clearly colonial in the sense that they tend to exist in clumps. Individual may survive alone but they would lose the stability associated with mass aggregation. Ascidians are filter feeders and assumed to play an important role in nutrient recycling. There is sparse information on what predates on ascidians. Their tough leathery exterior "tunic" may render them unattractive to many potential predators. Nevertheless there are reports of ascidian predation by fish and echinoderms (particularly starfish). There was, incidentally, no evidence of *Molgula* remains in any of the fish stomach contents that were examined in this survey. It is speculatively suggested that the high abundance of *Molgula* in the SP-1 area may be related to the virtual absence of echinoderms. As would be expected, *Molgula* were also recovered in the macrobenthic survey by Steffani (2010,). Discussions with Mr Malakia Shimhanda (on-board technician from the Namibian Ministry of Fisheries and Marine Resources – NatMIRC) revealed that *Molgula* is widely known in Namibian fishing areas. However, he remarked that, in 25 years at sea, he had never seen them recovered in such large numbers. It is likely that the reduced mesh size (20 mm), that was used to line the cod end in this survey, played a significant role in boosting catches. Bottom trawling and fishing intensity are also very likely to affect their distribution and abundance.

Figure 3/...

© NMP 2014

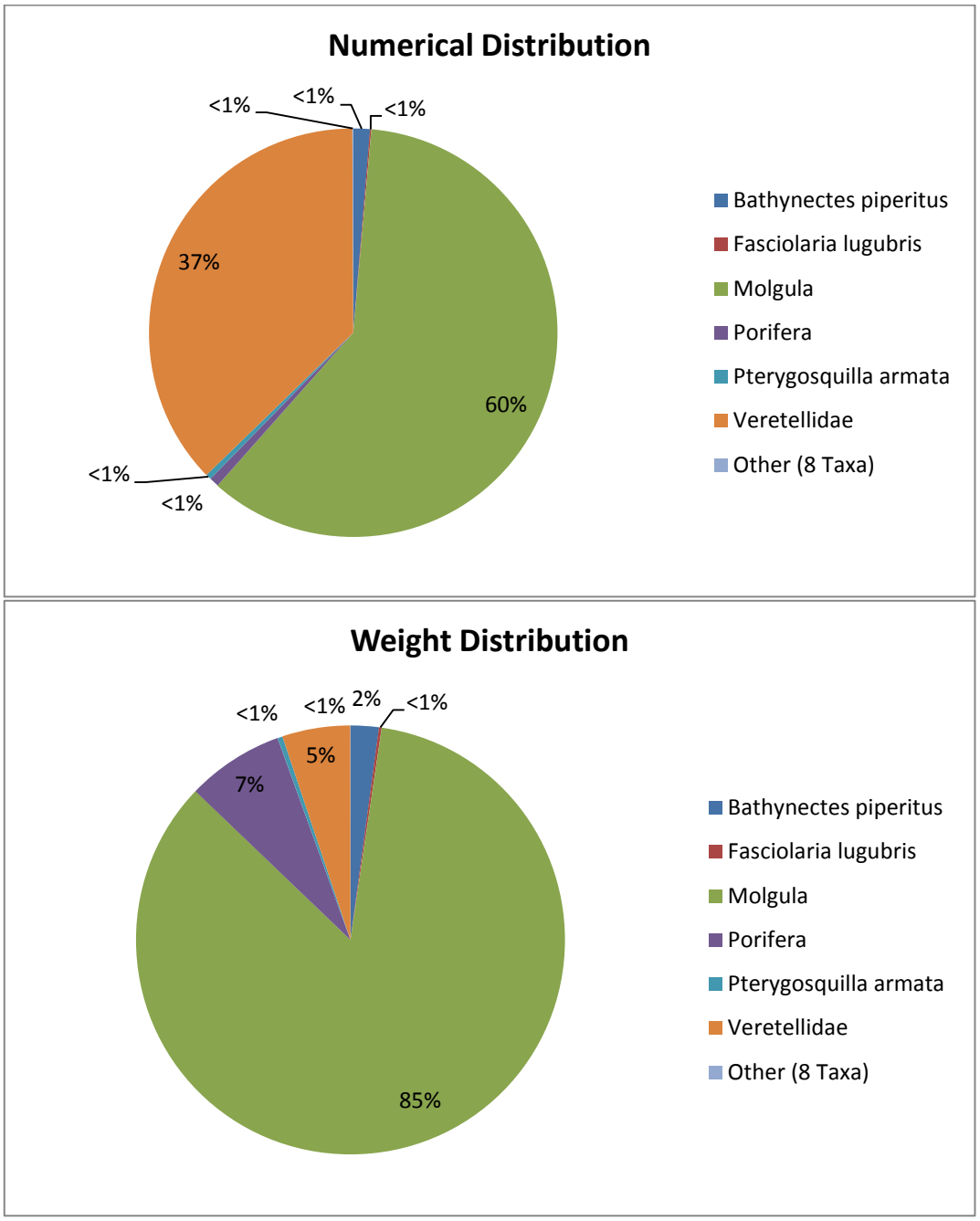


Figure 3: Relative proportions of all epibenthic taxa recorded in the trawling survey according to numbers (top and weights (bottom).

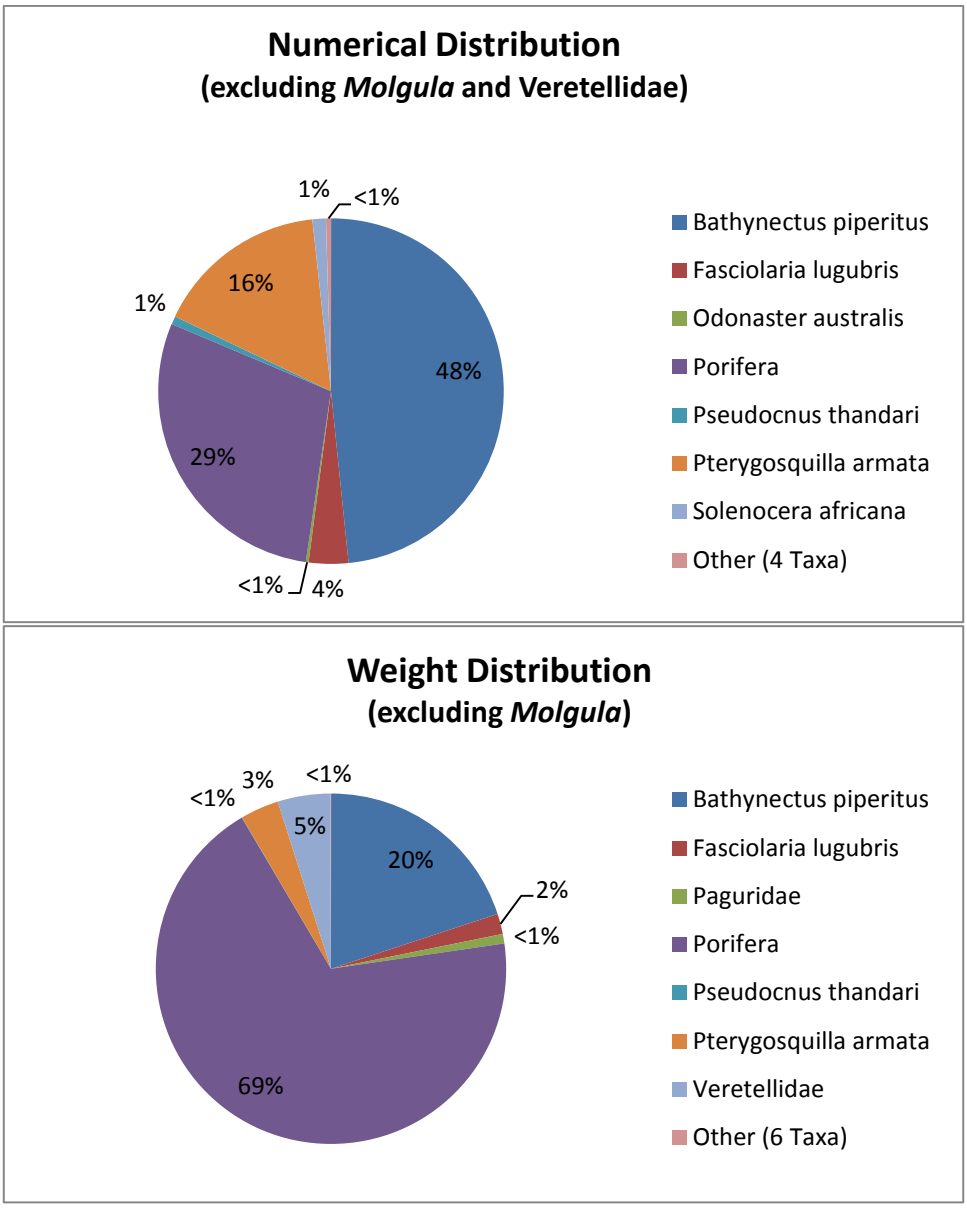


Figure 4: Relative proportions of epibenthic fauna recorded in the trawling survey after removal of selected super-abundant or heavy taxa (*Molgula* and/or Veretellidae).



Figure 5: Trawl contents at station 20 showing high abundance of spherical *Molgula* .



Figure 6: Close-up view of *Molgula* displaying aggregation.

The widespread presence of *Molgula* in the SP-1 area provides potential for efficient monitoring of contamination, and consequent bio-accumulation that may arise when dredging commences. Ascidians have many of the characteristics of an ideal "sentinel" organism (sedentary, filter feeding, long-lived, proven ability to accumulate contaminants non-lethally). Assessment of spatial contamination in the dredging area could be achieved by making use of existing populations or through the strategic placement of trans-located specimens.

Pennatulacea (sea pens, Family Veretellidae, Phylum Cnidaria). The Cnidaria (which includes jellyfish, anemones and hydroids) comprises a diverse, abundant and widely distributed group of marine organisms (Branch *et al.,* 2010). Only one member of this group was encountered in the epifauna survey, namely a sea-pen which was assigned to the family Veretellidae (Figure 7). Sea pens have a fleshy body covered with polyps and a soft unbranched peduncle that anchors the colony in mud or sand. The specimens recovered in this survey were generally small (2 to 3 cm) so would not be expected to be readily caught in the trawl.

© NMP 2014



Figure 7: Sea Pens (*Veretellidae*).

Interestingly, none was encountered in the cod-ends while relatively high numbers were consistently retained in the net wings. It was not possible to make direct counts of material in the net wings so a rough estimate was made, per running metre of the net, and this was extrapolated. Numbers appeared to be consistent for all trawls so a single extrapolated value was applied across the board. This is clearly an extremely rough estimate and should be treated with caution. Nevertheless it serves to indicate that high numbers of sea pens were present. It is likely that numbers were, in fact, much higher since the net wings constitute a very inefficient trap. Veretellidae were also recorded in the benthic faunal surveys (Steffani, 2010, 2014) and those studies would provide a firmer foundation for estimating abundance. They are clearly an important inhabitant of the SP-1 benthic environment.

Porifera (sponges). Sponges are simple, primitive, and somewhat characterless organisms. As a result, they have been very poorly described. One unidentifiable species (Figure 8) was recovered at 20 of the 24 stations in numbers ranging between 1 and 285. It has been labelled “sponge (brown)”. The brown coloration appears to have arisen from mud staining.



Figure 8: Porifera (sponge).

Gastropoda (whelks). Whelks are commonly recovered in bottom trawls. They are active predators or scavengers. Eight specimens of *Nassarius wolffi* (dog whelk) were recovered at station 13. This

species is widely spread along the Atlantic coast of West Africa and has been recorded as far south as Angola and northern Namibia. Somewhat more common was the "tulip whelk" (*Fasciolaria lugubris*) which was found at 16 of the 24 stations, in numbers ranging between 1 and 98 (Figure 9).



Figure 9 : The two gastropod whelks encountered in the survey. 1 – *Fasciolaria lugubris* (dorsal); 2 - Fasciolaria lugbris (ventral); 3 - Nassarius wolffi (dorsal); 4 – Nassarius wolffi (ventral).

Crustacea. Crustacea are usually common in bottom trawls. Some species are exploited commercially while others are usually discarded. This survey yielded six species, of which four are illustrated in Figure 10. Only two of these were found to be widespread and relatively abundant. A swimming crab (*Bathynectes piperitus*) was present at all stations in numbers ranging between 31 and 212. This species is a frequent by-catch in the trawl industry (Bianchi *et al*., 1999) and, in common with all portunid crabs, their fifth legs are flattened to enable swimming. They are active predators and scavengers. A mantis shrimp (*Pterygosquilla armata capensis*) was absent only from station 11 and was recorded in numbers ranging between 2 and 124. This is a highly specialised predator with massive raptorial claws (Branch *et al*., 2010). They may swarm in surface waters. The remaining four crustacean species were present in relatively small numbers and at only a few stations. Two specimens of mud prawn (*Callianassa australis*) were recovered at station 8. This species is reported by Kensley (1981) to occur between Saldanha Bay and Lüderitz at depths between 10 and 180 metres. It was also recorded in the SP-1 area by Steffani (2010). Eight specimens of unidentified hermit crabs (Paguridae) were recovered at station 13, while three specimens of the prawn *Funchalia woodwardi* were present at station 12. Finally, the prawn *Solenocera africana* had a slightly higher presence with recoveries at four stations in numbers ranging between 3 and 32. It is evident that, apart from the swimming crabs and mantis shrimps, crustacean numbers in the study area were exceedingly sparse.

© NMP 2014



Figure 10: Crustacea. 1 –Bathynectes piperitus; 2 – Solenocera africana; 3 – *Pterygosquilla armata capensis ;* 4 – *Callianassa australis.*

Echinodermata. Echinoderms are usually well represented in bottom trawls, globally, with urchins and starfish being particularly prominent. In the SP-1 study area they were virtually non-existent. The

total recovery for 24 trawls was 20 starfish (Asteroidea) and 43 sea cucumbers (Holothuroidea) (Figure 11). The starfish were divided between two taxa, namely an unidentified species of *Astropecten* and *Odontaster australis*. The latter has been previously recorded in deep waters off Cape Town, Lamberts Bay and Lüderitz (Clarke and Courtman-Stock, 1976). The sea cucumber was identified as *Pseudocnus thandari* (Moodley, 2008; Thandar *et al*., 2010). It has been recorded between St Helena Bay and northern Namibia at depths between 18 and 117 metres.



Figure 11: Echinoderms. 1 – *Odontaster australis;* 2 – *Astropecten* (aboral view); 3 – *Astropecten* (oral view); 4 - *Pseudoncnus thandari.*

3.3 COMPARISONS WITH OTHER TRAWLING SURVEYS

Drawing direct and valid comparisons between epifaunal catches in disparate bottom trawling surveys is fraught with difficulties. Trawling is not a precise sampling method and is influenced by numerous confounding factors which are likely to determine the numbers and types of organisms that are retrieved. These include the nature of the trawling gear, the skill of the operators, the

prevailing hydrographic conditions, the nature of the sea-bed, the season, the time of day, the water depth etc. These in turn are overlain by a plethora of biotic influences which might relate to issues such as breeding cycles, seasonal migration and feeding patterns. Nevertheless the need remains to evaluate these results within a broader framework. There have been no similar surveys on the central Namibian continental shelf. However, in recent years there has been renewed interest in the benthic ecology of the southern Benguela Current region, driven by a need to evaluate the impacts of trawling (Atkinson, 2009; Atkinson *et al*., 2011). These studies have focussed on the deeper waters (roughly 350 to 450 metres) between Cape Point and southern Namibia. While there are significant differences in location and depth between the two studies, a broad comparison would appear to be justified. Both studies were based on 24 trawls so may be directly compared.

Atkinson *et al.* (2011) recorded a total of 81 epifaunal taxa in their study, which is far in excess of the 14 recorded here. Echinoderms and crustaceans were particularly well represented in their samples, whereas they are very poorly represented here. The epifauna in the SP-1 area would thus appear to be highly impoverished, particularly in terms of crustaceans and echinoderms.

3.4 ENVIRONMENTAL DRIVERS

Apart from station 11, where a massive catch of jellyfish was made, and counts of other organisms were suppressed, there was notable uniformity in the epifauna across the study area. This is in line with a geophysical survey (Ludick, 2014) which confirmed that sediment type and sedimentary conditions were also uniform. Other factors which might be considered to influence the epifauna include water depth, salinity and oxygen concentration. The depth range was 198 to 255 metres, which would seem to be sufficiently narrow to be of little consequence. Salinities and oxygen concentrations were continuously monitored during trawling through a CTD that was attached to the tow line. The detailed results are presented in an accompanying report (Lwandle, 2014). Deployment of the CTD in this manner posed a number of technical challenges. Nevertheless the data have allowed broad conclusions to be drawn with regard to oceanographic conditions. The salinity and temperature readings were within expected ranges and indicated the presence of South Atlantic Central Water (SACW) in the study area for most of the survey. However, dissolved oxygen concentrations were, in many instances, significantly depressed towards the sea-bed. The natural periodic development of hypoxic conditions is well-documented in Namibian coastal waters and this is a clear a manifestation of that phenomenon. The link between impoverished crustacean and echinoderm communities amongst the epifauna and oxygen depletion seems obvious and draws support from the work of Steffani (2010, 2014) which revealed that the macrobenthic community structure in the SP-1 area was also reflective of a low oxygen environment. Periodic hypoxia may not be problematic for mobile organisms that are capable of avoiding low oxygen conditions. However it may impose severe limitations on those that lack this ability or are not physiologically pre-adapted to a low oxygen environment. Under conditions of periodic hypoxia one would expect the less mobile and more sensitive species to be chronically suppressed and, conversely, for the more mobile taxa to show increased abundance when oxygen levels rise. The presence of high numbers of sea squirts (*Molgula sp.*) and sea pens (Veretellidae) suggests that they are able to tolerate occasional hypoxia and maintain significant populations. On the other hand, portunid crabs (*Bathynectes piperitus*) and mantis shrimps (*Pterygosquilla armata capensis*), which were the only other taxa present in significant numbers, are strong swimmers and presumably capable of avoiding hypoxic conditions. Most of the remaining taxa, notably the gastropods, echinoderms, the sponge, the mud prawn and the hermit crab, have relatively limited mobility and would thus be vulnerable to the negative effects

© NMP 2014

of oxygen depletion. The situation is not clear for the two prawn species (*Funchalia woodwardi* and *Solenocera africana*), both of which were found in low numbers but appear to be adept swimmers.

While the frequency and extent of hypoxic episodes in the SP-1 area are currently unknown it is important to factor their existence into the bio-monitoring programme. Whether a low oxygen environment may be considered the norm, and higher oxygen levels the exception, (or *vice-verse*) is debatable. The programme should aim to monitor hypoxic events to enable partition of impacts between those putatively caused by dredging and those arising from the natural hypoxic episodes.

4 CONCLUSION

While there was a significant presence of epifaunal organisms in the SP-1 area, there was low diversity. This may be ascribed to the chronic effects of periodic hypoxia on the less mobile and more vulnerable taxa. The fauna was numerically dominated by ascidians (sea squirts) and pennatulids (sea pens), which are presumably capable of tolerating periodic hypoxia. Relatively high numbers of portunid crabs and mantis shrimps were also observed. These are strong swimmers and thus capable of circumventing periodic hypoxic events. The information gained in this survey may serve as a baseline for future impact monitoring. However the confounding effects of periodic hypoxia must be taken into account. Of particular interest, in this survey, was the widespread abundance of ascidians (*Molgula.*). It is suggested that these might serve as "sentinel organisms" for assessing possible contamination once dredging starts.

5 ACKNOWLEDGEMENTS

Thanks are due to Jeremy Midgley for solid logistical support, to Melanie Smith for sound project leadership, to fellow scientists (Melanie Smith, Kate Munnik, Victor Ncongo, Robert Williamson, Malakia Shimhanda and Ester Nangolo) for great team work, and to the Captain and the crew of FV *Zeearend* for unstinting assistance.

© NMP 2014

6 REFERENCES

Atkinson, L.J. 2009. Effects of demersal trawling on marine infaunal, epifaunal and fish asemblages: studies in the southern Benguela and Oslofjord. Thesis presented for the Degree of Doctor of Philosophy in the department of Zoology, Faculty of Science and Ma-Re Institute University of Cape Town. September 2009.

Atkinson, L.J., Field, J.G. and Hutchings, L. 2011.Effects of demersal trawling along the west coast of southern Africa : multivariate analysis of benthic communities. *Marine Ecology Progress Series* **430**: 241-255.

Bianchi, G., Carpenter, K.E., Roux, J.-P, Molloy, F.J., Boyer, D. and Boyer, H.J. 1999. FAO species identification field guides for fishery purposes. *The Living Marine Resources of Namibia. Rome*, FAO 265 pp.

Branch, G.M., Griffiths, C.L., Branch, M.L., & Beckley, L.E. 2010. *Two Oceans*. *A Guide to the Marine Life of southern Africa*. Struik Nature, Cape Town; 456 pp.

Clarke, A.M. and Courtman-Stock, J. 1976. *The echinoderms of southern Africa*. British Museum (Natural History). 277 pp.

Ludick, W. 2014. ML170 (SP-1) Sea Floor Conditions. Namibian Marine Phosphate. Unpublished Report. 6 pp.

Lwandle (2014). Namibian Marine Phosphate - Biomass Verification Survey: CTD Report. Prepared by Lwandle Technologies Pty Ltd. 30 July 2013

Moodley, M.N. 2008. A new dendrochirotid sea cucumber from the west coast of South Africa (Echinodermata: Holothuroidea: Cucumariidae). *African Zoology* **43** (1): 61-65.

NMP, 2012. Sandpiper Project Environmental Impact Assessment Report http://www.namphos.com/project/sandpiper/environment/item/57-environmental-marine-impact-assessment-report.html

Steffani, N. 2010. Biological baseline survey of the benthic macrofauna communities in the Phosphate Licence Blocks EPL 3415 and EPL 3233 in the Sandpiper/Meob JV Project Area. 29 pp.

Steffani, N. 2014. Benthic Macrofauna in the Sandpiper SP-1 Target Mining Area. Verification Survey. Draft Report. 53 pp.

Thandar, A.S., Zettler, M.L. and Arumugam, P. 2010. Additions to the sea cucumber fauna of Namibia and Angola, with descriptions of new taxa (Ecinodermata: Holothuroidea). *Zootaxa* 2655: 1-24.

© NMP 2014

Annexure 1: Epifauna Counts and Weights

© NMP 2014

Station Number		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Sampling Time (Day/Night)		N	D	D	D	D	D	D	D	D	D	D	D	N	N	N	N	D	N	N	N	N	N	N	N
Water Depth at start (m)		229	230	241	231	218	217	213	213	198	201	202	242	255	209	221	209	223	223	238	234	205	249	221	237
COUNTS																									
Astropecten	Starfish (long-armed)													5											
Bathynectus piperitus	Swimming Crab	92	88	41	129	143	197	94	145	73	107	31	87	119	172	175	156	98	59	73	176	212	68	126	79
Callianassa africana	Mud Prawn								2																
Fasciolaria lugubris	Whelk (tulip)	9	3	5	11			16						98	1	15	12	9	5	5	3	1	8	16	10
Funchalia woodwardi	Prawn												3					3							
Molgula	Sea Squirt	3226	8259	1275	44408	9207	5254	16044	4001	89	242		884		209	4622	2638	2308	2083	1873	15728		109	3014	328
Nassarius wolffi	Whelk (dog)													8											
Odontaster australis	Starfish (cushion star)									10	5														
Paguridae	Hermit Crab													8											
Porifera	Sponge (brown)	219	285	46		97	21	16	7	1	1			94	5	41	23	51		164	165	17	151	91	95
Pseudocnus thandari	Sea Cucumber					6	10	2								10	12				3				
Pterygosquilla armata capensis	Mantis Shrimp	54	50	39	26	34	25	27	19	2	4		39	53	12	20	40	80	40	67	36	3	124	101	18
Solenocera africana	Prawn													3					28	32					4
Veretellidae	Sea Pen	3240	3240	3240	3240	3240	3240	3240	3240	3240	3240	3240	3240	3240	3240	3240	3240	3240	3240	3240	3240	3240	3240	3240	3240
Total Counts		**6840**	**11925**	**4646**	**47814**	**12727**	**8747**	**19439**	**7414**	**3415**	**3599**	**3271**	**4253**	**3628**	**3639**	**8123**	**6121**	**5789**	**5455**	**5454**	**19351**	**3473**	**3700**	**6588**	**3774**
Numbers of Taxa		**6**	**6**	**6**	**5**	**6**	**6**	**7**	**6**	**6**	**6**	**2**	**5**	**9**	**6**	**7**	**7**	**7**	**6**	**7**	**7**	**5**	**6**	**6**	**7**
WEIGHTS (kg)																									
Astropecten	Starfish (long-armed)													0.03											
Bathynectus piperitus	Swimming crab	3.37	3.37	1.63	5.15	12.27	8.65	3.92	5.14	3	4.68	1.39	3.18	5.28	7.65	6.97	6.38	3.84	1.98	3.41	8.87	7.69	2.78	5.02	2.79
Callianassa africana	Mud Prawn								0.01																
Fasciolaria lugubris	Whelk (tulip)	0.02	0.06	0.11	0.11			3.02						5.92	0.02	0.32	0.15	0.39	0.19	0.16	0.06	0.01	0.25	0.33	0.47
Funchalia woodwardi	Prawn												0.03					0.03							
Molgula	Sea squirt	69.36	60.28	316.97	346.94	644.46	367.75	175.14	280.08	6.26	16.97		61.91		100.25	323.55	184.67	161.59	145.83	131.11	1100.93		7.61	210.96	22.95
Nassarius wolffi	Whelk (dog)													0.01											

© NMP 2014

Odontaster australis	Starfish (cushion star)									0.03	0.02													
Paguridae	Hermit crab													0.53										
Porifera	Sponge (brown)	26.27	27.57	21.88		12.27	10.24	1.85	3.24	0.38	0.69		19.98	44.98	0.69	19.68	3.19	24.69		26.19	31.77	2.52	72.59	12.03	45.82
Pseudocnus thandari	Sea Cucumber					0.06	0.03	0.002								0.05	0.03				0.03				
Pterygosquilla armata capensis	Mantis shrimp	0.8	1.07	0.86	0.56	0.72	0.51	0.71	0.53	0.06	0.07		1.04	1.5	0.5	0.57	0.72	1.22	0.67	2.66	1.06	0.07	3.02	1.68	0.43
Solenocera africana	Prawn													0.01					0.09	0.09					0.02
Veretellidae	Sea Pen	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9
Total Biomass (kg)		**111.72**	**104.25**	**353.35**	**364.66**	**681.68**	**399.08**	**196.542**	**300.9**	**21.63**	**34.33**	**13.29**	**98.04**	**70.16**	**121.01**	**363.04**	**207.04**	**203.66**	**160.66**	**175.52**	**1154.62**	**22.19**	**98.15**	**241.92**	**84.38**

Station Number		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Sampling Time (Day/Night)		**N**	**D**	**D**	**D**	**D**	**D**	**D**	**D**	**D**	**D**	**D**	**D**	**N**	**N**	**N**	**N**	**D**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
Water Depth at start (m)		**229**	**230**	**241**	**231**	**218**	**217**	**213**	**213**	**198**	**201**	**202**	**242**	**255**	**209**	**221**	**209**	**223**	**223**	**238**	**234**	**205**	**249**	**221**	**237**
STANDARDISED COUNTS																									
Astropecten	Starfish (long-armed)													4.55											
Bathynectus piperitus	Swimming Crab	92	88	41	117.3	143	203.8	64.09	145	73	107	31	87	108	172	175	156	98	65.6	73	176	212	68	126	79
Callianassa africana	Mud Prawn								1																
Fasciolaria lugubris	Whelk (tulip)	9	3	5	10			13.64						89.1	1	15	12		5.56	5	3	1	8	16	10
Funchalia woodwardi	Prawn												3					3							
Molgula	Sea Squirt	3226	7760	1275	40371	9207	5435	10939	4001	89	242		884		209	4622	2638	2308	2314	1873	15728		109	3014	328
Nassarius wolffi	Whelk (dog)													7.27											
Odontaster australis	Starfish (cushion star)									10	5														
Paguridae	Hermit Crab													7.27											
Porifera	Sponge (brown)	219	285	46		97	21.72	10.91	7	1	1		42	85.5	5	41	23	51		164	165	17	151	91	95
Pseudocnus thandari	Sea Cucumber					6	10.34	1.364								10	12				3				
Pterygosquilla armata capensis	Mantis Shrimp	54	50	39	23.64	34	25.86	18.41	19	2	4		39	48.2	12	20	40	80	44.4	67	36	3	124	101	18
Solenocera africana	Prawn													2.73					31.1	32					4
Veretellidae	Sea Pen	3240	3240	3240	2945	3240	3352	2209	3240	3240	3240	3240	3240	2945	3240	3240	3240	3240	3600	3240	3240	3240	3240	3240	3240

© NMP 2014

Total Counts		**6840**	**11426**	**4646**	**43467**	**12727**	**9049**	**13257**	**7413**	**3415**	**3599**	**3271**	**4295**	**3298**	**3639**	**8123**	**6121**	**5780**	**6061**	**5454**	**19351**	**3473**	**3700**	**6588**	**3774**
Numbers of Taxa		**6**	**6**	**6**	**5**	**6**	**6**	**7**	**6**	**6**	**6**	**2**	**6**	**9**	**6**	**7**	**7**	**6**	**6**	**7**	**7**	**5**	**6**	**6**	**7**
STANDARDISED WEIGHTS (kg)																									
Astropecten	Starfish (long-armed)													0.03											
Bathynectus piperitus	Swimming Crab	3.37	3.36	1.63	5.15	12.27	8.65	3.92	5.14	3	4.68	1.39	3.18	5.28	7.65	6.97	6.38	3.84	1.98	3.41	8.87	7.69	2.78	5.02	2.79
Callianassa africana	Mud Prawn								0.01																
Fasciolaria lugubris	Whelk (tulip)	0.02	0.06	0.11	0.11			3.02						5.92	0.02	0.32	0.15	0.39	0.19	0.16	0.06	0.01	0.25	0.33	
Funchalia woodwardi	Prawn												0.03					0.03							
Molgula	Sea Squirt	69.4	56.26	317	346.9	644.5	367.8	175.1	280	6.26	17		61.9		100	323.6	185	162	146	131	1101		7.61	211	23
Nassarius wolffi	Whelk (dog)													0.01											
Odontaster australis	Starfish (cushion star)									0.03	0.02														
Paguridae	Hermit Crab													5.29											
Porifera	Sponge (brown)	26.3	27.57	21.9		12.27	10.24	1.85	3.24	0.38	0.69		20	45	0.69	19.68	3.19	24.7		26.2	31.77	2.52	72.6	12	45.8
Pseudocnus thandari	Sea Cucumber					0.06	0.03	0.002								0.05	0.03				0.03				
Pterygosquilla armata capensis	Mantis Shrimp	0.8	1.07	0.86	0.56	0.72	0.51	0.71	0.53	0.06	0.07		1.04	1.5	0.5	0.57	0.72	1.22	0.67	2.66	1.06	0.07	3.02	1.68	0.43
Solenocera africana	Prawn													0.01					0.09	0.09					0.02
Veretellidae	Sea Pen	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Total Biomass (kg)		**101**	**89.52**	**343**	**354**	**671**	**388.4**	**185.8**	**290**	**10.9**	**23.6**	**2.59**	**87.3**	**64.2**	**110**	**352.3**	**196**	**193**	**150**	**165**	**1144**	**11.5**	**87.5**	**231**	**73.2**

© NMP 2014

SPECIALIST STUDIES – SECTION C

C2.7 Plankton Report

Prepared for:
Namibian Marine Phosphate (Pty) Ltd.

Prepared by:
Lwandle Technologies (Pty) Ltd.
Report compiled by Laura Weston and Robin Carter



August 2014

Job no: LT-149

MARINE SPECIALIST TEAM:

Laura Weston – Lwandle Technologies
Dr. Robin Carter – Lwandle Technologies

Date	Version	Revised	Reviewed
24/02/2014	1	Laura Weston	Robin Carter
31/07/2014	2	Laura Weston	Robin Carter
11/08/2014	3	Laura Weston	Kate Munnik

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed "Attention: Administration Manager," at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

contents

1 INTRODUCTION 1

2 PROJECT DESCRIPTION AND REGIONAL OVERVIEW 1

3 BIOLOGICAL OCEANOGRAPHY 3

3.1 SEASONALITY 3
3.1.1 Phytoplankton 3
3.1.2 Zooplankton 5
3.1.3 Ichthyoplankton 6
3.2 ALONG-SHELF DISTRIBUTION 8
3.2.1 Phytoplankton 8
3.2.2 Zooplankton 8
3.2.3 Ichthyoplankton 10
3.3 CROSS-SHELF DISTRIBUTION 11
3.3.1 Phytoplankton 11
3.3.2 Zooplankton 12
3.3.3 Ichthyoplankton 12
3.4 VERTICAL DISTRIBUTION 13
3.4.1 Phytoplankton 13
3.4.2 Zooplankton 13
3.4.3 Ichthyoplankton 15
3.5 CHARACTERISATION OF SPECIES AND FORMS PRESENT 16
3.5.1 Phytoplankton 16
3.5.2 Zooplankton 17
3.5.3 Ichthyoplankton 18
3.6 LONG-TERM VARIABILITY 18
3.7 IMPORTANCE OF PLANKTON IN THE FOOD WEB 20

4 SUMMARY 21

5 REFERENCES 22

© NMP 2014

figures

Figure 1: The oceanographic environment in the south east Atlantic 2
Figure 2: Latitude by month plots of (a) sea surface temperature and (b) surface chlorophyll-*a*. 4
Figure 3: The along-shelf distribution of copepod abundance in the northern Benguela. 9
Figure 4: Vertical distribution of zooplankton biomass at 25°S (redrawn from Timonin *et al*. 1992). 14
Figure 5: ADCP beam attenuation through the upper water column from -10 m to -100m at site 15 of the marine ecology verification survey. 14
Figure 6: ADCP beam attenuation through the upper water column from -10 m to -100 m at site 15 of the marine ecology verification survey. 15

© NMP 2014

1 INTRODUCTION

The environmental effects of dredging marine pelletal phosphate on the Namibian continental shelf have been investigated and included in a previously conducted Environmental Impact Assessment (NMP, 2010). Received comments on this *inter alia* pointed out that insufficient attention had been paid to zooplankton and ichthyoplankton that occupy the area. To address this, a literature review of the available information pertaining to plankton in the central Namibian region was commissioned by NMP to summarise the existing knowledge on the distribution and biology of these groups.

The proposed mining area is situated within the Benguela upwelling system off Namibia on the west coast of Africa. The Benguela is a unique system and is one of the most dynamic and productive ecosystems in the world, playing a major role both ecologically and economically in Namibia. It supports a large suite of species, including phytoplankton, zooplankton and ichthyoplankton, that all play an important role in the trophic dynamics of the region, supporting important fish resources. The purpose of this review is to provide information on the suite of phytoplankton, ichthyoplankton and zooplankton species and ecology in the northern Benguela Current continental shelf waters encompassing the proposed mining site off central Namibia.

2 PROJECT DESCRIPTION AND REGIONAL OVERVIEW

A detailed project description with all relevant technical data is provided in the general EIA. Below is a brief summary of the proposed mining project.

The Mining Licence Area (MLA) is located approximately 60 km offshore of the central Namibian coast (Figure 1). Within the MLA, there are two initial target sites. SP-1 is the primary target site where dredging will commence, and is located in the north of the MLA. It covers an area of 172 km^2, in water depths of 190-235 m. SP-2 is the same size as SP-1, but lies further south and slightly further offshore in water depths of 245-285 m. A further candidate area has been identified (SP-3), which is 88 km^2 in extent in water depths of 235-270 m.

© NMP 2014

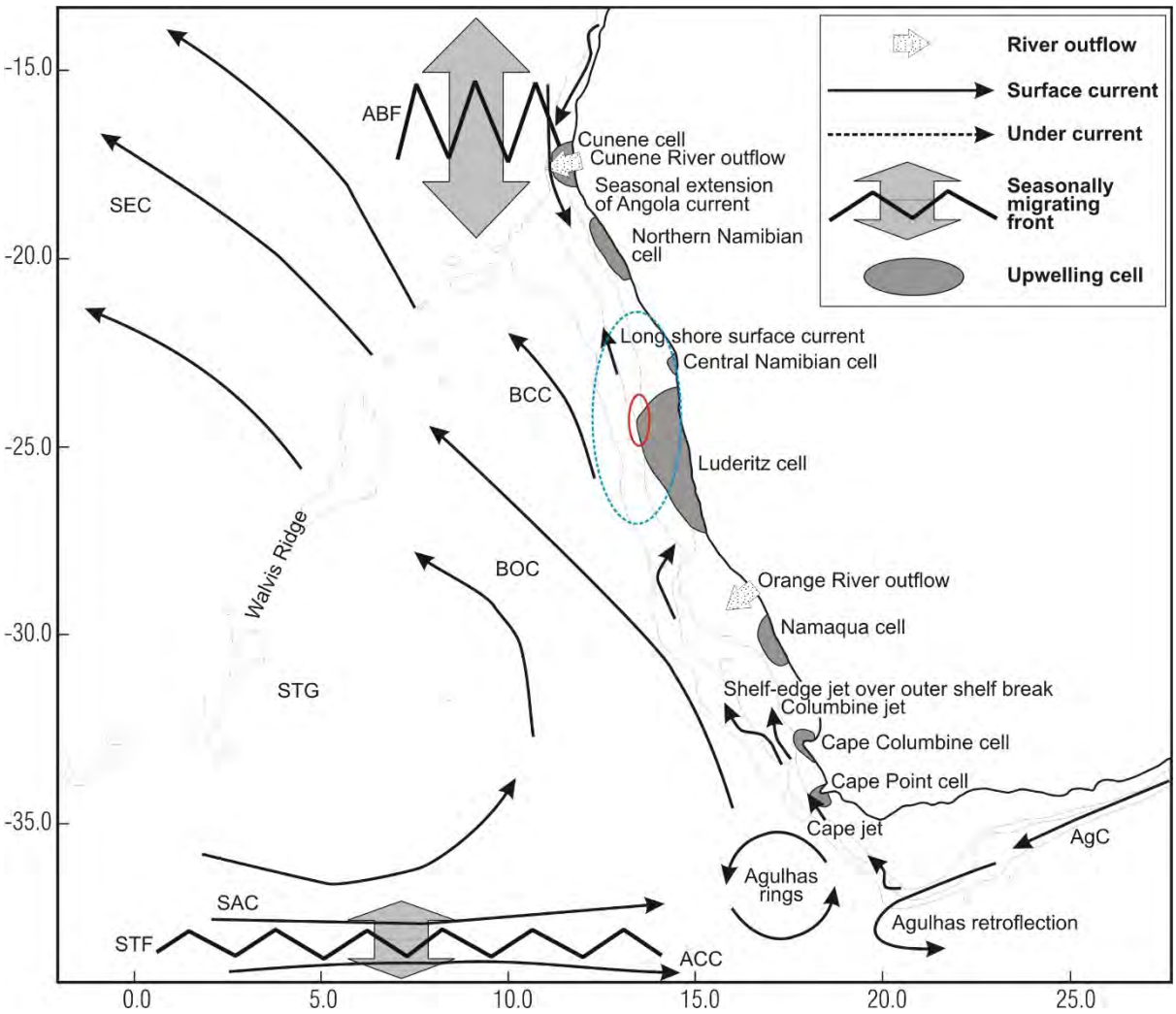


Figure 1: The oceanographic environment in the south east Atlantic showing surface and near-surface currents, frontal zones, upwelling cells, major areas of freshwater input and bathymetry. The dashed blue ellipse indicates the study site off central Namibia, and the solid red ellipse indicates the position of the Mining Licence Area (MLA). (SEC = South Equatorial Current; BOC = Benguela Oceanic Current; BCC = Benguela Coastal Current; SAC = South Atlantic Current; AgC = Agulhas Current; ABF = Angola-Benguela Front; STG = subtropical gyre; ACC = Antarctic Circumpolar Current)
(Redrawn from Hardman-Mountford *et al*. 2003).

The main oceanographic features of the study area are shown in Figure 1. The oceanographic environment in the south east Atlantic, off the west coast of southern Africa, is dynamic and in many ways, unique, where it is primarily defined by the Benguela Current (including the Benguela Oceanic Current and the Benguela Coastal Current). As already explained in detail in the EIA report and related appendices, the Benguela Current flows equatorward and is one of the four major eastern boundary currents of the world, forming the eastern boundary of the South Atlantic subtropical gyre (e.g. Weeks *et al*. 2004). It extends from Cape Agulhas (35°S) to approximately Namibe, Angola (15°S) out to a depth of approximately 500 m off the west coast of southern Africa. As with other eastern boundary currents, it is dominated by the occurrence of coastal upwelling, generated by equatorward winds causing the offshore (Ekman) transport of surface water. It is unique in that it is bordered by warm water systems in both the northern and southern regions - the Angola Current system in the north and the Agulhas Retroflection area in the south (Shannon 1985). Another

characteristic of the Benguela Current region is the extensive and for the most part, permanent oxygen minimum layer at 100 – 500 m depth (Ekau and Verheye 2005).

The Lüderitz upwelling cell, which may be the strongest, perennial, locally wind-driven, coastal upwelling region of any region in the world lies between 27°S and 24°S (Figure 1) (Hardman-Mountford *et al*. 2003). The upwelling at this site is strong throughout the year, but a short quiescent period can occur during autumn and a slight maximum can occur during spring (Shannon and Pillar 1986). Although this feature is spatially and temporally variable, it effectively divides the Benguela Current system into southern and northern regions (Shannon 1985). The central Namibian sub-region, between Lüderitz and Walvis Bay, forms a transitional zone between the Lüderitz upwelling cell and the northern Benguela, and is characterized by slightly lower upwelling intensity than that off the coast of Lüderitz (Shannon 1985). It is this region that is the main focus of this review and forms the study area, as the prospective mining site is located on the northern edge of the Lüderitz upwelling cell, south of Walvis Bay, between 24.1° and 24.3°S latitude (Figure 1).

3 BIOLOGICAL OCEANOGRAPHY

3.1 SEASONALITY

3.1.1 Phytoplankton

Off the coast of Lüderitz, there is a plentiful supply of nutrients to the surface waters, due to the perennial occurrence of intense upwelling causing water column mixing where the nutrient rich bottom water is brought to the surface. However, light is a limiting factor in the growth and production of phytoplankton, as the intense upwelling also results in the surface water replacing the bottom water. Phytoplankton cells are removed from the surface waters and therefore are not within the euphotic zone long enough to photosynthesize and create production. This results in low biological productivity in the vicinity of the Lüderitz upwelling cell and a reduced seasonal signal in this productivity, where a constant chlorophyll-*a* minimum is recorded in this area (Shannon *et al*. 1984; Demarcq *et al*. 2007).

Further north, on the northern border of the Lüderitz upwelling cell, there is a decrease in upwelling intensity, which results in more developed seasonality in the temperature of the water and the formation of thermoclines in the upper water column, with an increase in stratification in autumn (February to March) (Hardman-Mountford *et al*. 2003). This increases biological production. The seasonal effect in water temperature is reinforced by the seasonal warming of the northern Benguela waters during autumn due to the intrusion of equatorial waters, and is especially prominent in the areas on the northern boundary of the Lüderitz upwelling cell (Campillo-Campbell and Gordoa 2004). This seasonality in the physical conditions is reflected in the seasonal fluctuations in phytoplankton biomass (Figure 2).

© NMP 2014

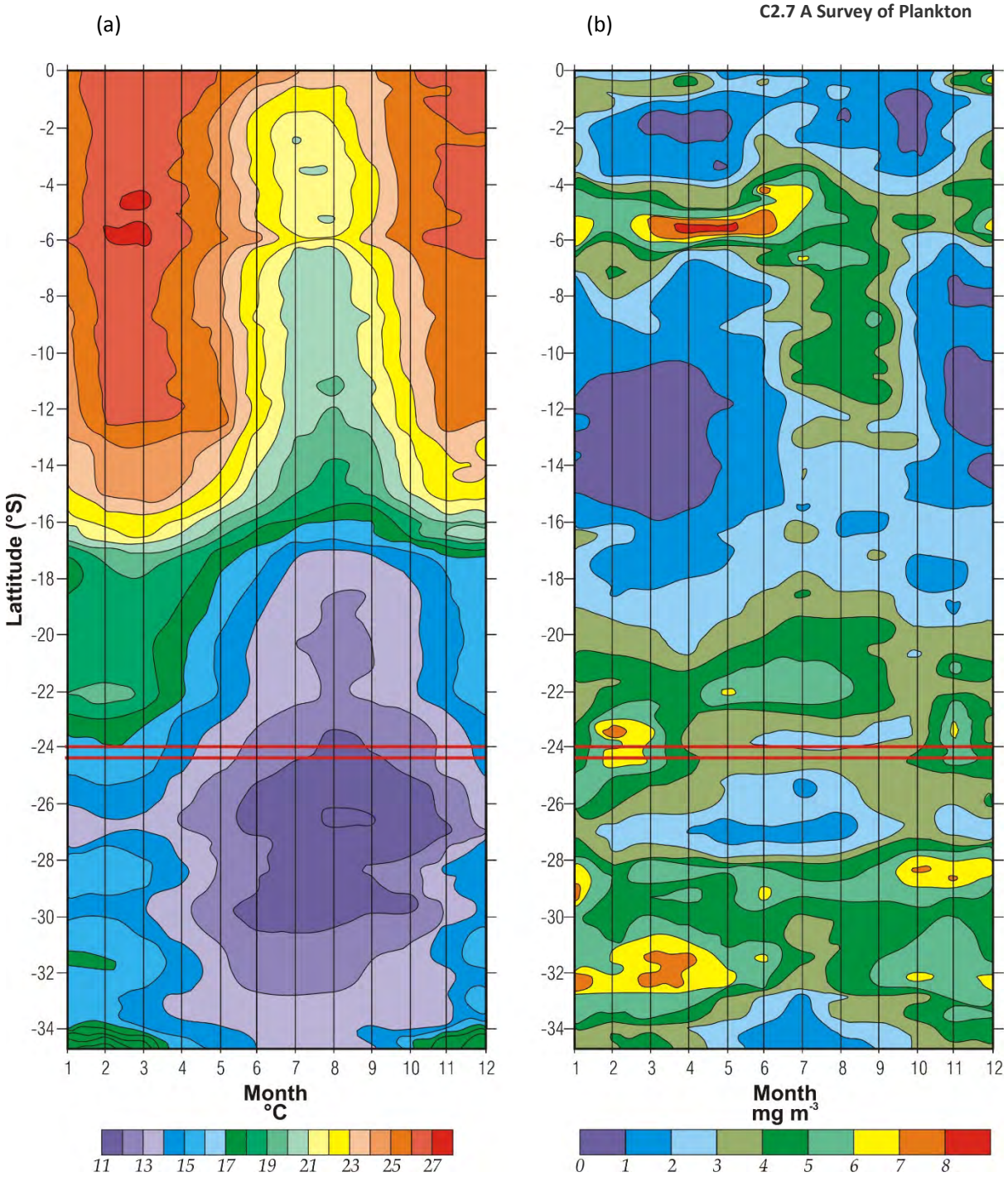


Figure 2: Latitude by month plots of (a) sea surface temperature and (b) surface chlorophyll-*a*. The plots show a) Coastal sea surface temperature(°C) , where the width of the coastal strip is considered to be 20 km and b) Coastal surface chlorophyll-*a* (mg.m^{-3}), where the width of the coastal strip is considered to be 50 km. The two red lines indicate the northern and southern boundaries of the proposed phosphate mining site off central Namibia. (Redrawn from Harman-Mountford *et al.* 2003)

The Mining Licence (ML 170), located at 24.0°S to 24.5° S latitude, should experience low surface water temperatures and low phytoplankton biomass in the austral winter/spring with both metrics increasing in the summer/autumn period. Biomass and productivity is generally higher and more extensive in the late summer and autumn months, when there is a reduction in upwelling and an increase in thermocline development, and thus sufficient nutrient and light availability. In

© NMP 2014

continental shelf waters north of 25°S, highest chlorophyll-*a* concentrations were found to occur from November through to March (Campillo-Campbell and Gordoa 2004). The increase in chlorophyll-*a* concentration was coupled with a seasonal increase in the offshore extent of the phytoplankton distribution (Demarcq *et al*. 2007). Offshore of Walvis Bay in particular, an increase in chlorophyll-*a* concentrations occurs between January and May, with a peak occurring in May during intermediate upwelling activity (Shannon *et al*. 1984). During this period, phytoplankton biomass increases significantly in the beginning of the quiescent phase when nutrients are readily available, and then stabilizes as nutrients are utilized and become more limited.

During periods of increased upwelling in winter and early spring, from June to September, chlorophyll-*a* concentrations are reduced (Campillo-Campbell and Gordoa 2004; Demarcq *et al*. 2007). Phytoplankton concentrations are particularly reduced in September (Shannon *et al*. 1984).

Overall, a strong seasonal signal in terms of phytoplankton biomass and distribution, with an increase during the summer and early autumn months, off the coast of central Namibia has been shown. This is strongly related to certain physical parameters, where the upwelling present in the region plays an especially important role. More than one peak in chlorophyll-*a* concentration during these months may occur.

3.1.2 Zooplankton

The short-term temporal variation in zooplankton distribution is linked to the availability of phytoplankton prey and so is related to the hydrographic conditions within the area (Shannon and Pillar 1986). The area off the coast of Lüderitz is characterized by the presence of perennial upwelling, while the area slightly further north, off the coast of Walvis Bay, is characterized by a more seasonal occurrence of coastal upwelling (Verheye *et al*. 1992). In this area and extending north of Walvis Bay zooplankton biomass has been found to peak during more quiescent periods from December through to May (Shannon and Pillar 1986; Verheye *et al*. 1992), coinciding with maximum phytoplankton production. More specifically, Unterüberbacher (1964) identified two peaks in zooplankton biomass in the Walvis Bay region: a primary peak occurring during summer from November to December, and a secondary peak occurring in autumn from March to June. Hansen *et al*. (2005) looking at the abundance of the dominant copepod species off Walvis Bay, reported similar distributions with the four most abundant copepod species (*Metridia lucens, Calanoides carinatus, Rhincalanus nasutus* and *Centropages brachiatus*) displaying a primary peak in abundance between October and December, and a minimum during September. This pattern appears to extend to euphausiids where highest abundances have been reported between January and March (Barange and Stuart 1991).

These seasonal patterns are however complicated by interspecies differences, changes in distribution patterns in response to upwelling, as well as some interannual variability. Timonin *et al*. (1992) found the seasonal variation in zooplankton biomass to have a spatial element. During quiescent conditions, zooplankton biomass increased further offshore on the shelf-break, while during and immediately after upwelling, zooplankton biomass increased closer inshore. In the study conducted by Hansen *et al*. (2005) from February through to December 2000, although the above mentioned seasonal patterns were shown for most copepod species, there was also a spatial element to the pattern, with inshore and offshore zones showing changes in species composition during active upwelling and quiescent phases. In contrast, Barange and Stuart (1991) found the

© NMP 2014

distribution patterns of the predominant euphausiids off Walvis Bay to remain relatively constant throughout the years from 1982 to 1984.

Overall, a seasonal signal in zooplankton biomass in central Namibian waters is apparent, and may be linked to seasonal variations in upwelling and phytoplankton availability. This pattern however has a spatial element for certain species, with higher zooplankton abundance occurring during quiescent phases further offshore, and increased zooplankton production during and immediately after active upwelling within inshore waters. To a certain extent, there may also be an interannual difference in the seasonality patterns displayed by zooplankton communities. Further south off the coast of Lüderitz, where the upwelling is more perennial, and there is less phytoplankton production and therefore less food availability, little seasonality in zooplankton biomass or distribution has been demonstrated.

3.1.3 Ichthyoplankton

The productive waters off the coast of Namibia support many fish species, some of which are commercially important, supporting large pelagic and demersal fisheries within the area (O'Toole 1977a; Crawford *et al*. 1987). Ichthyoplankton, or the eggs and larvae of fish, form a relatively minor component of the plankton assemblage within Namibian waters but are an important consideration in light of the large commercial fisheries. Information on ichthyoplankton allows for information on spawner biomass or recruitment to be extrapolated, and for ecological processes related to the fisheries to be investigated (Shannon and Pillar 1986).

As a result of the commercial importance of the fish stocks off the coast of Namibia, regular cruises have been conducted within the area since approximately the 1970s. These include the SWAPELS cruises that were conducted between 18 and 24°S, collecting quantitative information on the eggs and larvae of commercially important species such as anchovy and sardine (O'Toole 1977a; Shannon and Pillar 1986), and in recent years, these cruises have been augmented with a variety of other investigations in the same area, including surveys conducted by the Ministry of Fisheries and Marine Resources, Namibia (MFMR) (Lange 20013), as well as other ad-hoc research surveys (e.g. Olivar *et al*. 1992; Stenevik *et al*. 2001; Ekau & Verheye 2005; Giest *et al*. in press).

As with phytoplankton and zooplankton communities, the occurrence of intense coastal upwelling off the coast of Namibia has a large implication for the ichthyoplankton community present in the area (O'Toole 1977a). The seasonality that this upwelling displays, particularly further north where the influence of the perennial Lüderitz upwelling cell is less prominent, has an influence on the spawning habits of fish species in the area (Shannon and Pillar 1986). A seasonal signal in ichthyoplankton abundance and distribution off central to northern Namibia is thus shown.

Olivar (1987) conducted a study off the coast of central and northern Namibia, where *in situ* data on ichthyoplankton were collected during three cruises completed between 1979 and 1981. During these cruises, samples were collected off Walvis Bay, at approximately 23°S, slightly further north than the MLA. The data collected were compared between cruises, where some were conducted during the occurrence of intense upwelling, and others were conducted during quiescent periods. This allowed for the effect of upwelling, and by extension the seasonal effect, on ichthyoplankton distribution, abundance and diversity to be investigated. It was found that with the presence of upwelling activity off Walvis Bay during the winter and spring, there was a reduction in ichthyoplankton abundance and diversity. In contrast, with increasing water column stability,

ichthyoplankton abundance and diversity was found to increase. To a certain extent, this was species specific and was related to the spawning habits of the adults.

During the first two cruises, both conducted during periods of increased upwelling, similar ichthyoplankton assemblages were found (Olivar 1987). Larvae from the pelagic bearded goby *Sufflogobius bibarbatus* and the lantern fish *Lampanyctodes hectoris* were the most abundant. Both of these species are shown to spawn virtually all year round, and the larvae form an important component of the food web within the northern Benguela. The spawning of *S. bibartus* is known to peak during spring, while *L. hectoris* spawning peaks during spring and early summer (O'Toole 1977a; Shannon and Pillar 1986). The third cruise was conducted during a quiescent period, and the ichthyoplankton abundances were quite different. The larvae of horse mackerel *Trachurus trachurus capensis* were the most abundant. This species is known to spawn during summer and autumn, with a peak from January to March, primarily north of 22°S (Shannon and Pillar 1986; Geist *et al*. in press). The larvae of another goby, *Lesuerigobius sanzoi* and achovy *Engraulis capensis* were the next most abundant, with *L. sanzoi* spawning mainly in autumn and *E. capensis* spawning in summer and autumn (O'Toole 1977a).

Other species, specifically important commercial species, which show seasonality in spawning and thus result in seasonal signals in the abundance, distribution and community structure of ichthyoplankton off central Namibia are discussed below. The sardine *Sardinops sagax* spawns at least twice a year from August through to April, with spawning maxima in late winter to spring, and the other in late summer to autumn (King 1977; O'Toole 1977a; Shannon and Pillar 1986; Stenevik *et al*. 2001; Kreiner *et al*. 2011). This is related to environmental signals such as temperature and food (King 1977; Shannon and Pillar 1986).

The West Coast sole (*Austroglossus microlepis*) which is bycatch of the monkfish fishery in Namibian waters, and has a relatively short spawning season. A seasonal signal in larval abundance was shown off central Namibia, with a significant increase shown from early spring to early summer (O'Toole 1977b).

Hake, *Merluccius capensis and Merluccius paradoxus* eggs and larvae occur throughout Namibian waters, with *M. paradoxus* occurring in deeper waters, outside of the 400 m isobath, and *M. capensis* occurring more broadly from nearshore waters out to the 400 – 500 m isobaths (Sundby *et al*. 2001). Spawning of these species occurs from spring through to late summer (Shannon and Pillar 1986). *M. capensis* in particular displays peak spawning from October through to December, with a secondary peak during February/March during some years (Sundby *et al*. 2001). This pattern in ichthyoplankton production is consistent with the results of Olivar (1987), with an increase in hake eggs and larvae during more quiescent periods off central Namibia.

Overall, there is clear seasonality displayed in ichthyoplankton abundance and community structure off the coast of central Namibia, but this is relatively complex, and is largely species specific. In general environmental and hydrological factors drive changes in the spawning habits of species and distribution of eggs and larvae, and so affect the ichthyoplankton assemblages on a temporal scale.

© NMP 2014

3.2 ALONG-SHELF DISTRIBUTION

3.2.1 Phytoplankton

The main controlling features affecting the longshore distribution of phytoplankton in the Northern Benguela Current region are the Lüderitz upwelling cell and the Angola/Benguela Front (ABF) which is generally located between 14°-16° S (Meeuwis and Lutjeharms 1990). Shannon *et al*. (1984) showed that within the Lüderitz upwelling cell phytoplankton biomass was generally <5 $mg.m^{-3}$, of chlorophyll-*a*. Further north, on the northern boundary of the upwelling cell, towards Walvis Bay *in situ* chlorophyll-*a* concentrations increased significantly, ranging between 3 and 10 $mg.m^{-3}$. Brown *et al* (1991) demonstrated a similar pattern from *in situ* surface measurements of chlorophyll-*a* obtained between 1985 and 1989. At the northern extremity of the region the ABF separates the biologically productive waters of the Benguela Current from the more oligotrophic tropical waters of the Angola Current. In the frontal zone very tight gradients of phytoplankton biomass develop, ranging from >8 mg chlorophyll-*a* per m^3 south of 15° S to <3 mg/m^3 north of 14°S, with corresponding gradients in nitrate-nitrogen and phosphate-phosphorus (Wasmund *et al*., 2005). Between these two features phytoplankton distribution can be variable but in general biomass increases with distance downstream (north) from the Lüderitz upwelling cell towards Cape Frio where this pattern may be interrupted by the Cape Frio upwelling cell (Barthomolae and van der Plas 2007).

The seasonal variation in upwelling that is seen off the coast of Namibia affects the along-shelf patterns in the physical environment, which in turn affect the along-shelf distribution of phytoplankton. The distribution expands and contracts as upwelling decreases and increases in intensity (Campillo-Campbell and Gordoa 2004). As mentioned previously, the lowest concentrations of chlorophyll-*a* occur within the Lüderitz upwelling cell. Concentrations increase northwards from this, with moderate phytoplankton concentrations occurring mid-way along this gradient off the coast of Walvis Bay ((Campillo-Campbell and Gordoa 2004; Demarcq *et al*. 2007).

An anomaly in the above pattern was found to occur during February-March 2002. High chlorophyll-*a* concentrations were found to occur off the coast of Lüderitz (Barlow *et al*. 2009). During this particular period there was very low wind stress and so the occurrence of intense upwelling was limited. This allowed for a significant increase in primary production, with ample nutrient and light supply.

Overall, there is therefore a strong spatial variation in the along-shore distribution of phytoplankton within the region off the coast of Namibia, for the majority of the time. This is strongly dependent on the prevailing physical conditions, and so changes with a significant change in the occurrence of upwelling. This is represented diagrammatically in Figure 2**.**

3.2.2 Zooplankton

The along-shelf distribution of zooplankton in the northern Benguela is closely related to the hydrology within the area and the corresponding phytoplankton distribution (Timonin *et al*. 1992). In general, zooplankton biomass increases in a northerly direction from Lüderitz to Walvis Bay due to the suboptimal conditions for zooplankton development caused by the intense Lüderitz upwelling cell. Fearon *et al*. (1986) (in Verheye *et al*. 1992) found zooplankton, specifically copepod, biomass to peak inshore slightly south of Walvis Bay, while Olivar and Barange (1990) (in Verheye *et al*. 1992)

found copepod abundance to increase south of 22°S, further offshore, on the midshelf (Figure 3). More optimal conditions for zooplankton development are present downstream from the Lüderitz upwelling cell and so higher abundances are found within the region between Lüderitz and Walvis Bay.

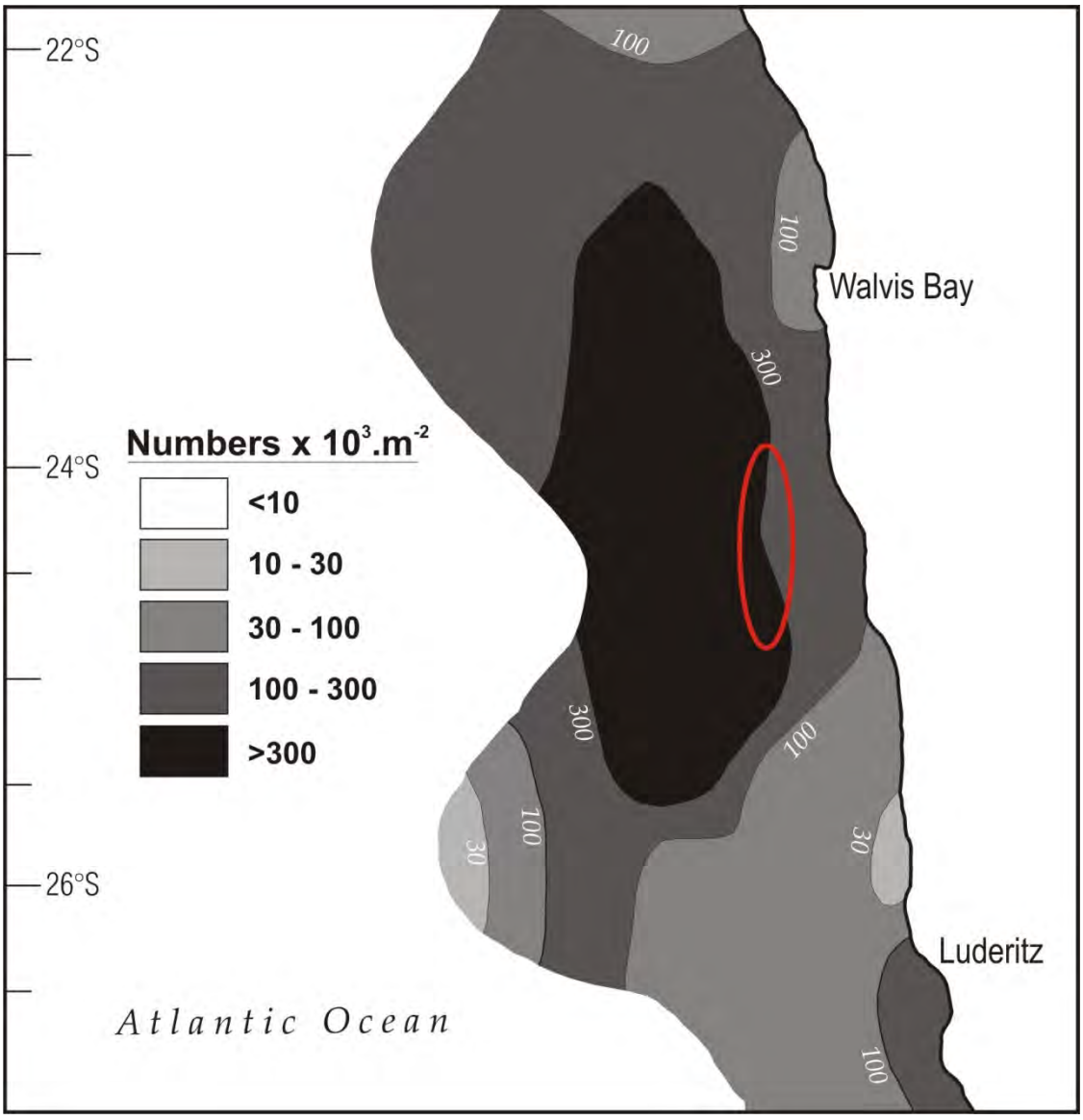


Figure 3: The along-shelf distribution of copepod abundance in the northern Benguela. Data were collected during the SNEC cruise in April 1986 using RMT-1x6 nets (200 µm mesh) in the upper 200 m (redrawn from Olivar and Barange 1990). The red ellipse indicates the position of the mining site.

In the study conducted by Barange *et al*. (1992) on euphausiid distribution, the Lüderitz upwelling cell was found to be a major boundary in zooplankton distribution, with abundance of euphausiid species increasing downstream (northwards) from the Lüderitz upwelling cell. However, it was found that the location of the boundary is variable, resulting in changes in distribution patterns of euphausiid species, particularly *Nyctiphanes capensis* and *Euphausia lucens.* Therefore, the along-shelf distribution of certain zooplankton species has a seasonal component.

© NMP 2014

3.2.3 Ichthyoplankton

The prevailing currents and hydrological features off the central Namibian coast have an influence on the distribution of fish eggs and larvae in this area (O'Toole 1977a), where the ichthyoplankton of some species has been found to be remote from the known distribution of the adults (Olivar *et al*. 1998). On a larger scale, the intense, perennial Lüderitz upwelling cell forms a barrier to ichthyoplankton transport and distribution off the west coast of Africa, resulting in ichthyoplankton and fish populations within the southern and northern Benguela, to a large extent, being considered as separate populations (Cole 1999; Lett *et al*. 2007). This distribution is largely species specific, and the interchange of some larval species is probable (Shannon and Pillar 1986), however, in general, the presence of ichthyoplankton within the Lüderitz upwelling cell only occurs when there are environmental anomalies, such as an intrusion of warmer waters into the area (Cole 1999).

The spawning of most species occurs offshore of Walvis Bay and further north (Shannon and Pillar 1986; Hewitson and Cruickshank 1993). In this area, 43 different species of eggs and 53 different species of larvae have been identified, with majority of these occurring off the northern Namibian coast. There is a clear diversity and abundance gradient, in both eggs and larvae, decreasing from north to south, towards the Lüderitz upwelling cell (Ekau and Verheye 2005). After spawning occurs, relatively little is known about the egg and larval patterns within the northern Benguela, until they reappear as juveniles. Offshore transport of the ichthyoplankton assemblages most likely occurs (Hewitson and Cruickshank 1993). However, the eggs and larvae of the South African sardine *S. sagax* have been recorded to occur inshore off the coast of Namibia with concentrated abundances occurring south of 22°S (Hart and Marshall 1951 and Mathews 1964, in Shannon and Pillar 1986; King 1977; Stenevik *et al*. 2001). This abundance presumably decreases towards Lüderitz (Olivar 1987). King (1977) identified two major spawning centres of sardine off the coast of Namibia that corresponded with the two spawning peaks mentioned earlier. Spawning during late winter/spring was found to occur primarily off the coast of Walvis Bay, while the spawning during late summer/autumn was found to occur further north at approximately 20°S. In more recent years, the spawning patterns, and thus the distribution of *S. sagax* eggs and larvae have changed with the decrease in spawner biomass, where spawning has been recorded to occur further north than Walvis Bay between 20 and 21°S (Stenevik *et al*. 2001; Ekau and Verheye 2005), however, Kreiner *et al*. (2011) still identified the area off Walvis Bay as an important spawning area, for at least some parts of the sardine spawning season.

Similarly, the spawning of anchovy has been recorded to occur primarily north of Walvis Bay, at approximately 20°S, where majority of the egg and larval biomass is present, although less intense spawning does occur slightly further south than Walvis Bay (Shannon and Pillar 1986; Ekau and Verheye 2005). The horse mackerel *T. trachurus* also spawns off northern Namibia, with its southern boundary of spawning occurring at 22°S at approximately Walvis Bay. The majority of the egg and larval biomass of this species is found between 17° and 20°S (Ekau and Verheye 2005; Geist *et al*. in press). West Coast sole larvae have been shown to occur slightly further south than those of horse mackerel, with increased abundances occurring between 20.5 and 24.5°S (O'Toole 1977b).

The two species of hake that occur off the coast of central Namibia, *M. capensis* and *M. paradoxus,* have a much wider spawning distribution with eggs and larvae being found to occur from the Angolan border in the north, to at least 28°S, with the area between 22 and 25°S being the principal spawning area (Shannon and Pillar 1986; Olivar *et al*. 1988; Sundby *et al*. 2001). The larvae of the goby *S. bibarbatus,* as well as that of the lantern fish *L. hectoris,* that both form a large proportion of

the central Namibian ichthyoplankton biomass, are also distributed along much of the Namibian coast, with goby larvae being reported as far south as 28°S, with highest concentration occurring between 23 and 24.4°S (O'Toole 1977a), and lantern fish larvae occurring up to 19°S (Olivar and Rubies 1985 in Shannon and Pillar 1986).

It is therefore clear that there is varied along-shelf distribution of the ichthyoplankton fauna off the coast of central Namibia. In general, there is an increased abundance of ichthyoplankton further north of Lüderitz, where the majority of the larvae and eggs are found in northern Namibian waters, where the majority of the adults spawn. This is however, species specific.

3.3 CROSS-SHELF DISTRIBUTION

3.3.1 Phytoplankton

The process of coastal upwelling occurs primarily because of the interaction between coastal winds and the Coriolis Effect which results in the Ekman transport of surface water perpendicular to the direction of the wind and upwelling against the coastal margin. This type of upwelling dominates the majority of the Benguela ecosystem. Correspondingly, the increased primary production occurs primarily within inshore waters. Shannon *et al*. (1984) identified a narrow coastal zone, approximately 30 km wide, off the coast of Namibia where there was increased primary production. Further offshore, production was found to be reduced. Off Walvis Bay, Barlow *et al*. (2009) found productivity at inshore stations to be approximately double that of the productivity at offshore stations. Similarly, Campillo-Campbell and Gordoa (2004) found chlorophyll-*a* maxima to occur primarily close inshore. Chlorophyll-*a* patches, signaling the presence of phytoplankton, were found to exist further offshore, however these were not as dense or as extensive as those found closer inshore. Within this area off central Namibia, phytoplankton biomass decreased seawards with very low levels beyond 100 km offshore. This is particularly apparent during the winter months when primary production is already reduced due to the occurrence of more intense upwelling. There is thus also a seasonal aspect to the cross-shelf distribution of phytoplankton cells observed off the coast of central Namibia, where a coincident increase in the offshore extent of phytoplankton distribution occurs with the increase in chlorophyll-*a* concentration in summer and autumn due to the decrease in upwelling activity during this time (Demarcq *et al*. 2007).

The cross-shelf distribution of phytoplankton biomass displayed off the coast of central Namibia is likely to be the result of the dominance of different functional phytoplankton groups in inshore and offshore areas. The increased productivity closer inshore is as a result of the dominance of diatoms, while the decreased productivity further offshore is as a result of the dominance of smaller flagellates (Barlow *et al*. 2009).

Physical transport also plays an important role in the cross-shelf distribution of chlorophyll-*a* off central Namibia (Campillo-Campbell and Gordoa 2004). Patches with high chlorophyll-*a* concentrations have been found offshore of Lüderitz. The occurrences of these phytoplankton maxima may be due to the offshore transport occurring within the region due to the high rate of upwelling.

Overall, primary productivity is lower offshore. There are however exceptions to this, where chlorophyll-*a* maxima are found offshore in relation to the shelf break. In these cases, offshore transport of water seems to play an important role in the distribution of phytoplankton.

© NMP 2014

3.3.2 Zooplankton

The cross-shelf distribution of zooplankton within the northern Benguela does not exactly match that of phytoplankton. The phytoplankton maxima occur closer inshore, while the zooplankton maxima occur further offshore (Shannon and Pillar 1986). During the study conducted by Timonin *et al*. (1992), it was found that during more quiescent phases, zooplankton abundance, particularly copepod abundance, peaked further offshore in the region of the shelf break/upper continental slope. Barange *et al*. (1992) conducted a study looking at the distribution of euphausiids within the entire Benguela ecosystem, using *in situ* data obtained from five South West African Pelagic Egg and Larvae Survey (SWAPELS) cruises and two Spanish Namibian Environmental Cruise (SNEC) surveys. These authors found that the longitudinal boundary of euphausiid distribution occurred at the shelf break at approximately the 200 m isobath. This longitudinal boundary was found to be most prominent north of 28°S, off the central Namibian coast.

3.3.3 Ichthyoplankton

As with the distribution of ichthyoplankton in relation to all other variables, the cross-shelf distribution of eggs and larvae off the coast of central Namibia is strongly related to the environmental conditions, which not only influence spawning patterns of the adults, but also can cause transport of the eggs and larvae further offshore. Again, this is, to an extent, species specific (Olivar *et al*. 1992). Shelf structure and bathymetry also play an important role in the distribution of ichthyoplankton off the coast of Namibia (Olivar *et al*. 1992) and some species show cross-shelf distribution in line with that of their phytoplankton prey (Shannon and Pillar 1986). In general, egg and larval abundance and diversity off the coast of Namibia decreases further offshore, beyond the continental shelf (Ekau and Verheye 2005). Larval distribution inshore increases recruitment success of species.

Sardine spawning occurs inshore off the coast of central Namibia, with larval abundance occurring within 50 km of the shore, and highest larval abundance occurring between 30 and 50 km offshore (O'Toole 1977a). This distribution coincides with that of their diatom prey (Shannon and Pillar 1986). The cross-shelf distribution of *S.sagax* eggs and larvae is however, also heavily dependent on the wind activity in the region. During quiescent periods, sardine eggs and larvae are confined to the upper surface layer of the water column. When upwelling intensifies, this upper surface layer is moved offshore through Eckman transport and as a result, a large proportion of the eggs and larvae are lost offshore. This movement is partially compensated for by the vertical mixing of the water column, caused by increased wind activity which is synonymous with intense upwelling, and causes an increase in the number of eggs and larvae in the subsurface layers which are moved inshore. This mechanism reduces the offshore loss of sardine eggs and larvae during periods of intense upwelling (Stenevik *et al*. 2001). Similarly, West Coast sole also spawn in close proximity to the shore, where O'Toole (1977b) found larvae no further than 16 km off the coast of central Namibia.

In contrast to sardine and West Coast sole, anchovy eggs are found further offshore, up to a distance of 120 km, off central and northern Namibia (Le Clus 1985 in Shannon and Pillar 1986). In a study conducted by O'Toole (1977a) over 85 percent of anchovy larvae collected were collected at distances greater than 30 km offshore, with highest concentrations occurring between 60 and 112 km offshore.

© NMP 2014

Horse mackerel and hake eggs are found further offshore than those of sardine, with the highest concentrations occurring on the outer shelf approximately 50 to 100 km offshore (O'Toole 1977a and Olivar and Rubies 1983 in Shannon and Pillar 1986). The hake, *M. capensis* spawns offshore at depths between 100 and 400 m (Sundby *et al*. 2001). The neutral or slightly negative buoyancy of the eggs and larvae, as well as cross-shelf transport, as a result of the upwelling subsurface circulation that is characteristic of the Benguela Current region, results in the presence of hake eggs and larvae close inshore, outside of the area of spawning (Sundby *et al*. 2001)

The goby *S. bibarbatus* was found to spawn further offshore, between the 100 and 200 m isobaths, while, further north of Walvis Bay the larvae of the lantern fish *L. hectoris* was also found offshore, between the 200 and 4000 m isobaths (Olivar *et al*. 1992). It was however interesting to note that in the study conducted by Olivar *et al*. (1992) *L. hectoris* larvae were found much closer inshore further south. This was probably partly due to the proximity of the 200 m isobath to the shore off Lüderitz. Additionally, although the species occurs up to depths of 3 000 m, adults are most abundant in waters shallower than 800 m, and so spawning probably occurs within these depths (Olivar *et al*. 1998). The presence of eggs and larvae of *L. hectoris* much further offshore is as a result of transport by upwelling filaments, especially within the region of the Lüderitz upwelling cell (Olivar *et al*. 1998).
Overall, it would seem that the cross-shelf distribution of the eggs and larvae of species off the coast of central Namibia, depend heavily on the wind activity, the resulting vertical mixing of the water column, and the transport of different water layers due to upwelling. For successful recruitment, larvae of most species need to remain inshore, and so transport offshore by upwelling filaments is disadvantageous. Again, however, this is species specific.

3.4 VERTICAL DISTRIBUTION

3.4.1 Phytoplankton

In the water column, light decreases exponentially with depth, where the depth of the euphotic zone corresponds with the depth where there is 1% of the light that is present at the surface (Ryther 1956). In the region off the coast of central Namibia, because of the prominent presence of upwelling, the water column remains well mixed for majority of the year, resulting in the surface chlorophyll-*a* measurements being a good indication of the subsurface chlorophyll concentrations (Shannon *et al*. 1984; Brown *et al*. 1991). During quiescent periods off the coast of Namibia, from February to March, Shannon *et al*. (1984) found that the vertical distribution of phytoplankton was closely linked to the stratification of the water column. During these times, subsurface maxima occurring up to a depth of 20 m were common, however, the concentrations were rarely above 20% greater than those within the corresponding surface waters.

3.4.2 Zooplankton

The maximum abundance of zooplankton within the northern Benguela primarily occurs within the surface layers, however, there is also an increase in biomass from approximately 200 m downwards (Verheye *et al*. 1992, Timonin *et al*. 1992). In the latter study it was found that, at 25°S, between Lüderitz and Walvis Bay, zooplankton concentrations peaked at the surface at 500 $mg.m^{-3}$, and then decreased. There was a secondary peak within the 200 to 700 m depth at 100 to 200 $mg.m^{-3}$. This is shown in Figure 4**.** The presence of the oxygen minimum layer in the Benguela current region has a significant impact on the vertical distribution of zooplankton off the coast of Namibia. The bimodal vertical distribution shown by majority of the zooplankton species within the area is possibly as a

result of this layer of hypoxic water, where species actively avoid the low oxygen waters between the surface layers and 200 m depth (Auel and Verheye 2007).

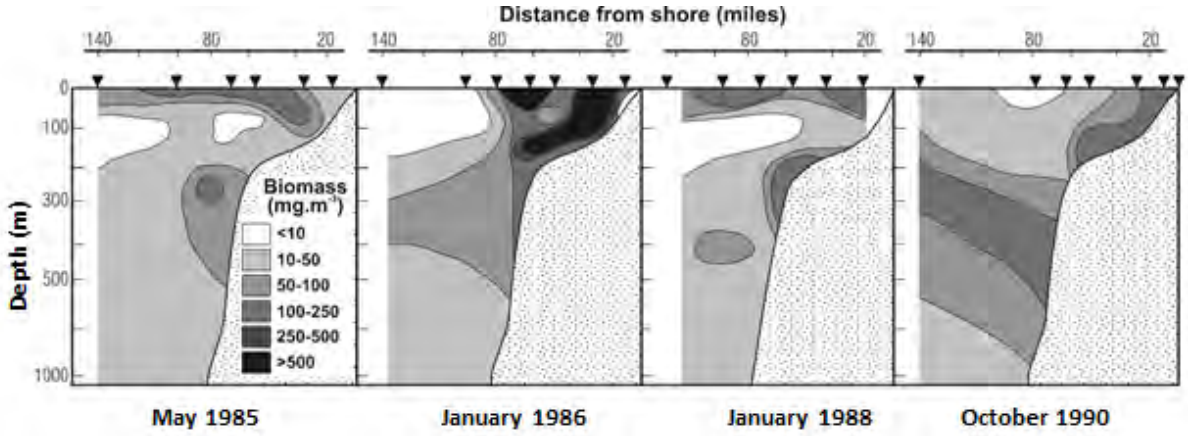


Figure 4: Vertical distribution of zooplankton biomass at 25°S (redrawn from Timonin *et al*. 1992).

These vertical distributions do however depend on species, where some zooplankton species such as the copepods *Calanoides carinatus* and *Rhincalanus nasutus* show a more homogenous vertical distribution (Timonin *et al*. 1992). Season also has an important impact on vertical distribution, where a more homogenous distribution is shown during periods of increased upwelling and water column mixing. The vertical distributions of some species are complicated by ontogenetic migration where certain life stages occupy different depths of water (Timonin *et al*. 1992).

Additionally, some zooplankton species, such as many euphausiids, copepods and jellyfish, display diurnal vertical migration (Barange *et al*. 1992; Brierley *et al*. 2001; Postel *et al*. 2007), where they are present in the upper water column layers at night, and then sink to deeper layers during the day. These members of the zooplankton community play an important role in the pelagic ecosystem. This migration forms scattering layers where dense concentrations of plankton are found. These layers are easily identified from echo-sounder backscatter because of the strong acoustic signal that they produce. Within the NMP MLA off central Namibia, such acoustic scattering layers have been found, and are clearly shown for two periods in Figures 5 and 6.

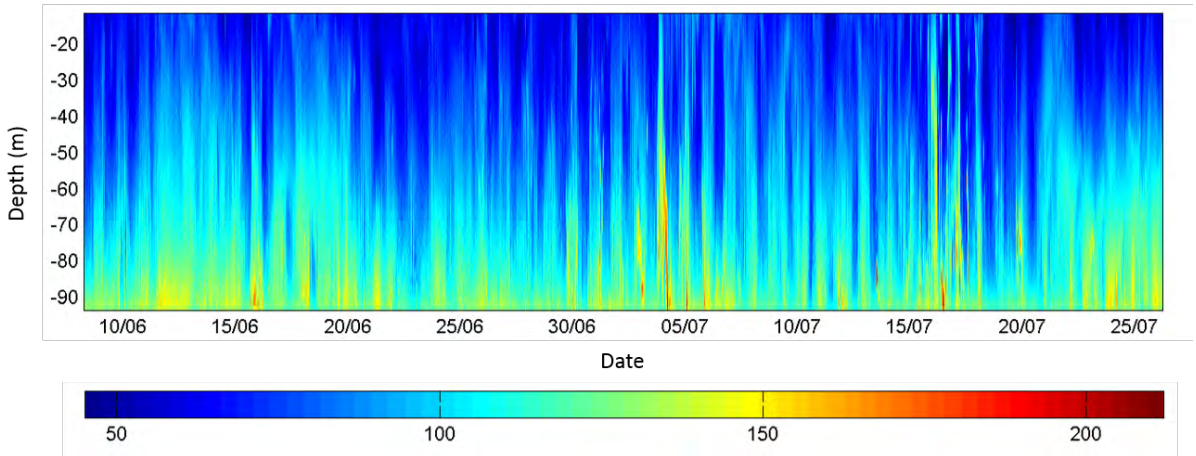


Figure 5: ADCP beam attenuation through the upper water column from -10 m to -100m at site 15 of the marine ecology verification survey.

Measurements were taken from 8 June 2013 to 26 July 2013 at site 15 within ML 170 off central Namibia. The high levels of backscatter can be seen to cycle on a daily basis, indicating the diurnal vertical migration of a large amount of the zooplankton community within the area.

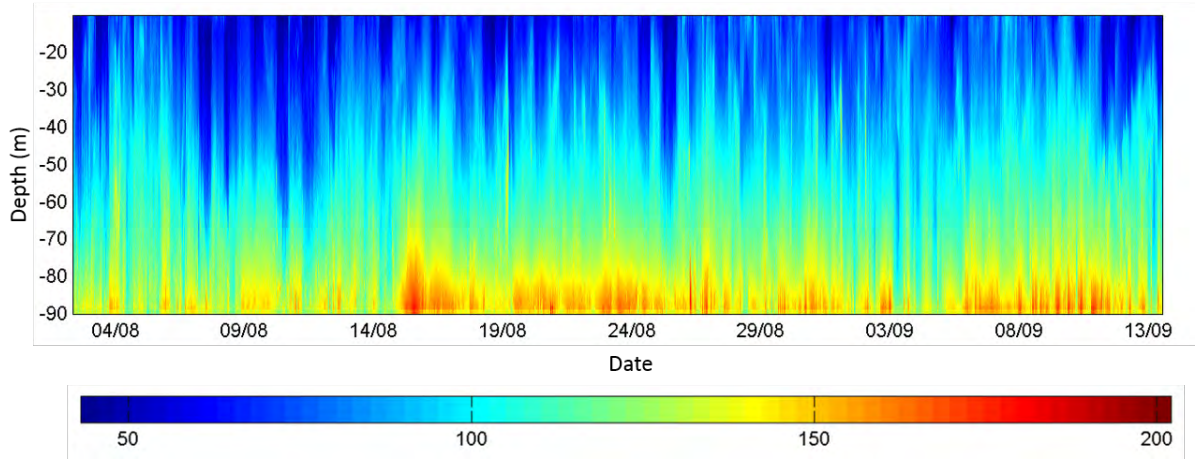


Figure 6: ADCP beam attenuation through the upper water column from -10 m to -100 m at site 15 of the marine ecology verification survey.
Measurements were taken from 2 August 2013 to 13 September 2013 at site 15 within ML 170 off central Namibia. The high levels of backscatter can be seen to cycle on a daily basis, indicating the diurnal vertical migration of a large amount of the zooplankton community within the area.

The presence of these scattering layers within the MLA indicates that there is a large zooplankton community within the area that undergoes diurnal migration. The dredging activities have the potential to affect the migration of the zooplankton communities through an increase in turbidity from sediment plumes decreasing light availability. Wallace *et al*. (2010) found that the presence of sea ice in an Arctic fjord influenced the diurnal migration of various zooplankton specie, through shading, thus having an effect on the acoustic scattering layer in that area. With the increase in sea ice coverage, and therefore a decrease in light availability, zooplankton migrations were asynchronous and occurred randomly, while zooplankton migrations at an ice-free site were more synchronized, occurring diurnally. Sediment plumes may have a similar effect on zooplankton communities in the area of the MLA, and this must be considered, although other properties such as food availability and zooplankton species composition also have an influence on migration behaviour. This underlines the importance of the requirement for monitoring of the turbidity within the region during mining, especially in terms of turbidity plume extent and duration and concomitant effects, if any, on diurnal migration patterns.

3.4.3 Ichthyoplankton

The upwelling off the coast of central Namibia, and especially that further south off the coast of Lüderitz, results in a well-mixed water column for the majority of the year. This results in the majority of the ichthyoplankton assemblage to be widely distributed within the upper 200 m of the water column for much of the year (Olivar *et al*. 1992). This does, however, seem to be species specific and involves the influence of many other mechanisms where ontogenetic stage, movement ability, buoyancy and other factors may play a role.

Newly spawned sardine eggs are distributed just below the upper mixed layer off the coast of central Namibia, but the eggs are buoyant and so travel rapidly into the surface layers, resulting in the

© NMP 2014

majority of the eggs and larvae being distributed in the upper 60 m of the water column during more stable periods (Stenevik *et al*. 2004; Ekau and Verheye 2005). In a study conducted by O'Toole (1977a), 75 percent of the total number of sardine eggs collected from thirty net hauls over a period of three days occurred in the upper 20 m of the water column. As a result of upwelling, these surface layers are transported further offshore, resulting in the gradual loss of eggs and larvae (Stenevik *et al*. 2001). During periods of increased upwelling, the transport of the eggs and larvae offshore is increased. However, because of the vertical mixing of the water column, more eggs and larvae are transported to depth and so there is a greater chance of their transport inshore (Stenevik *et al*. 2001). During increased upwelling, there is therefore a higher abundance of sardine eggs and larvae below 20 m (Stenevik *et al*. 2004). Vertical migration is an additional mechanism that acts on the vertical distribution of sardine larvae in particular, especially the larger larvae, and is therefore an important consideration in their vertical distribution.

Similarly, anchovy larvae also show vertical migration, which occurs on a daily basis (Stenevik *et al*. 2007). On average, the majority of anchovy larvae off the coast of central Namibia are distributed below 25 m, which is below the offshore moving Ekman layer (Stenevik *et al*. 2007). This prevents losses offshore, and increases the chances of recruitment success.

S. bibarbatus larvae were found off central Namibia at depths between 20 and 60 m, while hake eggs and larvae have been found slightly deeper between 20 and 150 m and *L. hectoris* larvae have been found throughout the water column, but in slightly larger larvae (< 5 mm), concentrations increased below 90 m depth (Olivar *et al*. 1992).

3.5 CHARACTERISATION OF SPECIES AND FORMS PRESENT

3.5.1 Phytoplankton

In general, phytoplankton community structure varies with water temperature in a regular and predictable pattern. Micro-phytoplankton (20 – 200 µm) such as the larger diatoms dominate at lower temperatures, while smaller flagellates dominate at intermediate temperatures and smaller pico-phytoplankton are most abundant at high temperatures (Bouman *et al*. 2003; Barlow *et al*. 2009). This is area specific, to a certain extent. Within the central Namibian waters, phytoplankton communities are generally dominated with diatoms and, to a lesser extent, dinoflagellates (Shannon and Pillar 1986; Heymans and Baird 2000a; Barlow *et al*. 2009). Diatoms are best able to compete for available nutrients and light and thus can develop dense blooms immediately after an active upwelling phase and the beginning of a quiescent phase. Dinoflagellates can grow more efficiently at lower nutrient concentrations in comparison to diatoms, and so dominate during the more quiescent phases (Sakko 1998). Diatoms tend to dominate the more inshore areas, while dinoflagellates along with flagellates are more important further offshore (Shannon and Pillar 1986, Barlow *et al*. 2009).

Shannon and Pillar (1986) reviewed several floristic studies undertaken in the northern Benguela from the 1950s to the 1980s. Off the coast of central Namibia the majority of the studies found diatoms to outnumber any other group of phytoplankton, followed by dinoflagellates which comprised about 4% of the phytoplankton assemblage in this area. Within the diatom group, the species *Chaetoceros* spp., *Rhizosolenia* spp., *Planktoniella sol, Nitzschia* spp., and *Asterionella glacialis (A. japonica)* were found to be the most common (Hart and Currie 1960, in Shannon and Pillar 1986). Other studies have found *Delphineis karstenii, Thalassiosira* spp., *Coscinodiscus* spp.,

© NMP 2014

Actinoptychus spp., *Leptocylindrus* spp., *Coscinosira polychorda, Thalassionema* spp., and *Thalassiothrix* spp. also to be present, with some species blooming during favourable conditions (Schuette 1980, Kollmer 1962, 1963, Pieterse and van der Post 1967 and Hulburt 1976, all in Shannon and Pillar 1986). Within the dinoflagellate group, *Peridinium* spp. and *Ceratium* spp. were found to be the most important (Shannon and Pillar 1986). Dinoflagellate blooms occur during quiescent periods during summer when there is a well-developed thermocline and water column stratification is at its highest. For example, this is demonstrated by the occurrence of red-tide blooms within the northern Benguela.

3.5.2 Zooplankton

The productive Benguela current ecosystem is typically low in species diversity in comparison with the more tropical Agulhas current region, but supports much larger populations (Shannon and Pillar 1986). Within the central Namibian region off Walvis Bay, copepods are numerically dominant, comprising 70 to 85% of the zooplankton community (Timonin *et al*. 1992; Hansen *et al*. 2005). Specifically *Paracartia spp.* are important in nearshore habitats, while *Centropages brachiatus, Calanoides carinatus* and *Metridia lucens* are more abundant further offshore over the continental shelf (Timonin *et al*. 1992; Hansen *et al*. 2005). *Rhincalanus nasutus* is also a dominant species within Namibian waters (Timonin *et al*. 1992; Hansen *et al*. 2005).

Euphausiids are common in the Benguela ecosystem, and form an important component of the food web. Their ability to form aggregations makes them important prey for fish species within the area. Barange *et al*. (1992) found that *Nyctiphanes capensis* was the dominant euphausiid species on the inner shelf north of Lüderitz, while *Euphausia hanseni* was the dominant species on the shelf-break in this region. These authors and Pillar *et al*. (1992) also documented the presence of *Euphausia lucens* off Walvis Bay, especially during the maximum upwelling period between June and November, although this species is more characteristic of the euphausiid community further south. *Thysanoessa gregaria* and *Nematoscelis megalops* are less abundant, but also play an important role in the community structure of euphausiids in central Namibian waters, particularly further offshore and on the shelf-break (Pillar *et al*. 1992).

Other species also occur within the northern Benguela, specifically off central Namibia. Within the chaetognath group, Venter (1969) (in Shannon and Pillar 1986) reported the occurrence of ten species off the central Namibian region. *Sagitta friderici* was the most common of these, constituting 90% of all chaetognath species recorded in the inshore areas of the region, while further offshore *S. tasmanica* was the most common chaetognath, representing 70% of this group. In a more recent study, Bohata and Koppelmann (2013) recorded 17 chaetognath species in waters off Walvis Bay. To a certain extent, species composition depended on the distance offshore, with species richness and diversity increasing with distance offshore. Nevertheless, in that study, it was found that *S. serratodentata* and *S. tasmanica* dominated all stations sampled. Cladocera including *Podon polyphemoides* and *Evadne noidmanni* also occur and are abundant throughout the year in the northern Benguela (Unteruberbacher 1964). Thaliaceans (salps and doliolids) have also been found to occur in waters off central Namibia (Olivar 1987; Shannon and O'Toole 1999).

Some cnidarian species are becoming dominant within the northern Benguela (Lynam *et al*. 2006), where jellyfish, considered to be a part of the plankton, are found along the entire length of the Namibian coast, and are especially common in central Namibian waters (Flynn *et al*. 2012; Gibbons, in Midgley 2012). *Chrysaora fulgida* and *Aequorea forskalea* have been recognized as the dominant

© NMP 2014

cnidarian taxa in the central Namibian region (Lynam *et al*. 2006; Gibbons, in Midgley 2012). The increase in cnidarian abundance is thought to be as a result of various anthropogenic effects, including increased fishing in the area, as jellyfish biomass off the coast of central Namibia has increased since the collapse of the Namibian pelagic fisheries in the 1960s and 1970s (Gibbons, in Midgley 2012). This results in a reduction in the mean trophic level of species landed, and thus allows for the proliferation of many cnidaria due to the abundance of food that was once consumed by the fished species (Lynam *et al*. 2006). The implication of an increase in jellyfish abundance is not only an increase in competition for food with pelagic fish species, many of which are commercially important, but also jellyfish have the potential to severely reduce recruitment of these pelagic fish species by preying on large numbers of ichthyoplankton (Flynn *et al*. 2012). Overall the increase in jellyfish abundance therefore has a potential negative effect on pelagic fish populations.

There is a variety of zooplankton species that characterize the northern Benguela and occur offshore between Lüderitz and Walvis Bay, within the project region. These species all show spatial and temporal variation dependent on various biotic and abiotic drivers. Some of these species, such as the jellyfish could have detrimental effects on other components of the ecosystem in central Namibian waters, as their numbers increase.

3.5.3 Ichthyoplankton

Central and northern Namibian waters support several large commercial fisheries, and so the presence of sardine *S. sagax,* hake *M. capensis* and *M. paradoxus,* horse mackerel *T. trachurus,* and anchovy *E. capensis ,* eggs and larvae are important in terms of supplying recruits to these fisheries (Lange 2003). Although these species are of commercial importance, their eggs and larvae off the coast of central Namibia are outnumbered by the eggs and larvae of the goby *S. bibarbatus* and the lantern fish *L. hectoris* (Olivar 1987). Other species that may contribute to the observed ichthyoplankton assemblage off the coast of central Namibia include the round herring *Etrumeus whiteheadi,* the mackerel *Scomber japonicus,* the west coast sole *Austroglossus microlepis,* snoek *Thyrsites atun,* the lightfish *Maurolicus muelleri,* and the frostfish *Lepidopus caudatus* (Shannon and Pillar 1986).

3.6 LONG-TERM VARIABILITY

The Benguela ecosystem is inherently a highly dynamic system. Changes in the physical environment occur at a variety of different spatial and temporal scales. Both intra- and inter-annual variability has been shown to occur (Shannon *et al*. 1992). The variation in the physical environment and the resulting changes in productivity within the northern Benguela do however seem to be more stable over more extended periods of time. Demarcq *et al*. (2007) show that there is a presence of interannual variation in phytoplankton biomass, but this is not very significant. The spatial patterns in chlorophyll-*a* distribution shown seem to hold true for the majority of the time, and also do not show a significant amount of interannual variability. There is a constant low phytoplankton biomass within the region of the Lüderitz upwelling cell where environmental conditions are not favourable for phytoplankton growth year-round.

Changes to the physical environment within the Benguela do however occur. These changes occur at a longer time scale, and typically are more inter-decadal in nature and may have significant effects on the productivity of the region. Characteristically warm oligotrophic water invades the system and upwelling reduces. These warm water occurrences are termed “Benguela Niños” because of their

similarity to the El Niño Southern Oscillation (ENSO) events that occur within the Pacific (Shannon *et al*. 1992). Such events have occurred approximately once a decade within the northern Benguela region, off the coast of central Namibia, in the vicinity of the proposed mining area. Shannon *et al*. (1992) investigated the changes in the Benguela ecosystem during the 1980s, and although these authors recorded the change in physical conditions during 1984, a change in phytoplankton biomass was not observed. These data were however very patchy, and so a variation in primary productivity with a significant change in environmental conditions due to an inter-decadal event would most likely be present, with Benguela Niños probably resulting in a reduction in the abundance of phytoplankton (Shannon *et al*. 1992).

During a study of zooplankton dynamics off the coast of Namibia, Timonin *et al*. (1992) recorded interannual variation in zooplankton community succession, which was attributed to interannual variation in the intensity of upwelling. However, the interannual variability in zooplankton abundance and distribution is not only influenced by environmental forcing, and is in fact much more complex than this. There is a variety of reasons that can explain variability in zooplankton biomass and zooplankton community composition over several years. Environmental conditions such as the intensity of upwelling not only affects the abundance of forage items, but also affects their dominant size. This has an influence on zooplankton abundance within the northern Benguela. It has been found that zooplankton biomass remains low with the occurrence of a high abundance of smaller phytoplankton species, presumably because the zooplankton species present within the northern Benguela are unable to feed on smaller particles (Shannon *et al*. 1992). Additionally, the presence of predators has an influence on the interannual variability in zooplankton populations within the northern Benguela, where grazing by species such as anchovy can decrease zooplankton abundance (Cury and Shannon 2004). The fluctuation in predator abundance thus will have a top-down effect on zooplankton populations and so may be partly responsible for interannual variability in zooplankton communities within the northern Benguela.

The occurrence of Benguela Niños which are more interdecadal in nature also have a significant effect on zooplankton abundance and distribution (Shannon *et al*. 1992). The occurrence of warmer water with a higher salinity and unusual oxygen concentrations results in a change in zooplankton community structure (Shannon and Pillar 1986). It was found that there was a notable increase in a warm water copepod, *Nannocalanus minor,* and a decline in some cool water copepods, predominantly *Paracalanus parvus,* as a result of the Benguela Niño event that occurred in 1963 (Shannon and Pillar 1986). This indicates the long-term variability of zooplankton within the region.

Similar to phytoplankton and zooplankton, the ichthyoplankton assemblages off the central Namibian coast also show long-term variability in abundance, distribution and diversity, associated with changes in environmental conditions (Cury and Shannon 2004). With the anomalous movement of water bodies during certain years, the transport of eggs and larvae can be affected, causing interannual variation in ichthyoplankton abundance and distribution. Cole (1999) recorded unusually high recruitment of clupeoids in 1987 in the northern Benguela, caused by the unusual northward transport of eggs and larvae from the southern Benguela. This was as a result of an anomalous intrusion of warmer water from the southern Benguela into the northern Benguela, suppressing the upwelling activity off Lüderitz.

Similar to phytoplankton and zooplankton populations, the ichthyoplankton assemblages within the northern Benguela change with the occurrence of a Benguela Niño. Fluctuations in the spawner

© NMP 2014

biomass have been recorded in the northern Benguela as a result of a Benguela Niño event, and thus, this affects the ichthyoplankton biomass (Shannon *et al*. 1992).

In addition to long-term variability as a result of changes in environmental conditions, the over-exploitation of many of the commercial fish stocks off the coast of Namibia has influenced long-term variability in ichthyoplankton abundance and community composition, and has resulted in regime shifts (Cury and Shannon 2004). During the late 1970s there was a collapse of several of the major commercial fish stocks, including hake and pilchard, in Namibian waters due to overexploitation (Lange 2003; David, in Midgley 2012). Since then, these populations have shown significant fluctuations (Shannon *et al*. 1992; Heymans *et al*. 2004). Presently, the Namibian sardine and anchovy stocks remain depleted due to insufficiently cautious management coupled with environmental anomalies (Payne *et al*. 2001; David, in Midgley 2012), while there has been a gradual increase and improvement in the state of the hake stock (Payne *et al*. 2001), resulting in it presently being the most valuable commercially exploited fishery in Namibia (David, in Midgley 2012). Horse mackerel catches have also improved, making it the largest fishery by volume in Namibian waters (David, in Midgley 2012). Due to a fluctuation in the abundance of these species, it can be assumed that the overexploitation results in a fluctuation in their eggs and larvae within the northern Benguela, causing severe long-term variation in the ichthyoplankton in the ecosystem.

3.7 IMPORTANCE OF PLANKTON IN THE FOOD WEB

Overall the northern Benguela upwelling system supports a productive ecosystem that sustains a number of living resources which are exploited for commercial gain (Heymans and Baird 2000a). The functioning of this ecosystem is complex, and is impossible to analyse fully, however, it is important to consider the various interactions between trophic groups to draw more holistic conclusions about ecosystem properties and functioning, and therefore the potential effects on the functioning of the ecosystem as a result of the phosphate dredging project (Heymans and Baird 2000b). Previous research has used a variety of models to estimate the trophic flows within the northern Benguela upwelling system (Hutchings *et al*. 1991; Heymans and Baird 2000a; Heymans and Baird 2000b; Shannon and Jarre-Teichmann 2000). All models highlight the importance of phytoplankton, zooplankton and ichthyoplankton in the functioning of this system. This is an important consideration in the development of the MLA off Walvis Bay, as an effect on one group or species has the potential to affect other trophic levels, which could include valuable commercial resources.

Within the northern Benguela upwelling system, phytoplankton is the only primary producer and the phytoplankton →zooplankton →pelagic fish →demersal fish energy flow pathway was shown to dominate (Heymans and Baird 2000a). The importance of phytoplankton in the functioning of the ecosystem was noted by Shannon and Jarre-Teichmann (2000), where a reduction in total phytoplankton production resulted in insufficient production to support the consumers within the ecosystem. This indicates the importance of phytoplankton, zooplankton and ichthyoplankton (ichthyoplankton would form a part of the zooplankton in this case) in the Benguela system, where the upper levels of primary and secondary consumers are entirely dependent on the planktonic communities within the area for healthy ecosystem functioning. The primary consumers included mesozooplankton and macrozooplankton, consisting primarily of copepods and euphausiids (Hutchings *et al*. 1991), and jellyfish (Heymans and Baird 2000a). The fish community was found to consist of a variety of pelagic and demersal fish already mentioned in this review.

It must however be noted that most of the production and consumption estimates used in these models were obtained from inshore waters where phytoplankton biomass is higher than that offshore between the 200 and 500 m isobaths (Hutchings *et al*. 1991). The MLA extends from the 200 m to the 300 m isobath, and so the production and consumption in the system within this region may differ slightly, where the abundance of the various phytoplankton, zooplankton and ichthyoplankton communities are seemingly less pronounced.

4 SUMMARY

- The phosphate [1]Mining Licence area (between 23.8° and 24.5°S) is approximately 60 km offshore of the central Namibian coast, and the target [2]mine site area is between 24.1° and 24.3°S, on the northern edge of the Lüderitz upwelling cell, in water depths between 190 and 300 m.
- The oceanographic environment off Namibia is dynamic, and in many ways unique. It is primarily defined by the Benguela current upwelling system and supports a productive ecosystem with a high abundance of phytoplankton, zooplankton and ichthyoplankton species. The distribution of these species differs with spatial and temporal variation affected by the occurrence of upwelling, where the perennial upwelling cell off Lüderitz plays a particularly important role.
- Within the Lüderitz upwelling cell species abundance is low, but the area further north off the central Namibian coast where the proposed mining site is located, forms a transitional zone between the southern and northern regions of the Benguela ecosystem, and so the influence of the Lüderitz upwelling cell is slightly reduced, resulting in increased species abundances.
- This species abundance, however, tends to decrease further offshore, which is important considering that the proposed mining site is located 60 km offshore.
- Although species abundance is greater off central Namibia, the species present in the vicinity of the mine site area are ubiquitous in the region.
- Phytoplankton communities in the area are dominated by diatoms and majority of the species found are found elsewhere in the world's oceans. The diatoms occur primarily within inshore waters, with biomass decreasing steadily seawards. The phytoplankton species found within the vicinity of the mining site are, therefore, not only ubiquitous but also occur within the mining site in decreased abundances in comparison to inshore waters.
- Zooplankton communities in the central Namibian region are dominated by copepods, which again, are not unique to the area. In contrast to the phytoplankton, the zooplankton is found slightly further offshore, where abundance peaks on the shelf-break at depths of approximately 200 m. The proposed mining site is located in water depths of 180- 300 m, and so an increased abundances of zooplankton will be present. However, the species present here will not be unique to the area.
- Central Namibian waters support several commercial fisheries, with sardine, anchovy, hake and horse mackerel being particularly important. The ichthyoplankton of these species found off central Namibia plays a pivotal role in recruitment to the fisheries, and are especially important

[1] The Mining Licence area (MLA) is 2230 km^2.
[2] The mine site area (Sandpiper-1) is 176 km^2 of which up to 60 km^2 is proposed to be mined during the 20 year mining licence period

in the light of the current depleted state of the sardine and anchovy fisheries. Generally, however, fish off the Namibian coast spawn in inshore waters north of Walvis Bay. Therefore, the proposed mining area off central Namibia is not within any important spawning or nursery grounds, particularly for the commercially important species.

- All of the species mentioned play an important role as producers or primary consumers within the northern Benguela upwelling system, resulting in the higher trophic levels relying on planktonic communities for healthy ecosystem functioning. This however, may be more pronounced in more inshore waters where plankton communities are more prolific.
- Overall, although the waters off central Namibia are productive and support large communities of species, the proposed mining site does not occur within any identifiably important area of phytoplankton, zooplankton or ichthyoplankton growth and development.

5 REFERENCES

Auel H. and Verheye H.M. 2007. Hypoxia tolerance in the copepod *Calanoides carinatus* and the effect of an intermediate oxygen minimum layer on copepod vertical distribution in the northern Benguela Current upwelling system and the Angola-Benguela Front. *Journal of Experimental Marine Biology and Ecology* **352**: 234- 243.

Barange M., Pillar S.C. and Hutchings L. 1992. Major pelagic borders of the Benguela upwelling system according to euphausiid species distribution. *South African Journal of Marine Science* **12**(1): 3- 17.

Barange M. and Stuart V. 1991. Distribution patterns, abundance and population dynamics of the euphausiids *Nyctiphanes capensis* and *Euphausia hanseni* in the northern Benguela upwelling system. *Marine Biology* **109**: 93- 101.

Barlow R., Lamont T., Mitchell-Innes B., Lucas M. and Thomalla S. 2009. Primary production in the Benguela ecosystem, 1999-2002. *African Journal of Marine Science* **31**(1): 97- 101.

Bartholomae C.H. and van der Plas A.K. 2007. Towards the development of environmental indices for the Namibian shelf, with particular reference to fisheries management. *African Journal of Marine Science* **29**(1): 25- 35.

Bohata K. and Koppelmann R. 2013. Chaetognatha of the Namibian upwelling region: Taxonomy, distribution and trophic position. *PLoS ONE* **8**(1): e53839.doi:10.1371/journal.pone.0053839.

Bouman H.A., Platt T., Sathyendranath S., Li W.K.W., Stuart V., Fuentes-Yaco C., Maass H., Horne E.P.W., Ulloa O., Lutz V. and Kyewalyanga M. 2003. Temperature as an indicator of optical properties and community structure of marine phytoplankton: implications for remote sensing. *Marine Ecology Progress Series* **258**(19): 19- 30.

Brierley A.S., Axelsen B.E., Buecher E., Sparks C.A.J., Boyer H. and Gibbons M.J. 2001. Acoustic observations of jellyfish in the Namibian Benguela. *Marine Ecology Progress Series* **210**: 55- 66.

Brown P.C., Painting S.J. and Cochrane K.L. 1991. Estimates of phytoplankton and bacterial biomass and production in the northern and southern Benguela ecosystems. *South African Journal of Marine Science* **11**(1): 537- 564.

Campillo-Campbell C. and Gordoa A. 2004. Physical and biological variability in the Namibian upwelling system: October 1997- October 2001. *Deep-Sea Research II* **51:** 147- 158.

Cole J. 1999. Environmental conditions, satellite imagery, and clupeoid recruitment in the northern Benguela upwelling system. *Fisheries Oceanography* **8**(1): 25- 38.

Crawford R.J.M., Shannon L.V. and Pollock D.E. 1987. The Benguela ecosystem. Part IV. The major fish and invertebrate resources. *Oceanography and Marine Biology: An Annual Review* **25:** 353- 505.

Cury P. and Shannon L. 2004. Regime shifts in upwelling ecosystems: Observed changes and possible mechanisms in the northern and southern Benguela. *Progress in Oceanography* **60:** 223- 243.

Demarcq H., Barlow R. and Hutchings L. 2007. Application of a chlorophyll index derived from satellite data to investigate the variability of phytoplankton in the Benguela ecosystem. *African Journal of Marine Science* **29**(2): 271- 282.

Ekau W. and Verheye H.M. 2005. Influence of oceanographic fronts and low oxygen on the distribution of ichthyoplankton in the Benguela and southern Angola currents. *African Journal of Marine Science* **27**(3): 629- 639.

Flynn B.A., Richardson A.J., Brierley A.S., Boyer D.C., Axelsen B.C., Scott L., Moroff N.E., Kainge P.I., Tjizoo B.M. and Gibbons M.J. 2012. Temporal and spatial patterns in the abundance of jellyfish in the northern Benguela upwelling ecosystem and their link to thwarted pelagic fishery recovery. *African Journal of marine Science* **34**(1): 131- 146.

Geist S., Kunzmann A., Verheye H.M., Eggert A., Schukat A. and Ekau W. In press. Distribution, feeding behavior and condition of Cape horse mackerel early life stages, *Trachurus capensis*, under different environmental conditions in the northern Benguela upwelling ecosystem off Namibia. *ICES Journal of Marine Science*: abc-def.

Hansen F.C., Cloete R.R. and Verheye H.M. 2005. Seasonal and spatial variability of dominant copepods along a transect off Walvis Bay (23°S), Namibia. *African Journal of Marine Science* **27**(1): 55- 63.

Hardman-Mountford N.J., Richardson A.J., Agenbag J.J., Hagen E., Nykjaer L., Shillington F.A. and Villacastin C. 2003. Ocean climate of the South East Atlantic observed from satellite data and wind models. *Progress in Oceanography* **59**: 181- 221.

Hewitson J.D. and Cruickshank R.A. 1993. Production and consumption by planktivorous fish in the northern Benguela ecosystem in the 1980s. *South African Journal of Marine Science* **13**(1): 15- 24.

Heymans J.J. and Baird D. 2000a. A carbon flow model and network analysis of the northern Benguela upwelling system, Namibia. *Biological Modelling* **126:** 9- 32.

Heymans J.J. and Baird D. 2000b. Network analysis of the northern Benguela ecosystem by means of NETWRK and ECOPATH. *Ecological Modelling* **131:** 97- 119.

Heymans J.J., Shannon L.J. and Jarre A. 2004. Changes in the northern Benguela ecosystem over three decades: 1970s, 1980s, and 1990s. *Ecological Modelling* **172:** 175- 195.

Hutchings L., Pillar S.C. and Verheye H.M. 1991. Estimates of standing stock, production and consumption of meso- and macrozooplankton in the Benguela ecosystem. *South African Journal of Marine Science* **11:** 499- 512.

© NMP 2014

King D.P.F. 1977. Distribution and relative abundance of eggs of the South West African pilchard *Sardinops ocellata* and anchovy *Engraulis capensis,* 1971/72. *Fisheries Bulletin (South Africa)* **9:** 23- 31.

Kreiner A., Yemane D., Stenevik E.K. and Moroff N.E. 2011. The selection of spawning location of sardine (*Sardinops sagax*) in the northern Benguela after changes in stock structure and environmental conditions. *Fisheries Oceanography* **20**(6): 560- 569.

Lange G-M. 2003. The value of Namibia's commercial fisheries. *DEA Research Discussion Paper: Number 55, February 2003.* 24pp.

Lett C., Veitch J., van der Lingen C.D. and Hutchings L. 2007. Assessment of an environmental barrier to transport of ichthyoplankton from the southern to the northern Benguela ecosystems. *Marine Ecology Progress Series* **347:** 247- 259.

Lynam C.P., Gibbons M.J., Axelsen B.E., Sparks C.A.J., Coetzee J., Heywood B.G. and Brierley A.S. 2006. Jellyfish overtake fish in a heavily fished ecosystem. *Current Biology* **16**(13): R492-R493.

Meeuwis J.P. and Lutjeharms J.R.E. 1990. Surface thermal characteristics of the Angola-Benguela front. *South African Journal of Marine Science* **9**(1): 261- 279.

Midgley J. 2012. Environmental Impact Assessment for the proposed dredging of phosphate enriched sediments from Marine Licence Area No. 170. Prepared for Namibian Marine Phosphate (Pty) Ltd. Prepared by J Midgley &Associates in association with EnviroDymanics and CSIR.

Midgley J. 2012. Environmental Impact Assessment for the proposed dredging of phosphate enriched sediments from Marine Licence Area No. 170. A Brief History of the Namibian Fishery: Appendix 3. Prepared for Namibian Marine Phosphate (Pty) Ltd. Prepared by J Midgley &Associates in association with EnviroDymanics and CSIR.

Olivar M-P. 1987. Ichthyoplankton assemblages off northern Namibia. *South African Journal of Marine Science* **5**(1): 627- 643.

Olivar M-P. and Barange M. 1990. Zooplankton of the northern Benguela region in a quiescent upwelling period. *Journal of Plankton Research* **12**(5): 1023- 1044.

Olivar M-P., Rubies P. and Salat J. 1988. Early life history and spawning of *Merluccius capensis castelnau* in the northern Benguela Current. *South African Journal of Marine Science* **6**(1): 245- 254.

Olivar M-P., Rubies P. and Salat J. 1992. Horizontal and vertical distribution patterns of ichthyoplankton under intense upwelling regimes off Namibia. *South African Journal of Marine Science* **12**(1): 71- 82.

Olivar M-P., Salat J. and Beckley L.E. 1998. Evidence of displacement of lanternfish larvae associated with surface water movement: case studies from southern Africa. *South African Journal of Marine Science* **19**(1): 233- 244.

O'Toole M.J. 1977a. Investigations into some important fish larvae in the south east Atlantic in relation to the hydrological environment. PhD thesis, University of Cape Town, South Africa, 272 pp.

O'Toole M.J. 1977b. Development and distributional ecology of the larvae of the West Coast Sole *Austroglossus microlepis. Fisheries Bulletin (South Africa)* **9**: 32- 45.

© NMP 2014

Payne A.I.L., Pillar S.C. and Crawford R.J.M. (Eds). 2001. A decade of Namibian Fisheries Science: An introduction by the Honourable Minister of Fisheries and Marine Resources of Namibia, Dr Abraham Iyambo. *South African Journal of Marine Science* **23**: 1- 4.

Pillar S.C., Stuart V., Barange M. and Gibbons M.J. 1992. Community structure and trophic ecology of euphausiids in the Benguela ecosystem. *South African Journal of Marine Science* **12**(1): 393-409.

Postel L., da Silva A.J., Mohrholz V. and Lass H-U. 2007. Zooplankton biomass varianility off Angola and Namibia investigated by a lowered ADCP and net sampling. *Journal of Marine Systems* **68**: 143- 166.

Ryther J.H. 1956. Photosynthesis in the ocean as a function of light intensity. *Limnology and Oceanography* **1**(1): 61- 70.

Sakko A.L. 1998. The influence of the Benguela upwelling system on Namibia's marine diversity. *Biodiversity and Conservation* **7**: 419- 433.

Shannon L.V. 1985. The Benguela ecosystem. Part I. Evolution of the Benguela. Physical features and processes. *Oceanography and Marine Biology: An Annual Review* **23:** 105- 182.

Shannon L.V., Crawford R.J.M., Pollock D.E., Hutchings L., Taunton-Clark J., Badenhorst A., Melville-Smith R., Augustyn C.J., Cochrane K.L., Hampton I., Nelson G., Japp D.W. and Tarr R.J.Q. 1992. The 1980s- a decade of change in the Benguela ecosystem. *South African Journal of Marine Science* **12**(1): 271- 296.

Shannon L.V., Hutchings L., Bailey G.W. and Shelton P.A. 1984. Spatial and temporal distribution of chlorophyll in southern African waters as deduced from ship and satellite measurements and their implications for pelagic fisheries. *South African Journal of Marine Science* **2**(1): 109-130.

Shannon L.V. and Jarre-Teichmann A. 2000. A model of trophic flows in the northern Benguela upwelling system during the 1980s. *South African Journal of Marine Science* **21**(1): 349- 366.

Shannon L.V. and O'Toole M.J. 1999. Integrated overview of the oceanography and environmental variability of the Benguela current region. *BCLME Thematic Report, 2.*

Shannon L.V. and Pillar S.C. 1986. The Benguela ecosystem. Part III. Plankton. *Oceanography and Marine Biology: An Annual Review* **24:** 65- 170.

Stenevik E.K., Sundby S. and Cloete R. 2001. Influence of buoyancy and vertical distribution of sardine *Sardinops sagax* eggs and larvae on their transport in the northern Benguela ecosystem. *South African Journal of Marine Science* **23:** 85- 97.

Stenevik E.K., Sundby S. and Cloete R. 2007. Diel vertical migration of anchovy *Engraulis encrasicolus* larvae in the northern Benguela. *African Journal of Marine Science* **29**(1): 127- 136.

Sundby S., Boyd A.J., Hutchings L., O'Toole M.J., Thorisson K. and Thorsen A. 2001. Interaction between Cape hake spawning and the circulation in the northern Benguela upwelling ecosystem. *South African Journal of Marine Science* **23**(1): 317- 336.

Timonin A.G., Arashkevich E.G., Drits A.V. and Semenova T.N. 1992. Zooplankton dynamics in the northern Benguela ecosystem, with special reference to the copepod *Calanoides carinatus. South African Journal of marine Science* **12**(1): 545- 560.

© NMP 2014

Unterüberbacher H.K. 1964. *The Pilchard of South West Africa (Sardinops ocellata): Zooplankton Studies in the Waters off Walvis Bay with Special Reference to the Copepoda.* Marine Research Laboratory, South West Africa, 78pp.

Verheye H.M., Hutchings L., Huggett J.A. and Painting J. 1992. Mesozooplankton dynamics in the Benguela ecosystem, with emphasis on the herbivorous copepods. *South African Journal of Marine Science* **12**(1): 561- 584.

Wallace M.I., Cottier F.R., Berge J., Tarling G.A. Griffiths C. and Brierley A.S. 2010. Comparison of zooplankton vertical migration in an ice-free and a seasonally ice-covered Arctic fjord: An insight into the influence of sea ice cover on zooplankton behavior. *Limnology and Oceanography* **55**(2): 831- 845.

Wasmund N., Lass H-U. and Nausch G. 2005. Distribution of nutrients, chlorophyll and phytoplankton primary production in relation to hydrographic structures bordering the Benguela-Angolan frontal region. *African Journal of Marine Science* **27**(1): 177- 190.

© NMP 2014

SANDPIPER PROJECT

Verification Programme Report: Mining Licence Area No. 170

SECTION C : SPECIALIST STUDIES

Section C.3

Fisheries and Biodiversity

C3.1: Verification Survey Report: Fish, Mammals and Seabirds
C3.2: Assessment of Fisheries Biomass and Stock Assessment
C3.3: Opinion on the Ecosystem Impacts related to Dredging of Phosphates offshore Namibia
C3.4: Reproduction Dynamics and Stock Distribution Study
C3.5: Review of the spawning activity, ichthyoplankton drift routes and the recruitment of Namibian marine fauna

SPECIALIST STUDIES – SECTION C

C3.1 Verification Survey Report: Fish Mammals and Seabirds

NAMIBIAN MARINE PHOSPHATE

VERIFICATION SURVEY

FISH, MAMMALS AND SEABIRDS

Prepared for:
Namibian Marine Phosphate (Pty) Ltd.

Prepared by:
Capricorn Fisheries Monitoring cc
Dave Japp and Melanie Smith

October 2014

CAPFISH (Pty) LTD
Unit 15, Foregate Square. Table Bay Boulevard, 8002, South Africa
Directors: Japp, Wissema, Heinecken, Wilkinson, Ncongo
Co Reg. No. 2004 / 004844 / 07

This report has been undertaken independently under contract to Namibian Marine Phosphate by Capricorn Fisheries Monitoring cc (Cape Town). The verification programme relates to the original Environmental Impact Assessment (March 2012) to assess the potential environmental and operational impacts of the proposed offshore dredging of phosphate. This verification assessment relates primarily to the proposed first phase of dredging in an area within the Mining Lease Area known as Sandpiper-1 (SP-1).

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed “Attention: Administration Manager,” at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

contents

SUMMARY v

1 INTRODUCTION 1

2 ENVIRONMENTAL IMPACT ASSESSMENT OVERVIEW 1

3 IMPACT CATEGORIES 4

4 VERIFICATION PROGRAMME 5

5 RESULTS OF THE VERIFICATION 6

5.1 ASSESSMENT OF FISHERIES BIOMASS AND STOCK ASSESSMENT 6
5.2 ASSESSMENT OF ECOSYSTEM IMPACTS 8
5.3 ASSESSMENT OF RECRUITMENT 9
5.4 HISTORICAL ASSESSMENT OF SPAWNING AND RECRUITMENT (SECTION C, CHAPTER 3.5) 10

6 VERIFICATION BIODIVERSITY SURVEY 12

6.1 BACKGROUND AND OBJECTIVES 12
6.2 METHODS AND MATERIALS 15
6.3 RESULTS 18
6.3.1 Fish 24
6.3.2 Epifauna 37
6.3.3 Seabirds 40
6.3.4 Marine mammals 43
6.3.5 Hydrography and environment 45
6.4 DISCUSSION AND CONCLUSIONS OF THE BIODIVERSITY SURVEY 48

7 A REVIEW OF THE MESOPELAGIC FISH AND PELAGIC GOBY 50

8 GEOPHYSICAL SURVEY AND HABITAT MAPPING ASSESSMENT 58

9 ASSESSMENT OF THE EFFECTS OF DREDGING NOISE ON MARINE FAUNA 64

10 OVERALL CONCLUSIONS OF THE VERIFICATION PROGRAMME 65

11 RECOMMENDATIONS 67

12 ACKNOWLEDGEMENTS 68

13 SUPPORTING DOCUMENTATION 68

Annexure 1. Coordinates for the original and actual trawl stations. 75
Annexure 2. Fish (monk and hake) length at 50% maturity and their length-weight relationship. 76

© NMP 2014

figures

Figure 1: Location of the proposed target dredging sites SP-1 (20 year mine plan established), SP-2 and SP-3 within the Sandpiper phosphate licence area (ML 170). 2
Figure 2: Illustration of zones and areas defined in the fisheries impact assessment (original EIA) (Japp 2012). 3
Figure 3: Location of the 24 trawl lanes within ML 170 and SP-1. 14
Figure 4: Configuration of the double belly monkfish trawl net fitted on the FV *Zeearend* 16
Figure 5: Total catch weight (kg) per 30 minute trawl (bar graph) and total catch per swept area (line graph) per station. The day (grey bars) and night time (black bars) trawls have also been presented. 20
Figure 6: Spatial distribution of all species by weight (kg/0.5min) per station 23
Figure 7: The weight of the fish per day (grey) and night (black) station. 25
Figure 8: Proportion of fish by weight at each station. Species include hake (*M. capensis*), monk 26
Figure 9: Goby weight (kg) per day (D) and night (N) station. 27
Figure 10: Spatial distribution of goby (*Sufflogobius bibarbatus*) by weight (kg) and number (red label) per station. 28
Figure 11: Length frequency distribution for monk. 29
Figure 12: Length frequency distribution of hake, split by male (blue) and female (red). 30
Figure 13: Length frequency of sole, split by male (blue) and female (red). 30
Figure 14: Length frequency of Angola flying squid, (both male and female combined). 31
Figure 15: Length frequency of horse mackerel, (both male and female combined). 31
Figure 16: Length frequency of jacopever (both male and female combined). 32
Figure 17: The percentage maturity stage against length (cm) for monk females. 33
Figure 18: The percentage maturity stage against length (cm) for monk males. 34
Figure 19: The percentage maturity stage against length (cm) for hake females. 34
Figure 20: The percentage maturity stage against length (cm) for hake males. 35
Figure 21: Number of prey items found in 337 monk individuals. 36
Figure 22: Number of prey items for 324 hake individuals. 36
Figure 23: Spatial distribution of seabird number and species counts (red labels) per station. 42
Figure 24: Spatial distribution of marine mammal numbers per station. 44
Figure 25: Down cast data for Station 6 in a cross-section view. Temperature, dissolved oxygen and salinity data are shown. Note the very low oxygen concentrations. 47
Figure 26: Distribution of main commercial mesopelagic fish species in the Benguela region. 51
Figure 27: Distribution of *Sufflogobius bibarbatus* in the Benguela. 52
Figure 28: Distribution and abundance of larvae of lanternfish (*Lampanyctodes hectoris*) from SWAPELS data. 54
Figure 29: Distribution of *Sufflogobius bibarbatus* in the Benguela. The figure represents a measure of mean relative abundance of gobies from all trawl hauls captured by the RV *Dr. Fridtjof Nansen* between 1985-2005. 55
Figure 30: Distribution and abundance of goby larvae during SWAPELS survey 1 (left) and survey 2 (right). Values represent cumulative standard haul totals for all cruises (adapted from O'Toole 1977) 57
Figure 31: Location of the diatomaceous mud-belt on the central Namibian shelf (adapted from Emeis *et al*. 2004) 59
Figure 32: Multi-beam Echo Sounder and Sidescan Sonar coverage within SP-1. Red shading shows shallow water, while blue is deeper water. 61
Figure 33: Multi Beam Echo Sounder bathymetry data. 62
Figure 34: Sidescan Sonar mosaic image. 63
Figure 35: Percentage of mature female monk per length class. 77
Figure 36: Percentage of mature male monk per length class. 77
Figure 37: Percentage of mature male hake per length class. 77

© NMP 2014

Figure 38: Percentage of mature female hake per length class. 77
Figure 39: Length-weight relationship for monk. 77
Figure 40: Length-weight relationship for hake. 77



Table 1: Percentage biomass estimates for monk and hake in MLA and the SP-1 site 7
Table 2: Standardised weight (kg) and number of species caught in 30 minutes per station. Catch rate (CPUE) per hour is also shown. D = Day: N = Night trawls 19
Table 3: Number (and where applicable weight) for all the species identified and recorded during the biodiversity survey. 21
Table 4: Proportion of the total fish, shark and squid species. Jellyfish are in a separate table. 24
Table 5: Number of samples per maturity stage for hake and monk males and females. 33
Table 6: Species and proportions of epifauna identified during the survey, with the exceptions of ascidians and brown sponges. 37
Table 7: Relative proportions of jellyfish, ascidians and sponges 38
Table 8: List of seabird sightings during the survey 41
Table 9: Number of marine mammal sightings per daylight station 43
Table 10: Summary statistics of the 'Trawl section' (excluding up and down casts) of each trawl 46
Table 11: A comparison of the average sound emitted by various relevant vessels including this used for whale watching (EIA Don Diego Technical Report unpublished) 65

© NMP 2014

SUMMARY

Namibian Marine Phosphate (Pty) Ltd (NMP) has applied to dredge for marine phosphate in Namibia, approximately 40-60 km offshore from Conception Bay. The phosphate will initially be extracted from the target dredge area described as Sandpiper-1 (SP-1). NMP has been granted a 20-year lease to dredge phosphate in this area, subject to the issue of an Environmental Clearance Certificate following the approval of an Environmental Impact Assessment (EIA) and Environmental Management Plan (EMP). The EIA was completed in March 2012, and, the EMP called for a Verification Programme to support the information used in the EIA and to address areas of uncertainty highlighted by the NMP appointed specialist consultants and in some instances by reviewing parties, including the authorities. The verification programme would also act as a reference or datum against which the actual impacts of dredging could be monitored in the future.

In the original EIA the, impacts were interpreted at different scales to assist in gauging the potential significance of the impacts relative to the proximity of the actual dredging operations. This scaling included the following zonation:

- In the target dredge area known as Sandpiper-1 (SP-1)[1];
- In an area immediately adjacent to SP-1 and within the Mining Lease Area (MLA); and
- Thereafter at a regular interval seawards (distance) from the perimeter of the MLA

Five likely impacts of marine dredging were identified and assessed. These were as follows:

- The impact on commercial fisheries;
- The impact on the main commercial and other fish species;
- The impact of the reproductive dynamics of the main commercial fish species and the potential impact on recruitment to the fisheries in the dredged area;
- The impact on biodiversity, in particular marine fauna; and
- The impact on seabirds and marine mammals.

To address levels of confidence in the original assessment and to expedite the verification requirements as detailed in the EMP (amended following consultation with MFMR and independent reviewers).

A Verification Programme consisting of several studies was undertaken. These studies and their outputs related to fish, mammals and seabirds, included the following:

1. An independent assessment of fisheries biomass in SP-1 and the MLA was conducted by Gaylard (Section C, Chapter 3.2), (Gaylard Chapter C 3.2): The report concluded that less than 0.2% of the biomass of each species assessed in Namibian waters (*Merluccius capensis, M paradoxus* and *Lophius vomerinus*) lies directly within the proposed SP-1 dredge site. The SP-1 site also makes no significant contribution to recruitment or spawner stock biomass for any of the species considered in the biomass assessment. Outside of SP-1 but still within the total MLA, the biomass of monk expected to contribute to the fishery recruitment was estimated to be 7%. It was emphasized that the broader impact is however likely to be negligible as the proportion of the potential biomass of hake and monk in SP-1 and recruiting to the commercial fisheries in the adjacent areas is extremely small when extrapolated beyond the actual area (a 60 km^2 portion of SP-1, (176 km^2) to be dredged.

[1] 1/3 (approx. 60km^2) of SP-1 (176 km^2) is to be dredged in the 20 year mining licence period

© NMP 2014

2. A professional independent review of the likely ecosystem impacts in the context of dredging within the broader northern Benguela system was also carried out (Cochrane, Section C, Chapter 3.3). The overall conclusion was that the combination of the high uncertainty typically associated with projections by ecosystem models and the small area that will be affected by the proposed dredging means that it is unlikely that ecosystem modelling would expose any unexpected or highly significant threats that have not already been considered in the specialist studies.

3. A specific study on the reproductive dynamics of the main commercial fish species was also commissioned (Nadjula Section C, Chapter 3.4). With respect to the stock structure and gonad maturation of the main commercial species the data available showed that there were no special characteristics of their reproductive dynamics in the proposed dredging area (SP-1). Further, the study showed that there was no deviation expected that would make the area unique with respect to these reproductive biological characteristics. The study also considered cohorts for all the species analysed and showed that a mix of small and large fish for most of the Namibian EEZ was typical and that for the MLA there were no indications of any deviation from this norm. In addition the study showed that the MLA was not a unique spawning area that supported significantly different levels of recruitment of the main commercial species to the fisheries in the proximity of the MLA. Monthly trends also did not indicate any gonad development beyond "maturing stage" of the commercial species found in the MLA. This supported the suggestion that fish move in and out of such grounds over time. Annual maturity trends have also not shown repeated dynamics, implying that spawning grounds for these species are not localized. Multiple cohorts observed per year and by area suggest that high and low recruitment events are a normal occurrence. This again indicated the lack of a "homing behaviour" for adults, with the boundaries for recruitment and spawning grounds not clearly defined.

4. Together with the reproductive assessment described above a detailed review of the main historical information, regarding in particular the spawning areas, ichthyoplankton drift areas and recruitment grounds from the ICSEAF papers as well reference material associated with the historical SWAPELS programme, was conducted (Japp and Smith, Section C, Chapter 3.5). The main conclusions were that horse mackerel, anchovy and sardine spawned outside the MLA. A low abundance of hake eggs occurred near the southern borders of the MLA off Hollams Bird Island although typically fish larvae were found in the MLA as well as broadly in areas across the Namibian shelf. The historical data also showed that juvenile hake and monk occurred within the MLA and in adjacent areas and that goby larvae were also abundant in the MLA.

The main part of the verification programme was an eight day biodiversity survey (Section D, Appendix 2.1 and 2.2) of the proposed target dredge area (SP-1). From the 18th – 27th June 2014, a commercial monk trawl vessel, the FV *Zeearend* was chartered (Appendix 2.4 & 2.5) to sample 24 stations in and around the SP-1 target dredge area, in water depths greater than 200 m. Trawls (30-min tows) were carried out, twelve by day and twelve by night. Catches of fish, invertebrates and epifauna were sampled, counted, weighed and measured. Environmental parameters were measured at each station using a CTD (Appendix 2.3). Marine mammals and seabird sightings were made during daylight within 500 m of the vessel. The specific objectives for the biodiversity survey were to establish a baseline for future monitoring and survey assessments and to collect the following:

- Abundance (density) data for the main commercial species such as hake, monk and horse mackerel;
- Biological data (length, sex, maturity stage, stomach content) from the main commercial fish species;
- Epifauna from all trawl locations;

© NMP 2014

- Environmental data (using visual observations and a CTD). To establish linkages between the environment and species distribution, recruitment and abundance; and
- Marine mammal and seabird data in the area;

These data were used to verify the information assessed in the EIA (Japp in Midgley 2012) and provided comparative information regarding the:

- Biodiversity reported on in the EIA;
- Size structure of the main commercial fish species compared with areas outside of the MLA;
- Biological information on the main commercial species to verify if there are any notable deviations from the information and assumptions made in the EIA;
- The spatial distribution of marine fauna, in and adjacent to SP-1 to check if there are any significant deviations from what was expected; and
- Recruitment based on size and sex structure of the main trawled species, in and adjacent to, SP-1 and to test if the results deviated significantly from that determined by the EIA.

A total of 14 fish species including two squid species (*Todarodes angolensis* and *Todaropsis sagittatus*) and one shark (*Hexanchus griseus*) was identified. Cape hake dominated the catch, amounting to 40% of the total fish weight. This was followed by monkfish, 35%, rat tail (*Coelorinchus simorynchus*) 14%, West Coast sole 3%, bearded goby 2%, and horse mackerel 0.4% of the total fish catch. Cape hake, monkfish and gobies were found in most of the trawls and there was little variation in the catches of commercial species across the survey area. Most female monkfish were immature, but many of the female Cape hake had active developing gonads.

In all, 14 taxa of epifauna were collected by the bottom trawl, including crabs, ascidians (sea squirts), brown sponges, sea pens, mantis shrimps, starfish and whelks. The colonial ascidian (*Molgula* sp.) was numerically the most dominant bottom living organism, contributing to 60% of the epifauna catch weight during the survey. This was followed by the pennate sea pens (family Veretellidae), which made up 37%. Both these groups were found widely distributed over the area surveyed. Jellyfish, particularly *Chrysaora fulgidia* (known locally as the red jelly) were also abundant in all trawl catches.

Fifteen species of seabird were recorded during the survey, of which 45% were White-chinned Petrel (*Procellaria aequinoactialis*), 20% Subantarctic Skua (*Catharacta antarctica*) and 12% Black-browed Albatross (*Thalassarche melanophrys*).

Only two species of marine mammal were observed during the survey, the Cape fur seal (*Arctocephalus pusillus pusillus*) and the dusky dolphin (*Lagenorhynchus obscurus*). Dolphins were only recorded along the eastern edge of the SP-1 area, whereas seals were observed throughout the survey area.

Hydrological data collected during the survey indicated a well-mixed layer of South Atlantic Central Water with typical winter values for temperature and salinity and low oxygen levels near the seafloor.

In general, the conclusions of the verification programme were that the size distribution of the main commercial species likely to be impacted (i.e. monk and hake) are consistent with what is known and with what was assumed in the initial EIA. For the area there is no evidence of unique spawning and recruitment characteristics. For *M. capensis*, the abundance of juvenile and pre-recruiting hake is consistent with what is known. Further, the proportions of juveniles and sex ratios (males and females) suggests no irregularities that would make the area to be dredged unique. With regard to monkfish, as expected, the verification survey has shows a mix of juveniles, adults and pre-recruiting fish. As the survey used monk-directed gear with a cod-end liner (20 mm mesh) to retain as much as possible, the proportion of juvenile fish caught was higher than would be expected. This finding was consistent also with the

© NMP 2014

biomass estimates (Gaylard, Section C, Chapter 3.2). Both the verification survey outputs and the biomass estimates for SP-1 confirm that the limited extent of the dredging (in particular SP-1) is likely to have only a very small impact relative to the overall abundance of the monk and hake stocks in Namibian waters. The impact on monk reproduction and the recruitment to the commercial fishery as a whole in SP-1 will also be minimal. Sole were also caught in the verification survey, however their abundance was not high. Further, predominantly large sole were caught suggesting that the SP-1 area and adjacent grounds are unlikely to be a significant recruiting area for sole to the monk trawl fishery.

The verification survey provided baseline data on biodiversity. In general fish diversity was lower than reported in the EIA. This is due to the fact that in the EIA data on fish diversity were consolidated from surveys using different gear types (hake, monk, midwater, purse seine). The fauna recorded in the verification survey was notably lower than reported in the EIA since the verification survey deployed dedicated monk trawl gear, no inference from the survey can be made regarding the availability and abundance of non-demersal species such as horse mackerel, sardine, mesopelagics and gobies (noting that both gobies and horse mackerel were, however, present in small numbers).

With respect to demersal fish species mammals and seabirds, no unique features were noted and the results are consistent with the initial assessment in the EIA (recognising that the abundance of some species, particularly sea birds and mammals will vary seasonally as well as spatially). Regarding mesopelagic species, none was recorded in the trawl catches. Mesopelagic species such as lantern fish are expected in the mid-water, however the gear used would not have targeted these species. Catches between night and day varied as expected and we assume normal diurnal behavioral patterns prevail with regard to fish and crustaceans.

With respect to epifauna (McClurg, Section C, Chapter 2.6) we noted the high abundance of ascidians. Based on the experience of the skipper this was not considered unusual and was typical of the substrate on which the trawls were made. The occurrence of these ascidians was not reported in the numerous surveys used in the EIA; however there were occasional observations of ascidians recorded from the recent macrofauna surveys (Steffani, Section C, Chapter 2.5). This species could have the potential to be used as a bio-indicator for future verification surveys. Their abundance may in part be due to the very low density of historical trawling of the region and in particular in SP-1: repeat trawling over the area is likely to systematically remove this species.

With regard to ecosystem impacts as a whole, the survey suggests that the area possesses no unique features and is consistent with the findings in the EIA. The primary issue in the ecosystem context is one of scale and it is the expert opinion that the area of impact (up to 3 km^2 annually and 60 km^2 for the 20 year mining lease period) is so small relative to the overall extent of the Benguela ecosystem that significant impacts on the ecosystem are unlikely. The current state of the modelling in both the northern and southern Benguela ecosystems is also unlikely to inform any differently from what is currently known on the likely impact on the broader ecosystem if dredging were to be undertaken in SP-1.

Mesopelagic fish, gobies and zooplankton were not recorded during the biodiversity survey, thus little is known about the potential effects of marine dredging on these fishes and the scattering layer in SP-1. (Weston, Section B: 2.7) Future verification surveys should attempt to track the scattering layer patterns using industrial or scientific echo sounders in order to infer the relative abundance of these species. Samples could also be taken if mid-water trawl gear were available on the survey vessel and if the vessel had adequate power to be able to tow such gear to nullify the avoidance behaviour of these species.

Interpretation of the geophysical data (Ludick, Section D, Appendix 3.2) conclusively indicated a flat, smooth seafloor with a homogeneous surficial sediment cover across the northern part of SP-1. No protruding obstacles were observed. The surficial sediment composition of the area was a muddy medium

© NMP 2014

sand. This was further supported by the trawl surveys suggesting that the habitat was homogeneous and primarily of firm sandy gravelly (shell) character.

Previous studies of the potential impacts of sound from dredging vessels on a variety of species showed that sound levels in all cases are well below those known to cause damage to marine life. Thus, if we assume that the sound frequency and decibel level of sound emanating from a typical Tailer Suction Hopper Dredger (TSHD) is similar to the vessel to be used at the mine site (SP-1) then dredging noise can be assessed to be a low impact.

Overall, the verification programme for the fish, mammals and seabirds component of the NMP impact assessment process confirmed that the confidence levels of the assessment in the EIA (Japp in Midgley 2012) supports the core assumptions, thereby strengthening areas of weakness and improving the confidence of the original assessments A summary of the assessment tables, after the verification programme, is presented below. Further, the verification programme strengthened the need to maintain the baseline information to be able to monitor for changes in the system around the area to be dredged. Continuation of the survey described in the verification programme should be an integral part of the NMP Environmental Management Plan. This will facilitate the ongoing management and monitoring of the dredging operation in SP-1 and can inform on the likely effects if the dredging activities were to expand beyond SP-1, into SP-2, SP-3 or indeed other areas.

Assessment criteria	Fisheries	Ecosystem	Reproduction	Biodiversity	Seabirds & Mammals
Extent	Specific dredge site (SP-1)	MLA	MLA	Specific dredge site (SP-1)	Specific dredge site (SP-1)
Duration	Long term	Permanent	Permanent	Permanent	Long term
Intensity	Serious effect	Moderate effect	Minor effect	Minor effect	Minor effect
Probability	Definite	Highly probable	Improbable	Improbable	Probable
Status	Negative	Negative	Negative	Negative	Negative
Significance (no mitigation)	Medium	Medium	Low	Low	Medium
Significance (with mitigation)	Medium to low	Medium	Low	Low	Low
Confidence	High	Low to medium	Low to medium	Low to medium	Medium
Confidence (post verification)	High	High	High	High	High

It is recommended that should an environmental clearance certificate be issued that monitoring through surveys continue. This should include a similar survey using similar design, gear and vessel annually. Further the monitoring of the baseline and knowledge base can be further strengthened if NatMIRC adapted their current hake and monk survey designs to incorporate the MLA and or SP-1 areas. This would also provide MFMR with an alternative independent estimate of conditions and changes that may occur in the dredged area over time.

Regarding noise emissions from dredgers, it is recommended that some acoustic monitoring at the target dredge site (SP-1) to determine the levels of dredging noise and to monitor whales and dolphins using Passive Acoustic Monitoring (PAM) devices should be undertaken. It is also recommended that marine mammal observers are trained to use such devices to be a part of a monitoring team on board the mining vessel or during dedicated monitoring surveys.

© NMP 2014

Little is known about the potential effects of marine dredging (in particular the potential impacts of sediment plumes) on scattering layers that include *inter alia* mesopelagic FISH species, gobies, plankton and zooplankton. Thus it is recommended that future monitoring surveys should attempt to track the scattering layer patterns and trends in order to infer the relative abundance and distribution of these species. This could be achieved using industrial or scientific echo sounders.

© NMP 2014

1 INTRODUCTION

Namibian Marine Phosphate Ltd (NMP) has applied to dredge for phosphate offshore on the Namibian continental shelf. The phosphate deposit lies approximately 60 km offshore from Conception Bay in water depths of 190 to 300 m and covers an area of 2233 km^2. The phosphate will be extracted by dredging in the target mine areas described as Sandpiper-1 (SP-1). SP-1 (176km^2) lies in water depths of 200 to 225 m, up to 60km^2 will be dredged during the 20-year mine licence period. Subsequently, upon further assessment and approval dredging may be undertaken in SP-2 and SP-3 (Figure 1). NMP has been granted a 20-year mining lease area (MLA-170), subject to the issue of an Environmental Clearance Certificate following the completion of an Environmental Impact Assessment (EIA) and an approved Environmental Management Plan (EMP). The initial impact assessment was completed in March 2012 and the EMP called for an Verification Programme (environmental baseline) to be undertaken (established) prior to mining, to act as a reference or datum against which the actual impacts of dredging could be assessed. The scope of the Verification Programme described in the 2012 EMP was augmented by integrating the recommendations from independent reviewing parties and the Ministry of Fisheries and Marine Resources (MFMR) (Section D, Appendix 4.4).

We report here on the verification process for the fish, mammals and seabirds component *(Japp, in Midgley 2012: Appendix 1a. Namibian Marine Phosphate – Environmental Impact Assessment of Fish, mammals and seabirds: Proposed monitoring and verification of Impacts in the proposed Mining Area*).

2 ENVIRONMENTAL IMPACT ASSESSMENT OVERVIEW

The displacement of the commercial fishing activities and the redistribution, survival and recruitment of fauna (fish, seabirds and mammals) could be influenced by the dredging of phosphate in several ways. For the purposes of the verification programme we have summarised the original basis for the identification and separation of each impact.

As identified in the EIA, impacts can be interpreted at different levels and or at different distances from the dredging activity. For example:

- In the immediate area - the actual area to be dredged within each of the designated areas: SP-1, SP-2 and SP-3;
- In an area immediately adjacent to the dredging site - each of these areas proposed to be dredged falls within the overall Mining Lease Area (MLA); or
- Thereafter at some distance from the dredging site - the MLA falls within the Namibian Exclusive Economic Zone (EEZ).

To assist us with the implications of scaling, especially in an ecosystem context, we selected arbitrary scales or distances from the dredging location with which to gauge the potential impact relative to the distance away from the dredging operation. These scales were described in the EIA and have been reiterated here as they have relevance to the verification process (Figure 2). These scales had no ecological basis other than to assist in the interpretation and quantification of possible impacts at a range of distances away from the actual planned dredging locations.

© NMP 2014

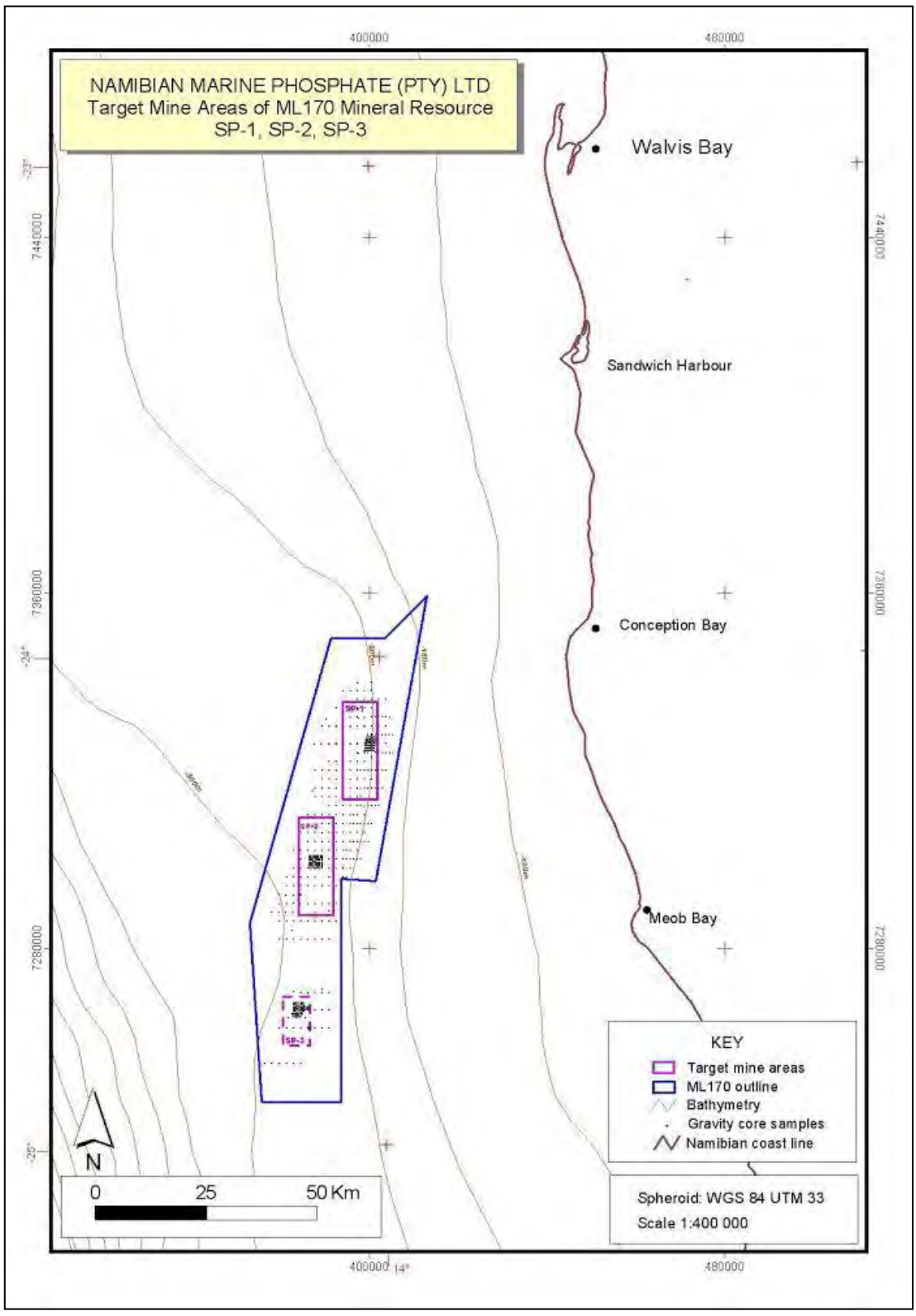


Figure 1: Location of the proposed target dredging sites SP-1 (20 year mine plan established), SP-2 and SP-3 within the Sandpiper phosphate licence area (ML 170).

© NMP 2014

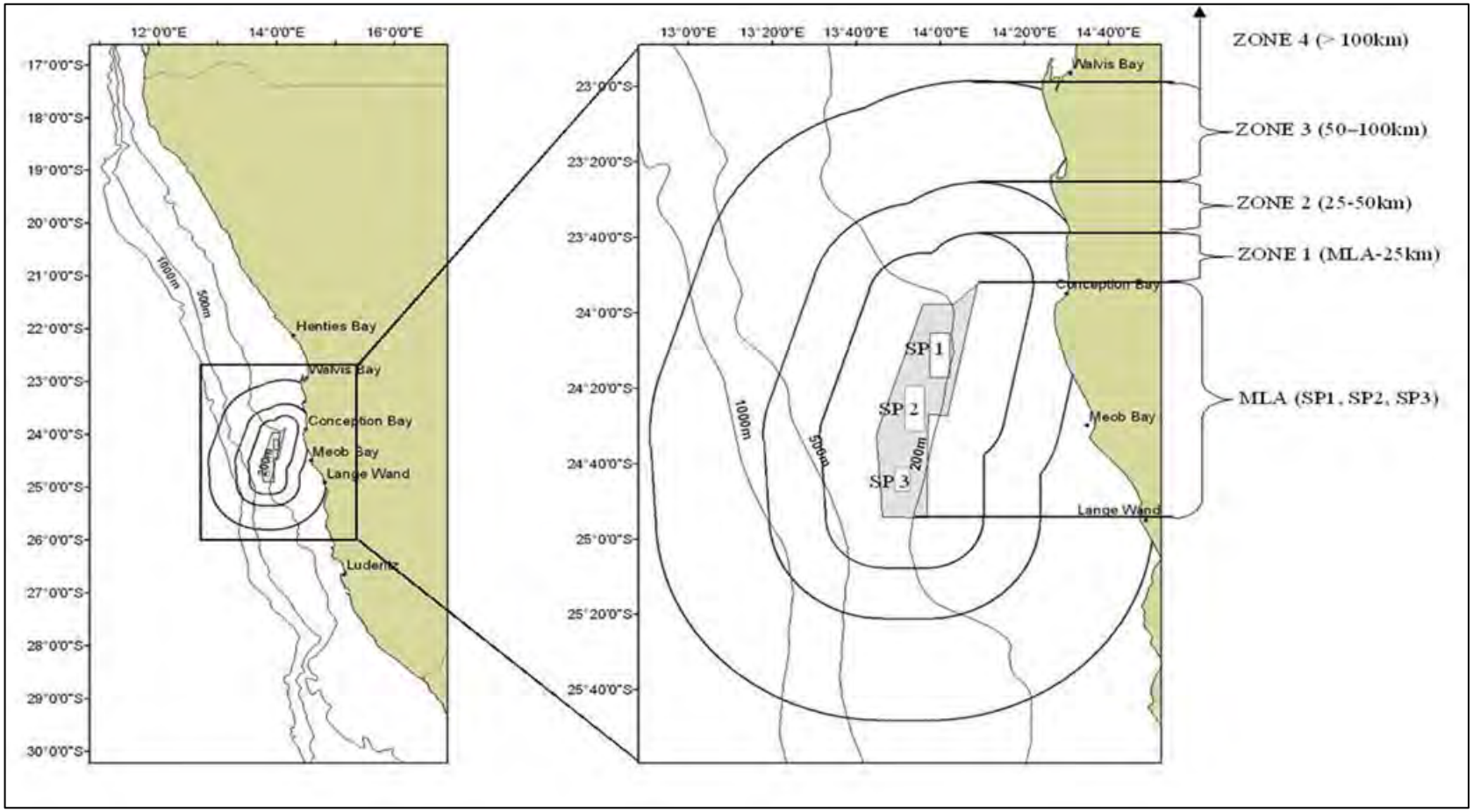


Figure 2: Illustration of zones and areas defined in the fisheries impact assessment (original EIA) (Japp 2012).

We also identified possible effects as either Direct or Indirect that broadly included the following:

Direct effects:

1. Exclusion of fishing to avoid dredging, and the loss of access to potential fishing grounds;
2. The removal of habitats (or disturbance of bacterial mats, if present) utilized by marine fauna;
3. The creation of sediment plumes (turbidity) that might affect species abundance (area avoidance, mortality, loss of feeding and spawning grounds);
4. Loss of biodiversity through direct physical removal of sediment and associated loss of fauna.

Indirect effects:

1. Displacing the normal behaviour of fish, seabirds and mammals due to the physical disturbance of the dredging activities (including noise from the dredging operation);
2. Disturbance of normal trophic interactions and the general ecosystem functioning.

In the context of the scaling we assumed that on average, demersal trawls are three hours long at 3.5 knots – or approximating 25 km long. Based on this assumption it is reasonable to assume that fishing operations in general will have to be altered from the historical norm (Figure 1).

3 IMPACT CATEGORIES

We categorized our Impact Assessment into five primary impacts as follows:

1. **Impact 1:** The likely impact of dredging **ON** commercial fisheries (hake and monk demersal trawl fishery, the hake longline fishery, the mid-water trawl fishery and the small pelagic purse seine fishery). The fishing sectors will not be able to operate effectively in SP-1. In addition there will be some disturbance on the fishing operations in SP-2 & SP-3 (if and when these areas are opend to dreding) due to a) the disturbance caused from actual dredging operations; b) associated sediment plumes; c) exclusion zones around the dredging site; and d) increase levels of maritime traffic associated with the dredging operation;
2. **Impact 2:** The likely impact of dredging **ON** the main commercial and non commercial fish species (hake, monk, horse mackerel, small pelagics, sole, snoek and bearded goby). The fish fauna is a critical component of the broader marine ecosystem and may be displaced and/or redistributed by the dredging operation primarily because of the a) actual dredging activities; b) habitat disturbance; and 3) sediment plumes (turbidity);
3. **Impact 3:** The likely impact of dredging **ON** the recruitment (or on the reproductive dynamics) of commercially important species (hake, monk, horse mackerel and small pelagics). The dispersal and survival of juveniles, eggs and larvae will be affected by a) physical disturbance of the habitat and consequently the fishing grounds and b) sediment plumes (turbidity);
4. **Impact 4**: The likely impact of dredging **ON** the fish biodiversity. Dredging operations will result in a reduction or loss in biodiversity because of the a) actual dredging operations, b) the habitat destruction and c) sediment plumes;
5. **Impact 5 :** The likely impact of dredging **ON** seabirds and marine mammals. Dredging operations will cause the displacement and/or redistribution of seabirds and mammals due to a) noise pollution b) artificial light intensity and c) disturbance of normal ecosystem processes.

NOTE: With respect to Impact 1 – the effect of dredging operations ON commercial fisheries is NOT a biological environmental impact and relates to disturbance of fishing industry operations.

© NMP 2014

4 VERIFICATION PROGRAMME

The programme was undertaken to address the levels of confidence raised by Japp (in Midgley 2012) of the original assessment, to expedite the verification requirements as detailed in the EMP (Midgley 2012) and to attend to the issues raised by the reviewers and other responses to the original EIA (Fisheries, Mammals and Seabirds), we undertook the following:

a) Review of information and references used as well as utilizing any new or other relevant information;
b) Commissioning an independent assessment of fisheries biomass in the MLA (Gaylard, Section C, Chapter 3.2). The main purpose of this was to obtain a realistic professional and independent estimate of commercial fish biomass in the MLA and target dredge area SP-1. This would be done in lieu of not being able to do a full standardized biomass assessment as suitable vessels and gear could not be accessed;
c) Commissioning of a professional independent review of the ecosystem issues in the context of dredging within the broader northern Benguela system (Cochrane, Section C, Chapter 3.3). In particular the assessment was to review the proposed dredging and uncertainty surrounding the ecosystem impacts in the context of the current resolution of marine ecosystem models;
d) Commissioning of a specific fisheries recruitment (reproductive dynamics) assessment (Nadjula, Section C, 3.4). Reviewers' comments suggested that the impacts of dredging require a recruitment study, which would include long-term studies. Given that the data for a long term recruitment study were not available from MFMR, the verification strategy adopted was to initiate a scientific review of the current knowledge of recruitment of the main commercial fish stocks, review any associated biological information and to interpret the information in a scientifically rigorous manner in the context of the proposed dredging;
e) In addition to fish recruitment (reproductive dynamics) to the commercial fisheries sector study, we also undertook a detailed review of the main historical data, in particular the ICSEAF papers as well reference material associated with the historical SWAPELS programme (Japp and Smith, Section C, Chapter 3.5). The aim was to identify egg and larval distributions associated primarily with the demersal and small pelagic fisheries in Namibia prior to Namibian independence;
f) The historical and current information on the mesopelgic species and the pelagic goby were reviewed to investigate the likelihood of impacts related to the proposed dredging in SP-1.
g) An investigation of the habitat of SP-1 was conducted (Ludick, Section D, Appendix 3.2). Data were collected during a geophysical survey, the seabed topography and the distribution of seafloor surficial sediments was determined using side-scan Sonar (SSS) and Multi-beam Echo Sounder (MBES) equipment (Section D, Appendix 3.1). Specific objectives were to characterise the seafloor of the target dredge area within SP-1 and also identify any obstructions on the seabed in advance of the trawl survey.
h) A review of the available information of the effects of marine noise was carried with the intention of assessing the impacts of dredging noise on marine fauna in SP-1.
i) A biological (verification) survey (Section D, Appendix 2.1) of the proposed primary target area to be dredged (SP-1) was commissioned. This investigation is designed along the lines of a standard scientific biomass survey with randomly selected trawl stations. The area of this survey would be a very small part of the broader Namibian EEZ but would respond to the concerns expressed by reviewers that the data available and provided by NatMIRC for the EIA had few historical data points in SP-1, SP-2 and SP-3. This survey would serve as a baseline as needed prior to the approval of dredging and would provide comparative data on the following:
    - The biodiversity reported on in the EIA (Japp in Midgley 2012);

© NMP 2014

- Size structure of the main commercial fish species compared with areas outside of the MLA;
- Biological information on the main commercial species to verify if there are any notable deviations from the information and assumptions made in the EIA (Japp in Midgley 2012);
- To check the spatial distribution of marine fauna, in and adjacent to, SP-1 and to check if there was any major deviation from what was expected; and
- Provide a recruitment index based on size and sex structure of the main trawled species, in and adjacent to, SP-1 and to test if the results deviated significantly from that determined in the EIA.

5 RESULTS OF THE VERIFICATION

5.1 ASSESSMENT OF FISHERIES BIOMASS AND STOCK ASSESSMENT

The biomass assessment focused on estimating the contribution of the MLA and surrounding areas to the biomass of three commercially exploited finfish species: shallow water hake *Merluccius capensis*, deep water hake, *M. paradoxus* and monk, *Lophius vomerinus.* The rationale for commissioning this work (Gaylard, Section C, Chapter 3.2) was:

- In response to the uncertainty regarding the likely impact of dredging on the biomass of commercial fish species in the area to be dredged, the study would contextualize the estimated biomass of monk and hake relative to biomass estimates for these stocks in Namibian waters;
- In lieu of not being able to standardize biomass estimates from the data collected during the biodiversity verification survey[2] the approach used by Gaylard therefore was to use the available survey data from NatMIRC scientific surveys (depth stratified and random trawls using calibrated trawl gear) and apply standard statistical techniques to estimate the relative biomass proportions in the areas to be dredged; and
- Provide an estimate of pertinent biological components of each species, in particular stock structure related to juveniles, recruitment and spawner biomass.

Details of the methodology are given in the supporting paper by Gaylard (Section C, Chapter 3.2). The work commissioned is scientifically and statistically rigorous using standard fisheries modelling and stock assessment methodology. Demersal survey data for 2007 through 2012 provided by NatMIRC were used to estimate biomass in 28 spatial strata (7 depth divisions by 4 latitude divisions) within the Namibian fishery. Densities within these strata were appropriately weighted in proportion to the spatial contributions of these strata to the MLA in general and to the SP-1 dredge site in particular.

These calculations resulted in the following estimates of the contribution of the MLA (covering an area of 2233 km^2) and the SP-1 site (covering an area of 176 km^2) (Table 1) to the various components of the fisheries resources under consideration[3]:

[2] The commercial vessel used for the Biodiversity Verification Survey was not calibrated with the vessel and gear used for the Namibian (NatMIRC) Surveys, thus a standardised biomass estimate could not be calculated from the data collected during the survey.
[3] Note: Only up to 60 km^2 of SP-1 (176km^2) is targeted for dredging during the 20 year licence issue period.

© NMP 2014

Table 1: Percentage biomass estimates for monk and hake in MLA and the SP-1 site

	MLA	95% Confidence Interval	SP-1	95% Confidence Interval
% of Area	1.3%		0.11%	
% of Biomass *M. capensis*	1.6%	(1.3% , 2%)	0.14%	(0.1% , 0.18%)
% of Mature Stock *M.capensis*	1.6%	(1.1% , 2%)	0.11%	(0.07% , 0.16%)
% of Recruits *M. capensis* (by No.)	1.6%	(1.1% , 2.2%)	0.20%	(0.12% , 0.28%)
% of Biomass *M. paradoxus*	0.01%	(0% , 0.035%)	0.00%	(0% , 0.01%)
% of Mature Stock *M. paradoxus*	0.001%	(0% , 0.003%)	0.00%	(0% , 0.001%)
% of Recruits *M. paradoxus* (by No.)	0.07%	(0% , 0.197%)	0.00%	(0% , 0.01%)
% of Biomass *L. vomerinus*	2.0%	(0.9% , 3.1%)	0.06%	(0.04% , 0.08%)
% of Mature Stock *L. vomerinus*	0.8%	(0.4% , 1.2%)	0.03%	(0.01% , 0.04%)
% of Recruits *L. vomerinus* (by No.)	7.0%	(1.8% , 12.3%)	0.20%	(0.07% , 0.34%)

The MLA is estimated to contain less than 1.6% of the Namibian biomass for *M. capensis*, which reduces to 0.14% if the SP-1 target dredge site only is considered. No notable departure from these proportions is estimated for either the recruits or the spawning adults. The 23^0 to 26^0 latitude band is a breeding ground for *M. capensis*, and contains a large proportion of juveniles. However, the overwhelming majority of these are at depths less than 200 m, whereas most (80%) of the MLA lies in water deeper than 200 m, and the mineral resource (phosphate deposits) area within SP-1 is in water deeper than 200 m.

M. paradoxus adults are scarce at depths of less than 300 m, and the younger fish (less than 27 cm) are predominantly found south of 26^0 S. Thus the MLA and in particular the SP-1 site have very little interaction with *M. paradoxus* (less than 0.2% of biomass is in the entire MLA).

For monk, the MLA is estimated to contribute about 2% to the overall biomass in Namibia. This is lower among the mature stock (0.8%), which tends to be in deeper water and further south within the MLA. The monk recruits however, are more prevalent in the MLA than those of hake, with an estimated 7% of recruits in the MLA. Most of this contribution to recruitment however, is in the 250 to 300 m depth range and is not in the target area to be dredged (SP-1). The SP-1 site is shallower than 250m (the target dredge area is between 225 and 200 m), and so this is estimated to contribute only 0.2% of recruitment to the fishery. We stress also that recruitment will be affected by many factors, including fishing pressure and variability in environmental and oceanographic conditions and will not necessarily remain constant from year to year.

In conclusion, less than 0.2% of the biomass of each species considered lies directly within the proposed SP-1 dredge site. The SP-1 site also makes no significant contribution to recruitment or spawner stock biomass for any of the species considered in this assessment. Outside of SP-1 and within the larger MLA, the biomass of monk expected to contribute to the recruitment to the fishery is estimated to be 7%. Note that this estimate relates only to the spawner biomass in this total area and not to the spawner biomass in SP-1 (which is < 0.2%). Further, note that recruitment to a fishery is highly variable and dependent on many factors other than actual spanner biomass, including fecundity and conducive environmental conditions. This quantitative assessment can therefore not make any biological judgement on the possible impact of dredging on recruitment to the fishery in

© NMP 2014

SP-1 other than that the spawner biomass is extremely small and based on the available historical fishing effort in the area the likely impact of the proposed dredging in the area will similarly be extremely small. It is emphasized that the broader impact is also likely to be negligible as the proportion of the potential biomass in SP-1 and recruiting to the commercial fisheries in the adjacent areas is extremely small when scaled to outside of the dredged area.

5.2 ASSESSMENT OF ECOSYSTEM IMPACTS

A review of the likely impacts of the dredging and related operations at the ecosystems level was commissioned (Cochrane, Section C, Chapter 3.3). The primary rationale for the review was:

- Responses to the EIA (Japp in Midgley 2012) referred to the uncertainty related to the effects the dredging may have on the broader ecosystem, raising the question that a precautionary approach was needed;
- Understanding the potential ecosystem impacts of the operation was a general weakness in the EIA (Japp in Midgley 2012). However, trophic modelling has been done on both the southern and northern Benguela systems (Heymans, *et al*. 2007, Roux and Shannon 2004, Shin *et al.* 2004, Travers *et al.* 2010, Travers-Trolet *et al*. 2014) and Namibia has advocated the application of an *Ecosystem Approach to Fisheries* (EAF);
- As it was difficult to contextualise the scaling effect (i.e. the extent to which dredging in a limited area may impact on the broader ecosystem) even though some complex modelling had been done on the system. The review was intended to provide a rational overview of these models and the extent to which they could respond to the assumptions and uncertainty made in the EIA (Japp in Midgley 2012), primarily for fisheries.

The overall conclusion of the review was that ecosystem modelling can be a valuable tool to investigate indirect and ecosystem impacts of natural or anthropogenic impacts on a part of the ecosystem. Spatially disaggregated ecosystem models have been applied in a number of localities and ecosystems around the world and have been found to be useful. In this case (phosphate dredging), however, the combination of the high uncertainty typically associated with projections by ecosystem models and the small area that will be affected by the proposed dredging means that it is unlikely that ecosystem modelling would expose any unexpected or highly significant threats that have not already been considered in the specialist studies.

That conclusion might not apply, however, if the area to be impacted by the dredging was found to be of particular importance in the ecosystem or in the life cycle of one or more key species. The assessment of the Verification Biodiversity Survey did not produce any results to suggest that the proposed target dredge (impacted) area has any unique or unusual features that would indicate such a disproportionate importance.

The expected ecosystem impacts of the dredging can be considered in the context of other actual or potential environmental impacts in the region, such as from trawling and other fishing impacts, diamond mining, and oil and gas exploration. At this stage, the only other anthropogenic activity taking place in the MLA is fishing with trawl nets, as reported in specialist report (Japp; Steffnie in Midgley 2012). The impacts of dredging in the specific area planned to be exploited can be expected to have considerably greater, and longer-lasting, direct impacts on the biota in that area than does bottom trawling. However, the limited area currently designated to be dredged means that, overall,

© NMP 2014

these impacts will almost certainly be considerably less across the northern Benguela shelf and southern slope environments as a whole than have been the impacts of trawling on these environments, noting that the impacts of trawling are well-managed and considered to be sustainable.

5.3 ASSESSMENT OF RECRUITMENT

As part of the verification programme a study on fisheries reproductive dynamics and stock distribution in Namibia was commissioned. The rationale for commissioning this work (Ndjuala, Section C, Chapter 3.4) was:

- There was uncertainty regarding the impact the dredging might have on recruitment of the main commercial fish species;
- The area to be dredged might be an important area for fish recruitment and this would have a negative impact on the commercial fishing sectors; and
- It was suggested that NMP should undertake studies on egg and larval distributions in the dredged area. Such studies were deemed impractical mainly because they required regular sampling (normally at monthly intervals) and to be of any value would need to be over a period of 10 years. The study commissioned aimed to collate the known and available information on fish recruitment in Namibia and to compare this with the likely distribution of recruitment in and around the areas to be dredged. The study would report on the likelihood that the spatial and temporal distribution of spawning and recruitment in the area to be dredged deviated from what was expected based on the historically and current knowledge.

This study combined analyses of fish size and maturity stages as a method of identifying recruits (juvenile fish) as well as spawners (adults or active gonad stage) and looked at these in spatial, depth and temporal gradients. Such analyses provide a three dimensional picture of fish distribution in terms of size and gonad maturation.

Survey data (1999 – 2012) from the Namibian National Marine Information and Research Centre (NatMIRC) were used for the following species: *Merluccius capensis*, *Merluccius paradoxus*, *Lophius vomerinus*, *Lophius vaillanti*, *Trachurus capensis* and *Sardinops sagax*. The information on the biological analysis of the gonad maturity stages and the gonad weight was recorded, together with fish size. Three approaches were taken:

1. Data were used to analyse stock structures for both spatial and temporal dynamics. Stock structure was also analysed for depth profiles;
2. Data were analysed for both spatial and temporal maturity development, and where necessary analysis for depth profiles was also undertaken; and
3. Where data were available, the Gonadosomatic Index (GSI) was evaluated for both spatial and temporal dynamics. However, due to the nature and interpretation of GSI in serial spawners (which is the egg production strategy used in hake and horse mackerel), the GSI results were not presented in this report as it would be a repetition of information gained from more reliable gonad maturity staging.

Size distribution

The results showed that no significant spawning areas for any species were observed, specifically not in the areas within the MLA. While the data showed there were certain dynamics relating to stock

structure (mainly offshore-onshore and vertically with depth for all species analysed, as well as latitudinal for *M. paradoxus*), there seemed to be a wide range of growth rates and does not define the stock structure, as shown by the cohort indicators. It was determined that the area proposed for dredging has no special biological reproductive characteristics for the main commercial species found in the area compared with the rest of the Namibian waters. For example, there are no specific indicators suggesting that the dredged area is exclusively home to adult fish (spawner biomass), and has no pronounced recruitment of small and young fish.

Data for horse mackerel, hake and monk were available for the period 1999 to 2014, covering the entire Namibian coast (17°S to 29°S), whereas for sardine there were only data from 2007 ranging from 22°S to 25°S. In the case of all these species, the data suggested no unique reproductive characteristics particular to the area to be dredged.

This analysis also showed that for all species analysed their distributions were heterogeneous. Variation in population structure was also not indicative of defined recruitment grounds and in particular the area around 23°S to 25°S showed patterns just as complex and undefined as previously observed in historical studies. The results of this study did not show any special features of the proposed dredging area, with respect to the rest of the Namibian coast in both space and time. Cohort analyses for all the species analysed were a mix of small and large fish for most of the areas, and therefore lacked signs of well-defined spawning areas and/or recruitment of small fish.

Gonad maturation
Whilst hake with more advanced gonad maturity were present around the latitudinal area of interest (between 23°S to 25°S), they were found mostly at greater depths (>250 m) than that of the proposed dredging activities (200 to 225 m in SP-1). Monthly trends also have not indicated any progress (beyond a maturing stage) in gonad maturity in that particular area, suggesting that fish do move in and out of such grounds over time. Annual maturity trends have also not showed repeated dynamics implying that spawning grounds for these species is not localized. These multiple cohorts as observed per year and by area are suggestive of high and low recruitment events. This has again indicated lack of homing for adults and undefined recruitment and spawning grounds.

It is recommended that various 'state of the stock' monitoring surveys be built into the environmental management plan. The presence of phosphate as a resource in this area and given the importance of information needed on the dynamics of the commercial fish stocks in the MLA, it is worth noting that in future, the area should be included in the routine surveys undertaken by MFMR. Results of such studies will play an important part as a control measure from which necessary actions could be derived, as well as adding to the baseline for future monitoring and evaluation and possibly further development plans. Similarly, results from such monitoring programmes could indicate the extent of the impact of phosphate mining. The continuation of the annual biodiversity survey is highly recommended as it adds to the knowledge base of this study, by focusing in the proposed area of dredging activity (SP-1) at a high sampling resolution.

5.4 HISTORICAL ASSESSMENT OF SPAWNING AND RECRUITMENT (SECTION C, CHAPTER 3.5)

The preparation of this document preceded the verification studies. As a result of changes in the Benguela Ecosystem and also due to the collapse of some fish stocks e.g. sardine, there is likely to have been changes in the spatial and temporal dynamics of the key fish species. The EIA (Japp in

Midgley 2012) did report the current status of the commercial fish species. Characteristics such as spawning and recruitment areas are however not well reflected in the current literature, partly because for some species, there has been considerable resource shrinkage due for example to overfishing. A retrospective analysis of the historical information, in particular the work undertaken by the International Commission for South East Atlantic Fisheries (ICSEAF) is pertinent. In addition the material reviewed also reported on valuable research undertaken on the distribution of fish eggs, larvae and other ichthyoplankton (the SWAPELS project). The purpose of this historical assessment was therefore to review the spawning areas, ichthyplankton drift areas and recruitment grounds from the historical and contemporary literature to support the fisheries EIA (Japp in Midgley 2012).

The review concluded the following:

- Aggregations of spawning horse mackerel and juveniles occur outside the MLA (Crawford *et al.* 1987, O'Toole 1977 and Boyer & Hampton 2001a) (Figure 3 in Section C, Chapter 3.5).
- Sardine spawn off Walvis Bay and further north near Palgrave Point. Only the northern extent of the MLA falls within the southern part of the spawning area (O'Toole 1977, Crawford *et al.* 1987) (Figures 4 – 6 in Section C, Chapter 3.5).
- Historically, spawning and larval distributions of anchovy took place north of Walvis Bay (outside the MLA) (Shannon & Pillar 1986, O'Toole 1977, Boyer & Hampton 2001a) (Figure 5 in Section C, Chapter 3.5).
- Snoek migrate southwards to spawn offshore and in deep waters near St Helena Bay and off the Cape Peninsula in South Africa. The MLA is at the eastern edge of the migration corridor (Boyer & Hampton 2001a, Crawford & de Villiers 1985, Griffiths 2002 and 2003) (Figure 8 in Section C, Chapter 3.5).
- Silver kob spawn very close inshore (<100 m) at Meob Bay and larvae drift northwards to the nursery grounds between Sandwich Harbour and the Ugab River mouth (Kirchner and Voges 1999, Van der Bank and Kirchner 1997, Holtzhausen *et al.* 2001, Kirchner and Holtzhausen 2001).
- A low abundance of hake eggs occurs to the south east of the MLA off Hollams Bird Island. Larvae are found in high abundance from Conception Bay to Palgrave Point in water depths between 100 – 300 m (Figure 9 in Section C, Chapter 3.5). A significant amount of juvenile *M. capensis* (<30 cm) occurs within the MLA (Sundby *et al.* 2001) (Figure 11 in Section C, Chapter 3.5), however according to the biomass estimates calculated by Gaylard (Section C, Chapter 3.2) only 1.6% of the juveniles occur in the MLA.
- According to the historical literature, juvenile monkfish occur within the MLA (Maartens 1999, Maartens and Booth 2005) (Figure 15 in Section C, Chapter 3.5). This is also reflected in the biomass estimates calculated by Gaylard (Chapter C 3.2) which showed that 7% of the monk juveniles could occur in the MLA.
- Goby larvae are in high abundance throughout Namibian coastal waters and in particular in the MLA. They also inhabit the bottom sediments and will be highly disturbed by the proposed dredging activity (Cruickshank *et al.* 1980, Cruickshank 1982 in Melo and Le Clus 2005, Utne-Palm *et al.* 2010) (Figures 18 and 19 in Section C, Chapter 3.5).
- Significant densities of west coast rock lobster occur far inshore and further south of the MLA but may be adversely affected by the sediment plumes (Cockcroft 2001, Pollock 1986). However, after a closer investigation of the extent of the sediment plume it was confirmed that the plume would be a maximum of 1.5 km long from the most southerly point of SP-1 and will not occur in the lobster distribution areas.

© NMP 2014

6 VERIFICATION BIODIVERSITY SURVEY

6.1 BACKGROUND AND OBJECTIVES

As part of the original baseline verification programme of the EIA (Japp in Midgley 2012), it was recommended that a structured biomass survey of the proposed dredging area (in particular the proposed target dredge area SP-1) be undertaken. However, following biomass estimate modelling using demersal survey data by Gaylard (Section C, Chapter 3.2) and a review of the ecosystem models by Cochrane (Section C, Chapter 3.3) as well as the spawning and recruitment statistical data assessment by Ndjaula (Section C, Chapter 3.4), it was recommended that a biodiversity survey (as opposed to a biomass survey) should be undertaken. For reasons previously indicated, research vessels equipped with standardised and calibrated trawl gear were not made available to NMP for a biomass (verification) survey.

The approach adopted therefore, was to focus on non-biomass estimates such as biodiversity, biological information, stock structure, recruitment, oceanographic parameters (measured using a CTD – Section D, Appendix 2.3) as well as epifauna, birds and mammals. The data collected would be used to verify as far as possible information assessed and determinations made in the EIA (Japp in Midgley 2012). The data collected would also be used as a baseline and information base for future surveys and would provide the opportunity to monitor and to track possible changes in the system associated with dredging.

Another criticism of the EIA (Japp in Midgley 2012) was that the NatMIRC data used had few locations within the MLA or areas to be dredged.[4]

It was considered optimal to undertake a biodiversity survey to verify the findings in the EIA (which used a desk-top approach) and to establish a baseline for future reference for biodiversity, fish abundance (density), recruitment (size distribution) and other biological aspects (spawning state of main commercial species etc.) within the actual MLA and SP-1 target dredge site. An industry-owned monkfish trawler, FV *Zeearend,* was used to undertake the biodiversity survey (Section D, Appendix 2.2). Specific objectives for the biodiversity survey were:

- Estimate the abundance (density) of the main commercial species such as hake, monk and horse mackerel;
- Collect biological information (length, sex, maturity stage, stomach content) from the commercial important/exploited species;
- Identify, collect and photograph epifaunal species and at the same time confirm the nature of the substrate and bottom profile;
- Collect environmental data (using visual observations and a CTD) to establish linkages between the environment and species distribution, recruitment and abundance;
- Record/identify the occurrence of surface species: marine mammals and seabirds in the area; and
- Establish a baseline for future monitoring and survey assessments.

[4] This was not considered a matter of significance when the EIA was undertaken. It is standard survey methodology in the marine environment to randomise sample stations and to extrapolate data on the basis of pre-determined assumptions e.g. that fish biomass is uniformly distributed by depth, or habitat type etc.

© NMP 2014

The survey design (Section D, Appendices 2.1, 2.4, 2.5) therefore aimed primarily at quantifying the biodiversity of the area and to compare this with the known information on the region. The survey also obtained commercial data on target catch (monk), hake and the other bycatch species. This allowed for a rough estimate of the abundance of spawning fish and recruitment creating a baseline for future surveys in the area if dredging proceeds.

Figure 3 shows the ML 170, the target dredge area (SP-1), the phosphate resource inside SP-1 (20-year mine plan) as well as the location of 24 sampling stations/trawl lanes of the biodiversity survey. The original locations of the stations were randomly selected such that a broad distribution of the entire SP-1, and just outside SP-1, would be sampled. However, given the conditions of the trawling permit limited the survey to waters deeper than the 200 m, most of the stations on the eastern side of SP-1 had to be randomly relocated westward to deeper water. The survey coordinates in decimal degrees of the start and end positions are given in Annexure 1. Of the 24 stations (each approximately 1.5 nm in length, with 30 minutes standard trawl time) 12 were sampled during the day and 12 during the night. The survey took eight days to complete.

Figure 3/...

© NMP 2014

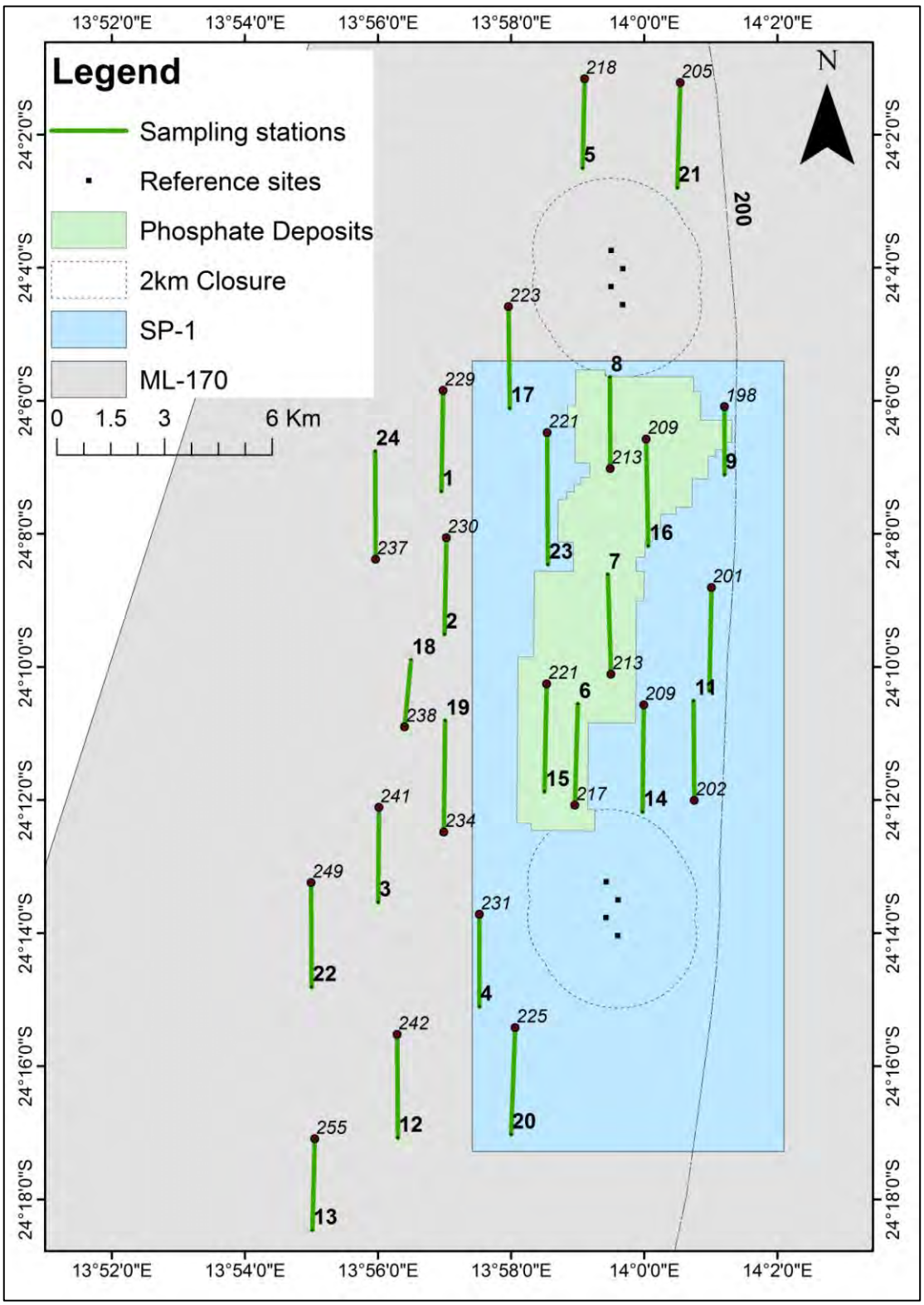


Figure 3: Location of the 24 trawl lanes within ML 170 and SP-1.
The station number (bold numbers) and depths (italic numbers) are also shown. Reference sites refers to the environmental sample sites, which were closed (2km around the sites) to the survey. Note all the stations are deeper than 200m.

6.2 METHODS AND MATERIALS

The survey took place from the 18th – 27th June 2014. A commercial vessel, the FV *Zeearend,* fitted with a double-belly monkfish bottom trawl net with a head length 86 m, footrope 108 m (0.108 km) and vertical net opening 45 m was used to sample 24 stations within, and in close proximity to, the target dredge area SP-1 (Figure 4). The distance between the wings during towing was approximately 40 - 50 m. The trawl was rigged with tickler chains along the footrope. The "Thyborun" trawl doors were 4.2 m square in size, weighing around 800 kg each. The codend mesh size was 120 mm but in order to retain small fish and epifauna, a 20 mm inner liner was integrated into the codend.

Trawl speed was an average of 3 knots, with trawl duration of 30 minutes (this being the time the net was in contact with the seabed). The fishing operation was in a north/south direction and the trawl distance covered at each station was approximately 1.5 nm. The survey took eight days (one day of no sampling, due to adverse weather conditions) to complete all 24 stations. Half the stations were sampled during the day (07h00 – 17h30) and the other half during the night (20h00 – 07h00) hours. Time, location and depth were recorded per station. Processing of the catches was achieved through integrated effort of the scientists and crew[5]. Key components (principally fishes and jellyfish) were extracted first and the remaining material was then transferred to a sorting table where it was rigorously screened for epifauna (McClurg: Section C, Chapter 2.6 and Section D, Appendix 2.2).

The entire catch (or a subsample in the case of large catches) was sorted into species. Monk, hake, and sole were further sorted by sex. The total catch weights (kg) of each species (and sex where applicable) were recorded. Length frequency (total length) data were collected for all commercial species. For non-commercial species such as rat tails, only a sample of the fish were weighed and counted[6]. If the catch was > 1.5 tonnes, the main fish species (hake, monk, sole and horse mackerel) were removed from the catch and the rest was sub-sampled by randomly selecting and measuring approximately 100 kg. Biological sampling of 15 fish per species (individual weight and length measurements, sex, maturity stage, and stomach contents) was done for hake and monk per station.

All invertebrate species retained by the net and landed as part of the catch were identified to the lowest possible taxon, counted and weighed. All large, whole epifauna species retained in the wings of the net were also included in the data counts. Photographs of invertebrates were taken for each trawl to provide an overview and a snapshot image of invertebrates occurring at each station.

[5] There was a team of six scientists and professional staff as well as support from the vessel's crew. Samplers included a specialist on epifauna (benthic), fish, environmental (CTD) and mammals and birds. In addition the team included two NatMiIRC scientists who provided local skills and experience related to Namibian species and conditions.
[6] The sample weight and number were then used to extrapolate a total catch weight and number.

© NMP 2014

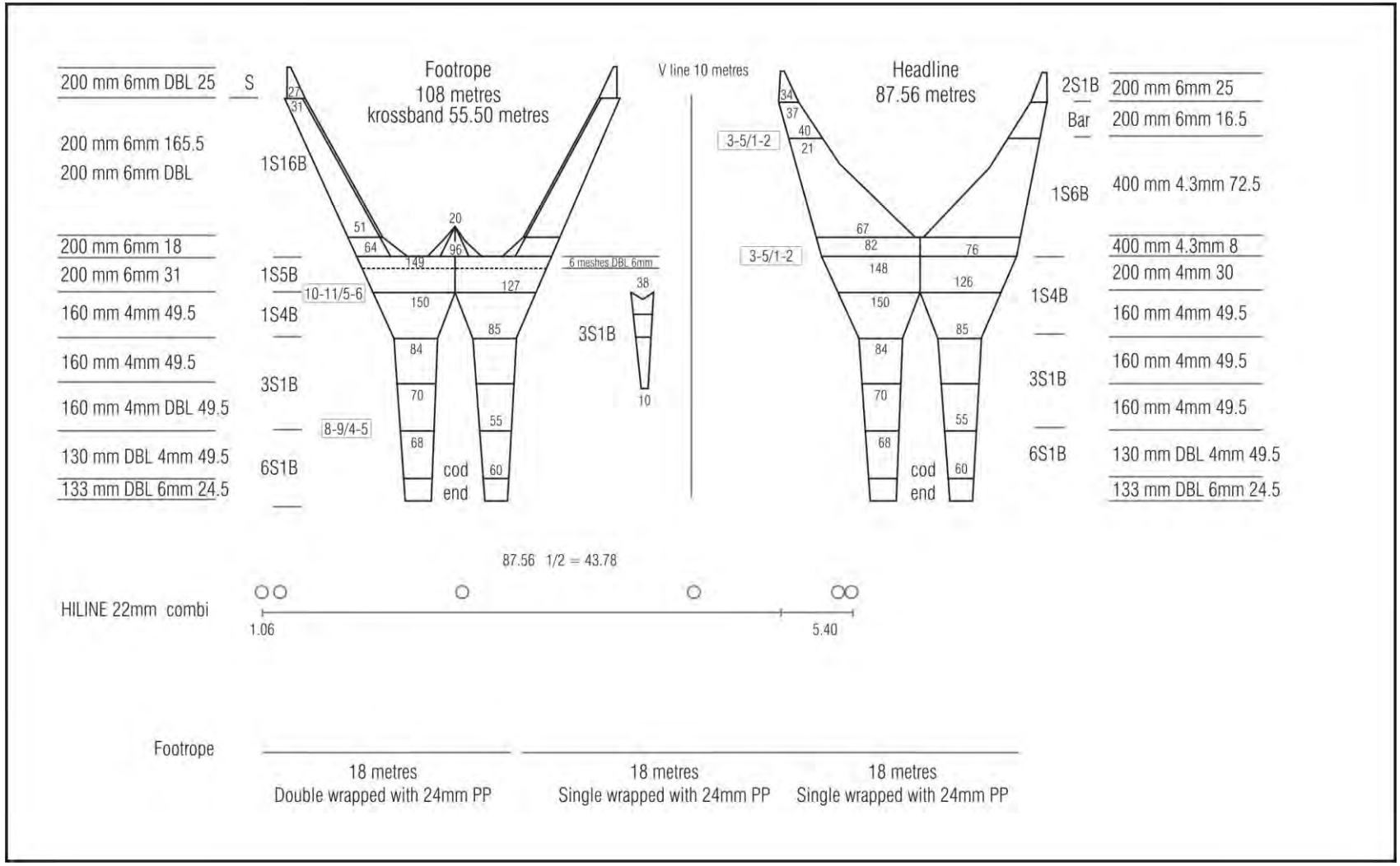


Figure 4: Configuration of the double belly monkfish trawl net fitted on the FV *Zeearend*

Not all the trawls were of exactly 30 minutes duration; therefore the data (weights and numbers) had to be standardized using the following equation:

$$W = \frac{w}{t} * 0.5$$

Where ***W*** is the standardised weight (kg/0.5 hr), ***w*** is the measured weight per species and ***t*** is the duration of the trawl (hours).

Not all the trawls were of exactly 30 minutes duration; therefore the data for number had to be standardized using the following equation:

$$N = \frac{n}{t} * 0.5$$

Where ***N*** is the standardised number (no/0.5hr), ***n*** is the number per species and ***t*** is the duration of the trawl (hours).

Density was calculated for each species per station using the swept area method. The swept area per hour at station, ***SA,*** was calculated by:

$$SA = d * (\frac{b}{t})$$

Where ***d*** is the trawl distance (km), a product of trawl speed and trawl duration multiplied[7] by 1.852 km, ***b*** represents the footrope length (0.108 km); and ***t*** is the duration of the trawl. Species density is assumed to be proportional to the mean catch rate (kg/hour). Thus the density is equal to the catch per area swept at a specific station (kg/SA).

Marine mammal sightings (strategy was taken from the Marine Mammal Observation standard procedures, JNCC 2010) and seabird observations were carried out during the day by visually recording and identifying the number of species within a 500 m radius of the vessel. A sixty minute observation period was initiated from when the net was deployed for i.e. observations were done throughout the setting (15 minutes), trawling (30 min) and hauling periods (15 min) of the trawl.

Hydrological data (salinity, temperature and oxygen) were collected using a multi-probe internal logging Conductivity, Temperature and Depth (CTD) recorder, which was encased inside a stainless steel protective frame and specially designed net bag, and attached to the head rope of the trawl net, using shackles and cable ties (Section D, Appendix 2.3). At the start of the trawl environmental data such as air pressure, wind direction, wind speed (Beaufort scale), cloud cover and sea surface colour were also recorded using the electronic equipment on the bridge and visual observations.

Substrate and/or sediment type was also recorded from visual observations of retained material on the trawl doors and foot rope; this provided an indication of the habitat type.

[7] 1.852 is the conversion from nautical miles to kilometres

6.3 RESULTS

Data were recorded on hard copies as well as entered electronically in a project specific Access database. Graphs, tables and spatial maps were created using Excel and ArcView GIS.

A summary of the entire catch weight (kg) and number of species standardized to 30 minutes per station is presented in Table 2. A total of 28 tonnes was caught with an average of 1.2 tonnes per station. Generally, catch weight was higher during day trawls than night trawls (Figure 5). Station number 11 was dominated by red jellyfish (*Chrysaora fulgida*) with 11 tonnes caught while the net descended and therefore does not show a true reflection of the catch composition for that station[8]. Station 13 had the lowest catch (246 kg) whereas Station 11 had the highest. Ascidians (*Molgula sp*) where found in 21 out of the 24 stations but were particularly abundant at Station 20 with 1.1 tonnes. A full breakdown of species weight (kg) and number per station can be found in the cruise report (Section D, Appendix 2.2).

A total of 48 species of fish (including jellyfish), epifauna, seabirds and mammals were identified during the survey, of which 17 were made up of fish and 14 the epifauna species, 15 were seabirds and 2 were marine mammals (Table 3). In terms of total numbers the epifauna comprised 131 423 specimens and the fish 38 421. This figure excludes red jellyfish (*Chrysaora fulgida*) which were not counted. The epifauna clearly dominated in terms of number of individuals caught. The total overall biomass value for the epifauna was 5 587 kg vs. 23 124 kg for the fish/pelagic component. This, includes red jellyfish, of which one trawl alone yielded 11 860 kg.

The spatial distribution by weight and number of taxa (i.e. fish and epifauna species counts), showing a biodiversity index, per station is presented in Figure 6. Station 7 had the highest number of species (21) whereas Station 8 had the lowest (16). Both of these stations were within the 20-year phosphate resource target dredge area and both stations had low to medium size catches (<900 kg). Analysis of the data does not show any differences in species weights or counts between the target dredge area, SP-1 and surrounding areas.

[8] Jellyfish were caught while the net was descending, this was confirmed from the echo sounder which showed a jellyfish layer in the midwater during the setting period. Further there were very few fish caught in the net because the jellyfish were already present when the net hit the sea floor (at the start of the fishing period).

© NMP 2014

Table 2: Standardised weight (kg) and number of species caught in 30 minutes per station. Catch rate (CPUE) per hour is also shown. D = Day: N = Night trawls

Trawl Number	Date Start	Fishing Time Start	Weight (kg) Standardised 30 mins	Number Standardised 30 mins	CPUE (kg/hr)	Density (kg/swept area)
N1	18-Jun-14	18:05	576	8415	1152	960
D2	20-Jun-14	07:35	433	5049	867	869
D3	20-Jun-14	12:35	675	6287	1351	1125
D4	20-Jun-14	16:12	751	44953	1502	1377
D5	24-Jun-14	15:05	1261	15752	2522	2102
D6	21-Jun-14	07:13	1348	10736	2695	2171
D7	21-Jun-14	11:56	578	14450	1155	1412
D8	21-Jun-14	16:00	762	9189	1524	1270
D9	22-Jun-14	07:05	724	4253	1447	1206
D10	22-Jun-14	10:22	1358	4734	2716	2263
D11	22-Jun-14	13:45	11849	3430	23699	19747
D12	22-Jun-14	17:00	907	5739	1814	1512
N13	25-Jun-14	00:55	247	3795	494	453
N14	24-Jun-14	21:55	367	4895	734	612
N15	23-Jun-14	19:00	706	10034	1412	1177
N16	23-Jun-14	22:20	491	7707	982	819
D17	23-Jun-14	12:55	791	7214	1583	1319
N18	26-Jun-14	00:55	407	7002	813	610
N19	25-Jun-14	21:55	523	7404	1047	872
N20	25-Jun-14	17:40	1362	20592	2724	2270
N21	24-Jun-14	18:55	373	5052	747	622
N22	26-Jun-14	18:52	625	7135	1249	1041
N23	24-Jun-14	01:35	587	8616	1174	978
N24	26-Jun-14	22:15	375	4835	751	625
TOTAL			**28048.86**	**150658**		**47411.04**
AVERAGE			**1169.88**	**9470**	**2340**	**1975.46**

© NMP 2014

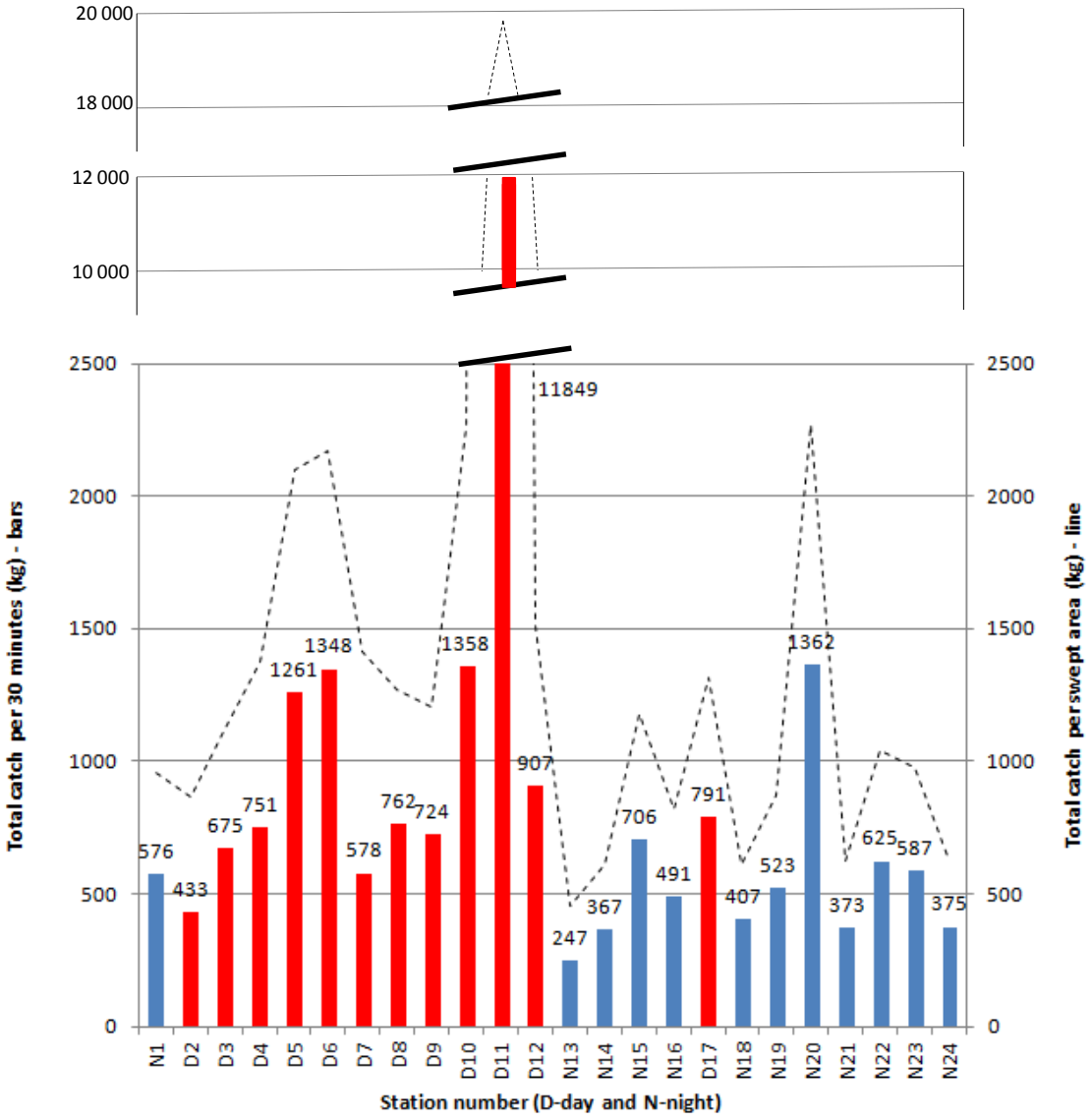


Figure 5: Total catch weight (kg) per 30 minute trawl (bar graph) and total catch per swept area (line graph) per station. The day (grey bars) and night time (black bars) trawls have also been presented.

Table 3: Number (and where applicable weight) for all the species identified and recorded during the biodiversity survey.

No	Common name	Genus	Species	Weight (kg)	Number
FISH AND PELAGIC COMPONENT					
1	Angelfish	*Brama*	*brama*	3.06	2
2	Bonefish (long fin)	*Pterothrissus*	*belloci*	3.23	17
3	Capensis	*Merluccius*	*capensis*	1920.89	13791.95
4	Goby (pelagic)	*Sufflogobius*	*bibarbatus*	56.20	6564
5	Gurnard Capensis	*Chelidonichthys*	*capensis*	0.60	2
6	Jacopever	*Helicolenus*	*dactylopterus*	54.42	928
7	Jelly fish (purple)	*Chrysaora*	*africana*	0.05	1
8	Jelly fish (red)	*Chrysaora*	*fulgida*	17722.98	0
9	Jelly fish (white)	*Aequorea*	*forskalea*	405.24	1959
10	Maasbanker	*Trachurus*	*trachurus*	21.42	143
11	Mackerel	*Scomber*	*japonicus*	8.38	4
12	Monk	*Lophius*	*vomerinus*	1703.56	3565.76
13	Rat Tail Short Nose Rough	*Coelorinchus*	*simorhynchus*	672.48	9530
14	Shark (bluntnose sixgill)	*Hexanchus*	*griseus*	2.79	2
15	Squid (Angola flying)	*Todarodes*	*angolensis*	174.29	1058
16	Squid (flying)	*Toderopsis*	*sagittatus*	0.05	1
17	West Coast sole	*Austroglossus*	*microlepis*	157.26	316.85
EPIFAUNA COMPONENT					
18	Hermit crab	*Parapaguridae*	*sp*	4.81	7
19	Mantis shrimp	*Squilla*	*sp*	19.64	853
20	Prawn	*Funchalia*	*woodwardi*	0.06	6
21	Prawn (Solenocera)	*Solenocera*	*africana*	0.22	70
22	Sea cucumber (white)	*Pseudocnus*	*thandari*	0.20	43
23	Sea pen	*Verellidae*	*sp*	28.37	76612
24	Sea squirts	*Molgula*	*sp*	4616.91	108813
25	Sponge (brown)	*Porifera*	*sp*	376.63	1334
26	Starfish (long armed)	*Astropecten*	*sp*	0.03	5
27	Starfish (short armed)	*Odontaster*	*australis*	0.05	15
28	Swimming crab	*Bathynectus*	*piperitus*	113.36	2613
29	Whelk (dog)	*Nassarius*	*wolfii*	0.01	7
30	Whelk (sponge)	*Faciolariidae (plus sponge)*	*sp*	2.82	25
31	Whelk (tulip)	*Fasciolariidae*	*lugubra*	7.23	188
SEABIRD COMPONENT					
32	Sub Antarctic skua	*Catharacta*	*antarctica*	-	436
33	Kelp gull	*Larus*	*dominicanus*	-	1
34	Tern	*Sternidae*		-	1
35	Cape Gannet	*Morus*	*capensis*	-	13
36	Cape cormorant	*Phalacrocorax*	*capensis*	-	1
37	Storm petrel	*Hydrobatidae*		-	75
38	Albatross	*Diomedeidae*			33
39	Shy albatross	*Thalassarche*	*cauta*	-	160
40	Black browed albatross	*Thalassarche*	*melanophrys*	-	253

© NMP 2014

No	Common name	Genus	Species	Weight (kg)	Number
41	Yellow nosed albatross	*Thalassarche*	*chlororhynchos/carteri*	-	9
42	Pintado petrel	*Daption*	*capense*	-	19
43	Petrel	*Hydrobatidae*		-	10
44	White chinned petrel	*Procellaria*	*aequinoctialis*	-	999
45	Shearwater	*Puffinus*		-	8
46	Sooty shearwater	*Puffinus*	*griseus*	-	104
MARINE MAMMAL COMPONENT					
47	Cape fur seal	*Arctocephalus*	*pusillus pusillus*	-	73
48	Dusky dolphin	*Lagenorhynchus*	*obscurus*	-	250

Figure 6/...

© NMP 2014

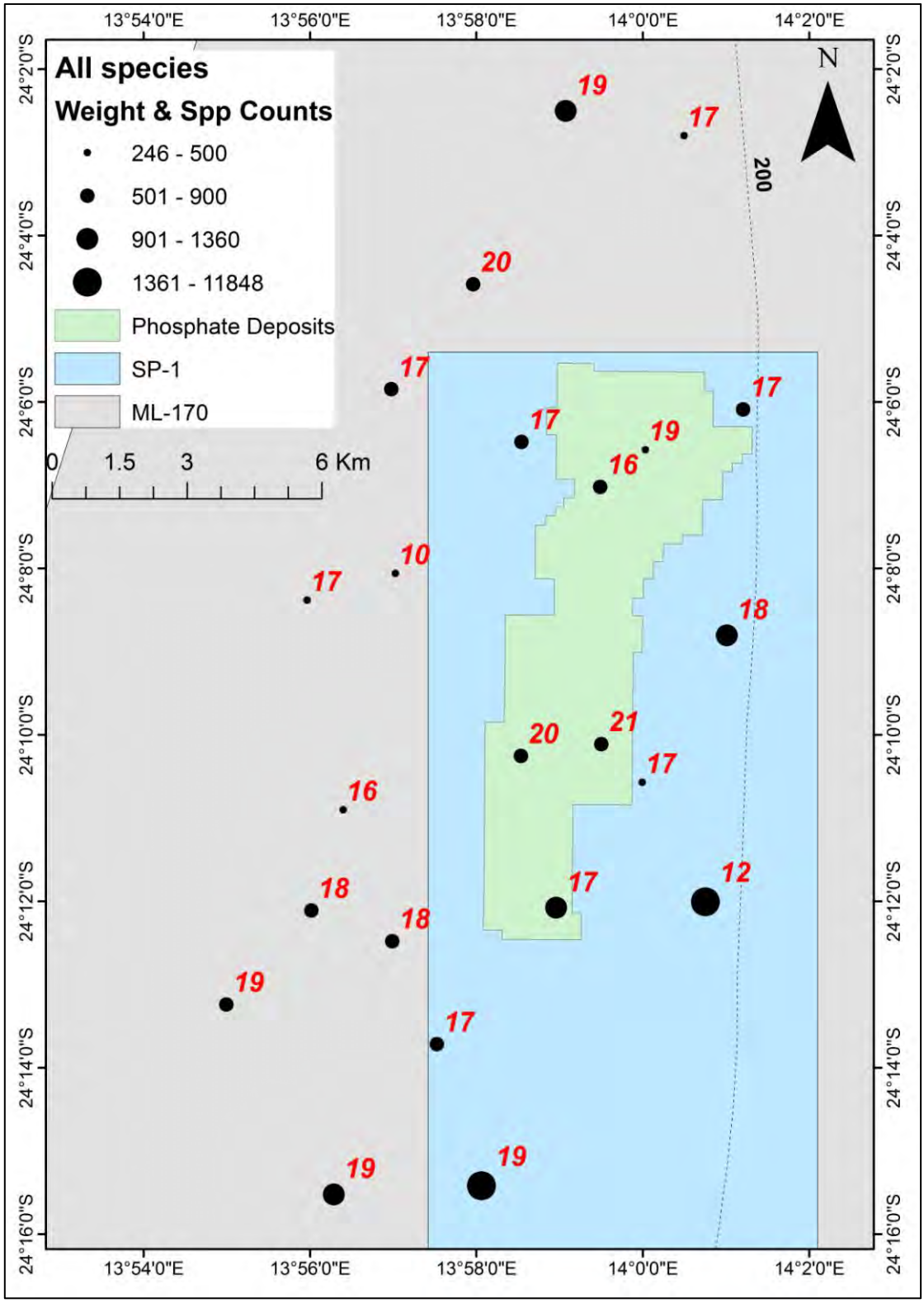


Figure 6: Spatial distribution of all species by weight (kg/0.5min) per station
Note. The large numbers (red) refer to the number/counts of taxa (i.e. diversity) caught per station.

© NMP 2014

6.3.1 Fish

A total of 14 fish species, including two squid species (*Todarodes angolensis* and *Todaropsis sagittatus*) and one shark species (*Hexanchus griseus*), was identified and measured during the survey (Table 4). Note that in order to show a clear representation of the fish species composition, Epifaun (6.3.2) have been removed and a separate analysis below.

The shallow water hake (*Merluccius capensis*) dominated catches, amounting to 40% by weight of the total fish catch, followed by monk (*Lophius vomerinus*), 35%, rattail (*Coelorinchus simorhynchus*) 14%, sole (*Austroglossus microlepis*) 3% and goby (*Sufflogobius bibarbatus*) 2%. Horse mackerel (*Trachurus capensis*) 0.4% of the total fish catch. Figure 7 shows the weight of the fish component per day and night time stations. The number of fish taxa per station is also presented.

Table 4: Proportion of the total fish, shark and squid species. Jellyfish are in a separate table.

No	Common name	Scientific name	Weight (Std)	Number (Std)	Weight proportion
1	Angelfish	*Brama brama*	3.06	2	0.0006
2	Bonefish (long fin)	*Pterothrissus belloci*	3.23	17	0.0007
3	Capensis	*Merluccius capensis*	1920.89	13792	0.4020
4	Goby (pelagic)	*Sufflogobius bibarbatus*	56.20	6564	0.0118
5	Gurnard capensis	*Chelidonichthys capensis*	0.60	2	0.0001
6	Jacopever	*Helicolenus dactylopterus*	54.42	928	0.0114
7	Maasbanker	*Trachurus trachurus*	21.42	143	0.0045
8	Mackerel	*Scomber japonicus*	8.38	4	0.0018
9	Monk	*Lophius vomerinus*	1703.56	3566	0.3565
10	Rattail short nose rough	*Coelorinchus simorhynchus*	672.48	9530	0.1407
11	Shark (bluntnose sixgill)	*Hexanchus griseus*	2.79	2	0.0006
12	Squid (angola flying)	*Todarodes angolensis*	174.29	1058	0.0365
13	Squid (flying)	*Toderopsis sagittatus*	0.05	1	0.0000
14	West coast sole	*Austroglossus microlepis*	157.26	317	0.0329
		TOTAL	**4779**	**35925**	**1.0000**

The proportion of hake, monk, sole and horse mackerel by weight per station is presented in Figure 8. Hake and monk were found in all the trawls whereas sole were found in 22 trawls. Hake were more abundant during the daylight trawls while monk and sole were more abundant during night trawls. Horse mackerel were found in five of the trawls, which were all daylight trawls and located along the eastern edge of the survey area i.e. inshore and in shallower water (less than 205 m). There is not much variation in catches of the main commercial species across the entire survey i.e. no difference in the proportion of fish caught inside the target dredging area (SP-1) when compared to the surrounding areas.

© NMP 2014

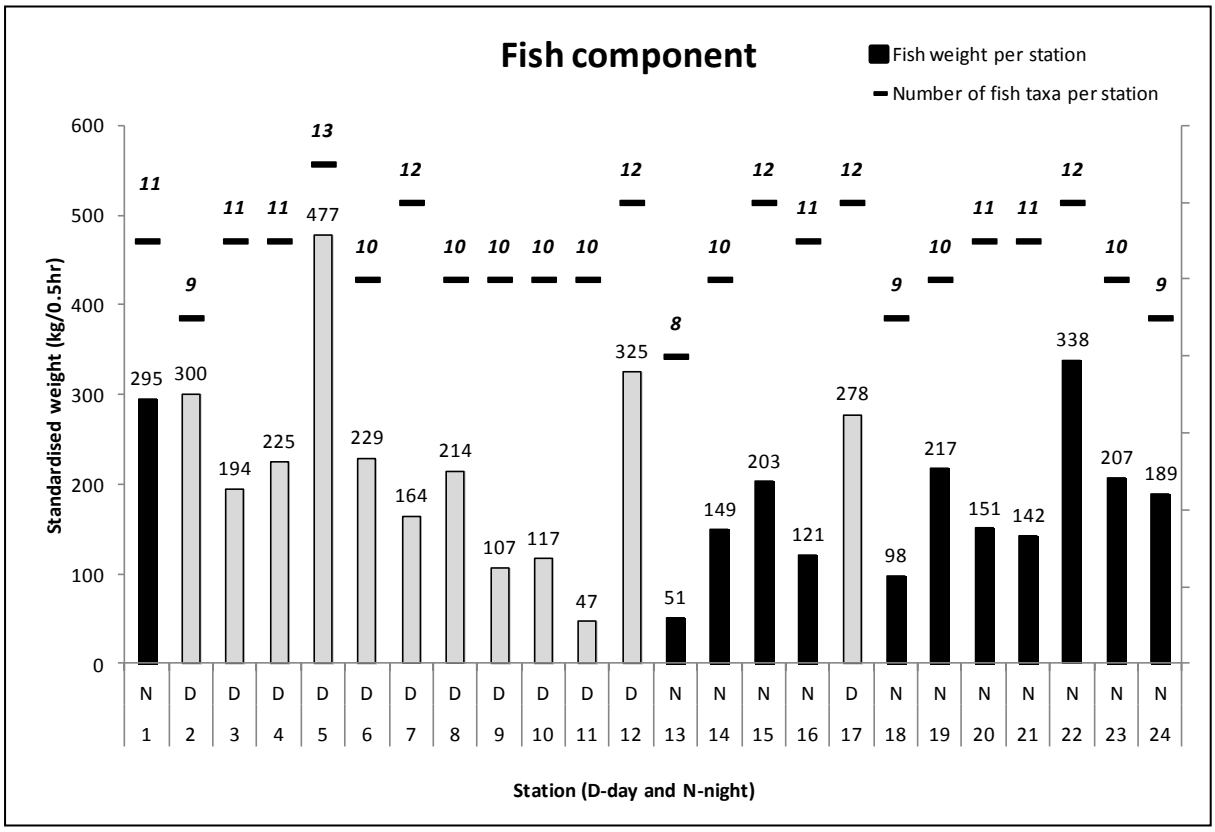


Figure 7: The weight of the fish per day (grey) and night (black) station.
The number of fish taxa per station has also been presented.

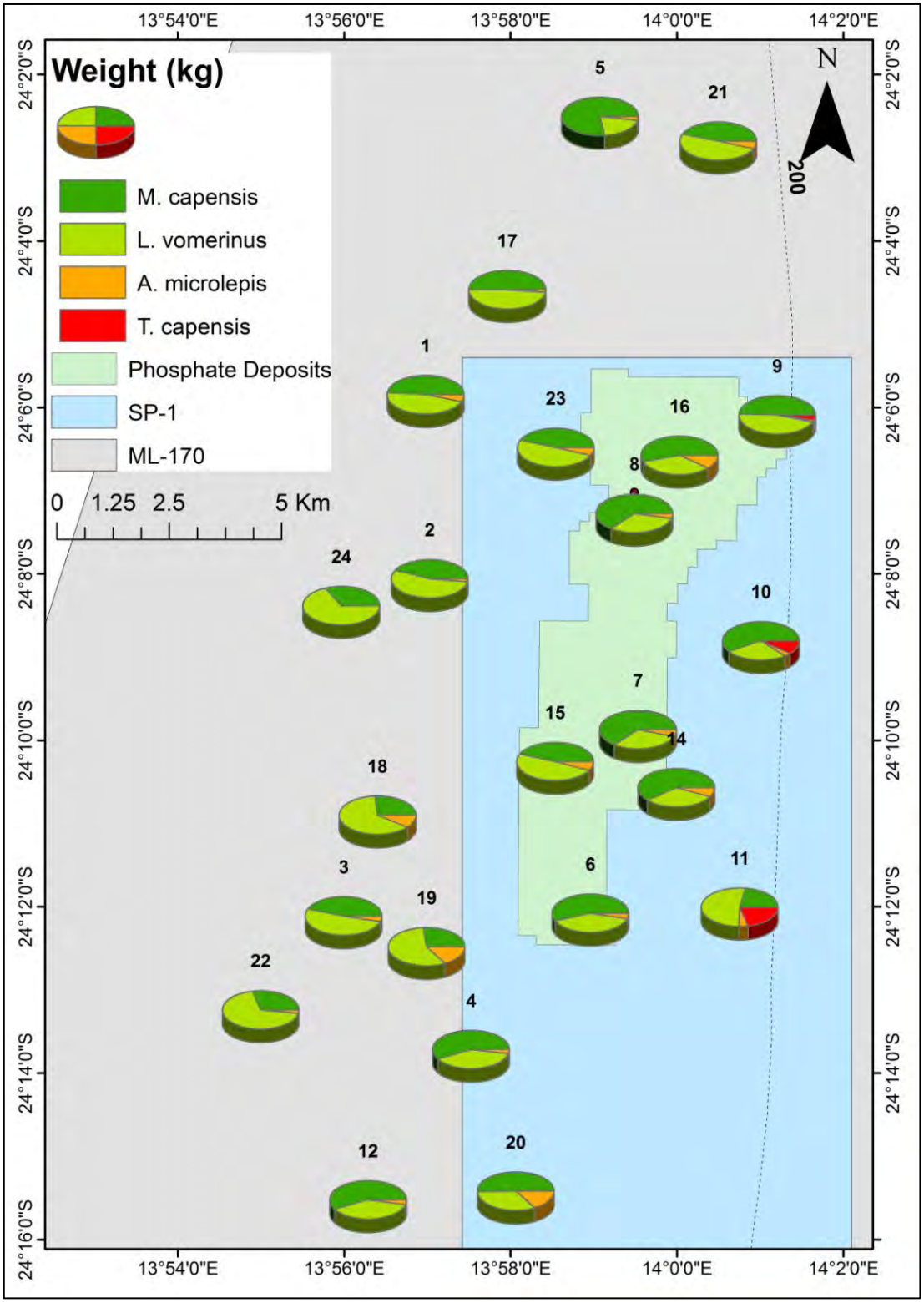


Figure 8: Proportion of fish by weight at each station. Species include hake (*M. capensis*), monk (*L. vomerinus*), sole *(A. microlepis*) and horse mackerel *(T. capensis*) per station.

Goby (*Sufflogobius bibarbatus*) were found at all the stations. Slightly fewer goby on average (2 kg) were caught during the day trawls than during the night (3 kg) Figure 9. This was a surprising result as the goby were expected to rise up the water column at night and therefore would have been unavailable to the bottom trawl gear. An average of 2.3 kg of goby amounting to an average of 273 individuals was caught per station. Station 18 had the highest number of gobies and Station 11 had the lowest (Figure 10).

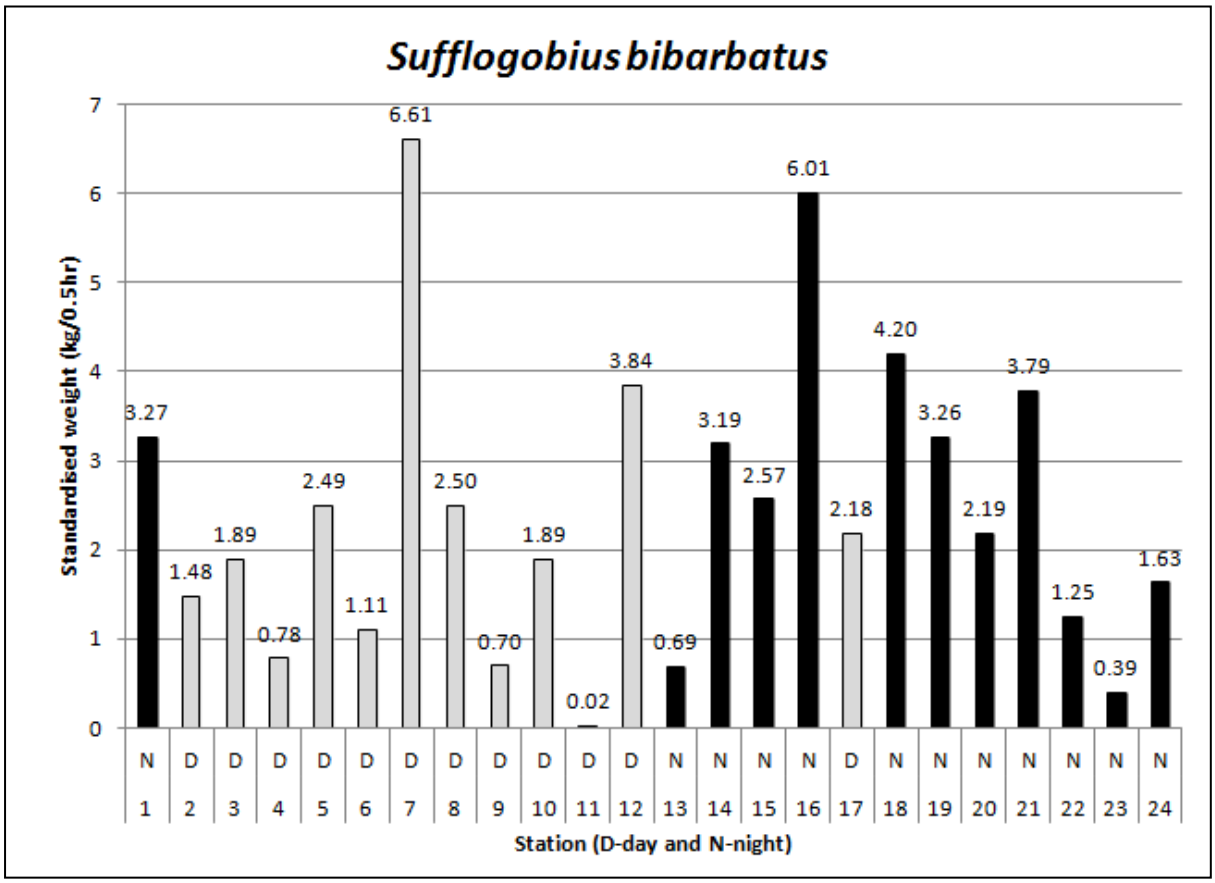


Figure 9: Goby weight (kg) per day (D) and night (N) station.

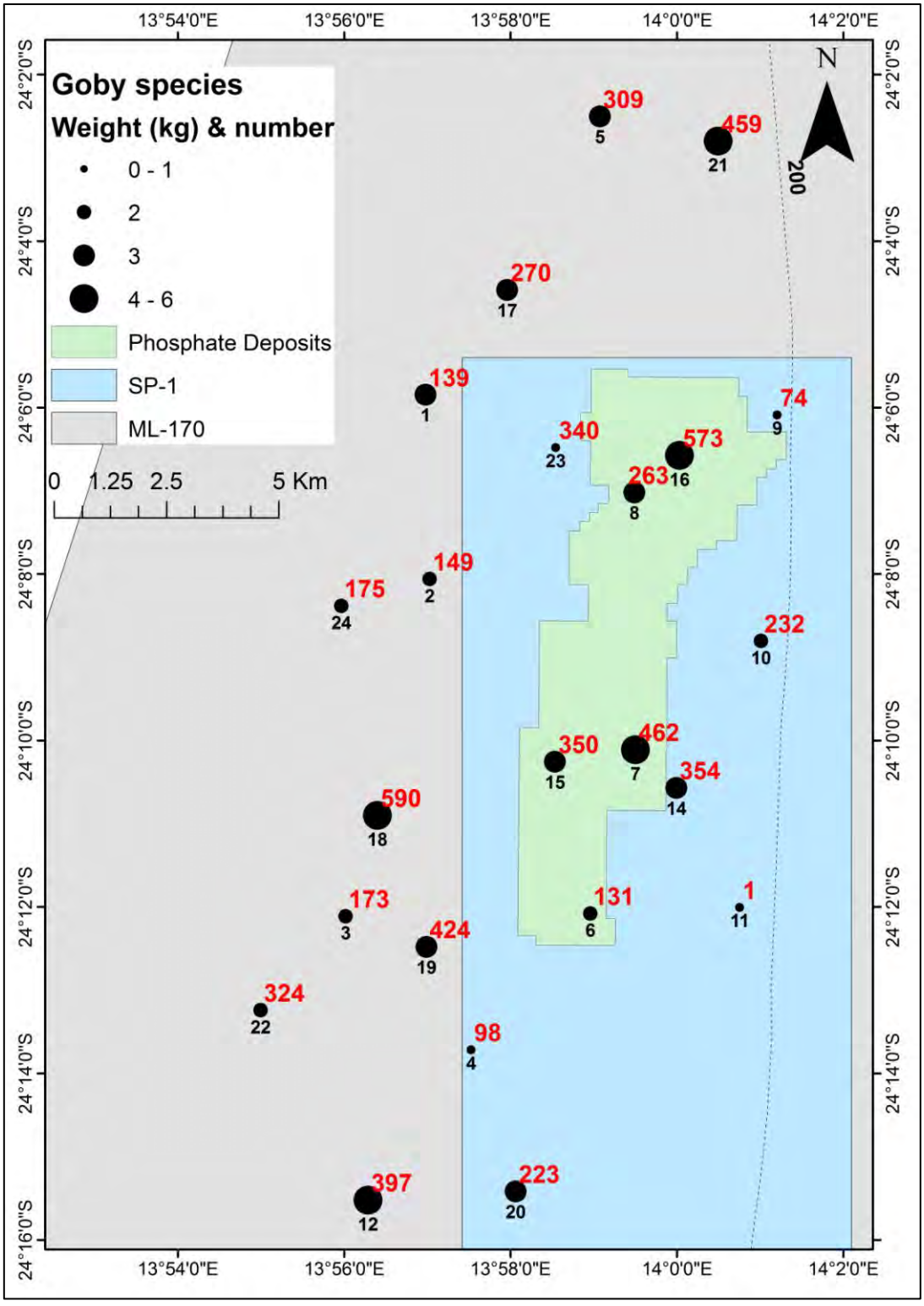


Figure 10: Spatial distribution of goby (*Sufflogobius bibarbatus*) by weight (kg) and number (red label) per station.

Fish length frequency

Length frequency distributions for monk, hake, sole, horse mackerel, squid and jacopever are presented in Figures 11 – 16. Sample size (n) and mean length per species are also shown. Adult hake and monk were split by sex during the survey whereas monk juveniles, sole and horse mackerel were recorded as combined sexes.

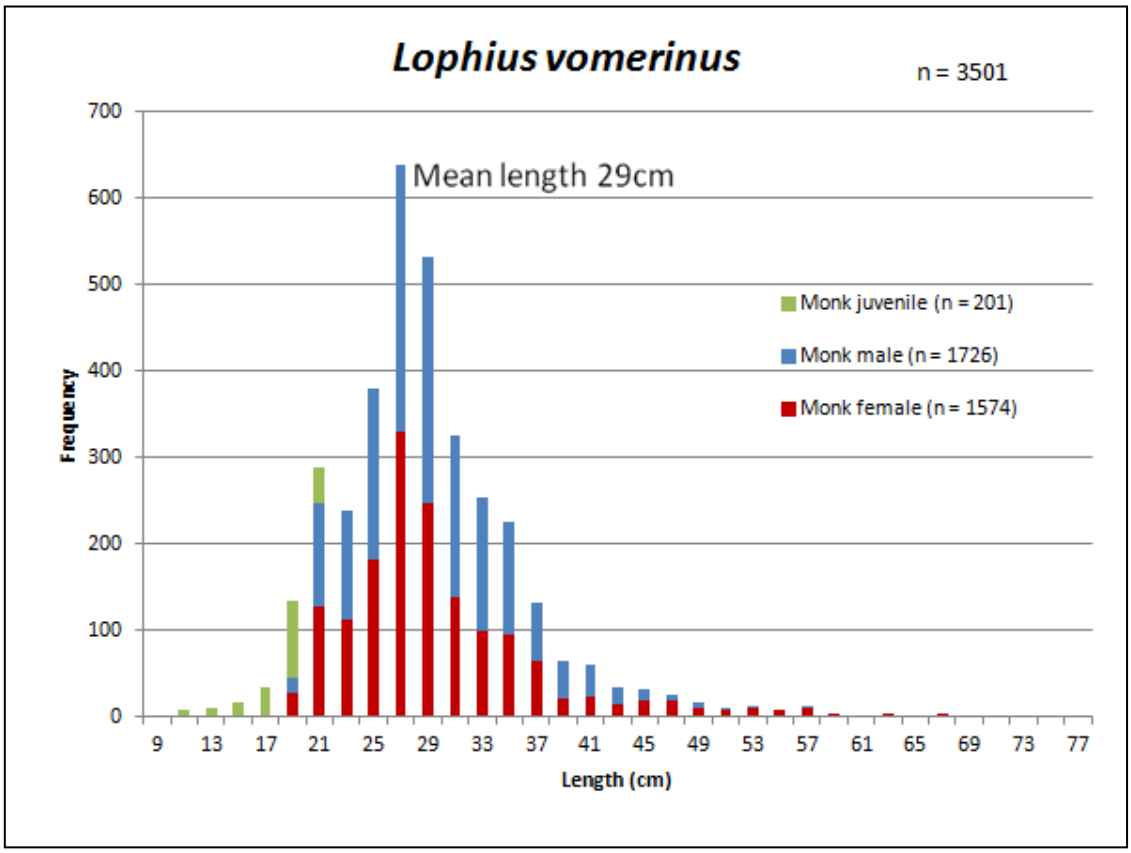


Figure 11: Length frequency distribution for monk.
[split by male (blue), female (red) and juveniles (green)]

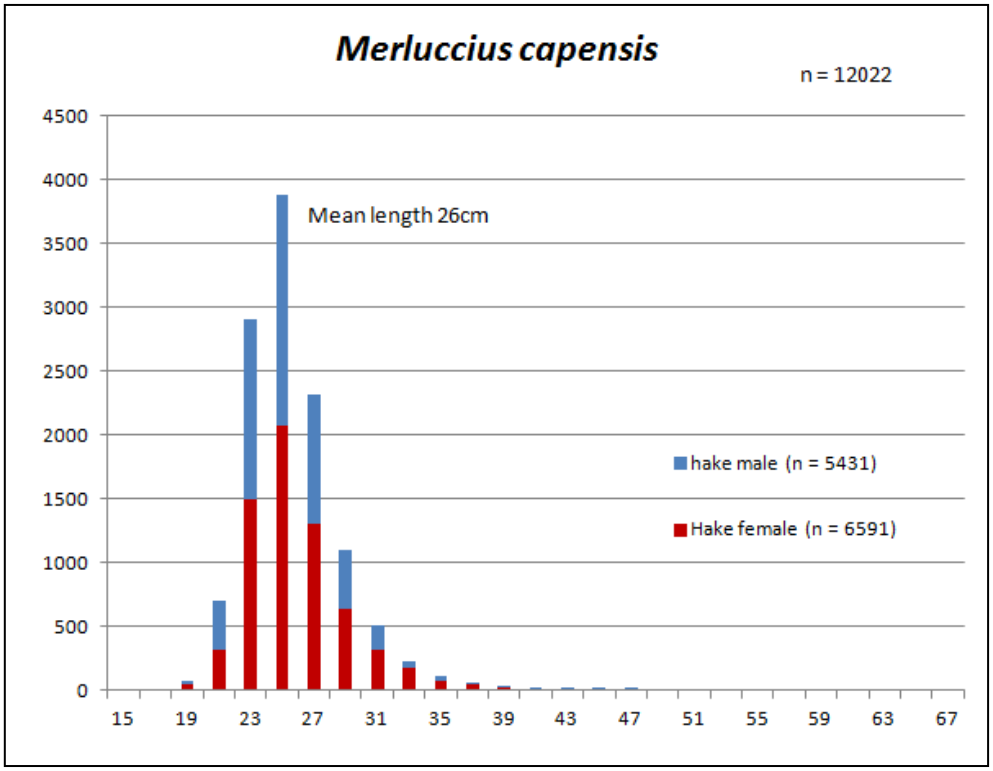


Figure 12: Length frequency distribution of hake, split by male (blue) and female (red).

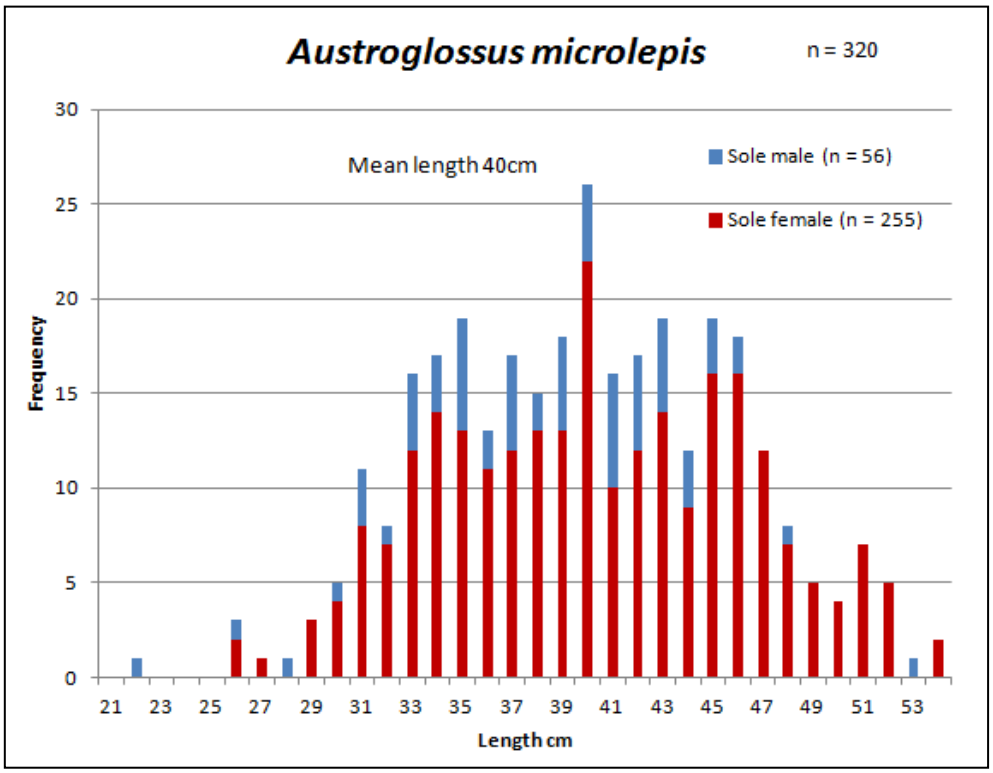


Figure 13: Length frequency of sole, split by male (blue) and female (red).

© NMP 2014

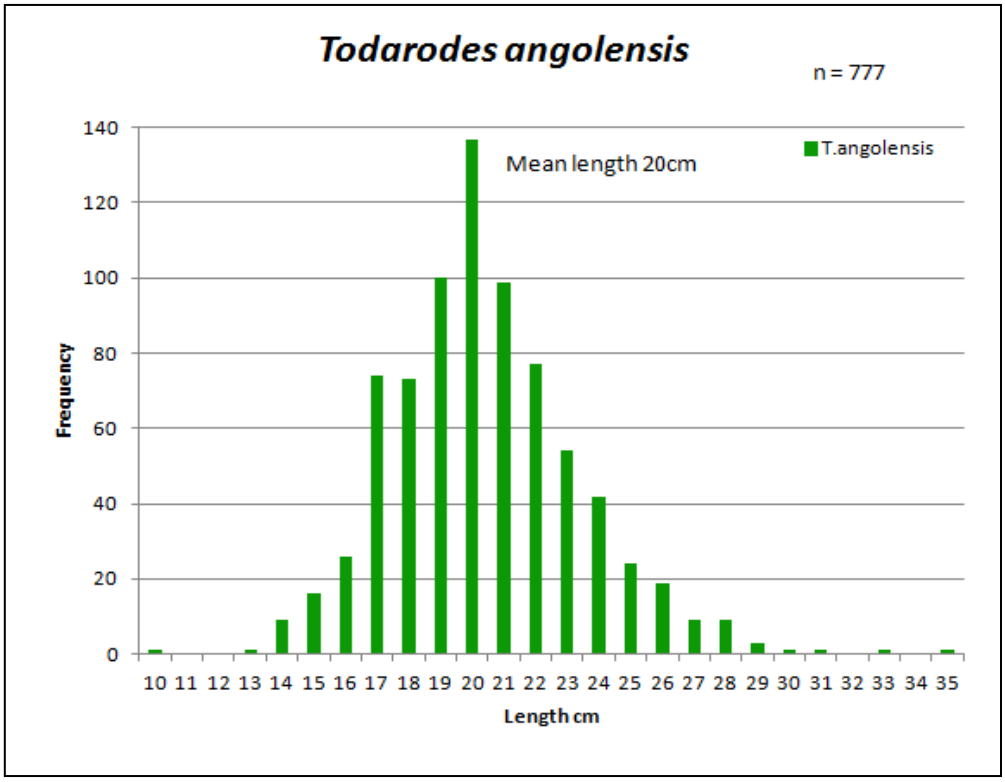


Figure 14: Length frequency of Angola flying squid, (both male and female combined).

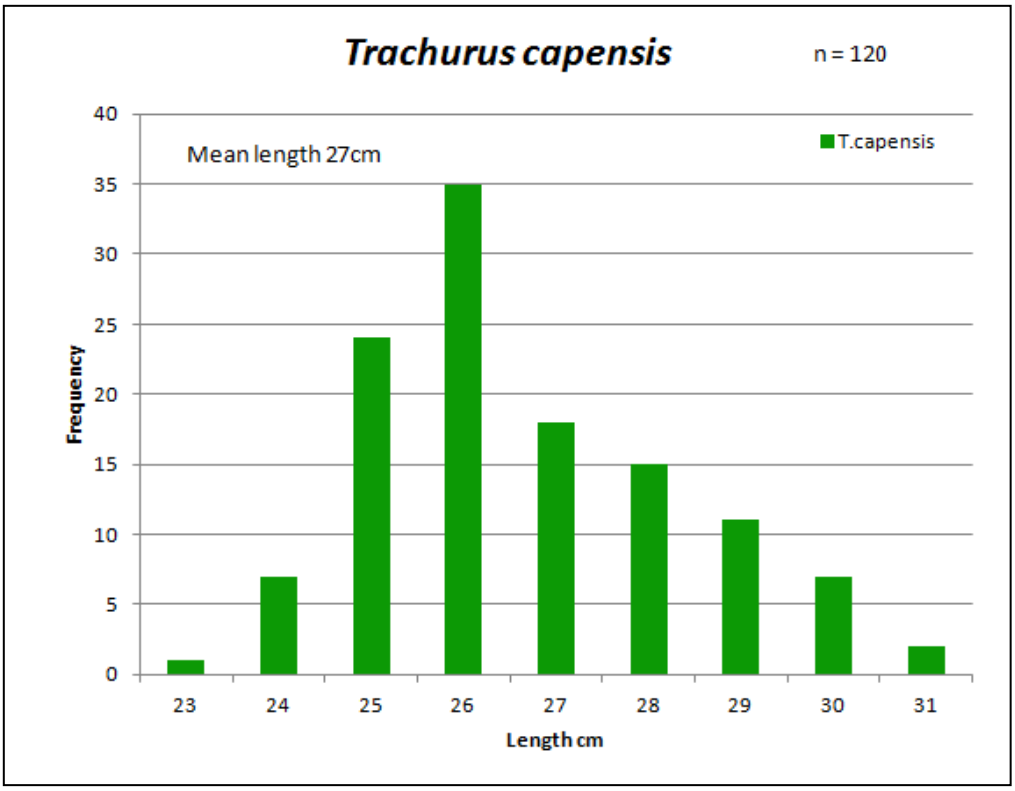


Figure 15: Length frequency of horse mackerel, (both male and female combined).

© NMP 2014

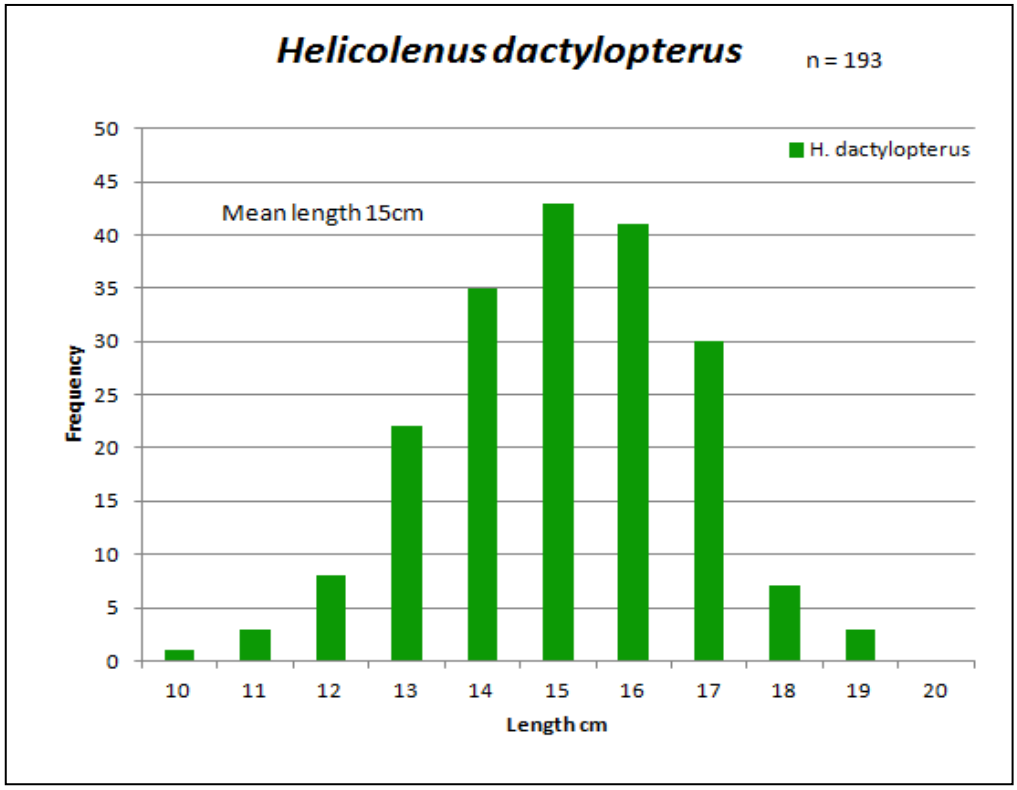


Figure 16: Length frequency of jacopever (both male and female combined).

Fish maturity

Maturity stages (1 – 5) and weight-per-stage was recorded for both monk and hake. Staging methods were adopted from Botha (1986) and are described in Table 5. Approximately 12 000 fish were staged, of which few Stage 4 (*spawning stage*) fish were recorded for both species. Almost 60% of the female monk was identified as stage 1 (*immature*) whereas only 1% of the female hake were immature. There were no stage 5 (*spent*) monk males recorded during the survey and the majority of the hake were stage 2 (*active*). The percentage maturity stage per length class for monk and hake are represented in Figures 17 – 20. Both male and female monk data suggested length at maturation from 32 cm and for hake from 22 cm.

According to scientific literature *M. capensis* spawn off central Namibia (25°S to 20°S), although the exact location varies between years (Assorov and Berenbeim 1983 cited in Sundby *et al*. 2001, Olivar *et al*. 1988, Sundby *et al*. 2001). It has also been suggested that *M. capensis* are serial spawners with females spawning numerous times a year (Osborne *et al.* 1999). Spawning appears to occur year round with peak spawning periods in occurring from mid-July to mid-September (Roux pers comm.). During this time *M. capensis* appear to move to waters <200m to spawn (Gordoa *et al*. 2006). Similarly, monk also spawns throughout the year with a peak spawning period in late winter and summer (Maartens and Booth 2005).

© NMP 2014

Table 5: Number of samples per maturity stage for hake and monk males and females.

Maturity stage	Number of samples (n)							
	L. vomerinus				*M. capensis*			
	Female	Female proportion	Male	Male proportion	Female	Female proportion	Male	Male proportion
Stage 1 – *Immature*	935	0.59	536	0.31	478	0.10	40	0.01
Stage 2 – *Active*	559	0.36	944	0.55	3542	0.74	1892	0.48
Stage 3 - *Ripe*	43	0.03	237	0.14	379	0.08	1353	0.35
Stage 4 – *Ripe/Hydrated*	26	0.02	9	0.01	12	0.00	356	0.09
Stage 5 – *Spent*	11	0.01	0	0.00	385	0.08	275	0.07
TOTAL	**1574**	**1**	**1726**	**1**	**4796**	**1**	**3916**	**1**

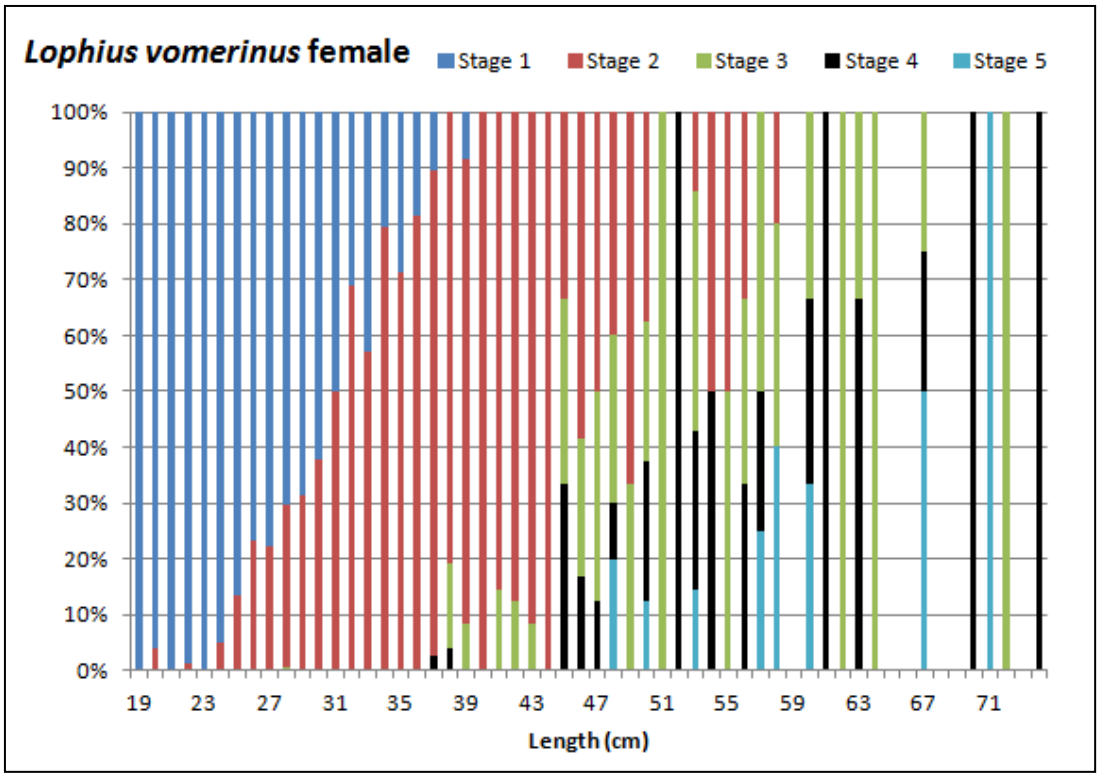


Figure 17: The percentage maturity stage against length (cm) for monk females.

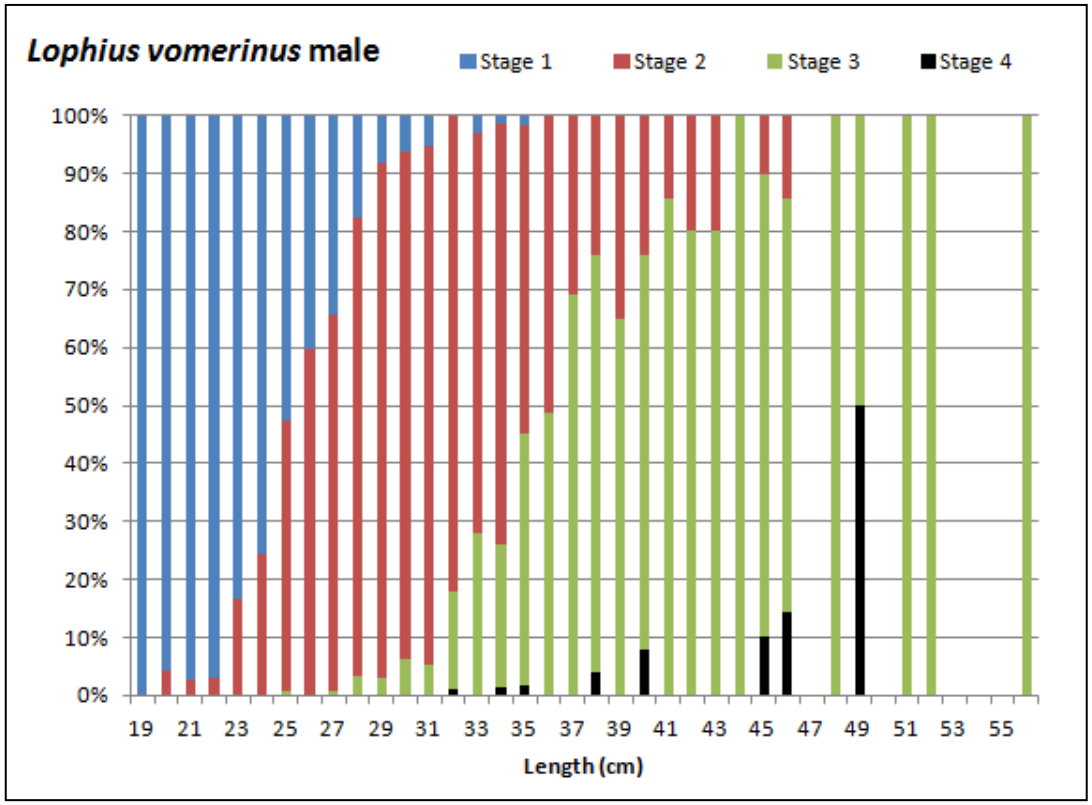


Figure 18: The percentage maturity stage against length (cm) for monk males.

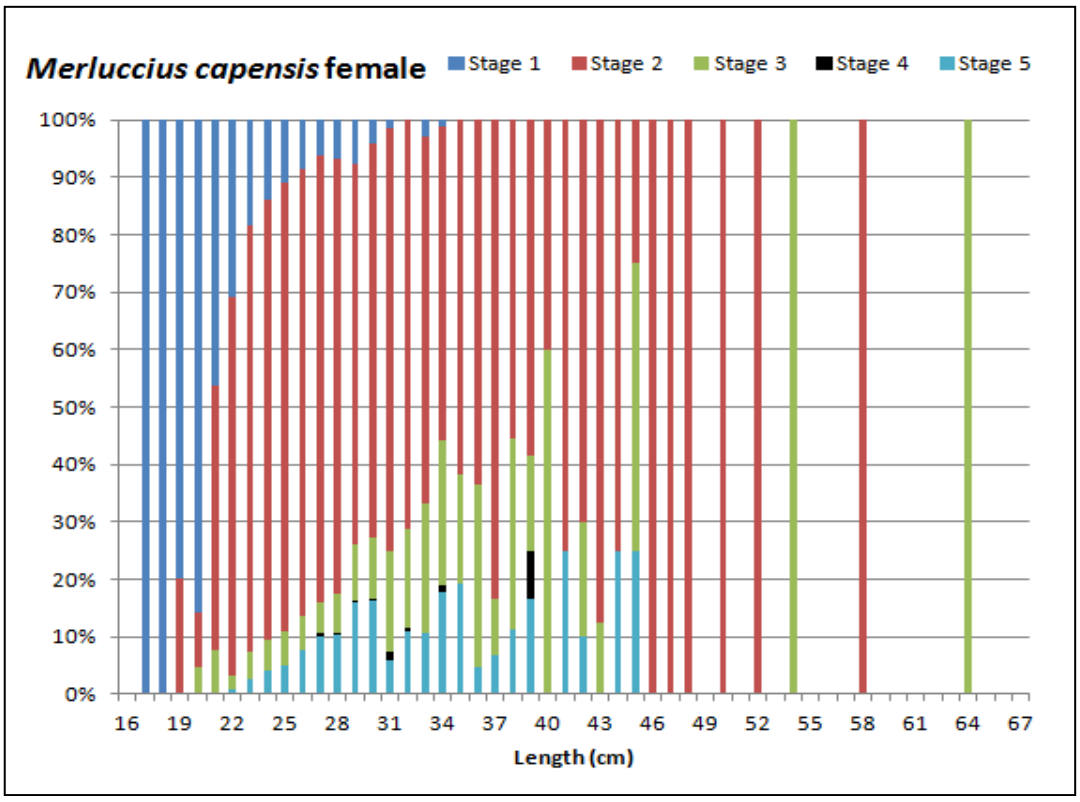


Figure 19: The percentage maturity stage against length (cm) for hake females.

© NMP 2014

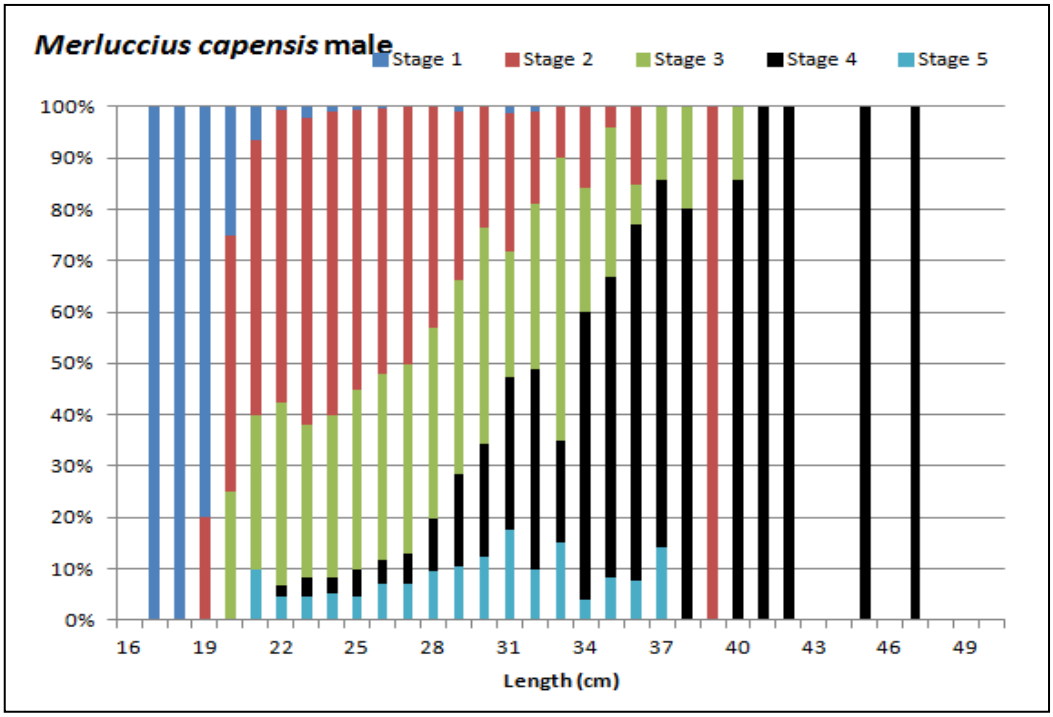


Figure 20: The percentage maturity stage against length (cm) for hake males.

Stomach contents

Monk and hake (approximately 15 individuals per species per station) were dissected for stomach content analysis (Figures 21 and 22). Prey items (number and length) were measured as well as stomach state, stomach fullness and digestion state. For monk most of the prey items were juvenile hake followed by goby. Ascidians were found undigested in the stomach of the monk suggesting that the ascidians were eaten accidently while the monk was in the net. For hake the majority of the prey items were euphausiids (krill) and goby.

© NMP 2014

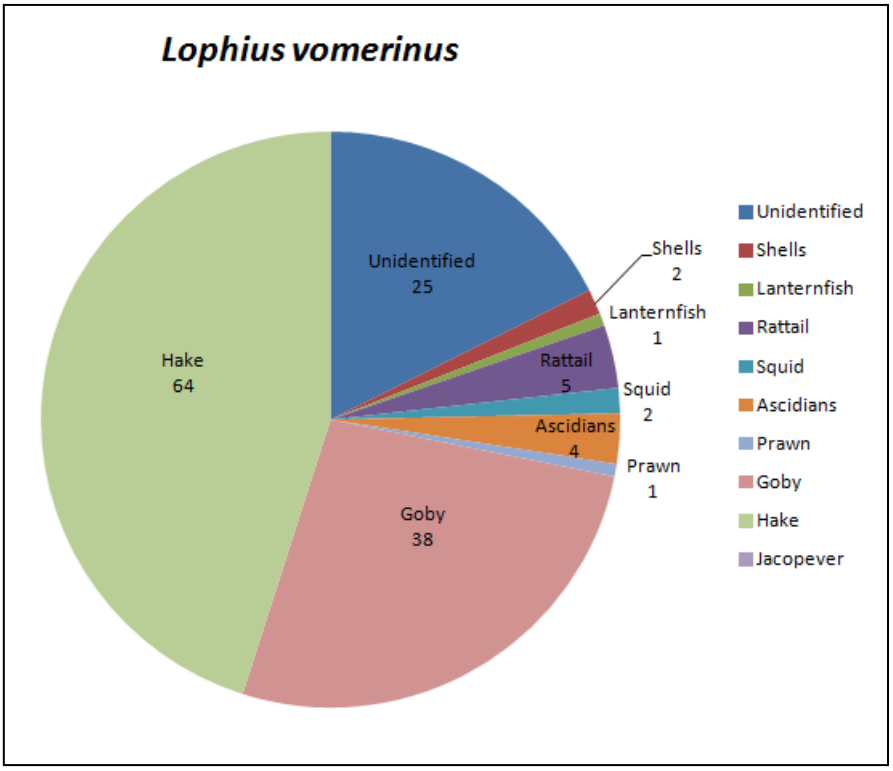


Figure 21: Number of prey items found in 337 monk individuals.

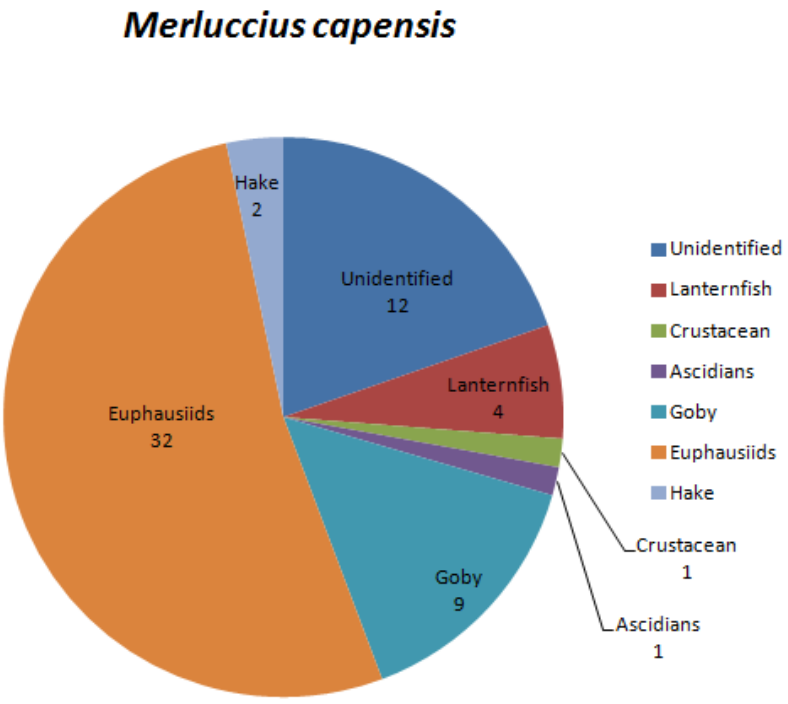


Figure 22: Number of prey items for 324 hake individuals.

6.3.2 Epifauna

The epifauan were assesed by McClurg, and reported in more detail in Section C, Chapter 2.6. The benthic environment within SP-1, where dredging is scheduled to commence, has been a particular area of focus. Studies there have included two detailed surveys of benthic fauna (Steffani 2010; Section C, Chapter 2.5). Project reviewers have expressed concern that these surveys, which were based on traditional grab sampling, were not fully comprehensive, in that the larger organisms inhabiting the sea bed (epifauna) were not adequately sampled. Epifaunal organisms tend to be larger, more mobile and occur in lower densities than their infaunal counterparts and may accordingly be missed in grab-based surveys. Partly in response to this criticism an additional survey, which focussed on epifauna, was performed in June 2014. This study formed part of a wider trawling survey aimed at further elucidating the biodiversity and fishery potential of the proposed dredging area and environs. Epifauna (sometimes referred to as megafauna) includes the larger, and typically more mobile, organisms that dwell on the sediment surface. It was determined that trawling, using the technical skills of local trawler-men, was the most appropriate route for the collection of the epifauna of this region. This epifauna survey could then be linked logistically to a broader biodiversity and fishery survey which comprises part of the verification programme.

The identities and weight of the epifauna organisms collected during the survey are listed in Tables 6 and 7. Ascidians are considerably the most dominant species of the epifauna component thus in order to show a clearer representation of the other epifauna species. ascidians, jellyfish and brown sponges data have been removed from Table 6 and a separate analysis is presented Table 7.

Table 6: Species and proportions of epifauna identified during the survey, with the exceptions of ascidians and brown sponges.

No	Common name	Scientific name	Weight (Std)	Number (Std)	Weight proportion
1	Hermit crab	*Parapaguridae* sp.	4.81	7	0.0272
2	Mantis shrimp	*Squilla* sp.	19.64	853	0.1111
3	Prawn	*Funchalia woodwardi*	0.06	6	0.0003
4	Prawn (Solenocera)	*Solenocera africana*	0.22	70	0.0012
5	Sea cucumber (white)	*Pseudocnus thandari*	0.20	43	0.0011
6	Sea pen	*Verellidae sp*	28.37	76612	0.1605
7	Starfish (long armed)	*Astropecten* sp.	0.03	5	0.0002
8	Starfish (short armed)	*Odontaster australis*	0.05	15	0.0003
9	Swimming crab	*Bathynectus piperitus*	113.36	2613	0.6412
10	Whelk (dog)	*Nassarius wolfii*	0.01	7	0.0001
11	Whelk (sponge)	*Faciolariidae (plus sponge)*sp.	2.82	25	0.0159
12	Whelk (tulip)	*Fasciolariidae lugubra*	7.23	188	0.0409
		TOTAL	**176.80**	**80442.07**	**1.0000**

© NMP 2014

Table 7: Relative proportions of jellyfish, ascidians and sponges

No	Common name	Scientific name	Weight (Std)	Number (Std)	Weight proportion
1	Jellyfish (purple)	*Chrysaora africana*	0.05	1	0.0000
2	Jellyfish (red)	*Chrysaora fulgida*	17722.98	0	0.7665
3	Jellyfish (white)	*Aequorea forskalea*	405.24	1959	0.0175
4	Sea squirts	*Molgula* sp.	4616.91	108813	0.1997
5	Sponge (brown)	*Porifera* sp.	376.63	1334	0.0163
		TOTAL	**23122**	**112106**	**1**

The results are presented for both counts and weights using the non-standardised results. In numerical terms the Ascidiacean sea squirt (*Molgula* sp.) was, by far, the most prolific, having contributed 60% of the total catch. This was followed by the Pennatulid sea pen (family Veretellidae) at 37%. The remaining 12 taxa were relatively insignificant and comprised only 3% of the total catch.

In terms of contributions to the total weight, *Molgula* sp. was again the highest contributor at 85% followed by Porifera (sponge) and then sea pens (Veretellidae) at 5%.The remaining taxa were again relatively insignificant in their weight contributions. A summary description of each epifaunal taxon encountered in the survey is given below.

Ascidiacea (sea squirts or ascidian tunicates). A single species (*Molgula* sp.) was encountered at 21 of the 24 stations, often in large numbers. Ascidians are widespread and common, they have several life forms which include solitary anchored individuals, and compound colonies. Ascidians are filter feeders and assumed to play an important role in nutrient recycling. Their tough leathery exterior "tunic" may render them unattractive to many potential predators. There was, incidentally, no evidence of digested *Molgula* sp. remains in any of the fish stomach contents that were examined in this survey. Discussions with Mr Malakia Shimhanda (on-board technician from NatMIRC) revealed that *Molgula* sp. is widely known in Namibian fishing areas. However, he remarked that, in 25 years at sea, he had never seen them recovered in such large numbers. It is likely that the reduced mesh size (20 mm), that was used to line the cod end in this survey, played a significant role in boosting catches of *Molgula* sp.

Pennatulacea (sea pens, Family Veretellidae, Phylum Cnidaria). The Cnidaria (which includes jellyfish, anemones and hydroids) comprises a diverse, abundant and widely distributed group of marine organisms (Branch *et al.,* 2010). Only one member of this group was encountered in the epifauna survey, namely a sea-pen which was assigned to the family Veretellidae. Sea pens have a fleshy body covered with polyps and a soft unbranched peduncle that anchors the colony in mud or sand. The specimens recovered in this survey were generally small (2 to 3 cm) so would not be expected to be readily caught in the trawl. Interestingly, none was encountered in the cod-ends while relatively high numbers were consistently retained in the net wings. Veretellidae were also recorded in the benthic faunal surveys (Steffani, 2010; Section C, Chapter 2.5).

Porifera (sponges). Sponges are simple, primitive, and somewhat characterless organisms. As a result, they have been very poorly described. One unidentifiable species was recovered at 20 of the 24 stations in numbers ranging between 1 and 285.

© NMP 2014

Gastropoda (whelks). Whelks are commonly recovered in bottom trawls. They are active predators or scavengers. Eight specimens of *Nassarius wolffi* (dog whelk) were recovered at station 13. Somewhat more common was the "tulip whelk" (*Fasciolaria lugubris*) which was found at 16 of the 24 stations, in numbers ranging between 1 and 98.

Crustacea. Crustacea are usually common in bottom trawls, This survey yielded six species, two of which are widespread and relatively abundant. A swimming crab (*Bathynectes piperitus*) was present at all stations in numbers ranging between 31 and 212. Mantis shrimp (*Pterygosquilla armata capensis*) was absent only from station 11 and was recorded in numbers ranging between 2 and 124. The remaining four crustacean species were present in relatively small numbers and at only a few stations. Two specimens of mud prawn (*Callianassa australis*) were recovered at station 8. It was also recorded in the SP-1 area by Steffani (2010). Eight specimens of unidentified hermit crabs (Paguridae) were recovered at station 13, while three specimens of the prawn *Funchalia woodwardi* were present at station 12. Finally, the prawn *Solenocera africana* had a slightly higher presence with recoveries at four stations in numbers ranging between 3 and 32. It is evident that, apart from the swimming crabs and mantis shrimps, crustacean numbers in the study area were exceedingly sparse.

Echinodermata. Echinoderms are usually well represented in bottom trawls, globally, with urchins and starfish being particularly prominent. In the SP-1 study area they were virtually non-existent. The total recovery for 24 trawls was 20 starfish (Asteroidea) and 43 sea cucumbers (Holothuroidea). The starfish were divided between two taxa, namely an unidentified species of *Astropecten* and *Odontaster australis*. The sea cucumber was identified as *Pseudocnus thandari* (Moodley, 2008; Thandar *et al*., 2010).

Jellyfish, sponge and ascidians. Three species of jellyfish (*Chrysaora fulgida, Aequorea forskalea* and *Chrysaora africana*) were identified during the survey. The abundance of *C. fulgida* in particular was the highest for all stations; this was removed from the catch, weighed and discarded, before sorting the remainder of the catch.

Comparisons with other trawling surveys

Drawing direct and valid comparisons between epifaunal catches in disparate bottom trawling surveys is fraught with difficulties. There have been no similar surveys on the central Namibian continental shelf. However, in recent years there has been renewed interest in the benthic ecology of the southern Benguela Current region, driven by a need to evaluate the impacts of trawling (Atkinson, 2009; Atkinson *et al.,* 2011). These studies have focussed on the deeper waters (roughly 350 to 450 metres) between Cape Point and southern Namibia. While there are significant differences in location and depth between the two studies, a broad comparison would appear to be justified, both studies were based on 24 trawls so they may be directly compared.

Atkinson *et al.* (2011) recorded a total of 81 epifaunal taxa in their study, which is far in excess of the 14 recorded in this study. Echinoderms and crustaceans were particularly well represented in their samples, whereas they are very poorly represented here. The epifauna in the SP-1 area would thus appear to be highly impoverished, particularly in terms of crustaceans and echinoderms.

Environmental Drivers

Apart from station 11, where a massive catch of jellyfish was made, and counts of other organisms were suppressed, there was notable uniformity in the epifauna across the study area. This is in line with a geophysical survey (Ludick, Section D, Appendix 3.2) which confirmed that sediment type and sedimentary conditions were also uniform. Other factors which might be considered to influence the

© NMP 2014

epifauna include water depth, salinity and oxygen concentration. The depth range was 198 to 255 metres, which would seem to be sufficiently narrow to be of little consequence. Salinities and oxygen concentrations were continuously monitored during trawling through a CTD that was attached to the tow line. The detailed results are presented in an accompanying report (Section D, Appendix 2.3). The salinity and temperature readings were within expected ranges and indicated the presence of South Atlantic Central Water (SACW) in the study area for most of the survey. However, dissolved oxygen concentrations were in many instances significantly depressed towards the sea-bed. The link between impoverished crustacean and echinoderm communities amongst the epifauna and oxygen depletion seems obvious. Periodic hypoxia may not be problematic for mobile organisms that are capable of avoiding low oxygen conditions. However it may impose severe limitations on those that lack this ability or are not physiologically pre-adapted to a low oxygen environment. The presence of high numbers of sea squirts (*Molgula* sp.) and sea pens (Veretellidae) suggests that they are able to tolerate occasional hypoxia and maintain significant populations. On the other hand, portunid crabs (*Bathynectes piperitus*) and mantis shrimps (*Pterygosquilla armata capensis*), which were the only other taxa present in significant numbers, are strong swimmers and presumably capable of avoiding hypoxic conditions. Most of the remaining taxa, notably the gastropods, echinoderms, the sponge, the mud prawn and the hermit crab, have relatively limited mobility and would thus be vulnerable to the negative effects of oxygen depletion.

Concluding remarks

While there was a significant presence of epifaunal organisms in the SP-1 area, there was low diversity. This may be ascribed to the chronic effects of periodic hypoxia on the less mobile and more vulnerable taxa. The fauna was numerically dominated by ascidians (sea squirts) and pennatulids (sea pens), which are presumably capable of tolerating periodic hypoxia. Relatively high numbers of portunid crabs and mantis shrimps were also observed. These are strong swimmers and thus capable of circumventing periodic hypoxic events. The information gained in this survey may serve as a baseline for future impact monitoring. Of particular interest, in this survey, was the widespread abundance of ascidians (*Molgula* sp.).

6.3.3 Seabirds

A total of 15 species of seabirds was recorded during the survey (Table 8). Of these, 45% were White-chinned Petrels (*Procellaria aequinoctialis*), 20% Sub-Antarctic Skua (*Catharacta antarctica*), 12% Black-browed Albatross (*Thalassarche melanophrys*) with the remaining species making up 23%. Not all the birds were identified to their species level.

Spatial distribution of seabird numbers per station is presented in Figure 23. Station 6 and 17 had the highest number of birds but Station 9 had the highest bird species counts. Seabird observations were only carried out during daylight trawls.

© NMP 2014

Table 8: List of seabird sightings during the survey

No	Common name	Scientific name	Adult	Juvenile	Unidentified	Total	Proportion
1	Sub Antarctic skua	*Catharacta antarctica*	436			436	0.20
2	Kelp gull	*Larus dominicanus*		1		1	0.00
3	Tern	*Sternidae*			1	1	0.00
4	Cape Gannet	*Morus capensis*	12	1		13	0.01
5	Cape cormorant	*Phalacrocorax capensis*	1			1	0.00
6	Storm petrel	*Hydrobatidae*	18		57	75	0.03
7	Albatross	*Diomedeidae*			33	33	0.02
8	Shy albatross	*Thalassarche cauta*	135	25		160	0.07
9	Black browed albatross	*Thalassarche melanophrys*	235	18		253	0.12
10	Yellow nosed albatross	*Thalassarche chlororhynchos/carteri*	8		1	9	0.00
11	Pintado petrel	*Daption capense*	2		17	19	0.01
12	Petrel	*Hydrobatidae*			10	10	0.00
13	White chinned petrel	*Procellaria aequinoctialis*	12		987	999	0.45
14	Shearwater	*Puffinus* spp.			8	8	0.00
15	Sooty shearwater	*Puffinus griseus*	2		102	104	0.05
					TOTAL	**2196**	**1.00**

© NMP 2014

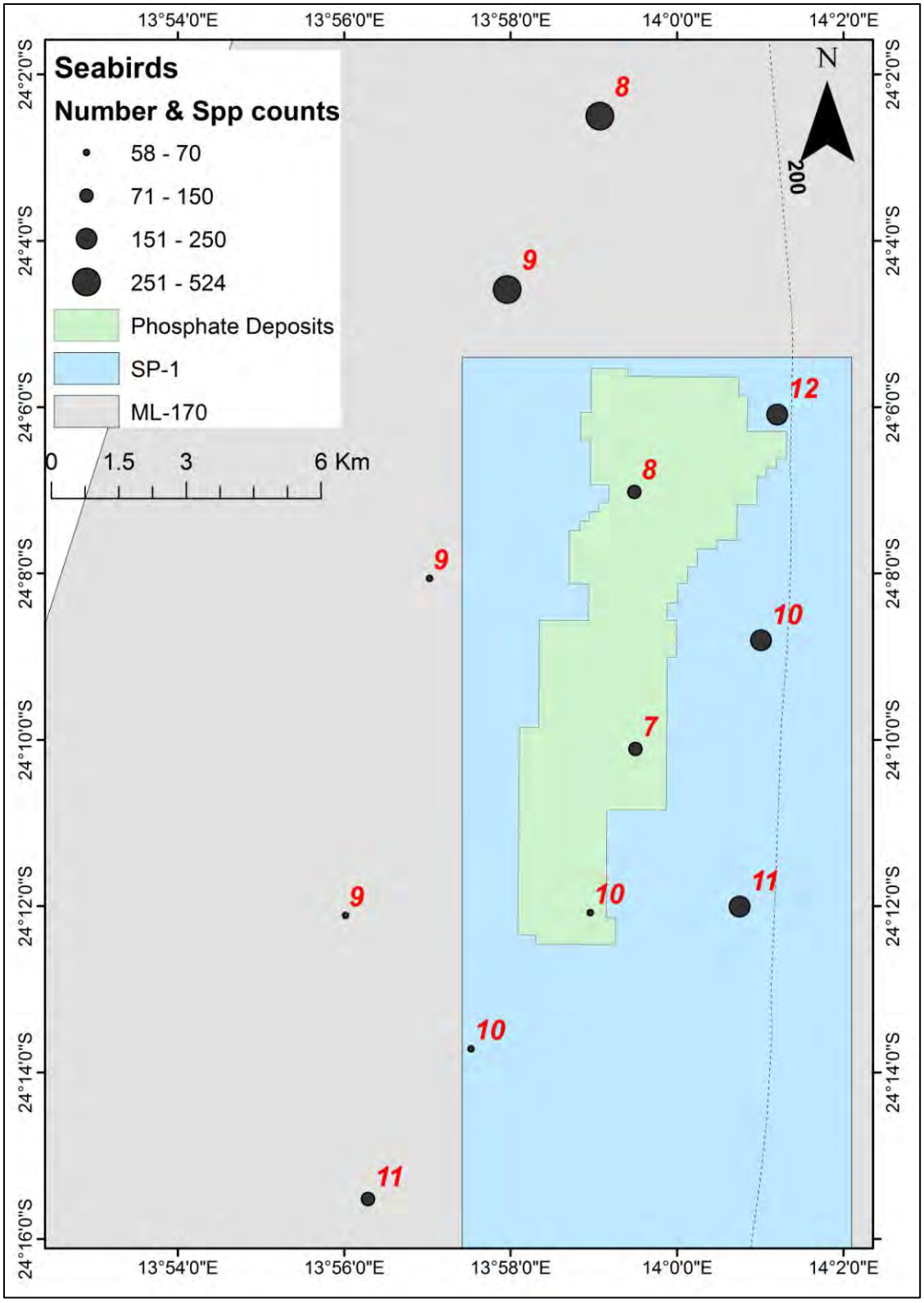


Figure 23: Spatial distribution of seabird number and species counts (red labels) per station.

6.3.4 Marine mammals

Two species of marine mammals were identified during the survey, namely the cape fur seal (*Arctocephalus pusillus pusillus)* and the dusky dolphin (*Lagenorhynchus obscurus)* (Table 9). Marine mammal observations were only carried out during daylight trawls. Seals were present at all stations and the dusky dolphin was observed at Station 7 and 9, where 100 and 150 individual dolphins were recorded, respectively.

The spatial distribution of mammal numbers is presented in Figure 24. Seal numbers were highest along the western edge of the target dredge area (in deeper water). Dusky dolphin was observed twice inside the target dredge area (SP-1).

Table 9: Number of marine mammal sightings per daylight station

Station number	Common name	Scientific name	Number
2	Cape fur seal	*Arctocephalus pusillus pusillus*	16
3	Cape fur seal	*Arctocephalus pusillus pusillus*	7
4	Cape fur seal	*Arctocephalus pusillus pusillus*	5
5	Cape fur seal	*Arctocephalus pusillus pusillus*	4
6	Cape fur seal	*Arctocephalus pusillus pusillus*	4
7	Cape fur seal	*Arctocephalus pusillus pusillus*	12
7	Dusky dolphin	*Lagenorhynchus obscurus*	150
8	Cape fur seal	*Arctocephalus pusillus pusillus*	9
9	Cape fur seal	*Arctocephalus pusillus pusillus*	5
9	Dusky dolphin	*Lagenorhynchus obscurus*	100
10	Cape fur seal	*Arctocephalus pusillus pusillus*	1
11	Cape fur seal	*Arctocephalus pusillus pusillus*	3
12	Cape fur seal	*Arctocephalus pusillus pusillus*	4
17	Cape fur seal	*Arctocephalus pusillus pusillus*	3
		TOTAL	**323**

© NMP 2014

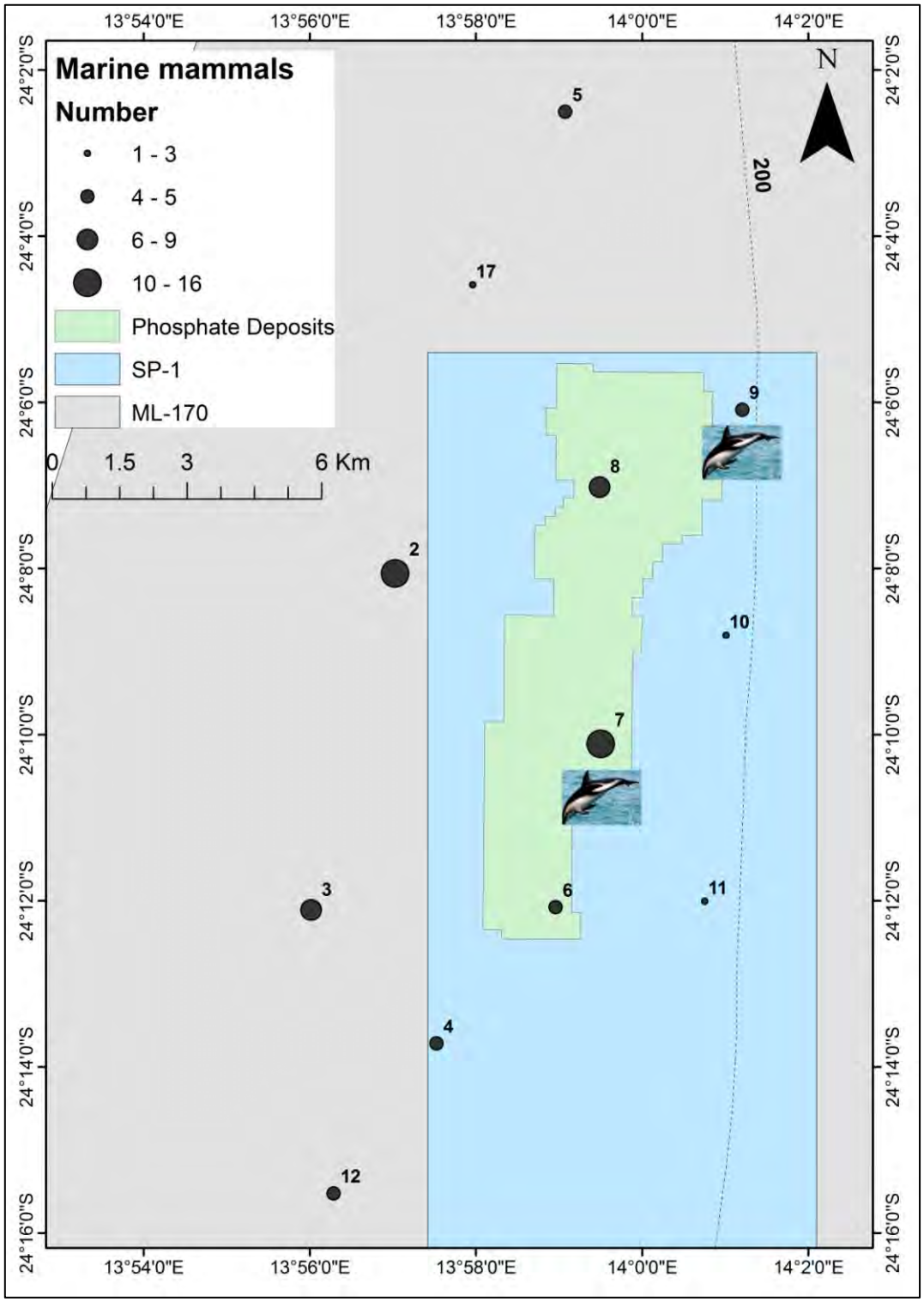


Figure 24: Spatial distribution of marine mammal numbers per station.
Station numbers have also been shown.

6.3.5 Hydrography and environment

The CTD with its temperature, salinity and oxygen sensors was attached to the trawl net to allow for sampling during trawling. The CTD report is presented in Section D, Appendix 2.3. In summary, 22 of the 24 trawls undertaken during the biodiversity verification survey provided acceptable results for temperature (with the exception of trawls 23 and 24) and 19 trawls yielded reasonable salinity data (exceptions being Trawls 13,14,17,20 and 21). The trawls where successful temperature and/or salinity data were recorded can be compared with the fisheries and biodiversity data from the respective trawls.

Temperature profiles showed a well-mixed upper water column in most instances, with slight stratification occurring from Trawl 10 onwards (Figure 25). This is to be expected as the survey took place just after an extended period of rough seas with considerable wave action in the survey area. The weather conditions calmed significantly from trawl 5 onwards and this may be the cause of slight stratification of the upper layers of the water column. In general the upper water column was approximately 2.5 to 4°C warmer than the near seafloor temperatures (>200 m). The temperature on or near the sea floor throughout the survey averaged 10.68°C. This is within the range of expected winter values for the region (Shannon and Nelson 1996).

Salinity and temperature data indicated the presence of South Atlantic Central Water (SACW) for the majority of the survey. SACW upwells from approximately 200 m below the surface with a salinity of 34.7 to 35.65 PSU and temperatures between 8 and 16°C (Shannon and Nelson 1996, Mohrholz *et al.* 2001, Duncombe Rae 2005). The dissolved oxygen levels near the seafloor for most of the trawls were reasonably low (approx. 3 to 10%) as can be expected in the continental shelf zone offshore of Namibia (Monteiro PMS & van der Plas AK. 1996).

© NMP 2014

Table 10: Summary statistics of the 'Trawl section' (excluding up and down casts) of each trawl

Name	Station	Day/ Night	Date	Time	Temperature (°C)		Dsvl. Oxygen (%)		Salinity (PSU)	
					Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
1	1	N	18-Jun-14	18:05	10.85	0.05	18.49	0.53	35.12	0.01
2	2	D	20-Jun-14	07:35	10.01	0.03	N/A	N/A	34.29	0.79
3	3	D	20-Jun-14	12:35	10.25	1.14	19.48	8.83	35.11	0.21
4	4	D	20-Jun-14	16:12	10.08	1.07	19.63	6.79	34.99	0.61
5	6	D	21-Jun-14	07:13	9.86	0.01	2.59	0.16	34.26	1.31
6	7	D	21-Jun-14	11:56	9.97	0.01	5.14	0.11	34.45	1.27
7	8	D	21-Jun-14	16:00	10.18	0.02	4.16	0.17	34.99	0.49
8	9	D	22-Jun-14	07:05	10.57	0.01	5.39	0.16	34.83	0.69
9	10	D	22-Jun-14	10:22	10.54	0.01	5.34	1.08	34.76	0.75
10	11	D	22-Jun-14	13:45	10.49	0.01	4.01	0.92	35.18	0.05
11	12	D	22-Jun-14	17:00	9.72	0.03	2.36	1.7	34.11	1.48
12	17	D	23-Jun-14	12:55	10.58	0.04	3.45	0.76	34.78	0.82
13	15	N	23-Jun-14	19:00	10.65	0.02	3.24	0.59	32.68*	1.53
14	16	N	23-Jun-14	22:20	11.4	0.06	8.2	5.99	33.03*	1.71
15	23	N	24-Jun-14	01:35	11.36	0.15	1.08	2.1	34.9	0.31
16	5	D	24-Jun-14	15:05	11.2	0.03	2.51	0.71	34.44	0.87
17	21	N	24-Jun-14	18:55	11.39	0.02	3.86	2.68	34.00*	1.21
18	14	N	24-Jun-14	21:55	11.47	0.02	N/A	9.66	34.35	1.05
19	13	N	25-Jun-14	00:55	10.63	0.05	N/A	10.4	34.84	0.54
20	20	N	25-Jun-14	17:40	11.38	0.02	N/A	10	33.71*	1.47
21	19	N	25-Jun-14	21:55	11.49	0.66	N/A	17.27	33.31*	1.7
22	18	N	26-Jun-14	00:55	10.92	0.02	N/A	21.7	34.26	1.24
23	22	N	26-Jun-14	18:52	N/A	N/A	N/A	N/A	N/A	N/A
24	24	N	26-Jun-14	22:15	N/A	N/A	N/A	N/A	N/A	N/A

© NMP 2014

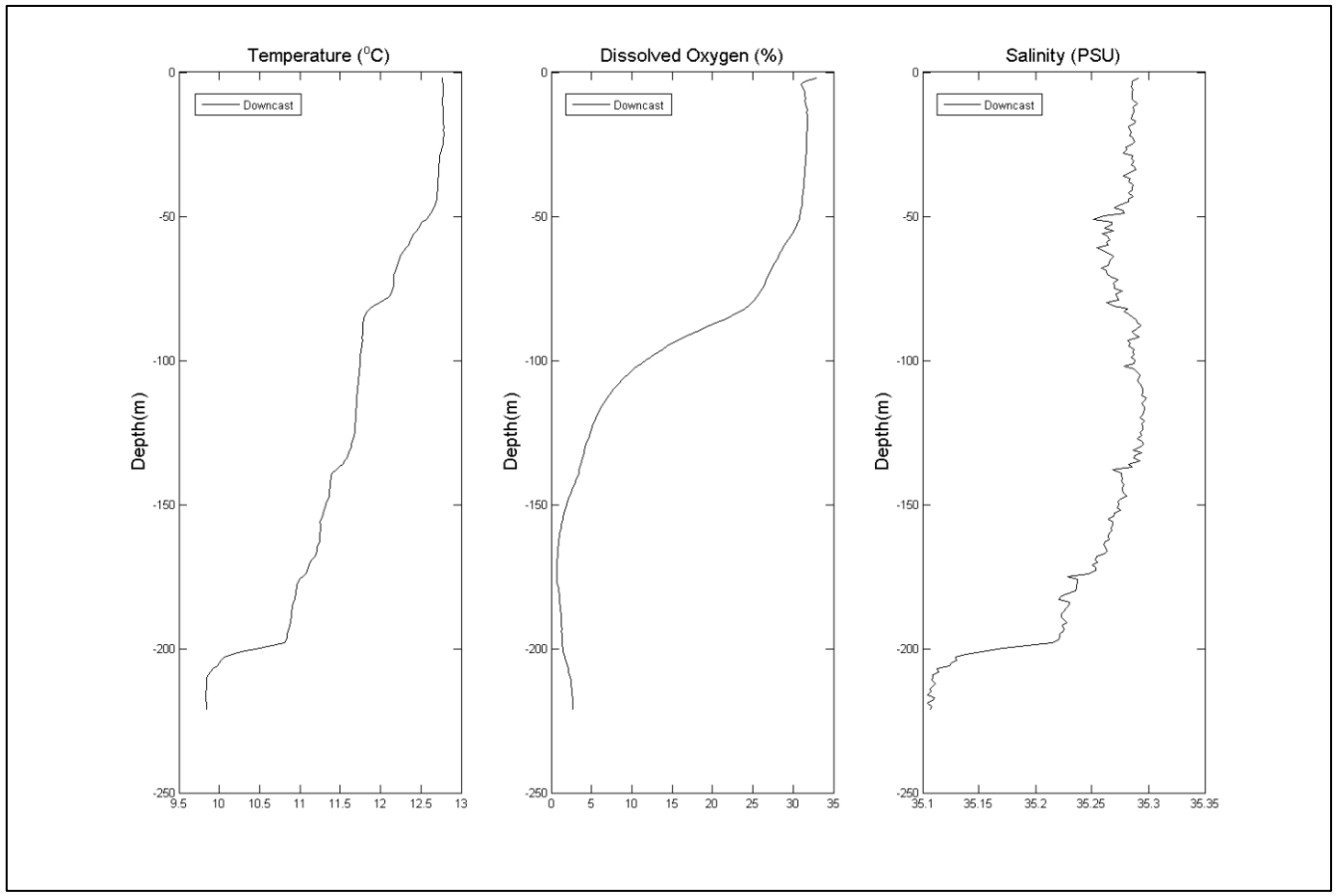


Figure 25: Down cast data for Station 6 in a cross-section view. Temperature, dissolved oxygen and salinity data are shown. Note the very low oxygen concentrations.

6.4 DISCUSSION AND CONCLUSIONS OF THE BIODIVERSITY SURVEY

Typically, because of the extent of the offshore environment, surveys undertaken for fisheries, benthic sampling and other biological and oceanographic processes are sub-samples and are randomised, requiring extrapolation of information across wide areas (normally including the entire continental shelf). It was mostly for this reason that information used in the EIA (Japp in Midgley 2012) was based almost entirely on historical survey data provided by NatMIRC. This data and its assessment formed the initial baseline for the fisheries impact assessment of the EIA (Japp in Midgley 2012). The target dredge area (SP-1) within the MLA is relatively small, and as expected, information provided using exact station locations did not necessarily coincide with the area (SP-1) targeted for dredging. The main objective for the verification survey was therefore to gather quality *in situ* data specifically from inside and just outside SP-1 (within the MLA) to verify the EIA determined baseline, which was established on the available data.

The execution of the designed biodiversity survey was successful and all of the designed work scope was accomplished. The survey was designed to identify and quantify the biodiversity of epifauna, demersal and pelagic fish, seabirds and mammals in the area to be compared with the known information from the region. The survey also obtained data on commercial species such as monk, hake and the other bycatch species to allow for rough estimates of, for example, spawning and recruitment, size distribution and other biological parameters. The sampling approach mirrored typical offshore fisheries survey sampling design with the exception of a standardised swept area biomass estimate (due to the non-availability of a suitable calibrated vessel and gear). The survey however, allowed for substantive verification and confirmation of the main determinations and data extrapolations from historical survey information that was used in the EIA (Japp, in Midgley 2012). This verified information provides a baseline of data from the target dredge site and increases the confidence levels of the assessment significantly, when compared with the original EIA assessment associated with data extrapolations.

Biodiversity

A total of 48 species of fish, jellyfish, epifauna, seabirds and mammals was identified during the survey. Of this, 14 fish species (including shark, squid and jellyfish) were identified which is relatively low when compared to the cumulative survey data from the combined hake, monk and small pelagic research cruises where approximately 40 fish species were identified in and immediately adjacent to the MLA. The primary reason for this difference is associated with the gear deployed – a larger number of pelagic species would for example have been recorded on pelagic-directed surveys. The species complexity obtained in the verification survey therefore reflects the availability of species typically caught in commercial monk and/or demersal trawl nets. The verification data therefore are a subset (indicator) of the total biodiversity.

Bird observations were carried out during daylight stations for 60 minutes during the entire trawling operation (i.e. from the setting to the end of hauling). Fifteen (15) species of seabirds typical to this area were identified. Of these, 54% of the species are considered Endangered, Threatened and Protected (ETP) namely, the White-chinned Petrel, Shy Albatross, Cape Gannet, Yellow-nosed Albatross and the Cape Cormorant. Their occurrence on the survey was expected and consistent with the known range of these species.

© NMP 2014

Two species of mammals were identified, the Cape fur seal (found at every station) and the dusky dolphin (at two stations only), both of which are common to the region. We conclude that there is a likelihood that numerous seabird and mammal species will occasionally be found in or near the MLA (target dredge site SP-1) and that impacts on these species will relatively be minimal.

Species Availability and Catch Levels

A total of 28 tonnes was recorded by the survey with an average of 1.2 tonnes per station. Trawls were 30 minutes and generally catches in day trawls were larger (by weight) than night trawls. These results are not dissimilar to the catch weights caught by the MFMR research surveys for monk (Kathena *et al.* 2010) and hake (Kainge *et al.* 2004) along the entire Namibian coast. Hake dominated the catches in the verification survey, amounting to 40% by weight of the total fish catch, followed by monk with 35%, rattail 14%, sole 3% and goby 2%. Horse mackerel constituted 0.4% of the total fish catch. A high abundance of red jellyfish was found at all the stations but particularly at Station 11, where 11 tonnes were caught. Similarly, ascidians were also in high abundance at all the stations but particularly high at Station 20.

Recruitment

To determine a rough estimate of recruitment the length frequency data as well as maturity stage were recorded for the main commercial species such as monk and hake. The mean length of monk and hake was 29 cm and 26 cm, respectively. The size distribution pattern is consistent with what is expected for juvenile hake and monk with depth-related recruitment. Typically recruiting fish are found in relatively shallow water (<200 m) and then migrate deeper as they mature.

Monk juveniles were in high abundance contributing to 45% of the total sampled monk catch. Approximately 62% of the monk were smaller than the length at 50% maturity (34.5 cm). These results are comparable with the conclusions made by Gaylard (Section C, Chapter 3.2) in that monk recruits are expected to be prevalent in the MLA[9]. For monk the results for length at 50% maturity (34.5cm females and male 27 cm) were similar to Maartens (1999) in that juveniles in her study reached sexual maturity at 32.1 cm for females and 23.7 cm for males.

Fewer than 6% of the sampled and staged hake were juveniles and fewer than 8% were smaller than the length of 50% maturity (21 cm). Juvenile hake are therefore expected to be displaced from the dredging area, but their mobility should limit the likelihood of mortality. The distribution of stage 4 adult hake is an indicator that these fish are not commonly spawning in the SP-1 and its immediate vicinity. Hake recruitment therefore, is not expected to be impacted significantly. We note however that maturity estimates and spawning activity estimates are constrained by the data limitations i.e. to survey periods.

Horse mackerel juveniles (<21 cm) were not observed during the survey. They occur mostly northwards of the MLA (Zone 2 and beyond). The impact on the recruitment of horse mackerel is therefore expected to be negligible.

Trophic structure

[9] An estimated 7% of monk recruits were in the MLA and 0.2% in SP-1.

No direct conclusions could be made with respect to trophic structure. Stomach samples were taken and typically reflect the presence of the species composition in the trawls. These data however will form a baseline for future surveys. For hake the majority of the prey items were euphausiids and gobies. These results are comparable with diet analyses carried out by (Maartens 1999, Singh and Johannas 2013). For monk the main prey items were hake and gobies.

In conclusion, this initial baseline survey is a "snapshot" compared with historical data gathered in and around SP-1 of the MLA. This survey has proven to be a suitable sampling platform for monitoring the changes in fish availability, abundance, recruitment, biodiversity, marine mammals, seabirds and other fauna. Additional sampling stations can be included if necessary in subsequent surveys and changes in the parameters measured can be tracked over the lifetime of the exploitation of marine phosphate. This information can then be used to fine tune the management of dredging operation including possible future expansion of the operation.

7 A REVIEW OF THE MESOPELAGIC FISH AND PELAGIC GOBY

Among the largest potential commercial fishery stocks are the vast numbers of mesopelagic fish that are found in the mid-layers of the world ocean, typically from 100 to 1000 metres below the surface. While there are many species from many families that constitute this fauna, the lanternfish or myctophids of the family *Myctophidae* such as (*Lampanyctodes hectoris* and *Maurolicus muelleri*) and the pelagic goby (*Sufflogobius bibarbatus*) are perhaps the most widespread and ubiquitous (Figures 26 and 27) occurring on occasions in great abundance.

Both mesopelagics and gobies play an important role in this ecosystem (Staby and Krakstad 2008). They feed mostly on plankton and convert this energy to provide an important component, as a lower level trophic species, to species higher in the food chain (i.e. birds, mammals, pelagic and demersal fish).

Mesopelagic fish

In the northern Benguela region off the Namibian coast Rubies (1985) reported on a total of 41 lanternfish species. Of these, 25 originated solely from the Valdivia Bank 400 miles offshore on the Walvis Ridge, 10 were specific to the northern Benguela area, and six were common in both areas (Rubies 1985). Two species belonging to the oceanic lanternfish genus *Symbolophorus* and the pseudo oceanic warm-water genus *Diaphus* were also common off the coast of Namibia (Prosch et al. 1995). Of the 14 species of sternoptychids (hatchet fishes) found in South African waters, 11 have been recorded in the eastern south Atlantic (Prosch *et al.* 1995). Hulley (1991) gives a general account of 28 genera, comprising 125 species, of the lanternfish most likely to be found in the southern African region. This account covers a detailed description by Hulley (1986) of the distribution of lanternfish occurring in the southern Benguela.

Recent surveys undertaken by the Norwegian research vessel R.V. *Dr. Fridtjof Nansen* and reported by Staby and Krakstad (2008) showed a similar distribution pattern of mesopelagic species to that reported by O'Toole (1977) in Figure 28. The data indicated that *L. hectoris* and *M. muelleri* were more abundant in the region compared with the other mesopelagic families however *Yarella blackfordi* and *Photichthys argenteus* (Photichthyidae) were also widely distributed and abundant in

© NMP 2014

trawl catches. Little however is known about their biology, ecology, vertical distribution and behaviour, life history parameters, or abundance of these mesopelagic species. The same can be said about *Stomias boa boa* (Stomiidae) and the bristlemouth fish *Triplophos hemingi* (Gonostomatidae).

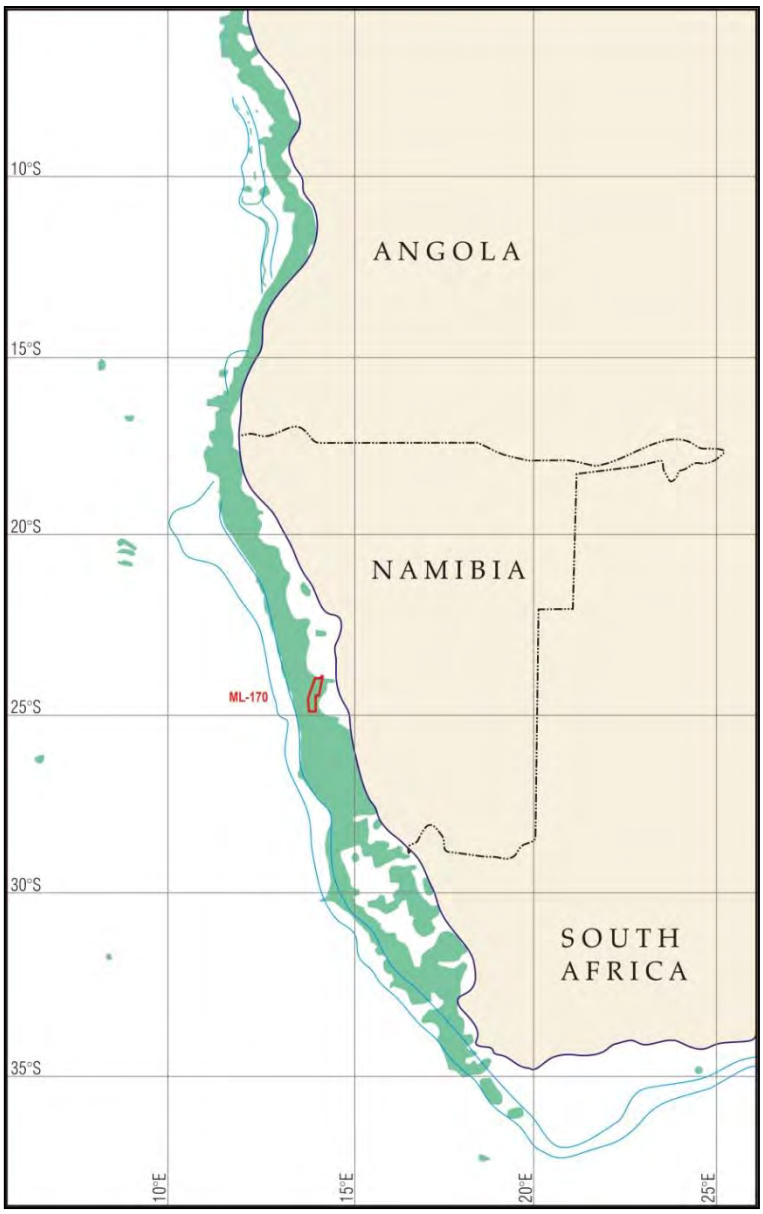


Figure 26: Distribution of main commercial mesopelagic fish species in the Benguela region.
Myctophidae (Lanternfish)

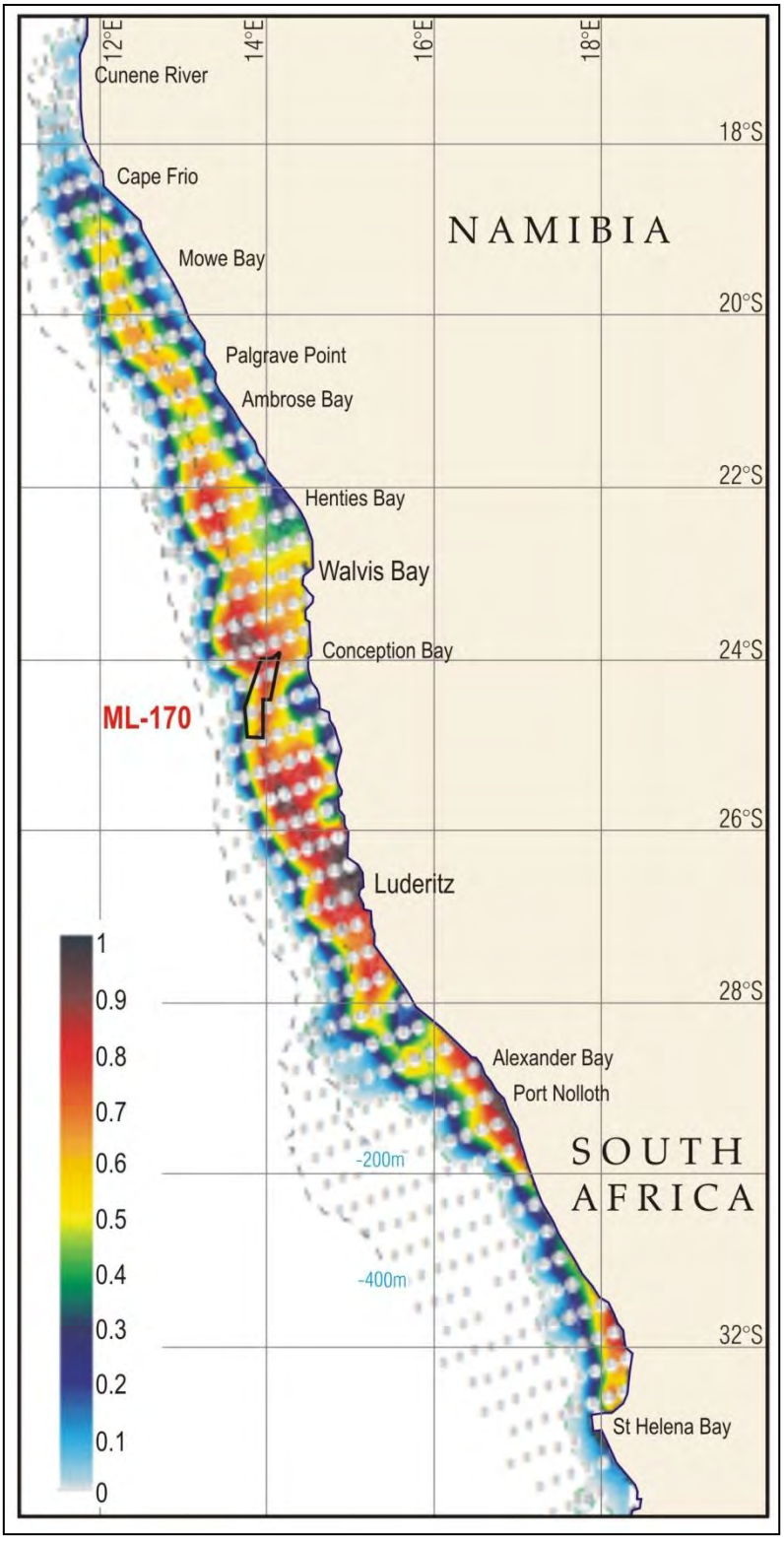


Figure 27: Distribution of *Sufflogobius bibarbatus* in the Benguela.
The figure represents a measure of frequency of occurrence from Nansen and Africana survey data.

The reported historical distribution and abundance of larvae and early juveniles of lanternfish (Ahlstrom 1976) were reviewed with reference to the proposed marine phosphate dredging area

(ML 170). The data for lanternfish larvae (*Lampanyctodes hectoris*) from the Southwest African Pelagic Egg and Larval Survey (SWAPELS) indicated that these species were widely distributed between latitudes 19° and 25°S (Figure 28). Larvae were found at distances of 8 – 112 km from the coast but were most abundant in offshore waters especially between Mowe Point (20°20'S) and Cape Cross (22°S) and between Walvis Bay (23°S) and Hollam's Bird Island (25°S). The occurrence of high density sites of larvae at the southern limit of the sampling grid suggested that considerable spawning of these species is likely to occur off Hollam's Bird Island. The main spawning period was understood to be from spring to early summer (between August and November), which coincided with the peak upwelling periods in the area.

© NMP 2014

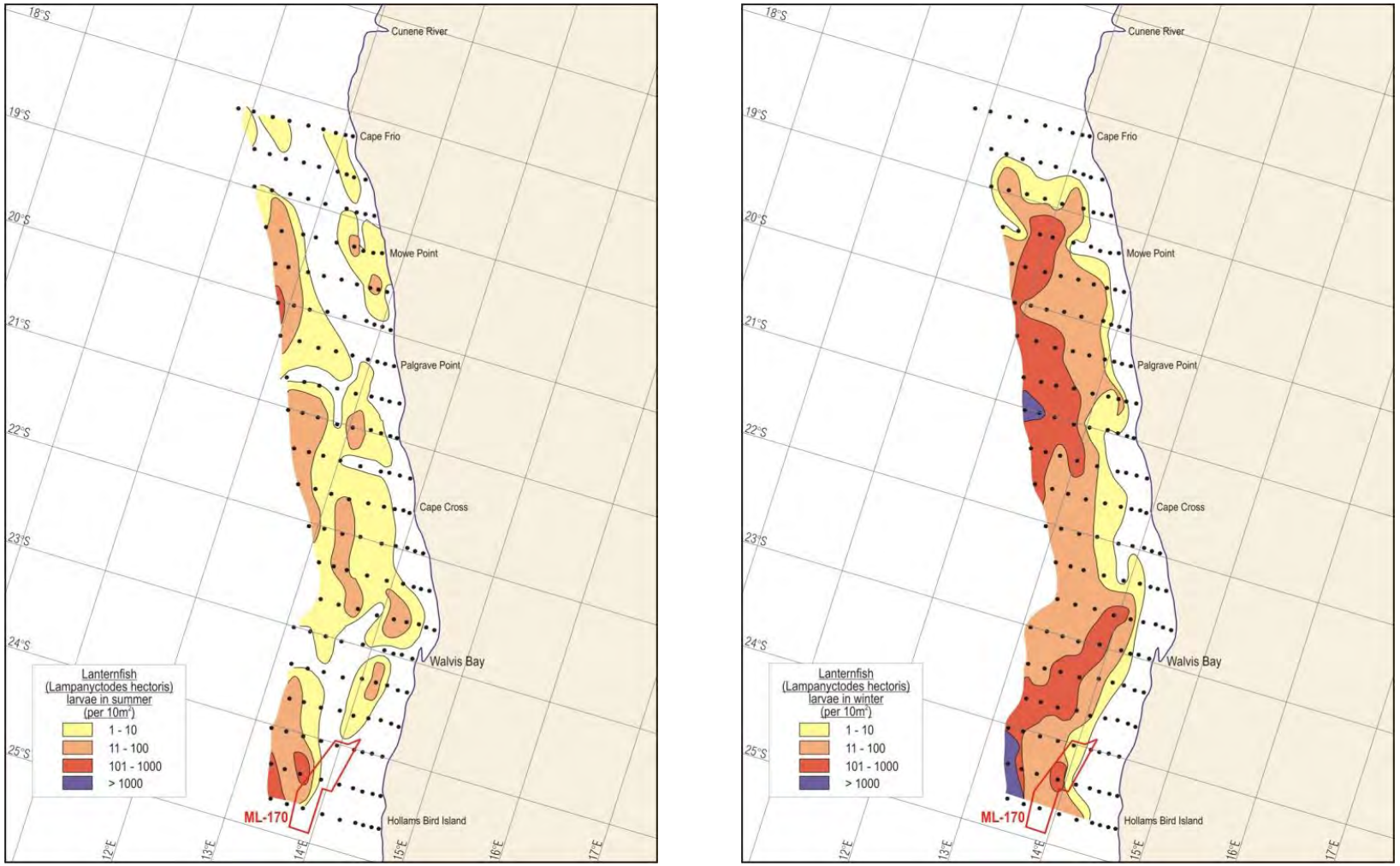
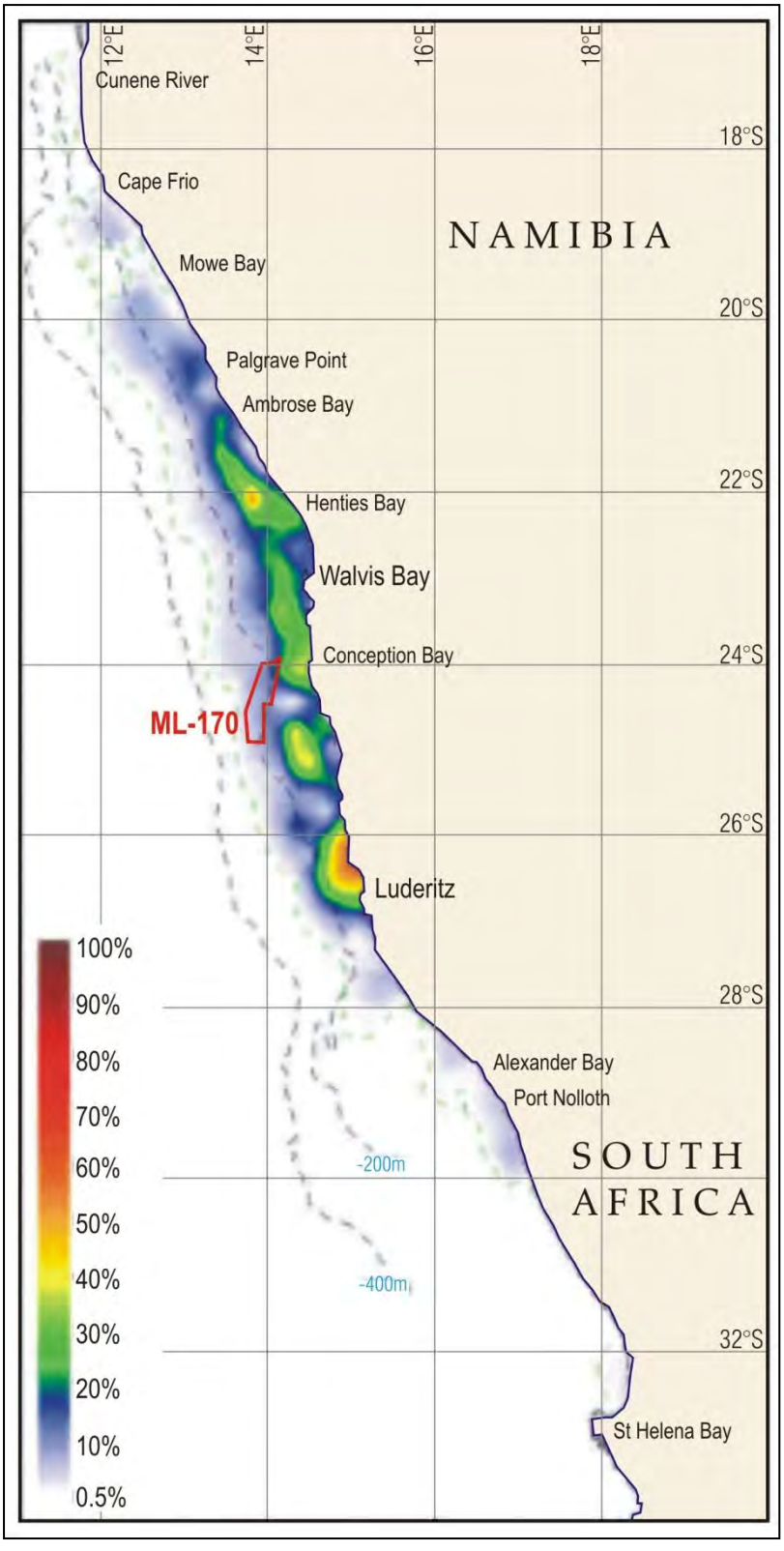


Figure 28: Distribution and abundance of larvae of lanternfish (*Lampanyctodes hectoris*) from SWAPELS data.
Numbers represent cumulative standard haul totals (adapted from O'Toole 1997).



Pelagic goby

The pelagic goby (*Sufflogobius bibarbatus*) also occurs extensively throughout Namibian waters generally in water depths of between 200 and 1000 m. According to Staby and Krakstad (2008) the goby stock is much smaller than previously reported by O'Toole (1977) (Figure 29). However, there is still a lack of knowledge regarding the seasonal dynamics, and spatial and temporal variations in fish size distribution and the life history parameters of the species although a recent study (Melo and Le Clus 2005) has expanded our knowledge on reproduction. Melo and Le Clus (2005) suggested that the pelagic goby might be a serial batch spawner, based on the extended spawning season from July to April, and the presence of more than one batch of yoked oocytes in the ovaries. They also showed that gobies mature late at 2-3 years of age, and males mature at a greater size and age than females.

Figure 29: Distribution of *Sufflogobius bibarbatus* in the Benguela. The figure represents a measure of mean relative abundance of gobies from all trawl hauls captured by the RV *Dr. Fridtjof Nansen* between 1985-2005.

The historical distribution and abundance of larvae and early juveniles of pelagic goby (O'Toole 1978) were reviewed with reference to the proposed marine phosphate dredging area (ML 170). During two ichthyoplankton surveys off South West Africa (Namibia), pelagic goby larvae (*S. bibarbatus*) was found in abundance and were widely distributed along the Namibian coast in the upper 50 m layer (O'Toole 1977). From all the larval organisms collected during these surveys (SWAPELS) goby constituted 61% (Figure 30).

The main spawning season has been reported to be from July to February, with a peak in late winter to early spring (O'Toole 1977). Spawning has been reported to be most intense in coastal waters south of Walvis Bay, but with less intense spawning over a more extended area during summer (O'Toole 1977).

Figure 30/...

© NMP 2014

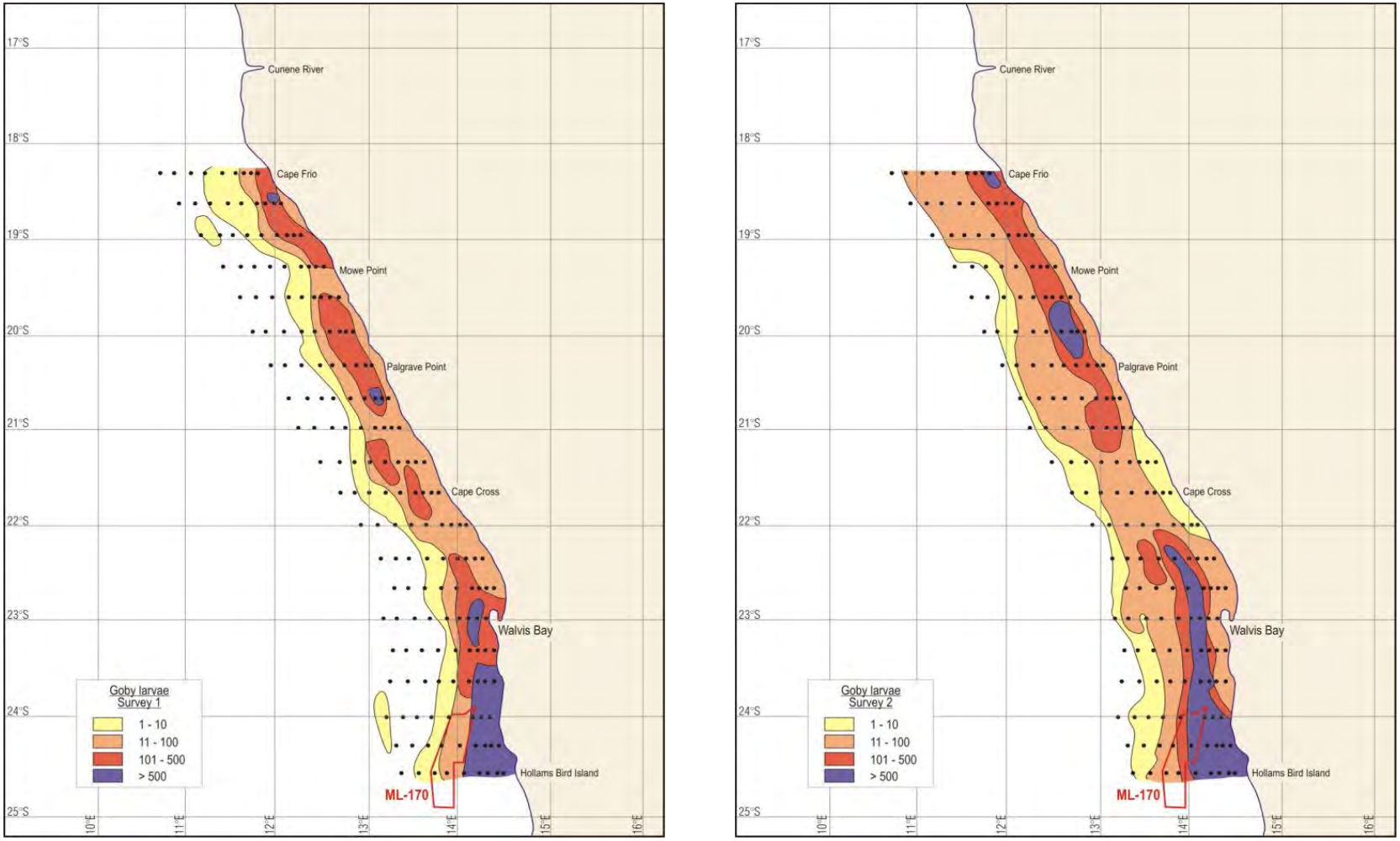


Figure 30: Distribution and abundance of goby larvae during SWAPELS survey 1 (left) and survey 2 (right). Values represent cumulative standard haul totals for all cruises (adapted from O'Toole 1977)

Conclusions

Mesopelagic fish and gobies are well known for their diurnal vertical migrations producing strong "scattering" layers that are typically seen on echo sounders. During daylight hours most species remain within the light-limited bathypelagic zone. At sundown, as the surface light intensity diminishes, these species begin to rise towards the surface (but still remain well below the sea surface). They are thought to do this to avoid predation, and also because they are following the diurnal vertical migrations of zooplankton upon which they feed (O'Toole 1977, Crawford *et al.* 1985, Prosch *et al.* 1995).

L. hectoris is the only mesopelagic fish species that has been targeted and caught in reasonable amounts by the purse seine fishery in South Africa (Crawford 1980; Crawford 1987). This species has also been recorded in catches in Namibian waters but only as a bycatch in the purse seine fishery. Not only are these mesopelagic species numerous they are also found across the entire shelf of the Benguela ecosystem. Areas of abundance cover the mid-shelf areas that include the MLA. Research on this group suggests that these species are an important prey species for many top predators, including the deep water hake *Merluccius paradoxus* (Staby and Krakstad 2008).

Little is known about the potential effects of marine dredging (in particular the potential impacts of sediment plumes) on these scattering layers that include mesopelagic species, gobies, plankton, zooplankton. As the available information on the precise distribution of these species in the MLA and specifically in SP-1 is data deficient, no clear inference can be made on the impact dredging may have other than the dredging operation is likely to disrupt aggregations of mesopelagic species and the scattering layers of which they are a part.

The biodiversity verification survey, which used a net designed to catch bottom fish and particularly monk, did not capture any mesopelagic fish. The high mobility of this group of fish has been the primary reason why the commercial fishing sector has been unable to target them. Obtaining scientifically defensible indices of abundance of mesopelagic species in and around SP-1 would require a sophisticated research vessel with purpose built fishing gear. Future monitoring surveys should attempt to track the scattering layer patterns in order to infer the relative abundance of mesopelagic species, gobies and zooplankton. This could be achieved using industrial or scientific echo sounders with the frequency resolution suitable for the target strengths of the most commonly expected species. Samples of the species indicated on the acoustic scattering layers could also be taken if mid-water trawl gear were available on the survey vessel and if the vessel had adequate power to be able to tow such gear to nullify the avoidance behaviour of these species. The acoustic tracks would nevertheless provide adequate information on which to gauge the presence of these species and can be used as a baseline to monitor responses of this group of species to dredging operation.

8 GEOPHYSICAL SURVEY AND HABITAT MAPPING ASSESSMENT

The Namibian marine habitat is characterised by widespread areas of low oxygen waters overlying the diatomaceous mud-belt on the central Namibian shelf (Chapman and Shannon 1985; Dingle and Nelson 1993). Methane and hydrogen sulphide are reported to accumulate over large areas under this mud belt (Emeis *et al*. 2004). Blow outs of these toxic gases are frequently recorded at the ocean surface, affecting the movement and distribution of many pelagic and demersal species (Weeks *et al.*

© NMP 2014

2004). However, despite its widespread occurrence across the Namibian shelf, the reported distribution of the mud belt indicates that it does not overlap with the proposed area for phosphate dredging i.e. the MLA (Figure 31, Emeis *et al*. 2004)

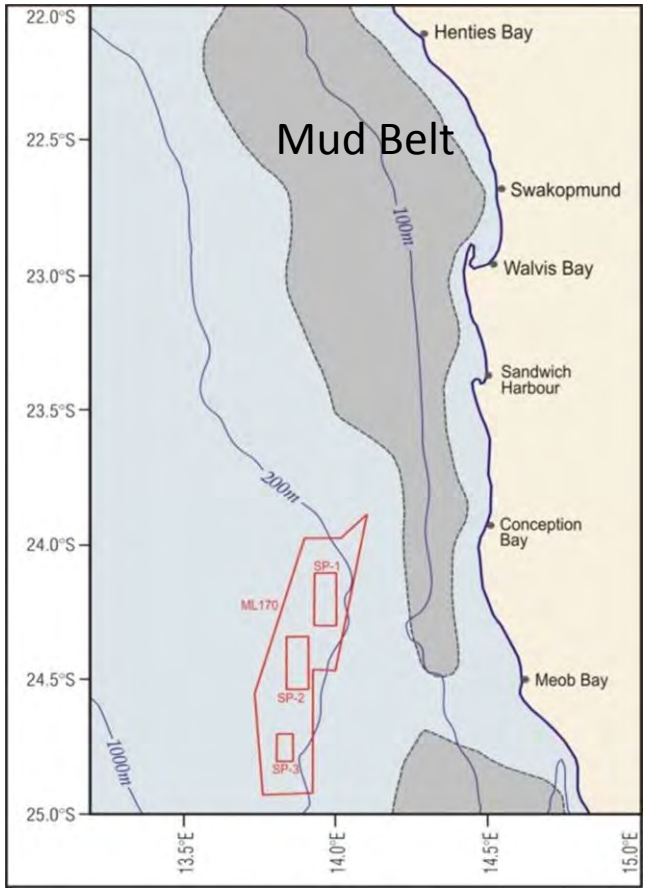


Figure 31: Location of the diatomaceous mud-belt on the central Namibian shelf (adapted from Emeis *et al*. 2004)

The geophysical survey

A geophysical survey was undertaken over a period of five days during September 2013 in the SP-1 area with the purpose of mapping the habitat and to determine the distribution of seafloor surficial sediments (Ludick: Section D, Chapter 3.2). The vessel, MV *DP Star* was fitted with Sidescan-Sonar (SSS) and Multi-beam Echo Sounder (MBES) equipment with the objective of characterising the seafloor of the target dredge area SP-1.

A block of 4 x 5 km², covering the proposed first 10 years of dredging inside SP-1, was selected as the survey location. A series of parallel north-south lines were run with side scan sonar and/or multi-beam echo sounders.

From the data, a 5 m x 5 m bathymetric digital terrain model grid was produced from the processed bathymetry and colour-shaded by water depth (Figure 32). This figure shows an overall flat seafloor

© NMP 2014

with depths ranging between 204 and 220 m. The 1 m isobaths contoured from the data, to a vertical resolution of 20 cm, strikes north-south with an eastward dip of around 0.3 degrees. A single, shallow depression (less than 1 m deep) in the sediment however was identified and appeared to be an exception to the rule. No positive relief features in the form of reef outcrops or shipwrecks of any kind was present in the data.

The backscatter image (called the Pseudo-backscatter mosaic) (Figure 33) with a 50 cm pixel resolution produced from the MBES data showed a featureless, homogeneous surficial seafloor, indicating a medium muddy sand surface (Ludick: Section D, Chapter 3.2). This was determined by applying the automated surficial seabed classification Angle versus Range Analysis (ARA). Further, the Sidescan Sonar (Figure 34) also confirmed a smooth seafloor with an absence of any features or variance. The ARA result indicated a medium sand surface for all of the mosaic, which is consistent with the Backscatter result.

The biodiversity survey (trawl verification survey)

In addition to the data provided by the geophysical surveys, the semi-random sampling methodology using bottom trawl gear provided no evidence to suggest that the substrate type was mud. Further, throughout the trawl survey, a homogenous bottom type was noted. There was no evidence of reef structures or areas with irregular bottom types. No mud was noted on trawl doors or footropes and the species trawled were consistent with a firm sandy / gravelly (shell) substrate amenable to trawling, as was expected. In some areas large numbers of typical substrate residing species were recorded. These include, for example, the ascidians and the sea pens, which together constituted for 76% of the overall epifauna component. Typical bottom-dwelling fish species recorded such as monkfish and sole are known to have sand and mud substrate preferences although no inference on habitat could be made on the availability of these species to the trawl gear as they could equally have occurred over muddy, sandy or gravelly substrate types.

Conclusions

The geophysical data conclusively indicated a flat, smooth seafloor with a homogeneous surficial sediment cover across the entire survey block. No protruding obstacles (natural or artificial) were observed.

The surficial sediment composition of the area was well known through a large amount of gravity cores that were taken across SP-1 for the purpose of resource development. The top few centimetres consists of a mixture of silty sand particles, with typically dense shell (Section D, Chapter 3.2). This confirms the muddy medium sand conclusion reached with the various images produced by the geophysical survey and is further supported by the trawl surveys suggesting habitat was homogeneous and primarily of firm sandy gravelly character.

© NMP 2014

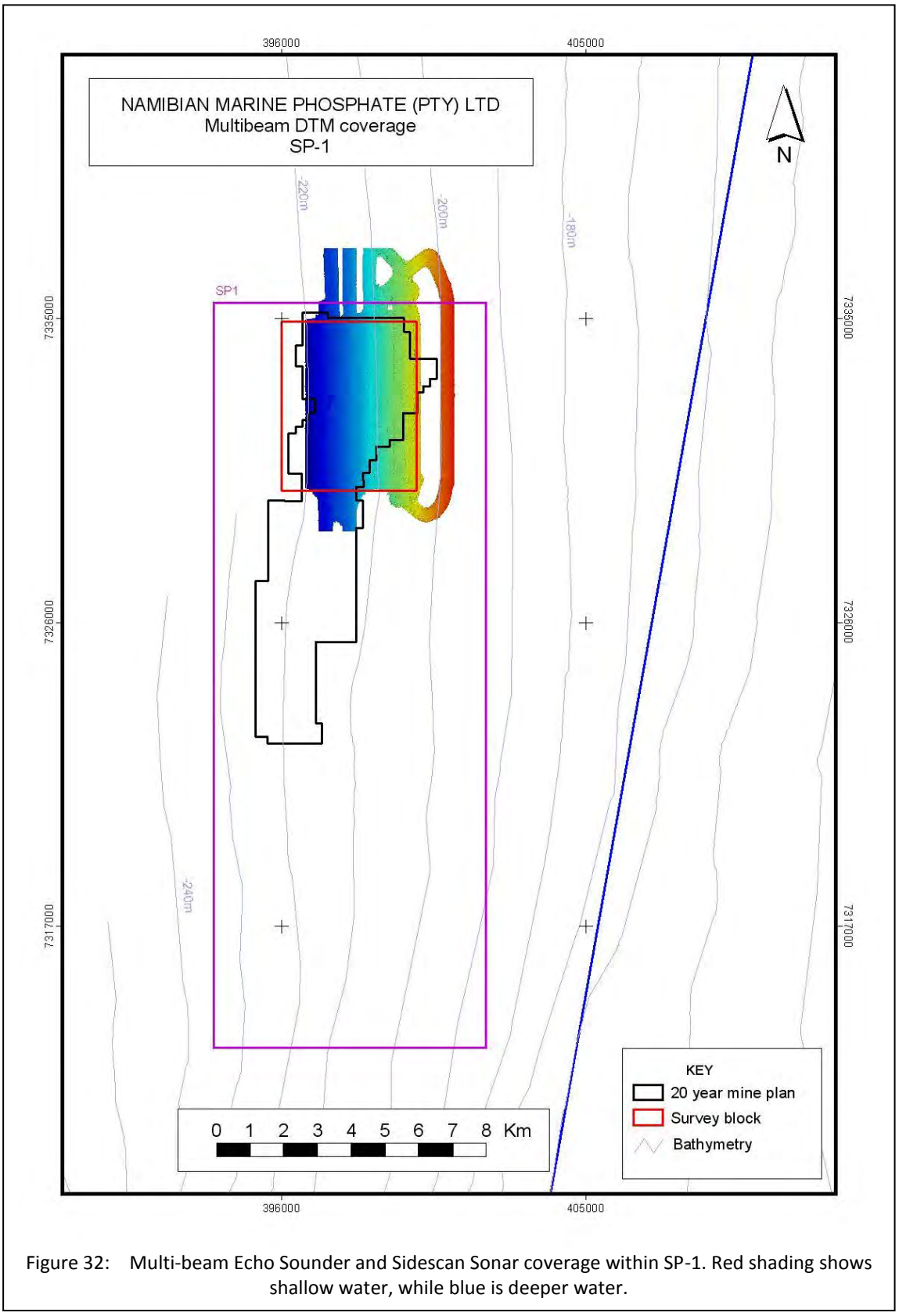


Figure 32: Multi-beam Echo Sounder and Sidescan Sonar coverage within SP-1. Red shading shows shallow water, while blue is deeper water.

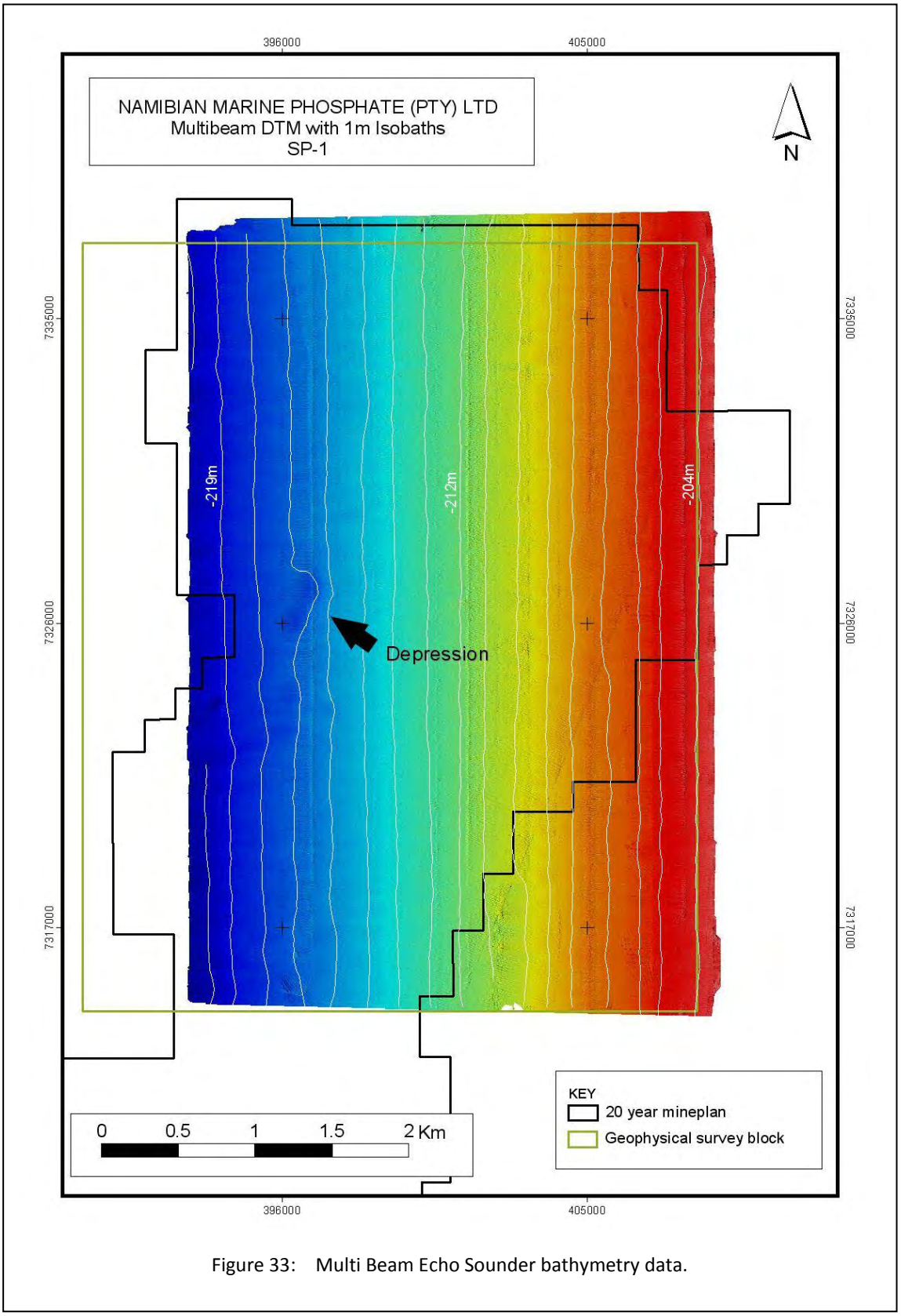


Figure 33: Multi Beam Echo Sounder bathymetry data.

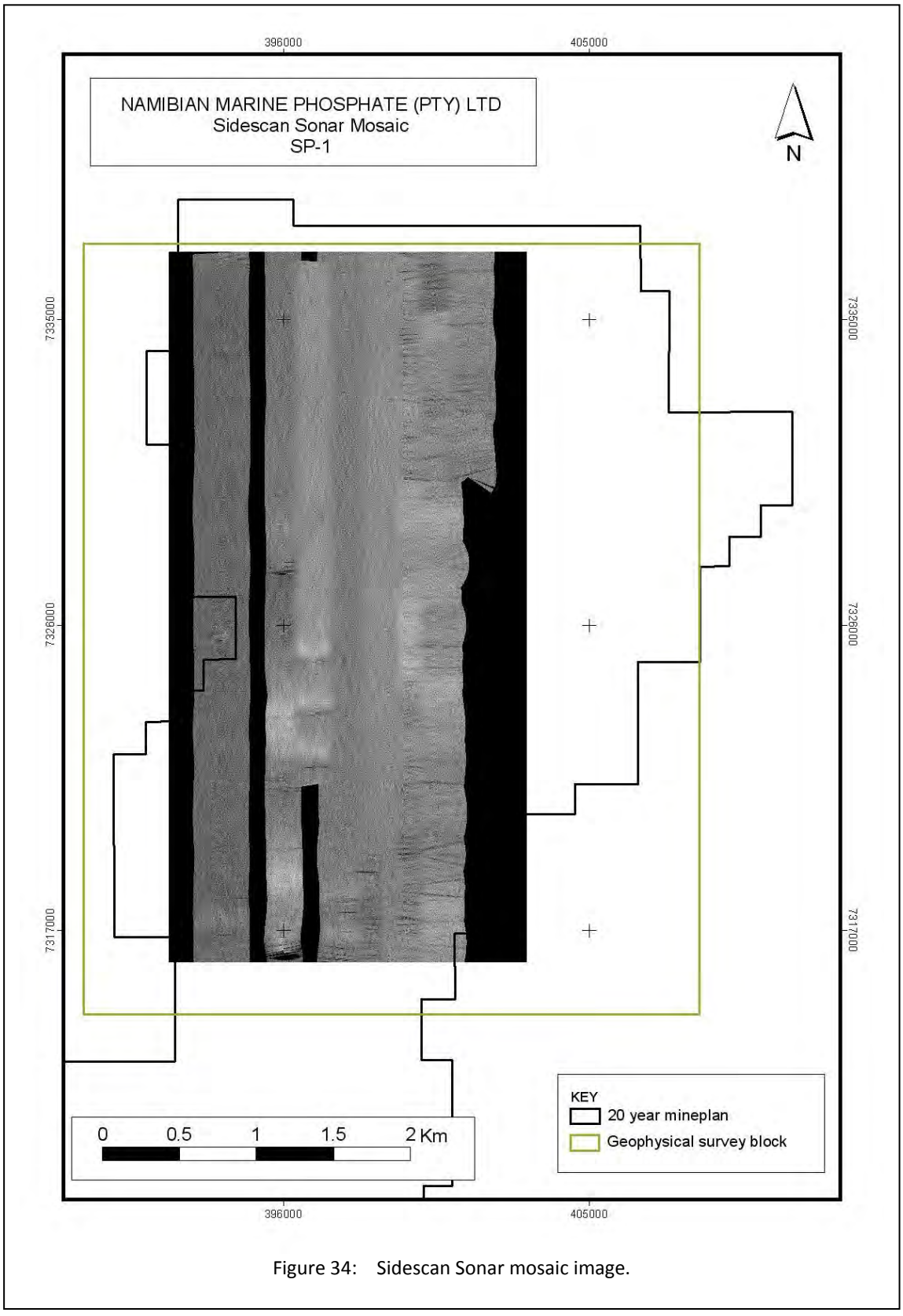


Figure 34: Sidescan Sonar mosaic image.

9 ASSESSMENT OF THE EFFECTS OF DREDGING NOISE ON MARINE FAUNA

Sounds can have a variety of effects on marine fauna, ranging from subtle to strong behavioural reactions such as startle response or even the complete avoidance of an area. It is well documented that short and implosive sounds such as those produced from pile driving strikes, seismic airguns and military sonar can cause behavioural reactions by fishes and cetaceans up to distances of several tens of kilometres from the sound sources (OSPAR 2009, Robinson *et al*. 2011, for example). Certain sounds can also mask biologically important signals such as communication calls between baleen whales or fish. If the sound level that the animals receive is high enough, sound can affect hearing either temporarily or permanently and extremes can lead to injury or even death. The latter, however, usually occurs only in the case where animals are very close to very high intensity sounds, without having the opportunity to first move away. Research on the effects of underwater sound on marine fauna has increased over the last decade, but there are still many unanswered questions, especially with regards to the significance of sound impacts for conservation objectives. In particular, the translation of individual effects into consequences at the population level involves significant uncertainty.

Notwithstanding, marine dredging operations typically produce regular and continuous low frequency sound below 1 kHz with estimated source sound pressure levels ranging between 168 and 186 dB re 1 µPa at 1 m (Thomsen *et al.* 2009). Looking at these relatively high sound pressure levels, dredging noise has the potential to affect on marine fauna (fish, invertebrates and marine mammals) by inducing adverse behavioural reactions and by causing physiological damage (Thomsen *et al.* 2009). Previous studies indicated that dredging can trigger avoidance behaviour in marine mammals, and that marine fish can detect dredger noise over considerable distances (Richardson *et al.* 1995; Defra 2003). Despite these initial results, there are essential questions remaining on the potential effects of dredging noise. Studies to date have been sparse, undertaken on a few dredgers and at a very limited number of sites.

The few studies however, that have been conducted regarding the potential effects of dredging on marine fauna have predicted that vibration and frequency levels close to the dredger are relatively low and the data available indicate that dredging is not as “noisy” as for example seismic surveys, container ships and/or tankers; but are louder than for example most fishing vessels and whale watching vessels (Table 11). A detailed assessment of the potential impacts of sound from dredging vessels on a variety of species showed that sound levels in all cases are well below those known to cause damage to marine life (EIA Don Diego Technical Report unpublished). Thus, given the sound frequency and decibel level of sound emanating from a typical Tailer Suction Hopper Dredger (TSHD) intended to be used in this project, the dredging noise impact can be assessed as low.

© NMP 2014

Table 11: A comparison of the average sound emitted by various relevant vessels including this used for whale watching (EIA Don Diego Technical Report unpublished)

Vessel	Ref Frequency Hz	Amplitude dB at 1m
Container ship	20Hz – 10 kHz	188dB
Tanker	20Hz – 10kHz	186dB
Dredger	250Hz – 4kHz	176 dB
Fishing vessel	100 Hz – 4kHz	170dB
Whale watching boat	100Hz – 20.3kHz	146-160dB increasing with speed.

10 OVERALL CONCLUSIONS OF THE VERIFICATION PROGRAMME

The verification process for the fish, mammals and seabirds component of the NMP impact assessment process has confirmed the following:

1. The verification programme has increased the confidence levels of the determinations in the EIA (Japp in Midgley 2012), supporting the core assumptions, thereby strengthening areas which were of concern and or uncertainty in the original assessment.
2. The verification programme aimed to address several key issues, in particular the concern that the proposed dredging will have a significant effect on fisheries. The verification programme has confirmed the following in this regard:
    a. The biomass of key commercial fish species likely to be impacted by the dredging of phosphate will be low, particularly as the dredging process is confined to a proportionately small area relative to the known biomass of these species (hake and monkfish in particular). It is our considered opinion that the impact on the commercial fishery biomass will be low;
    b. With regard to recruitment, the verification programme has confirmed our initial assessment that the impact of dredging in SP-1 is of moderate intensity and medium significance. However, the area to be dredged (SP-1) is generally understood to be in the "usual" distribution of the main commercial species and that their size distribution and their general biological dynamics are what was to be expected;
    c. The verification survey programme has shown that the size distribution of the main commercial species likely to be impacted (monk and hake) is consistent with what is known and with what was assumed in the initial EIA. There appears to be no unique spawning and recruitment characteristics. For hake, the abundance of juvenile and pre-recruiting hake (*M. capensis* only) is consistent with what is known and the proportions of juveniles and sex ratios (males and females) suggests no irregularities that would make the area to be dredged unique. With regard to monkfish, as expected, the verification survey has shown a mix of juveniles, adults and pre-recruiting fish. We note that as the survey used monk-directed gear and since it used a cod-end liner to retain as much as possible, it is expected that a higher proportion of juvenile fish would be caught. The area does therefore have a higher proportion (than hake) both of juvenile and pre-recruiting monkfish. The biomass estimates of Gaylard (Section C, Chapter 3.2) confirm this as well, but also that the scale of the dredging (in particular SP-1) is extremely limited when compared to the abundance of the monk resource. The impact on monk recruitment and the fishery as a whole will be low.

© NMP 2014

d. Sole were also caught in the verification survey. Abundance was not high and is in all likelihood consistent with what is expected (as a proportion of a monk-directed catch). Further, predominantly large sole were caught suggesting that the SP-1 area and adjacent grounds are unlikely to be a significant recruiting area. The area is nevertheless an extremely small proportion of the overall distribution of the stock.
e. The general fish diversity is low – no inference from the verification survey can be made regarding non-demersal species such as horse mackerel and gobies. Both of these species were found in small quantities. Part of the verification programme incorporated historical spatial and temporal distributions of small pelagic species as well as the assessment done by Ndjaula (Section C, Chapter 3.4). We note that the resource has reduced to such an extent that it would be irrational and illogical to assume that the location of the MLA and in particular SP-1, that small pelagic species would be impacted by either the dredging operation or by the plume so generated. The plume effect has been shown to be relatively limited in extent (Section C, Chapters 2.1 and 2.2).
f. With regard to mesopelagic species, none was noted in the trawl catches. Catches between night and day varied as expected and we assume normal diurnal behavioral patterns prevail with regard to fish and crustaceans. Mesopelagic species such as lantern fish are expected in the mid-water and the monk gear used would not target these species. We would expect however if mesopelagic species were abundant in the area that they would be recorded in small quantities either in the trawls or in the wings of the net. This did not occur.

3. The verification survey also provided baseline data on biodiversity. The diversity of fish is low compared with the EIA – this is expected as the EIA consolidated information on all the species and all the surveys (types) in and around the proposed dredging area. With respect to fish species, epifauna and mammals and seabirds, no unique features were noted and the results are consistent with the initial assessment (accepting that abundance of some species, particularly sea birds and mammals will vary seasonally as well as spatially).
4. With regard to the oceanographic conditions (Section D, Appendix 2.3) as derived from the CTD measurements we make no inference other than that no unusual conditions were noted that would result in uncertainty in interpretation of the data on marine fauna;
5. With regard to ecosystem (Section C, Chapter 3.1) impacts as a whole, the survey itself suggests that the area possesses no unique features. We noted that there are occasional large catches of jellyfish as well as of ascidians. This is typical of the area inside and near the MLA and the skipper of the monk trawl survey vessel (a regular trawler skipper) confirmed that this is consistent with what would be expected for that area.
6. Further, with regard to ecosystems (Section C, Chapter 3.1) as a whole, the uncertainty stated in the original EIA is supported. The primary issue is one of scale and it is the considered view that the area of impact (up to 3 km^2 annually and 60 km^2 for the 20-year mining lease period) is so small relative to the overall Benguela ecosystem that significant impacts on the ecosystem are unlikely. Typical ecosystem modeling which has been done on both the northern and southern Benguela is unlikely to provide any useful guidance on either the large scale or localized impacts as determined by the EIA. The verification process has strengthened the need to maintain a baseline and to monitor this for changes in the system around the area to be dredged. This will facilitate management of the process and inform the likely effects if these activities were to expand and if incorporated into the management plan for the area, will allow for appropriate responses to any changes.
7. Mesopelagic fish, gobies and zooplankton (Section C, Chapter 2.7) are well known for their diurnal vertical migrations producing strong scattering layers that are typically seen on echo sounders. Little is known about the potential effects of marine dredging (in particular the

© NMP 2014

potential impacts of sediment plumes) on these scattering layers. Obtaining scientifically defensible indices of abundance of these species in and around SP-1 would require a sophisticated research vessel with purpose built fishing gear. Future monitoring surveys should attempt to track the scattering layer patterns using industrial or scientific echo sounders in order to infer the relative availability of these species. Samples could also be taken if mid-water trawl gear were available on the survey vessel and if the vessel had adequate power to be able to tow such gear to nullify the avoidance behaviour of these species. The echo-sounder tracks would nevertheless provide adequate information on which to gauge the presence of these species and can be used as a baseline to monitor responses of this group of species to dredging operation.

8. The geophysical data (Section D, Appendix 3.2) conclusively revealed a flat, smooth seafloor with a homogeneous surficial sediment cover across the entire survey block. No protruding obstacles were observed. The various images produced by the geophysical survey show that the surficial sediment composition of the area was a muddy medium sand. This was further supported by the trawl surveys, suggesting that the habitat was homogeneous and primarily of firm sandy gravelly (shell) character
9. Previous studies of the potential impacts of sound from dredging vessels on a variety of species showed that sound levels in all cases are well below those known to cause damage to marine life. Thus, if we assume that the sound frequency and decibel level of sound emanating from a typical Tailer Suction Hopper Dredger (TSHD) intended to be used in this project, then dredging noise impact can be assessed as low.

11 RECOMMENDATIONS

i. It is recommended that should an environmental clearance certificate be issued that monitoring (baseline time series) continues. This should include a similar survey using similar design annually. For continuity similar vessels and gear should be used such that results are comparable and so that a baseline biomass index can be further developed
ii. There is a lack of specific mine site information on noise emissions from dredgers and their potential effects; thus it is recommended that some acoustic monitoring at the target dredge site (SP-1) to determine the levels of dredging noise and to monitor whales and dolphins using Passive Acoustic Monitoring (PAM) devices should be undertaken. It is also recommended that marine mammal observers could be trained to use such devices and could be a part of a monitoring team on board the dredging vessel or during dedicated monitoring surveys.
iii. Future surveys should attempt to track the scattering layer patterns in order to infer the relative availability of mesopelagic species, gobies and zooplankton. This could be achieved using industrial or scientific echo sounders. Samples of could also be taken if mid-water trawl gear were available on the survey vessel and if the vessel had adequate power to be able to tow such gear to nullify the avoidance behaviour of these species. However, echo-sound data should be adequate to gauge the presence of these species, which can be used as a baseline to monitor responses of these groups of species to dredging operation.
iv. The monitoring of the baseline can be strengthened if NatMIRC adapted their current survey design for both the monk and hake annual surveys. For relatively low additional cost and effort the MLA and or SP-1 areas can be incorporated into these surveys. This would strengthen the baseline as well as providing MFMR with an alternative independent estimate of conditions and changes that may occur in the dredged area.

© NMP 2014

12 ACKNOWLEDGEMENTS

Thanks are due to Jeremy Midgley and Mike Woodborne for solid logistical and technical support, to fellow scientists; Kate Munnik, Victor Ncongo, Dr Robert Williamson, Malakia Shimhanda and Ester Nangolo for great team work and to Tim Reddel, Andries Olivier, Captain Francois Bouman and the crew of FV *Zeearend* for unstinting assistance. Thanks also to the Namibian Ministry (MFMR) in particular, the NatMIRC Scientists Paul Kiange, John Kathema and Dr Chris Batholomae for their exceptional cooperation and acknowledged efforts in making this project possible. Special thanks to James Gaylard, Dr Hilkka Ndjaula and Dr Kevern Cochrane for their outstanding contributions.

13 SUPPORTING DOCUMENTATION

Ahlstrom EH, Moser HG and O'Toole MJ (1977). Development and distribution of larvae and early juveniles of the commercial lanternfish, *Lampanyctodes hectoris* (Gunther), off the west coast of southern Africa with a discussion of phylogenetic relationships of the genus. *Bull South Calif Acad Sci* **75**: 138-152.

Assorov VV and Berenbeim Y. (1983) Spawning grounds and cycles of Cape hake in the Southeast Atlantic. *ICSEAF Colln. Scient. Pap. Int. Commn. SE. ATL. Fish*. **10**: 27 – 30.

Atkinson LJ (2009). Effects of demersal trawling on marine infaunal, epifaunal and fish assemblages: studies in the southern Benguela and Oslofjord. Thesis presented for the Degree of Doctor of Philosophy in the department of Zoology, Faculty of Science and Ma-Re Institute University of Cape Town. September 2009.

Atkinson LJ, Field JG and Hutchings L (2011).Effects of demersal trawling along the west coast of southern Africa : multivariate analysis of benthic communities. *Marine Ecology Progress Series* **430**: 241-255.

Bianchi G, Carpenter KE, Roux J-P, Molloy FJ, Boyer D and Boyer HJ (1999). *FAO species identification field guides for fishery purposes. The Living Marine Resources of Namibia.* Rome, FAO 265 pp.

Branch GM, Griffiths CL, Branch ML and Beckley LE (2010). *Two Oceans*. *A Guide to the Marine Life of southern Africa*. Struik Nature, Cape Town; 456 pp.

Botha L (1986). Reproduction, sex ratio, and rate of natural mortality of Cape hakes *Merluccius capensis* Cast. and *M. paradoxus* Franca in the Cape of Good Hope area. *S. Afr. J. Mar. Sci* **4**: 23-35.

Boyer DC and Hampton I (2001a), An overview of the living marine resources of Namibia. *S. Afr. J. Mar. Sci* **23**: 5-35.

Boyer DC, Fossen H and Kreiner A (2001). Changes in abundance of the northern Benguela sardine stock during the decade 1990–2000, with comments on the relative importance of fishing and the environment. In *A Decade of Namibian Fisheries Science.* Payne AIL, Pillar SC. and R. J. M. Crawford (Eds). *S. Afr. J. Mar. Sci*. **23**: 67–84.

© NMP 2014

CEDA 2011. CEDA position paper: underwater sound in relation to dredging. *Terra et Aqua*. Number 125.

Cedras RB, Salvanes A and Gibbons MJ (2011): Investigations into the diet and feeding ecology of the bearded goby *Sufflogobius bibarbatus* off Namibia, *African Journal of Marine Science*, **33:2**, 313-320.

Chapman P and Shannon LV (1985). The Benguela ecosystem. Part II. Chemistry and related processes. *Oceanogr Mar Biol, Ann Rev* **23**: 183-251.

Clarke AM and Courtman-Stock J (1976). *The echinoderms of southern Africa*. British Museum (Natural History). 277 pp.

Cockcroft AC (2001). *Jasus lalandii* 'walkouts' or mass strandings in South Africa during the 1990s: an overview. *Marine and Freshwater Research* **25**: 1085-1093.

Crawford RJM and de Villiers G (1985). Snoek and their prey – interrelationships in the Benguela upwelling system. *S. Afr. J. Mar. Sci* **81**: 91-97.

Crawford RJM, Cruickshank RA, Shelton PA and Kruger I (1985). Partitioning of a goby resource amongst four avian predators and evidence for altered trophic flow in the pelagic community of an intense, perennial upwelling system. *S Afr J Mar Sci:* 215-228.

Crawford RJM, Shannon LV and Pollock DE (1987). The Benguela ecosystem. Part IV. The major fish and invertebrate resources. *Oceanogr. Mar. Biol. Ann. Rev*. **25**: 353-505.

Cruickshank RA, Cooper J and Hampton I (1980). Extension to the geographical distribution of pelagic goby *Sufflogobius bibarbatus* off South West Africa and some mensural and energetic information. *Fisheries Bulletin of South Africa* **13**: 77-82.

Currie H, Grobler K and Kemper J (2000). Namibian Islands' Marine Protected Area - WWF South Africa Report Series – 2008/Marine/003 Project funded by WWF South Africa and NACOMA.

Defra (2003). Preliminary investigation of the sensitivity of fish to sound generated by aggregate dredging and marine construction. *Project AE0914 Final Report.* Defra / Department for Environment, Food And Rural Affairs, London, UK.

Dingle RV and Nelson G (1993). Sea bottom temperature, salinity and dissolved oxygen on the continental margin off south western Africa. *S. Afr. J. mar. Sci.* 13: 33–49.

Duncombe Rae (2005). A demonstration of the hydrographic partition of the Benguela upwelling ecosystem at 26°40'S. *African Journal of Marine Science* **27(3**):617–628.

Emery WJ and Meincke J (1986). Global water masses: Summary and review. Department of Oceanography, University of British Columbia, Vancouver, B.C., V6T 1W5, Canada.

© NMP 2014

Emeis K-C, Brüchert V, Currie B, Endler R, Ferdelman T, Kiessling A, Leipe T, Noli-Peard K, Struck U, and Vogt T (2004). Shallow gas in shelf sediments of the Namibian coastal upwelling ecosystem. *Continental Shelf Research,* 24:627-642.

Fairweather T and Leslie R (2008). *Merluccius capensis* and *M. paradoxus* length at 50% maturity based on research survey biological data. *MCM/2008/AUG/SWG-DEM/42*

Gordoa A, Lesch H and Rodergas S (2006). Bycatch: complementary information for understanding fish behaviour. Namibian Cape hake. (*M. capensis* and *M. paradoxus*) as a study. *ICES Journal of Marine Science* **63**: 1513-1519.

Griffiths MH (2002). Life History of South African snoek, *Thyristes atun* (Pisces: Gempylidae): a pelagic predator of the Benguela ecosystem. *Fisheries Bulletin* **100**: 690-710.

Griffiths MH (2003). Stock structure of snoek *Thyrsites atun* in the Benguela: a new hypothesis. *S. Afr. J. Mar. Sci.* **25**: 383-386.

Heymans J, Shannon L and A Jarre (2004). Changes in the northern Benguela ecosystem over three decades: 1970s, 1980s, and 1990s. *Ecological Modelling* **172** (2004) 175–195.

Heymans J (2004). The effects of internal and external control on the Northern Benguela ecosystem. (upbub).

Heymans JJ, Sumalia UR and Christensen V (2009). Policy options for the northern Benguela ecosystem using a multispecies, multi-fleet ecosystem model *Progress in Oceanography.* 83. 417–425.

Heymans S and Sumalia (2012). R.U.Updated ecosystem model for the northern Benguela Ecosystem, Namibia, (in ECOFISH Ecosystem Models, Le Quesne, Arreguín-Sánchez and Heymans) Scottish Association for Marine Science, Dunbeg, Oban PA37 1QA, Scotland and Fisheries Centre, 2202 Main Mall, Vancouver, BC, V6T1Z4, Canada.

Holtzhausen JA, Kirchner CH and Voges SF (2001). Observations of the linefish resources of Namibia, 1990-2000, with special reference to west coast steenbras and silver kob. *S. Afr. J. Mar. Sci.* **23**: 135-144.

Hulley PA (1986). Lanternfishes of the southern Benguela region. Part 1. Faunal complexity and general distribution. *Ann S. Afr. Mus* **97**: 227-249

Hulley PA (1991) Order Myctophiformes. In: Smith MM, and Heemstra PC (Eds). *Smith's Sea Fishes.* Southern Book Publishers, Johannesburg: pp 282-322.

Hundt M, Utne-Palm AC and Gibbons MJ (2011). Cross-shelf observations of diet and diel feeding behaviour of the bearded goby *Sufflogobius bibarbatus* off Namibia. *African Journal of Marine Science* 2011, **33(1**): 119–126.

Japp 2012. Appendix 1a. Namibian Marine Phosphate – Environmental Impact Assessment of Fish, mammals and seabirds: Proposed monitoring and verification of Impacts in the proposed Mining Area). In: Midgley 2012. Sandpiper Project Environmental Impact

Assessment Report
http://www.namphos.com/project/sandpiper/environment/item/57-environmental-marine-impact-assessment-report.html.

JNCC (2010). Marine mammal recording forms (Detailed sighting records).Joint Nature Conservation Committee.

Kathena J, Iitembu J and A. van der Plas (2010). Cruise Report (RV '*Welwitchia*) Monkfish Biomass Survey 04 – 22 Nov. 2010 (National Marine Information and Research Centre (NatMIRC) Swakopmund, 2010.

Kirchner CH and Voges SF (1999). Growth of Namibian silver kob *Argyrosomus inodorus* based on otoliths and mark-recapture data. *S. Afr. J. Mar. Sci.* **21**: 201-209.

Kirchner CH and Holtzhausen JA (2001). Seasonal movements of Siver kob, *Argyrosomus inodorus*, (Griffiths and Heemstra) in Namibian waters. *Fisheries Management and Ecology Journal*. **8**: 239-251.

Ludick W (2014). ML170 (SP-1) Sea floor conditions. Namibian Marine Phosphate. Unpublished Report. 6 pp.

Maartens L (1999). An Assessment of the monkfish resource of Namibia. Submitted in fulfilment of the requirements for the degree of doctor of philosophy of Rhodes University.

Maartens L and Booth AJ (2005). Aspects of the reproductive biology of monkfish *Lophius vomerinus* off Namibia. *S. Afr. J. Mar. Sci.* **27**: 325–329.

Melo YC and Le Clus F (2005). Growth and reproduction of the pelagic goby *SufflogobiUs bibartus* off the Orange River, southern Africa. *African Journal of Marine Science* **27**: 265-273.

Mohrholz V, Schmidt M, Lutjeharms JRE (2001). The hydrography and dynamics of the Angola Benguela Frontal Zone and environment in April 1999. *S. Afr. J. Mar. Sci.* **97**:199–210.

Monteiro PMS, van der Plas AK (1996). Low Oxygen Water (LOW) variability in the Benguela System: Key processes and forcing scales relevant to forecasting. In: Wefer G, Berger WH, Siedler G, Webb DJ (eds) *The south Atlantic: Present and past circulation.* Spinger-Verlag Berlin, Germany, pp 163–210.

Moodley MN (2008). A new dendrochirotid sea cucumber from the west coast of South Africa (Echinodermata: Holothuroidea: Cucumariidae). *African Zoology* **43** (1): 61-65.

Olivar MP, Rubies P and Salat J (1988). Early life history and spawning of *Merluccius capensis* Castelnau in the northern Benguela Current. *S. Afr. J. Mar Sci.* **16**: 245 – 254.

Osborne RF, Mello YC, Hofmeyr MD and Japp DW (1999) Serial spawning and batch fecundity of *Merluccius capensis* and *M paradoxus*. *African Journal of Marine Science* **21**: 211 – 216.

© NMP 2014

OSPAR (in press) Draft preliminary comprehensive overview of the impacts of anthropogenic underwater sound in the marine environment, OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic.

O'Toole MJ (1976). Incidental collections of small and juvenile fishes from egg and larval surveys off South West Africa (1972-1974). *Fish Bull (S Afr):* 23-33.

O'Toole MJ (1977). Investigation into some important fish larvae in the South-East Atlantic. PhD Thesis, University of Cape Town 299 p.

Pollock DE (1986). Review of the fishery for and biology of the Cape rock lobster *Jasus lalandii* with notes on larval recruitment. *Canadian Journal of Fisheries and Aquatic Sciences* **43**: 2107-2117.

Prosch RM, Hulley PA, and Cruickshank RA (1995). Mesopelagic fish and some other forage species. In: Payne AIL, and Crawford RJM (Eds). *Oceans of life off Southern Africa.* Vlaeberg, Cape Town: 130-135.

Richardson WJ, Malme CI, Green Jr CR, Thomson DH (1995) *Marine mammals and noise*, Vol 1. Academic Press, San Diego, California, USA.

Robinson SP; Theobald PD; Hayman G; Wang LS; Lepper PA; Humphrey V; Mumford S (2011). Measurement of noise arising from marine aggregate dredging operations, MALSF (MEPF Ref no. 09/P108). Published by the MALSF ISBN 978 0907545 57 6.

Roux JP and Shannon LJ (2004). Ecosystem approach to fisheries management in the northern Benguela: the Namibian experience, *African Journal of Marine Science*, **26:1**, 79-93.

Rubies P, Bas C and Margalef R (1985). Zoography of the lanternfishes (Osteichthyes, Myctophidae) of southwest Africa. In: Bas C, Margalef R, and Rubies P (Eds). *International symposium on the most important upwelling areas of Western Africa (Cape Blanco and Benguela).* Instituto de Investigaciones Pesqueras, Barcelona: 573-586.

Ryan PG (1991). The impact of the commercial lobster fishery on seabirds at the Tristan da Cunha Islands, South Atlantic Ocean. *Conservation Biology* **57**, (3): 339 – 350.

Salvanes AG, Utne-Palm AC, Currie B and Braithwaite VA (2011). Behavioural and physiological adaptations of the bearded goby, a key fish species of the extreme environment of the northern Benguela upwelling. *Mar Ecol Prog Ser* Vol. **425**: 193–202.

Shannon LV and Pillar SC (1986). The Benguela ecosystem. Part III Plankton. *Oceanography and Marine Biology.* An Annual Review **24**: 65-170.

Shannon LV and Nelson G (1996). The Benguela: Large scale features and processes and system variability. In: Wefer G, Berger WH, Siedler G, Webb DJ (eds) T*he south Atlantic: Present and past circulation.* Spinger-Verlag Berlin, Germany, pp 163–210.

Shin YJ, Shannon LJ and Cury PM (2004). Ecosystem Approaches to Fisheries in the Southern Benguela. *African Journal of Marine Science*. **26**: 95–114.

© NMP 2014

Singh L, Melo Y and Glazer J (2011). Merluccius capensis and M. paradoxus length at 50% maturity based on histological analyses of gonads from surveys. *FISHERIES/2011/JUL/SWG-DEM/33.*

Singh S and Johannes E (2013). Hake diet data update: Validation and some analyses *FISHERIES/2013/AUG/SWG-DEM/22.*

Singh L (2013). Length weight relationship of both hake species. *FISHERIES/2013/OCT/SWG-DEM/58.*

Staby A and Krakstad JO (2008). Review of the state of knowledge, research (past and present) of the distribution, biology, ecology, and abundance of non-exploited mesopelagic fish (Order *Anguilliformes, Argentiniformes, Stomiiformes, Myctophiformes, Aulopiformes*) and the bearded goby (*Sufflogobius bibarbatus*) in the Benguela Ecosystem. *BCLME project LMR/CF/03/08.*

Steffani N (2010). Biological baseline survey of the benthic macrofauna communities in the Phosphate Licence Blocks EPL 3415 and EPL 3233 in the Sandpiper/Meob JV Project Area. 29 pp.

Steffani N (2013). Benthic Macrofauna in the Sandpiper SP-1 Target Mining Area. Verification Survey. Draft Report. 53 pp.

Sundby S, Boyd AJ, Hutchings L, O'Toole MJ, Thorisson K and Thorsen A (2001). Interaction between Cape hake spawning and the circulation in the northern Benguela upwelling ecosystem. *S. Afr. J. Mar Sci.* **23**: 317-336.

Thandar AS, Zettler ML and Arumugam P (2010). Additions to the sea cucumber fauna of Namibia and Angola, with descriptions of new taxa (Ecinodermata: Holothuroidea). *Zootaxa* **2655**: 1-24.

Thomsen F, McCully S, Wood D, Pace F and White P (2009). A generic investigation into noise profiles of marine dredging in relation to the acoustic sensitivity of the marine fauna in UK waters with particular emphasis on aggregate dredging: PHASE 1 Scoping and review of key issues.) Marine Aggregate Levy Sustainability Fund (MALSF) MEPF Ref No. MEPF/08/P21

Travers MK, Watermeyer LJ, Shannon, Shin Y-J (2010). Changes in food web structure under scenarios of overfishing in the southern Benguela: Comparison of the Ecosim and OSMOSE modelling approaches. *Journal of Marine Systems* **79**: 101–111.

Travers-Trolet M, Shin Y-J, Shannon LJ, Moloney CL, Field JG (2014). Combined Fishing and Climate Forcing in the Southern Benguela Upwelling Ecosystem: An End-to-End Modelling Approach Reveals Dampened Effects. PLoS ONE 9(4): e94286. doi:10.1371/journal.pone.0094286.

Utne-Palm AC, Salvanes AGV, Currie B, Kaartveldt S, Nilsson GE, Braithwaite VA, Stecyk JAW, Hundt M, van der Bank M, Flynn B, Sandvik GK, Klevjer TA, Sweetman AK, Bruchert V, Pittman

© NMP 2014

K, Peard KR, Lunde IG, Strandabo RAU, Gibbons MJ (2010). Trophic structure and community stability in an overfished ecosystem. *Science* **329**: 333-329.

Van der Bank FH and Kirchner CH (1997). Biochemical genetic markers to distinguish two sympatric and morphologically similar Namibian marine fish species, *Argyrosomus coronus* and *Argyrosomus indorus* (Perciformes: Sciaenidae). *African Journal of Zoology* **111**: 441-448.

Weeks SJ, Currie B, Bakun A, and Peard KR (2004). Hydrogen sulphide eruptions in the Atlantic Ocean off southern Africa: implications of a new view based on SeaWiFS satellite imagery. *Deep-Sea Research Part I,* **51**:153-172.

© NMP 2014

Annexure 1. Coordinates for the original and actual trawl stations.

Station Number	Date Start	Time Start	Day or Night	Start Bottom Depth	End Bottom Depth	Trawl time (hr)	Start latitude	Start longitude	End latitude	End longitude
1	18-Jun-14	18:05	N	229	231	0.5	-24.10	13.95	-24.12	13.95
2	20-Jun-14	07:35	D	230	235	0.5	-24.13	13.95	-24.16	13.95
3	20-Jun-14	12:35	D	241	244	0.5	-24.20	13.93	-24.23	13.93
4	20-Jun-14	16:12	D	231	232	0.5	-24.23	13.96	-24.25	13.96
5	24-Jun-14	15:05	D	218	216	0.5	-24.02	13.99	-24.04	13.98
6	21-Jun-14	07:13	D	217	219	0.5	-24.20	13.98	-24.18	13.98
7	21-Jun-14	11:56	D	213	214	0.7	-24.17	13.99	-24.14	13.99
8	21-Jun-14	16:00	D	213	213	0.5	-24.12	13.99	-24.09	13.99
9	22-Jun-14	07:05	D	198	198	0.5	-24.10	14.02	-24.12	14.02
10	22-Jun-14	10:22	D	201	202	0.5	-24.15	14.02	-24.17	14.02
11	22-Jun-14	13:45	D	202	203	0.5	-24.20	14.01	-24.18	14.01
12	22-Jun-14	17:00	D	242	244	0.5	-24.26	13.94	-24.28	13.94
13	25-Jun-14	00:55	N	255	255	0.6	-24.28	13.92	-24.31	13.92
14	24-Jun-14	21:55	N	209	210	0.5	-24.18	14.00	-24.20	14.00
15	23-Jun-14	19:00	N	221	222	0.5	-24.17	13.98	-24.20	13.98
16	23-Jun-14	22:20	N	209	209	0.5	-24.11	14.00	-24.14	14.00
17	23-Jun-14	12:55	D	223	224	0.5	-24.08	13.97	-24.10	13.97
18	26-Jun-14	00:55	N	238	238	0.5	-24.18	13.94	-24.16	13.94
19	25-Jun-14	21:55	N	234	233	0.5	-24.21	13.95	-24.18	13.95
20	25-Jun-14	17:40	N	225	225	0.5	-24.26	13.97	-24.28	13.97
21	24-Jun-14	18:55	N	205	205	0.5	-24.02	14.01	-24.05	14.01
22	26-Jun-14	18:52	N	249	252	0.5	-24.22	13.92	-24.25	13.92
23	24-Jun-14	01:35	N	221	221	0.5	-24.11	13.98	-24.14	13.98
24	26-Jun-14	22:15	N	237	235	0.5	-24.14	13.93	-24.11	13.93

© NMP 2014

Annexure 2. Fish (monk and hake) length at 50% maturity and their length-weight relationship.

Fish length at 50% maturity

All monk and hake with inactive gonads were considered to be immature (except for those gonads which were inactive and spent), whereas all stages from active to spent were considered as representing mature fish. Mature and immature fish were sorted into 4 cm size classes and the percentage of mature fish was calculated for each length class. The resultant curves are shown in Figures 35 – 40. Females of both species matured at greater lengths than males. The percentage of fish below the length of 50% maturity was calculated for monk females (80%), monk males (45%), hake females (6%) and hake males (8%).

© NMP 2014

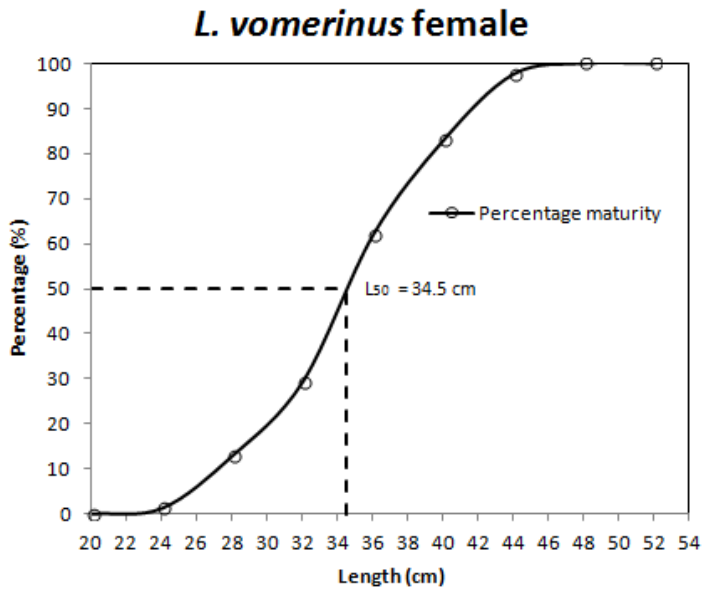


Figure 35: Percentage of mature female monk per length class.
Length at 50% maturity is also shown.

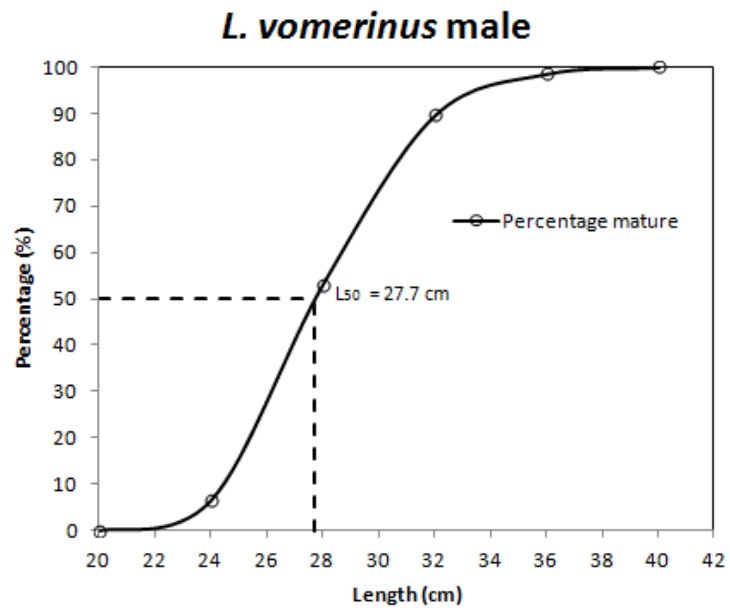


Figure 36: Percentage of mature male monk per length class.
Length at 50% maturity is also shown.

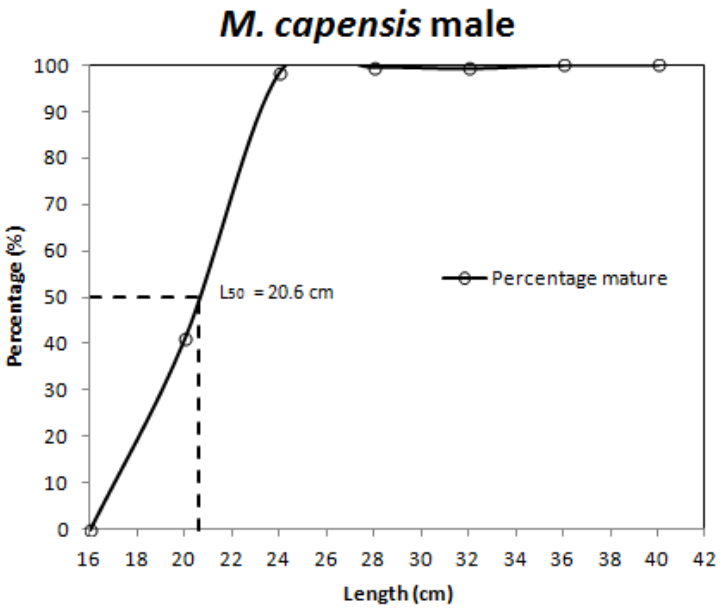


Figure 37: Percentage of mature male hake per length class.
Length at 50% maturity is also shown.

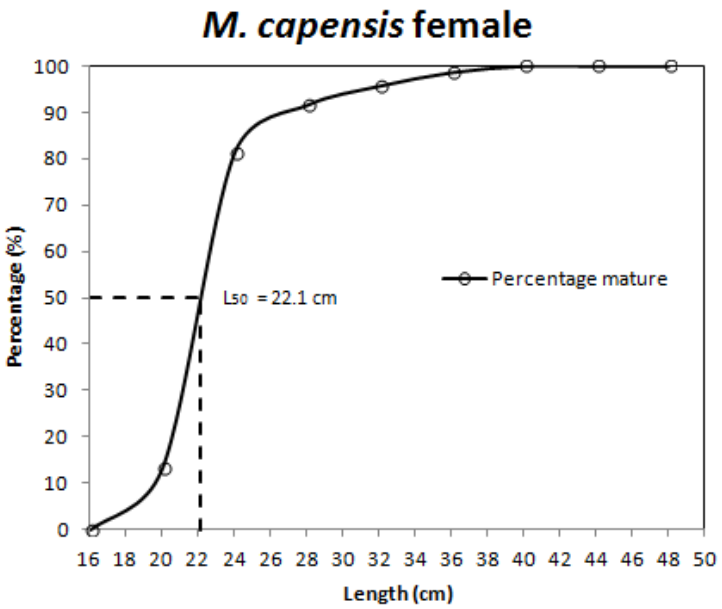


Figure 38: Percentage of mature female hake per length class.
Length at 50% maturity is also shown.

Fish length – weight

Biological testing, consisting of individual weight and length measurements, sex, maturity stage and stomach contents were carried out for monk and hake for each station. Length-weight relationships are presented for monk and hake in Figure 47 and 48, respectively.

© NMP 2014

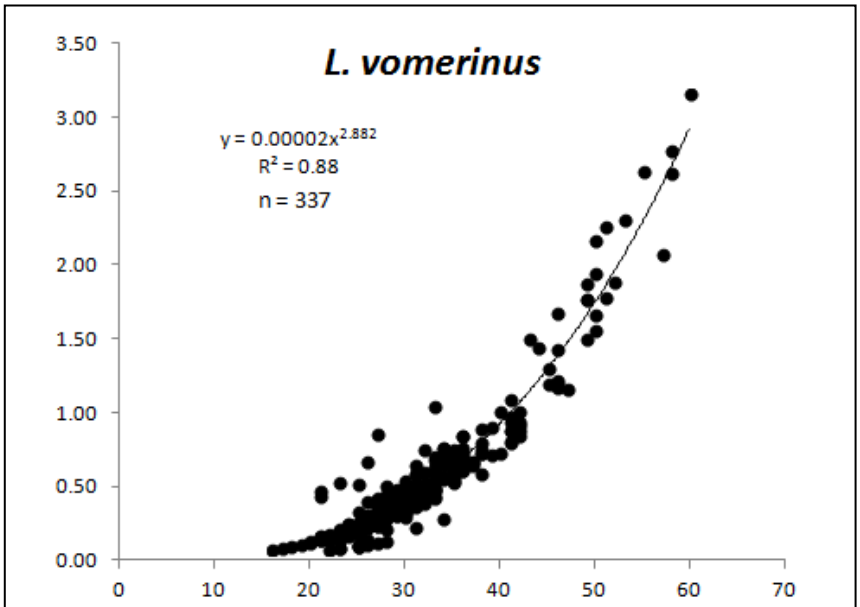


Figure 39: Length-weight relationship for monk.

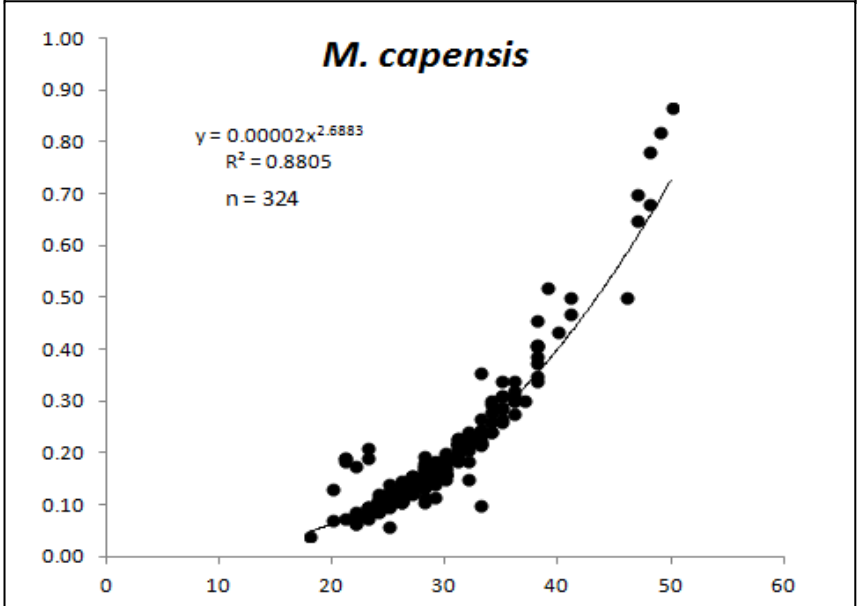


Figure 40: Length-weight relationship for hake.

SECTION C - SPECIALIST STUDIES

C3.2 Fisheries Biomass and Stock Assessment

NAMIBIAN MARINE PHOSPHATE

VERIFICATION SURVEY

BIOMASS AND STOCK ESTIMATES OF HAKE AND MONK IN THE MINING LEASE AREA ML 170 OF NAMIBIAN PHOSPHATE

Prepared for:
Namibian Marine Phosphate (Pty) Ltd.

Prepared by:
Capricorn Fisheries Monitoring cc
James Gaylard
Independent Fisheries Stock Assessment Scientist

Cape Town

November 2013

JAMES GAYLARD
Independent Fisheries Stock Assessment Scientist Cape Town
jamesdgaylard@gmail.com

CAPFISH (Pty) LTD
Unit 15, Foregate Square. Table Bay Boulevard, 8002, South Africa
Directors: Japp, Wissema, Heinecken, Wilkinson, Ncongo
Co Reg. No. 2004 / 004844 / 07

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed "Attention: Administration Manager," at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

contents

SUMMARY iv

1 INTRODUCTION 1

2 DATA 2

3 METHODS 3

3.1 BIOMASS ESTIMATES: GENERAL APPROACH 3
3.2 STRATIFICATION 4
3.3 LENGTH CLASSES 4
3.4 CALCULATIONS: MASS AND DENSITY PER STATION. 5
3.5 CALCULATIONS: STRATIFIED MEAN AND VARIANCE 6
3.6 CALCULATIONS: CONTRIBUTION OF MLA AND S-1 SITE TO THE RESOURCE. 8

4 RESULTS 8

5 CONCLUSIONS 9

6 REFERENCES 9

7 ADDITIONAL TABLES AND FIGURES. 10

ANNEXURE A: AREA CALCULATIONS 33

figures

Figure S1. Position of demersal Survey Trawls relative to the Mining Lease Area (MLA) and landmark Reference points. iv
Figure S2. MLA and the Sandpiper dredging sites, SP-1 & (SP-2 & SP-3). iv
Figure 1. Position of demersal Survey Trawls relative to the Mining Lease Area (MLA) and landmark reference points. 1
Figure 2. MLA 170 and the Sandpiper sites. 1
Figure 3. Position of survey stations inside the MLA for the demersal surveys in years 2007 through 2012, by longitude and latitude. 3
Figure 4. Position of Survey trawls (2007 to 2012) in the MLA by depth and latitude. (Note that due to the scaling used in this figure, the MLA appears distorted and does not reflect the exact geographical shape as in Figure 3). 3
Figure 5. Maturity at length for *M. capensis* 5
Figure 6(a) *M. capensis* Density estimates (log scale) by latitude and depth division, panelled by length class. Error bars represent 2 standard errors either side of the mean. 30

© NMP 2014

Figure 6(b) *M. paradoxus* Density estimates (log scale) by latitude and depth division, panelled by length class. Error bars represent 2 standard errors either side of the mean. 31
Figure 6(c) *L. vomerinus* Density estimates (log scale) by latitude and depth division, panelled by length class. Error bars represent 2 standard errors either side of the mean. 32
Figure A1. Schematic plot of the MLA and Sandpiper sites 34
Figure A2. 50m depth contours in the Sandpiper areas and the surrounding area. 35

tables

Table 1. Demersal surveys used in this study 2
Table 2. Stratification with sample sizes (number of survey trawls) per stratum. 4
Table 3. Length Classes by Species 4
Table 4. Parameters of the Length: Weight Function (Source: Kainge 2011) 6
Table 5. Area by stratum, for the resource, the MLA and the dredging site SP-1. 10
Table 6(a). Summary of biomass and recruitment Estimates, Average 2007 to 2012 (Approach 2) 11
Table 6(b). Biomass and recruitment estimates, Comparison of Approach 1 and Approach 2. 12
Table 7(a). Estimated percentage contribution of the MLA and the SP-1 dredging site to the *M. capensis* resource 13
Table 7(b). Estimated percentage contribution of the MLA and the SP-1 site to the *M. paradoxus* resource 13
Table 7(c). Estimated percentage contribution of the MLA and the SP-1 site to the *L.vomerinus* resource 13
Table 8(a). Density and biomass estimates by stratum, *M. capensis* juveniles (0 to 16 cm) 14
Table 8(b). Density and biomass estimates by stratum, *M. capensis* recruits (17 to 27 cm) 15
Table 8(c). Density and biomass estimates by stratum, *M. capensis* maturing stock (28 to 36 cm) 16
Table 8(d). Density and biomass estimates by stratum, *M. capensis* mature stock (37 cm +) 17
Table 8(e). Recruits (numbers) by stratum, *M. capensis* recruits (17 to 27 cm) 18
Table 9(a). Density and biomass estimates by stratum, *M. paradoxus* juveniles (0 to 16 cm). 19
Table 9(b). Density and biomass estimates by stratum, *M. paradoxus* recruits (17 to 27 cm). 20
Table 9(c). Density and biomass estimates by stratum, *M. paradoxus* maturing stock (28 to 35 cm). 21
Table 9(d). Density and biomass estimates by stratum, *M. paradoxus* mature stock (36 cm+). 22
Table 9(e). Recruits (numbers) by stratum, *M. paradoxus* recruits (17 to 27 cm). 23
Table 10(a). Density and biomass estimates by stratum, *L. vomerinus* juveniles (0 to 16 cm). 24
Table 10(b). Density and biomass estimates by stratum, *L. vomerinus* recruits (17 to 27 cm). 25
Table 10(c). Density and biomass estimates by stratum, *L. vomerinus* maturing stock (28 to 35 cm). 26
Table 10(d). Density and biomass estimates by stratum, *L. vomerinus* mature stock (36 cm +). 27
Table 10(e). Recruits (numbers) by stratum, *L. vomerinus* recruits (17 to 27 cm). 28
Table 11. *L. vomerinus* catch per depth range from the November Monk surveys 2007 to 2010 between 23 and 26 degrees latitude. 29
Table A1. Coordinates of the vertices of the polygons defining the MLA and the SP-1 dredging site 34
Table A2. Calculations of Area of the MLA and decomposition by Depth Range 36
Table A3. Calculations of Area of Resource Habitat by Stratum 37

© NMP 2014

SUMMARY

Namibian Marine Phosphate (Pty) Ltd has identified the existence of a high grade phosphate deposit on the Namibian continental shelf. This deposit lies approximately 40-60 km offshore from Conception Bay in water depths of 190 to 300 m. A specialist study was undertaken by Japp (in Midgley 2012) to assess the possible impacts of the proposed mining of the phosphate resource on fish, fisheries, seabirds and marine mammals. The Mining Lease Area (MLA 170) lies between latitudes 23.9°S and 24.9°S. MLA 170 contains three proposed Sandpiper dredging sites. The plan is to initially dredge within the Sandpiper-1 (SP-1) area only. Figures S1 and S2 below show the location of the MLA relative to the demersal fishery (represented here by survey stations) and the position of the Sandpiper sites within the MLA.

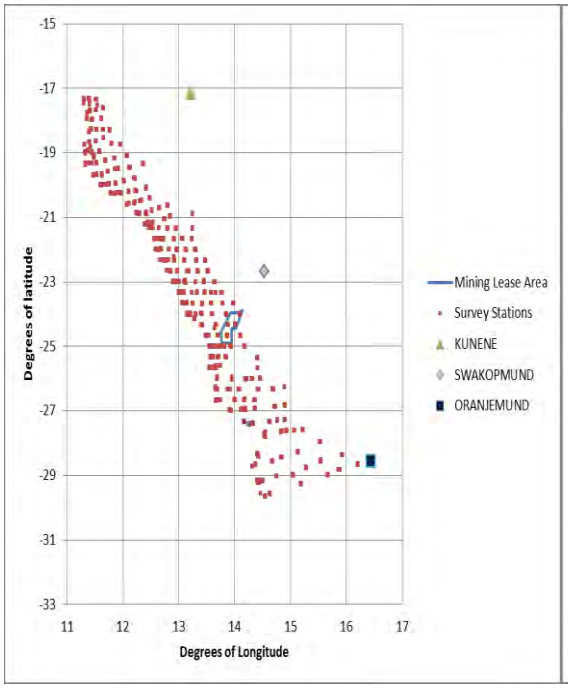


Figure S1. Position of demersal Survey Trawls relative to the Mining Lease Area (MLA) and landmark Reference points.

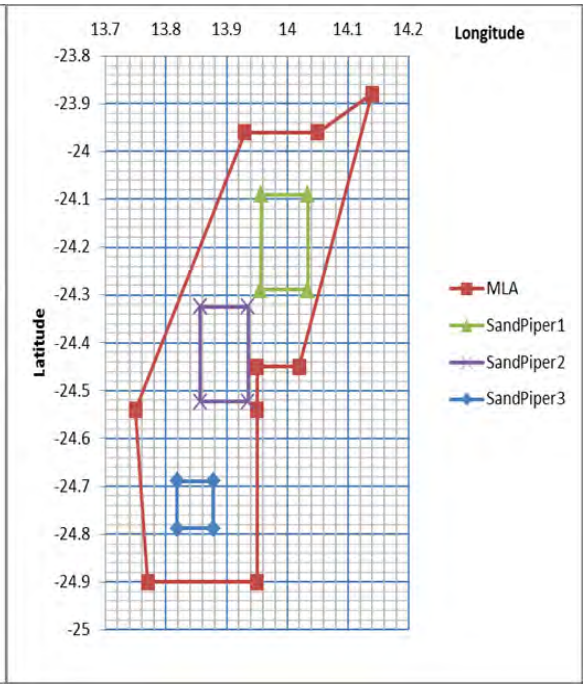


Figure S2. MLA and the Sandpiper dredging sites, SP-1 & (SP-2 & SP-3).

The present study acts as a supplement to Japp (in Midgley 2012), in which we focus on estimating the contribution of the MLA and surrounding areas to biomass for three commercially exploited finfish:

- *Merluccius capensis* (Cape hake)
- *Merluccius paradoxus* (Deep-water Cape hake)
- *Lophius vomerinus* (Cape monk)

For each of these we considered 4 size categories: juveniles, recruits, maturing stock and mature stock. Demersal survey data for 2007 through 2012 provided by NatMIRC were used to estimate biomass in 28 spatial strata (7 depth divisions by 4 latitude divisions) within the Namibian fishery. Densities within these strata were appropriately weighted up in proportion to the area contributions of these strata to the MLA in general and to the Sandpiper-1 dredge site in particular. These calculations resulted in the following estimates of the contribution of the MLA and the SP-1 site to the various components of the fisheries resources under consideration:

© NMP 2014

	MLA	95% Confidence Interval	SP-1	95% Confidence Interval
% of Area	1.3%		0.11%	
% of Biomass *M. capensis*	1.6%	(1.3% , 2%)	0.14%	(0.1% , 0.18%)
% of Mature Stock *M.capensis*	1.6%	(1.1% , 2%)	0.11%	(0.07% , 0.16%)
% of Recruits *M. capensis (b*y number)	1.6%	(1.1% , 2.2%)	0.20%	(0.12% , 0.28%)
% of Biomass *M. paradoxus*	0.01%	(0% , 0.035%)	0.00%	(0% , 0.01%)
% of Mature Stock *M. paradoxus*	0.001%	(0% , 0.003%)	0.00%	(0% , 0.001%)
% of Recruits *M. paradoxus* (by number)	0.07%	(0% , 0.197%)	0.00%	(0% , 0.01%)
% of Biomass *L. vomerimus*	2.0%	(0.9% , 3.1%)	0.06%	(0.04% , 0.08%)
% of Mature Stock *L. vomerimus*	0.8%	(0.4% , 1.2%)	0.03%	(0.01% , 0.04%)
% of Recruits *L. vomerimus* (by number)	7.0%	(1.8% , 12.3%)	0.20%	(0.07% , 0.34%)

The MLA is estimated to contain less than 1.6% of the Namibian biomass for *M. capensis*, which reduces to 0.14% if the SP-1 dredge site only is considered. These estimated biomasses approximate the relative proportions of each area. No notable departure from these proportions is estimated for either the recruits or the spawning adults. The 23^0 to 26^0 latitude band is a breeding ground for *M. capensis*, containing a large proportion of juveniles, however the overwhelming majority of these are at depths less than 200 m, whereas most of the MLA lies in deeper waters.

M. paradoxus adults are scarce in depths of less than 300 m, and the younger fish (less than 27 cm) are predominantly found south of 26^0 S. Thus the MLA and in particular the SP-1 site have very little interaction with *M. paradoxus* (less than 0.2% of biomass in entire MLA.

For monk, the MLA is estimated to contribute about 2% to overall biomass. This is less (0.8%) among the mature stock which tend to lie in deeper water and further South. The monk recruits however are more prevalent in the MLA than for hake, with an estimated 7% of recruits in the MLA (Table 7c). Most of this contribution to recruitment however is in the 250 to 300 m depth range and is not in the area to be dredged (SP-1). The SP-1 site is shallower than 250 m, and so this is estimated to contribute only 0.2% of recruitment to the fishery. We stress also that recruitment will be affected by many factors, including fishing pressure and variability in environmental and oceanographic conditions and will not necessarily remain constant from year to year.

In conclusion, less than 0.2% of each species considered lies directly within the proposed SP-1 mining site. The SP-1 site also makes no significant contribution to recruitment or spawner stock biomass for any of the species considered in this assessment. Outside of SP-1 and within the larger MLA, the biomass of monk expected to contribute to the recruitment to the fishery is estimated to be 7%. This assessment makes no judgement on the possible impact on recruitment of dredging only in SP-1 on the area outside of SP-1 and within the total MLA. It is emphasized that, as the proportion of the potential biomass in SP-1 and recruiting to the commercial fisheries in the adjacent areas is extremely small, the broader impact, if scaled outside of the dredged area, is likely to be minimal.

© NMP 2014

1 INTRODUCTION

Namibian Marine Phosphate (Pty) Ltd has identified the existence of a high grade phosphate deposit on the Namibian continental shelf. This deposit lies approximately 60 km offshore from Conception Bay in water depths of 190 to 300 m. A specialist fishery study was undertaken by Japp (in Midgley 2012) to assess the possible impacts of the proposed dredging of the phosphate resource on fish, fisheries, seabirds and marine mammals. For a broader background, refer to Japp and Smith (2012).

The Mining Lease Area (MLA 170) has been demarcated between latitudes 23.9 ^{o}S and 24.9^{o}S. The MLA contains three proposed dredging sites (SP-1, SP-2, SP-3). This is illustrated in Figures 1 and 2 below. Also shown in Figure.1 is the distribution of trawls in the annual demersal surveys conducted by the Namibian National Marine Information and Research Centre (NatMIRC), which serves as a good representation of the extent of the demersal fishery off the Namibian coast.

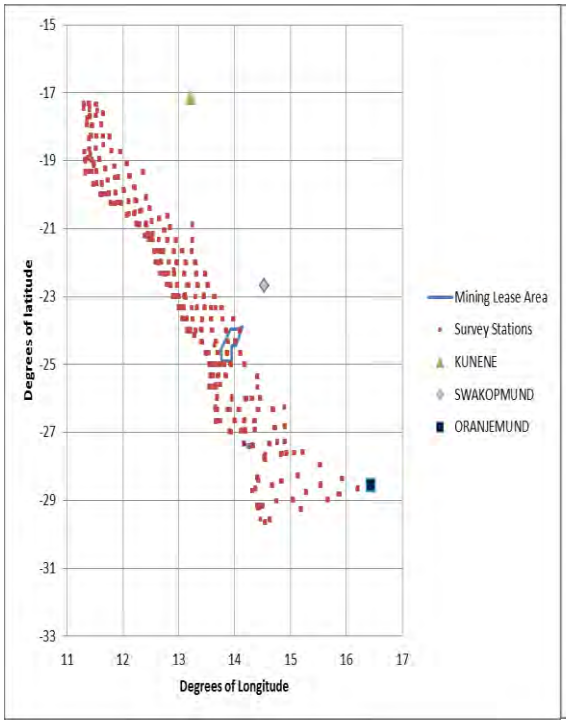


Figure 1. Position of demersal Survey Trawls relative to the Mining Lease Area (MLA) and landmark reference points.

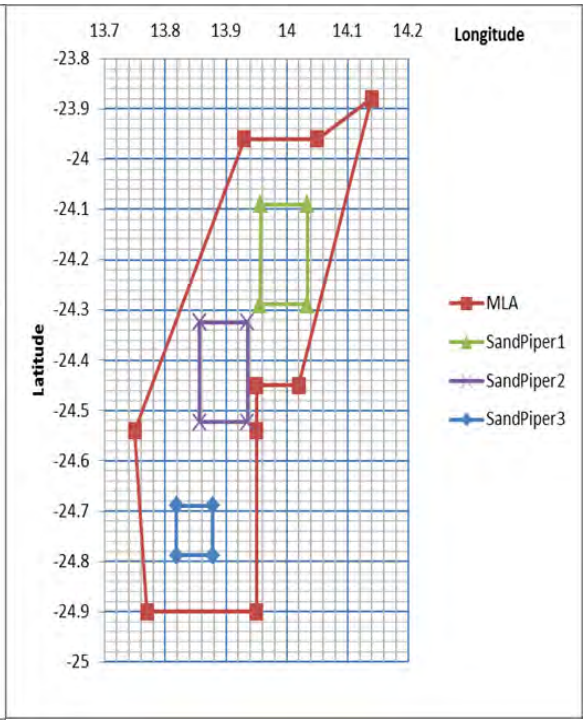


Figure 2. MLA 170 and the Sandpiper sites.

The present study acts to augment the EIA assessment of Japp (in Midgley 2012), in which I focus on estimating the contribution of the MLA and surrounding areas to biomass for three commercially exploited finfish:

- *Merluccius capensis* (Cape hake)
- *Merluccius paradoxus* (Deep-water Cape hake)
- *Lophius vomerinus* (Cape monk)

I estimate for each of these four species:

- The contribution of the MLA and the SP-1 dredging site to total resource biomass
- The contribution to recruitment
- The contribution to spawner stock

2 DATA

Data used in this part of the study are:

1. Demersal Survey data for 2007 through 2012, provided by NatMIRC. Data used include the following for each trawl station:

    a. Catch weight by species,
    b. Sample weight by species,
    c. Frequencies by species and 1cm length class.
    d. Depth
    e. Latitude
    f. Longitude
    g. Trawl speed
    h. Wing spread
    i. Trawl distance

Table 1. Demersal surveys used in this study

Survey	Number of Stations	Date of first Trawl
2007502	213	11 January 2007
2008501	212	12 January 2008
2009501	222	12 January 2009
2010501	217	14 January 2010
2011501	217	14 January 2011
2012501	217	13 January 2012
TOTAL	**1298**	

2. Monk Survey data 2007 through 2010

3. Details of the geography of the Sandpiper sites and the mining lease area

© NMP 2014

3 METHODS

3.1 BIOMASS ESTIMATES: GENERAL APPROACH

Annual biomass estimates conducted by NatMIRC, using the demersal surveys, are calculated using 100 m depth bands, with no further stratification performed by latitude or other dimensions (Kainge 2011).

Given that our focus in this study is to estimate biomass in a particular (and relatively small) component of the habitat, it was felt that a finer-scale stratification was needed in order to adequately capture local effects which may differ from the norm, for example the possibility of a greater than average density of juveniles in and around the MLA.

Two approaches were considered:

- *Approach 1:* To use observations from within the region of interest itself to directly estimate densities in the SP-1 dredging site and surrounding MLA.
- *Approach 2:* To estimate biomass in appropriate strata in a larger area surrounding the region of interest, and to infer densities inside the MLA by appropriate weighting of strata in proportion to the areas represented by those strata.

Only 24 survey trawls were conducted in the MLA between 2007 and 2012, and these are clustered in four specific locations (see Figure 3) so that Approach 1 was considered too unreliable an estimator. We have thus adopted Approach 2 as the principal method, but have performed the calculations for Approach 1 as well for comparison.

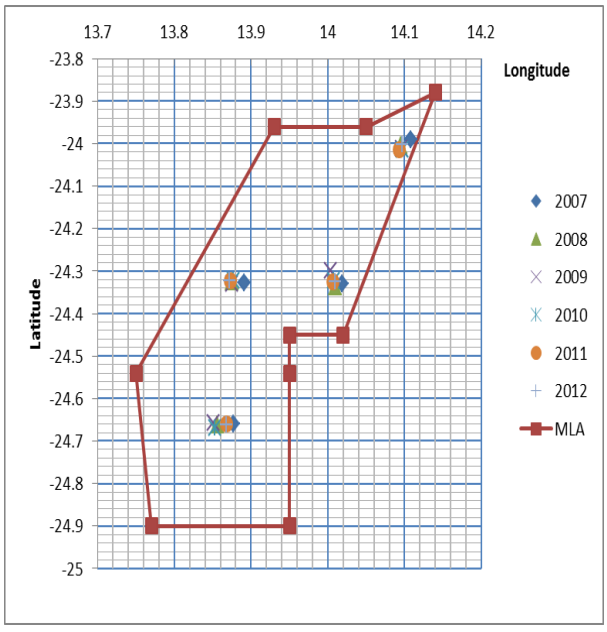


Figure 3. Position of survey stations inside the MLA for the demersal surveys in years 2007 through 2012, by longitude and latitude.

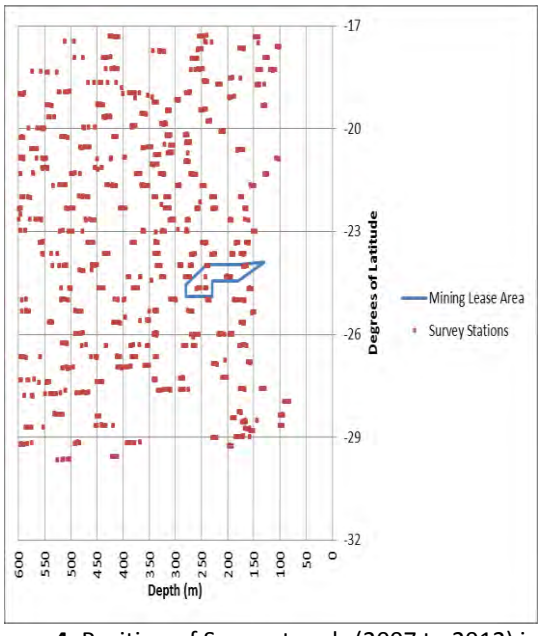


Figure 4. Position of Survey trawls (2007 to 2012) in the MLA by depth and latitude. (Note that due to the scaling used in this figure, the MLA appears distorted and does not reflect the exact geographical shape as in Figure 3).

3.2 STRATIFICATION

Because the objective is to estimate an average expected biomass in the MLA over an extended period of time, rather than an annual index, we have aggregated the data over the 6 years (2007 to 2012) for which data were available for this study.

Strata defined for the purposes of this study are 4 latitude divisions by 7 depth divisions as illustrated in Table 2 below. Thus 28 strata are defined in all, which is comparable to the 30 effective strata used in the annual resource biomass estimates over the same period (5 depth divisions by 6 years).

Table 2. Stratification with sample sizes (number of survey trawls) per stratum.

Latitude (^{0}S)	500 to 600 m	400 to 500 m	300 to 400 m	250 to 300 m	200 to 250 m	150 to 200 m	100 to 150 m	Total
17 to 20	35	45	45	31	33	18	43	250
20 to 23	73	54	97	51	22	29	17	343
23 to 26	43	50	66	36	35	66	3	299
26 to 30	59	61	55	24	19	71	11	300
Total	**210**	**210**	**263**	**142**	**109**	**184**	**74**	**1192**

3.3 LENGTH CLASSES

In order to develop separately contributions of the MLA to recruitment, spawning stock etc. I have conducted calculations on four size classes for each species, which we define as follows:

Table 3. Length Classes by Species

Juveniles	1 to 16 cm
Recruits	17 to 27 cm
Maturing Stock	28 to 36 cm
Mature Spawning Stock	37 cm +

Note that for *M. capensis* the first two classes defined above are consistent with Kainge et al (Kainge 2011), who omit the "juvenile" class from biomass estimates (on the grounds that escape from the gear is both large and inconsistent. NatMIRC (Kainge 2011) also produce an annual recruitment index for *M. capensis* using the "recruit" class, but on a numbers rather than mass basis. The 37cm cut-off for "mature spawning stock" is the estimated length at 95% maturity (Kirchner 2012)[1]. (See Figure 5 below). An alternative here would be to produce a maturity weighted biomass estimate summed across all length classes, but it is felt that the current method makes for simpler categorisation and is sufficient to estimate the contribution of the MLA to this component of the fishery. For the other two species, *M. paradoxus* and *L. vomerinus*, I adopt the same length classes for consistency.

[1] This refers to the ogive in Figure 5 which estimates the relative proportion of fish that are estimated to have obtained maturity at a particular length interval

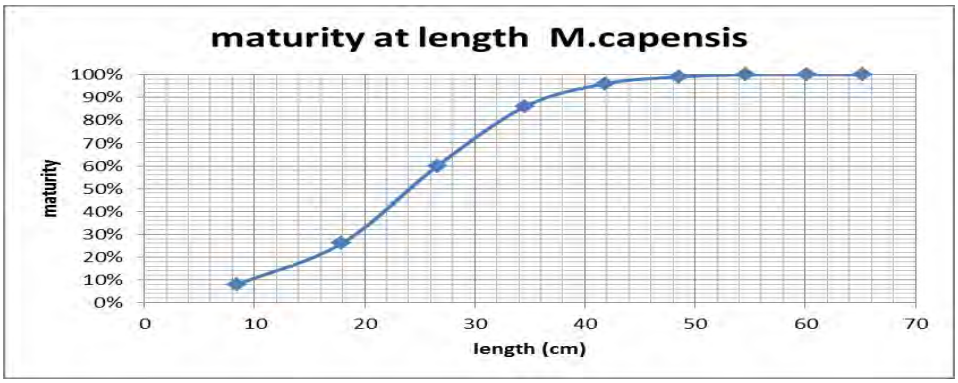


Figure 5. Maturity at length for *M. capensis*

3.4 CALCULATIONS: MASS AND DENSITY PER STATION.

In the notation below, dependence on species is taken as understood and omitted for simplicity. The calculations are in effect repeated independently for each of the four species considered in the study.

The mass of fish of length l in the trawl catch at station *i* is calculated as

$$w_{i,l} = a.l^b.n_{i,l}.f_i \quad (1)$$

where:

$n_{i,l}$ is the number of fish of length l in the sample at station *i*

a and b are parameters of the length : weight function for each species, the values of which can be found in Table 4 below.

$$f_i = \frac{W_i}{\sum_{l=1}^{150} a.l^b.n_{i,l}} \quad (2)$$

is a normalising factor, ensuring that

$$W_i = \sum_{l=1}^{150} w_{i,l} \quad (3)$$

where

W_i is the total catch of species in the trawl *i*, recorded in the data provided.

Mass within each of 4 length classes are calculated as

$$W_{J,i} = \sum_{l=1}^{16} w_{i,l} \quad \text{(Juveniles)} \quad (4)$$

$$W_{R,i} = \sum_{l=17}^{27} w_{i,l} \quad \text{(Recruits)} \quad (5)$$

© NMP 2014

$W_{M,i} = \sum_{l=28}^{36} w_{i,l}$ (Maturing) (6)

$W_{S,i} = \sum_{l=36}^{150} w_{i,l}$ (Mature spawning stock) (7)

Density per station (kg per square mile) is calculated as

$$\partial_i = \frac{W_i}{d_i.\Omega/1852}$$ [2] (8)

where:

d_i is the distance (miles) trawled at station *i*, which is provided in the data
Ω = 18.5 is the gear wingspread in metres
1852 is the conversion factor from metres to miles.

Similarly, for each of the 4 length classes L ε {J; R; M; S}:

$$\partial_{L,i} = \frac{W_{L,i}}{d_i.\Omega/1852}$$ (9)

Table 4. Parameters of the Length: Weight Function (Source: Kainge 2011)[3]

	a	b
M. capensis	0.006	3.007
M. paradoxus	0.005	3.096
L. vomerinus	0.013	3.012

3.5 CALCULATIONS: STRATIFIED MEAN AND VARIANCE

For each stratum s, the mean density is calculated as:

$$\partial_s = \frac{1}{m_s} \sum_{i\,\varepsilon\,s} \partial_i$$ (10)

with error variance:

$$V_s = \frac{1}{m_s(m_s-1)} \sum_{i\,\varepsilon\,s} (\partial_i - \partial_s)^2$$ (11)

where:

m_s is the number of stations trawled in stratum s.

[2] This assumes a swept area which is the product of distance trawled and wingspread, an assumption which is consistent with the methods of Kainge(201l)
[3] Where applicable, parameters for males and females have been averaged.

I calculate stratified biomass estimates for three regions R = H (entire resource habitat), M (mining lease area) or D (SP-1 Dredging site) as

$$B^R = \ {}_S A_S^R . \partial_s \quad (12)$$

with error variance:

$$V = \ {}_S A_S^{R\,2} . V_s \quad (13)$$

and coefficient of variation:

$$\mathrm{CV} = \frac{\overline{\mathrm{V}}}{\mathrm{B}} \quad (14)$$

where:

$\mathrm{A_S^R}$ is the area, in square miles, represented by stratum S, in region R. These areas are given in Section 6, Table 5.

Whereas Equations (11) to (14) are for the species as a whole, we conduct similar calculations for each length class L, as follows:

$$\partial_{s,L} = \tfrac{1}{m_s} \quad i \,\varepsilon\, s \; \partial_{i,L} \quad (15)$$

$$V_{s,L} = \tfrac{1}{m_s(m_s-1)} \quad i \,\varepsilon\, s \; (\partial_{iL} - \partial_{s,L})^2 \quad (16)$$

$$B_L{}^R = \ {}_S A_S^R . \partial_{s,L} \quad (17)$$

with error variance:

$$V_L = \ {}_S A_S^{R\,2} . V_{s,L} \quad (18)$$

and coefficient of variation:

$$\mathrm{CV}_L = \frac{\overline{\mathrm{V}_L}}{\mathrm{B}} \quad (19)$$

3.6 CALCULATIONS: CONTRIBUTION OF MLA AND S-1 SITE TO THE RESOURCE.

1000 Random draws[4] were taken from each of the estimates of B_L^H , B_L^M and B_L^D assuming normal distributions with mean and variances as estimated a in part 4.5 (see Tables 6.) The ratios $\frac{B_L^D}{B_L^H}$ and $\frac{B_L^B}{B_L^H}$ were calculated for each iterate. The median, 2.5th and 97.5th percentiles were captured to constitute estimates and 95% confidence intervals respectively.

4 RESULTS

Table 6(a) shows the biomass estimates by length class and estimates of recruitment for the Resource, MLA 170 and SP-1 site, using Approach 2, which is the preferred method. Table 6(b) shows comparative results for Approaches 1 and 2. All further results reflect Approach 2 only.

Tables 7(a) to (c) provide the estimates of the contributions of the MLA and SP-1 site as a proportion of the resource. Tables 8(a) to 10(e) provide detailed density and biomass estimates by stratum, species and size class. These are also plotted in Figs 6(a) to (d).

The MLA is estimated to contain less than 2% of the Namibian biomass of *M. capensis*, which reduces to 0.2% if the SP-1 mining site only is considered. This is roughly in line with the area contribution as seen in Table 7(a). No notable departures from this proportion is estimated for either the recruits or the spawning adults. We note that the 23 to 26 degree latitude band is a breeding ground for *M. capensis*, containing a large proportion of juveniles, however the overwhelming majority of these are at depths less than 200 m, whereas most of the MLA lies in deeper waters.

M. paradoxus adults are scarce in depths of less than 300 m, and the younger fish (less than 27 cm) are predominantly found south of 26 degrees. Thus the MLA and in particular the SP-1 site have very little interaction with *M. paradoxus* (less than 0.2% of biomass in entire MLA). See Figure 6(b) and Table 9.

For monk, the MLA is estimated to contribute about 2% to overall biomass. This is less (0.7%) among the mature stock which tend to lie in deeper water and further south (Table 9(e)). The recruits however are more prevalent in the MLA, with an estimated 7% of recruits in the MLA (Table 7(c)). Note that most of this contribution is in the 250 to 300 m depth range (Table 10b). The SP-1 site is shallower than 250 m, and so this is estimated to contribute only 0.2% of recruits.

[4] The implicit assumption here is that error in the estimates of Biomass in the resource, MLA and SP-1 site respectively are uncorrelated. This is in effect a conservative assumption as there is likely to be some positive correlation so that the resulting margins of error are likely in fact to be over-estimated.

© NMP 2014

5 CONCLUSIONS

In conclusion, less than 0.2 % of each species considered lies directly within the proposed SP-1 dredging site. The SP-1 site also makes no significant contribution to recruitment or spawner stock biomass for any of the species considered in this assessment. Outside of SP-1 and within the larger MLA, the biomass of monk expected to contribute to the recruitment to the fishery is estimated to be 7%. This assessment makes no judgement on the possible impact on recruitment of dredging only in SP-1 on the area outside of SP-1 and within the total MLA. It is emphasized however that as, the proportion of the potential biomass in SP-1 and recruiting to the commercial fisheries in the adjacent areas is extremely small, the broader impact, if scaled outside of the mined area, is likely to be minimal.

6 REFERENCES

Kainge, P. J. Kathena, J. Iitembu, A. van der Plas and O. Alvheim. (2011). Surveys of the Hake Stocks. Survey No. 2011501: 12 January – 24 February 2011. Namibian Ministry of Fisheries and Marine Resources. Cruise Report No 1/2011.

Kirchner, C; P. Kainge, and J. Kathena. (2012). Evaluation of the Status of the Namibian Hake Resource (*Merluccius* spp.) Using Statistical Catch-at-Age Analysis.

Maartens, L. (1999). An assessment of the monkfish resource of Namibia. PHD. Rhodes University. Grahamstown. South Africa.

Japp, D. and M. Smith (2012) Appendix A to the Environmental Impact Assessment Report, Dredging of marine phosphates from ML 170, Fisheries, Mammals and Seabirds Specialist Study.

Acknowledgements:

The authors would like to acknowledge the support of Dr Paul Kainge from the Ministry of Fisheries in Namibia for providing the necessary data, and Dr Carola Kirchner for providing valuable support and background information.

7 ADDITIONAL TABLES AND FIGURES.

Table 5. Area by stratum, for the resource, the MLA and the dredging site SP-1.[5]

Latitude (°S)	Depth (m)	Resource Area	MLA Area	SP-1
26 to 30	100 to 150	892		
	150 to 200	5757		
	200 to 250	753		
	250 to 300	951		
	300 to 400	1781		
	400 to 500	984		
	500 to 600	638		
23 to 26	100 to 150	243	3	
	150 to 200	5352	127	18
	200 to 250	1386	227	33
	250 to 300	1426	286	
	300 to 400	2138		
	400 to 500	806		
	500 to 600	465		
20 to 23	100 to 150	1379		
	150 to 200	2352		
	200 to 250	871		
	250 to 300	2020		
	300 to 400	3142		
	400 to 500	871		
	500 to 600	790		
17 to 20	100 to 150	3487		
	150 to 200	1460		
	200 to 250	1307		
	250 to 300	1228		
	300 to 400	1457		
	400 to 500	726		
	500 to 600	379		
	TOTAL	**45040.18**	**643**	**51**

[5] Detailed calculations can be found in Annexure 1.

© NMP 2014

Table 6(a). Summary of biomass and recruitment Estimates, Average 2007 to 2012 (Approach 2)

		Resource	s.e.	MLA	s.e.	SP-1	s.e.
Area (Sq Miles)	100m to 600m depth range	45 040		643		51	
M. capensis	Biomass Juvenile	35 673	28277	826	670	114	94
	Biomass Recruits	247 144	30955	3 869	733	488	112
	Biomass Maturing Stock	167 422	26440	2 886	499	279	64
	Biomass Mature Stock	360 456	26142	5 602	750	408	77
	Biomass Total	896 634	70888	14 579	1461	1 289	177
	Biomass Total Excluding Juveniles	858 910	65622	13 873	1364	1 176	150
	Number of Recruits (millions)	3 417	402	56	9	7	1
M. paradoxus	Biomass Juvenile	635	182	0	0	0.0	0.0
	Biomass Recruits	25 341	4201	16	15	0.0	0.0
	Biomass Maturing Stock	44 888	4830	5	3	0.0	0.0
	Biomass Mature Stock	80 332	6051	1	1	0.0	0.0
	Biomass Total	151 337	11064	21	16	0.0	0.0
	Biomass Total Excluding Juveniles	150 561	11042	21	16	0.0	0.0
	Number of Recruits (millions)	269	44	0.19	0	0.0	0.0
L. vomerinus	Biomass Juvenile	160	50	4	2	0.3	0.1
	Biomass Recruits	2 232	410	166	62	4.7	1.6
	Biomass Maturing Stock	3 290	519	119	39	3.2	1.0
	Biomass Mature Stock	13 706	1175	107	27	3.5	1.1
	Biomass Total	19 431	1644	398	107	11.7	2.2
	Biomass Total Excluding Juveniles	19 229	1629	393	106	11.5	2.2
	Number of Recruits (millions)	10	2	0.72	0	0.02	0.01

© NMP 2014

Table 6(b). Biomass and recruitment estimates, Comparison of Approach 1 and Approach 2.

				Approach 1		Approach 2	
		Resource	s.e.	MLA	s.e.	MLA	s.e.
Area (Sq Miles)	100m to 600m depth range	45 040		643		643	
M. capensis	Biomass Juvenile	35 673	28277	115	59	826	670
	Biomass Recruits	247 144	30955	15410	6307	3 869	733
	Biomass Maturing Stock	167 422	26440	10645	8157	2 886	499
	Biomass Mature Stock	360 456	26142	5030	2065	5 602	750
	Biomass Total	896 634	70888	31208	13587	14 579	1461
	Biomass Total Excluding Juveniles	858 910	65622	26178	13587	13 873	1364
	Number of Recruits (millions)	3 417	402	150	55	56	9
M. paradoxus	Biomass Juvenile	635	182	0.0	-	0	-
	Biomass Recruits	25 341	4201	0.0	-	16	15
	Biomass Maturing Stock	44 888	4830	0.0	-	5	3
	Biomass Mature Stock	80 332	6051	0.0	-	1	1
	Biomass Total	151 337	11064	0.0	-	21	16
	Biomass Total Excluding Juveniles	150 561	11042	0.0	-	21	16
	Number of Recruits (millions)	269	44	0.0	-	0.19	0.2
L. vomerinus	Biomass Juvenile	160	50	9	9	4	2
	Biomass Recruits	2 232	410	212	190	166	62
	Biomass Maturing Stock	3 290	519	22	12	119	39
	Biomass Mature Stock	13 706	1175	30	16	107	27
	Biomass Total	19 431	1644	277	209	398	107
	Biomass Total Excluding Juveniles	19 229	1629	248	209	393	106
	Number of Recruits (millions)	10	2	0.90	0.80	0.72	0.3

© NMP 2014

Table 7(a). Estimated percentage contribution of the MLA and the SP-1 dredging site to the *M. capensis* resource

	MLA	95% Confidence Interval	SandPiper-1	95% Confidence Interval
% of Area	1.3%		0.11%	
% of Biomass	1.6%	(1.3% , 2%)	0.14%	(0.1% , 0.18%)
% of Mature Stock	1.6%	(1.1% , 2%)	0.11%	(0.07% , 0.16%)
% of Recruits	1.6%	(1.1% , 2.2%)	0.20%	(0.12% , 0.28%)

Table 7(b). Estimated percentage contribution of the MLA and the SP-1 site to the *M. paradoxus* resource

	MLA	95% Confidence Interval95% CI	SandPiper-1	95% Confidence Interval95% CI
% of Area	1.3%		6.9%	
% of Biomass	0.01%	(0% , 0.035%)	0.00%	(0% , 0.01%)
% of Mature Stock	0.001%	(0% , 0.003%)	0.00%	(0% , 0.001%)
% of Recruits	0.07%	(0% , 0.197%)	0.00%	(0% , 0.01%)

Table 7(c). Estimated percentage contribution of the MLA and the SP-1 site to the *L.vomerinus* resource

	MLA	95% Confidence Interval	SandPiper-1	95% Confidence Interval
% of Area	1.3%		0.11%	
% of Biomass	2.0%	(0.9% , 3.1%)	0.06%	(0.04% , 0.08%)
% of Mature Stock	0.8%	(0.4% , 1.2%)	0.03%	(0.01% , 0.04%)
% of Recruits	7.0%	(1.8% , 12.3%)	0.20%	(0.07% , 0.34%)

© NMP 2014

Table 8(a). Density and biomass estimates by stratum, *M. capensis* juveniles (0 to 16 cm)

Latitude (°S)	Depth (m)	mean density	s.e.	Resource Biomass	s.e.	Biomass in MLA	s.e.	Biomass in SP-1	s.e.
26 to 30	100 to 150	181.3	0.4	162	67	0	0	0	0
	150 to 200	116.7	43.1	672	248	0	0	0	0
	200 to 250	348.8	316.9	263	238	0	0	0	0
	250 to 300	9.3	6.7	9	6	0	0	0	0
	300 to 400	0.0	0.0	0	0	0	0	0	0
	400 to 500	0.0	0.0	0	0	0	0	0	0
	500 to 600	0.0	0.0	0	0	0	0	0	0
23 to 26	100 to 150	1329.1	1226.0	323	298	5	4	0	0
	150 to 200	5921.8	5282.1	31693	28269	751	670	106	43
	200 to 250	245.0	90.3	340	125	56	20	8	8
	250 to 300	51.9	23.8	74	34	15	7	0	9
	300 to 400	0.2	0.2	0	0	0	0	0	0
	400 to 500	0.0	0.0	0	0	0	0	0	0
	500 to 600	0.0	0.0	0	0	0	0	0	0
20 to 23	100 to 150	124.8	44.0	172	61	0	0	0	0
	150 to 200	549.1	156.1	1291	367	0	0	0	0
	200 to 250	392.8	226.3	342	197	0	0	0	0
	250 to 300	105.0	29.7	212	60	0	0	0	0
	300 to 400	9.5	4.2	30	13	0	0	0	0
	400 to 500	0.0	0.0	0	0	0	0	0	0
	500 to 600	0.0	0.0	0	0	0	0	0	0
17 to 20	100 to 150	10.4	5.0	36	18	0	0	0	0
	150 to 200	6.4	3.1	9	4	0	0	0	0
	200 to 250	31.9	17.1	42	22	0	0	0	0
	250 to 300	0.7	0.5	1	1	0	0	0	0
	300 to 400	1.6	1.1	2	2	0	0	0	0
	400 to 500	0.0	0.0	0	0	0	0	0	0
	500 to 600	0.0	0.0	0	0	0	0	0	0
TOTAL				**35673**	**28277**	**826**	**670**	**114**	**94**

© NMP 2014

Table 8(b). Density and biomass estimates by stratum, *M. capensis* recruits (17 to 27 cm)

Latitude (°S)	Depth (m)	mean density	s.e.	Resource Biomass	s.e.	Biomass in MLA	s.e.	Biomass in SP-1	s.e.
26 to 30	100 to 150	6966.3	0.2	6214	1504	0	0	0	0
	150 to 200	5207.5	1741.7	29981	10028	0	0	0	0
	200 to 250	10054.7	4514.2	7567	3397	0	0	0	0
	250 to 300	4097.6	2146.1	3895	2040	0	0	0	0
	300 to 400	0.8	0.5	1	1	0	0	0	0
	400 to 500	0.0	0.0	0	0	0	0	0	0
	500 to 600	0.0	0.0	0	0	0	0	0	0
23 to 26	100 to 150	408.7	465.0	99	113	1	2	0	0
	150 to 200	13549.4	3768.0	72515	20166	1411	393	241	43
	200 to 250	7451.9	2693.7	10331	3734	1551	561	247	8
	250 to 300	3165.8	914.0	4514	1303	905	261	0	9
	300 to 400	45.0	19.6	96	42	0	0	0	0
	400 to 500	0.0	0.0	0	0	0	0	0	0
	500 to 600	0.0	0.0	0	0	0	0	0	0
20 to 23	100 to 150	10528.8	6636.1	14514	9148	0	0	0	0
	150 to 200	14451.6	3830.0	33984	9007	0	0	0	0
	200 to 250	13556.8	4625.6	11814	4031	0	0	0	0
	250 to 300	2781.6	814.0	5619	1644	0	0	0	0
	300 to 400	186.0	65.7	584	206	0	0	0	0
	400 to 500	0.0	0.0	0	0	0	0	0	0
	500 to 600	0.0	0.0	0	0	0	0	0	0
17 to 20	100 to 150	3714.2	1056.2	12951	3683	0	0	0	0
	150 to 200	4063.3	1884.8	5931	2751	0	0	0	0
	200 to 250	6115.0	2768.6	7993	3619	0	0	0	0
	250 to 300	15091.1	11499.1	18530	14120	0	0	0	0
	300 to 400	6.9	3.0	10	4	0	0	0	0
	400 to 500	0.0	0.0	0	0	0	0	0	0
	500 to 600	0.0	0.0	0	0	0	0	0	0
TOTAL				**247144**	**30955**	**3869**	**733**	**488**	**112**

© NMP 2014

Table 8(c). Density and biomass estimates by stratum, *M. capensis* maturing stock (28 to 36 cm)

Latitude (°S)	Depth (m)	mean density	s.e.	Resource Biomass	s.e.	Biomass in MLA	s.e.	Biomass in SP-1	s.e.
26 to 30	100 to 150	2102.8	0.3	1876	580	0	0	0	0
	150 to 200	2159.8	734.3	12435	4228	0	0	0	0
	200 to 250	7804.0	3518.1	5873	2648	0	0	0	0
	250 to 300	9558.1	2782.9	9086	2646	0	0	0	0
	300 to 400	266.4	108.9	475	194	0	0	0	0
	400 to 500	0.0	0.0	0	0	0	0	0	0
	500 to 600	0.0	0.0	0	0	0	0	0	0
23 to 26	100 to 150	0.0	0.0	0	0	0	0	0	0
	150 to 200	5602.3	3054.0	29983	16344	584	318	100	43
	200 to 250	5421.2	1018.4	7516	1412	1128	212	179	8
	250 to 300	4106.7	1123.0	5856	1601	1174	321	0	9
	300 to 400	426.0	189.9	911	406	0	0	0	0
	400 to 500	0.0	0.0	0	0	0	0	0	0
	500 to 600	0.0	0.0	0	0	0	0	0	0
20 to 23	100 to 150	1480.3	812.2	2041	1120	0	0	0	0
	150 to 200	3083.9	761.5	7252	1791	0	0	0	0
	200 to 250	4454.3	1242.0	3882	1082	0	0	0	0
	250 to 300	4093.6	1184.1	8269	2392	0	0	0	0
	300 to 400	1031.8	225.6	3242	709	0	0	0	0
	400 to 500	2.0	1.4	2	1	0	0	0	0
	500 to 600	0.0	0.0	0	0	0	0	0	0
17 to 20	100 to 150	3160.6	1235.6	11020	4308	0	0	0	0
	150 to 200	5071.1	1014.4	7402	1481	0	0	0	0
	200 to 250	20615.0	13861.2	26946	18118	0	0	0	0
	250 to 300	17943.0	4728.5	22032	5806	0	0	0	0
	300 to 400	901.5	419.1	1314	611	0	0	0	0
	400 to 500	15.4	10.0	11	7	0	0	0	0
	500 to 600	0.0	0.0	0	0	0	0	0	0
TOTAL				**167422**	**26440**	**2886**	**499**	**279**	**64**

© NMP 2014

Table 8(d). Density and biomass estimates by stratum, *M. capensis* mature stock (37 cm +)

Latitude (°S)	Depth (m)	mean density	s.e.	Resource Biomass	s.e.	Biomass in MLA	s.e.	Biomass in SP-1	s.e.
26 to 30	100 to 150	408.8	1.0	365	363	0	0	0	0
	150 to 200	4488.5	873.1	25842	5027	0	0	0	0
	200 to 250	4243.5	1765.7	3194	1329	0	0	0	0
	250 to 300	11075.4	3537.7	10529	3363	0	0	0	0
	300 to 400	5842.2	2074.3	10407	3695	0	0	0	0
	400 to 500	33.9	19.0	33	19	0	0	0	0
	500 to 600	0.0	0.0	0	0	0	0	0	0
23 to 26	100 to 150	0.0	0.0	0	0	0	0	0	0
	150 to 200	3880.9	974.0	20770	5213	404	101	69	43
	200 to 250	10251.3	2260.8	14212	3134	2134	471	339	8
	250 to 300	10717.8	2013.9	15283	2872	3064	576	0	9
	300 to 400	5814.1	1055.4	12428	2256	0	0	0	0
	400 to 500	7.7	6.0	6	5	0	0	0	0
	500 to 600	6.9	6.9	3	3	0	0	0	0
20 to 23	100 to 150	5838.9	2901.4	8049	4000	0	0	0	0
	150 to 200	7717.6	2881.3	18149	6776	0	0	0	0
	200 to 250	12626.7	5338.3	11003	4652	0	0	0	0
	250 to 300	12428.6	3033.1	25107	6127	0	0	0	0
	300 to 400	13084.7	1804.5	41107	5669	0	0	0	0
	400 to 500	259.7	137.4	226	120	0	0	0	0
	500 to 600	1.5	1.5	1	1	0	0	0	0
17 to 20	100 to 150	679.9	269.2	2371	939	0	0	0	0
	150 to 200	10024.3	4156.5	14631	6067	0	0	0	0
	200 to 250	30547.0	9215.2	39928	12045	0	0	0	0
	250 to 300	42433.8	10163.5	52104	12480	0	0	0	0
	300 to 400	21746.5	6436.7	31694	9381	0	0	0	0
	400 to 500	4151.7	1513.1	3013	1098	0	0	0	0
	500 to 600	1.2	1.2	0	0	0	0	0	0
TOTAL				**360456**	**26142**	**5602**	**750**	**408**	**77**

© NMP 2014

Table 8(e). Recruits (numbers) by stratum, *M. capensis* recruits (17 to 27 cm)

Latitude (°S)	Depth (m)	numbers per sq. mile	s.e.	Recruits (millions)	s.e.	Recruits (millions) in MLA	s.e.	Biomass in SP-1	s.e.
26 to 30	100 to 150	110500.6	0.2	99	24	0	0	0	0
	150 to 200	71175.4	24323.2	410	140	0	0	0	0
	200 to 250	167292.4	72114.0	126	54	0	0	0	0
	250 to 300	68120.1	30326.4	65	29	0	0	0	0
	300 to 400	42.7	18.9	0	0	0	0	0	0
	400 to 500	0.0	0.0	0	0	0	0	0	0
	500 to 600	0.0	0.0	0	0	0	0	0	0
23 to 26	100 to 150	2420.3	2964.2	1	1	0	0	0	0
	150 to 200	183356.0	45289.8	981	242	19	5	3	1
	200 to 250	108527.0	34841.3	150	48	23	7	4	1
	250 to 300	49412.0	13044.5	70	19	14	4	0	0
	300 to 400	831.0	326.6	2	1	0	0	0	0
	400 to 500	0.0	0.0	0	0	0	0	0	0
	500 to 600	0.0	0.0	0	0	0	0	0	0
20 to 23	100 to 150	133395.3	83812.5	184	116	0	0	0	0
	150 to 200	186091.2	48516.1	438	114	0	0	0	0
	200 to 250	183373.7	62465.0	160	54	0	0	0	0
	250 to 300	40067.9	10715.6	81	22	0	0	0	0
	300 to 400	3209.3	946.7	10	3	0	0	0	0
	400 to 500	0.0	0.0	0	0	0	0	0	0
	500 to 600	0.0	0.0	0	0	0	0	0	0
17 to 20	100 to 150	52914.5	14004.1	185	49	0	0	0	0
	150 to 200	56726.7	24499.0	83	36	0	0	0	0
	200 to 250	82713.5	33317.1	108	44	0	0	0	0
	250 to 300	216227.3	164311.3	266	202	0	0	0	0
	300 to 400	170.0	61.5	0	0	0	0	0	0
	400 to 500	0.0	0.0	0	0	0	0	0	0
	500 to 600	0.0	0.0	0	0	0	0	0	0
TOTAL				**3417**	**402**	**56**	**9**	**7**	**1**

Table 9(a). Density and biomass estimates by stratum, *M. paradoxus* juveniles (0 to 16 cm).

Latitude (°S)	Depth (m)	mean density	s.e	Resource Biomass	s.e.	Biomass in MLA	s.e.	Biomass in SP-1	s.e.
26 to 30	100 to 150	17.8	1.0	16	17	0	0	0	0
	150 to 200	94.0	29.2	541	168	0	0	0	0
	200 to 250	100.8	90.4	76	68	0	0	0	0
	250 to 300	0.0	0.0	0	0	0	0	0	0
	300 to 400	1.3	1.2	2	2	0	0	0	0
	400 to 500	0.0	0.0	0	0	0	0	0	0
	500 to 600	0.0	0.0	0	0	0	0	0	0
23 to 26	100 to 150	0.0	0.0	0	0	0	0	0	0
	150 to 200	0.0	0.0	0	0	0	0	0	0
	200 to 250	0.0	0.0	0	0	0	0	0	0
	250 to 300	0.0	0.0	0	0	0	0	0	0
	300 to 400	0.0	0.0	0	0	0	0	0	0
	400 to 500	0.0	0.0	0	0	0	0	0	0
	500 to 600	0.0	0.0	0	0	0	0	0	0
20 to 23	100 to 150	0.0	0.0	0	0	0	0	0	0
	150 to 200	0.0	0.0	0	0	0	0	0	0
	200 to 250	0.0	0.0	0	0	0	0	0	0
	250 to 300	0.0	0.0	0	0	0	0	0	0
	300 to 400	0.0	0.0	0	0	0	0	0	0
	400 to 500	0.0	0.0	0	0	0	0	0	0
	500 to 600	0.0	0.0	0	0	0	0	0	0
17 to 20	100 to 150	0.0	0.0	0	0	0	0	0	0
	150 to 200	0.0	0.0	0	0	0	0	0	0
	200 to 250	0.0	0.0	0	0	0	0	0	0
	250 to 300	0.0	0.0	0	0	0	0	0	0
	300 to 400	0.0	0.0	0	0	0	0	0	0
	400 to 500	0.0	0.0	0	0	0	0	0	0
	500 to 600	0.0	0.0	0	0	0	0	0	0
TOTAL				**635**	**182**	**0**	**0**	**0**	**0**

Table 9(b). Density and biomass estimates by stratum, *M. paradoxus* recruits (17 to 27 cm).

Latitude (°S)	Depth (m)	mean density	s.e	Resource Biomass	s.e.	Biomass in MLA	s.e.	Biomass in SP-1	s.e.
26 to 30	100 to 150	135.6	1.0	121	127	0	0	0	0
	150 to 200	1136.5	304.9	6543	1755	0	0	0	0
	200 to 250	2369.9	1107.8	1784	834	0	0	0	0
	250 to 300	3481.0	2834.8	3309	2695	0	0	0	0
	300 to 400	5358.8	1387.3	9546	2471	0	0	0	0
	400 to 500	1702.6	648.5	1675	638	0	0	0	0
	500 to 600	175.3	108.3	112	69	0	0	0	0
23 to 26	100 to 150	0.0	0.0	0	0	0	0	0	0
	150 to 200	0.0	0.0	0	0	0	0	0	0
	200 to 250	0.0	0.0	0	0	0	0	0	0
	250 to 300	55.7	50.8	79	72	16	15	0	0
	300 to 400	625.2	100.8	1336	215	0	0	0	0
	400 to 500	89.9	24.0	73	19	0	0	0	0
	500 to 600	10.7	6.0	5	3	0	0	0	0
20 to 23	100 to 150	0.0	0.0	0	0	0	0	0	0
	150 to 200	0.0	0.0	0	0	0	0	0	0
	200 to 250	0.0	0.0	0	0	0	0	0	0
	250 to 300	2.4	2.4	5	5	0	0	0	0
	300 to 400	222.5	51.1	699	161	0	0	0	0
	400 to 500	24.6	8.8	21	8	0	0	0	0
	500 to 600	0.4	0.3	0	0	0	0	0	0
17 to 20	100 to 150	0.0	0.0	0	0	0	0	0	0
	150 to 200	0.0	0.0	0	0	0	0	0	0
	200 to 250	0.0	0.0	0	0	0	0	0	0
	250 to 300	0.0	0.0	0	0	0	0	0	0
	300 to 400	1.9	0.9	3	1	0	0	0	0
	400 to 500	38.2	28.4	28	21	0	0	0	0
	500 to 600	4.2	2.7	2	1	0	0	0	0
TOTAL				**25341**	**4201**	**16**	**15**	**0**	**0**

Table 9(c). Density and biomass estimates by stratum, *M. paradoxus* maturing stock (28 to 35 cm).

Latitude (°S)	Depth (m)	mean density	s.e	Resource Biomass	s.e.	Biomass in MLA	s.e.	Biomass in SP-1	s.e.
26 to 30	100 to 150	0.0	#DIV/0!	0	0	0	0	0	0
	150 to 200	91.2	48.2	525	278	0	0	0	0
	200 to 250	148.0	69.0	111	52	0	0	0	0
	250 to 300	3048.7	2218.9	2898	2109	0	0	0	0
	300 to 400	11299.4	2132.6	20128	3799	0	0	0	0
	400 to 500	6098.2	1488.0	6000	1464	0	0	0	0
	500 to 600	476.6	306.3	304	196	0	0	0	0
23 to 26	100 to 150	0.0	0.0	0	0	0	0	0	0
	150 to 200	0.0	0.0	0	0	0	0	0	0
	200 to 250	0.0	0.0	0	0	0	0	0	0
	250 to 300	15.8	11.5	23	16	5	3	0	0
	300 to 400	3038.6	480.8	6495	1028	0	0	0	0
	400 to 500	1170.3	374.5	944	302	0	0	0	0
	500 to 600	111.0	46.7	52	22	0	0	0	0
20 to 23	100 to 150	0.0	0.0	0	0	0	0	0	0
	150 to 200	0.0	0.0	0	0	0	0	0	0
	200 to 250	0.0	0.0	0	0	0	0	0	0
	250 to 300	46.0	46.5	93	94	0	0	0	0
	300 to 400	1648.2	294.8	5178	926	0	0	0	0
	400 to 500	925.9	277.0	806	241	0	0	0	0
	500 to 600	41.2	13.9	33	11	0	0	0	0
17 to 20	100 to 150	0.0	0.0	0	0	0	0	0	0
	150 to 200	0.0	0.0	0	0	0	0	0	0
	200 to 250	0.0	0.0	0	0	0	0	0	0
	250 to 300	6.0	6.1	7	8	0	0	0	0
	300 to 400	235.1	118.8	343	173	0	0	0	0
	400 to 500	1077.9	388.3	782	282	0	0	0	0
	500 to 600	436.9	239.0	165	91	0	0	0	0
TOTAL				**44888**	**4830**	**5**	**3**	**0**	**0**

© NMP 2014

Table 9(d). Density and biomass estimates by stratum, *M. paradoxus* mature stock (36 cm+).

Latitude (°S)	Depth (m)	mean density	s.e	Resource Biomass	s.e.	Biomass in MLA	s.e.	Biomass in SP-1	s.e.
26 to 30	100 to 150	0.0	#DIV/0!	0	0	0	0	0	0
	150 to 200	14.8	9.3	85	54	0	0	0	0
	200 to 250	73.1	40.1	55	30	0	0	0	0
	250 to 300	682.1	443.5	648	422	0	0	0	0
	300 to 400	11846.6	2634.9	21103	4694	0	0	0	0
	400 to 500	12903.7	1914.9	12695	1884	0	0	0	0
	500 to 600	4080.0	833.6	2605	532	0	0	0	0
23 to 26	100 to 150	0.0	0.0	0	0	0	0	0	0
	150 to 200	0.0	0.0	0	0	0	0	0	0
	200 to 250	0.0	0.0	0	0	0	0	0	0
	250 to 300	2.5	2.5	4	4	1	1	0	0
	300 to 400	4489.1	881.1	9596	1883	0	0	0	0
	400 to 500	6682.8	1403.1	5389	1132	0	0	0	0
	500 to 600	4512.0	502.9	2099	234	0	0	0	0
20 to 23	100 to 150	0.0	0.0	0	0	0	0	0	0
	150 to 200	0.0	0.0	0	0	0	0	0	0
	200 to 250	0.0	0.0	0	0	0	0	0	0
	250 to 300	32.0	32.3	65	65	0	0	0	0
	300 to 400	2687.5	534.0	8443	1678	0	0	0	0
	400 to 500	5708.2	1133.0	4971	987	0	0	0	0
	500 to 600	5762.8	878.4	4552	694	0	0	0	0
17 to 20	100 to 150	0.0	0.0	0	0	0	0	0	0
	150 to 200	0.0	0.0	0	0	0	0	0	0
	200 to 250	0.0	0.0	0	0	0	0	0	0
	250 to 300	13.9	14.2	17	17	0	0	0	0
	300 to 400	905.1	386.1	1319	563	0	0	0	0
	400 to 500	3297.5	702.3	2393	510	0	0	0	0
	500 to 600	11336.5	2422.3	4293	917	0	0	0	0
TOTAL				**80332**	**6051**	**1**	**1**	**0**	**0**

Table 9(e). Recruits (numbers) by stratum, *M. paradoxus* recruits (17 to 27 cm).

Latitude (°S)	Depth (m)	mean density	s.e	Recruits (millions)	s.e.	Recruits (millions) in MLA	s.e.	Recruits (millions) in SP-1	s.e.
26 to 30	100 to 150	2123.7	1.0	2	2	0	0	0	0
	150 to 200	15130.5	4141.1	87	24	0	0	0	0
	200 to 250	28974.9	13641.6	22	10	0	0	0	0
	250 to 300	30038.0	23629.1	29	22	0	0	0	0
	300 to 400	53875.6	15271.3	96	27	0	0	0	0
	400 to 500	14108.1	4984.9	14	5	0	0	0	0
	500 to 600	1408.6	937.4	1	1	0	0	0	0
23 to 26	100 to 150	0.0	0.0	0	0	0	0	0	0
	150 to 200	0.0	0.0	0	0	0	0	0	0
	200 to 250	0.0	0.0	0	0	0	0	0	0
	250 to 300	648.6	600.2	1	1	0	0	0	0
	300 to 400	5245.8	828.2	11	2	0	0	0	0
	400 to 500	755.3	200.9	1	0	0	0	0	0
	500 to 600	84.4	47.7	0	0	0	0	0	0
20 to 23	100 to 150	0.0	0.0	0	0	0	0	0	0
	150 to 200	0.0	0.0	0	0	0	0	0	0
	200 to 250	0.0	0.0	0	0	0	0	0	0
	250 to 300	15.6	15.8	0	0	0	0	0	0
	300 to 400	1714.5	367.4	5	1	0	0	0	0
	400 to 500	191.6	68.4	0	0	0	0	0	0
	500 to 600	3.6	2.6	0	0	0	0	0	0
17 to 20	100 to 150	0.0	0.0	0	0	0	0	0	0
	150 to 200	0.0	0.0	0	0	0	0	0	0
	200 to 250	0.0	0.0	0	0	0	0	0	0
	250 to 300	0.0	0.0	0	0	0	0	0	0
	300 to 400	15.1	7.0	0	0	0	0	0	0
	400 to 500	309.3	232.8	0	0	0	0	0	0
	500 to 600	32.6	21.6	0	0	0	0	0	0
TOTAL				**269**	**44**	**0**	**0**	**0**	**0**

© NMP 2014

Table 10(a). Density and biomass estimates by stratum, *L. vomerinus* juveniles (0 to 16 cm).

Latitude (°S)	Depth (m)	mean density	s.e	Resource Biomass	s.e.	Biomass in MLA	s.e.	Biomass in SP-1	s.e.
26 to 30	100 to 150	0.0	0.0	0	0	0	0	0	0
	150 to 200	3.6	2.3	21	13	0	0	0	0
	200 to 250	0.0	0.0	0	0	0	0	0	0
	250 to 300	0.0	0.0	0	0	0	0	0	0
	300 to 400	0.0	0.0	0	0	0	0	0	0
	400 to 500	0.0	0.0	0	0	0	0	0	0
	500 to 600	0.0	0.0	0	0	0	0	0	0
23 to 26	100 to 150	0.0	0.0	0	0	0	0	0	0
	150 to 200	10.2	7.8	54	42	1	1	0	0
	200 to 250	3.2	1.5	4	2	1	0	0	0
	250 to 300	8.1	6.3	12	9	2	2	0	0
	300 to 400	0.0	0.0	0	0	0	0	0	0
	400 to 500	0.0	0.0	0	0	0	0	0	0
	500 to 600	0.0	0.0	0	0	0	0	0	0
20 to 23	100 to 150	6.2	6.1	9	8	0	0	0	0
	150 to 200	6.2	4.5	15	11	0	0	0	0
	200 to 250	7.9	4.5	7	4	0	0	0	0
	250 to 300	14.5	8.0	29	16	0	0	0	0
	300 to 400	1.7	1.0	5	3	0	0	0	0
	400 to 500	0.7	0.7	1	1	0	0	0	0
	500 to 600	0.0	0.0	0	0	0	0	0	0
17 to 20	100 to 150	0.0	0.0	0	0	0	0	0	0
	150 to 200	0.0	0.0	0	0	0	0	0	0
	200 to 250	0.0	0.0	0	0	0	0	0	0
	250 to 300	0.7	0.5	1	1	0	0	0	0
	300 to 400	2.3	1.5	3	2	0	0	0	0
	400 to 500	0.0	0.0	0	0	0	0	0	0
	500 to 600	0.0	0.0	0	0	0	0	0	0
TOTAL				**160**	**50**	**4**	**2**	**0**	**0**

© NMP 2014

Table 10(b). Density and biomass estimates by stratum, *L. vomerinus* recruits (17 to 27 cm).

Latitude (°S)	Depth (m)	mean density	s.e	Resource Biomass	s.e.	Biomass in MLA	s.e.	Biomass in SP-1	s.e.
26 to 30	100 to 150	0.0	0	0	0	0	0	0	0
	150 to 200	51.2	16.9	295	97	0	0	0	0
	200 to 250	11.8	9.8	9	7	0	0	0	0
	250 to 300	27.0	17.2	26	16	0	0	0	0
	300 to 400	0.0	0.0	0	0	0	0	0	0
	400 to 500	1.0	0.5	1	1	0	0	0	0
	500 to 600	0.4	0.3	0	0	0	0	0	0
23 to 26	100 to 150	0.0	0.0	0	0	0	0	0	0
	150 to 200	53.7	38.9	288	208	6	4	1	1
	200 to 250	114.2	43.5	158	60	24	9	4	1
	250 to 300	477.5	214.4	681	306	137	61	0	0
	300 to 400	18.8	5.7	40	12	0	0	0	0
	400 to 500	3.0	1.5	2	1	0	0	0	0
	500 to 600	0.8	0.5	0	0	0	0	0	0
20 to 23	100 to 150	72.7	47.8	100	66	0	0	0	0
	150 to 200	64.8	40.5	152	95	0	0	0	0
	200 to 250	101.5	42.6	88	37	0	0	0	0
	250 to 300	82.1	22.1	166	45	0	0	0	0
	300 to 400	52.2	9.1	164	29	0	0	0	0
	400 to 500	4.2	1.3	4	1	0	0	0	0
	500 to 600	0.8	0.6	1	0	0	0	0	0
17 to 20	100 to 150	0.0	0.0	0	0	0	0	0	0
	150 to 200	0.0	0.0	0	0	0	0	0	0
	200 to 250	3.2	2.6	4	3	0	0	0	0
	250 to 300	16.2	12.1	20	15	0	0	0	0
	300 to 400	22.3	6.3	32	9	0	0	0	0
	400 to 500	0.7	0.8	1	1	0	0	0	0
	500 to 600	0.0	0.0	0	0	0	0	0	0
TOTAL				**2232**	**410**	**166**	**62**	**5**	**2**

© NMP 2014

Table 10(c). Density and biomass estimates by stratum, *L. vomerinus* maturing stock (28 to 35 cm).

Latitude (°S)	Depth (m)	mean density	s.e	Resource Biomas	s.e.	Biomass in MLA	s.e.	Biomass in SP-1	s.e.
26 to 30	100 to 150	0.0	#DIV/0!	0	0	0	0	0	0
	150 to 200	137.6	32.6	792	188	0	0	0	0
	200 to 250	32.5	14.9	24	11	0	0	0	0
	250 to 300	454.9	413.1	432	393	0	0	0	0
	300 to 400	26.7	9.1	48	16	0	0	0	0
	400 to 500	5.4	2.1	5	2	0	0	0	0
	500 to 600	2.7	1.9	2	1	0	0	0	0
23 to 26	100 to 150	0.0	0.0	0	0	0	0	0	0
	150 to 200	36.3	31.7	194	170	4	3	1	1
	200 to 250	76.6	25.2	106	35	16	5	3	1
	250 to 300	348.4	133.3	497	190	100	38	0	0
	300 to 400	109.4	23.2	234	50	0	0	0	0
	400 to 500	34.0	11.7	27	9	0	0	0	0
	500 to 600	4.6	2.1	2	1	0	0	0	0
20 to 23	100 to 150	37.3	31.0	51	43	0	0	0	0
	150 to 200	21.2	11.6	50	27	0	0	0	0
	200 to 250	73.2	31.6	64	28	0	0	0	0
	250 to 300	122.9	28.9	248	58	0	0	0	0
	300 to 400	125.0	18.9	393	59	0	0	0	0
	400 to 500	12.3	4.2	11	4	0	0	0	0
	500 to 600	6.6	3.7	5	3	0	0	0	0
17 to 20	100 to 150	0.0	0.0	0	0	0	0	0	0
	150 to 200	0.0	0.0	0	0	0	0	0	0
	200 to 250	0.0	0.0	0	0	0	0	0	0
	250 to 300	8.3	7.0	10	9	0	0	0	0
	300 to 400	58.8	18.5	86	27	0	0	0	0
	400 to 500	10.8	4.3	8	3	0	0	0	0
	500 to 600	0.0	0.0	0	0	0	0	0	0
TOTAL				**3290**	**519**	**119**	**39**	**3**	**1**

© NMP 2014

Table 10(d). Density and biomass estimates by stratum, *L. vomerinus* mature stock (36 cm +).

Latitude (°S)	Depth (m)	mean density	s.e	Resource Biomas	s.e.	Biomass in MLA	s.e.	Biomass in SP-1	s.e.
26 to 30	100 to 150	0.0	#DIV/0!	0	0	0	0	0	0
	150 to 200	331.2	90.8	1907	523	0	0	0	0
	200 to 250	1196.0	565.8	900	426	0	0	0	0
	250 to 300	1167.2	555.5	1110	528	0	0	0	0
	300 to 400	1321.7	234.9	2354	418	0	0	0	0
	400 to 500	546.1	86.6	537	85	0	0	0	0
	500 to 600	181.7	46.1	116	29	0	0	0	0
23 to 26	100 to 150	1026.2	1256.9	250	306	4	4	0	0
	150 to 200	13.9	6.3	74	34	1	1	0	0
	200 to 250	99.7	32.3	138	45	21	7	3	1
	250 to 300	285.4	88.6	407	126	82	25	0	0
	300 to 400	868.1	212.0	1856	453	0	0	0	0
	400 to 500	535.4	126.0	432	102	0	0	0	0
	500 to 600	790.6	175.2	368	82	0	0	0	0
20 to 23	100 to 150	23.8	20.9	33	29	0	0	0	0
	150 to 200	111.9	63.2	263	149	0	0	0	0
	200 to 250	122.6	90.3	107	79	0	0	0	0
	250 to 300	312.0	77.2	630	156	0	0	0	0
	300 to 400	336.8	51.2	1058	161	0	0	0	0
	400 to 500	73.6	18.9	64	16	0	0	0	0
	500 to 600	303.8	64.4	240	51	0	0	0	0
17 to 20	100 to 150	1.9	1.9	7	7	0	0	0	0
	150 to 200	0.0	0.0	0	0	0	0	0	0
	200 to 250	1.8	1.9	2	2	0	0	0	0
	250 to 300	136.8	101.4	168	124	0	0	0	0
	300 to 400	318.5	112.8	464	164	0	0	0	0
	400 to 500	211.8	73.3	154	53	0	0	0	0
	500 to 600	177.9	67.2	67	25	0	0	0	0
TOTAL				**13706**	**1175**	**107**	**27**	**4**	**1**

Table 10(e). Recruits (numbers) by stratum, *L. vomerinus* recruits (17 to 27 cm).

Latitude (°S)	Depth (m)	mean density	s.e	Recruits (millions)	s.e.	Recruits (millions) MLA	s.e.	Recruits (millions) SP-1	s.e.
26 to 30	100 to 150	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	150 to 200	206.3	93.6	1.2	0.5	0.0	0.0	0.0	0.0
	200 to 250	44.8	35.6	0.0	0.0	0.0	0.0	0.0	0.0
	250 to 300	95.9	55.2	0.1	0.1	0.0	0.0	0.0	0.0
	300 to 400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	400 to 500	4.2	2.1	0.0	0.0	0.0	0.0	0.0	0.0
	500 to 600	2.2	1.6	0.0	0.0	0.0	0.0	0.0	0.0
23 to 26	100 to 150	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	150 to 200	288.3	204.2	1.5	1.1	0.0	0.0	0.0	0.0
	200 to 250	475.9	178.1	0.7	0.2	0.1	0.0	0.0	0.0
	250 to 300	2057.1	922.6	2.9	1.3	0.6	0.3	0.0	0.0
	300 to 400	72.6	22.4	0.2	0.0	0.0	0.0	0.0	0.0
	400 to 500	10.5	5.2	0.0	0.0	0.0	0.0	0.0	0.0
	500 to 600	3.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0
20 to 23	100 to 150	437.5	288.4	0.6	0.4	0.0	0.0	0.0	0.0
	150 to 200	275.3	164.9	0.6	0.4	0.0	0.0	0.0	0.0
	200 to 250	524.8	234.9	0.5	0.2	0.0	0.0	0.0	0.0
	250 to 300	365.8	103.6	0.7	0.2	0.0	0.0	0.0	0.0
	300 to 400	256.4	53.5	0.8	0.2	0.0	0.0	0.0	0.0
	400 to 500	19.1	6.3	0.0	0.0	0.0	0.0	0.0	0.0
	500 to 600	1.8	1.3	0.0	0.0	0.0	0.0	0.0	0.0
17 to 20	100 to 150	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	150 to 200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	200 to 250	23.6	21.1	0.0	0.0	0.0	0.0	0.0	0.0
	250 to 300	73.9	57.1	0.1	0.1	0.0	0.0	0.0	0.0
	300 to 400	127.7	40.0	0.2	0.1	0.0	0.0	0.0	0.0
	400 to 500	2.5	2.5	0.0	0.0	0.0	0.0	0.0	0.0
	500 to 600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL				**10.2**	**1.9**	**0.7**	**0.3**	**0.02**	**0.01**

© NMP 2014

Table 11. *L. vomerinus* catch per depth range from the November Monk surveys 2007 to 2010 between 23 and 26 degrees latitude.

Depth (m)	Mean catch (kg) per 30 minute trawl	Number of trawls	std error
100	1.1	2	0.2
150	16.4	22	6.4
200	25.6	21	5.5
250	26.5	8	8.5
300	24.9	23	3.6
400	16.2	8	6.0
500	13.8	7	7.6

© NMP 2014

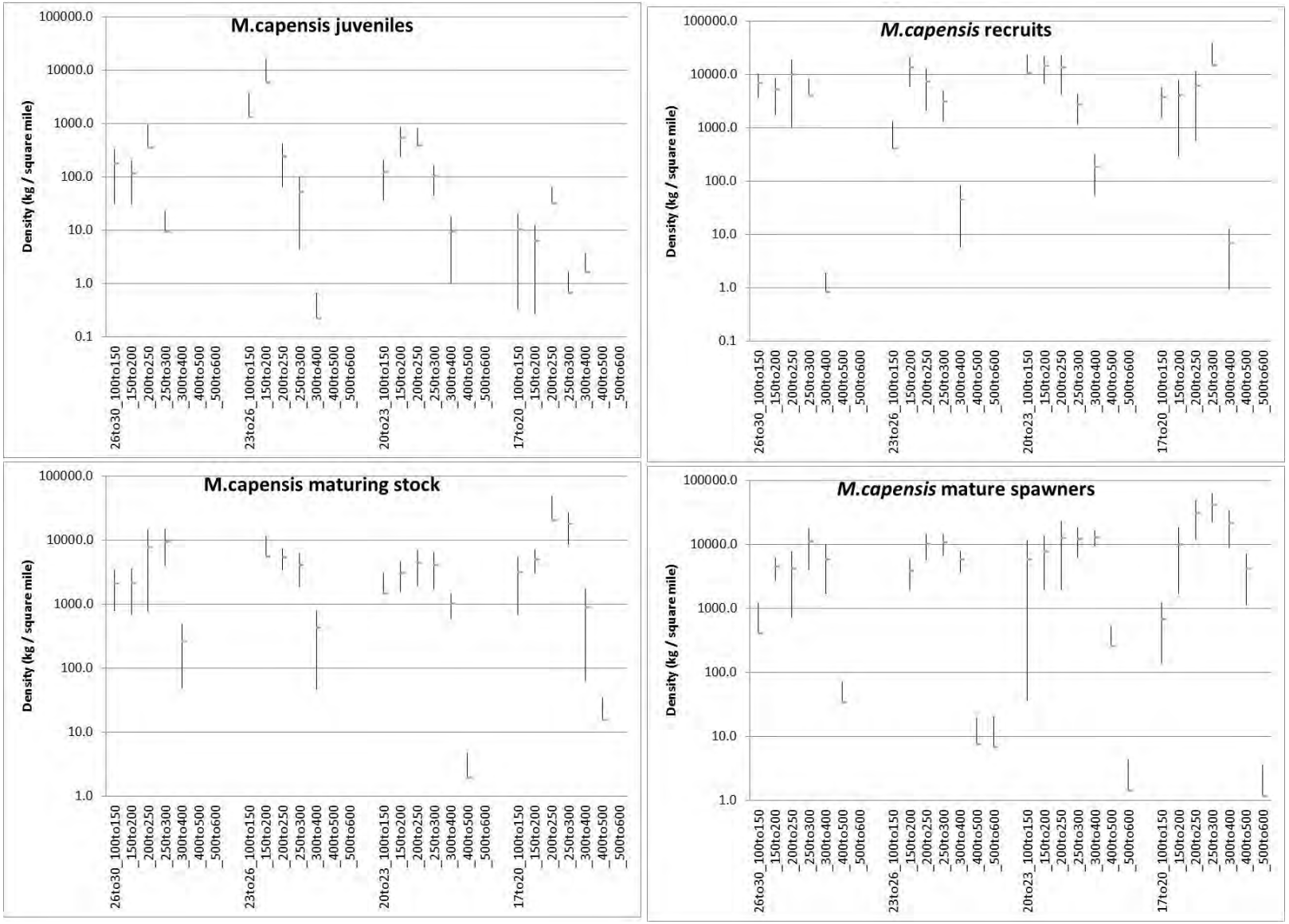


Figure 6(a) *M. capensis* Density estimates (log scale) by latitude and depth division, panelled by length class.
Error bars represent 2 standard errors either side of the mean.

© NMP 2014

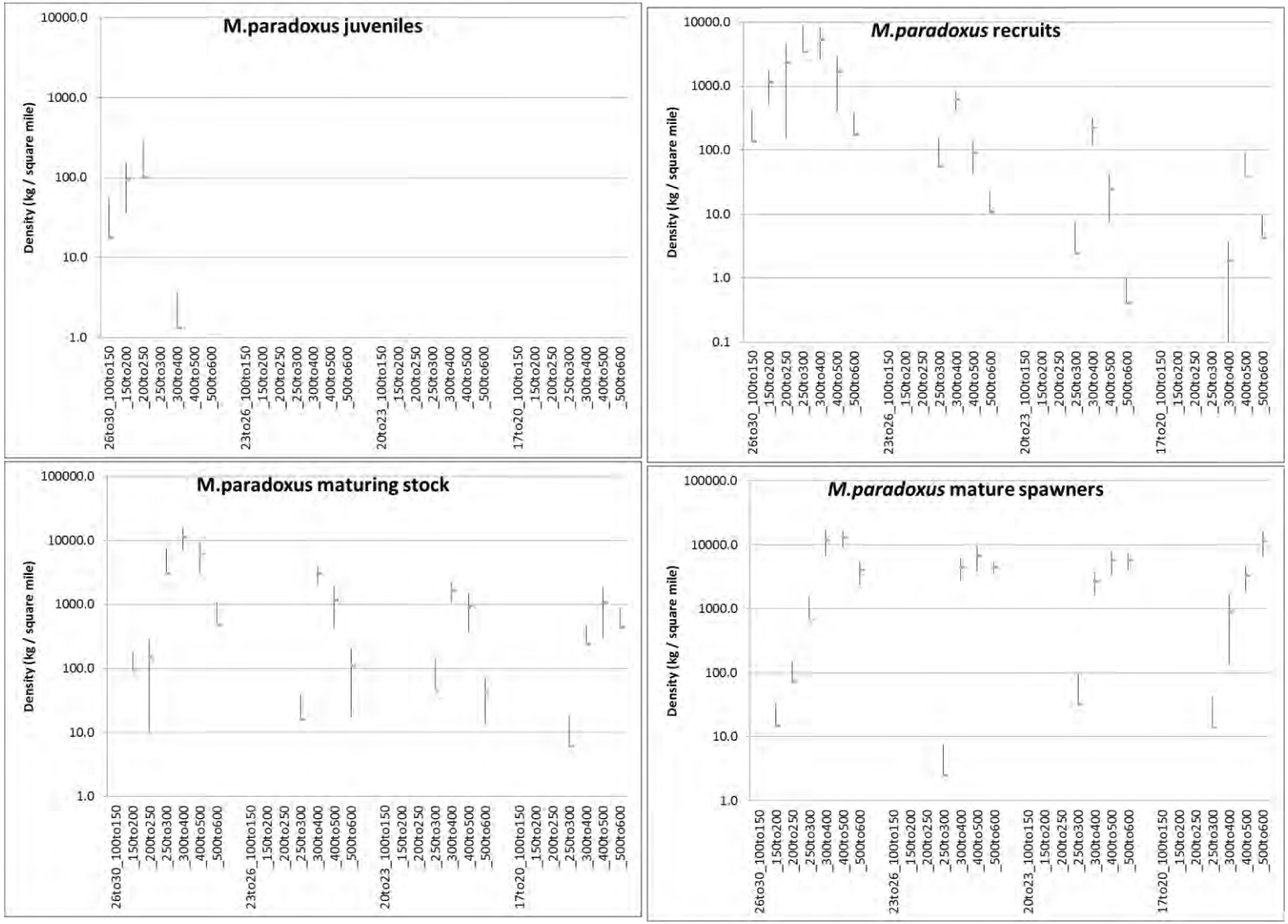


Figure 6(b) *M. paradoxus* Density estimates (log scale) by latitude and depth division, panelled by length class.
Error bars represent 2 standard errors either side of the mean.

© NMP 2014

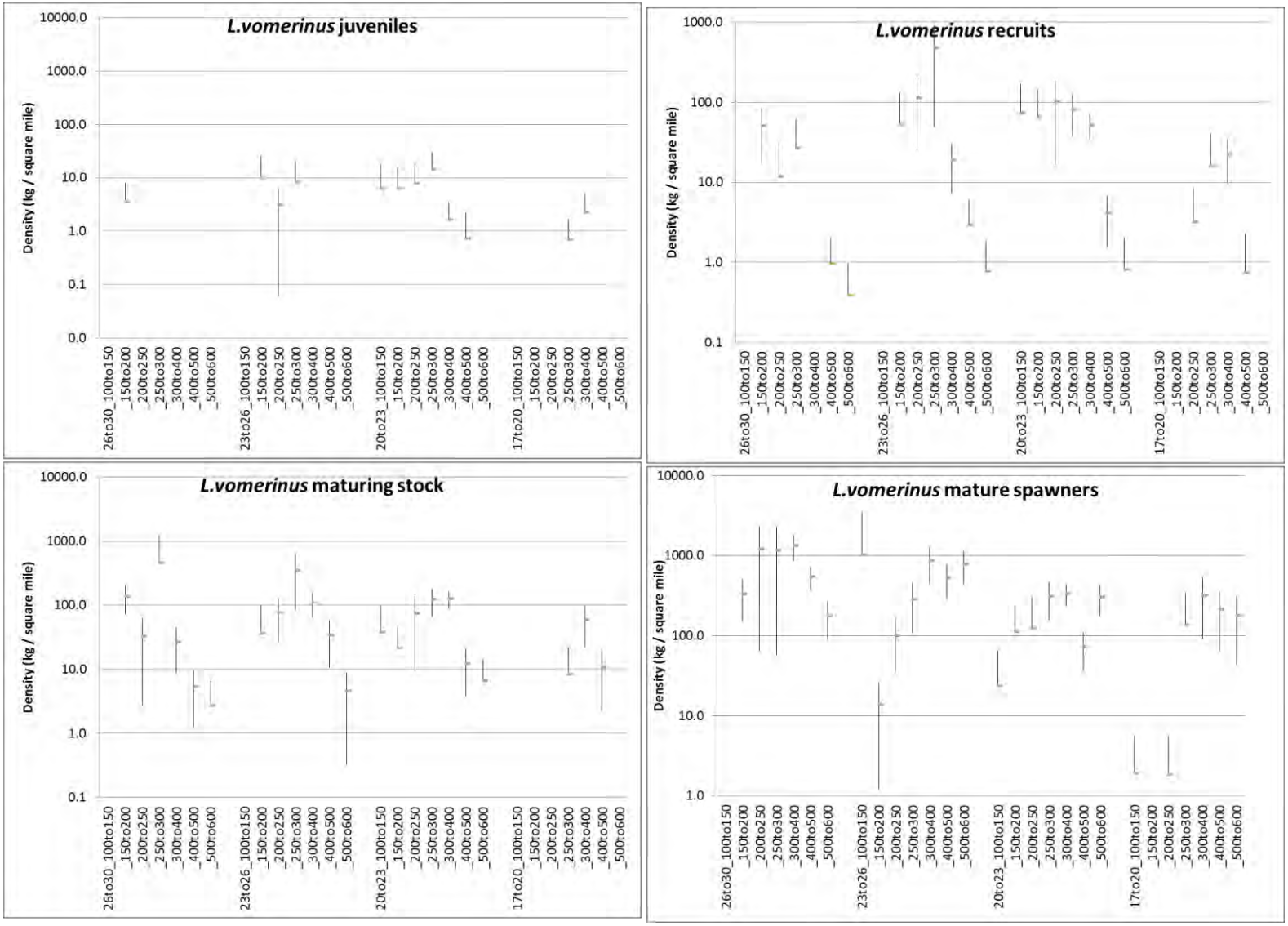


Figure 6(c) *L. vomerinus* Density estimates (log scale) by latitude and depth division, panelled by length class.
Error bars represent 2 standard errors either side of the mean.

© NMP 2014

ANNEXURE A: AREA CALCULATIONS

The stratification adopted for this study and resulting biomass calculations require area estimates for each of 28 strata intersecting with (a) the MLA (b) the Sandpiper 1 mining site and (c) the resource habitat as a whole.

MLA Area

Areas were calculated by decomposition of the MLA into trapezia.

For each trapezium, let X and Y denote longitude and latitude respectively, with subscripts T, B, TL, TR, BL, BR denoting top, bottom, top left, top right, bottom left and bottom right.

The length (North to South) in miles of each trapezium is calculated as:

$$L = (Y_T - Y_B)*60 \qquad (A1)$$

The widths (East to West) of the North and South boundaries are, respectively

$$W_T = (X_{TR} - X_{TL}).\cos(Y_T)*60 \qquad (A2)$$

$$W_B = (X_{BR} - X_{BL}).\cos(Y_B)*60 \qquad (A3)$$

The area of the trapezium in square miles is then approximately

$$A = L.(W_T + W_B)/2 \qquad (A4)$$

In each Trapezium the proportions by 50m depth zone are estimated using the contours illustrated in Figure A1. Figure A2 and Table A1 show the coordinates used in the calculations. Table A2 shows detailed outputs of these area calculations.

Resource Habitat Area

Areas by 100 m depth range (100 m to 600 m) are given in Kainge (2011). Subdivision of these areas into the strata used in this study is done by assuming area is proportional to number of survey stations. Details of these calculations are shown in Table A3.

© NMP 2014

Table A1. Coordinates of the vertices of the polygons defining the MLA and the SP-1 dredging site.

	Longitude	Latitude
	14.05	-23.96
	14.14	-23.88
	14.02	-24.45
	13.95	-24.45
	13.95	-24.54
	13.95	-24.90
	13.77	-24.90
	13.75	-24.54
MLA	13.93	-23.96
	13.96	-24.09
	14.03	-24.09
	14.03	-24.29
SP-1	13.96	-24.29
	13.86	-24.32
	13.94	-24.32
	13.94	-24.52
SP-2	13.86	-24.52
	13.82	-24.69
	13.82	-24.79
	13.88	-24.79
SP-3	13.88	-24.69

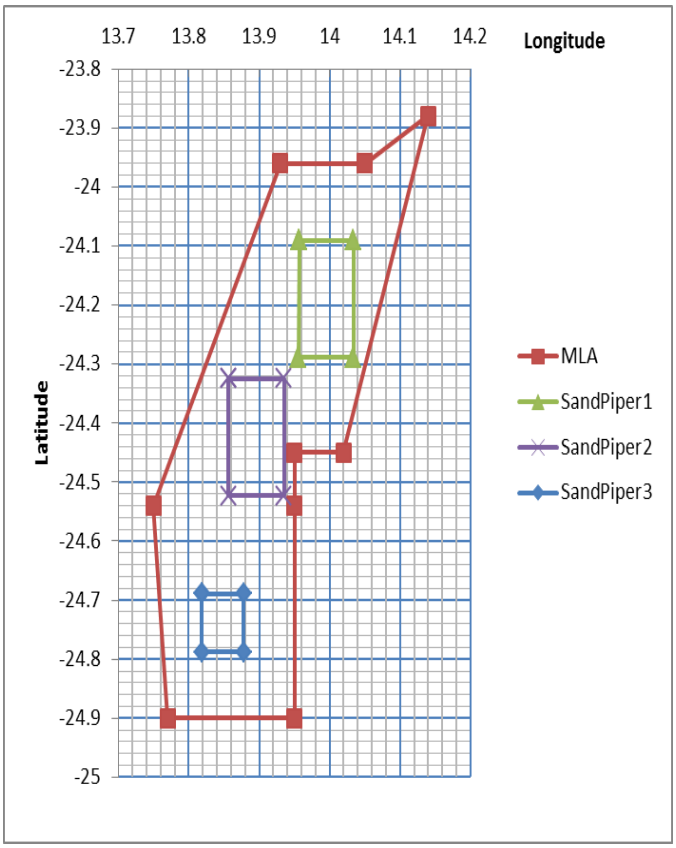


Figure A1. Schematic plot of the MLA and Sandpiper sites (SP-1, SP-2 and SP-3).

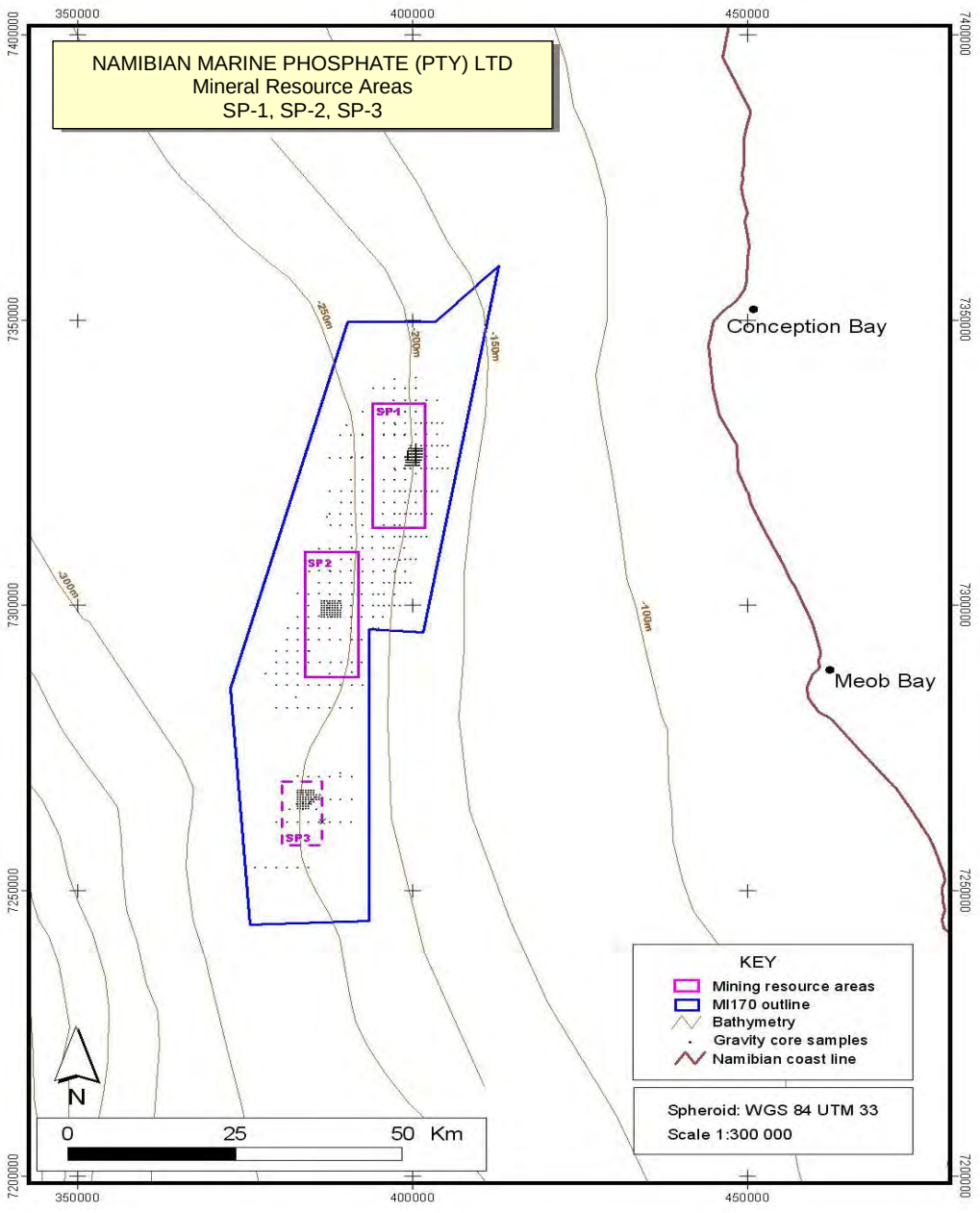


Figure A2. 50 m depth contours in the Sandpiper areas (SP-1, SP-2 and SP-3) and the surrounding area.

Table A2. Calculations of Area of the MLA and decomposition by Depth Range

	proportions by depth range				Dimensions						Area	
	100-150 m	150-200 m	200-250 m	250-300 m	Top Width Degrees	Bottom Width Degrees	Height Deg	Top Width miles	Bottom Width miles	Height miles	Sq miles	Sq km
Upper Triangle	35%	65%			0.0000	0.0750	0.0800	0.000	4.112	4.800	9.9	32.6
Triangle to SP-1		46%	50%	4%	0.1950	0.2100	0.1306	10.692	11.503	7.833	86.9	287.4
SP-1		35%	65%		0.0772	0.0789	0.1986	4.230	4.314	11.917	50.9	168.3
left of SP-1			25%	75%	0.0669	0.1253	0.1986	3.667	6.851	11.917	62.7	207.2
Right of SP-1		100%			0.0658	0.0258	0.1986	3.606	1.413	11.917	29.9	98.9
SP-1 to SP-2		26%	28%	46%	0.2300	0.2300	0.0348	12.578	12.575	2.090	26.3	86.9
SP-2			13%	87%	0.0789	0.0789	0.1990	4.313	4.306	11.940	51.5	170.1
Left of SP-2				100%	0.0367	0.1067	0.1990	2.005	5.823	11.940	46.7	154.5
Right of SP-2 Upper		55%	45%		0.1144	0.0844	0.1260	6.257	4.612	7.560	41.1	135.8
Right of SP-2 Lower		100%			0.0144	0.0144	0.0730	0.789	0.788	4.380	3.5	11.4
SP-2 to SP-3			35%	65%	0.2000	0.1900	0.1670	10.918	10.358	10.020	106.6	352.4
SP-3			60%	40%	0.0594	0.0594	0.0980	3.241	3.238	5.880	19.0	63.0
Left of SP-3				100%	0.0586	0.0536	0.0980	3.195	2.920	5.880	18.0	59.4
Right ofSP-3			100%		0.0719	0.0719	0.0980	3.922	3.919	5.880	23.1	76.2
SP-3 to bottom			45%	55%	0.1850	0.1800	0.1120	10.077	9.796	6.720	66.8	220.7
Total MLA Area Sq miles	**3.5**	**126.8**	**226.7**	**285.9**							**642.7**	
Total MLA Area Sq km	**11.4**	**419.1**	**749.3**	**945.0**								**2124.8**
SP-1 Area Sq miles	**0**	**17.8**	**33.1**								**50.9**	
SP-1 Area Sq km	**0**	**58.9**	**109.4**									**168.3**

© NMP 2014

Table A3. Calculations of area of resource habitat by stratum

100 m Depth Division	Area of 100 m Depth Division [Kainge (2011)] (km^2)	Depth Subdivision	Latitude	Number of Trawls	% of Depth Division	Stratum Area
100 to 200	20921	100 to 150	17to20	43	16.7%	3486.8
			20to23	17	6.6%	1378.5
			23to26	3	1.2%	243.3
			26to30	11	4.3%	892.0
		150 to 200	17to20	18	7.0%	1459.6
			20to23	29	11.2%	2351.6
			23to26	66	25.6%	5351.9
			26to30	71	27.5%	5757.3
100 to 200	9942	200 to 250	17to20	33	13.1%	1307.1
			20to23	22	8.8%	871.4
			23to26	35	13.9%	1386.3
			26to30	19	7.6%	752.6
		250 to 300	17to20	31	12.4%	1227.9
			20to23	51	20.3%	2020.1
			23to26	36	14.3%	1425.9
			26to30	24	9.6%	950.6
300 to 400	8518	300 to 400	17to20	45	17.1%	1457.5
			20to23	97	36.9%	3141.6
			23to26	66	25.1%	2137.6
			26to30	55	20.9%	1781.3
400 to 500	3387	400 to 500	17to20	45	21.4%	725.8
			20to23	54	25.7%	870.9
			23to26	50	23.8%	806.4
			26to30	61	29.0%	983.8
500 to 600	2283	500 to 600	17to20	35	16.6%	378.7
			20to23	73	34.6%	789.9
			23to26	43	20.4%	465.3
			26to30	59	28.0%	638.4

© NMP 2014

SECTION C - SPECIALIST STUDIES

C3.3 Opinion on the Ecosystem Impacts related to Dredging of Phosphates offshore Namibia

NAMIBIAN MARINE PHOSPHATE

VERIFICATION SURVEY

OPINION ON THE ECOSYSTEM IMPACTS RELATED TO DREDGING OF PHOSPHATES OFFSHORE NAMIBIA

Prepared for:
Namibian Marine Phosphate (Pty) Ltd.

Prepared by:
Capricorn Fisheries Monitoring cc
Dr K.L. Cochrane

October 2014

CAPFISH (Pty) LTD
Unit 15, Foregate Square. Table Bay Boulevard, 8002, South Africa
Directors: Japp, Wissema, Heinecken, Wilkinson, Ncongo
Co Reg. No. 2004 / 004844 / 07

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed "Attention: Administration Manager," at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

SUMMARY

Ecosystem modelling is often a valuable tool for the investigation of indirect and ecosystem ramifications of natural or human impacts on a part of the ecosystem. Spatially disaggregated ecosystem models have been applied in a number of localities and ecosystems around the world and have been found to be useful. In this case, however, the combination of the high uncertainty typically associated with projections by ecosystem models and the small area that will be impacted by the proposed dredging mean that it is unlikely that ecosystem modelling would expose any unexpected, highly significant threats that have not already been considered in the specialist studies.

That conclusion might not apply, however, if the area to be impacted by the dredging was found to be of particular importance in the ecosystem or in the life cycle of one or more key species, and therefore that some ecological impacts could be disproportionately higher than would be expected from considering only the impacted area as a proportion of the total area of a species distribution or of the ecosystem as a whole. The results from the Verification Biodiversity Survey did not produce any results to suggest that the proposed impacted area has any unique or unusual features that would indicate such a disproportionate importance.

The expected ecosystem impacts of the dredging can be considered in the context of other actual or potential environmental impacts in the region, such as from trawling and other fishing impacts, diamond mining, and oil and gas exploration. At this stage, the only other anthropogenic activity taking place in the MLA is fishing with trawl nets, as reported in specialist report Appendix 1a (Japp, in Midgley 2012). The impacts of extraction in the specific area planned to be dredged can be expected to have considerably greater, and longer-lasting, direct impacts on the biota in that area than does bottom trawling. However, the limited area currently designated to be dredged means that, overall, these impacts will almost certainly be considerably less across the northern Benguela shelf and southern slope environments as a whole than have been the impacts of trawling on these environments, noting that the impacts of trawling are well-managed and considered to be sustainable.

© NMP 2014

contents

SUMMARY ii

1 INTRODUCTION 1

2 SUMMARY OF KEY FINDINGS FROM INITIAL EIA ASSESSMENT 1

3 AVAILABLE MODELS AND POTENTIAL FOR APPLICATION 3

3.1 ECOSPACE AS A POTENTIAL MODELLING FRAMEWORK IN THE CONTEXT OF THE MLA 3

4 INDICATIONS OF LIKELY ECOSYSTEM IMPACTS BASED ON AVAILABLE MODELLING STUDIES 4

4.1 TAXONOMIC DETAIL 4

4.2 ECOSYSTEM CONSEQUENCES OF HUMAN INTERVENTIONS 5

5 POTENTIAL FOR APPLICATION OF MODELLING TO EVALUATE THE ECOSYSTEM IMPACTS OF THE PROPOSED DREDGING 8

6 IMPACTS OF SCALING-UP DREDGING BEYOND SP-1 OR EXPANSION INTO OTHER AREAS ON THE NAMIBIAN SHELF 8

7 COMMENTS ON THE IMPLICATIONS OF THE RESULTS OF THE VERIFICATION BIODIVERSITY SURVEY: AN ECOSYSTEM PERSPECTIVE 9

8 CONCLUSIONS 10

9 REFERENCES 11

Annexure 1: Species and species groups 12

tables

Table 1. Summarised results of the projected ecosystem consequences of selected management actions as simulated by the Roux and Shannon EwE model (Roux and Shannon 2004). 6

© NMP 2014

This review was commission by Namibian Marine Phosphate (Pty) Ltd (NMP). The objective was to provide an independent professional opinion on the ecosystem impacts of the proposed dredging.

Terms of Reference

1. Review the impact assessment undertaken by NMP for the offshore component of the proposed dredging, providing opinion on the EIA context relating particularly to the broader ecosystem. The reviewer should consider in particular the Benguela Ecosystem and the modelling done for the Benguela and or similar marine ecosystems;
2. The opinion should consider in particular the fisheries section of the EIA as well as the ecosystem issues in the other sections of the EIA report (substrate, plumes, oceanography, etc) or wherever ecosystem issues have been raised;
3. The reviewer is not required to undertake ecosystem modelling, but should review the current models (generic) and any models applicable to ecosystems in the Benguela and their potential application (if any) to the proposed dredging for phosphates.
4. Consider the ecosystem impacts of the proposed dredging and give an opinion on the broader impacts (scaling effects) – consider also the impacts of scaling up dredging beyond SP-1 or expansion into other areas on the Namibian shelf.
5. Review the EIA verification survey proposed and if in any way, data collected can support / provide information for possible use in the ecosystem models to better understand the impacts of the proposed dredging.
6. Consider the dredging impacts in the context of the other environmental impacts in the Benguela such as trawling extent, other fishing impacts, diamond mining, oil and gas exploration.

1 INTRODUCTION

The Mining Licence Area (MLA) is located on the Namibian continental shelf approximately 60 km off the coast of Conception Bay. The area of the mining lease area covers 2233 km^2 within which there are three areas identified for exploitation: Sandpiper-1 (SP-1), Sandpiper-2 (SP-2) and Sandpiper-3 (SP-3). It is proposed to exploit each area systematically over time starting in SP-1. A mining licence (covers an area of 2233 km^2) has been granted for 20 years, dredging may only commence once the company has been issued with an Environmental Contract from the authorities. The company proposes to mine an area of approximately 3 km^2 annually, which will lead to dredging an area of 60 km^2 over the period licenced.

2 SUMMARY OF KEY FINDINGS FROM INITIAL EIA ASSESSMENT

The specialist report Appendix 1a (Japp in Midgley 2012) on fish resources, fisheries, marine mammals and birds of the Environmental Impact Assessment (EIA) for the proposed phosphate dredging considered the following five primary impacts of dredging:

1) on commercial fisheries;
2) on the main commercial fish species;
3) on the recruitment of commercially important species;
4) on fish biodiversity and

© NMP 2014

5) on seabirds and marine mammals.

The details are available in that report. In summary, this report concluded that:

- The mining licence area covers a surface area in which an estimated 0.86% of the hake trawl catch, 0.32% of the midwater horse mackerel catch and 6.34 % of the monk trawl fisheries catch had been taken in the six most recent years for which suitable data were available;
- Impact on the commercial fisheries catch in the actual mined areas (SP-1) will be < 0.05% except for the monk trawl fishery where it is expected that about 1.08% of the historical catch will be directly impacted in SP-2 and SP-3 combined and 0.0% in SP-3.
- The dredging area does not overlap significantly with the fishing grounds for horse mackerel and other small pelagic species;
- The direct impact will be the physical removal and destruction of substrate. This will be serious and likely to last for at least 20 years. Significant alteration of the ecosystem is expected only in the immediate target dredging sites and will affect essential habitat occupied by some key fisheries resources including monk, gobies and hake. Gobies are considered a key trophic species in the ecosystem.
- Recruitment of monk fish is likely to be negatively affected but the extent of this impact could not be assessed. No other major impacts on fish recruitment were identified. Sediment plumes are not expected to significantly affect recruitment as the area of dredging operations will be small and plumes should disperse quickly within a short distance from the dredging operations.
- There are likely to be negative impacts on birds and mammals in the dredging areas but their likely intensity and significance could not be evaluated. Bird mortality caused by bird strikes could be expected and will require mitigation.

The specialist report on the water column (Appendix 1b – Carter, in Midgley 2012) considered a number of potential impacts on the water column from the dredging activities and concluded that, apart from the risk of ecosystem impacts from the introduction of alien species, all the others were of low significance or not of significance. Particularly relevant to this report on ecosystem modelling, the significance of negative impacts from the generation of a turbid plume was estimated as low. The study assumed that the dimensions of plumes generated by dredging would be 1 500 m long by 800 m wide and that the concentration of sediment in the plume would be between 20 mg/ℓ and 100 mg/ℓ. The study reported that at the lower limit of these concentrations, there could be chronic effects on marine biota after 3 days of exposure while acute effects could occur from concentrations above 100 mg/ℓ. The longevity of plumes was estimated to be about 16 hours.

The specialist report on benthos (Appendix 1c – Steffani, in Midgley 2012) came to the following conclusions:

- ML 170 is located on the outer shelf beyond the inner shelf break and is characterised by a generally sandy environment where organic matter and nutrient concentrations in the sediments are likely to be relatively low.
- It occurs in the southern offshore fringe of the oxygen minimum zone (OMZ) and has low dissolved oxygen levels (<0.5 ml/ℓ) at the bottom throughout the year but is generally not anoxic. Hydrogen sulphide pore and bottom water concentrations are likely to very low but may be higher in deeper sediments.
- There is very little known about the benthic fauna of the Namibian OMZ but a macrofauna baseline survey across SP-1 (2010) showed relatively low species richness of the benthic

© NMP 2014

macrofauna assemblages which were dominated by polychaetes, especially the spionid polychaete *Paraprionospio pinnata*. Crustaceans were poorly represented.

- The dredging will result in the loss of benthic organisms through the removal of the substratum. It will also lead to the re-suspension of sediments into the water column and subsequent re-deposition of the suspended sediments. The impact of the removal of the upper layer of sediments was estimated to be of medium significance but it was noted that in the proposed development, the area actually dredged will be limited to a maximum of 60 km^2 after 20 years.

3 AVAILABLE MODELS AND POTENTIAL FOR APPLICATION

Many different types of model have been developed to simulate ecosystem processes in aquatic systems. Some of the more highly developed and widely used were described by Plaganyi (2007) and include, for example, Ecopath with Ecosim (EwE), the European Regional Seas Ecosystem Model (ERSEM), the Integrated Generic Bay Ecosystem Model (IGBEM), ATLANTIS, and the Spatial Ecosystem and Population Dynamics Model (SEAPODYM). EwE and Atlantis are generic models and could be adapted to include most ecosystem components (Plaganyi, 2007). In addition, multispecies models that incorporate size and spatial structure have been developed for the southern Benguela, based on an approach known as Object-oriented Simulator of Marine ecOSystems Exploitation (OSMOSE, Shin *et al*., 2004; Travers-Trolet *et al*., 2014).

Ecopath with Ecosim is the most widely used approach and, by October 2008, there were 5,649 registered users of EwE in 164 different countries and over 300 papers making use of the approach had been published, demonstrating its wide scientific credibility. It was developed by a group of researchers based at the University of British Columbia, Canada. EwE includes three main packages: Ecopath, which provides a static, mass-balanced framework for representing the trophic relationships within an ecosystem; Ecosim, which extends Ecopath into a time dynamic simulation model; and Ecospace which extends Ecopath and Ecosim into a framework that enables dynamic simulations across space and time. Ecospace was developed mainly to enable consideration of the design and impacts of marine protected areas but can be used for spatial simulations with different objectives[1].

EwE has been applied in the Benguela ecosystem in a number of studies including some focused on the northern Benguela such as Roux and Shannon (2004) and Heymans and Sumaila (2007).

3.1 ECOSPACE AS A POTENTIAL MODELLING FRAMEWORK IN THE CONTEXT OF THE MLA

Ecospace is based on the Ecopath with Ecosim modelling approach but allows for the division of the modelled system into a spatial grid with the Ecosim model replicated within each spatial cell. Movement between cells can be driven in the model by estimates of the dispersal rate for each species or taxonomic group in the model, constraints on movement caused by, for example, land-water boundaries, habitat preferences (which would be simulated by higher emigration rates, lower feeding rates and higher vulnerability to predation in non-favourable cells), and other fishing and ecological processes. This modelling application potentially could be applied to exploring the ecosystem impacts of dredging by developing a model that differentiates between cells which are rendered unfavourable or less favourable as a result of the dredging activities and those which are

[1] http://www.ecopath.org/about

unaffected. Running such a model over time would provide estimates of how the direct negative impacts on the ecosystem in the impacted areas spread, both within the affected areas and beyond, across the ecosystem as a whole.

Several studies have been undertaken using Ecospace, generally in relation to the size and placement of marine protected areas (MPAs). For example, an Ecospace model of the Northern Gulf of California was constructed in which the area was sub-sudivided into a 40 x 40 spatial grid with each cell being a square of 10 km x 10 km (Lecari *et al*. 2007). The effectiveness of MPAs in the central Pacific was examined using an Ecospace model covering the area from 0°N to 35°N and 150°W to 160°E, which was sub-divided into a grid made up of 34 rows and 50 columns, with each grid cell being approximately 100 km x 100 km.

Heymans and Sumaila developed an Ecospace model of the northern Benguela from 15°S to 29°S and 10°E to 17°E which encompasses the MLA. They divided the area into 140 rows and 70 columns, with each cell being a 10 km square. The whole area was then sub-divided into 11 different habitat types of differing areas ranging from less than 0.1% of the total area (Luderitz Harbour) to 57.9% (deep areas south of the Walvis Ridge). Should it be decided to undertake a modelling exercise to assess the likely impacts of the dredging across the ecosystem, it should be possible to use this model as a starting point and modify it to represent the desired spatial and ecosystem structure.

4 INDICATIONS OF LIKELY ECOSYSTEM IMPACTS BASED ON AVAILABLE MODELLING STUDIES

4.1 TAXONOMIC DETAIL

The existing ecosystem models of the northern Benguela give good indications of the current state of knowledge on the relative abundance, distribution and taxonomic resolution of the biodiversity of the Northern Benguela ecosystem. The MLA occurs within two of the 11 habitats included in the Heymans and Sumaila (2007) model:

- the Shelf (30 - 200 m depth) and
- Southern Slope (200 - 500 m) habitats.

The species and species groups included in each of them are listed in Annexure 1. This reflects a high degree of knowledge on the commercially-important fish species and those of conservation interest: i.e. sharks, seals, seabirds and marine mammals, but very limited knowledge of other fish and invertebrate species, including invertebrates that occupy the shelf and slope benthic habitats. Monkfish, hakes and pelagic gobies are explicitly included, with hakes and pelagic gobies split into juveniles and adults.

The northern Benguela model of Roux and Shannon (2004), while not spatially disaggregated, was constructed with a very similar taxonomic structure to that of Heymans and Sumaila (Annexure 1).

Judging by these two modelling exercises, in particular the species and groupings that were used, it is unlikely that there would be sufficient relevant information at greater taxonomic detail to be able to construct a realistic model with much greater taxonomic resolution and detail than they have included.

© NMP 2014

4.2 ECOSYSTEM CONSEQUENCES OF HUMAN INTERVENTIONS

Heymans and Sumaila did not use their model to investigate the consequences of human impacts on the system or parts of the system but Roux and Shannon used their model to estimate the likely ecosystem ramifications of a number of simulated changes in fishing harvest strategies. They examined the impacts of both reductions and increases in fishing or harvest mortality by simulating the trajectories over time of all other species and species groups. Some of their results are shown in Table 1, in particular those in which they simulated an increase in fishing mortality as this would lead directly to an increased in mortality of the target species and thereby a reduction in biomass. These effects would be similar in direction (but not necessarily scale) to the direct impacts of dredging, if it is assumed that habitat destruction by dredging would lead to a proportionate reduction in biomass of those fish species dependent on that habitat. It should be noted, though, that whereas the impacts of fishing mortality, as simulated in the model, cease as soon as fishing is stopped, the impacts of dredging have a longer-lasting impact because of habitat destruction. Potentially this could mean that dredging could lead to a longer-term reduction in the maximum population size (carrying-capacity) of a species strongly dependent on the benthic environment. In contrast, fishing mortality alone leads only to a reduction in the population size at the time.

The results in Table 1 demonstrate that changes in abundance and productivity of particular species do lead to changes in biomass and production of other species. For example, starting a serious fishery on pelagic goby was found to lead to an 87% decline in biomass of gobies which resulted in substantial increases in biomass of competitors, including anchovy and sardine, and a decline in biomass of *M. capensis* which preys on pelagic gobies. The decline of the shallow water hake, *M. capensis,* in turn led to an increase in the biomass of deep water hake *M. paradoxus* which is an important prey species for the larger individuals of *M. capensis.* In another trial, increasing the fishing mortality on *M. capensis* led to a reduction in biomass of that species, small changes in biomass of *M. paradoxus* and considerable increases in the biomass of dolphins and seabirds, presumably as a result of increases in availability of prey species previously kept at lower biomasses by *M. capensis* predation.

The specialist report on fish resources, fisheries, marine mammals and birds report (Appendix 1a – Japp, in Midgley 2012) found that monkfish would be the species most affected by the proposed dredging activities, as would the fishery targeting monkfish. It was reported that just over 1% of the monkfish catch would be affected. It also concluded that recruitment of monkfish could be affected but could not estimate the extent of that impact. Roux and Shannon (2004) included monkfish within one of the multi-species 'demersals' groups. They did not report on any simulations involving direct changes in fishing mortality on these demersal groups and therefore do not give any indication of the likely ecosystem ramifications of a reduction in monkfish biomass or production. However, Heymans and Sumaila (2007) did include a specific monkfish species in their model and reported that the simulated diet of monkfish in the model was: 36.7% hake, 29.4% demersals, 6.6% horse mackerel, 0.2% gobies, 1% cannibalism, 12.3% small pelagics, 3.9% anchovy, 0.4% mesopelagics, 8.4% cephalopods and 1.2% macrobenthos. Based on this diet, it could be assumed that a reduction in biomass of monkfish would lead to a reduction in predation mortality on those species in proportion to:

i) the reduction in monkfish biomass and
ii) the proportional representation of the species in the monkfish diet.

© NMP 2014

Therefore, for example, hakes and other demersals could be expected to show the biggest increases while for most other taxonomic groups the responses would be considerably smaller. This does not take into account interactions between the species preyed on by monkfish, which could affect these simple forecasts. For example, the increase in *M. capensis* caused by reduced predation by monkfish could be expected to lead to higher predation on juvenile *M. paradoxus* which could offset the effect of reduced predation by monkfish on that species.

An important feature of the results shown in Table 1 and other results reported in Roux and Shannon (2004) is that the indirect impacts on other species of a management intervention on a target species were invariably smaller, as a percentage change in biomass, than the magnitude of change in the directly impacted species. For example, a fourfold increase in fishing mortality of large horse mackerel led to an estimated 88% decline in horse mackerel biomass, while the largest percentage response amongst other groups was a 59% increase in seabirds. Similarly, a 50% reduction in the Cape fur seal population led to increases in biomass of anchovy and sardine of 16 and 10% respectively. These results suggest that the indirect impacts on other species of any reductions in e.g. hakes, monkfish or pelagic gobies will be lower, as percentage changes in biomass, than the direct impacts on those species. In other words, the Roux and Shannon (2004) results do not give evidence that direct impacts on the species and taxonomic groups examined in their study could lead to much bigger, non-linear, indirect responses in other elements of the ecosystem.

Table 1. Summarised results of the projected ecosystem consequences of selected management actions as simulated by the Roux and Shannon EwE model (Roux and Shannon 2004).

Management Action	**Changes in other groups as projected by model (% change in biomass)**
Opening fishery on pelagic goby (removing 50% of goby production).	Goby -87 Anchovy +51 Sardine +27 Small horse mackerel +21 *M. capensis – 25* *M. paradoxus* +16
Increasing fishing mortality on small and large horse mackerel (fourfold)	Sardine – negligible Seabirds +70 Large pelagics +35 *M. capensis – 30* *M. paradoxus* +17
Removal of 50% of gelatinous zooplankton production	Anchovy +22 Cephalopods and horse mackerel +33 Large pelagic fish and whales +42 *M. capensis* +20 *M. paradoxus* +33 Pelagic goby -8 Seabirds -6
50% reduction in Cape fur seal population	Anchovy +16 Sardine +10 Most other groups between -5 and +5
Increasing fishing mortality on large *M. capensis* (fourfold)	Large *M. capensis* – 36 Small *M. capensis* -27 *M. paradoxus* between -5 and +5 Dolphins +17 Seabirds +22

Examination of similar simulations undertaken on the southern Benguela are, however, not entirely consistent with the results from the northern Benguela suggesting that the indirect impacts on other species arising from a reduction in one species will be proportionately smaller than the initial reduction. That conclusion, therefore, may not always be applicable. Simulations undertaken using an EwE model of the southern Benguela estimated that heavy pulse fishing on hake reduced the biomass of hake substantially but, under one particular assumption on the nature of predator-prey relations known as wasp-waist control, indicated that the indirect impacts of the hake reduction led to larger reductions in the biomass (as a proportion of the original biomass) of chub mackerel and horse mackerel than had taken place with hake. Under the assumption of wasp–waist control, recovery from the change for some groups was slow and they had still not reverted to their biomasses 35 years after the perturbation (Shannon *et al*. 2000). Simulations using an OSMOSE model found that overfishing of hake led to reduction in biomass of adult *M paradoxus* to approximately 70% of its original biomass which in turn led to an increase in biomass of silver kob to about 1.3 times its initial biomass and of snoek to about 1.5 times its initial biomass (Travers *et al*, 2010). In these examples, the indirect impacts, as a proportion of the original biomass of the impacted stock, were as large or larger than the direct impacts on the targeted stock.

Ecosystem models inevitably include high levels of uncertainty that lead to equivalent uncertainty in the results. This is demonstrated in the study by Travers at al. (2010), which compared the forecasts of two models, an EwE model and an OSMOSE model. The authors concluded that the two models simulated similar trophic functioning in the southern Benguela but that there were differences in the results of the simulations in both the directions of change of species and other indicators (i.e. increases or decreases) and in their variability. They ascribed these differences to different assumptions made in constructing the models.

In a separate study to explore the combined effects of climate forcing and fishing on the southern Benguela, the authors constructed an end-to-end model in which the trophic interactions were simulated using an OSMOSE model with a simplified food-web structure. The results were that the simulations of these two drivers in combination generated changes in biomass that were less pronounced than, or dampened, compared to the changes that occurred when the impacts of only one driver were simulated (Travers-Trolet *et al*. 2014). The severely simplified representation of the composition and structure of the food web in that study would have influenced the results but they nevertheless illustrate the complexities of regulation and responses of species to perturbations.

The studies referred to in this assessment reveal the uncertainties associated with ecosystem models. At the current state of development of ecosystem understanding and simulation, it is not possible to forecast indirect impacts with any degree of certainty. However, overall the results referred to suggest that indirect impacts resulting from the direct impacts of a perturbation, such as fishing or dredging, on a species are likely to be of the same general order of magnitude as those direct impacts. The results further indicate that the indirect impacts are most likely to be smaller or, at most, slightly larger as a proportion of the original condition, than the direct impacts. There was no evidence to suggest that indirect impacts disseminated through the food web would be disproportionately larger than the original direct impacts and therefore that direct impacts on the scales simulated here could generate serious, unexpected consequences in all or some components of the ecosystem.

© NMP 2014

5 POTENTIAL FOR APPLICATION OF MODELLING TO EVALUATE THE ECOSYSTEM IMPACTS OF THE PROPOSED DREDGING

In principle, a spatially disaggregated ecosystem model could be used to assess the likely impacts of the proposed dredging on the ecosystem as a whole. However, the practical utility of this in this particular case is highly questionable.

The first factor to be taken into account is that the projections of ecosystem models typically have high uncertainty associated with them as a result of a combination of incomplete knowledge of the functional relationships within the ecosystem and similarly incomplete knowledge of the value of the parameters associated with those relationships. As model complexity is increased, which would include through the addition of spatial complexity, these uncertainties increase further (Plaganyi 2007).

Notwithstanding this uncertainty, ecosystem models can still give an indication of likely or possible trends. However, in this particular case, ecosystem modelling is unlikely to be useful for the following reasons:

- The area impacted by the proposed dredging, as a proportion of the distribution of most of the key ecological compartments (3km^2 per year to a maximum, assuming no recovery, of 60 km^2 over 20 years, as a proportion of more or less the whole northern Benguela), will be small. As a result, the uncertainties in the projections are likely to be much larger than the magnitude of the impacts and any true trends would probably be buried in the high uncertainty and resulting wide confidence intervals of the projections.
- A primary conclusion from this short report is that
    - i) direct impacts on specific species will lead to indirect impacts on predators, prey and competitors of the directly impacted species;
    - ii) the indirect impacts are most likely to be smaller or at most slightly larger in terms of percentage changes in biomass than the direct impacts;

This conclusion, coupled with the wide confidence intervals discussed in the previous point, suggest that it is very unlikely, based on available knowledge, that ecosystem modelling would uncover any surprising ecosystem impacts of greater significance than the impacts already assessed in the three specialist studies referred to in the Introduction. Nevertheless the uncertainty inherent in ecosystem understanding and knowledge must be recognized and this requires a precautionary approach in planning for any human activities that could impact on components of the ecosystem.

6 IMPACTS OF SCALING-UP DREDGING BEYOND SP-1 OR EXPANSION INTO OTHER AREAS ON THE NAMIBIAN SHELF

The conclusions of the specialist reports in Appendices a), b) and c) of the EIA (Midgley 2012) were that any impacts on the ecosystems and biodiversity of the dredging activity would be of low or medium significance at most. In relation to commercial species, only impacts on the monk trawl fishery were above low significance: it was estimated that just over 1% of the historical catch would be directly impacted in the dredged areas and that impacts of unknown magnitude on monkfish recruitment are likely. Further, it is stated in specialist report Appendix 1 c (of the EIA) that the available information indicated a benthic environment of generally sandy conditions in which benthic

species diversity was generally low. This suggests that it is unlikely that the benthic habitat in the dredged area has a particularly key role in ecosystem processes.

A major factor mitigating higher risks in the EIA is the small size of the proposed dredging area. If this area is increased, the impacts will increase, at least in direct proportion to the increase in area and, above certain thresholds, impacts could increase disproportionately. The same principle applies to any wider ecosystem impacts. As a result of the generally low significance of the direct impacts, it is concluded here that the ecosystem impacts are likely to be similarly low. If the direct impacts are scaled-up by increasing the dredging area, the ecosystem impacts will also be scaled-up, probably linearly but with the likelihood of encountering critical thresholds, above which the impacts could lead to disproportionately severe consequences. The nature and value of these thresholds is currently unknown. They could include, for example, damage to habitats critical in the life cycle of one or more species or reduction of predation mortality to a degree that causes important shifts in trophic relationships and structure. As stated above this lack of knowledge and limited understanding of the functioning of the ecosystem as a whole requires the application of a precautionary approach. Therefore, before a significant increase in dredging area is contemplated, it will be essential to reconsider the potential for ecosystem impacts. This should include revisiting the value of ecosystem modelling and wider *in situ* sampling extended over at least a year in order to monitor seasonal differences.

7 COMMENTS ON THE IMPLICATIONS OF THE RESULTS OF THE VERIFICATION BIODIVERSITY SURVEY: AN ECOSYSTEM PERSPECTIVE

As part of the verification programme of the EIA, a biodiversity survey was undertaken to investigate and verify, if appropriate, some of the findings of the desk-top reports of the EIA and to establish a baseline for future reference for biodiversity, abundance of the main commercial fish species, recruitment and size distribution and some other biological aspects within the actual MLA and SP-1 target dredge site. The results from the survey were to be compared with the available information on these features from the region (Section C, Chapter 3.1). The survey was undertaken from 18 to 27 June 2014.

A total of 48 different species was identified of which 17 were fish, 14 were epifauna species, 15 were seabirds and 2 were marine mammals. The shallow water hake (*Merluccius capensis*) was the dominant fish species caught, accounting for 40 % by weight of the total fish catch, with monk (*Lophius vomerinus*) accounting for 35%, rattail (*Coelorinchus simorhynchus*) for 14%, sole (*Austroglossus microlepis*) for 3%, goby (*Sufflogobius bibarbatus*) for 2 %, while horse mackerel (*Trachurus capensis*) accounted for 0.4 % of the total fish catch. The size distribution of fish species was generally consistent with previous results. Juvenile monk fish were abundant, making up 45% of the total number sampled from the catch, while less than 6% of the sampled hake were juveniles. No horse mackerel juveniles were observed. Full details of the results for fish and other components of the biodiversity are presented in Section C, Chapter 3.1.

Japp and Smith (Section C, Chapter 3.1) reported that the results of the survey were consistent with and therefore supported the information and conclusions provided in the initial specialist report (Appendix 1a of the EIA, Midgley 2012) on fish resources (see summary earlier in this report). These included that the biomass of the main commercial species likely to be impacted by dredging would be low and that the impacts on recruitment, including recruitment to the monk stock, would be low.

© NMP 2014

The results of the survey also indicated that the area did not possess any unique features in relation to biodiversity and oceanographic conditions.

8 CONCLUSIONS

Ecosystem modelling is often a valuable tool for investigation of indirect and ecosystem ramifications of natural or human impacts on a part of the ecosystem. Spatially disaggregated ecosystem models have been applied in a number of localities and ecosystems around the world and have been found to be useful. In this case, however, the combination of the high uncertainty typically associated with projections by ecosystem models and the small area that will be impacted by the proposed dredging mean that it is unlikely that ecosystem modelling would expose any unexpected, highly significant threats that have not already been considered in the specialist studies.

That conclusion might not apply, however, if the area to be impacted by the dredging was found to be of particular importance in the ecosystem or in the life cycle of one or more key species, and therefore that some ecological impacts could be disproportionately higher than would be expected from considering only the impacted area as a proportion of the total area of a species distribution or of the ecosystem as a whole. The results from the Verification Biodiversity Survey did not produce any results to suggest that the proposed impacted area has any unique or unusual features that would indicate such a disproportionate importance.

The expected ecosystem impacts of the dredging can be considered in the context of other actual or potential environmental impacts in the region, such as from trawling and other fishing impacts, diamond mining, and oil and gas exploration. At this stage, the only other anthropogenic activity taking place in the MLA is fishing with trawl nets, as reported in specialist report (Appendix 1a – Japp, in Midgley 2012). The impacts of dredging in the specific area planned to be dredged can be expected to have considerably greater, and longer-lasting, direct impacts on the biota in that area than does bottom trawling. However, the limited area currently designated to be dredged means that, overall, these impacts will almost certainly be considerably less across the northern Benguela shelf and southern slope environments as a whole than have been the impacts of trawling on these environments, noting that the impacts of trawling are well-managed and considered to be sustainable.

© NMP 2014

9 REFERENCES

Heymans, S.J.J. and Sumaila, U.R. 2007. Updated ecosystem model for the northern Benguela ecosystem, Namibia, p. 25–70. In: Le Quesne, W.J.F., Arreguín-Sánchez, F. and Heymans, S.J.J. (eds.) *INCOFISH ecosystem models: transiting from Ecopath to Ecospace*. Fisheries Centre Research Reports 15(6). Fisheries Centre, University of British Columbia.

Japp, D.W. and M. Smith. Namibian Marine Phosphate. Verification of EIA (fish, birds and mammals). Report prepared for Namibian Marine Phosphate by Capricorn Fisheries Monitoring cc (Cape Town).

Lecari, D., Arreguín-Sánchez, F. and Le Quesne, W. 2007. An ecosystem simulation model of the northern Gulf of California, p. 100–113. In: Le Quesne, W.J.F., Arreguín-Sánchez, F. and Heymans, S.J.J. (eds.) I*NCOFISH ecosystem models: transiting from Ecopath to Ecospace.* Fisheries Centre Research Reports 15(6). Fisheries Centre, University of British Columbia.

Plagányi, É.E. 2007. Models for an ecosystem approach to fisheries. FAO Fisheries Technical Paper. No. 477. Rome, FAO. 2007. 108p.

Roux, J-P & L. J. Shannon (2004): Ecosystem approach to fisheries management in the northern Benguela: the Namibian experience, *African Journal of Marine Science*, **26**:(1): 79-93.

Shin, Y-J., L. J. Shannon and P. M. Cury. 2004. Ecosystem Approaches to Fisheries in the Southern Benguela. *African Journal of Marine Science*. **26**: 95–114.

Travers, M., K. Watermeyer, L.J. Shannon,Y.-J. Shin. 2010. Changes in food web structure under scenarios of overfishing in the southern Benguela: Comparison of the Ecosim and OSMOSE modelling approaches. *Journal of Marine Systems* **79**: 101–111.

Travers-Trolet M, Shin Y-J, Shannon LJ, Moloney CL, Field JG. 2014. Combined Fishing and Climate Forcing in the Southern Benguela Upwelling Ecosystem: An End-to-End Modelling Approach Reveals Dampened Effects. PLoS ONE 9(4): e94286. doi:10.1371/journal.pone.0094286

© NMP 2014

Annexure 1: Species and species groups

Species and species groups identified as having preferred habitats on the Shelf and Southern Slope in Heymans and Sumaila (2007) Ecospace model (* indicates species or species group included in the EcoSpace model but not in these two habitats).

Group	Shelf	Southern Slope	Roux *et al* EwE Model
Marine mammals	X	X	X (Cetaceans)
Seals*			X
Birds	X	X	X
Sharks	X	X	X (Chondrichthyans)
Tuna	X	X	X (large pelagics)
Snoek	X	X	
Other linefish	X	X	
Anchovy juveniles	X		
Anchovy adults	X		X (single category)
Sardine juveniles	X		
Sardine adults	X		X (single category)
Goby juveniles	X		
Goby adults	X	X	X (single category)
Other small pelagics	X	X	X
Mesopelagics	X	X	X
Horse mackerel juveniles	X		X (small)
Horse mackerel adults	X	X	X (large)
Hake juveniles	X	X	X (small *M. capensis)*)
Hake adults		X	X (large, split into *M. capensis* and *M. paradoxus*))
Monkfish		X	
Other demersals	X	X	X (split into pelagic-feeding and benthic feeding demersals)
Cephalopods	X	X	X
Macrobenthos	X	X	X
Crabs		X	
Lobster*			
Jellyfish juveniles	X	X	
Jellyfish adults	X	X	
Gelatinous zooplankton			X
Macrozooplankton	X	X	X
Mesozooplankton	X	X	X
Microzooplankton			X
Benthic producers*			
Phytoplankton	X	X	X
Detritus	X	X	X

SECTION C - SPECIALIST STUDIES

C3.4 Fish Reproduction Dynamics and Stock Distribution

NAMIBIAN MARINE PHOSPHATE

VERIFICATION SURVEY

REPRODUCTION DYNAMICS AND STOCK DISTRIBUTION STUDY WITH RESPECT TO A PROPOSED DEVELOPMENT OF PHOSPHATE DEPOSITS IN THE SANDPIPER PHOSPHATE LICENCE AREA OFF THE COAST OF CENTRAL NAMIBIA

Prepared for:
Namibian Marine Phosphate (Pty) Ltd.

Prepared by:
Capricorn Fisheries Monitoring cc
Dr Hilkka O.N. Ndjaula

June 2014

CAPFISH (Pty) LTD
Unit 15, Foregate Square. Table Bay Boulevard, 8002, South Africa
Directors: Japp, Wissema, Heinecken, Wilkinson, Ncongo
Co Reg. No. 2004 / 004844 / 07

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed "Attention: Administration Manager," at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

SUMMARY

With respect to the stock structure and gonad maturation of the main commercial species the data available showed that there were no special characteristics of their reproductive dynamics in the proposed dredging area (MLA). Further, the study showed that there was no deviation expected that would make the area unique with respect to these reproductive biological characteristics. The study also considered cohorts for all the species analysed and showed that a mix of small and large fish for most of the Namibian EEZ was typical and that for the MLA there were no indications of any deviation from this norm and that the MLA was not a unique spawning area that supported significantly different levels of recruitment of the main commercial species to the fisheries in the proximity of the MLA. Monthly trends also did not indicate any gonad development beyond "maturing stage" of the commercial species found in the MLA. This supported the suggestion that fish move in and out of such grounds over time. Annual maturity trends have also not shown repeated dynamics, implying that spawning grounds for these species are not localized. Multiple cohorts observed per year and by area suggest that high and low recruitment events occur. This again indicated the lack of a "homing behaviour" for adults and that recruitment and spawning grounds are not clearly defined.

© NMP 2014

contents

SUMMARY ii

1 BACKGROUND 1

2 GENERAL INTRODUCTION 2

2.1 HISTORICAL SPAWNING BEHAVIOUR OF COMMERCIAL SPECIES IN NAMIBIAN WATERS 3

3 APPROACH TO THE STUDY (METHODOLOGY) 4

4 RESULTS 6

4.1 STOCK STRUCTURE (SIZE DISTRIBUTION/ RECRUITS VS ADULTS) 6

4.1.1 Hake 6
4.1.2 Monkfish 11
4.1.3 Horse mackerel 15
4.1.4 Sardine 17

4.2 MATURITY 18

4.2.1 Hake 20
4.2.2 Horse mackerel 20
4.2.3 Sardine maturity 20

5 DISCUSSION 24

6 CONCLUSION 25

6.1 SIZE DISTRIBUTION 25
6.2 GONAD MATURATION 26

7 REFERENCES 27

ANNEXURE 1: HAKE SIZE DISTRIBUTION 28
ANNEXURE 2: TERMS OF REFERENCE 29

© NMP 2014

figures

Figure 1. The location of the Sandpiper Phosphate mining licence area (ML 170) and the three target areas off the coast of central Namibia 1
Figure 2. The distribution of mean size per depth and latitude of hake and monkfish. 7
Figure 3. Hake population structure as observed over the years along the entire Namibian coast. 8
Figure 4. Hake population structure at all latitudes in Namibia from 2007 to 2012. 9
Figure 5. Hake population structure at various depths along the entire Namibian coast during 2007 to 2012. 10
Figure 6. Monkfish population structure as observed over the years along the entire Namibian coast. 11
Figure 7. Monkfish population structure at all latitudes along Namibia's coast from 2001 to 2012. 12
Figure 8. Monk population structures at various longitude along the entire Namibian coast during 2001 to 2012. 13
Figure 9. Monk population structures at various depths along the entire Namibian coast during 2001 to 2012. 14
Figure 10. Horse mackerel fish size structure over the year. 15
Figure 11. Horse mackerel size structure along latitudes and longitude. 16
Figure 12. Sardine population structure along the coast of Namibia during the period 2007 to 2012 and along the latitudes 16 - 24^0S. 17
Figure 13. Sardine population structure along the coastline of Namibia during the period 2007 to 2012 and along the latitudes 16 to 24°S. 18
Figure 14. The areas in which spawning (stage 4 hake and 5-horse mackerel and sardine) was recorded for hake (*M. capensis)*, horse mackerel and sardine. 19
Figure 15. Maturity stage profiles for two hake species (HKC = *M. capensis* HKO = *M. paradoxus*) in Namibia. 21
Figure 16. Maturity stage profiles for horse mackerel in Namibia. 22
Figure 17. Maturity stage profiles for sardine in Namibia. 23

tables

Table 1. Data sets provided by NatMIRC and used in this investigation 4
Table 2. Macroscopic maturity stage classifications of the hake species, which are used in the field (Botha, 1986). 5

© NMP 2014

1 BACKGROUND

This report presents the results of an investigative study, aimed at describing the reproduction dynamics of commercially important fish species in Namibian waters, mainly within the area proposed for phosphate dredging. This report seeks to establish an understanding and to set the baseline of the current reproduction dynamics of the main commercial fish species in the area concerned. Namibian Marine Phosphate (NMP) (PTY) Ltd has been granted a mining licence (ML 170) for the area situated offshore from the Namibian coast (Figure 1). There are three general target areas, Sandpiper-1 (SP-1), Sandpiper-2 (SP-2) and Sandpiper-3 (SP-3), with dredging initially proposed for SP-1.

In accordance with the Terms of Reference (Annexure 2) this investigation seeks to provide a professional opinion on the likely area of impact of the proposed dredging and likelihood that the reproduction and reproductive potential of six commercial species potentially would be impacted relative to the known distribution of these species and their reproductive biology. The six commercial fish species include, hake (*Merluccius capensis* and *M. paradoxus*), monk (*Lophius vomerinus* and *L. vaillanti*), horse mackerel (*Trachurus capensis*) and sardine (*Sardinops sagax).*

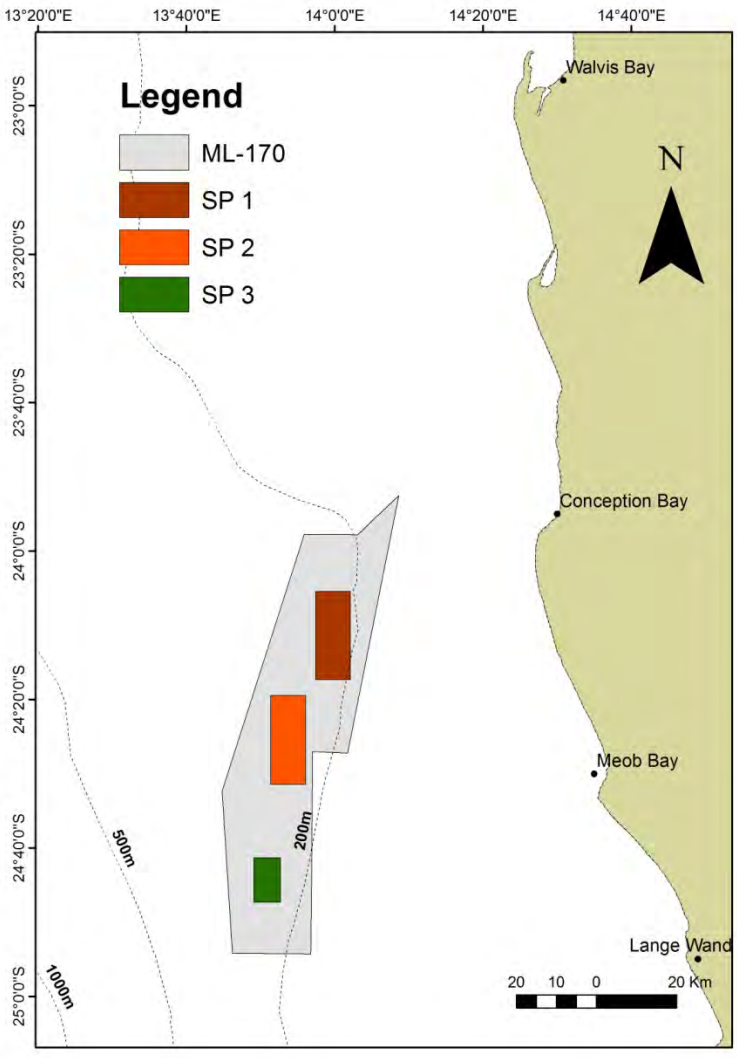


Figure 1. The location of the Sandpiper Phosphate mining licence area (ML 170) and the three target areas off the coast of central Namibia

2 GENERAL INTRODUCTION

A fundamental requirement of the precautionary approach to fisheries management is to identify the stock complexity (Hilborn *et al*., 2001), and where multiple species are differentially exploited, such understanding is necessary for a meaningful resource management system. A multiplicity of fish species forms part of the complex ecosystem in the Namibian marine environment, including the area proposed for phosphate dredging. The spatial and temporal dynamics of population cohort analysis is expected to provide an understanding of reproduction dynamics of the commercial fish species in Namibian waters, information which could highlight the homing, the movement, and the possible changes in various components of these populations and their life history traits. Similarly, knowledge of the population cohort structure and composition are also useful in identifying the location of adult fish aggregations (likely spawning stock), aggregation of juveniles or small fish (likely recruitment stock). Such analysis of population cohort structures and composition is therefore a good proxy for spawning and or recruitment grounds, as it could suggest separate grounds for the younger or adult cohorts of the population. Such knowledge will also suggest separate reproduction grounds, be it bathymetrically separated or isolated by various oceanographic conditions, which are well known to vary along the Namibian coast (Shannon & O'Toole 1998, Shannon *et al*., 2006). Such analysis therefore will be useful in evaluating the intensity and extent of the potential impact of phosphate dredging on fish species population dynamics and the related fisheries.

In order to establish the nature and vulnerability of fish to phosphate dredging such as environmental changes in the area, knowledge of spawning aggregations and reproduction ground preference for the species in question is required. With respect to mapping spawning and reproduction grounds, it is desirable to identify signs of spawning, which include identification of eggs at the earliest developmental stage or the availability of fish in their late gonad maturation as a sign of active spawning in a particular area. Other proxies such as the Gonado Somatic Index[1] (GSI), as well as the presence of the adult population (regarded as the spawning stock) have typically been used as indicators of spawning signs at a particular area or season.

The presence of larvae and juvenile fish in an area or during a particular time can also be used as an indication of reproduction. Similarly, knowledge of the distribution patterns and abundance of eggs and larvae within and around the area of concern is important in evaluating and discussing the impacts of any varied or altered environment. However, for most of the main commercial fish species found in Namibian waters, there have been few dedicated ichthyoplankton or egg surveys intended to identify spawning areas (except for sardine and anchovy). In the absence of egg and larvae surveys, the closest we can investigate is the gonad maturation dynamics of the species in question, in the form of maturity stages of the fish reproductive organs and relative gonad weight through GSI analysis. While GSI is generally used in spawning proxies, its use in indeterminate spawners (egg production is continuous during a spawning season) has been questioned (Kainge *et al*., 2007 and references therein, Ndjaula *et al*., 2013) and might not be a reliable proxy for spawning time and location. Although GSI does indicate the time and area when the gonads are largest, a reduction in gonad size due to the released egg batches during a particular spawning event could lead to a misinterpretation of spawning by indeterminate spawners. Similarly, although visual maturity staging

[1] The GonadoSomatic Index (GSI) is the ratio of fish gonad weight to total body weight and is particularly useful in identifying spawning time and location. It is represented by the formula: GSI = [Gonad Weight / Total Tissue Weight] x 100.

(referred also as macroscopic staging) also has its drawbacks with regard to maturity classifications, it can be more reliable than GSI in indeterminate spawners because fish that have no visible eggs are classified either immature or spent, to indicate that such is the case before spawning or after spawning respectively. The maturity stage which indicates visible eggs does therefore become an important proxy of the spawning signature and spawning residency, even when batches are released, which would otherwise translate into low GSI. The use of visual maturity staging was therefore regarded as less biased, and thus was selected for the analysis of potential spawning prevalence in this study.

This study has combined analyses of fish size and maturity stages as a way of identifying recruits (juvenile fish) as well as spawners (adults or active gonad stage) and looked at these in a spatial, temporal and depth gradient. Such analyses will give a three dimensional picture of fish distribution in size and gonad maturation composition.

2.1 HISTORICAL SPAWNING BEHAVIOUR OF COMMERCIAL SPECIES IN NAMIBIAN WATERS

The spawning areas, ichthyoplankton drift areas and reproduction grounds from the historical and contemporary literature has been reviewed as part of this project's initial Environmental Impact Assessment (Japp in Midgley 2012). They summarized their study with the following:

- A low abundance of hake eggs occur near the MLA off Hollam's Bird Island. Larvae are found in high abundance from Conception Bay to Palgrave Point. A significant number of juvenile *M. capensis* is likely to occur within the MLA;
- According to the historical literature juvenile monkfish are likely to be distributed within the MLA;
- Aggregations of spawning horse mackerel and juveniles are most prevalent outside the MLA;
- Sardine spawn off Walvis Bay and only the northern extent of the MLA coincides with the assumed southern part of the spawning area;
- Historically spawning and larval distributions of anchovy took place north of Walvis Bay (outside the MLA);
- Snoek migrate southwards to spawn offshore and in deep waters near St Helena Bay and off the Cape Peninsula in South Africa. The MLA is within the assumed migration corridor of this species;
- Silver kob spawn inshore of the MLA in Meob Bay and larvae drift northwards to the nursery grounds between Sandwich Harbour and the Ugab River mouth;
- Goby larvae are in high abundance in the MLA. They also inhabit the bottom sediments and are likely to be locally disturbed by the proposed dredging activity; and
- West coast rock lobster are found inshore and south of the MLA.

This study did not attempt to replicate the above reported review, but used the actual data to investigate the reproduction and population structure dynamics of the commercially important species, with respect to the MLA.

© NMP 2014

3 APPROACH TO THE STUDY (METHODOLOGY)

This reproduction dynamics assessment utilises the existing data from the Namibian Ministry of Fisheries and Marine Resources (MFMR) and information from a literature review of international peer-reviewed scientific literature, information from MFMR internal reports, information available on the internet, as well as studies conducted in the proposed mining area. Information obtained through personal communication during the consultation is also included where appropriate.

The data were collected from 1999 to 2012 during the assessment surveys by the Namibian National Marine Information and Research Centre (NatMIRC), and at times, during port sampling (Table 1). When and where available, data were gathered for the entire coast, and for as far back in time as 1999 (horse mackerel). For some species, data were provided for the past six years and only for the areas within the close proximity of ML 170. Data were made available for the following species: *Merluccius capensis*, *Merluccius paradoxus*, *Lophius vomerinus*, *Lophius vaillanti*, *Trachurus capensis* and *Sardinops sagax*. Various stations from surveys were grouped together by degree of latitude, longitude and depth to investigate the stock as a whole.

Table 1. Data sets provided by NatMIRC and used in this investigation

Dataset	Dates	Species	GSI	Maturity staging	Area
Hake survey data	2007 – 2012	*Merluccius capensis, M. paradoxus*	Yes	Yes	Entire Namibian coast (17°S to 29°S)
Monk survey data	2007 – 2012	*Lophius vomerinus, L. vaillanti*	No	Yes	Between 22- 26°S
Horse mackerel survey data	1999 – 2012	*Trachurus capensis,*	Yes	Yes	Between 16- 24°S
Small pelagic survey data	2007 – 2012	*Sardinops sagax*	Yes	Yes	Between 16- 24°S
Port Sampling	2006 – 2013	*M. capensis, M. paradoxus*	Yes	Yes	Entire Namibian coast (17°S to 29°S)

Ideally, a study of reproduction should consider the potential spawning stock, egg and larvae availability as well as the presence of young-of-the-year cohorts in the population. However, knowledge of all such components is not undertaken in the current fisheries monitoring and management approach conducted by MFMR. The information available for the main commercial species in this regard is the biological analysis of the gonad maturity stages and the gonad weight, together with fish size. Data obtained from MFMR however were sufficient and were used for this analysis of reproduction dynamics. Three approaches were taken.

1) Data were used to analyse stock structures for both spatial and temporal dynamics. Stock structure was also analysed for depth profiles.

2) Data were analysed for both spatial and temporal maturity development, and where necessary analyses for depth profiles were also undertaken.

3) Where data were available, GSI was evaluated for both spatial and temporal dynamics. However, due to the nature and interpretation of GSI in serial spawners (which is the egg

production strategy used in hake and horse mackerel), the GSI results were not presented in this report, as it would be a repetition of information gained from more reliable gonad maturity staging.

Care was taken to not use the data from the biological samples for the population structure analysis to avoid duplication, because such samples are mostly, if not always taken from the length frequency samples. Care was also taken in the case of hake and monkfish where two species are analysed, so that the data are correctly presented.

Maturity proportions were calculated as the number of fish according to assigned maturity stages considering its frequency in each latitude, month and depth (represented as a percentage of that group). Staging scales used for hake are presented in Table 1, which is more or less the same for all classification keys used in other species, which are often spread over 7 stages in pelagic species.

Table 2. Macroscopic maturity stage classifications of the hake species, which are used in the field (Botha, 1986).

Stage	Female	Male
1 Inactive	Gonads small, slender, transparent, no visible signs of eggs	Gonads very small, slender, transparent and ribbon like, unlobed
2 Active	Gonads larger and filling with small, pink-orange, opaque and visible eggs	Larger and distended, white opaque, typically lobed
3 Ripe	Gonads very large in relation to fish size, distended and filled with clearly visible opaque eggs-some eggs already translucent; colour of ovaries bright orange to deep pink	Gonads very large in relation to fish size, white opaque, distended with sperm, with pronounced lobes
4 Ripe and running	Translucent eggs can be extruded through the cloaca with slight abdominal pressure	Gonads very large and distended, with sperm flowing spontaneously
5 Spent	Gonads visually completely empty, but large, flabby, prominently veined and often bloodshot	Gonads very large, lobed, flabby but not distended

© NMP 2014

4 RESULTS

4.1 STOCK STRUCTURE (SIZE DISTRIBUTION/ RECRUITS VERSUS ADULTS)

Fish size distribution for commercial species that occur in MLA 170 (hake and monkfish) showed population cohort structures which indicate no special dynamics exclusive to the proposed phosphate mining area (Figure 2, area at 23° and 24° degrees south) in space and time. The area covered was sufficient for the analysis, either spanning the entire coast or two degrees of latitude from the mining site. This was generally true for all species studied, with the exception of the pelagic species (horse mackerel and sardine), whose dynamics were random. In all species, the proportions of the younger stock were generally not recorded in MFMR surveys. Further results of this study are summarized below per species.

4.1.1 Hake

Hake, a serial spawner may potentially be impacted by the proposed phosphate dredging activities (Figure 2). Analyses of the population structure of the two species separately indicated dynamics that showed similar structure over the years with a broader size frequency for *M. capensis* than for *M. paradoxus* (Figure 3). *M. paradoxus* size structure indicated multiple cohorts every year since 2007, but this was not clearly indicated for *M. capensis*, despite a broader size distribution (Figure 3). *M. paradoxus* is differentially distributed along the coast, with larger fish found in the north and smaller fish found in the south, as opposed to *M. capensis*, which is distributed along the coast in one broad cohort, peaking at 30 cm fish size (Figure 4). The presence of juveniles is observed for *M. paradoxus* in the far southern part of Namibia, while there is not a pronounced area of juvenile *M. capensis* (Figure 4).

Depth stratification analysis confirmed that *M.capensis* is distributed in shallower water than *M. paradoxus* (Figure 5), with bigger fish found in deeper waters for both species. Similarly, there is a visible movement of larger *M. paradoxus* into deeper water, as opposed to a consistent homogeneous depth distribution of *M. capensis* (Figures 2 and 5). These differences in spatial dynamics for the two hake species are also evident in the length data extracted from monkfish surveys (Annexure 1).

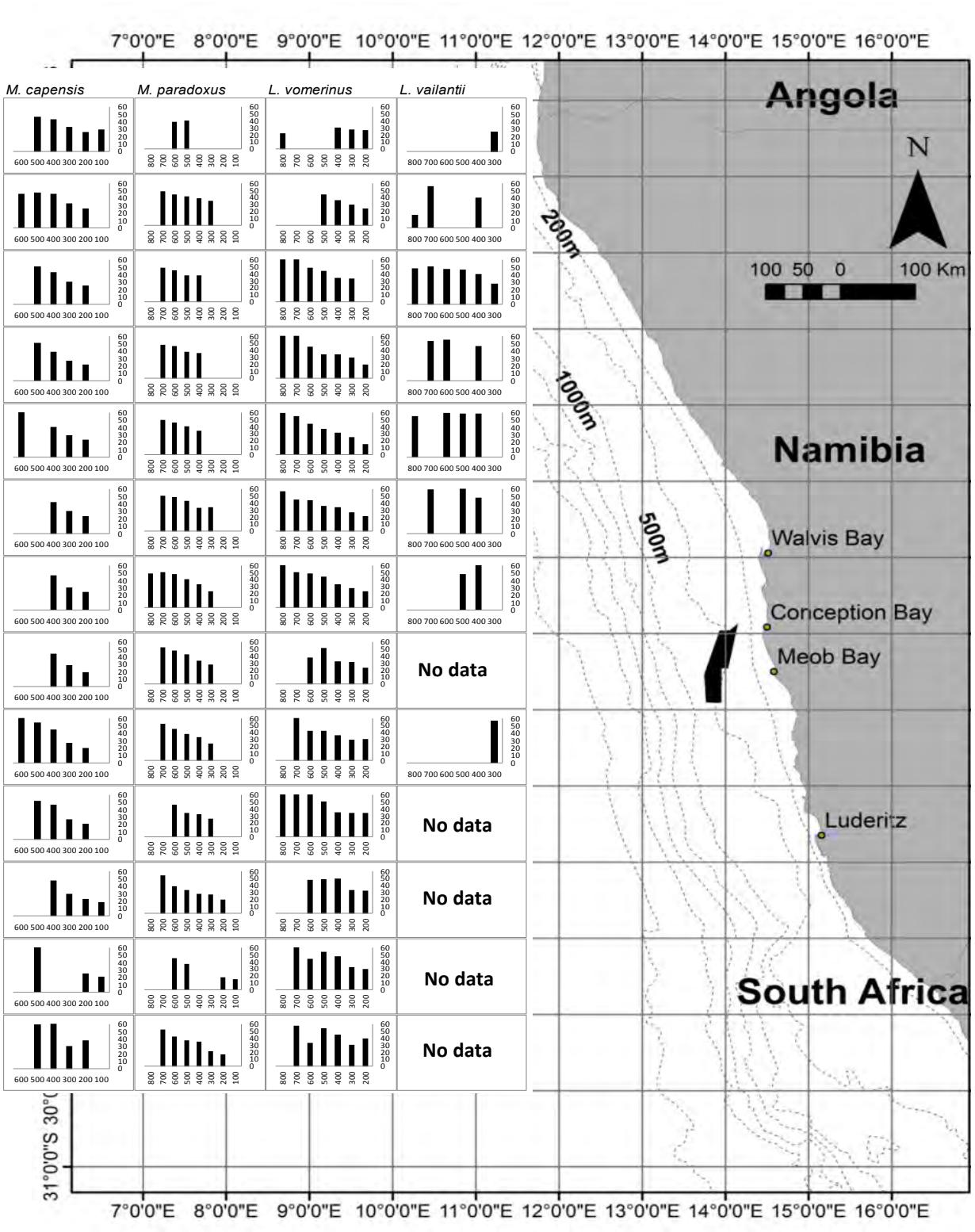


Figure 2. The distribution of mean size per depth and latitude of hake and monkfish.
Graphs show depth (x-axis in 100 m intervals) against mean length (y-axis in 10 cm units).
Scale is not precise and used only schematically.

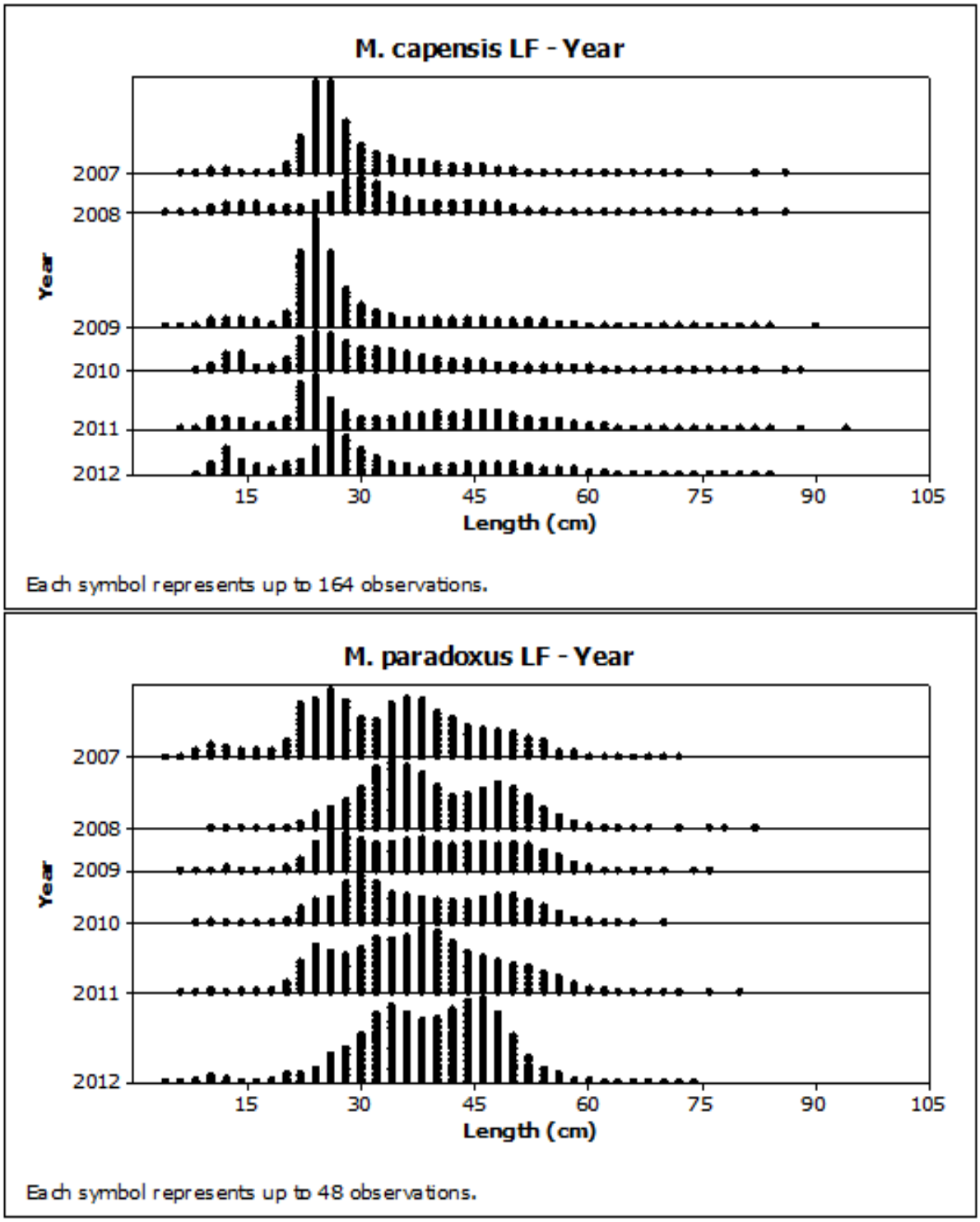


Figure 3. Hake population structure as observed over the years along the entire Namibian coast.

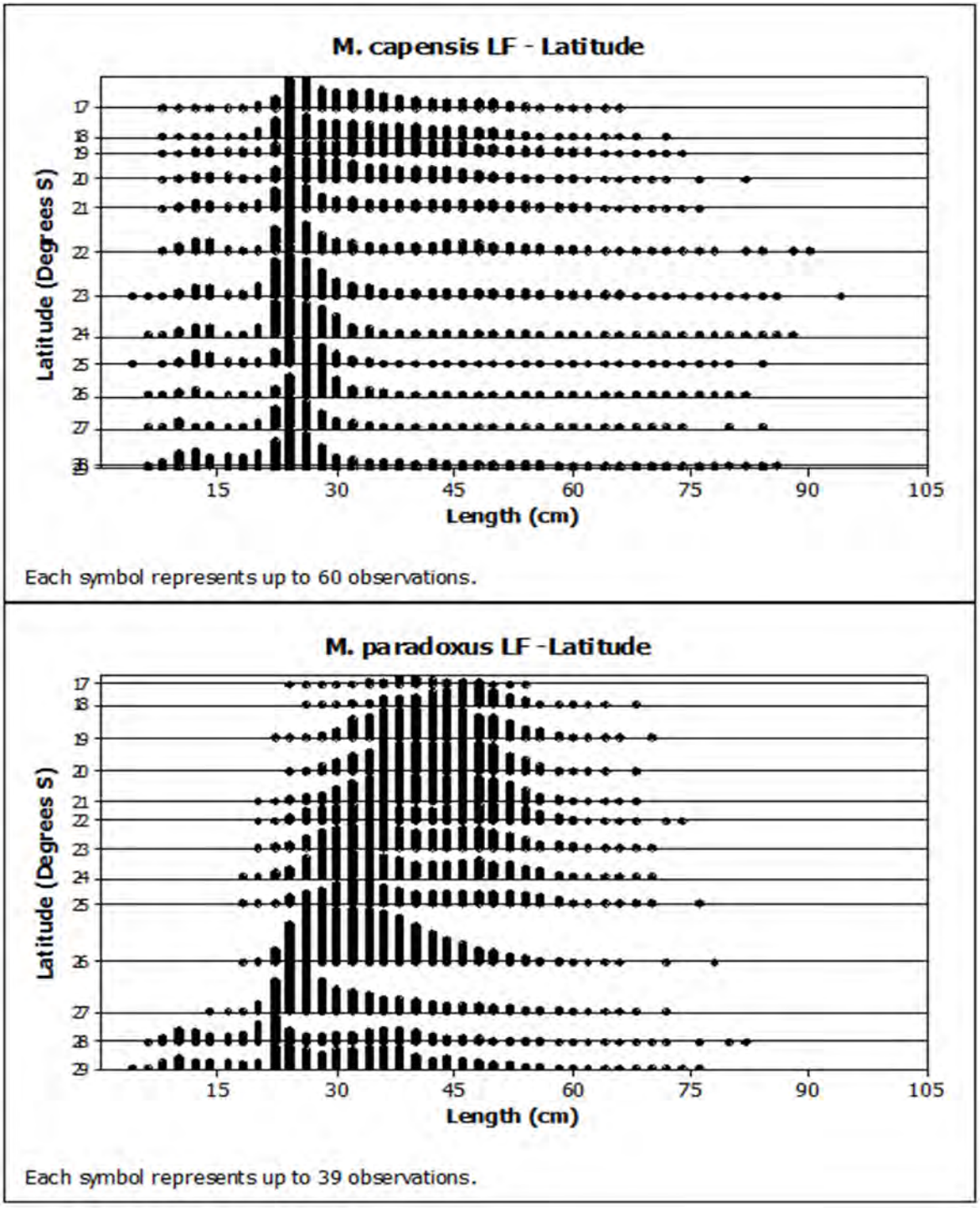


Figure 4. Hake population structure at all latitudes in Namibia from 2007 to 2012.

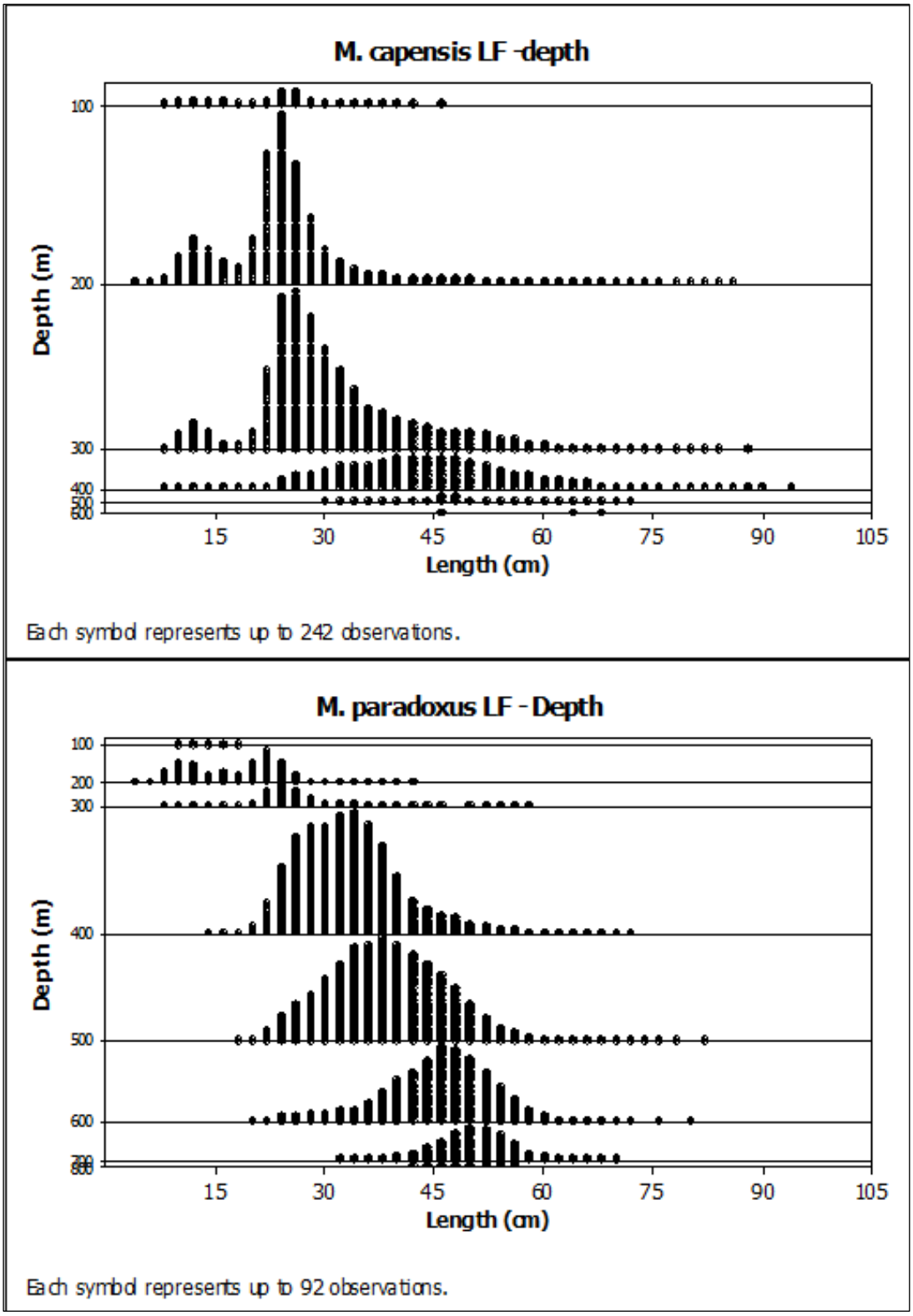


Figure 5. Hake population structure at various depths along the entire Namibian coast during 2007 to 2012.

4.1.2 Monkfish

Due to the predominantly southern distribution of monkfish in Namibian waters, there is a concern that the proposed phosphate dredging activities could potentially impact the reproductive potential. The two species *Lophius vomerinus* and *L. vaillanti* showed population dynamics with no unique features particular to the proposed mining lease area (ML 170) in relation to the rest of the stock distribution and dynamics (Figure 2). Since 2001, *L. vomerinus* has been dominated by similarly broader cohorts that peaked at fish smaller than 40 cm, although fish as large as over 100 cm have been observed (Figure 6). The picture was however different for *L. vaillanti*, which showed no strong cohort dynamics, possibly due to small sample size. The absence of smaller than 20 cm *L. vaillanti* since 2001 was observed, although the sample size was too small to draw any conclusion.

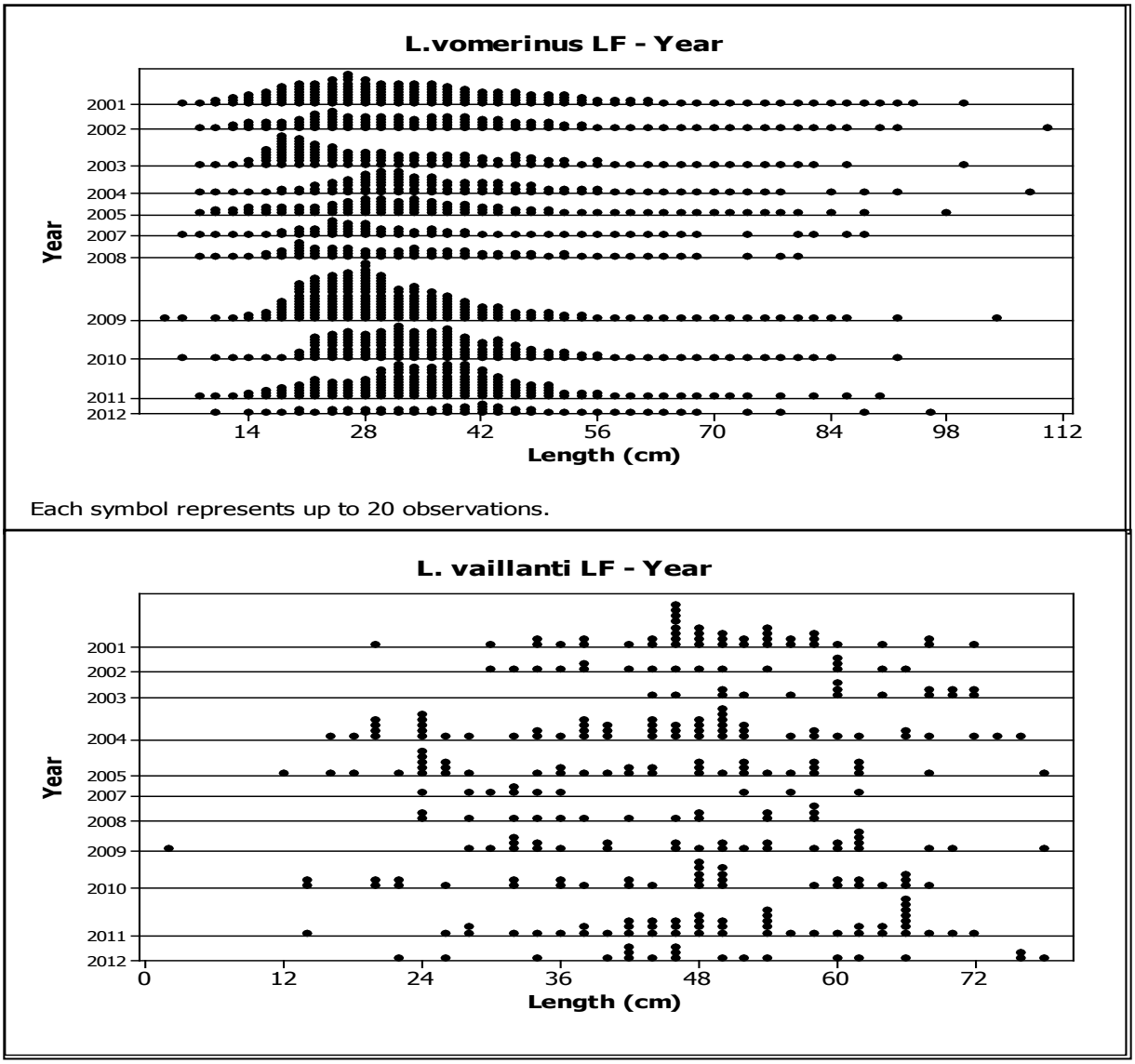


Figure 6. Monkfish population structure as observed over the years along the entire Namibian coast.

With regard to spatial dynamics, single broad cohorts for both species were homogeneous along the entire coastline, with a tendency of larger *L. vaillanti* dominant south of 22°S (Figure 7). Cohorts

were again observed to be broad across longitudinal profiles (Figure 8), indicating a mix of big and small fish.

In respect of depth stratification, there is a visible trend of *L. vomerinus* fish to increase in size with depth but not for *L. vaillanti* (Figure 9 and 2). An overlay of these three spatio-temporal layers in the cohort structure does not suggest any localized reproduction ground for these two species as both juveniles and adults co-exist.

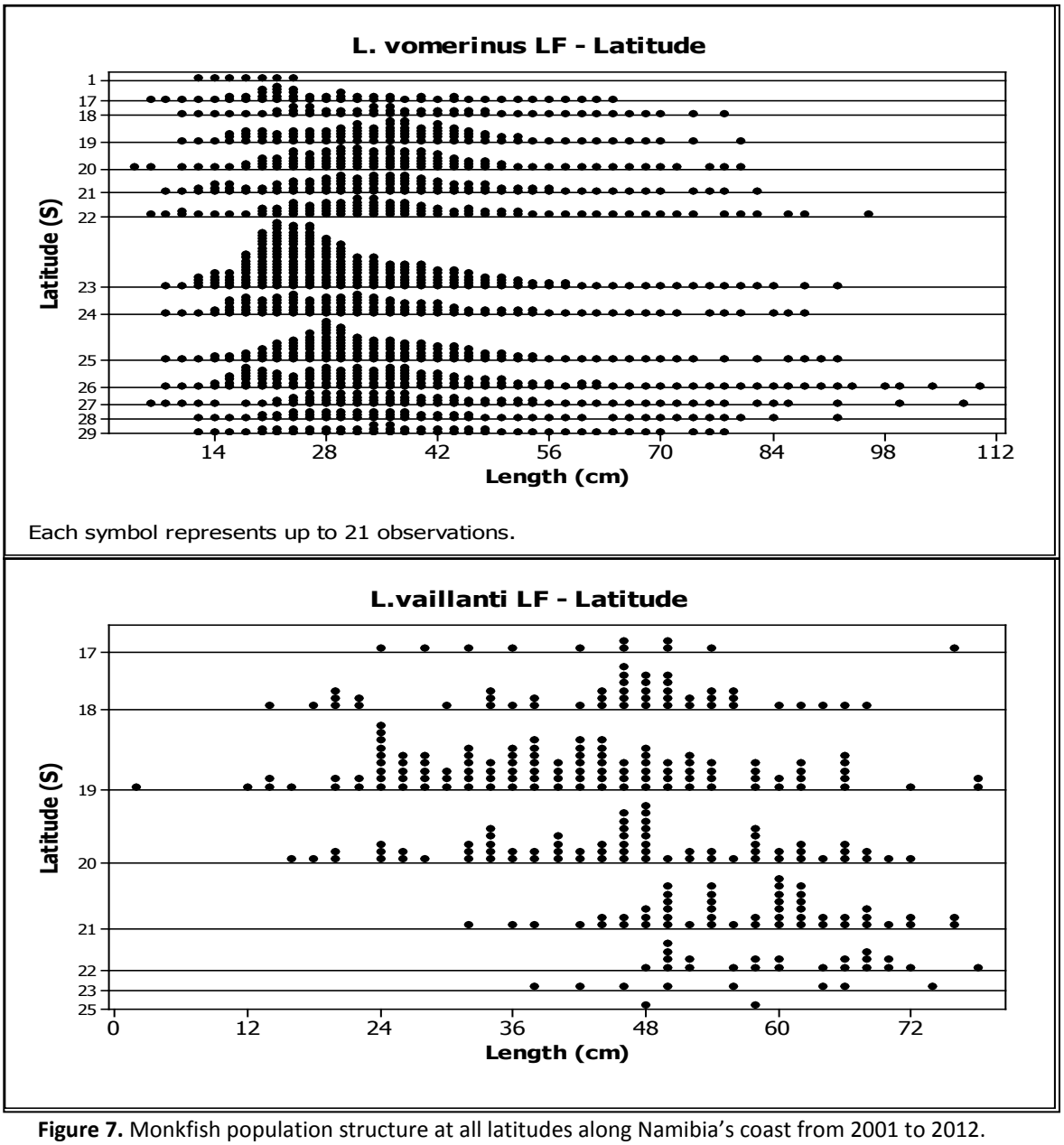
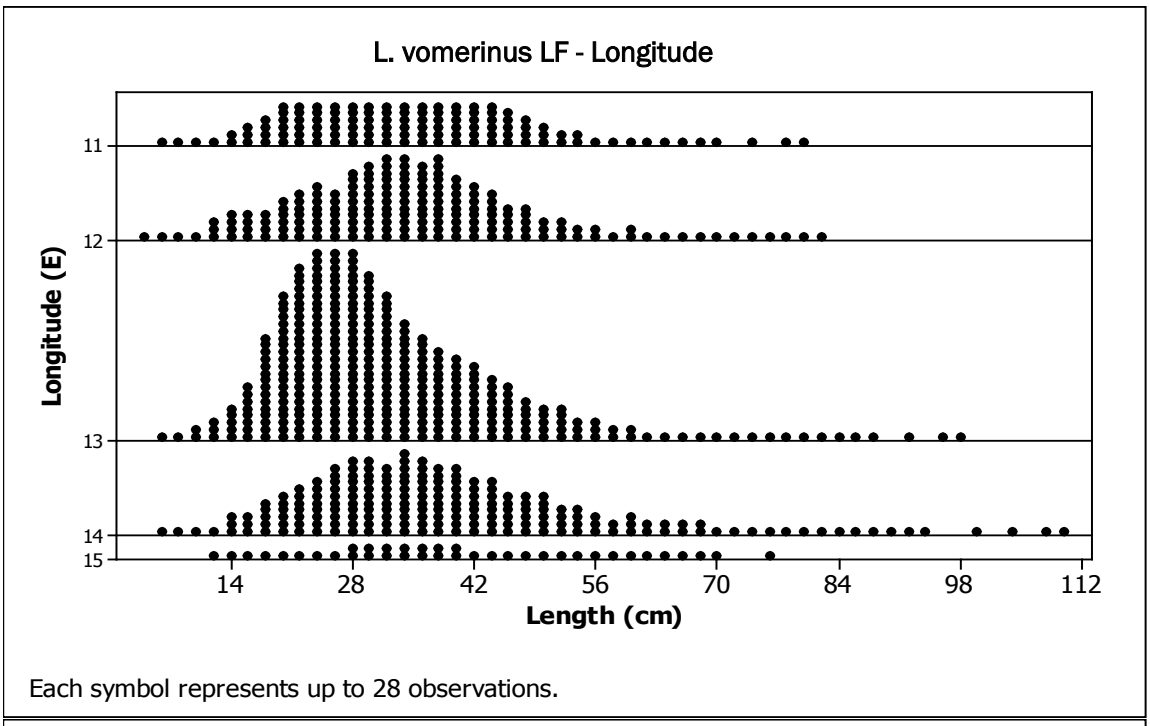


Figure 7. Monkfish population structure at all latitudes along Namibia's coast from 2001 to 2012.



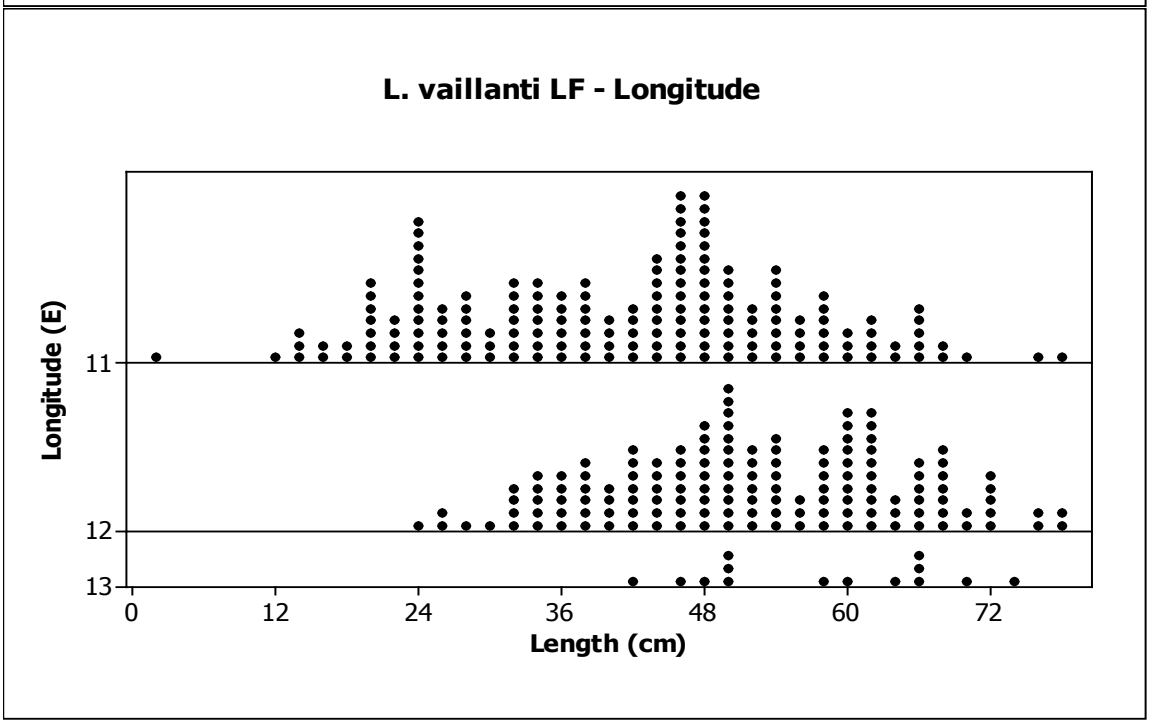


Figure 8. Monk population structures at various longitude along the entire Namibian coast during 2001 to 2012.

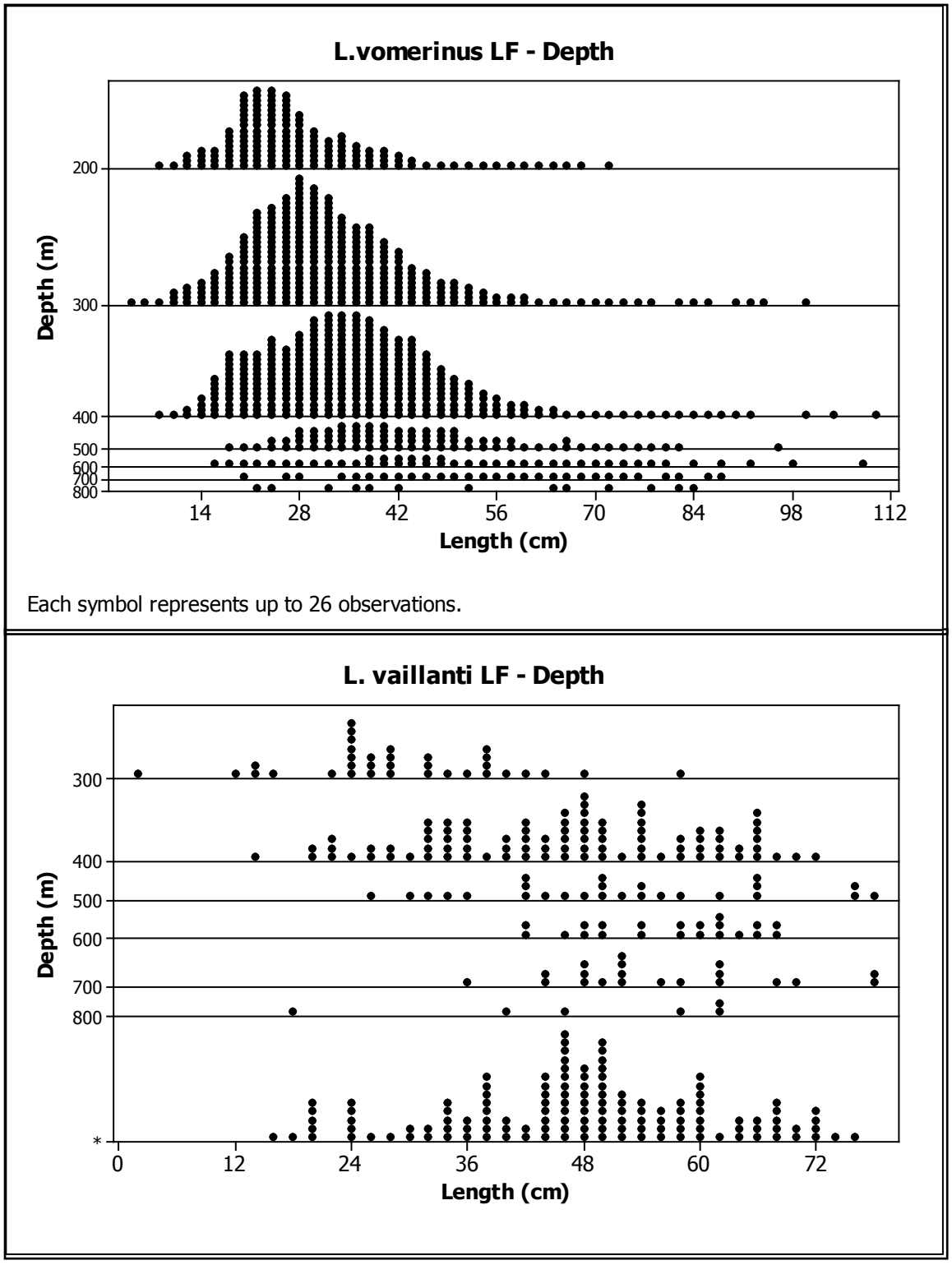


Figure 9. Monk population structures at various depths along the entire Namibian coast during 2001 to 2012.

4.1.3 Horse mackerel

Horse mackerel (*Trachurus capensis*) is a serial spawner with a population size structure that varies over time. This is observed in samples from both horse mackerel dedicated surveys and from sardine dedicated surveys (Figure 10). Historically (as far back as 1999), distinct cohorts were mainly observed for fish below 27 cm, although horse mackerel exceeding 60 cm were observed. Only fish smaller than 30 cm were observed among the sardine targeted samples. Multiple cohorts are observed in one particular year, (Figure 10), as well as at various areas (Figure 11) suggesting a heterogeneous horse mackerel population in time and space in Namibian waters. No horse mackerel data were available for the area south of 24°S since there is a low abundance of horse mackerel in this area and surveys do not extend into this area.

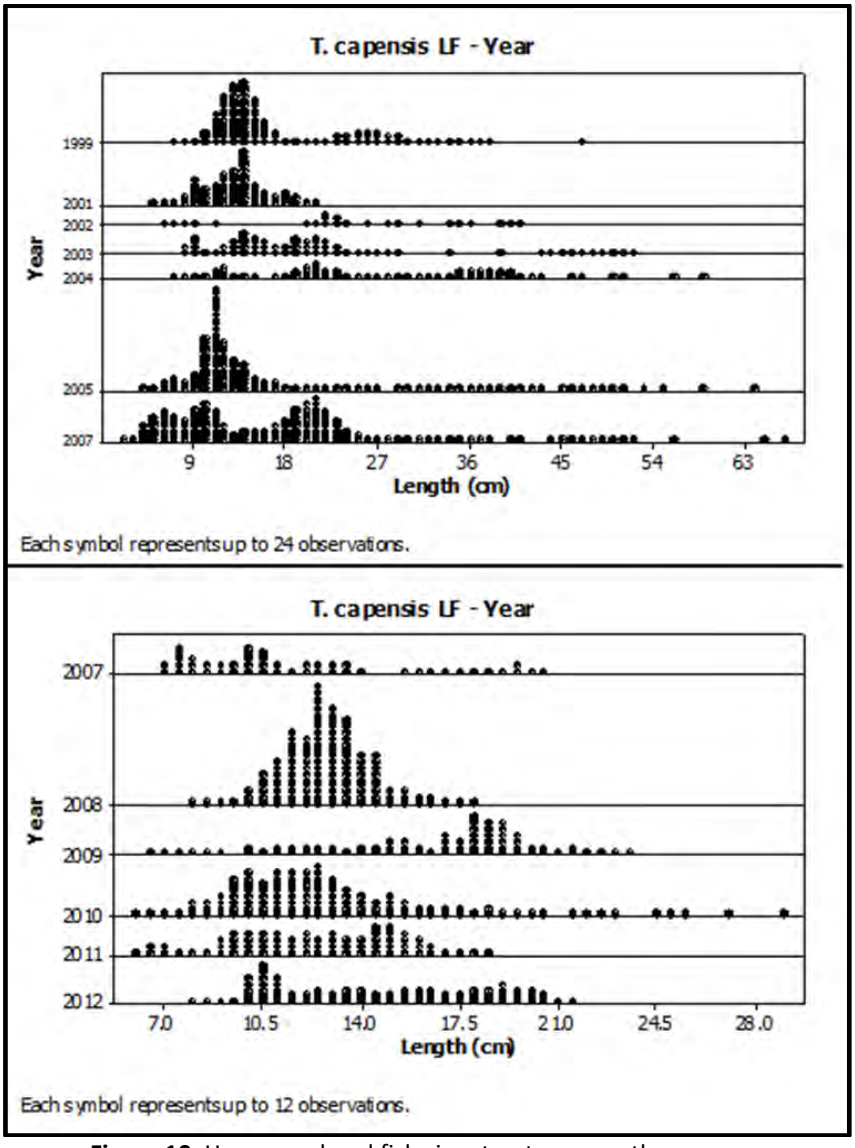


Figure 10. Horse mackerel fish size structure over the year.
The data for the top figure are from the horse mackerel surveys and the data for the bottom figure are from the sardine surveys

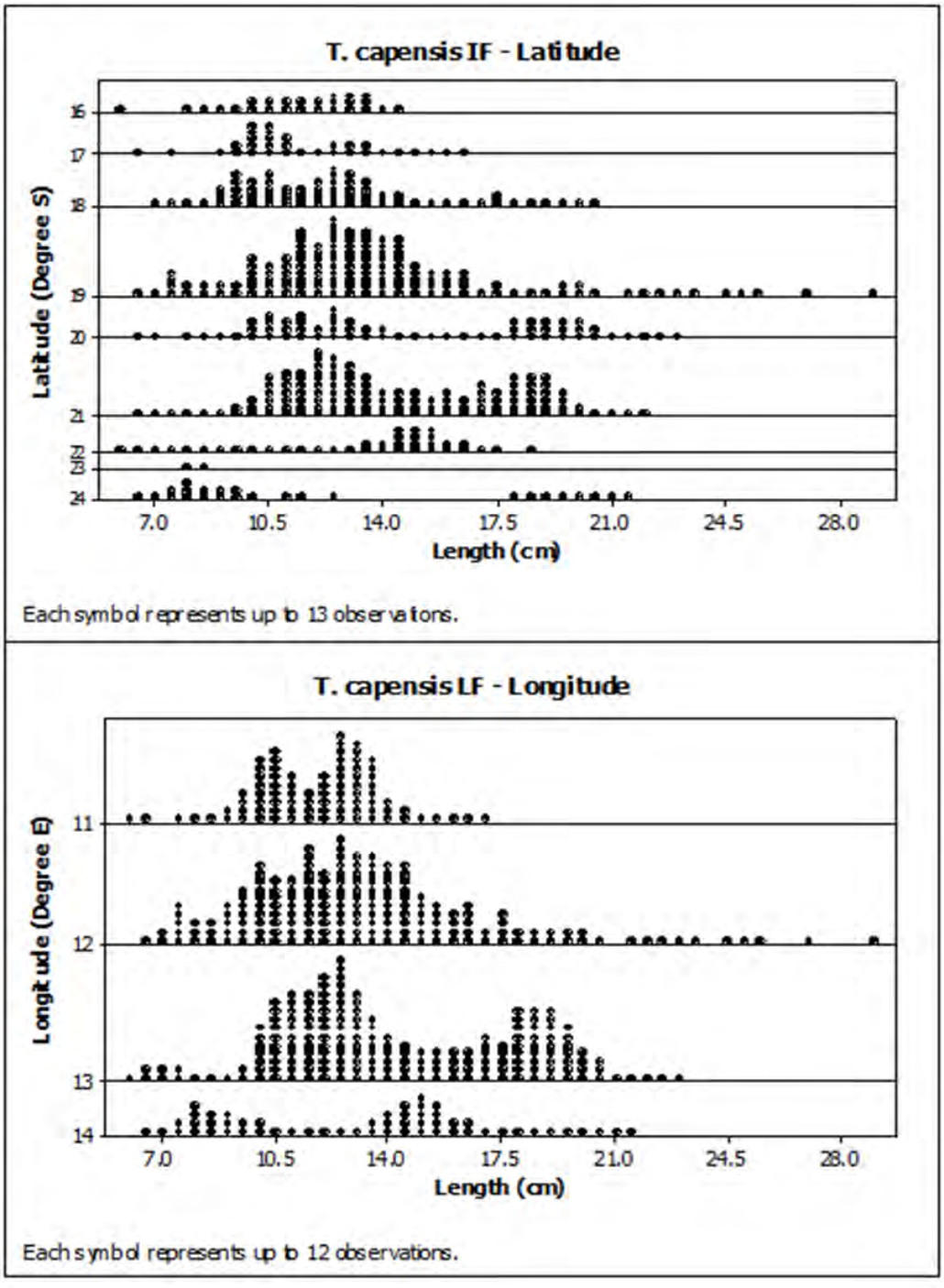


Figure 11. Horse mackerel size structure along latitudes and longitude.

4.1.4 Sardine

Cohort analysis for sardine (*Sardinops sagax*) indicated more defined and well separated cohorts as opposed to the other species. These cohorts were also more heterogeneously distributed both spatially and temporally (Figure 12). A strong recruitment cohort is observed for the year 2010, which corresponds to the cohort observed at 17°S and 11°E. There is a general shift of bigger fish to the south, although patches of small fish are also observed at southern areas. Longitudinal distribution of sardine cohorts (Figure 13) also suggests multiple cohorts at all longitudes. In all these respects, the population structure through cohort analysis indicated a more co-existing stock, as observed through broader cohorts with multiple peaks suggestive of recruitment waves, with cohorts moving in and out of particular areas.

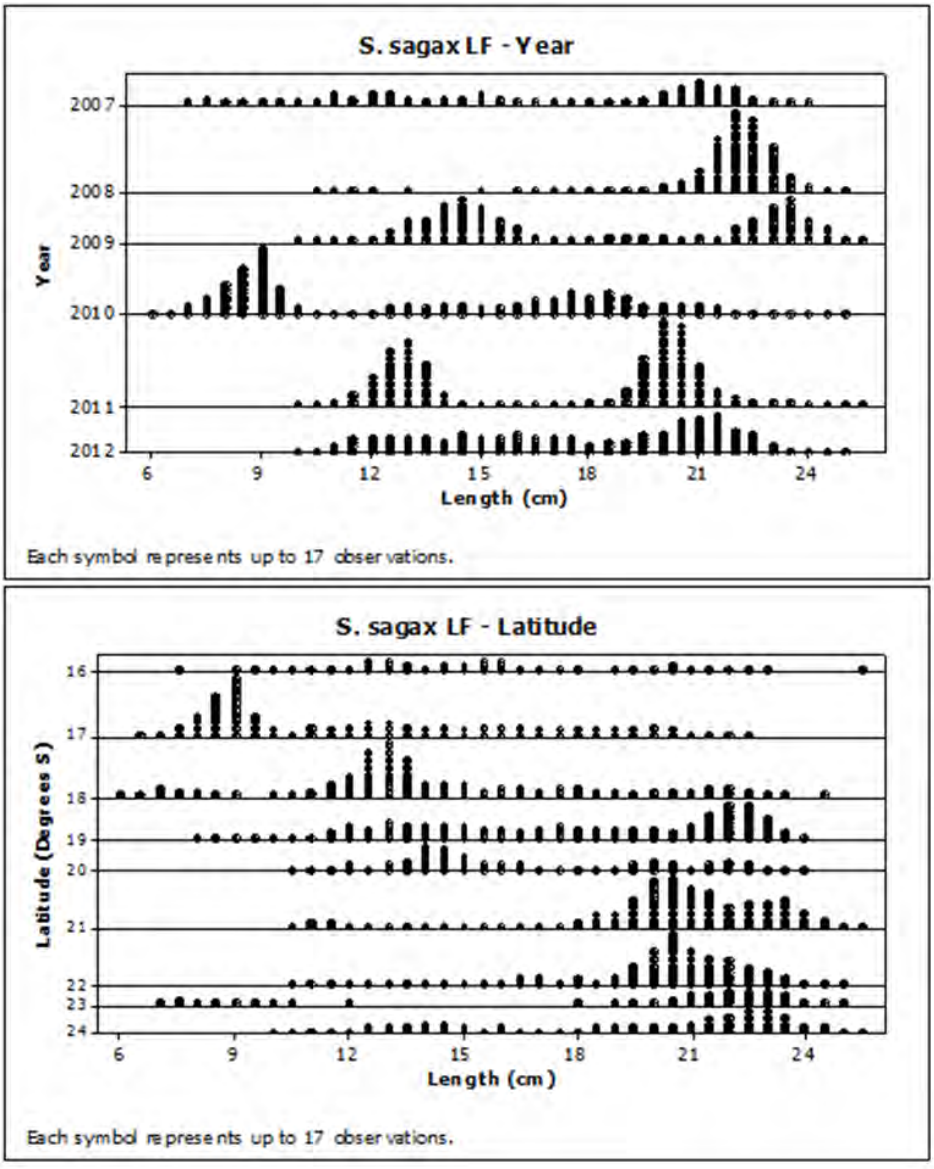


Figure 12. Sardine population structure along the coast of Namibia during the period 2007 to 2012 and along the latitudes 16 - 24^{0}S.

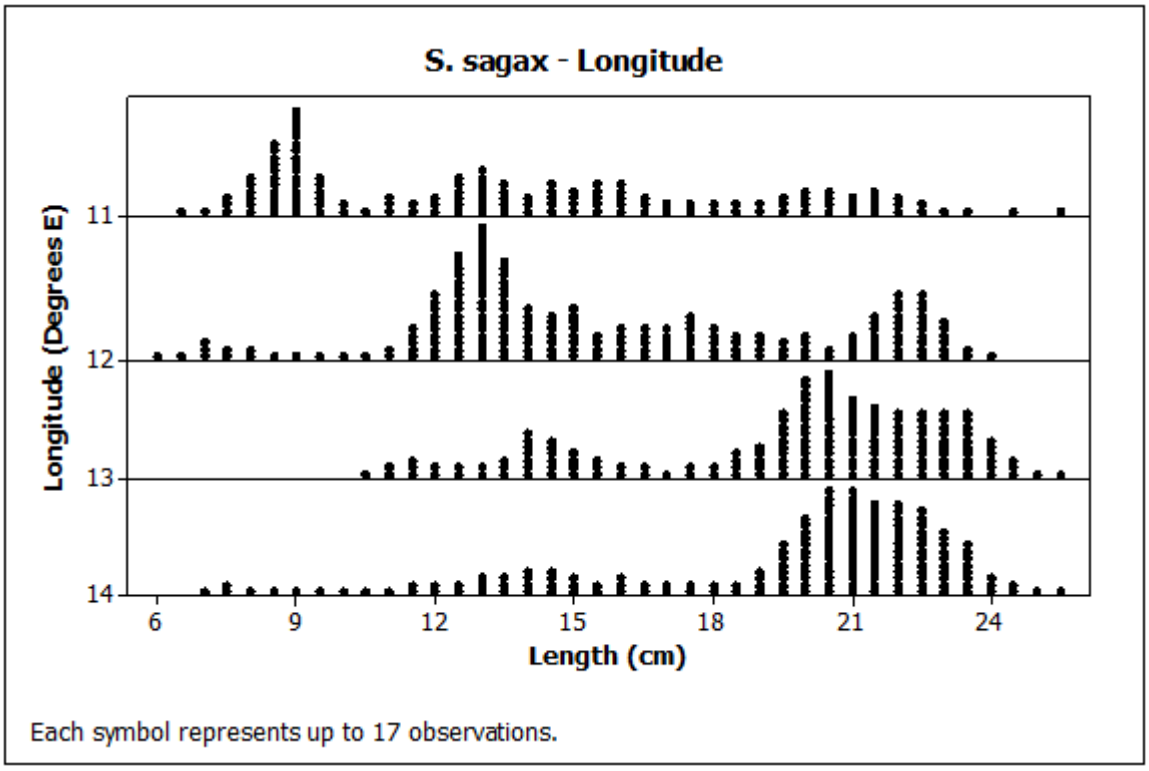


Figure 13. Sardine population structure along the coastline of Namibia during the period 2007 to 2012 and along the latitudes 16 to 24°S.

4.2 MATURITY

To assess the relevance of the proposed area as a spawning ground, maturity stages for hake, horse mackerel and sardine were mapped spatially and temporally. Fisheries observer data for hake species were also included, but no maturity information was available for monkfish species. The results showed that the maturity dynamics over the years and along the coast did not indicate unique features specific to the area proposed for dredging activities and in relation to the surrounding or the rest of the sampled coast. Using gonad maturity stage 4 and 5 as a proxy the results also demonstrated large areas over which spawning occurred (Figure 14).

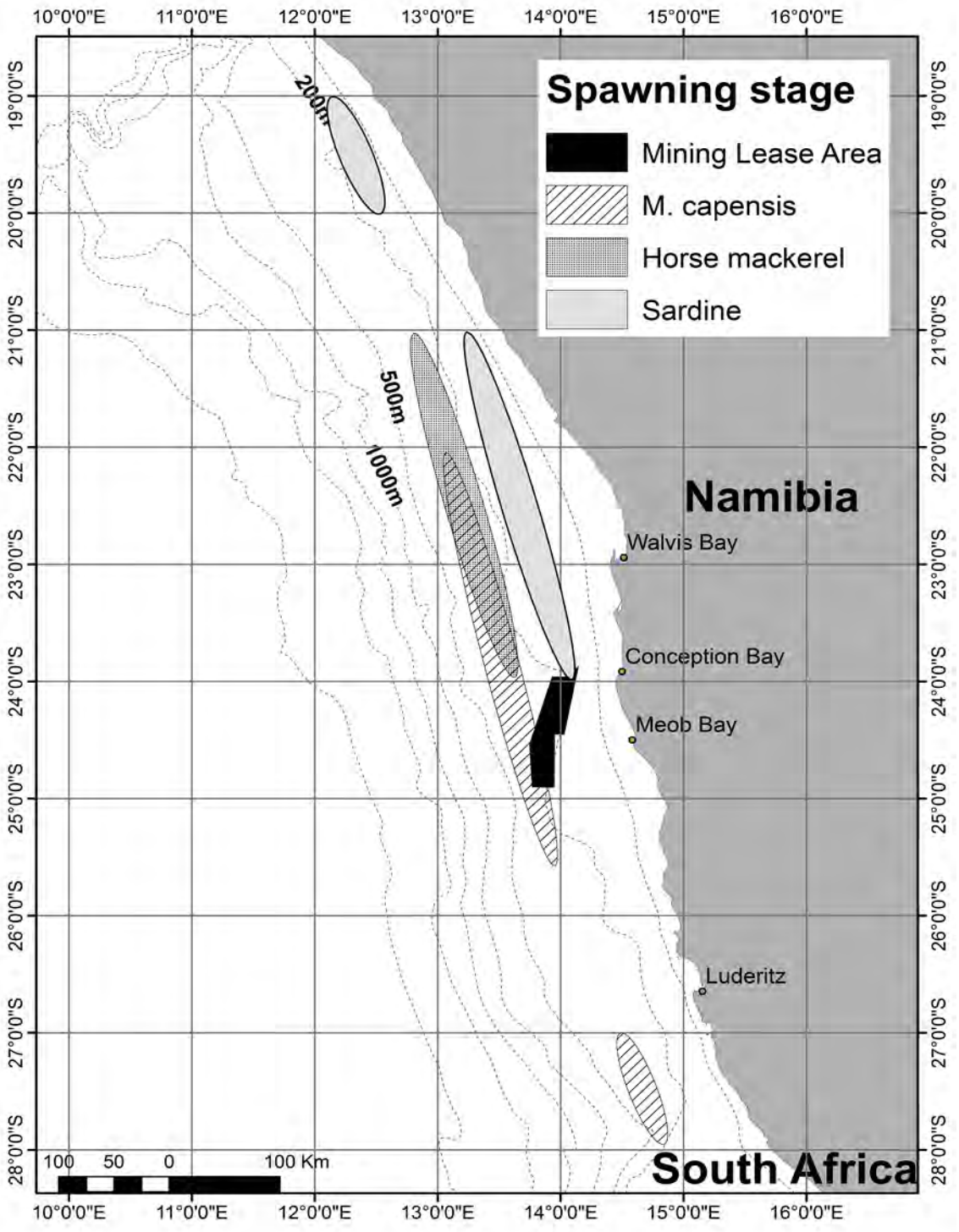


Figure 14. The areas in which spawning (stage 4 hake and 5-horse mackerel and sardine) was recorded for hake (*M. capensis)*, horse mackerel and sardine.

4.2.1 Hake

Maturity dynamics for hake indicated that more advanced stages (stage 3, 4 and 5) peak in the months June, July and August for *M. capensis* (Figure 15). *M. paradoxus* has been dominated by fish in the early maturity stages (stages 1 and 2), with as little as 10% at maturity stage 3 in March and April (Figure 15). On a spatial gradient, more stage 3 fish were observed at latitude 25°S for *M. capensis,* at depths greater than 300 m.

4.2.2 Horse mackerel

Only three months of data are available to profile maturity stages for horse mackerel, indicating a very large proportion of juveniles (maturity stage 0) in April at 24° S (Figure 16).

4.2.3 Sardine maturity

Sardine maturity profiles were also not available for a full year, but one can observe signs of spawning in March, June and October, when maturity stages 4, 5 and 6 are observed (Figure 17 -top). The presence of those three stages is generally spread along the entire coastline; with high prevalence of stage 3 and 4 at latitudes 21°S to 24°S (Figure 17- bottom).

© NMP 2014

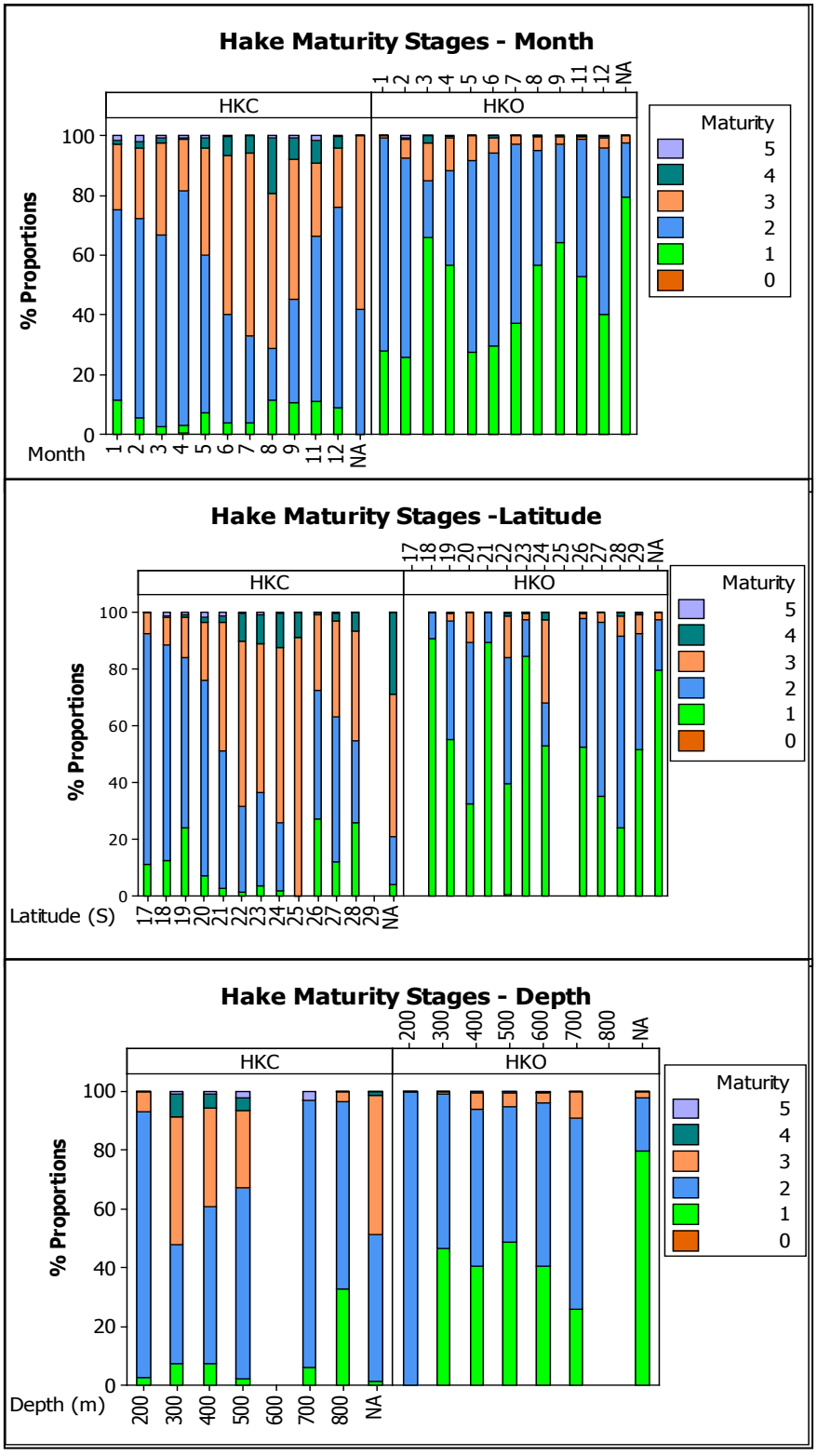


Figure 15. Maturity stage profiles for two hake species (HKC = *M. capensis* HKO = *M. paradoxus*) in Namibia. The top graph is mapped against months (January =1 to December =12), the middle graph is maturity mapped against latitudes (degrees South) and the bottom graph is maturity mapped against depths (m).

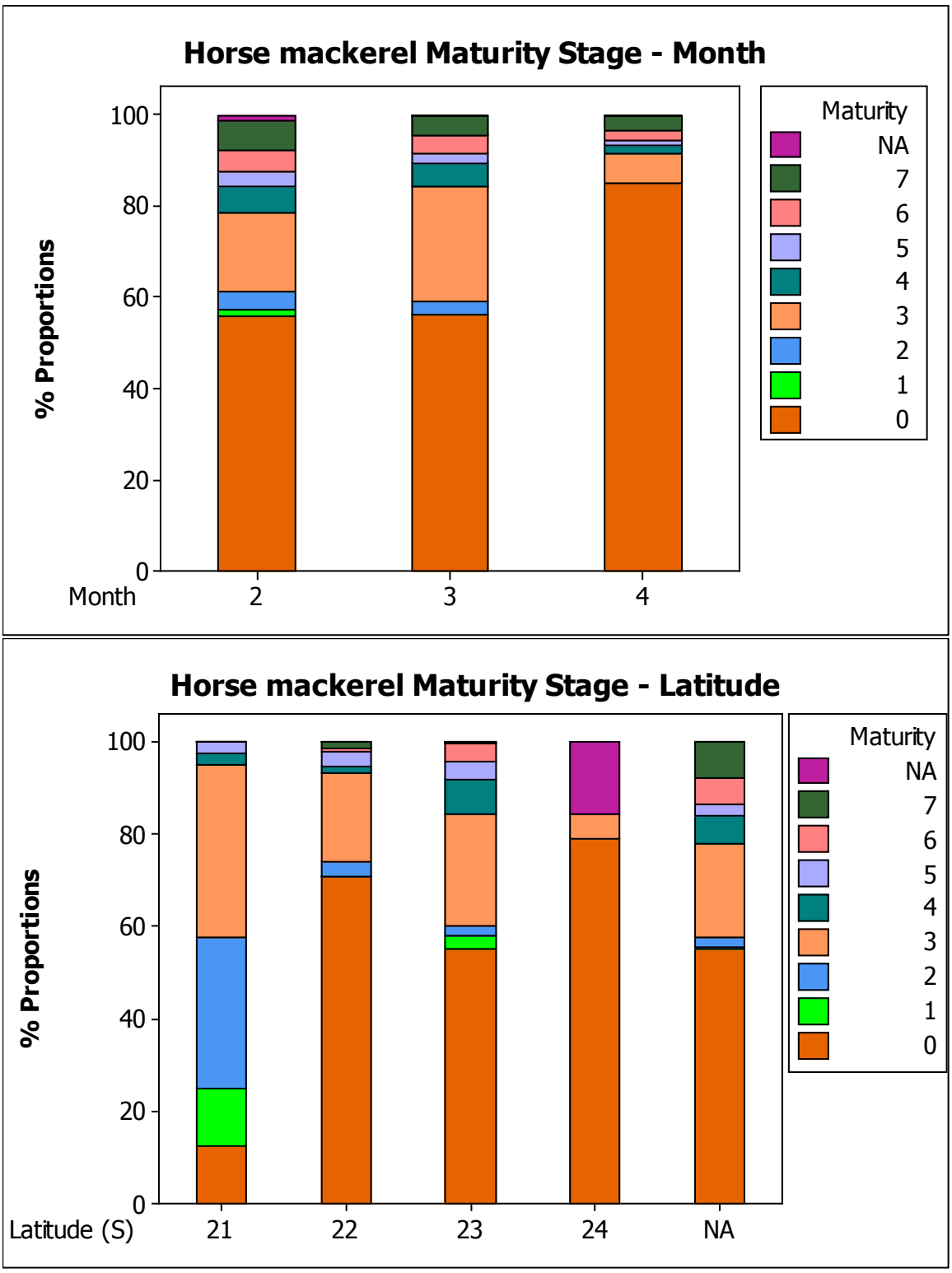


Figure 16. Maturity stage profiles for horse mackerel in Namibia.
The top graph is mapped against months (January =1 to December =12), the bottom graph is maturity mapped against latitudes (degrees South). NA refers to fish that did not have maturity assigned (top graph) or have no latitude assigned (bottom graph).

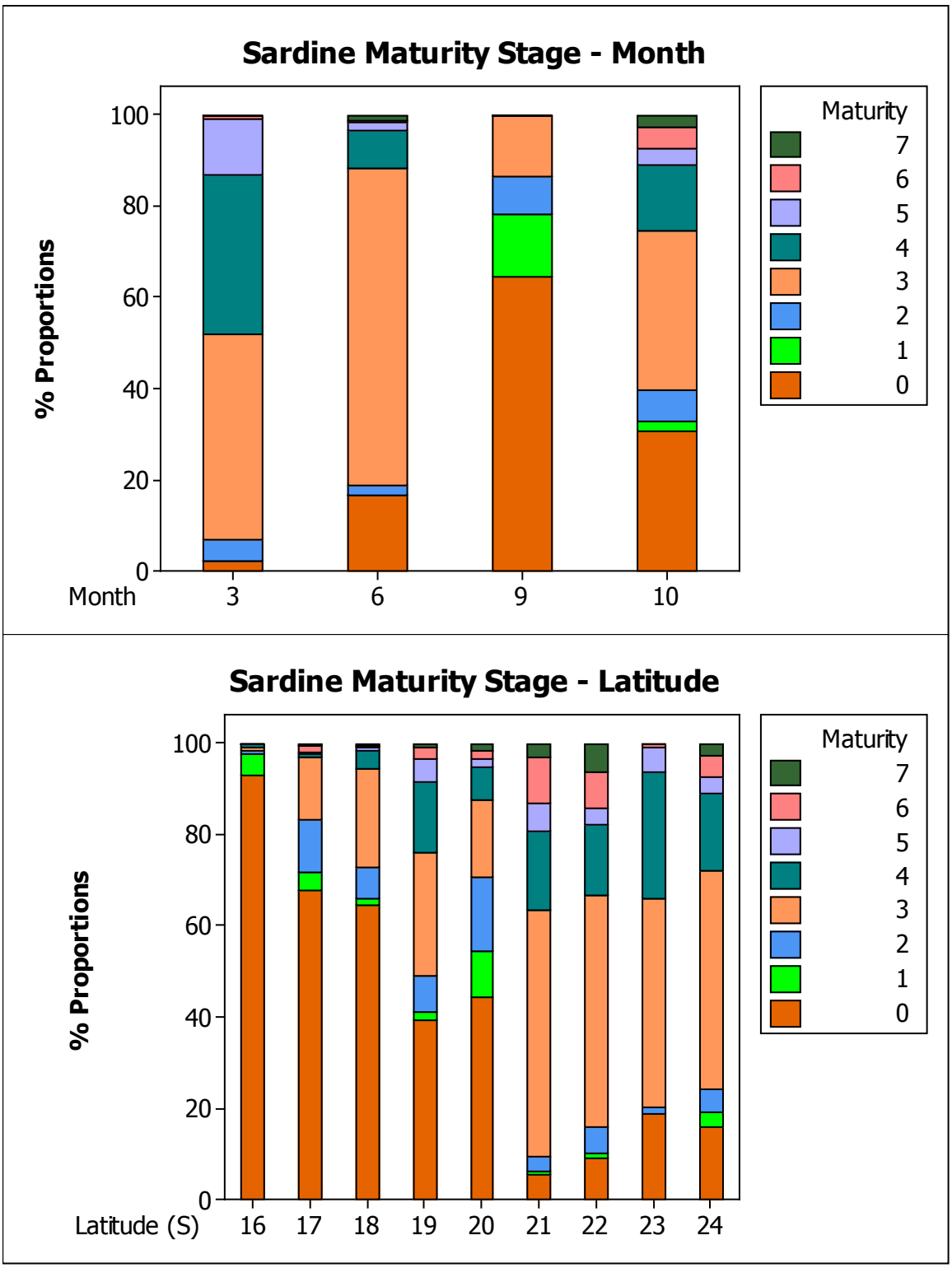


Figure 17. Maturity stage profiles for sardine in Namibia.
The top graph is mapped against months (January =1 to December =12), the bottom graph is maturity mapped against latitudes (degrees South).

5 DISCUSSION

The results of an investigative study, aimed at presenting the reproduction dynamics of commercially important species along the entire Namibian coast, mainly within the area proposed for phosphate mining are presented here. This report seeks to establish an understanding and to set the baseline of the current reproduction dynamics with respect to the Sandpiper phosphate mining licence area (ML 170).

Observed multiple cohorts both in spatial and temporal analysis suggest that factors other than habitat preference are responsible for the distribution of Namibian marine species. The presence of both adults and juveniles (simultaneously or at separated times) imply that grounds that are good for adults at one particular time could be occupied by adults or both adults and juveniles at another time. Such dynamics are indicative of varied environmental and oceanographic conditions thus fish do migrate extensively in response to conditions relevant for their life stage. Discrimination of factors that determine reproductive areas remains poorly understood (based on the historical and current information) and many more observations and analysis beyond the scope of this study would be needed. It can however be stated that these results suggest that when a particular area is not favourable for reproduction or other biological requirements, fish will move out of an area and into other more suitable areas. Keeping in mind the importance of environmental effects on reproduction, it is important to remember that Namibian waters fall within the strong Benguela upwelling system, where differential behaviour of the upwelling goes from one extreme (calm/weakest) to another (strongest). Major stock fluctuations have undoubtedly been influenced by the large-scale environmental perturbations, such as the Benguela Niño that occur periodically in the system (Shannon & O'Toole 1998, Shannon *et al*. 2006). Reproduction success and failure in such conditions is therefore better viewed through spawning stock biomass than a perceived stable environment. These cohort structures will therefore provide a good baseline in assessing how these stocks will respond to the potential impacts of phosphate dredging.

Several studies have reported that reproduction in sardine stocks is highly dependent on density-independent and density-dependent factors (Daskalov *et al*., 2003). We have observed in this study that variation in the stock structure for the Namibian sardine population suggests that conditions elsewhere (be they environmental or anthropogenic) in the ocean can impact its reproductive potential, because the data do not suggest any specific area (at small scale) where sardine are consistently found. The proposed dredging is therefore likely to have less of an effect upon the spawning dynamics of a highly migratory species such as the sardine.

The observed maturity profile dynamics are a somewhat rough but nevertheless a recognised method of analysing reproductive potential of any stock. The observed maturity profiles suggest the months from June to August as the months when *M. capensis* are in their most advanced maturity stage at depths deeper than 300 m. This advanced stage is still far from the spawning stage, and as observed in Kainge *et al*., 2007, no hake spawning activities have been observed in Namibia, except maturation and larger fish aggregations in the southern part of Namibia. Besides these *M. capensis* observations, other species (*M. paradoxus*, horse mackerel and sardine) for which maturity analyses were done in this study, no conclusion can be drawn from them as their data were not sufficiently adequate and these data covered a few months and the surveys did not extend into the area of interest. The presented results can however be used for drawing broader conclusions.

© NMP 2014

An aspect that was initially a concern is the use of data collected for a different purpose being used for this investigation. It was believed and assumed that these data are the true representation of the species population dynamics and the best available database, which is used for the current management decisions to which their fisheries status quo is mapped. The purpose of this study is to identify possible impacts of the proposed dredging activities on reproduction of the main commercial species (hake, monk, horse mackerel and sardine), and this database and approach is one way to make the best use of the available data. This information provides the status quo of these species with respect to spatio-temporal stock distribution, and it provides a baseline against which any further and future analyses could be evaluated.

Acknowledging that a better understanding of recent reproduction dynamics is needed, results of this study have generally agreed with the historical information. This could indicate that the system is perhaps robust enough to have sustained the dynamic environmental variability in the Benguela region. The extent to which the impact from phosphate dredging is assessed should therefore be seen in context with the acceptance that the Benguela Current is well known for its environmental variability; complex species interactions; ecosystem changes which can still not be separated in terms of natural and/or anthropogenic causes; non-linear impacts of environmental variability as well as resource exploitation impacts.

Results from this study indicated a homogenous system. The extent and severity to which any impact from phosphate dredging activities could be extrapolated is therefore difficult to quantify and perhaps of little relevance at this point, because the study area showed no unique features with respect to the entire Namibian coast(from latitude 17°S to latitude 29°S).

However, the results from this investigation could be used, together with data collected during a verification / monitoring survey, to show how (if any) mining activities could affect the current observed dynamics. It is therefore necessary to recognize that a state of the stock monitoring survey be built into the environmental management plan. Results of such studies will play an important part as a baseline for future monitoring and evaluation plan, and could be used as indicators of impacts phosphate mining might have on the reproductive biology and reproduction of commercial fish species found in the dredged area.

6 CONCLUSION

6.1 SIZE DISTRIBUTION

No significant spawning areas were observed, specifically not in the areas surrounding the proposed mining site. While the data show there are certain dynamics relating to stock structure (mainly offshore-onshore and vertical with depth for all species analysed, as well as latitudinal for *M. paradoxus*), growth seems to be generally poorly defined since stock structure, as shown by the cohort indicators, is generally broad. The area proposed for dredging has no special biological reproductive characteristics for the main commercial species found in the area to be dredged compared with the rest of the Namibian waters. For example, there are no specific indicators suggesting the dredged area is exclusively home to adult fish (spawner biomass), and has no pronounced recruitment of small and young fish.

© NMP 2014

For horse mackerel, hake and monk, data were available from 1999 to date, covering the entire coast (17°S to 29°S), whereas for sardine there were only data from 2007 ranging from 22°S to 25°S. In the case of hake, the data available suggest no significant reproductive characteristics particular to the area to be dredged.

This analysis has also shown that for all species analysed their distributions were heterogeneous. Variation in population structure was also not indicative of defined reproduction grounds and in particular the area around 23 to 25°S showed patterns just as complex and undefined as previously observed in historical studies. The results of this study did not show any special features of the proposed dredging area, with respect to the rest of the Namibian coast in both space and time. Cohort analyses for all the species analysed were a mix of small and large fish for most of the areas, and therefore lacking signs of well defined spawning areas and/or recruitment of small fish.

6.2 GONAD MATURATION

Whilst hake with more advanced gonad maturity were present around the latitudinal area of interest, they were found mostly in greater depths than those of the proposed dredging activities. Monthly dynamics have also not indicated any progress (beyond a maturing stage) in gonad maturity at that particular area, suggesting that fish do move in and out of such grounds over time. Annual maturity dynamics have also not shown repeated dynamics, implying that spawning grounds for these species is not localized. However, more data are needed to fully assess any risk to the resource. These multiple cohorts as observed per year and by area, are suggestive of high and low reproduction events. This has again indicated lack of homing for adults and undefined reproduction and spawning grounds.

It is recommended that various ‘state of the stock’ monitoring surveys could be built into the environmental management plan. The presence of phosphate as a resource in this area and given the importance of information needed on the dynamics of the commercial fish stocks in the MLA, it is worth noting that moving forward, the area should be included in the routine surveys undertaken by MFMR. Results of such studies will play an important part as a control measure, as well as a baseline for future monitoring and evaluation plans. Similarly, results from such monitoring programmes could indicate the extent of the impact of phosphate mining. The currently planned verification survey is highly recommended as it will add resolution to this study, by focusing in the proposed area at high sampling resolution. *Note*: this verification survey was undertaken in June 2014 and is reported in Section C, Chapter 3.1.

© NMP 2014

7 REFERENCES

Botha, 1986 Reproduction, sex ratio and rate of natural mortality of Cape hakes *Merluccius capensis* cast. and *M. paradoxus* Franca in the Cape of Good Hope Area. *South African Journal of Marine Science*. **4**: 23 - 35

Hilborn R, Maguire JJ, Parma AM and Rosenberg AA (2001) The precautionary approach and risk management: can they increase the probability of successes in fisheries management? *Canadian Journal of Fisheries and Aquatic Sciences* **58**: 99 – 107.

Japp DW and Smith M (2011) Review of the spawning activity, icthyplankton drift routes and the recruitment of Namibian marine fauna with reference to the proposed marine phosphate mining area, Internal Report, Capricorn Fisheries. Pp. 21.

Kainge P, Kjesbu A, Thorsen A and Salvanes AG (2007). *Merluccius capensis* spawn in Namibian waters, but do *M. paradoxus*? *African Journal of Marine Science* **29**: 379 -392.

Ndjaula HON, Krakstad J-O, and Kjesbu OS (2013) Reproductive biology of horse mackerel *Trachurus capensis* and *Trachurus trecae* in Namibia and Angola, *African Journal of Marine Science*,**35**(2) : 141-150.

Osborne RF, Mello YC, Hofmeyr MD and Japp DW (1999) Serial spawning and batch fecundity of *Merluccius capensis* and *M. paradoxus*. *South African Journal of Marine Science* **21**: 211-216.

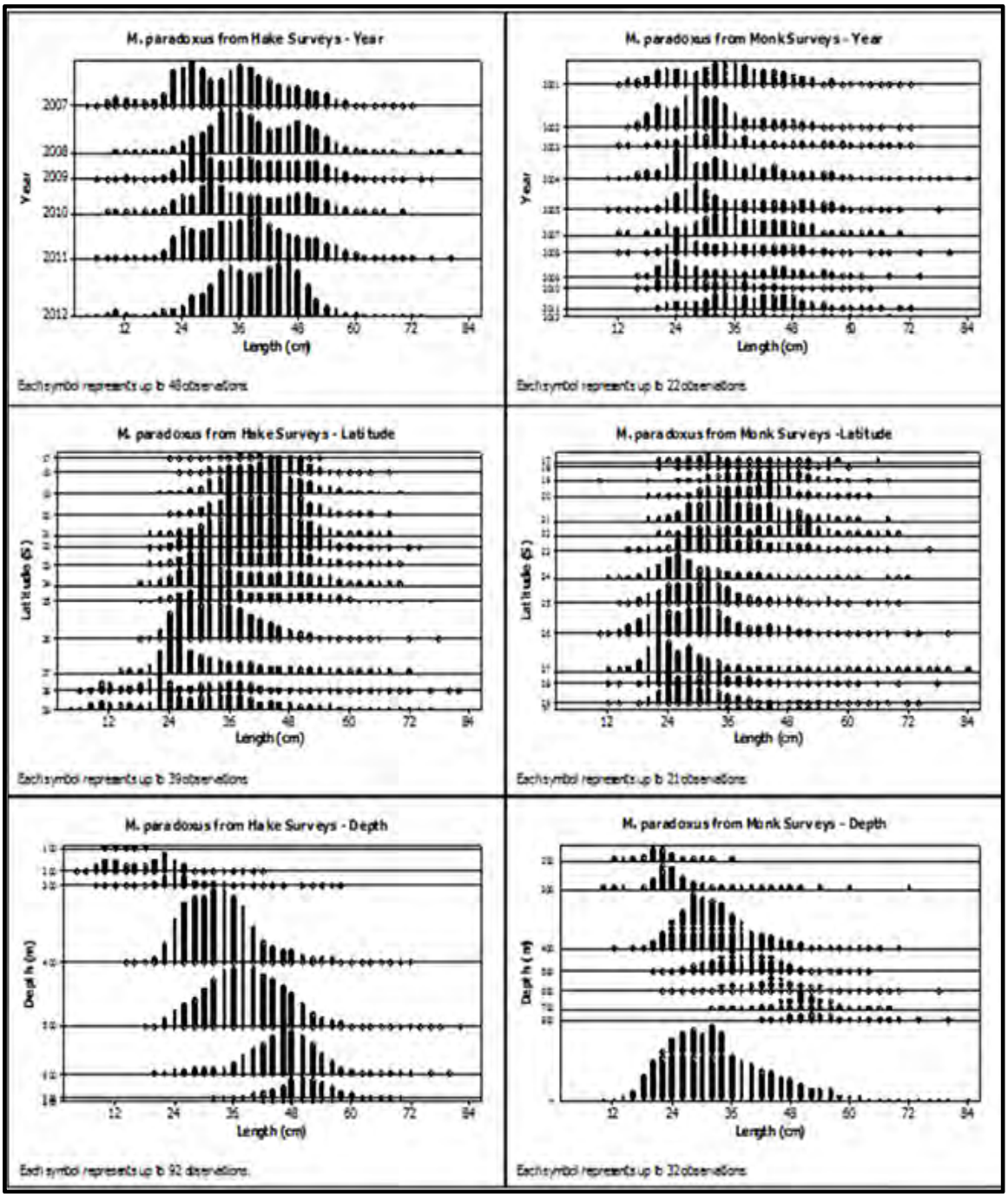
Shannon LV and O'Toole MJ (1998) An Overview of the Benguela Ecosystem. Collected papers, First Regional Workshop, Benguela Current Large Marine Ecosystem (BCLME) Programme, UNDP. 22-24 July 1998, Cape Town, South Africa.

Shannon, V., Hempel, G., Melanotte-Rizzoli, P., Moloney, C. and Woods, J. eds. (2006) *Benguela: Predicting a Large Marine Ecosystem*. Elsevier Science.

© NMP 2014

ANNEXURE 1: HAKE SIZE DISTRIBUTION

M. paradoxus size distribution from data collected on monk survey (right column), presented together with *M. paradoxus* size distribution from hake surveys for comparison purposes.



ANNEXURE 2: TERMS OF REFERENCE

Dredging of Phosphates offshore Namibia (Sandpiper Project)

Overview of the recruitment of the principal commercial fish species found in Namibian waters. Provide an opinion on the extent of the known recruitment and the possible impacts on this recruitment in a spatial and temporal context relative to the proposed mining for Phosphates in the Sandpiper Mining Lease area.

1. Undertake a review of the available literature and information available on the recruitment of the main commercial fish species in Namibian waters. By recruitment it is meant to include a) egg and larval distributions, b) spawning frequency and areas, c) juvenile abundance and migrations (north south, inshore offshore, shallow deep etc), d) Substrate preferences if any d) recruitment to the main fishery sectors in particular monk and hake.
   The species should as far as possible include (but not exclusively):

   a) Hakes (2 species)
   b) Monk (2 species)
   c) Horse mackerel
   d) Pilchard
   e) Other small pelagic species (anchovy, red eye herring, lantern and light fishes)
   f) Rock lobster
   g) Pelagic gobies

2. Review the available literature and or available information on seabirds and seals and related colonies in the proximity of the Sandpiper MLA and provide an opinion on the possible impact the dredging may have on their behaviour;

3. Report on the historical and on-going research undertaken on the recruitment/ spawning of the above species and the extent to which it may cover the area impacted by the Sandpiper mining area.

4. Provide an opinion on the scaling effect – that is the likely area of impact of the proposed dredging and likelihood that recruitment and reproductive potential of the main commercial species may be impacted relative to the known distribution of these species and their reproductive biology.

5. With respect to this reproductive knowledge comment on the uncertainty that may prevail due to environmental effects – e.g. sea surface warming, current regimes.

6. Provide a report of no more than 20 pages – this should include a comprehensive reference list. Appendices containing relevant information should also be included.

© NMP 2014

SECTION C - SPECIALIST STUDIES

C3.5 Review of the Spawning Activity, Ichthyoplankton Drift Routes and the Recruitment of Namibian Marine Fauna

REVIEW OF THE SPAWNING ACTIVITY, ICHTHYOPLANKTON DRIFT ROUTES AND THE RECRUITMENT OF NAMIBIAN MARINE FAUNA

Prepared for:
Namibian Marine Phosphate (Pty) Ltd.

Prepared by:
Capricorn Fisheries Monitoring cc
Report compiled by Melanie Smith and David Japp

October 2014

CAPFISH (Pty) LTD
Unit 15, Foregate Square. Table Bay Boulevard, 8002, South Africa
Directors: Japp, Wissema, Heinecken, Wilkinson, Ncongo
Co Reg. No. 2004 / 004844 / 07

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed “Attention: Administration Manager,” at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

SUMMARY

- Aggregations of spawning horse mackerel and juveniles occur outside the MLA;
- Sardine spawn off Walvis Bay and further north near Palgrave Point. Only the northern extent of the MLA falls within the southern part of the spawning area;
- Historically spawning and larval distributions of anchovy took place north of Walvis Bay (outside the MLA);
- Snoek migrate southwards to spawn offshore and in deep waters near St Helena Bay and off the Cape Peninsula in South Africa. The MLA is at the eastern edge of the migration corridor
- Silver kob spawn very close inshore (<100 m) at Meob Bay and larvae drift northwards to the nursery grounds between Sandwich Harbour and the Ugab River mouth;
- A low abundance of hake eggs occurs to the south east of the MLA off Hollams Bird Island. Larvae are found in high abundance from Conception Bay to Palgrave Point in water depths between 100 – 300 m. A significant quantity of juvenile *M. capensis* (<30 cm) occurs within the MLA.;
- According to the historical literature juvenile monkfish occur within the MLA;
- Goby larvae are in high abundance throughout Namibian waters and in particular in the MLA They also inhabit the bottom sediments and will be highly disturbed by the proposed dredging activity and;
- Significant densities of west coast rock lobster occur inshore and to the south of the MLA.

© NMP 2014

contents

SUMMARY ii

1 INTRODUCTION 1

1.1 DETAILS OF THE MINING LICENCE AREA (MLA): 1

2 IMPACTS ON THE MARINE ECOSYSTEM 3

2.1 INTRODUCTION 3

2.2 COMMERCIAL AND ECOLOGICALLY IMPORTANT SPECIES 3

2.2.1 Pelagic fish species 3

2.2.2 Demersal fish species 13

2.2.3 West coast rock lobster 27

2.3 DIETS AND TROPHIC INTERACTIONS IN THE BENGUELA ECOSYSTEM 27

3 CONCLUSIONS 31

4 REFERENCES 32

© NMP 2014

figures

Figure 1: Location of the phosphate mining licence area (ML 170) 2
Figure 2: General distribution of Namibian Cape horse mackerel (Axelsen *et al* 2004). 4
Figure 3: Distribution and abundance of horse mackerel larvae during survey 1 (left) and survey 2 (right). 5
Figure 4: Spatial distributions of anchovy (left) and sardine (right) spawning in Feb/Mar 1986 7
Figure 5: Distribution and abundance of sardine larvae during survey 1 (left) and survey 2 (right). 8
Figure 6: Distribution of sardine eggs (density per 10 m^3 of surface water) (left) and larvae (density per 10m^3 of surface water) during January 2004 9
Figure 7: Distribution of eggs (open circle) and larvae (solid circle) for red eye herring 10
Figure 8: Migration of snoek (de Jager 1955) 12
Figure 9: Distribution of hake *Merluccius* spp eggs (left) and larvae (right). 14
Figure 10: Distribution and abundance of hake larvae (Redrawn from O'Toole 1977) 15
Figure 11: Density of hake (*Merluccius capensis*) juveniles, <30 cm in summer (left) and winter (right) (Redrawn from Macpherson *et al.* 1987) 16
Figure 12: Density of hake (*Merluccius paradoxus*) juveniles, <30 cm in summer (left) and winter (right) 1986 (Macpherson *et al.* 1987) 17
Figure 13: Distribution of GSI values (%) per geographical position for *M. paradoxus* (left) and *M. capensis* (right) (Redrawn from Kainge *et al*. 2007) 18
Figure 14: Drift routes for hake eggs and larvae in subsurface circulation (35 – 50 m) 19
Figure 15: Density of monk (*Lophius upsicephalus*) juveniles, <30 cm in summer (left) and winter (right) 1986 21
Figure 16: Density of west coast sole (*Austroglossus microlepis*) in summer (left) and winter (right) (1986) 23
Figure 17: Distribution and abundance of goby larvae during survey 1 (left) and survey 2 (right). 24
Figure 18: The distribution and abundance of goby larvae off Namibia, numbers per haul Aug 1972 – Apr 1973 25
Figure 19: Density of kingklip (*Genypterus capensis*) in summer (left) and winter (right) (1986) 26
Figure 20: Seasonal phytoplankton and zooplankton distribution off Namibia (Mar/Apr 1981) 29

tables

Table 1: Mining Licence Area Coordinates 1

© NMP 2014

1 INTRODUCTION

Capricorn Fisheries Monitoring cc (Capfish) is contracted to provide an expert report on the impact of the potential phosphate dredging on fish and fisheries on behalf of Namibian Marine Phosphate (Pty) Ltd. We will be examining the spatial distribution of ecologically and commercially important marine species with particular reference to the proposed Mining Licence Area (MLA) ML 170, and surrounding areas that may be influenced (Figure 1). The information herein will represent a review of the scientific research that has been conducted along the Namibian coast combined with information gained from scientists specialising in particular areas of interest. Additionally, where possible, data gathered by the MFMR will be incorporated.

The purpose for this document is to review the spawning areas, ichthyoplankton drift areas and recruitment grounds from the historical and contemporary literature to support information that may be included in the verification programme report.

1.1 DETAILS OF THE MINING LICENCE AREA (MLA):

- 20 year licence
- MLA 2230 km^2
- Approx area 8x22 km SP-1 target dredge site
- 1.5 – 3 m thick deposit
- Up to 3 km^2 and 5.5 million tons mined pa
- Distance from the coast 40 – 60 km offshore
- Dredging depths between 200 – 225 m
- MLA coordinated , Table 1

Table 1: Mining Licence Area Coordinates

Licence	Nr	Lat	Long
ML-170	1	-23.96343370	14.05147937
ML-170	2	-23.87533718	14.14423400
ML-170	3	-24.45413073	14.02868536
ML-170	4	-24.45018472	13.95007468
ML-170	5	-24.54029930	13.94935730
ML-170	6	-24.90419192	13.94641012
ML-170	7	-24.90280251	13.76999757
ML-170	8	-24.53860218	13.74669922
ML-170	9	-23.96279819	13.93140136

© NMP 2014

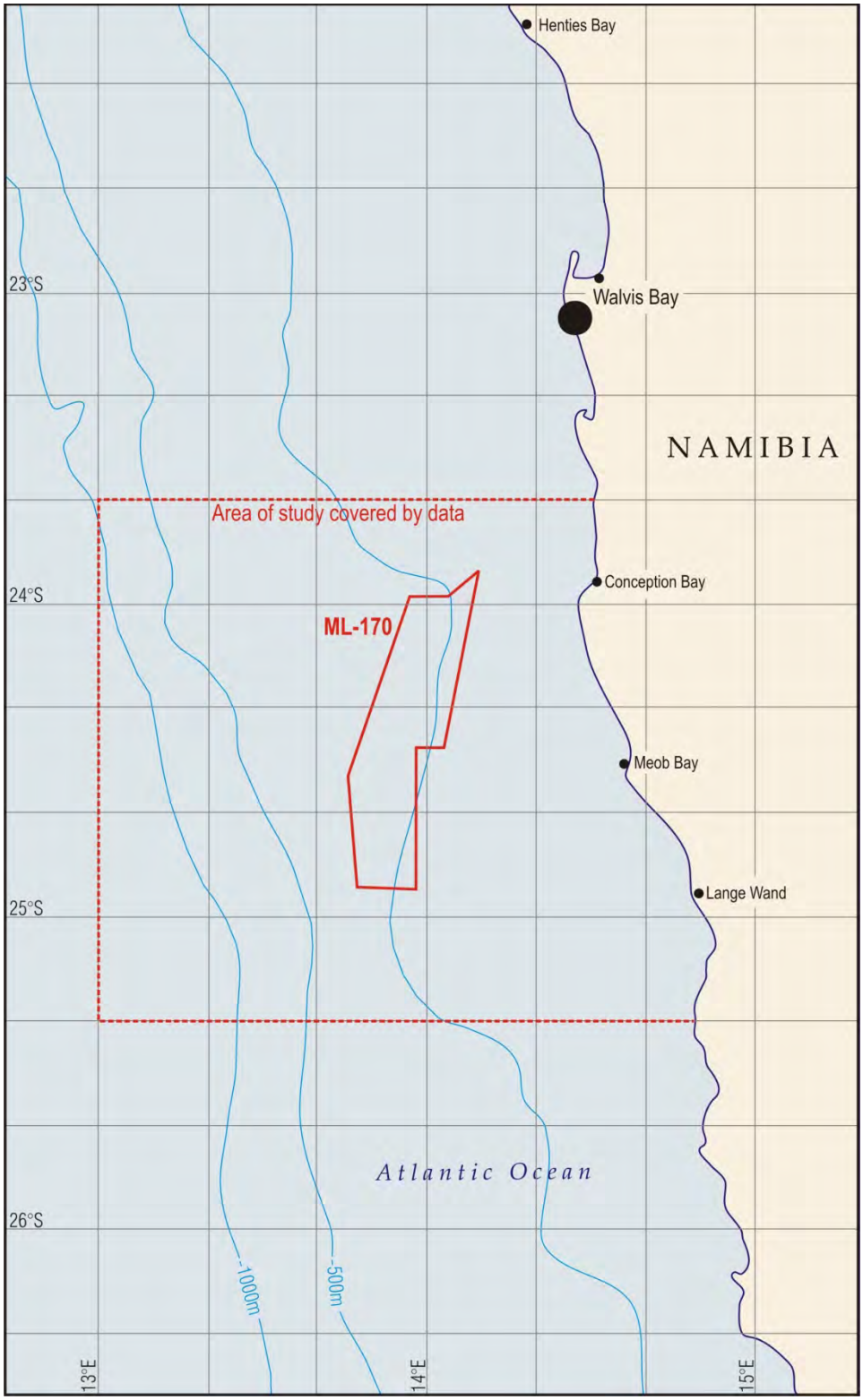


Figure 1: Location of the phosphate mining licence area (ML 170)

2 IMPACTS ON THE MARINE ECOSYSTEM

2.1 INTRODUCTION

In particular, we want to know the impacts of phosphate dredging on the survival, recruitment, migration and distribution of the main commercial and ecological important fish species in particular:

- Pelagic fish species
  - Horse mackerel
  - Sardine
  - Anchovy
  - Red eye herring
  - Snoek
- Demersal fish species
  - Hake
  - Monk
  - West coast sole
  - Orange roughy
  - Bearded goby
  - Kingklip
- Inshore species
  - West coast steenbras
  - Silver kob
  - West coast rock lobster
- Diets and trophic interactions of the Benguela ecosystem

2.2 COMMERCIAL AND ECOLOGICALLY IMPORTANT SPECIES[1]

2.2.1 Pelagic fish species

Horse mackerel

Off the Namibian coast, horse mackerel *Trachurus trachurus* generally occur in water depths of less than 100 m (Crawford *et al*. 1987). Adults generally occur north of 21°S where spawning is heaviest between October and March in the mixing zone between warm oceanic water and cool coastal waters (O'Toole 1977). Nursery grounds are located adjacent to these spawning grounds but closer to shore. Juveniles migrate south to Walvis Bay, especially in winter (Figure 3). Maturing fish then move offshore and migrate north to spawn (Boyer and Hampton 2001a). According to the historical literature the main spawning area is found between Cape Frio and Palgrave Point inside the 200 m isobath (Figure 2). More than 90% of spawning occurs outside the MLA and the closest to the MLA that horse mackerel eggs were recorded was to the north at 22°30'S. Furthermore, the nursery ground for juvenile horse mackerel is between Cape Frio and Ambrose Bay and thus outside of the MLA.

[1] The figures that follow are taken from the ICSEAF journals, scientific publications and doctoral theses. The red outline on all the spatial maps (Figures 2 – 18) represents the location of the MLA. Note this red outline is purely for representation and is not in the exact location according to the coordinates.

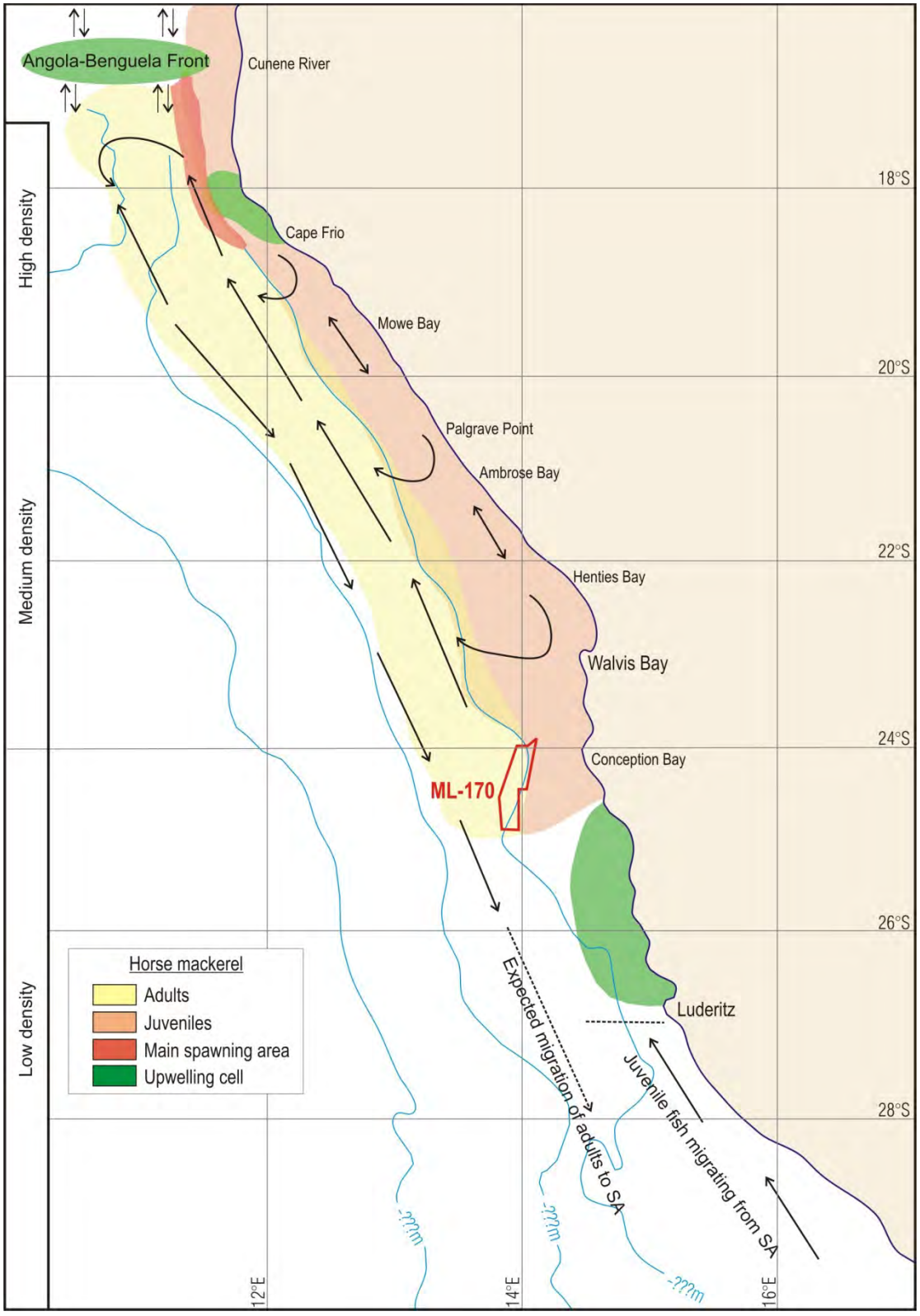


Figure 2: General distribution of Namibian Cape horse mackerel (Axelsen *et al* 2004). Taken from Mundjulu 2009.

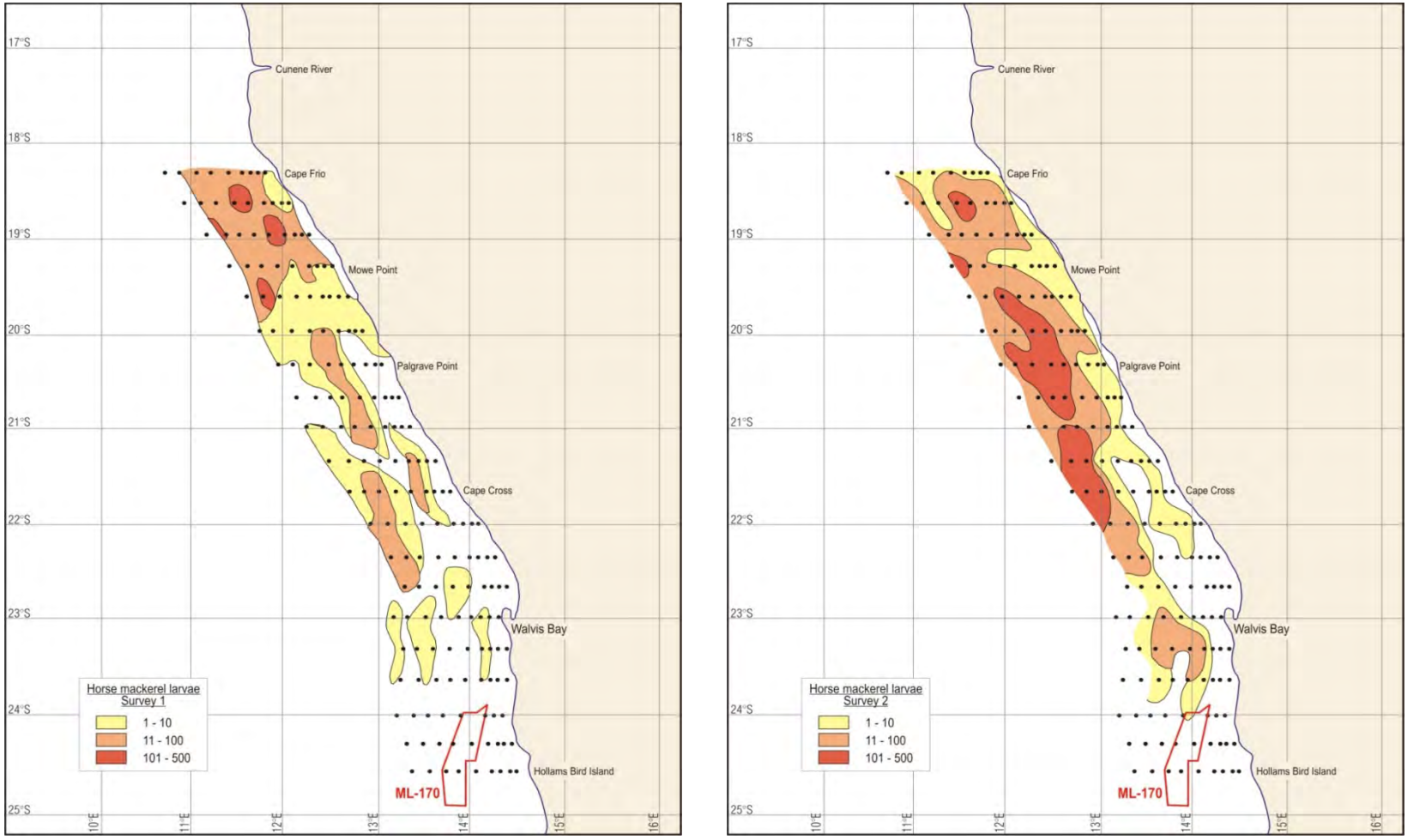


Figure 3: Distribution and abundance of horse mackerel larvae during survey 1 (left) and survey 2 (right). Values represent cumulative standard haul totals for all cruises (Redrawn from O'Toole 1977)

© NMP 2014

Sardine

According to the historical literature, spawning of sardine *Sardinops sagax* took place at two locations roughly 60 km off the Namibian coast: off Walvis Bay and further north at the meeting of the Benguela and Angolan Current systems (O'Toole 1977; Figure 4 (right)). Spawning in the north for young adults peak in late summer / autumn around the 200 m isobath (Crawford *et al*. 1987). In contrast, older fish spawned further south in summer, in cooler waters close to upwelling zones. Following spawning, larvae drifted southward along the coast. Sardine would then migrate northwards where juveniles and young adults would spawn for the first time. Adult fish would subsequently return south to spawn off Walvis Bay (Boyer and Hampton 2001a). Following the collapse of the sardine stock in the 1970s, spawning in the south is thought to have weakened (Crawford *et al*. 1987) as the migration of adult sardine has contracted (Boyer and Hampton 2001a). It should be noted that the northern extent of the mining licence area (MLA) falls within the southern part of the sardine spawning area (Figure 5 and Figure 6).

Anchovy

The distribution and movement patterns of anchovy *Engraulis encrasicolus* in Namibian waters were similar to those of sardine described above. The only exceptions were that significant spawning of anchovy took place north of Walvis Bay (Shannon and Pillar 1986; Figure 4 (left)) only and larvae occurred in high density further than 100 km offshore (O'Toole 1977). Due to the very small size of current stocks, the present distribution and movement of anchovy off Namibia is unclear, and it is possible that their life history has changed from that previously recorded (Boyer and Hampton 2001a).

Red eye herring

Similar to other small pelagic species the red eye herring *Etrumeus whiteheadi* is widely distributed along the Namibian coast (Boyer and Hampton 2001a; Olivar 1988). Spawning has not been studied in Namibian waters but is thought to occur throughout the year reaching a peak in late winter and early summer (Boyer and Hampton 2001a).

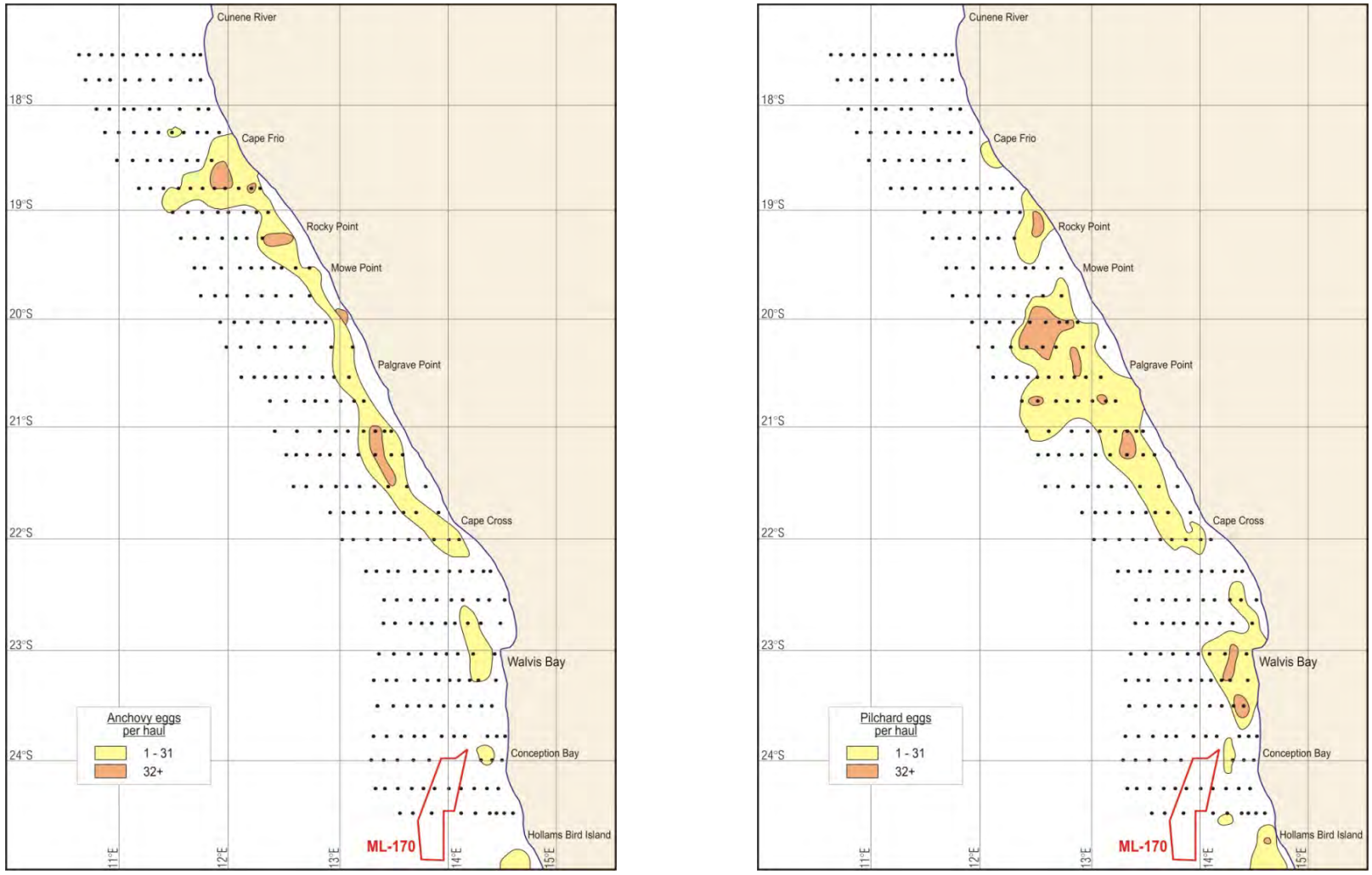


Figure 4: Spatial distributions of anchovy (left) and sardine (right) spawning in Feb/Mar 1986 (Redrawn from Le clus *et al.* 1987).

© NMP 2014

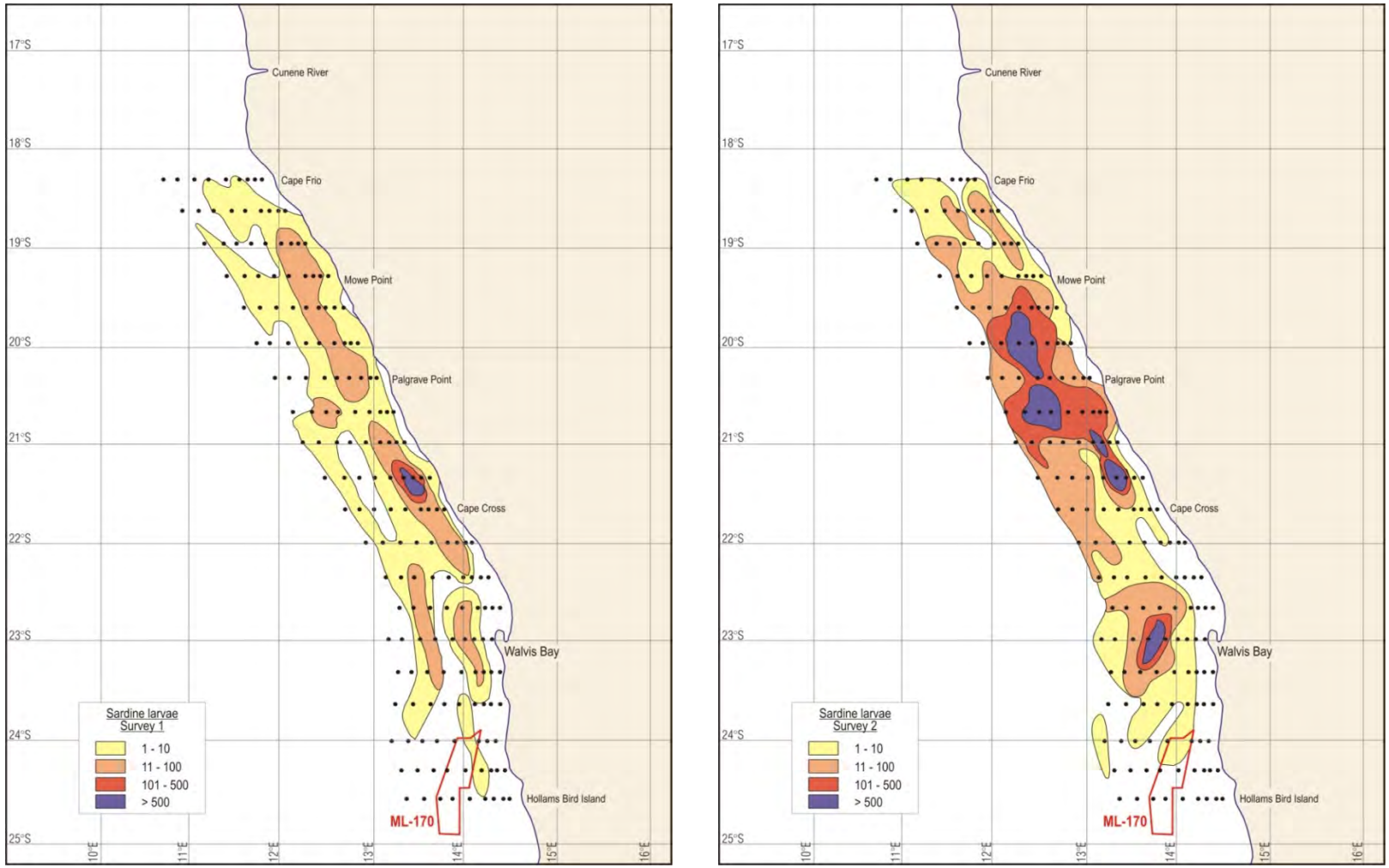


Figure 5: Distribution and abundance of sardine larvae during survey 1 (left) and survey 2 (right).
Values represent cumulative standard haul totals for all cruises (Redrawn from O'Toole 1977)

© NMP 2014

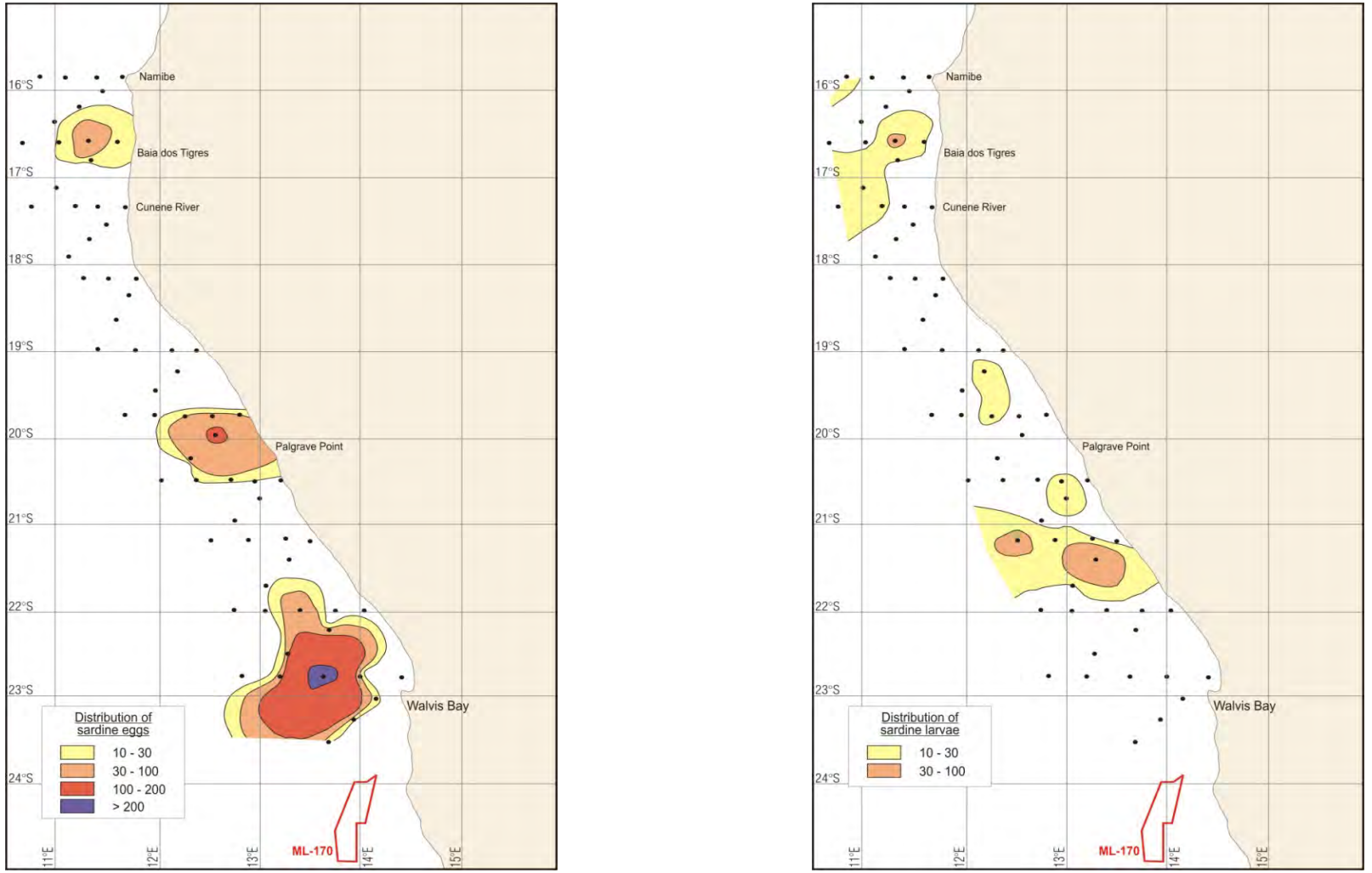


Figure 6: Distribution of sardine eggs (density per 10 m^3 of surface water) (left) and larvae (density per 10m^3 of surface water) during January 2004 (Redrawn from Tjizoo 2006)

© NMP 2014

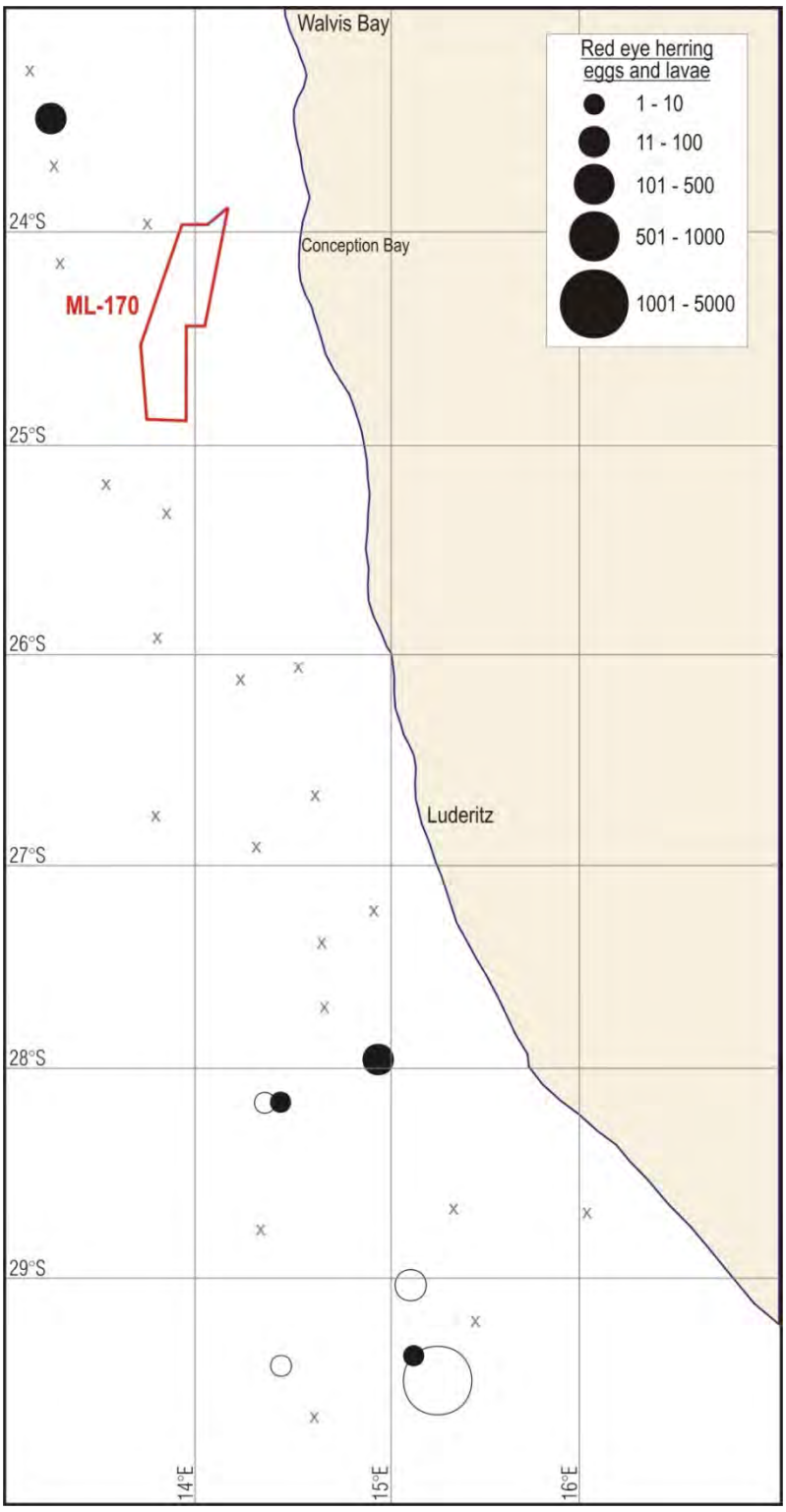


Figure 7: Distribution of eggs (open circle) and larvae (solid circle) for red eye herring (Redrawn from Olivar 1988)

Snoek

Snoek (*Thyrsites atun)* is an important predatory fish that occurs along the entire length of the Namibian coast (Boyer and Hampton 2001a). The Luderitz upwelling cell is understood to separate the species into two stocks, although a certain amount of mixing does occur between the two (Griffiths 2003). This species occurs mainly in cool upwelled waters where it is an important predator of small pelagic species (Crawford and de Villiers 1985). Spawning patterns have not been established for the Namibian stock, but it is likely that these fish move offshore to spawn along the shelf break during winter and spring, as has been recorded for snoek off the South African west coast (Griffiths 2002).

The snoek migration patterns reported in a historical investigation by Davies (1954) showed that immature (juvenile) snoek caught in Namibia migrate southwards near the end of summer to be caught in commercial fishing areas of St Helena Bay and off Cape Peninsula during winter. It is presumed that at the end of the fishing season at the Cape, the snoek move in a westerly direction towards deeper water where spawning probably takes place. After spawning a northerly return migration takes place offshore in deeper water and the fish return to Namibia again. When snoek are found in this area again they are in poor condition and show signs of having recently spawned (Figure 8).

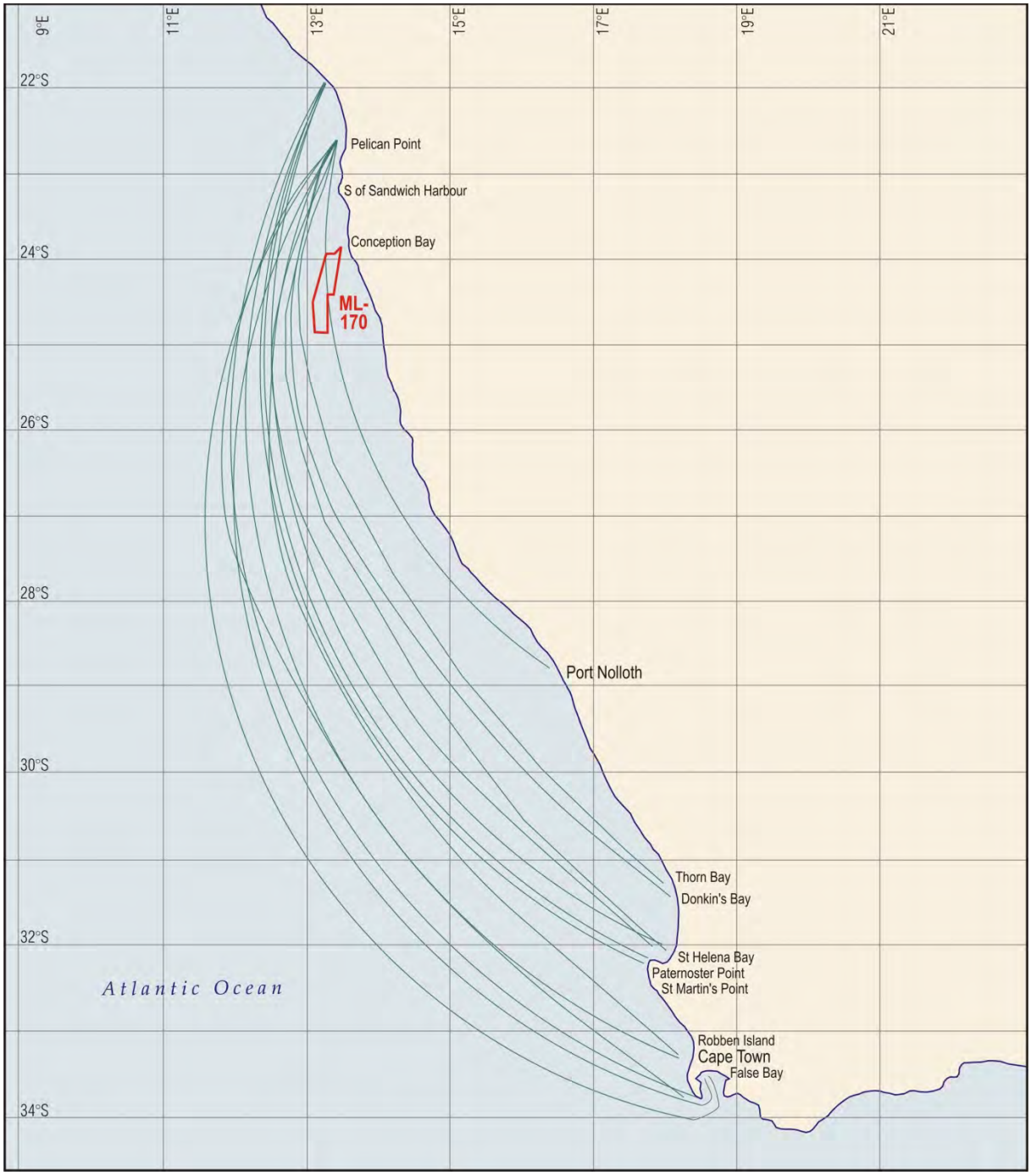


Figure 8: Migration of snoek (de Jager 1955)

Steenbras
Two stocks of west coast steenbras *Lithognathus aureti* occur in Namibian waters, a southern population around Meob Bay and a northern population in central and northern Namibia (Holtzhausen and Kirchner 2001). The southern population falls within the restricted area of the Namib Naukluft Park. No spawning migration is known for this species, although males of the northern population appear to disperse south in search of gravid females (Holtzhausen *et al*. 2001).

Silver kob
Silver kob *Argyrosomus inodorus* occur along the entire length of the Namibian coast but are most abundant from Meob Bay to Cape Frio (Kirchner and Voges 1999). Namibian stocks are distinct from those occurring off South Africa (Van der Bank and Kirchner 1997). Spawning adults move southwards from the northern end of their distributional range in early summer. Spawning grounds occur at Meob Bay and Sandwich Harbour (Holtzhausen *et al*. 2001), from here larvae drift northward to the nursery area between Sandwich Harbour and the Ugab River mouth. Two years after spawning juveniles reach the area north of the Ugab River and it is to this same area that adults return after spawning (Holtzhausen and Kirchner 2001).

2.2.2 Demersal fish species

Hake
In general *Merluccius paradoxus* adults occur further south than *M. capensis* and juveniles (of both species) occur in water shallower than 100 m. Figures 9 – 13 illustrate the spatial distributions of hake eggs and larvae, juveniles (<30 cm) and spawning adults.

Elevated concentrations of egg were identified between Cape Frio and Rocky Point, off Palgrave Point, between Cape Cross and Sandwich Harbour, and to a lesser extent near the mining licence area off Hollams Bird Island (Sundby *et al* 2001, Figure 9). The horizontal distribution of all hake larvae shows that they occur further south than the eggs and were more abundant inshore (<100m depths) just north of Walvis Bay (Figure 10).

A significant number of juvenile *M. capensis* (<30 cm) occur within the MLA whereas *M. paradoxus* appear to concentrate further south (Figures 11 and 12). The gonadosomatic index (GSI) and the incidence of advanced maturity stages of *M. paradoxus* were low along the entire coast throughout the year, but with a few exceptions in the south (between Lüderitz and Orange River). By contrast, *M. capensis* spawn along the entire coast throughout the year, but mainly between July and October. (Figure 13)

The drift routes of eggs and larvae into the nursery areas, based on ADCP data, are shown in Figure 14 (Sundby *et al* (1998). North of St Helena Bay the jet current diverges into an offshore and an inshore branch. The offshore branch, which flows along the shelf edge, may cause loss of eggs and larvae by moving them well away from their nursery areas. However, Sundby *et al* (1998) believed that the inshore branch of the Benguela jet current transports eggs and larvae of both species to nursery grounds but that their distribution across the shelf (*M. paradoxus* spawn deeper than *M. capensis*) would most likely lead to species-specific drift routes, which could explain why the two species may have different nursery areas (*M. paradoxus* further offshore compared to *M. capensis*).

© NMP 2014

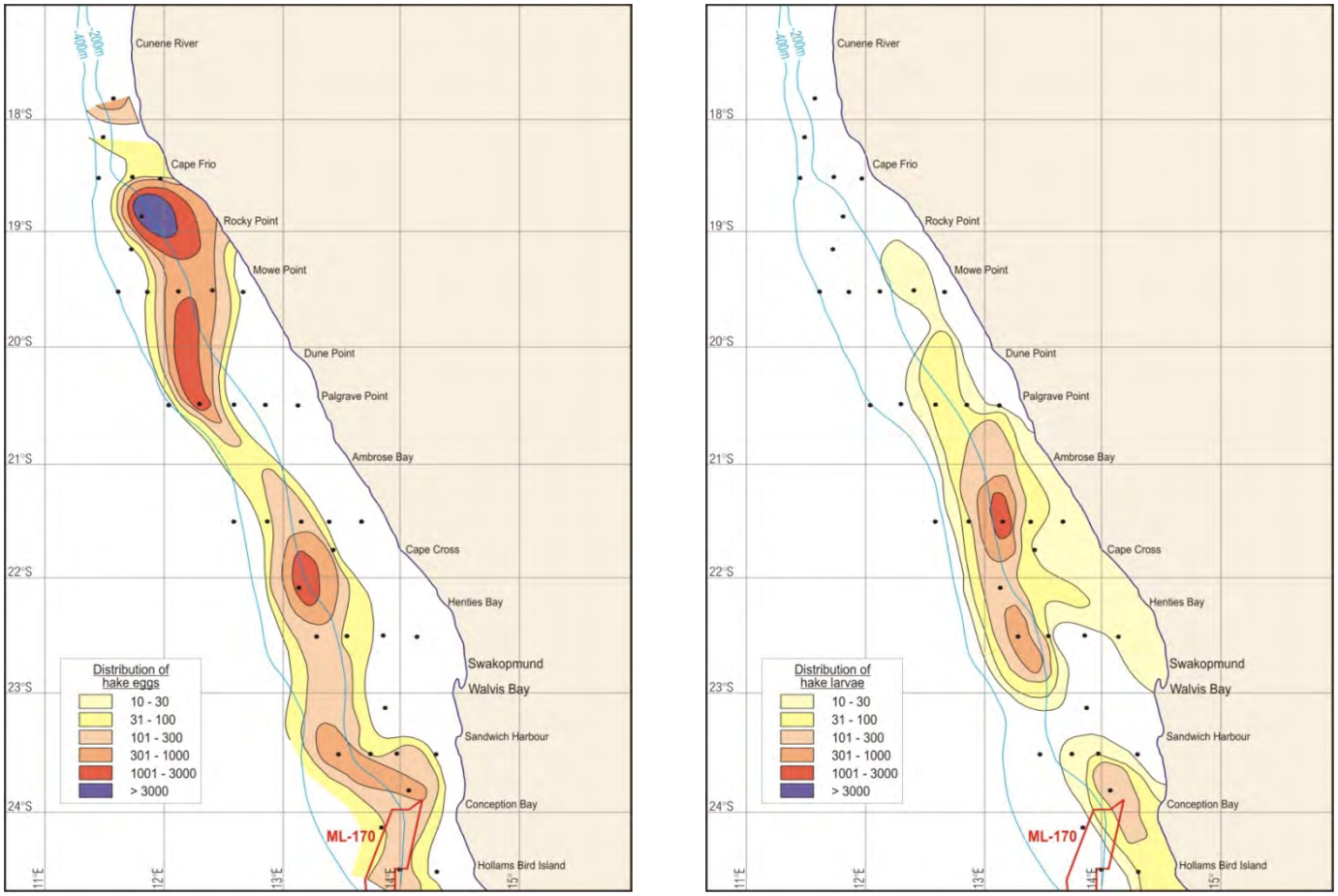


Figure 9: Distribution of hake *Merluccius* spp eggs (left) and larvae (right). Number per 10 m^2 for Sep/Oct 1998 (Sundby *et al.* 2001)

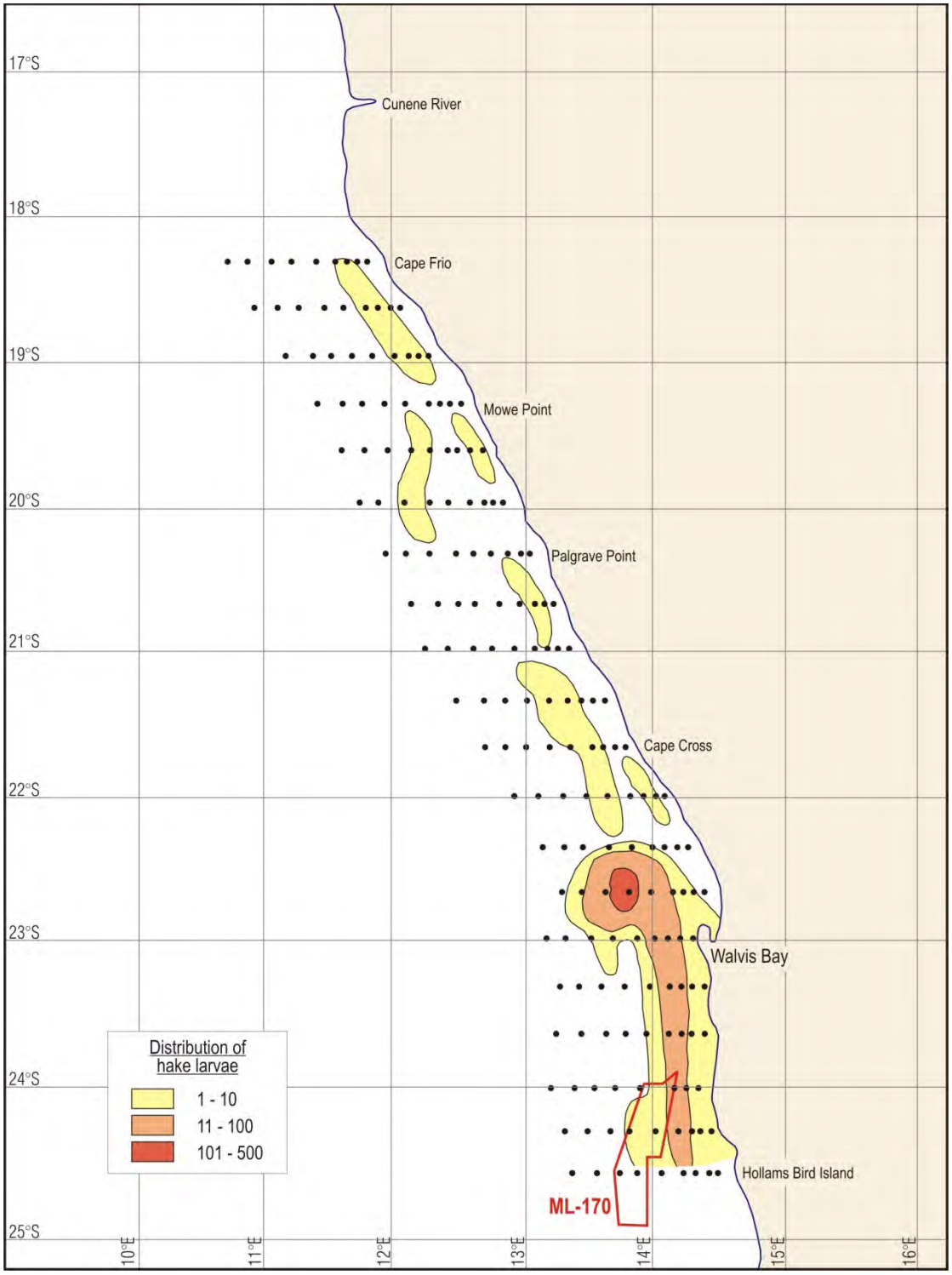


Figure 10: Distribution and abundance of hake larvae (Redrawn from O'Toole 1977)

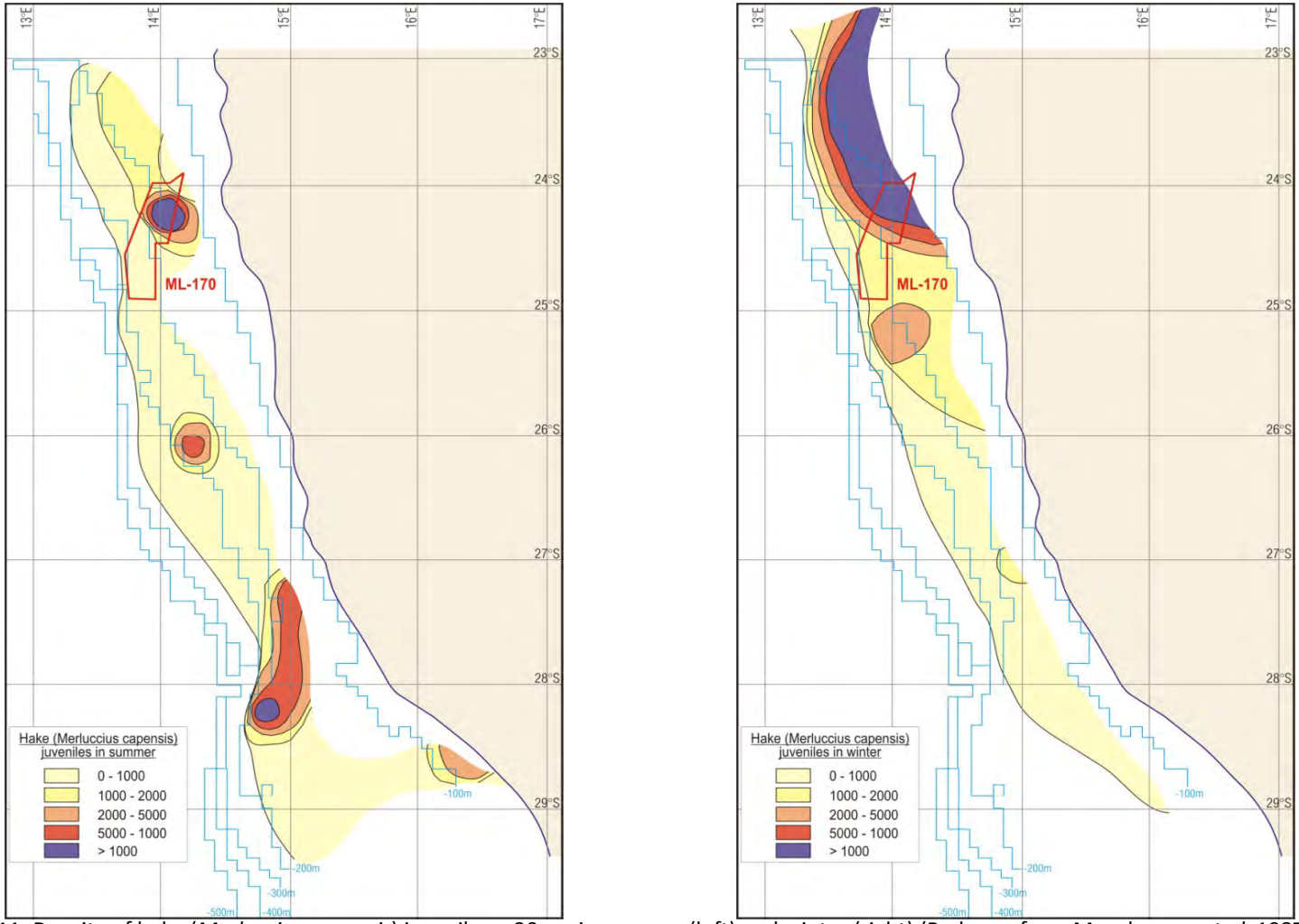


Figure 11: Density of hake (*Merluccius capensis*) juveniles, <30 cm in summer (left) and winter (right) (Redrawn from Macpherson *et al.* 1987)

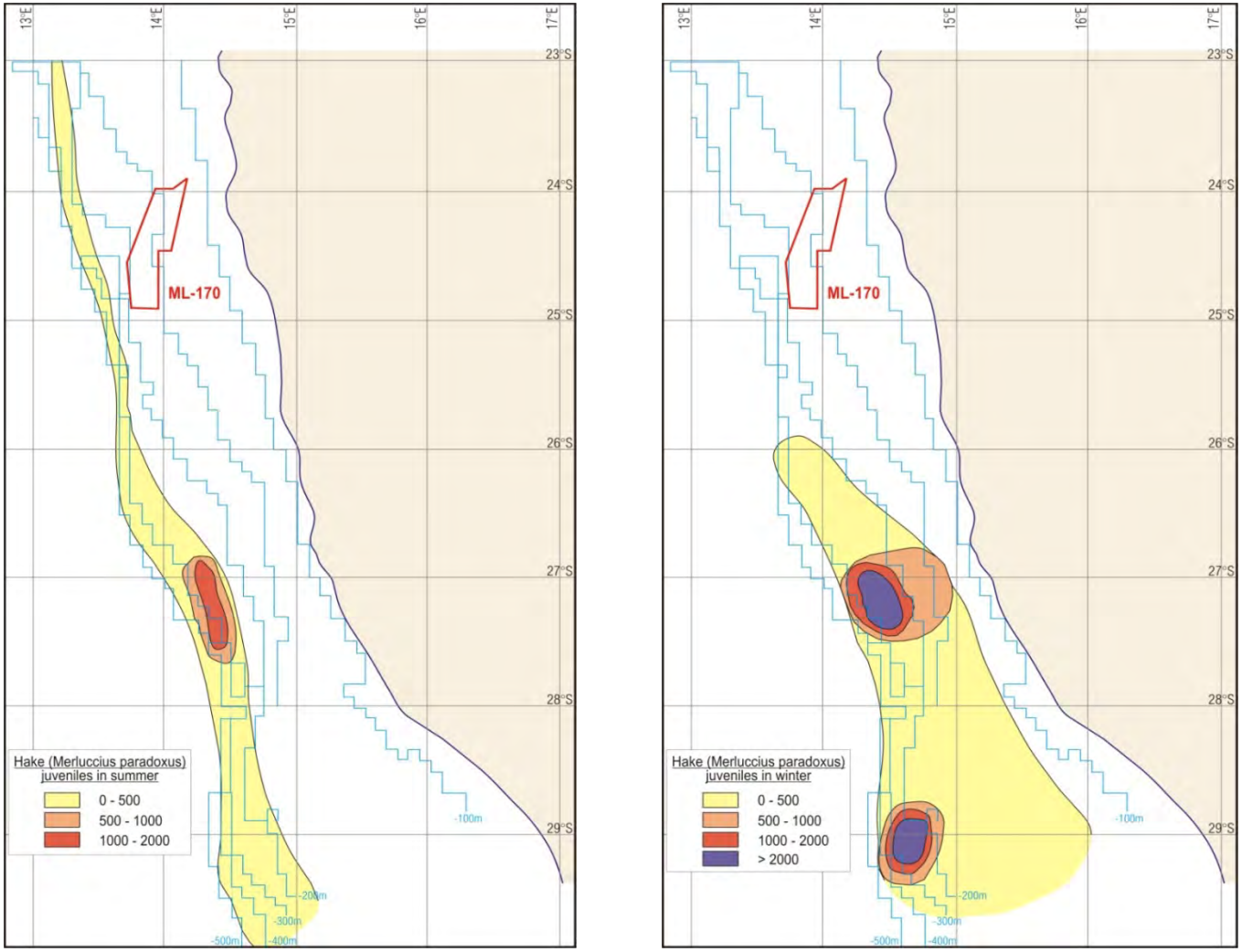


Figure 12: Density of hake (*Merluccius paradoxus*) juveniles, <30 cm in summer (left) and winter (right) 1986 (Macpherson *et al.* 1987)

© NMP 2014

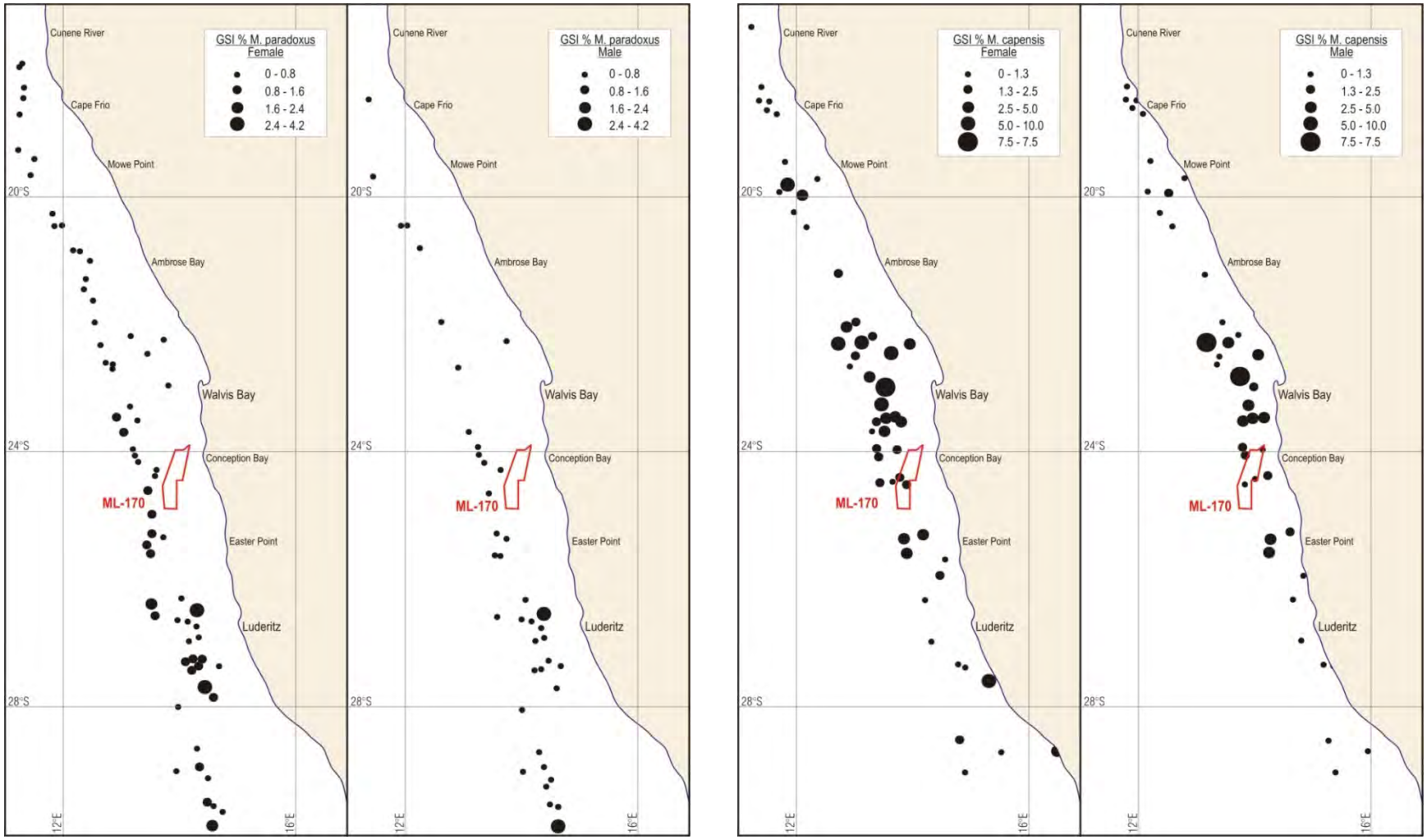


Figure 13: Distribution of GSI values (%) per geographical position for *M. paradoxus* (left) and *M. capensis* (right) (Redrawn from Kainge *et al*. 2007)

© NMP 2014

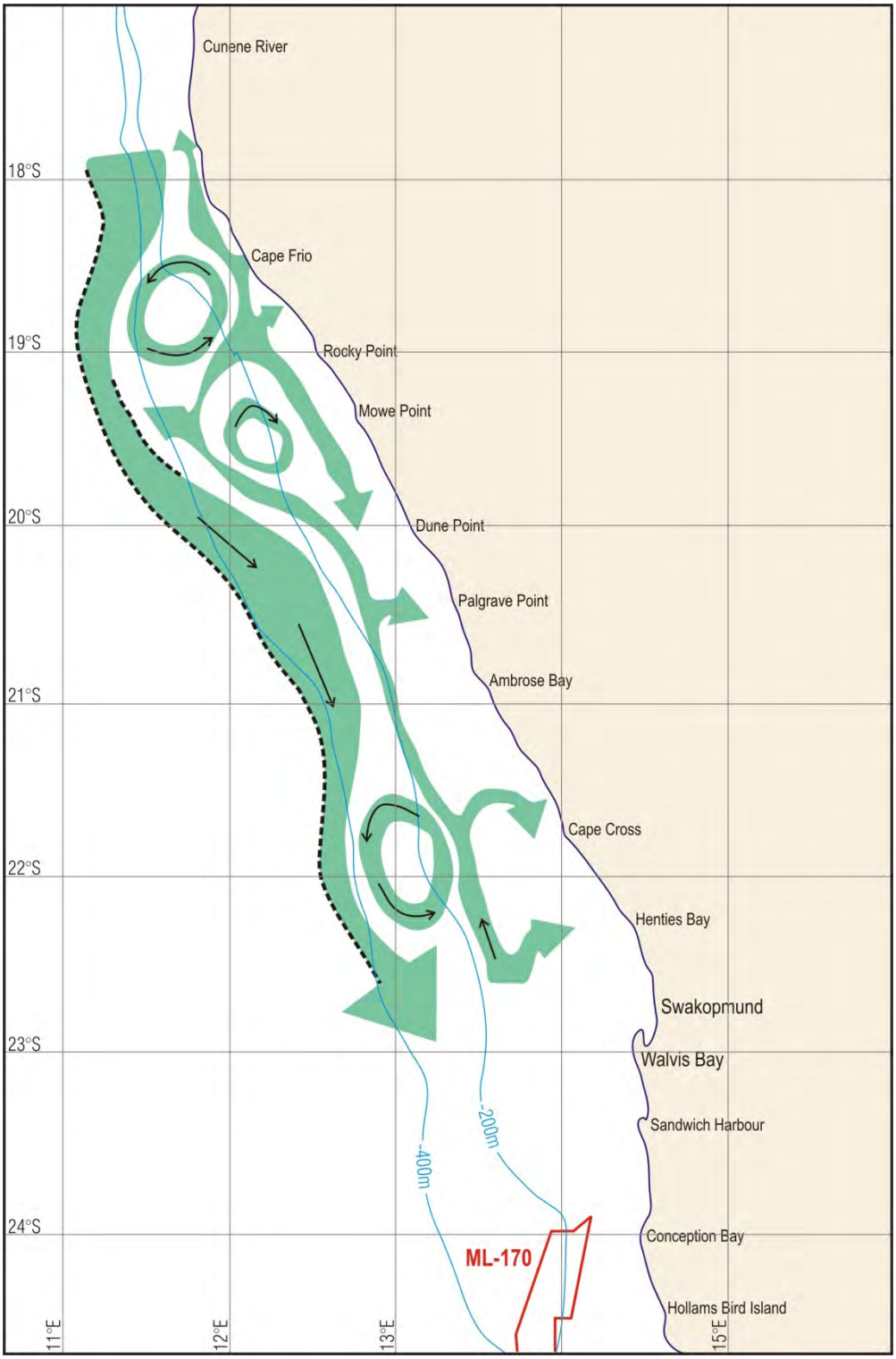


Figure 14: Drift routes for hake eggs and larvae in subsurface circulation (35 – 50 m) mapped by hydrography and ADCP during (Sep/Oct 1998) (Redrawn from Sundby *et al.* 1998)

Monkfish

Leslie and Grant (1991) concluded that *Lophius upsicephalus* was a junior synonym of *L. vomerinus.* The two most common monkfish species found off Namibia are *L. vomerinus* and *L. vaillanti*. *L. vomerinus* extends from northern Namibia (21°S) to Durban, South Africa (30°S; 31°E) (Leslie and Grant, 1990). *L. vaillanti* occurs north of Walvis Bay (23°S). Both are demersal species and in Namibia they inhabit areas from the subtidal zone to depths of more than 600 m. (Maartens *et al.* 1999).

This species spawns throughout the year with a peak in spawning taking place in late winter and summer (Maartens and Booth 2005). Monkfish are known to recruit off Walvis Bay at depths of 150 m and 300 m, and near the Orange River at depths of 100 m to 300 m (Maartens and Booth 2005). Juveniles (<30 cm) occur within the MLA during summer and winter (Figure 15).

© NMP 2014

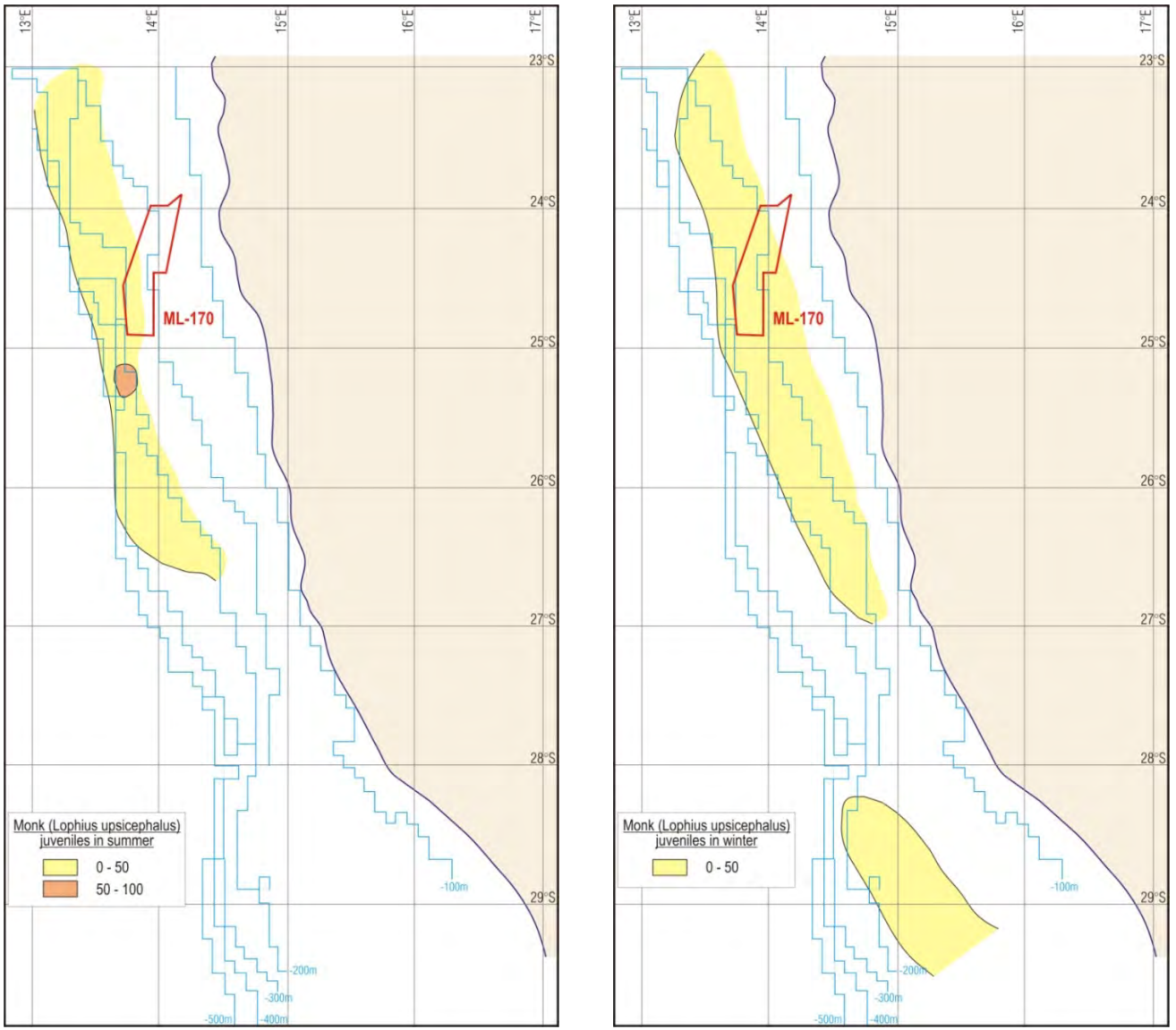


Figure 15: Density of monk (*Lophius upsicephalus*) juveniles, <30 cm in summer (left) and winter (right) 1986 (Redrawn from Macpherson *et al.* 1987)

© NMP 2014

West coast sole

The west coast sole *Austroglossus microlepis* occurs from northern Namibia (Figure 16) to False Bay in South Africa (Diaz de Atarloa 2002). *A. microlepis* inhabits muddy substrata at depths of 100-300 m (Heemstra and Gon 1995), where adults prey on polychaete worms, crustaceans, molluscs, and fish (e.g. gobies) (Bianchi *et al*. 1999). No information exists in the published literature regarding spawning and recruitment of west coast sole along the Namibian coast.

Orange roughy

Orange roughy (*Hoplostethus atlanticus*) is a deep sea species occurring at depths of 600 – 1400 m (Branch 2001). These fish are unusual in that they are very long-lived (> 100 years) and slow growing (reaching sexual maturity at around 25 years), have low fecundity and show low natural mortality (Boyer and Hampton 2001a, Boyer and Hampton 2001b, Branch 2001). Off Namibia this species has a restricted spawning period of less than a month in late July, when spawning takes place in dense aggregations close to the bottom in small areas typically between 10 and 100 km^2 in extent (Boyer and Hampton 2001b).

Bearded goby

The bearded goby (*Sufflogobius bibarbatus*) occurs from the Kunene River to the east coast of South Africa (Cruickshank *et al*. 1980). Juveniles of this species usually inhabit inshore waters shallower than 200 m, with the greatest concentrations occurring within 10 km to 30 km of the coast (Cruickshank *et al*. 1980, Cruickshank 1982 in Melo and Le Clus 2005). In contrast, adults occur across the shelf (Melo and Le Clus 2005, Utne-Palm *et al*. 2010). Gobies feed on bacteria and other invertebrates in the sediments. Following the collapse of the Namibian sardine stocks, bearded gobies became an important food source for commercial fish such as hake and horse mackerel as well as seabirds and seals (Crawford *et al*. 1985, Crawford *et al*. 1987, Boyer and Hampton 2001b). They are prey for hake, horse mackerel, seals, penguins and seabirds. High abundance of goby larvae occur in the MLA therefore removal of their spawning and feeding grounds could threaten recruitment and reduce the amount of food availability for top predators (Figures 17 and 18).

Recent research has shown that gobies have been able to withstand these levels of predation due to unique physiological and behavioural adaptations, which enables them to inhabit environments which are inhospitable to their predators (Utne-Palm *et al*. 2010). During the day bearded gobies rest on or hide in muddy sediments on the seafloor and feed on polychaete worms and diatoms, which constitute an estimated 7% of their diet (Utne-Palm *et al*. 2010). While at the sea bottom these fish are exposed to extremely low levels of oxygen and high levels sulphide, conditions that are fatal to most other organisms (including their predators). At night the gobies ascend into the water column where they reoxygenate and digest the food they consumed earlier (Utne-Palm *et al*. 2010).

Kingklip

Kingklip (*Genypterus capensis*) are endemic to Southern African waters and are distributed from Walvis Bay in Namibia (Figure 19) to Algoa Bay in South Africa. They are a benthic species occurring mainly in offshore deep water between 100 – 550 m and are found in rocky areas of the shelf and upper continental slope. Kingklip are relatively slow-growing and long-lived. They feed on dragonets, mantis shrimps, hake, squid and various fishes. From the historical information kingklip do not overlap with the MLA since they occur mostly in deep water (>200m). In winter their distribution is in the south where they do not overlap with the MLA (Figure 19).

© NMP 2014

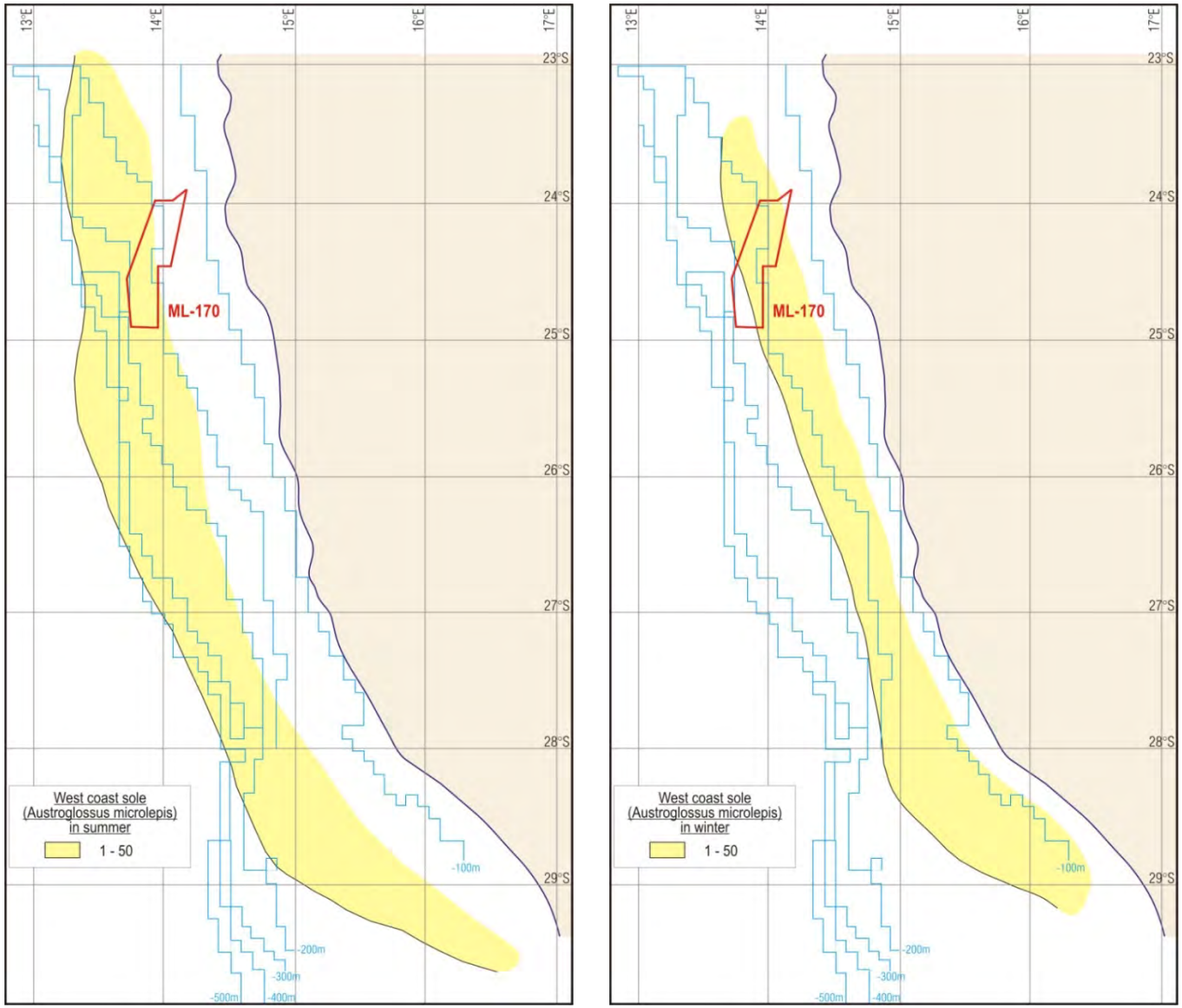


Figure 16: Density of west coast sole (*Austroglossus microlepis*) in summer (left) and winter (right) (1986) (Macpherson *et al.* 1987).

© NMP 2014

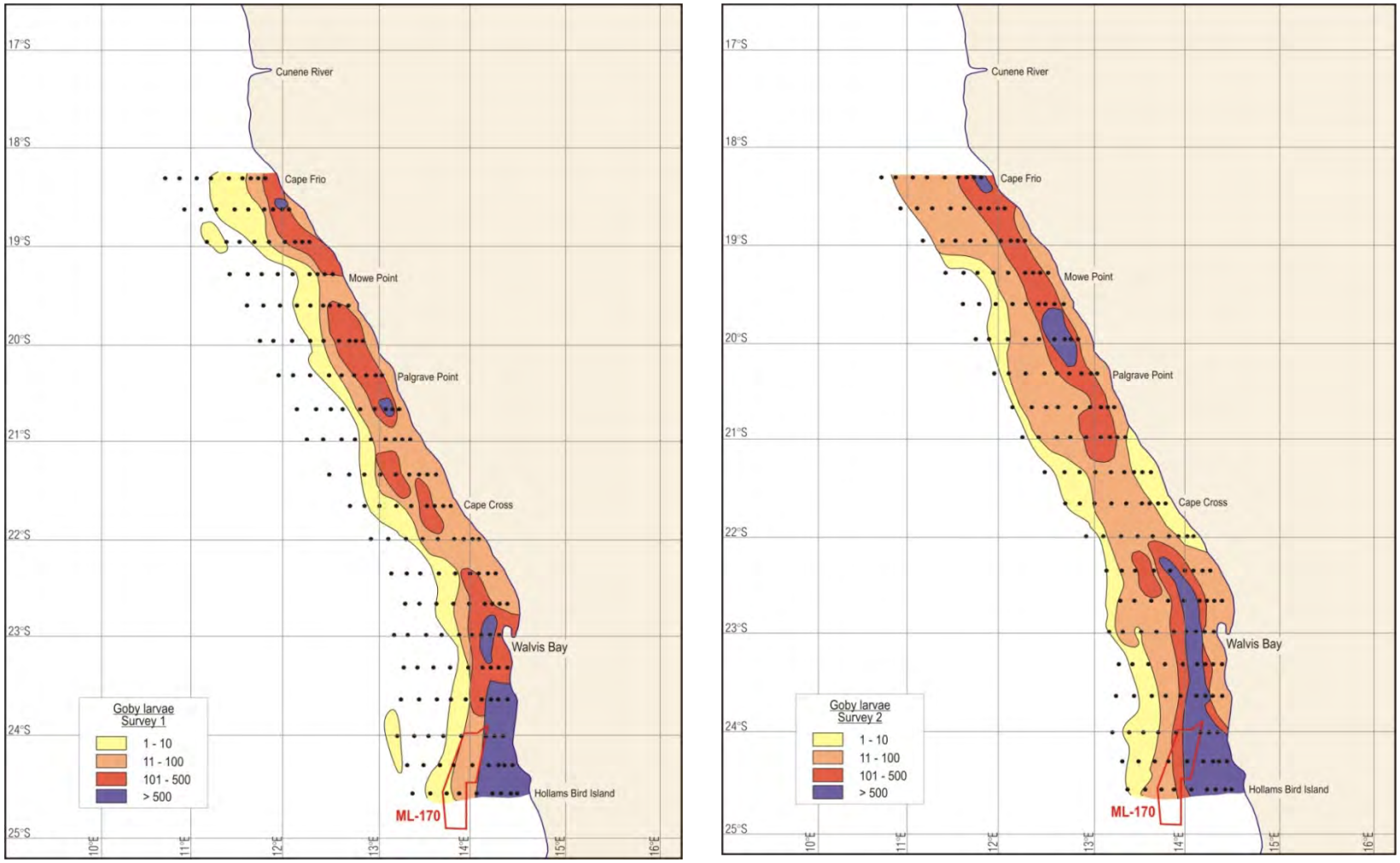


Figure 17: Distribution and abundance of goby larvae during survey 1 (left) and survey 2 (right).
Values represent cumulative standard haul totals for all cruises (O'Toole 1977)

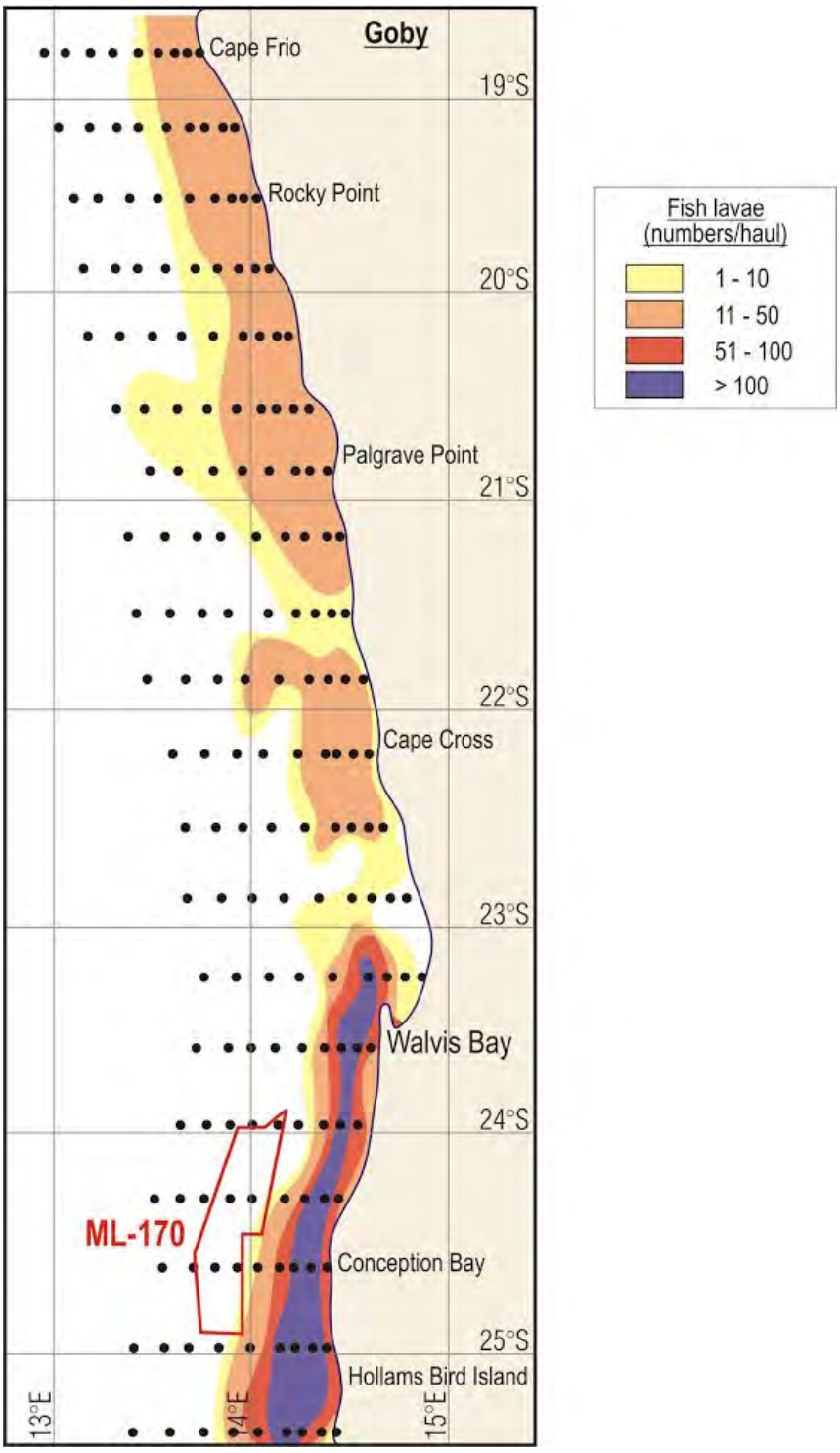


Figure 18: The distribution and abundance of goby larvae off Namibia,
numbers per haul Aug 1972 – Apr 1973
(Redrawn from O'Toole 1977)

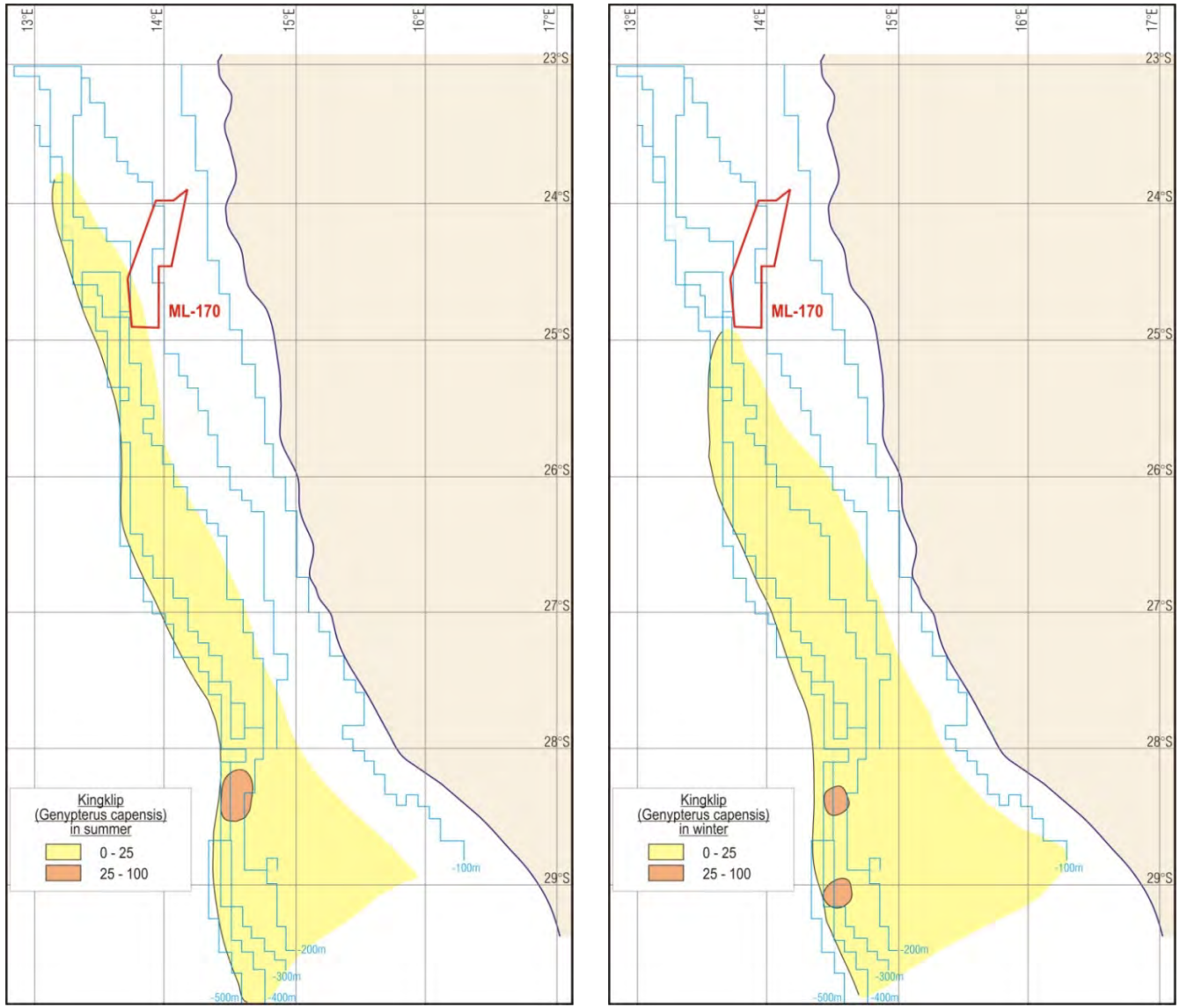


Figure 19: Density of kingklip (*Genypterus capensis*) in summer (left) and winter (right) (1986) (Redrawn from Macpherson *et al.* 1987).

© NMP 2014

2.2.3 West coast rock lobster

While the west coast rock lobster *Jasus lalandii* occurs from Cape Cross to the east coast of South Africa, significant densities only occur south of Meob Bay (Cockcroft 2001). The spawning cycle of this species is strongly related to the annual moulting cycle. Males moult in spring and mating takes place after the females have moulted in late autumn and early winter (Boyer and Hampton 2001a). Females carry their eggs until they hatch in October and November, releasing planktonic larvae (Pollock 1986). These larvae remain in the plankton for several months before becoming free-swimming (Crawford *et al*. 1987) and settling in nearshore rocky areas. Adults generally occur further offshore than juveniles, except in central Namibia where the whole population is forced close to the shore by low-oxygen conditions (Pollock and Beyers 1981). Seasonal variability in dissolved oxygen near the seabed also drives seasonal changes in the depth distribution of adult lobsters (especially males) (Grobler and Noli-peard 1997).

2.3 DIETS AND TROPHIC INTERACTIONS IN THE BENGUELA ECOSYSTEM

Historical distributions of phytoplankton and zooplankton in the Benguela Current off the Namibian coast are represented in Figures 20 and 21 respectively. Horse mackerel of up to two years of age feed predominantly on zooplankton that they consume near the water surface. Research in the 1980s found that off Namibia the diet of adult horse mackerel comprised 95% euphausiid shrimps (Konchina 1986 cited in Boyer and Hampton 2001a). The trophic structure of the northern Benguela system off Namibia has altered substantially in the last two decades (Kirkman 2007, Utne-Palm *et al*. 2010) and bearded goby (*Sufflogobius bibartus*) have become an increasingly important food source for predators (Crawford *et al*. 1987, Boyer and Hampton 2001a), consequently there may have been a shift in diet of Namibian horse mackerel to also focus on bearded goby.

While juvenile sardine primarily feed on zooplankton, phytoplankton is also utilised by adults in areas where it is consistently abundant (James 1988). Anchovy also feed predominantly on zooplankton (James 1988). Different size selectivity between sardine and anchovy is thought to minimise competition for food between these two co-existing species (Louw *et al*. 1998). Red eye herring feeds almost entirely on zooplankton (James 1988).

The diet of snoek consists mainly of fish. Inshore (>150 m) there is a focus on small pelagic species (e.g. sardines and anchovy) while offshore snoek also feed on demersal fish (e.g. hake) (Griffiths 2002). The west coast steenbras feeds mainly on the mussels *Choromytilus meridionalus* and *Perna perna* (Holtzhausen and Kirchner 2001).

In northern Namibia silver kob feed mainly on pelagic fish, shrimps and squid, whereas in the central and southern Namibia shrimps dominate the diet of these fish (Kirchner 1999). Monkfish are non-selective predators which lure their prey by moving their illicium (Gordoa and Macpherson 1990). These fish feed during the day (Macpherson 1985) with their most important prey being shallow water hake (*M. capensis*) (Maartens *et al*. 1999).

When off the seabed bearded gobies tend to associate with swarms of jellyfish which are avoided by their predators and which account for up to 60% of their diet (Utne-Palm *et al*. 2010). It is unclear if this constitutes live jellyfish taken at night, or dead jellyfish which are consumed in the benthic environment during the day. This consumption of jellyfish is of huge ecological importance, as gobies make nutrients and energy available to their predators that would otherwise essentially be lost to the foodchain (Utne-Palm *et al*. 2010).

The diet of west coast rock lobster is dominated by mussels (especially *Aulacomya ater*), except in areas where mussel abundance is low and lobsters feed on a variety of invertebrates such as sea urchins, starfish, gastropods and seaweeds (Pollock and Beyers 1981). Cannibalism is known to occur in crowded conditions (Boyer and Hampton 2001a).

© NMP 2014

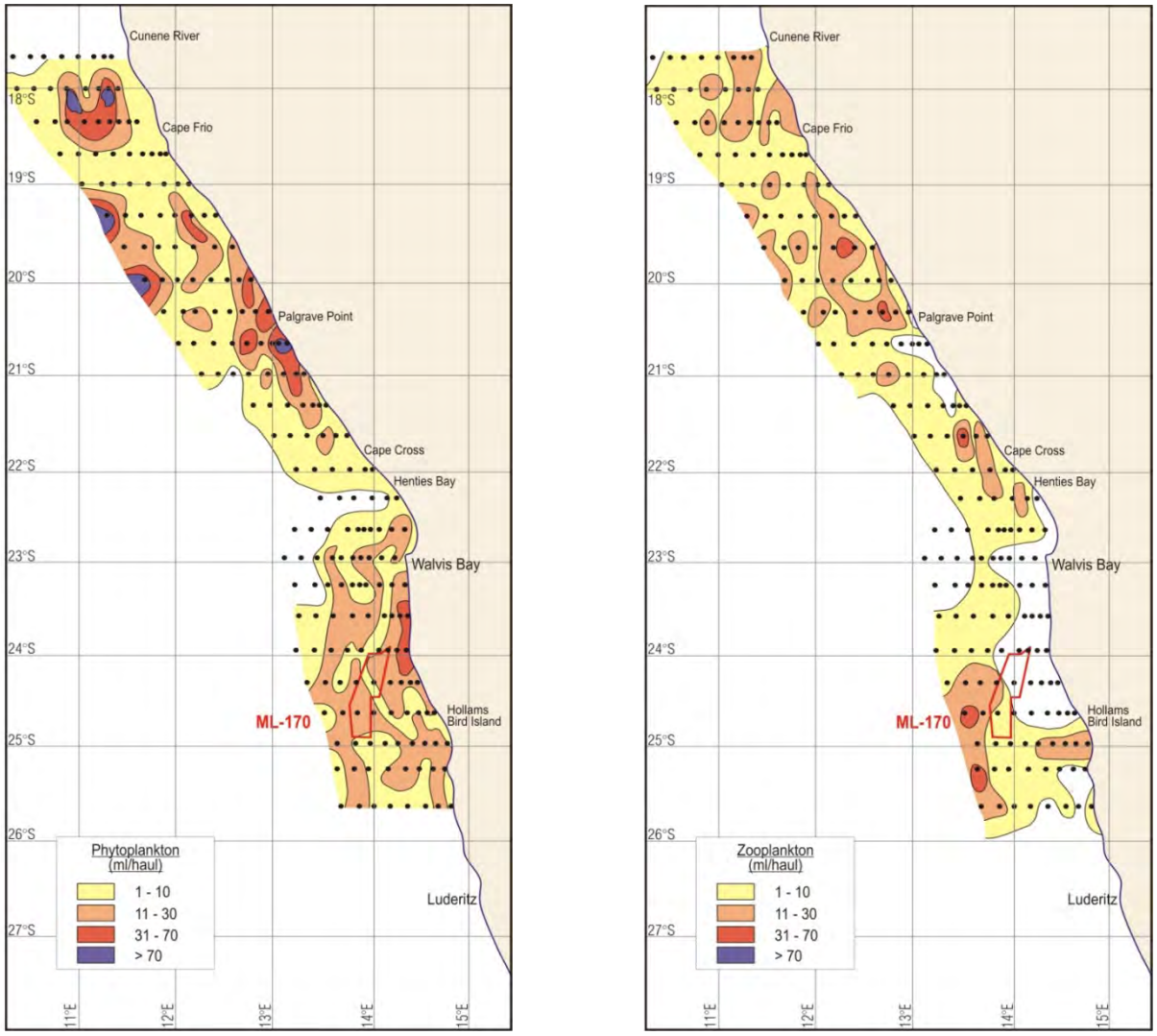


Figure 20: Seasonal phytoplankton and zooplankton distribution off Namibia (Mar/Apr 1981) (Redrawn from Le Clus 1985).

© NMP 2014

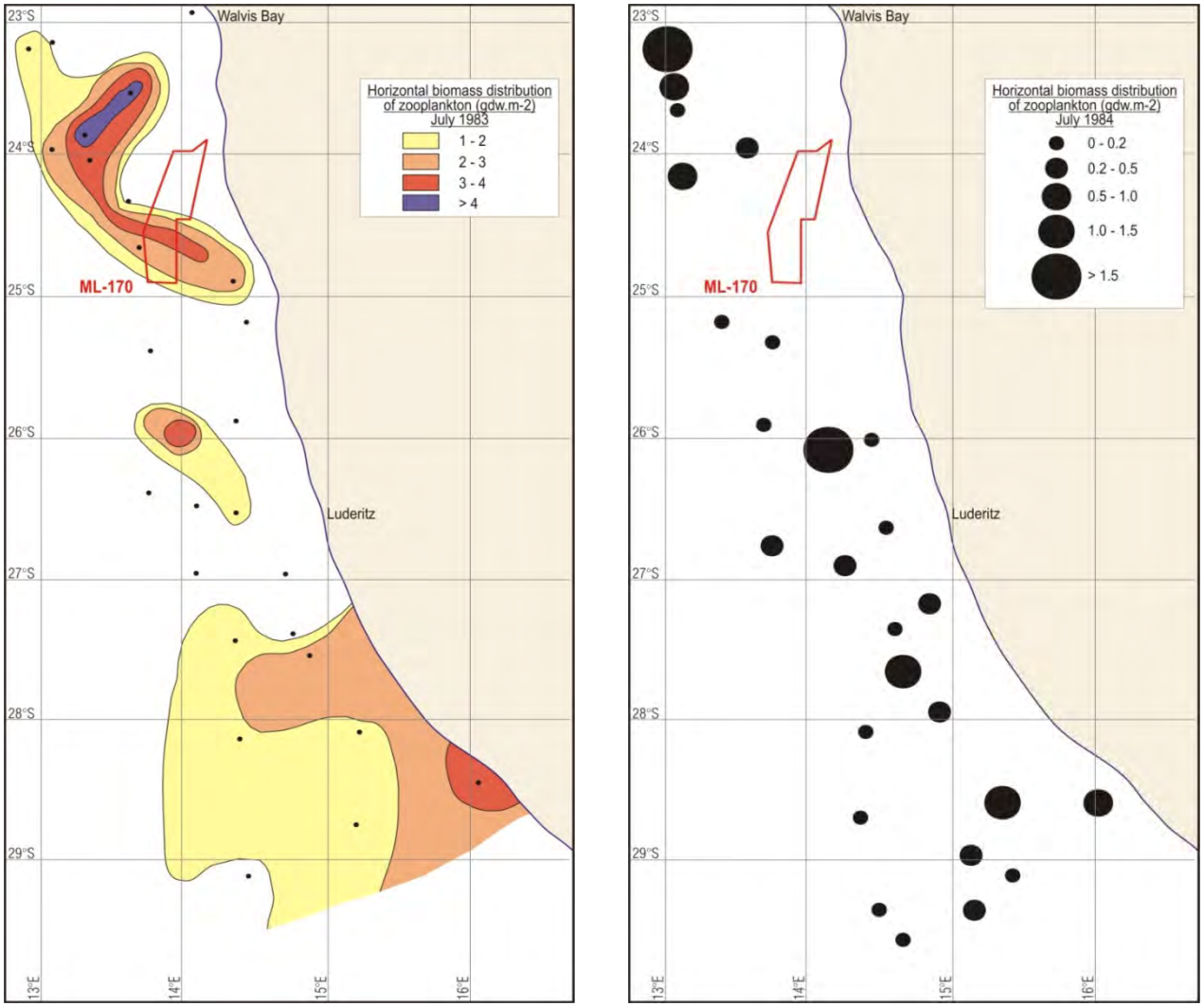


Figure 21: Horizontal biomass distribution of zooplankton in July 1983 and July 1984 (Redrawn from Fearon *et al*. 1985).

3 CONCLUSIONS

Reviewing the historical literature and in particular the work undertaken by the International Commission for South East Atlantic Fisheries (ICSEAF) and the valuable research on the distribution of fish eggs, larvae and other ichthyoplankton (the SWAPELS programme), is essential to understand the Benguela Ecosystem and the likely changes in the spatial and temporal dynamics of key fish species. Thus the purpose of this historical assessment was to review the historical (and recent) literature to support the Environmental Impact Assessment (EIA) (Japp in Midgley, 2012). The conclusions were:

- Aggregations of spawning horse mackerel and juveniles occur outside the MLA;
- Only the northern extent of the MLA falls within the southern part of the sardine spawning area;
- Historically, spawning and larval distributions of anchovy took place north of Walvis Bay (outside the MLA);
- Snoek migrate southwards to spawn offshore and in deep waters near St Helena and off the Cape Peninsula in South Africa. The MLA is situated at the eastern edge of the migration corridor;
- Silver kob spawn very close inshore (<100 m) at Meob Bay and larvae drift northwards to the nursery grounds between Sandwich Harbour and the Ugab River mouth;
- A low abundance of hake eggs occurs to the south east of the MLA off Hollams Bird Island;
- Hake larvae were found in high abundance from Conception Bay to Palgrave Point in water depths between 100 – 300 m;
- A significant amount of juvenile *M. capensis* (<30 cm) occurs within the MLA;
- According to the historical literature, juvenile monkfish occur within the MLA;
- Goby larvae are in high abundance throughout the entire Namibian coastline and inside the MLA and;
- West coast rock lobster occurs far inshore and further south of the MLA.

4 REFERENCES

Axelsen BE, Krakstad JO, and Bauleth-D'Almeida G (2004). Aggregation dynamics and diel vertical migration in Cape horse mackerel (*Trachurus trachurus capensis*) in the Namibian Benguela. Implications for acoustic abundance estimation. In 'Ecological, Economic and Social Aspects of Namibian Fisheries'. Eds: UR Sumaila, SI Steinshamn, MD Skogen and D Boyer pp. 135–164. Eburon Publishers: Delft.

Bianchi G, Carpenter KE, Roux JP, Molloy FJ, Boyer D and Boyer HJ (1999). *Field guide to the living marine resources of Namibia*. FAO Rome 265p.

Boyer DC and Hampton I. (2001a). An overview of the living marine resources of Namibia. *South African Journal of Marine Science* **23**: 5-35.

Boyer DC and Hampton I (2001b). Development of acoustic techniques for assessment of orange roughy *Hoplostethus atlanticus* biomass off Namibia and of methods for correction for bias. *South African Journal of Marine Science* **23**: 223-240.

Branch TA (2001). A review of orange roughy *Hoplostethus atlanticus* fisheries, estimation methods, biology and stock structure. *South African Journal of Marine Science* **23**: 181-203.

Cockcroft AC (2001). *Jasus lalandii* 'walkouts' or mass strandings in South Africa during the 1990s: an overview. *Marine and Freshwater Research* **25**: 1085-1093.

Crawford RJM and de Villiers G (1985). Snoek and their prey – interrelationships in the Benguela upwelling system. *South African Journal of Science* **81**: 91-97.

Crawford RJM, Shannon LV and Pollock DE (1987). The Benguela ecosystem. Part IV. The major fish and invertebrate resources. *Oceanogr. Mar. Biol. Ann. Rev*. **25**: 353-505.

Cruickshank RA, Cooper J and Hampton I (1980). Extension to the geographical distribution of pelagic goby *Sufflogobius bibarbatus* off South West Africa and some mensural and energetic information. *Fisheries Bulletin of South Africa* **13**: 77-82.

Cruickshank, R.A. (1982) Possible utilization of lanternfish and gobies in SWA waters. S. Afr Shipp News Fish Ind Rev **37**: 29-33.

Davies DH (1954). The South African pilchard *(Sardinops ocellata).* Development, occurrence and distribution of eggs and larvae, 1950-51. *Investl. Rep. Div. Fish. S. Afr.* **15**: 1 - 26.

De Jager B vD (1955). The South African pilchard *(Sardinaps ocellata).* The development of the snoek *(Thyrsites atun)* as a predator of the pilchard. Investl. Rep. Div. Fish. S. Afr. **19**: 111.

Diaz de Astarloa JM (2002). A review of the flatfish of the south Atlantic ocean. Revista de Biologia Marina y *Oceanografia* **37**: 113-125.

Fearon J, Boyd AJ and Kruger I (1985). The distribution and adundance of the dominant groups of epibenthic zooplankton off Namibia in January 1985 in relation to surface temperature,

salinity and chlorophyll. *Collection of Scientific Papers International Commission for the Southeast Atlantic Fisheries.* Vol. **13.** Part 1.

Gordoa A and Macpherson E (1990). Food selection by the sit-and-wait predator, the monkfish, *Lophius upsicephalus*, off Namibia (South West Africa). *Environmental Biology of Fishes* **27**: 71-76.

Griffiths MH (2002). Life History of South African snoek, *Thyristes atun* (Pisces: Gempylidae): a pelagic predator of the Benguela ecosystem. *Fisheries Bulletin* **100**: 690-710.

Griffiths MH (2003). Stock structure of snoek *Thyrsites atun* in the Benguela: a new hypothesis. *South African Journal of Marine Science* **25**: 383-386.

Grobler CAF and Noli-Peard KR (1997). *Jasus lalandii* fishery in post-Independence Namibia: monitoring population trends and stock recovery in relation to a variable environment. *Marine and Freshwater Research* **48**: 1015-1022.

Heemstra PC and Gon O (1995). Family No. 262: Soleidae. In: Smith MM, Heemstra PC (eds) *Smiths sea fishes*. Southern Book Publishers. Johannesburg. 868-874.

Holtzhausen JA, Kirchner CH and Voges SF (2001). Observations of the linefish resources of Namibia, 1990-2000, with special reference to west coast steenbras and silver kob. *South African Journal of Marine Science* **23**: 135-144.

Holtzhausen JA and Kirchner CH (2001). Age and growth of two populations of west coast steenbras *Lithognathus aureti* in Namibian waters, based on otolith readings and mark-recapture data. *South African Journal of Marine Science* **23**: 169-179.

James AG (1988). Are clupeid microphagists herbivorous or omnivorous? A review of the diets of some commercially important clupeids. *South African Journal of Marine Science* **7**: 161-177.

Kainge P, Kjesbu A, Thorsen A and Salvanes AG (2007). *Merluccius capensis* spawn in Namibian waters, but do *M. paradoxus*? *African Journal of Marine Science* **29**: 379 -392.

Kirchner CH (1999). Population dynamics and stock assessment of the exploited silver kob (*Argyrosomus inodorus*) in Namibian waters. PhD Thesis. University of Port Elizabeth 204 pp.

Kirchner CH and Voges SF (1999). Growth of Namibian silver kob *Argyrosomus inodorus* based on otoliths and mark-recapture data. *South African Journal of Marine Science* **21**: 201-209.

Kirkman SP (ed) (2007). Final Report of the BCLME (Benguela Current Large Marine Ecosystem) Project on Top Predators as Biological Indicators of Ecosystem Change in the BCLME. Avian Demography Unit, Cape Town.

Konchina VY (1986). Fundamental trophic relationships of the rockfishes *Sebastes mentella* and *Sebastes fasciatus* (Scorpaenidae) of the northwestern Atlantic. *J. Ichthyol.* **26**(1):53-65.

© NMP 2014

Le Clus F (1985). Effects of a warm water intrusion on the anchovy fishery in Namibia. *Collection of Scientific Papers International Commission for the Southeast Atlantic Fisheries* **12** (1), 99–106.

Le Clus F, Hewitson JD, Melo YC, Cooper RM, and Malan PE (1987). The multispecies pelagic fishery of Namibia 1982– 1986 and stock assessments for pilchard and anchovy. *Collection of Scientific Papers International Commission for the South- east Atlantic Fisheries* **9** (2), 121–145.

Leslie, R.W. and W.S. Grant, 1991. Redescription of the southern African anglerfish *Lophius vomerinus* Valenciennes, 1837 (Lophiiformes: Lophiidae). Copeia **1991**(3):787-800.

Louw GG, van der Lingen CD and Gibbons MJ (1998). Differential feeding by sardine *Sardinops sagax* and anchovy *Engraulis capensis* recruits in mixed shoals. *South African Journal of Marine Science* **19**: 227-232.

Maartens L, Booth AJ and Hecht T (1999). The growth of monkfish *Lophius vomerinus* in Namibian waters, with a comparison of otolith and illicia methods of aging. *Fisheries Research* **44**: 139-148.

Maartens L and Booth AJ (2005). Aspects of the reproductive biology of monkfish *Lophius vomerinus* off Namibia. *South African Journal of Marine Science* **27**: 325–329.

Macpherson E (1985). Daily ration and feeding periodicity of some fishes off the coast of Namibia. *Marine Ecology Progress Series* **26**: 253-260.

Macpherson E and Roel BA (1987). Trophic replationships in the demersal fish community off Namibia, In: The Benguela and Comparable Ecosystem. Payne AIL, Gulland, JA and KH Brink (Eds). *S. Afr. J. Mar. Sci.* **5**: 585 – 596.

Melo YC and Le Clus F (2005). Growth and reproduction of the pelagic goby *Sufflogobuis bibartus* off the Orange River, southern Africa. *African Journal of Marine Science* **27**: 265-273.

Mundjulu IE (2009). Trends in the fishery and population traits of the Namibian stock of Capehorse mackerel Trachurus trachurus capensis (Castelnau, 1861) Master thesis in International Fisheries Management. Norwegian College of Fishery Science. Institute of Aquatic Bio-Sciences. University of Tromsø.

Olivar MP, Rubies P and Salat J (1988). Early life history and spawning of *Merluccius capensis* Castelnau in the northern Benguela Current. *South African Journal of Marine Science* **6**: 245-254.

O'Toole MJ (1977). Investigation into some important fish larvae in the South-East Atlantic. PhD Thesis, University of Cape Town 299 p.

Pollock DE and Beyers CJ (1981). Environment, distribution and growth rates of West Coast rock lobster *Jasus* lalandii (H. Milne Edwards). *Transactions of the Royal Society of South Africa* **44**: 379-400.

© NMP 2014

Pollock DE (1986). Review of the fishery for and biology of the Cape rock lobster *Jasus lalandii* with notes on larval recruitment. *Canadian Journal of Fisheries and Aquatic Sciences* **43**: 2107-2117.

Shannon LV and Pillar SC (1986). The Benguela ecosystem. Part III Plankton. *Oceanography and Marine Biology An Annual Review* **24**: 65-170.

Sundby S, Thorsen A, Kjesbu O, Thorisson K, Kiange P, Boyd A and Osborne R (1998). Investigation on spawning hake and their eggs and larvae, 23 September – 6 October 1998. Cruise Reports of "Dr. Fridtjof Nansen". BENEFIT Surveys No. 3/98. Institute of Marine Research, Bergen. 28 p. + 70 figs.

Sundby S, Boyd AJ, Hutchings L, O'Toole MJ, Thorisson K and Thorsen A. (2001). Interaction between cape hake spawning and the circulation in the northern Benguela upwelling ecosystem. *South African Journal of Marine Science* **23**: 317-336.

Tjizoo BM, Moroff N and Uumati MU (2006). Cruise report of the R.V. Welwitchia. Pilchard survey of the northern Benguela (15°30'–25°00'S) 13–29 October 2006. Unpublished report, Ministry of Fisheries and Marine Resources, Namibia.

Utne-Palm AC, Salvanes AGV, Currie B, Kaartveldt S, Nilsson GE, Braithwaite VA, Stecyk JAW, Hundt M, van der Bank M, Flynn B, Sandvik GK, Klevjer TA, Sweetman AK, Bruchert V, Pittman K, Peard KR, Lunde IG, Strandabo RAU, Gibbons MJ. 2010 Trophic structure and community stability in an overfished ecosystem. *Science* **329**: 333-329.

Van der Bank FH and Kirchner CH (1997). Biochemical genetic markers to distinguish two sympatric and morphologically similar Namibian marine fish species, *Argyrosomus coronus* and *Argyrosomus inodorus* (Perciformes: Sciaenidae). *African Journal of Zoology* **111**: 441-448.

© NMP 2014

SANDPIPER PROJECT

Verification Programme Report: Mining Licence Area No. 170

Glossary

GLOSSARY

Term	Definition
16S rRNA gene	A gene which is found in all bacteria. As it plays a role in formation of proteins it is essential and is used in phylogenetic analysis.
A260/A280	The ratio of absorbance at 260 nm and 280 nm used to assess the purity of DNA and RNA. A ratio of ~1.8 is accepted as "pure" for DNA and ~2.0 is generally accepted as "pure" for RNA.
Absolute quantification	An analysis method which determines how many copies of a gene are present. As samples are quantified compared with a known standard the actual number of copies can be determined.
Amplicon	A piece of DNA (i.e the amplified gene of interest – for this study it was a segment of the 16S rRNA gene) generated by PCR.
Amplification cycles	The conditions used to amplify DNA by PCR. It is a three step process involving the *denaturation* of the DNA (separating the molecule), *annealing* of the primer to the DNA and *elongation* in which the target gene is copied. This process is repeated 35-40 times to allow for the exponential amplification of the target gene.
Anoxia	Anoxic conditions describe an environment deprived of oxygen, i.e. zero dissolved oxygen
Anoxia/anoxic	Containing no dissolved oxygen.
Authigenic	Authigenic minerals form *in situ* within the depositional site in response to geochemical processes.
AVS analysis	Acid volatile sulphide fraction measured when sulphide is liberated from a sediment sample after acidification
Benthic	Referring to organisms living in or on the sediments of aquatic marine habitats.
Benthic organisms	Organisms living in or on sediments of aquatic marine habitats.
Benthos	The sum total of organisms living in, or on, the sediments of aquatic marine habitats.
Biodiversity	The variety of life forms, including the plants, animals and micro-organisms, the genes they contain and the ecosystems and ecological processes of which they are a part.
Biomass	The living weight of a plant or animal population, usually expressed on a unit area basis.
Biota	The sum total of the living organisms of any designated area.
cDNA conversion	The process of converting RNA to cDNA. As RNA is relatively unstable and readily degrades once extracted from a cell, RNA is converted into cDNA which is stable and can be used for later analysis and quantification.
Centrifugation	Use of centrifugal force for the sedimentation/separation of heterogeneous mixtures with a centrifuge.
Clay	Sediments containing particles smaller than 4 microns ESD
Community	An assemblage of organisms characterised by a distinctive combination of species occupying a common environment and interacting with one another.
Copy number	The number of copies of a gene.
Dissolved oxygen (DO)	Oxygen dissolved in a liquid, the solubility depending upon temperature, partial

© NMP 2014

GLOSSARY

Term	Definition
	pressure and salinity, expressed in milligrams/litre or millilitres/litre.
DNA amplification/PCR	Technique used to synthesize large quantities of specific DNA sequences/genes from a small amount of starting material.
DNA/RNA extraction	Extracting the nucleic acids (DNA/RNA) from the bacterial cells present in the sediment samples.
Ebullition	the action of bubbling or boiling
Epifauna	Organisms which live at, or on, the sediment surface being either attached (sessile) or capable of movement.
Equimolar ratios	Equal number of molecules from each sample were combined to ensure even representation.
Gel electrophoresis	The separation of DNA molecules according to size and charge in a gel matrix subject to an electrical field. It used to determine the size of DNA fragment.
Gravel	Gravel is the coarse sediment fraction containing particles larger than 2 mm in size.
Habitat	The place where a population (e.g. animal, plant, micro-organism) lives and its surroundings, both living and non-living.
Hypoxia	Hypoxic conditions describe an environment where dissolved oxygen concentrations are less than 2.8 mg/l (2 ml/l) and greater than zero.
Hypoxia/hypoxic	Low dissolved oxygen conditions (<0.5 ml/ℓ dissolved O_2) that are physiologically stressful to marine organisms.
Infauna	Animals of any size living within the sediment. They move freely through interstitial spaces between sedimentary particles or they build burrows or tubes.
LOI	Loss on ignition is a gravimetric technique which determines the organic matter of a solid sample lost after ignition at 450°C
Lysis	Breaking down the cell wall (the membrane which surrounds a microorganism) to release its nucleic acids.
Macrofauna	Benthic invertebrate animals >500 microns in size, or >300 microns in deeper water.
MATLAB	Software that allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages.
Meiofauna	Benthic invertebrate animals > 0.042 mm or > 0.032 (previously >0.063 mm).
Metagenomic – Also called environmental or community genomics.	It is the study of all the genomes recovered from an environmental sample without isolating/culturing them. Can be used to identify all the microorganisms present in a sample.
Microbial taxa	A term used to refer to a group of microbial organisms. It can refer to very closely related microorganisms (strains, species and genera) or to larger groupings (family and phylum).
Milli Q water	Milli-Q is a trademark created by Millipore Corporation to describe “ultrapure” water of "Type 1", as defined by various authorities (e.g. ISO 3696), as well as their devices for producing such water
Mud	Based on the Wentworth scale, mud collectively describes the texture of the size fraction of sediment samples that is smaller than 62.5 microns ESD.
Normoxic	Oxygen concentrations > hypoxic threshold of 2.8 mg/litre to saturation (~8 mg /litre) in surface waters
Nucleic acid	Polymeric biological macromolecules, essential for all forms of life. Includes DNA and RNA. Nucleic acids function in encoding, transmitting and expressing genetic information.
ORP (Redox potential)	Oxidation reduction potential or “Redox Potential” is a measure of the tendency of a chemical species to acquire electrons and thereby be reduced
Oxic	Describes oxygenated conditions, where dissolved oxygen levels are above

© NMP 2014

GLOSSARY

Term	Definition
	2 mg/l (1.4 ml/l)
Oxygen minimum zone (OMZ)	Zone in the ocean where oxygen saturation is perennially at hypoxic (<0.5ml/ℓ) conditions.
PCR	Polymerase chain reaction
PCR inhibitor	Impurities/chemicals which inhibit the enzymes used in PCR.
Phylogenetic analysis	Using genetic information to investigate evolutionary relationships (akin to a 'family tree').
Phylum	The major taxonomic group of animals and plants; contains classes
Phylum Delta Proteobacteria	A group of bacteria which include the strictly anaerobic sulphate-reducing bacteria (including *Desulfovibrio*, *Desulfobacter*, *Desulfococcus* and *Desulfonema*) and sulphur-reducing bacteria (e.g. *Desulfuromonas* species). Ferric iron-reducing *Geobacter* species, and syntrophic *Pelobacter* and *Syntrophus* species are also included in this phylum.
Phylum Firmicutes	Diverse group of Gram positive bacteria, which are found in a wide range of habitats. The phylum includes several genera of anaerobic, sulphate reducing organisms.
Population	Population is defined as the total number of individuals of the species or taxon.
Primer efficiency	A measure of how well a primer set amplifies a target gene by PCR. For qPCR a primer efficiency of 2 is considered ideal as this means that the number of copies are doubled every amplification cycle. Primers with a lower efficiency will result is less amplification which may lead to incorrect quantification.
Primers	Short pieces of DNA (oligonucleotides) which are used in PCR. They are specific for the gene of interest and ensure that only this gene is amplified.
QC standard	Quality control standard is a solid or liquid standard prepared from an independent external source to monitor the accuracy of an analytical method
Quantitative PCR /Real time PCR	Technique based on PCR which is used to amplify and simultaneously detect/quantify a target DNA molecule/gene (determine how many copies of the gene are present).
Redfield Ratio	Atomic ratio of carbon, nitrogen and phosphorus found in phytoplankton and throughout the deep oceans.
RNAlater	Reagent used to stabilize and prevent the degradation of RNA in environmental samples until the samples can be processed.
Roche LC480/Lightcycler 480	The instrument used to perform the qPCR.
Sand	According to the Wentworth scale, sand is classified as the fraction of particles between the sizes of 62.5 µm and 2 mm.
SEM concentration	Simultaneously extracted metal concentration-measured in the residual solution after liberation of sulphide from the sediment sample after acidification
Silt	Sediments in the size fraction >4 microns ESD and <62.5 microns ESD
Soliton	A class of non-sinusoidal, non-linear more or less isolated waves that occur frequently in nature
Species	A group of organisms that resemble each other to a greater degree than members of other groups and that form a reproductively isolated group that will not produce viable offspring if bred with members of another group.
Spectrophotometer	Instrument used to determine the concentration/amount of nucleic acid.
Sulphur- or sulphate reducing bacteria	Anaerobic bacteria that use sulphate or sulphur (or both) during respiration.
Sulphur oxidising bacteria	Organisms which oxidise reduced sulphur compounds such as hydrogen sulphide, inorganic sulphur and thiosulphate to sulphuric acid.
SYBR-Green	A dye which binds specifically to nucleic acids and can therefore be used to

© NMP 2014

GLOSSARY

Term	Definition
	quantify the amount of DNA in a sample.
Taxon (plural – taxa)	Any group of organisms considered to be sufficiently distinct from other such groups to be treated as a separate unit (e.g. species, genera, families).
Vario Elementar	An instrument used for the determination of organically and inorganically bound carbon and nitrogen solids.
WAVESMON	Data collection software which provides intuitive deployment planning, easy data collection, and complete processing displays from ADCP's.

Abbreviation	Definition
ADCP	Acoustic Doppler Current Profiler is a hydroacoustic current meter, similar to a sonar, measuring water current velocities over a depth range using the Doppler effect.
AVS	Acid volatile sulphides
BBL	Benthic boundary layer
BCC	Benguela Current Commission
CapFish	Capricorn Fisheries Monitoring cc.
cDNA	Complementary DNA which is used as a stable RNA analogue
Chl	Chlorophyll, the green pigment found in chloroplasts found in plants.
cm/s	centimetres per second
CPUE	Catch per unit effort
CRM	Certified reference materials are 'controls' or standards used to check the quality and metrological traceability of products, to validate analytical measurement methods, or for the calibration of instruments
CSIR	Council for Scientific and Industrial Research
CSS	Current shear stress
CTD	An instrument used to determine the Conductivity and Temperature seawater and to record the depth at which the measurements are made.
DNA	Deoxyribonucleic acid: Encodes genetic information in the form of genes. Found in the genome of organisms.
DO	Dissolved oxygen, a relative measure of the amount of oxygen that is dissolved in a given medium.
DOC	Dissolved organic carbon
EAF	Ecosystems approach to fisheries
EAFM	Ecosystem approach to fisheries management
EBM	Ecosystem based management
EEZ	Exclusive economic zone
EIA	Environmental Impact Assessment, a formal process used to predict the environmental consequences (positive or negative) of a plan, policy, programme or project.
EIA	Environmental impact assessment
EMP	Environmental management plan
EPA	The United States Environmental Protection Agency (EPA or sometimes USEPA) is an agency of the U.S. Federal Government which was created for the purpose of protecting human health and the environment by writing and enforcing regulations based on laws passed by Congress
ESACW	Eastern South Atlantic Central Water

© NMP 2014

GLOSSARY

Abbreviation	Definition
ESD	Equivalent spherical diameter
ETP	Endangered, threatened and protected
FIA	Flow injection analyser is an instrument used for the colorimetric determination of analytes such as nitrate, phosphate, ammonia and chloride.
GIS	Geographic information systems
GSI	Gonadosomatic index
ICP MS	Inductively coupled plasma mass spectrometry is an analytical technique used for the detection of trace metals were the inductively coupled plasma produces excited atoms, ions and isotopes with specific molecular masses which are measured with a mass spectrometer.
ICP OES	Inductively coupled plasma optical emission spectrometry is an analytical technique used for the detection of trace metals where the inductively coupled plasma produces excited atoms and ions that emit electromagnetic radiation at wavelengths characteristic of a particular element
ICSEAF	International Commission of the South-East Atlantic Fisheries
Ma	Megaannum one million (1,000,000) years
MET	Ministry of Environment and Tourism, Namibia
MFMR	Ministry of Fisheries and Marine Research, Namibia
ML 170	Mining licence 170, held by Namibian Marine Phosphate (Pty) Ltd
MLA	Mining licence area
MME	Ministry of Mines and Energy, Namibia
MSI	Metocean Services International, a company that provides an entire range of oceanographic and meteorological services to the offshore oil and gas market.
mV	Millivolts
NatMIRC	National Marine Information and Research Centre, Swakopmund, Namibia
NCEP	National Centre for Environmental Protection
NMP	Namibia Marine Phosphate (Pty) Ltd
NTU	Nephelometric Turbidity Units, unit in which turbidity is measured.
ODV	Software for the analysis and visualization of oceanographic, atmospheric and other geo-referenced profile or time-series data.
ORP	Oxidation-Reduction Potential
PEL	Probable effect level
POC	Particulate organic carbon, measured by high temperature combustion.
POM	Particle organic matter
PON	Particulate organic nitrogen, measured by high temperature combustion.
PSA	Particle size analysis is the collective name of the technical procedures, or laboratory techniques which determines the size range, and/or the average, or mean size of the particles in a powder or liquid sample
PSU	Practical Salinity Units, unit in which salinity is measured.
PUC	Poleward undercurrent
qPCR	Quantitative polymerase chain reaction (polymerase is the enzyme used to make more copies of the gene)
RNA	Ribonucleic acid: Since RNA is translated into a functional protein, analysis of RNA is more informative than analysis of DNA as it shows which genes are being actively expressed at any given time.
ROV	Remotely operated vehicle
SA	Swept area

© NMP 2014

GLOSSARY

Abbreviation	Definition
SACW	South Atlantic Central Water
SADCO	Southern African Data Centre for Oceanography, retrieves and manipulates multi-disciplinary marine information from the areas around southern Africa.
SAIEA	Southern African Institute for Environmental Assessment
SANAS	South African National Accreditation Service
SANUMARC	Sam Nujoma Marine and Coastal Resources Research Centre, Henties Bay Namibia
SEM	Simultaneously extracted metal
sp	Species
SP-1	Sandpiper-1
SP-2	Sandpiper-2
SP-3	Sandpiper-3
SS	Shear stress
SWAPELS	South West African Pelagic Egg and Larval Survey
TEL	Threshold effect level
TN	Total nitrogen
TSHD	Trailing Suction Hopper Dredger
TSS	Total suspended solids
UCCB	University Central Consulting Bureau, University of Namibia
UML	Upper mixed layer
UML	Upper mixed layer
UNAM	University of Namibia
UWC	University of Western Cape
Vbbl	Velocity of the benthic boundary layer
VP	Verification Programme

© NMP 2014









Sandpiper Project
Verification Programme

Volume 2: Appendices

Namibian Marine Phosphate (Pty) Ltd
Mining Licence Area No. 170

November 2014



J. Midgley and Associates

CSIR
our future through science

DISCLAIMER

This Verification Programme study was coordinated and prepared by J Midgley and Associates in accordance with reasonable professional standards and the terms of the contract agreed to between Namibian Marine Phosphate (Pty) Ltd and J Midgley and Associates.

J Midgley and Associates makes no warranties, express or implied, whether arising by operation of law, course of performance or dealing, custom, usage in the trade or profession or otherwise, including without limitation implied warranties.

The CSIR provided independent review and process quality control services to the Verification Programme study in accordance with reasonable professional standards and the terms of the contract agreed to between Namibian Marine Phosphate (Pty) Ltd and the CSIR.

The CSIR makes no warranties, express or implied, whether arising by operation of law, course of performance or dealing, custom, usage in the trade or profession or otherwise, including without limitation implied warranties.

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed "Attention: Administration Manager," at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

Sandpiper Project
Verification Programme

VOLUME 2: APPENDICES

Namibian Marine Phosphate (Pty) Ltd
Mining Licence Area No. 170

Application:

This report has been prepared to verify the findings of the NMP Final EIA (Midgley 2012), as submitted to the authorities (April 2012): Ministry of Environment and Tourism. The need for, and scope of, the Verification Programme was detailed in the EMP (Midgley 2012), The scope subsequently was expanded following consultations with MFMR, the Fishing Industry, and the NatMIRC scientists (2012 / 2013).

Report co-ordinated and prepared by:

Mr Jeremy Midgley Pr.Sci.Nat
J. Midgley & Associates
PO Box 110
Constantia 7806
South Africa
Email: mwjmidg@mweb.co.za

Independent Programme Reviewer and Process Quality Controller:

Mr Patrick Morant Pr.Sci.Nat
CSIR
PO Box 320
Stellenbosch 7599
South Africa
Email: pmorant@csir.co.za



November 2014

© NMP 2014

Contents

SECTION D: APPENDICES

1.0 Water Column and Sedimentary Environment

1.1: Project Execution Plan: Verification Survey MV *DP Star*
1.2: Cruise Report: Verification Survey MV *DP Star*
1.3: Project Execution Plan: Thiobacteria Survey MV *Snowgoose*
1.4: Cruise Report: Thiobacteria Survey MV *Snowgoose*
1.5: Project Execution Plan: Core sampling MV *Snowgoose*
1.6: Gravity Core: Analysis requirements
1.7: Cruise Report: Core Sampling MV *Snowgoose*
1.8: MSI Instrument Mooring Report: Day 0 to 45
1.9: MSI Instrument Mooring Report: Day 45 to 90
1.10: CSIR Chemical Analysis Method Statement

2.0 Fisheries and Biodiversity

2.1: PEP Biodiversity Survey FV *Zeerarend*
2.2: Cruise Report Biodiversity Survey FV *Zeearend*
2.3: CTD Deployment Report FV *Zeearend*
2.4: Sailing Orders Biodiversity Survey FV *Zeearend*
2.5: Biodiversity Induction Module FV *Zeearend*

3.0 Geophysics

3.1: Geophysical Processing Procedures
3.2: Geophysical Habitat Mapping

4.0 Process Documentation

4.1: Verification Project Timelines
4.2: MFMR Response to the 2012 EIA
4.3: Final Scope of the Verification Programme submitted to the Authorities

5.0 Curricula vitae and Terms of Reference

5.1: Curricula vitae
5.2: Terms of Reference

6.0 Dredging Project Description

6.1: Dredging Operations

© NMP 2014

SANDPIPER PROJECT

Verification Programme Report: Mining Licence Area No. 170

SECTION D : APPENDICES

APPENDIX 1: Water Column and Sedimentary Environment
APPENDIX 2: Fisheries and Biodiversity
APPENDIX 3: Geophysics
APPENDIX 4: Process Documentation
APPENDIX 5: Curricula Vitae and Terms of Reference
APPENDIX 6: Dredging Project Description

SANDPIPER PROJECT

Verification Programme Report:
Mining Licence Area No. 170

SECTION D : APPENDICES

APPENDIX 1

Water Column and Sedimentary Environment

1.1: Project Execution Plan: Verification Survey MV *DP Star*
1.2: Cruise Report: Verification Survey MV *DP Star*
1.3: Project Execution Plan: Thiobacteria Survey MV *Snowgoose*
1.4: Cruise Report: Thiobacteria Survey MV *Snowgoose*
1.5: Project Execution Plan: Core sampling MV *Snowgoose*
1.6: Gravity Core: Analysis requirements
1.7: Cruise Report: Core Sampling MV *Snowgoose*
1.8: MSI Instrument Mooring Report: Day 0 to 45
1.9: MSI Instrument Mooring Report: Day 45 to 90
1.10: CSIR Chemical Analysis Method Statement

APPENDIX 1 - WATER COLUMN AND SEDIMENTARY ENVIRONMENT

1.1 Project Execution Plan: Verification Survey MV *DP Star*

NAMIBIAN MARINE PHOSPHATE

VERIFICATION SURVEY

WATER COLUMN AND SEDIMENTS

PROJECT EXECUTION PLAN

Prepared for:
Namibian Marine Phosphate (Pty) Ltd.

Prepared by:
Lwandle Technologies (Pty) Ltd.
Report compiled by Kate Munnik and Robin Carter



08 March 2013

Job no: 13-149

LWANDLE TECHNOLOGIES (PTY) LTD
The Old Warehouse, Black River Park, Fir Road, Observatory 7925, South Africa
Directors: C.P. Matthysen, B.J. Spolander
Co Reg. No. 2003/015524/07

MARINE SPECIALIST TEAM

Robin Carter – Lwandle Technologies, Cape Town
Kate Munnik – Lwandle Technologies, Cape Town
Timothy Mc Clurg - Lwandle Technologies, Cape Town
Andrew Russell - Lwandle Technologies, Cape Town
Henry Gilham - Lwandle Technologies, Cape Town
Sannette Gildenhuys- Metocean Services International, Cape Town

Date	Version	Revised	Reviewed
21/01/13	0.1		Robin Carter
14/07/2013	1.0	Kate Munnik	Robin Carter
17/07/2013	1.5	Kate Munnik	Robin Carter
19/07/13	2.1	Kate Munnik	Robin Carter

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed “Attention: Administration Manager,” at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

contents

1 PURPOSE AND SCOPE 1

2 WORK PROCEDURE 7

2.1 SURFICIAL SEDIMENT AND WATER COLUMN FEATURES 7

2.1.1 Installation and Sampling 7
2.1.2 Sediment Properties 7
2.1.3 Water Column Properties 11
2.1.4 Water column properties-temporal variability 14

3 SAMPLE PRESERVATION AND CURATION 15

4 SAMPLING ANALYSIS 16

5 HEALTH AND SAFETY 16

5.1 PERSONAL PROTECTIVE EQUIPMENT 16
5.2 WORK ON DECK 16
5.3 RISK ANALYSIS 17
5.4 EMERGENCY PROCEDURES AND CONTACT NUMBERS 19

ANNEXURE 1: SHIP REQUIREMENTS FOR SAMPLES AND THEIR STORAGE 21
ANNEXURE 2: EQUIPMENT LIST 22
ANNEXURE 3: DATA SHEETS 23

figures

Figure 1-1: Location of Mining Licence Area (MLA) 170 offshore central Namibia. MLA 170 is a consolidation of EPLs 3414 and portions of EPLs 3323 & 3415. 2
Figure 1-2: Location of the proposed target dredging sites SP-1 (20 year mine plan established), SP-2 and SP-3 within the three resource areas of the ML 170 mineral resource. 3
Figure 1-3 : Verification sampling sites in Mine Area SP-1. 4
Figure 1-4: The verification sites for SP-2. 5
Figure 1-5: The verification sites in SP-3. 6
Figure 5-1: Risk factor table taken from OGP *HS&E Guidelines for Metocean Surveys*. 17

© NMP 2014

tables

Table 5-1: RA for the mobilisation of equipment and loading of ship 18
Table 5-2: RA for work on vessel deck 18
Table 5-3: RA for the handling and analysis of sediment samples 18
Table 5-4: RA for the deployment and recovery of Rosette and CTD 19
Table 5-5: RA for the packaging and unloading of samples 19
Table 5-6: Emergency contact details: 19

© NMP 2014

1 PURPOSE AND SCOPE

Namibian Marine Phosphate (NMP) is proposing to extract marine pelletal phosphate ore from deposits on the Namibian continental shelf. The phosphate will be extracted by dredging and the assessment of the environmental impacts associated with the project is therefore strongly reliant on a sound understanding of the sediment properties of the dredge area. The purpose of this verification survey is to confirm the sediment properties, water quality and local oceanographic processes of the seafloor and water column within the proposed dredge area. This information will then be used, in conjunction with previous scientific investigations of the region, to further inform the assessment of impacts on the marine environment as a result of the proposed dredging operations. This will aid in the final assessment of the impacts as detailed in the EIA / EMPR.

The survey will include the collection of seafloor sediments, macrobenthos and meiofauna using sediment sampling devices such as a box core or a Day grab (where seabed properties prevent or limit efficient use of the box core). Water column features will be measured via profiling using a CTD, with additional sensors, and water sampling at various intervals down the water column to provide samples for chemical analyses.

A previously deployed fixed mooring, providing time series data of current speeds and water column dynamics, will also be serviced during this cruise.

The focused survey area is defined as mine area SP-1, which is within MLA 170 (Figure 1-1), and is situated south west of Walvis Bay, directly offshore of Conception Bay and Meob Bay. The Sandpiper Phosphate licence area (MLA 170) includes mine target areas; SP-1, SP-2 and SP-3 (Figure 1-2). SP-1, where the verification survey will take place, is the primary dredging target area of the project (a 20 year mine plan is established for this site), while the dredging of SP-2 and SP-3 will take place subsequently.

© NMP 2014

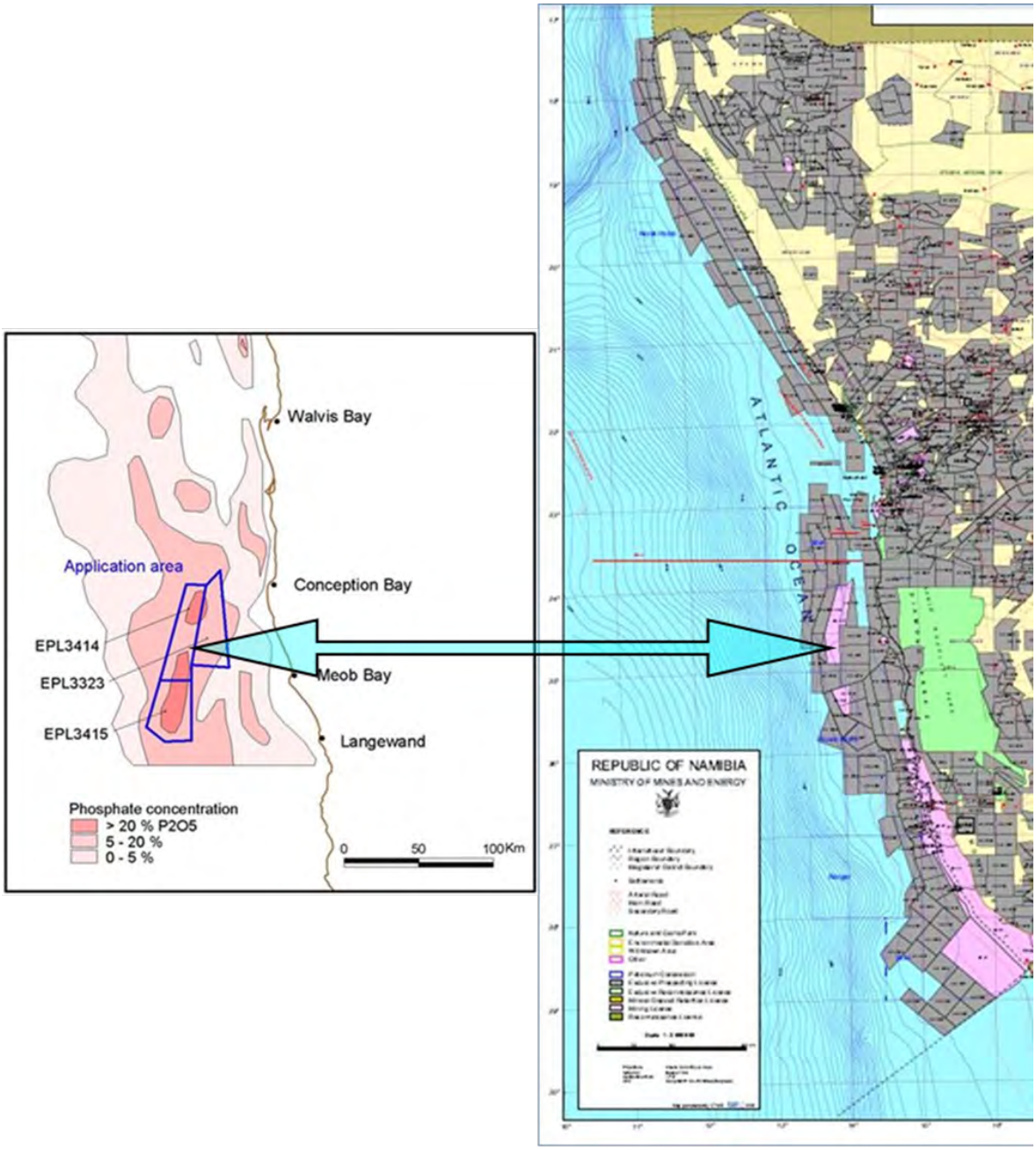


Figure 1-1: Location of Mining Licence Area (MLA) 170 offshore central Namibia. MLA 170 is a consolidation of EPLs 3414 and portions of EPLs 3323 & 3415.

© NMP 2014

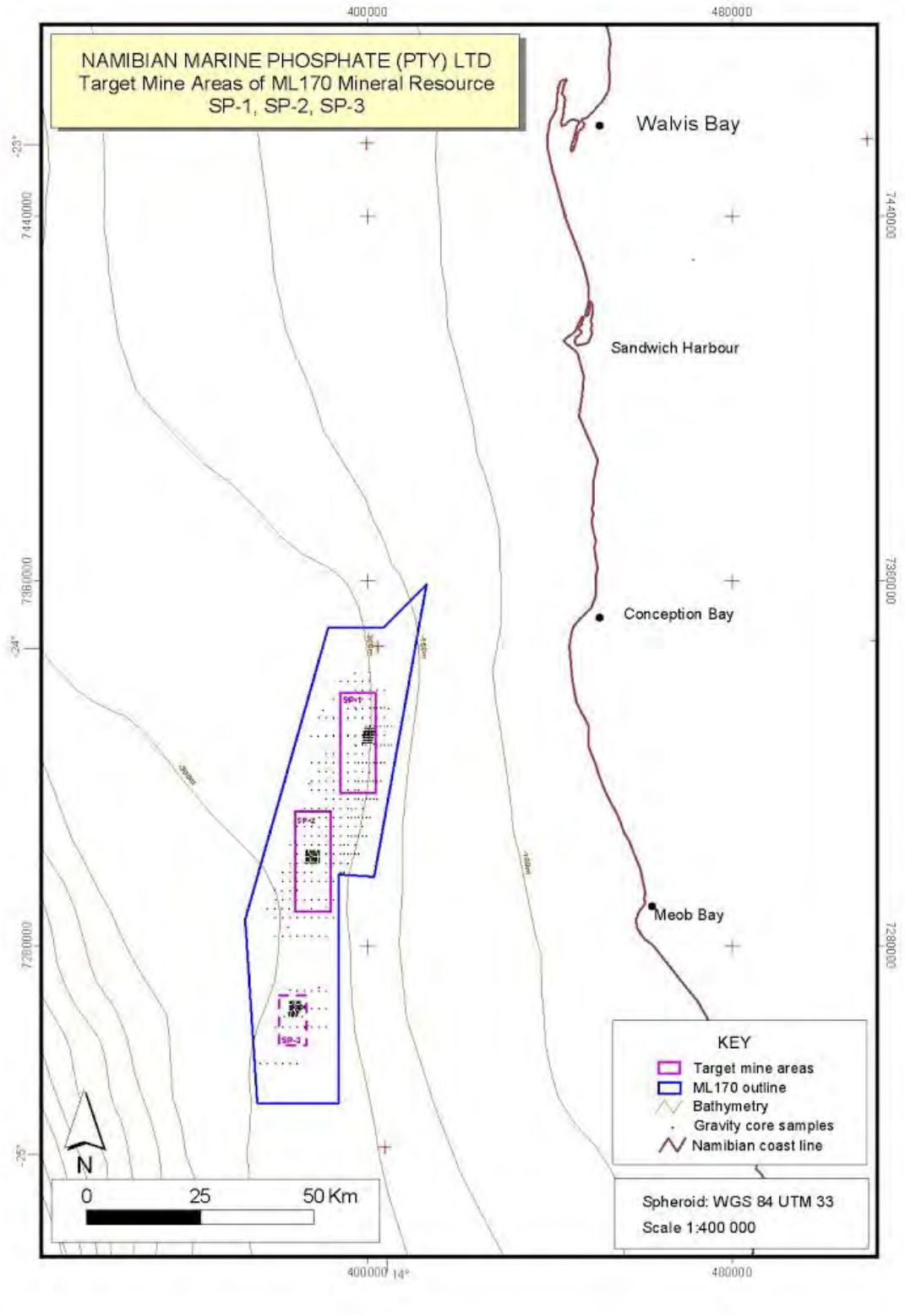


Figure 1-2: Location of the proposed target dredging sites SP-1 (20 year mine plan established), SP-2 and SP-3 within the three resource areas of the ML 170 mineral resource.

© NMP 2014

Sampling procedures for this verification survey will involve sampling of the water column, sediments and benthos (for a companion investigation) in the mining licence area. A grid of sampling sites will be placed across SP-1 such that the broad distributions of sediment properties across the entire mine site can be determined. Figure 1-3 shows the sampling station layout. The location of the oceanographic mooring that is to be serviced during the survey is also shown.

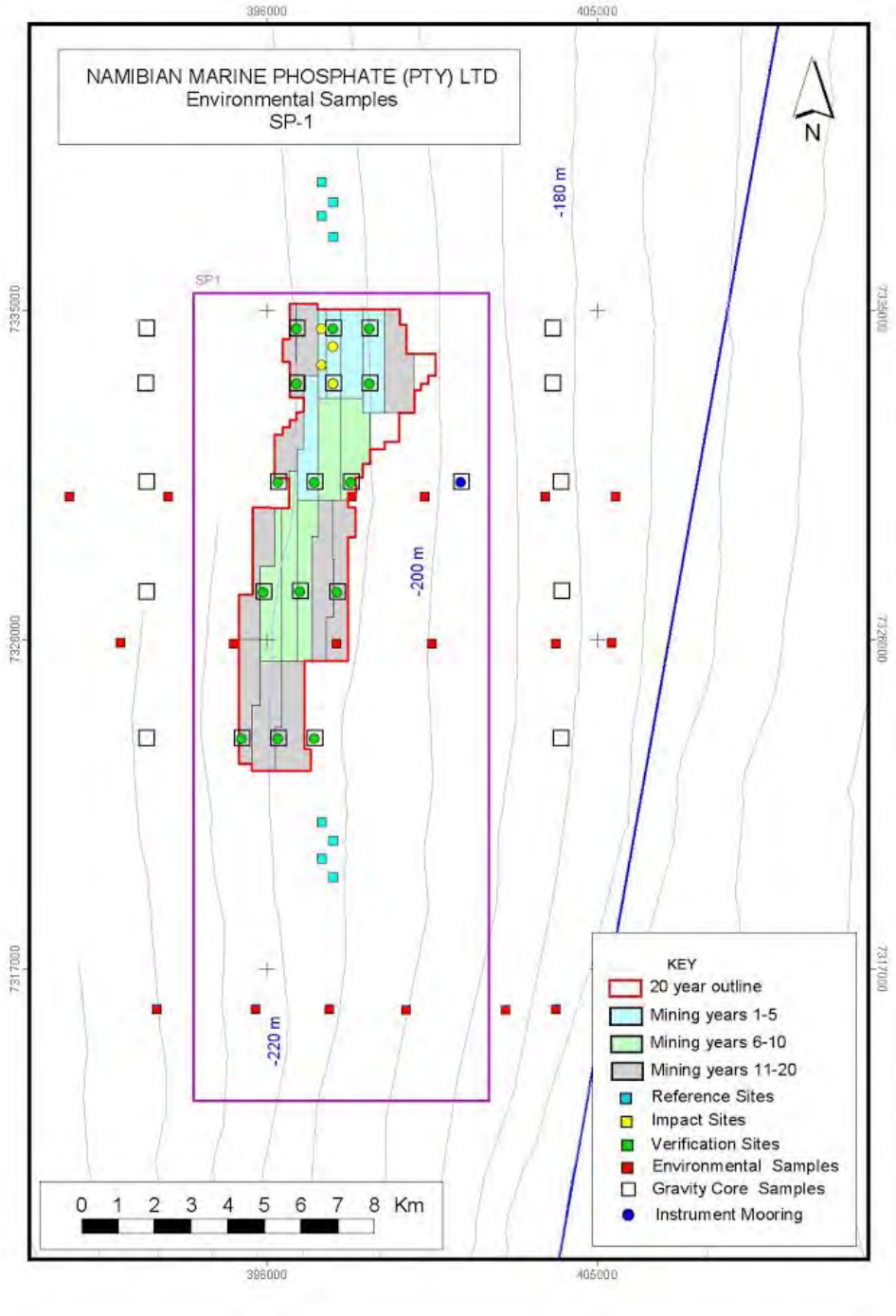


Figure 1-3 : Verification sampling sites in Mine Area SP-1.

Note that the verification survey sites are represented by black open squares. Green squares represent sites identified for benthos verification sampling (Steffani); additional sampling sites for the macrobenthos, meiofauna and sediment properties monitoring programme are shown in yellow (impact) and blue (reference). The blue square shows the provisional moored instrumentation site.

© NMP 2014

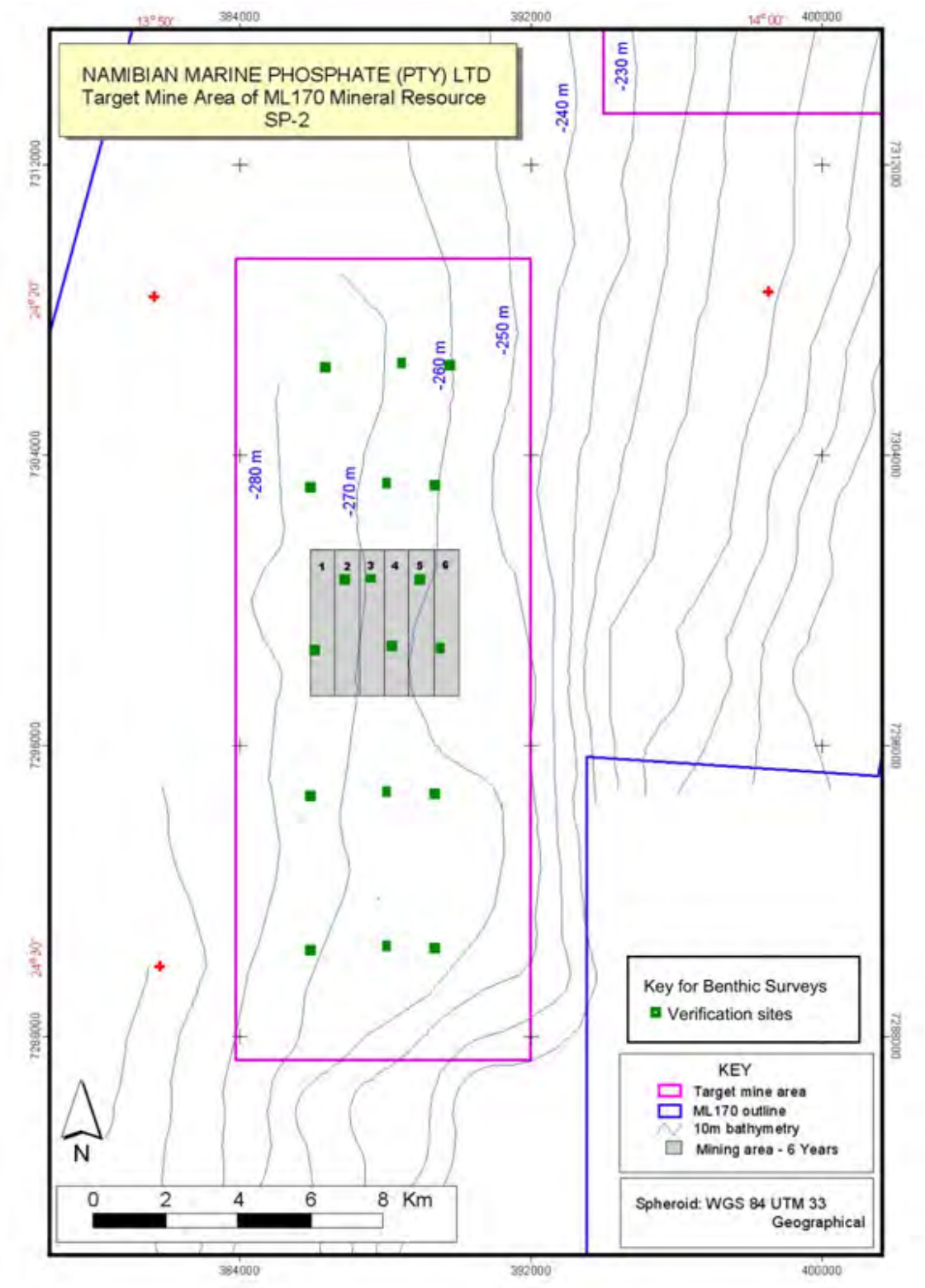


Figure 1-4: The verification sites for SP-2.

© NMP 2014

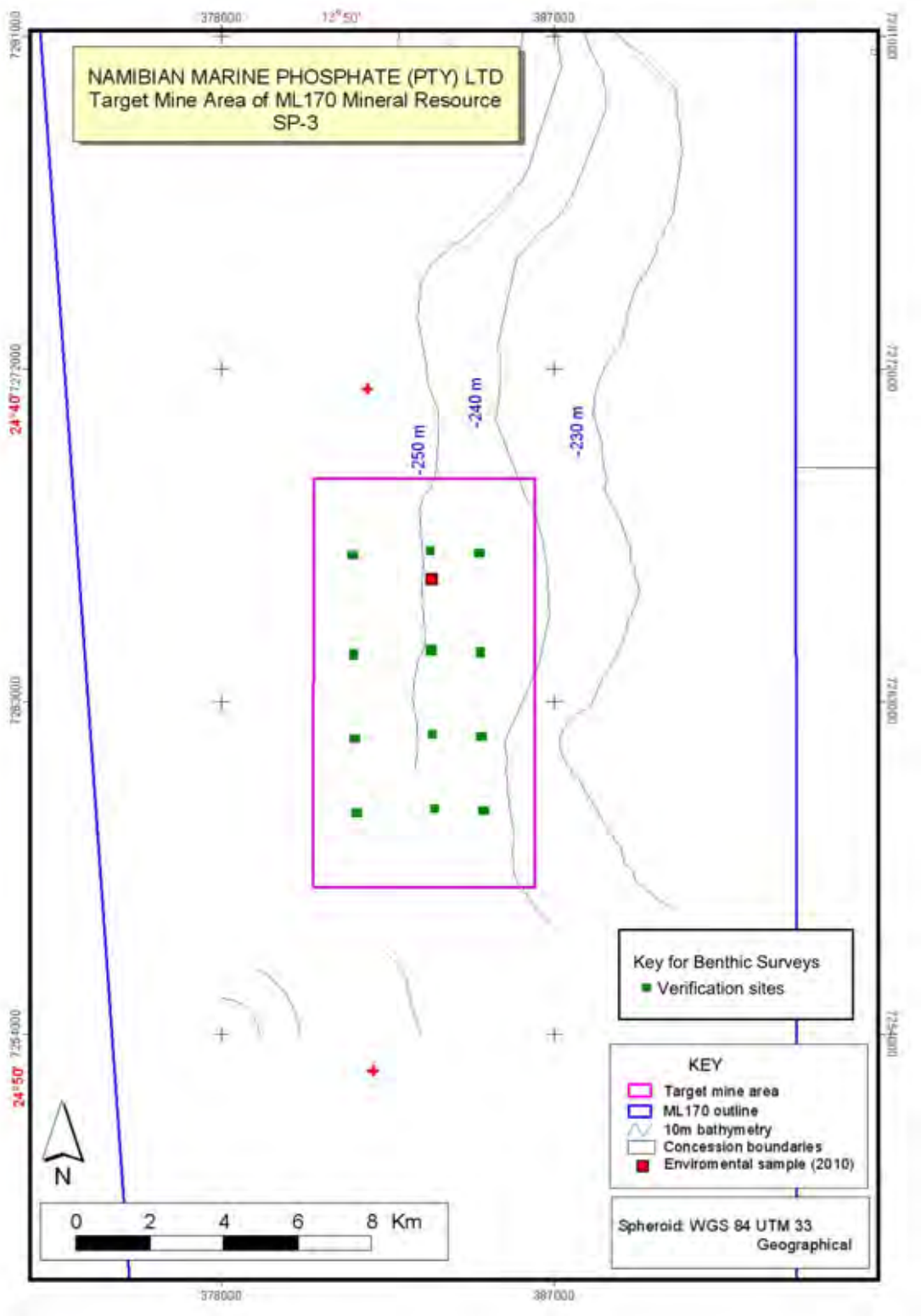


Figure 1-5: The verification sites in SP-3.

2 WORK PROCEDURE

2.1 SURFICIAL SEDIMENT AND WATER COLUMN FEATURES

Equipment and personnel will be mobilised to the port of embarkation (Walvis Bay). Following loading of the survey vessel, equipment will be carefully unpacked and assembled. Electronic equipment will be powered up and tested to determine whether any breakages have occurred during transit. Repairs or replacements will be made if and where necessary.

2.1.1 Installation and Sampling

Prior to the vessel steaming to the survey area, a test run of the sediment and water column sampling procedures will be carried out in Walvis Bay. This will involve a run through of all the procedures outlined below. After the test deployment of the relevant equipment, the data will be downloaded and quality checked. At this stage any problems that may have emerged during the sampling procedures or with the quality of the captured data can be resolved through adjustments to the instrumentation or the deployment procedures. Should any changes to the deployment procedures be necessary, they must be noted in detail and the procedures described below should be amended accordingly.

The sampling procedures must be explained to the scientific team and the crew that will be involved before the test run commences and each participant should understand their roles and responsibilities during the sampling activities. The importance of following these procedures and of maintaining the integrity of all samples collected during the survey must be emphasised. The importance of ensuring that all work areas are kept clean free from any oil/grease contamination should too be made clear.

The following procedures are to be followed during the deployment and recovery of the sampling equipment at the various stations:

2.1.2 Sediment Properties

Once the captain/party chief is happy with the position of the vessel, the deployment of the sampling equipment can begin. The vessel should be at least within 150 m of the relevant sampling location before commencing with the sampling procedure. Note: The vessel must be within 50 m of the four Impact sites. One of the field team can also take a GPS reading/drop a way point to ensure the correct position is recorded.

A Box core (GOMEX) will be used to sample surficial sediments for particle size and texture, chemical properties, macrobenthos and meiofauna. In total, 26 verification box core samples will be undertaken. These will be collected in a configuration of 5 transects of 5 stations each (Figure 1-3) and an additional box core sample will be carried out at the site of the mooring deployment. 12 Monitoring sites (reference and impact sites) will also be sampled during the verification survey; these are situated to the north (reference), middle (impact) and south (reference) of the 20 year mining outline. At each of these monitoring sites 5 replicate samples will be collected, using the same methodology as will be used for the verification sites. Sampling at SP-2 and SP-3 will take place upon completion of the collection of SP-1 samples. Subsamples from each box core retrieval will be collected for meiofauna analysis as well as the analysis of sediment particle size, heavy metals, AVS and SEM, organic C and N content. At all of the verification sites located within the 20-year mining

area as well as for the 12 benthos monitoring sites, subsamples of sediment will also be sieved for the collection of benthos. As stated above at the 12 monitoring sites 5 replicate box core samples are to be taken and processed.

Deployment:

- The box corer will be deployed with assistance from the ship's crew after extensive explanation and demonstration as well as the trial run in Walvis Bay.
- Preparing the corer:
    - Fit the weights to the frame
    - Securely attach the corer to the winch cable with the safety locking pins in place, 2nd party to check attachment.
    - Remove the locking pins and 'load' the box core. For this the spade and/or flaps need to be placed in the 'open/cocked' position. To do this the lower release hook must be rotated down to the tripped position. This will allow the locking tabs to be slid into position; the lower release hook can then be rotated back into the cocked position. The spade and the flaps will now be secured in the open position. The lower and upper release hooks must then be joined. Tension can then be applied by the winch to hooks, and the corer is raised in the cocked position **NOTE: Do not place your fingers inside of the sampling box when loading the spade or flaps, or once they are in the 'open/cocked' position, as this may cause serious injury.** Replace the safety locking pin.
    - Tension must be kept on the release hooks to ensure the corer does not trip.
- Once the ship has been correctly positioned for deployment, disengage the safety locking pin and hoist the corer over the gunwale of the vessel and slowly lower through the water surface (too rapid a lowering may prematurely fire the sampler).
- The box core is then lowered to the seafloor at approx. 0.5 m/sec.
- The sample box of the corer will penetrate the sediment under its own weight (plus the added weights).
- As the corer is pulled out of the sediment the spade will swing below the sample to secure it in the sample box.
- Weighted flaps above the box will also be released and will enclose the box ensuring the sample is protected during recovery.
- The corer is then winched back up towards the vessel, also at a constant speed.
- Once out of the water, the corer is lowered gently into its stand on the deck, and safely secured (including safety locking pins).
- The box core is then prepared for sample extraction with the upper flaps being opened, the sub-cores for sediment property and chemical analyses are then inserted. It is important that this is done while wearing gloves (nitrile gloves) to ensure minimum contamination of the sample.

If this set-up (using the Box corer) fails twice, the Day Grab will need to be deployed instead. The deployment of the Box corer will be considered a failure if it contains less than 20 cm of sediment (approx. 40%) (i.e. if there are less than 12.5 litres of sediment retrieved in the box). For this deployment the following procedures need to be followed (the sample collection procedures will remain the same):

- The Day grab will be deployed with assistance from the ship's crew after extensive explanation and demonstration as well as the trial run.
- Preparing the grab:

© NMP 2014

  - With the grab firmly located on its support stand, and with the 'jaws' in a closed position, firm attachment is made to the winch cable. A second party must verify that the attachment is firm.
  - The grab is loaded by lifting the two 'landing pads' and manually opening the two 'jaws' to their full extent. At this point the release bar may be slotted between the two retaining lugs attached to the 'jaws'. Once the release bar is securely retained by the lugs, upward pressure on the 'landing pads' may be released. Loading requires the coordinated effort of three people, two to apply upward pressure on the 'landing pads' and the third to secure the release bar in position. **Care must be taken to keep fingers away from the cutting edge of the 'jaws' as premature closing may cause serious injury.** The grab is now ready to be deployed.
- Once the ship has been correctly positioned for deployment, the grab is hoisted over the gunwale of the vessel and slowly lowered to the water surface (rapid lowering may prematurely trigger the grab).
- The grab is then lowered to the seafloor at approx. 0.5 m/sec.
- The jaws of the grab will be released as the 'landing pads' make contact with the seabed. Subsequent lifting of the weighted rig will result in their firm closure around a portion of sediment.
- The full grab is then winched back to the vessel at a constant speed.
- Once out of the water, the grab is lowered gently into its stand on the deck and safely secured.

Sample collection:

- Photographs and observations:
  - Add detailed label (date, time, site number) and scale object and photograph sediment in sample box. Record the photograph number on the data sheet.
  - Measure the volume of sediment in the corer using a stainless steel rule, and noting the distance between the top of the grab and the surface of the sediment. If <0.4 full, the box core will need to be redeployed. If there are 2 'failures' then change over to the Day grab for sampling.
  - Classify the sediment in broad texture gradings: mud, muddy sand, fine sand, medium sand, coarse sand, gravel. Note whether shells/shell fragments are present.
  - Check whether H_2S is present (odour).
  - Determine the amount of surface bioturbation (biological activity).
  - Record water depth and sample site location as obtained from the vessel DGPS and echo sounder
- Chemical samples:
  - Try to disturb the sediment sample structure as little as possible during this process
  - For each sample CLEARLY label the container (bottle/bag) with the station number, date and time.
  - For each sample record the type of sub-corer used (diameter and length) as well as the number of cores required to obtain the correct volume.
  - Extract approx. 750 ml of sediment using a plastic ladle/a 50 mm sub-core with a hole in the side (that has been covered with tape):
    - After retrieving the sub-core remove the tape and insert the modified syringe. Using the syringe, extract a horizontal sub-core. This sediment can then be discarded.

© NMP 2014

        - Next, place the ORP probe into the 'hole' left by the syringe, being careful not to damage the platinum point.
        - The edge of the 'hole' should then be covered with silicone grease/similar to prevent any air from entering into the extracted area.
        - Once the ORP reading has stabilized, it must be recorded in the relevant section of the datasheet.
        - After this, the remainder of the sediment in the plastic sub-core must be placed into a labelled plastic bag for particle size and metal analysis. A label must be written on the outside of the bag with a permanent marker (as well as with pencil on a piece of water proof paper placed inside the bag).
    - Using a stainless steel spatula/ a 50 mm sub-core, extract approx. 250 ml sediment and place into a labelled glass bottle, with sufficient head space for freezing.
    - The spatulas must be rinsed in clean with seawater between each sample extraction.
- Sample storage:
    - Plastic bags: samples to be placed as soon as possible, and in an ordered manner, into the freezer.
    - Glass bottles: samples are to be placed into the freezer (also in an ordered manner) as soon as possible.
- Biological sampling:
    - Samples for macrofauna and meiofauna are to be extracted.
    - For the macrofauna samples: These samples are to be collected at the monitoring sites (impact and reference sites) as well as at the verification sites within the 20 year mining licence. The verification sites not identified for benthos sampling (green squares in Figure 1-3) will only have chemical samples collected from them.
    - Place the large sub-corers, 6 in total to collect approx. 5 ℓ of sediment (probably easier if this is done one at a time) into the box core and place the rubber stopper over the protruding ends, this should create enough of a vacuum for the sub-cores to be extracted from the box corer with the sediment remaining inside the pipe.
    - Place the extracted sediment into a 5 litre bucket, and record the number and type of plastic sub-corers used to obtain 5 litres.
    - Next place the sediment into the Wilson's autosiever using the 300 micron screen, with the additional approx. 3 000 micron screen on the top of the 'stack'. The extra sieve is to be used to prevent shell clogging the 300 micron screen. It is important to check that the shell material caught in the 3 000 micron sieve is cleared of all macrofauna through assiduous rinsing with seawater.
    - It is probably best to add sediment gradually to the siever whilst it is running to prevent clogging of screen. If necessary, as it may be with mud samples, place the lid on the sieve and increase water supply rate to speed up sieving process.
    - Label a plastic snap-on lid container (800 ml) as well as a sheet of waterproof paper with station number, date and time.
    - The benthos and remaining sediment must then be washed carefully into the 800 ml labelled plastic container. Allow the sample to settle and drain off excess water, until at least a 1 cm deep layer of water is visible above the fauna/sediment collected at the base of the container. Estimate total volume (nearest 100 ml). Where required by the retained volume of sediment, use additional 800 ml sample containers.
    - Add neutralized formalin as per instructions below.
- For the meiofauna samples: Place one of the smaller (50 mm) sub-cores into the box corer on the same side as was used for the extraction of samples for chemical analyses.

© NMP 2014

- Insert corer vertically to a depth of 10.0 cm (this will give a total sediment volume of 200 ml when using the 50 mm diameter piping). Remove core sample. This can usually be achieved by gently angling the corer to 45° and lifting. If, however, the sediment is particularly soft or "clayey" it may be necessary to excavating substrate from beside the corer and place a gloved hand underneath the base of the corer before lifting.
- Transfer into a 500 ml plastic screw top container ensuring that all sediment is removed from the corer. If necessary, remove sediment from the corer using a plastic spatula. Particular care should be given to the surface layers of substrate as significant numbers of meiofauna are present in the top 2.0 cm.
- Ensure that there is 1-2 cm of supernatant water in the jar.
- Label the jar, lid and sample label (waterproof paper) with station number, date and time. Preserve the sample with 4% neutralised formalin as below and store.

- Formalin (for both meiofauna and macrofauna):
  - An equal volume of formalin needs to be added to the sample (i.e. if the sample volume is 200 ml, add 200 ml formalin)
  - Formalin concentration should be approx. 8 % (dilution factor of 5 x concentrated neutralised formalin). This will achieve a 4 % final concentration.
- Storage:
  - Clear any grit/sediment from around the pot thread and seal tightly. Mix fully by inverting the container several times – particularly important with fine-grained/muddy sediments as fixative may not reach materials present at the base of the container.
  - Place the 800 ml and 500 ml containers, upright, into a plastic sample bin/crate.

Decontamination

- Before and between deployments, box core and all sample collecting instruments must be washed down with seawater and this should be recorded on the log.

2.1.3 Water Column Properties

A Multi-probe internal logging CTD and rosette sampler will be lowered through the water column to within 5 m of the seafloor. The CTD will be fitted with temperature, conductivity, dissolved oxygen, chlorophyll fluorescence, pH, light (PAR) and turbidity sensors. The rosette sampler will be made up of 5 Niskin sampling bottles. CTD profiling and water quality sampling will be carried out at one site on each of the 5 transects; one of these will be the mooring location. Sampling will be carried out at depths of 0 m (independently of the rosette), 10 m, 20 m, 50 m, 100 m, and approx. 200 m.
Deployment:

- Prior to deployment:
  - Turn on the CTD and additional probes, ensure they are clean and unobstructed (remove caps) and in working order.
  - Set the CTD for continuous logging at 6 Hz frequency (using previously installed Ruskin software), ensure all previous data stored on the CTD logger has been downloaded and is cleared. Complete a CTD deployment sheet and ensure to save a copy (print screen) of the logger configuration.
  - Insert batteries and pre-programme the rosette sampler to fire at the selected depths (10 m, 20 m, 50 m, 100 m, approx. 200 m). This is done using previously installed Oceanlab software, with a PC connected to the motor unit of the rosette sampler (via a programming cable).

© NMP 2014

- Once the rosette sampler has been programmed, disconnect the programming cable, and ready the Niskin bottles for sampling.
- Ensure the Niskin bottles are in the correct firing position, and there are no obstacles preventing the caps from closing properly.
- Switch ON the motor unit of the rosette sampler.
- Attach the CTD/rosette to that deployment wire, 2nd party to check secure attachment.
- If the rosette sampler fails, individual Niskin bottles will need to be lowered over the gunwale manually and fired using a messenger (as explained below)
- *Only in the event of the rosette sampler failing and for the surface (actually 0.5 m depth) sample:*
  - *Check that the messenger operates correctly on the available winch cable, if not; a rope can be used and the Niskin bottle lowered by hand. Check that the rope is compatible with the messenger.*
  - *Ensure the Niskin bottle is in the firing position.*
  - *Suspend the Niskin bottle from the winch cable with a weight attached (to keep the bottle vertical).*
  - *Take samples at the appropriate depths, in this case it will be important to confirm the depth levels are accurate. [If a rope is used instead of a winch cable, samples will be collected at 10 m, 20 m, 30 m, 50 m, and 100 m].*
  - *Retrieve Niskin bottle and continue with sample collection as below.*

- Rosette sampler (CTD and Niskin bottles) will be lowered into the water column using a davit arm/A frame and winch, operated by the ship's crew. The field team will need to monitor the depth of the rosette sampler using the echo sounder and associated sonar bell device.
- The transducer for the echosounder will need to be secured to the gunwale of the boat. After which the echosounder can be turned on and an accurate reading from the sonar bell should be provided once the rosette sample is submerged in the water.
- Probe equilibration:
  - Hold CTD at 3 m depth (or deeper if ship is rolling) for approximately 2 minutes.
  - Bring the CTD back up to the immediate subsurface (<u>without</u> exposing the probes to air; this is important as air exposure will require re-equilibration).
- Pay out the CTD at a constant speed of approx. 0.5 m/sec or less to a depth of approx. 200 m (or a depth that is slightly deeper than the trigger depth defined in the pre-programming of the rosette sampler).
- As the rosette sampler passes the prescribed 'unlocking' pressure, an instruction needs to be passed to the winch operator to stop the winch, and begin with a slow and steady retrieval of the sampler.

© NMP 2014

Recovery:

- Recover to the ship at a similar rate as per deployment. The Niskin bottles will be triggered by the rosette's motor unit on arrival at the specified depth's during the recovery.
- Once on deck, secure rosette sampler and detach the rosette sampler and CTD from winch wire.
- Ensure the motor unit of the rosette sampler is switched off.

Sample collection (to be carried out on all bottles including the surface bottle):

- DO & pH calibration checks (all sampled depths)
    - Fit the provided silicone tubing to the bottom tap of the Niskin bottle.
    - Place the calibrated dioptode probe into the measuring container.
    - Open the tap and fill the container with water from the Niskin bottle, until it is slowly over-flowing over the edges of the container.
    - Switch on dioptode probe and record reading
    - Remove the dioptode probe and replace with the calibrated solid state pH and associated temperature probe.
    - Switch on and record readings.
    - Remember to leave enough water inside of the Niskins for the rest of the sample collection.
- Water sampling (all sampled depths)
    - Label each plastic and glass bottle with the station number, date and time
    - Before taking the remainder of the water samples, mix up the water in the Niskins by carefully tipping the rosette sampling unit from side to side.
    - Next rinse out a labeled 1 litre plastic bottle with the sampled water (ie water from inside the Niskin that you are sampling from), and then fill it.
    - This bottle can then be stored in a black crate, out of direct sunlight.
    - After this (i.e. each closed Niskin) fill a 150 ml plastic bottle and 250 ml glass bottle (both labelled). Ensure each sample bottle is thoroughly rinsed with water from the associated Niskin before filling with sampled water.
    - Ensure there is enough headspace for freezing both the glass and plastic sampling bottles.
    - Surgical gloves should be worn to avoid sample contamination.
    - Store the 250 ml glass bottle and 150 ml plastic bottle upright in a freezer
    - Complete log sheets
- CTD and rosette data downloads:
    - Ensure that the CTD and Rosette are clean and dry and that there is no dripping water or seawater that may fall onto the electronics.
    - For the CTD: Open the CTD and terminate logging.
        - Download and conduct visual checks on the measured data. Check for abnormalities or data gaps.
        - Store data, if it's OK and clear memory, put caps back on sensors and store in a safe place.
        - If the CTD will not be used again for an extended period, remove the batteries from the logger.
    - For the rosette: Unplug the dummy plug from the top of the motor unit
        - Attach the PC cable to the plug, and the other end into the serial port/adapter of the laptop.

© NMP 2014

- Open Oceanlab on the laptop and then turn ON the motor unit.
- Download the latest data file and save to the laptop once the file has been checked for abnormalities.

As with the CTD, if the motor unit is not going to be used again for an extended period, remove the batteries from the battery canister.

Analyses

- Analyses of the water samples will be conducted under subcontract by CSIR using their published methods according to SANAS. The variables to be analysed for include:
  - Total suspended solids (primarily for in-situ calibration of CTD turbidity (OBS) sensor
  - Particulate organic matter
  - Dissolved organic carbon
  - Heavy metal concentrations

2.1.4 Water column properties-temporal variability

This sampling equipment includes the following:

- Near seabed mooring for near seabed temperature, dissolved oxygen, turbidity and high frequency current measurements.
- Midwater mooring for high frequency currents and upper water column turbidity measurements (ADCP beam attenuation).

A mooring has been designed (in accordance with the above) and deployed by Metocean Services International (MSI) and will be serviced during the verification survey. Method statements are to be provided by MSI.

© NMP 2014

3 SAMPLE PRESERVATION AND CURATION

The preservation and curation of all samples collected while on board the research vessel will be the responsibility of the Lwandle scientific crew carrying out each activity with the assistance of the ship's crew. It is very important that the samples are preserved and stored correctly to avoid any loss of data while the vessel is underway, or during transportation back to South Africa.

All permissions, authorisations and permits required for transporting the chemical/biological samples any associated sampling equipment back into South Africa will need to be organized by NMP.

On board:

- All sample containers to be clearly labelled with the relevant station number, date etc. This information is to match that in the sample record data sheets.
- Check sample conditions in fridge and freezer daily. Ensure power connection to all fridges / freezers containing samples remains stable.
- Check integrity of biological samples daily (i.e. no leaks/drying etc.).

During transport back to South Africa:

- Water and sediment samples
    - Ensure sufficiently inert packing material to safeguard samples and increase insulation.
    - Add an operating temperature logging device (TidBit) to each of the freezers.
    - Use the strapping provided to keep boxes tightly closed.
    - Clearly label the cool boxes/freezers with number and type of samples and destination.
    - These samples must be transported back to South Africa overland via Swift Air or other courier to be arranged by the client.
- Benthos
    - Ensure that the biological sample containers are tightly sealed and are stored upright.
    - Use inert packing material to add support to containers.
    - Seal the lid of the sample crate with cable ties.
    - Clearly label the crates with number and type of samples and destination.
    - Samples are to be transported back to RSA by road (courier service).
- Data
    - After each CTD and rosette deployment download data and store copies on laptop and portable hard drive.
    - Carry laptop and portable hard drive separately when travelling.
- Gear
    - Repack all into the crates that they were delivered in. Ensure that these are numbered and have inventory lists with them. Also ensure that Lwandle stickers/address markers are clearly evident.

© NMP 2014

4 SAMPLING ANALYSIS

Sediment samples will then be analysed back in Cape Town, the following analyses will be carried out:

- Organic content, POC and PON concentrations;
- Heavy metal concentrations;
- AVS and SEM;
- ORP.

5 HEALTH AND SAFETY

Jeremy Midgley (for NMP) will be responsible for the overseeing of health and safety aspects for the duration of the trip.

5.1 PERSONAL PROTECTIVE EQUIPMENT

Personal protective equipment (PPE) must be worn on the vessel as directed by the vessel master.

The following general offshore PPE is provided by Lwandle to offshore personnel:

- Bright Coveralls or at least long working pants with a reflective vest
- Safety footwear
- Safety helmet (as required during lift operations)
- Gloves
- Masks, safety glasses and nitrile gloves for working with formalin
- Self-inflatable life jackets
- Safety harnesses

5.2 WORK ON DECK

Particular care is required when handling any over-side equipment, each member of the field team is to ensure that the correct and safe procedures are understood and implemented for all work taking place on the deck of the vessel. The field team should ensure their safety harnesses are properly secured for any work undertaken near the gunwale of the vessel.

If the weather conditions begin to deteriorate, the field team should continually assess the situation and stop work whenever necessary. This is especially true in conditions where equipment becomes unstable, or instrumentation begins swaying excessively on the winch.

All the members on the field team will have the full authority to issue a “Stop work” command if anyone perceives a hazard during work operations. Most technical/manual activities are to be undertaken by trained boat crew.

A toolbox meeting should be held prior to any new tasks and or beginning of every shift being undertaken, and a refresher meeting should occur whenever necessary.

© NMP 2014

5.3 RISK ANALYSIS

A number of risk assessments have been carried out in alignment with the tasks that the field team will be carrying out. The risk assessments have been prepared on the basis of the risk factor table presented in Figure 5-1. The risk assessment tables should be read in conjunction with the associated deployment and recovery procedures.

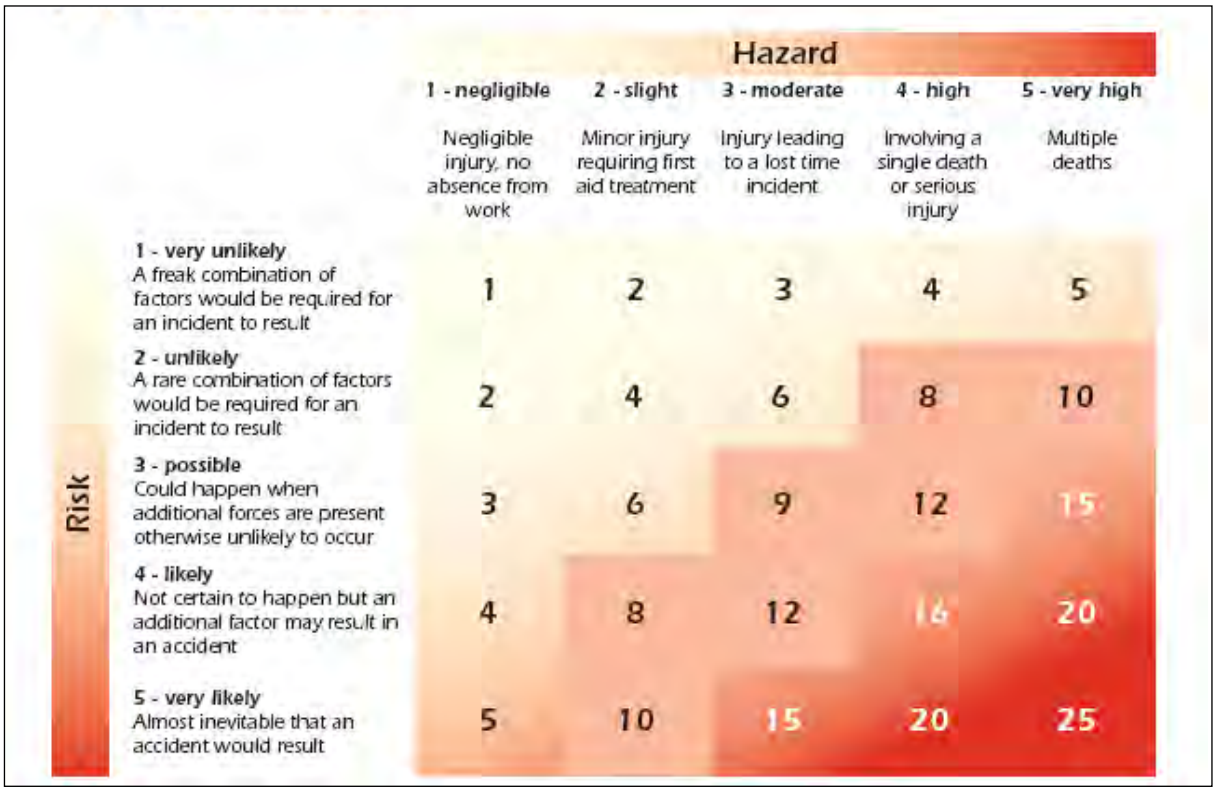


Figure 5-1: Risk factor table taken from OGP *HS&E Guidelines for Metocean Surveys*[1].

[1] International Association of Oil and Gas Producers. http://www.ogp.org.uk/pubs/348.pdf

Table 5-1: RA for the mobilisation of equipment and loading of ship

Risk	H	R		Mitigation	H	R	
Theft/loss of valuables/ equipment/ personnel	4	3	12	• Keep all valuables out of sight while travelling. • Ensure equipment is securely packaged before transportation. • Be vigilant when travelling.	2	3	6
Scratches from securing equipment/moving/carrying boxes	2	3	6	• Use of PPE. • Ensure all boxes/crates are properly secured. • Ensure vessel crew is responsible for hoisting.	1	2	2
Injury to personnel and / or damage to equipment from uncontrolled lifting/dropping of boxes/equipment	4	3	12	• Use of PPE • Lift carefully, bend knees and not back.	1	2	2

Table 5-2: RA for work on vessel deck

Risk	H	R		Mitigation	H	R	
Personal injury due to Slips/trips/falls	4	3	12	• Use of PPE, especially safety shoes when on deck • Ensure deck is cleared of potential trip hazards	1	2	2
Personal injury due to falling over gunnel	5	3	15	• Use of PPE, especially life jackets and safety harnesses when working near the gunnel. • Work close to the gunnel only when it is safe to do so, if weather conditions are not favourable –Stop work.	3	2	6

Table 5-3: RA for the handling and analysis of sediment samples

Risk	H	R		Mitigation	H	R	
Injury to personnel/equipment from mishandling samples/grabs	4	3	12	• Use of PPE • Be vigilant when handling equipment and samples • Ensure no one puts their fingers close to the jaws of either grab.	1	2	2
Personal injury due to exposure to formalin	4	2	8	• Use of PPE • Use supplied gas mask • Only use formalin in well ventilated areas • Wash hands after work with formalin	3	1	3

© NMP 2014

Table 5-4: RA for the deployment and recovery of Rosette and CTD

Risk	H	R		Mitigation	H	R	
Personal (hands/head/feet)injury or damage to equipment due to mishandling of rosette	3	3	9	• Use of PPE, especially hardhats, safety boots • Ensure care is taken when setting up Niskin bottles, keep fingers away from the tops/bottoms of open bottles • Ensure care is taken when hoisting/lowering rosette unit.	3	2	6

Table 5-5: RA for the packaging and unloading of samples

Risk	H	R		Mitigation	H	R	
As per table Table 5-1	0	0	0		0	0	0

5.4 EMERGENCY PROCEDURES AND CONTACT NUMBERS

In the case of any emergency the following numbers are to be called either from a satellite phone, local sim card, or on board telephone (Table 5-6). Please ensure that this list of numbers is placed in an area visible to all field staff during work on board the vessel and while travelling.

Table 5-6: Emergency contact details

Name	Position	Email	Phone number
Jeremy Midgley	NMP representative	mwjmidg@mweb.co.za	+ 27 21 7886212 +27 832649484
Bill Ludick	NMP representative	bludick@mweb.co.za	0814822386 (Namibian number)
Mike Woodborne	NMP land project coordinator	mike.woodborne@uclresources.com.au mike.woodborne@gmail.com	+61 410307205 / +37281054658
Kate Munnik	Project manager, Lwandle Technologies	kate@lwandle.co.za	+27 21 705 0819 +27 83 6267240
Craig Matthysen	Director, Lwandle Technologies	craig@lwandle.co.za	+27 21 705 0819 +27 83 473 6772
Robin Carter	Director, Lwandle Technologies	robin@lwandle.co.za	+27 82 922 3504
Hospital	Walvis Bay Medipark T/a Welwitchia Hospital	Street Address: Gertrude Rikumba Kandanga Hilukilwa Street, Walvis Bay	+26 464 21 8911
Police Station	Walvis Bay Police Station	Walvis Bay, Namibia	+264 64 21 9048 / 64 202 055 / 10111/
Sea Rescue	Namibian Sea Rescue		208 2221 or 081 129 6295

© NMP 2014

Name	Position	Email	Phone number
SOS international emergency number (for Discovery clients)			+27 11 541 1222

Personal Emergency information

Name	Medical aid number	Emergency Contact	Phone number
Andrew Russell (Lwandle Party Chief)	Discovery number: (coastal saver): 428148065	David Russell (Father)	+27824420142
Timothy McClurg (Scientific Officer)	Discovery number: 223996381	Helen McClurg (wife)	+27 31 762 1356 +27 83 681 67 66
Henry Gilham (Field team)	Discovery number: 034823460 (Dependant 1) (Main Member: Rene Gilham)	Rene Gilham (wife)	+27 21 685 7319 +27 83 3767141 / +27 79 4033492
Sanette Gildenhuys (MSI party chief)	Discovery number: 338712940	Antoinette Homan (Sister)	+27 72 613 6543
Jeremy Midgley (Client rep)	Discovery number: 018173110	Carol Midgley (wife)	+27 21 7885233 (home) 27 849060222
Bill Ludick (Client rep)	Profmed number; 4886801	Caryn Scrimgeour (Partner)	+27 849108474 (Cell) +27 21 9759166

While on board, Lwandle staff will be required to follow and adhere to all health and safety requirements/instructions given to them by the vessel captain.

© NMP 2014

ANNEXURE 1: SHIP REQUIREMENTS FOR SAMPLES AND THEIR STORAGE

Deployment of sampling equipment

- Winch/davit arm: deployment and recovery of rosette and CTD, and Gomex box core. (Winch: forward and reverse gear necessary, must be able to perform at 0.5 m/s or faster, and be capable of supporting at least 500 kg.
- Power supply for laptops (setting up rosette sample and CTD)
- Steel cable: at least 250 m in length. (Steel cable: compatible with winch, with load capacity of at least 500 kg).
- GPS system, with relatively accurate depth reading/echo sounder
- Full safety specifications/certifications

Sample prep

- Mountings / deck space for autosiever
- Deck space for removing box core samples (approx. 3 m^2)
- Sea water and freshwater supply.
- Formalin storage area (safety)

Sample storage

- Fridge space
- Freezer space
- Power supply requirements for fridge and freezer.

© NMP 2014

ANNEXURE 2: EQUIPMENT LIST

Deployment of sampling equipment

- Rope: compatible with Niskin bottles and messenger (approx. 4 mm thick) at least 250 m long.
- Manuals
- GPS
- Laptops
- CTD
- Corer and Day grab
- Rosette
- Sonar bell and echo sounder
- Spares for all – weights for box core
- Siphon tubing: silicone tubing 10 mm diameter.
- Deployments sheets
- Sampling/deployment protocols hand book (all sheets laminated)

Sample prep

- Coring /suction tubes/containers: plastic tubes of various lengths and diameters
- Spades/spatulas/plastic/metal
- Bags/containers: large Zip-loc bags and 250 ml honey jars
- Gloves nitrile
- Formalin
- Markers for labelling
- Camera
- Clip board
- Data sheets
- Water proof paper
- Core containers (sub sampling)
- Autosiever and sieves – with back-ups for sieves
- Dioptode probe
- pH and temperature probe(s)

Sample storage

- Boxes/ crates/drums
- Rope/strapping
- External hard drive to duplicate logged memory

© NMP 2014

ANNEXURE 3: DATA SHEETS

SAMPLING JOURNAL **Sign. In:** **Page nr: of**

Vessel: DP Star	**Area: Namibia**	**Project code: 149**	**Survey nr:**

Grab station nr.	**Date**	**Position**		**Depth (m)**
		Latitude N/S	**Longitude E/W**	
CTD St.				

Weather:	**Wind:**	**Wave height (m):**
Time Start:	**Time Finish:**	**Duration:**

Sample equipment used (bite area, weight):			
Type of bottom sediment:			
Colour:	**Odor:**		
Observation of animals:	**No. rejected samples:**		
Observation of oil, waste etc.:	**Empty:**	**Stone:**	**Open:**

Sample nr	Vol. (cm)	Bottles bio.	Pack Box :	Time:	Pict:	Colour:	Macrofauna: plastic 800ml	# of cores used	Chemical: 375 ml glass	Meiofauna: Honey jar	Metal analysis: Zip lock	OPC probe:	Remarks:	Grab nr.
1														
2														
3														
4														
5														

Sign. Out:
NB: REDEPLOY GOMEX CORER IF SAMPLE IS LESS THAN 20 CM. IF GOMEX CORER DOES NOT RETRIEVE ENOUGH SEDIMENT ON 2 ATTEMPTS – SWITCH TO DAY GRAB.

Comments:

WATER SAMPLES: NMP 149

DATE:	
SITE #:	

© NMP 2014

DEPTH:								
ROSETTE SAMPLING DEPTHS							**Comments:**	**DATA CHECKED AND SAVED TO PC AND HARDDRIVE: Y/N**
Unlocking depth dbars								
Niskin #	Corresponding depths/dbars	DO%	pH	1 L PLastic	250 ml Glass	150 ml Plastic		
1		**NA**	**NA**	**NA**	**NA**	**NA**		
2								
3								
4								
5								
6								
7	SURFACE SAMPLE							

CTD PROFILING		
Time in/ Time out	**DATA CHECKED**	**DATA DOWNLOADED AND SAVED TO PC AND HD**

© NMP 2014

Deployment and Recovery sheets: RBR CTD:

1	**XR-620 – Summer MOB**	
	Site #	
	Technicians name	
	Date of set-up	
	New batteries inserted?	
	O-rings checked and greased?	
	Configured and screen shot saved?	
	Configuration details	
	1. Sampling period (6Hz)	
	2. Start time	
	3. End time	
	4. Averaging (off)	
	5. Sensors set to auto-ranging	
	6. LED on (only XRX)	
	Log Book to record times and number of each station dips	

1	**XR-620 – Summer DEMOB**	
	Site #	
	Technicians name	
	Date of set-up	
	New batteries inserted?	
	O-rings checked and greased?	
	Configured and screen shot saved?	
	Configuration details	
	1. Sampling period (6Hz)	
	2. Start time	
	3. End time	
	4. Averaging (off)	
	5. Sensors set to auto-ranging	
	6. LED on (only XRX)	
	Log Book to record times and number of each station dips	

© NMP 2014

Deployment and Recovery sheets: ROSETTE SAMPLER:

1	**Hydrobios Multiple depth water sampler**	
	Site #	
	Technicians name	
	Date of set-up	
	New batteries inserted?	
	O-rings checked and greased?	
	Configured and screen shot saved?	
	Configuration details	
	1. Turn on switch	
	2. Check batteries	
	3. Reset bottles to 0	
	4. Trigger depths set	
	5. Data sent to on board computer	
	6. Time in	
	7. Time out	
	8. If sampling is finished. Turn off	
	Log Book to record times and number of each station dips	

Deployment and Recovery sheets: ROSETTE SAMPLER:

1	**Hydrobios Multiple depth water sampler**	
	Site #	
	Technicians name	
	Date of set-up	
	New batteries inserted?	
	O-rings checked and greased?	
	Configured and screen shot saved?	
	Configuration details	
	1. Turn on switch	
	2. Check batteries	
	3. Reset bottles to 0	
	4. Trigger depths set	
	5. Data sent to on board computer	
	6. Time in	
	7. Time out	
	8. If sampling is finished. Turn off	
	Log Book to record times and number of each station dips	

© NMP 2014

Toolbox Meetings

A toolbox meeting will be held prior to each operation, inclusive of Client rep, Party chief, technicians and divers discussing the following:

- Anticipated operations to be undertaken
- Any hazards that have not been actioned
- Individual concerns of employees

The toolbox meeting will be documented according in the following format:

Date & time of meeting		**Date & time of report**	
Location		Vessel	
List of attendees		Present weather conditions	

Matters for discussion

Scope of work summary		Comments	
Review and acceptance of JSA		Signed	

Signatures

Party Chief		Dive Master	
Client Rep			

© NMP 2014

APPENDIX 1 - WATER COLUMN AND SEDIMENTARY ENVIRONMENT

1.2 Cruise Report: Verification Survey MV *DP Star*

NAMIBIAN MARINE PHOSPHATE

VERIFICATION SURVEY

CRUISE SUMMARY REPORT

Prepared for:
Namibian Marine Phosphate (Pty) Ltd.

Prepared by:
Lwandle Technologies (Pty) Ltd.
Report compiled by Andrew Russell

4 September 2013

Job no: 149

LWANDLE TECHNOLOGIES (PTY) LTD
The Old Warehouse, Black River Park, Fir Road, Observatory 7925, South Africa
Directors: C.P. Matthysen, B.J. Spolander
Co Reg. No. 2003/015524/07

MARINE SPECIALIST TEAM

Robin Carter – Lwandle Technologies, Cape Town
Andrew Russell – Lwandle Technologies, Cape Town
Henry Gilham – Lwandle Technologies, Cape Town
Timothy McClurg – Lwandle Technologies, Cape Town
Sunette Gildenhuys – Metocean Services International

Date	Version	Revised	Reviewed
20/08/2013	1	Andrew Russell	Kate Munnik
2/09/2013	2	Andrew Russell	Jeremy Midgley
04/09/2013	3	Andrew Russell	Kate Munnik

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed “Attention: Administration Manager,” at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

contents

1 INTRODUCTION **1**

2 WORK CARRIED OUT **1**

2.1 SAMPLING SCHEDULE 1
2.2 SAMPLING ROUTINE 5
2.2.1 Sediment grabs 5
2.2.2 Water column profiling and sampling 8
2.3 VARIATION TO METHODS 9
2.4 LESSONS LEARNT 9
2.5 SAMPLE PROCUREMENT AND ANALYSIS 10

figures

Figure 2.1: The verification sampling stations. 4
Figure 2.2: Example: Detail of site sample label 5
Figure 2.3: Wilsons autosiever used for sorting benthic samples. 7
Figure 2.4: Shell debris left over after sieving on the 3 mm sieve. 7
Figure 2.5: Hydrobios multiple water sampler and CTD deployment 9
Figure 2.6: Scientific survey team 10

tables

Table 2-1: Summary of the sampling completed on the verification and buoy sites: 2
Table 2-2: Summary of the sampling of the monitoring sites: 3

© NMP 2014

1 INTRODUCTION

Prior to the commencement of dredging activities involved in the recovery of phosphates from the Sandpiper-1 (SP-1) marine deposit off the Namibian coast, Namibian Marine Phosphate (NMP) commissioned a marine 'verification survey' which was undertaken by Lwandle Technologies. This verification survey was carried out from the vessel MV *DP Star* from the 24th of July until the 4th of August 2013. This component of the marine survey focused on the sampling of sediments and the water column at the verification sites and monitoring sites (identified as reference and impact sites) situated across the NMP Mining Licence Area, with specific reference to the primary dredge target area SP-1. Due to adverse weather conditions the collection of benthos samples from secondary dredge targets SP-2 and SP-3, which fall outside the planned 20-year mine plan, could not be undertaken.

On completion of this component of the verification assessment Lwandle Technologies, through the review of Dr Robin Carter, will provide an evaluation of the impacts of the proposed dredging activities on the marine environment.

The details of the survey plan and sampling methods are described below.

2 WORK CARRIED OUT

2.1 SAMPLING SCHEDULE

The Lwandle team arrived in Walvis Bay on Tuesday 23rd July 2013, and boarded the vessel MV *DP Star* on Wednesday 24th July 2013. Sampling commenced at location SP1VS15 (mooring site) on the 26th of July, after being delayed by bad weather. It was also at this site that the Metocean Services International (MSI) buoy and instrument string was recovered successfully. The buoy and instrument string was successfully redeployed on the 2nd of August. Over the next 9 days a total of 38 sites were sampled. Out of these sites, 6 comprised CTD and rosette deployments as well as Day grab deployments. The remainder (32) were solely Day grab deployment sites, where benthic sediment samples were collected.

Before the survey could begin the GOMEX box corer was trialled to test whether it could retrieve samples of adequate volume and composition. It was first trialled twice at SP1VS15, which was known to be consolidated sediment and then twice at SP1VS01, an area of supposedly soft sediment. It failed on all four attempts. From this point onward the Day grab was used to collect sediment samples, as specified in the Project Execution Plan (PEP). This method ensured sample collection uniformity, allowing for subsequent sample analysis standardisation and conformity. The box corer was again trialled (3 deployments) at SP1VS12, and again failed to retrieve samples of adequate volume and composition.

In order to standardise sample collection and storage the Lwandle team worked as a unit for the first 2 working days of the survey. This also helped to familiarise the guests and independent observers from the University of Namibia with the sampling procedure. Subsequently, a 24-hour schedule divided into 8 hour shifts was initiated.

© NMP 2014

The sampling requirements of SP-1 were met and all samples were recovered and stored successfully.

The breakdown of the executed daily activities for the cruise is provided below (Table 2-1).

Table 2-1: Summary of the sampling completed on the verification and buoy sites: Environmental survey of SP-1 (24th July - 4th August 2013).

DATE	Sampling Sites	Activities at site
	VERIFICATION SITES	
26-Jul-13	SP1VS01	benthos grab (Day grab)
27-Jul-13	SP1VS02	benthos grab
27-Jul-13	SP1VS03	benthos grab
28-Jul-13	SP1VS04	benthos grab + CTD and rosette
27-Jul-13	SP1VS05	benthos grab
26-Jul-13	SP1VS06	benthos grab
27-Jul-13	SP1VS07	benthos grab
27-Jul-13	SP1VS08	benthos grab
28-Jul-13	SP1VS09	benthos grab + CTD and rosette
27-Jul-13	SP1VS10	benthos grab
26-Jul-13	SP1VS11	benthos grab
27-Jul-13	SP1VS12	benthos grab
27-Jul-13	SP1VS13	benthos grab
30-Jul-13	SP1VS14	benthos grab + CTD and rosette
27-Jul-13	SP1VS16	benthos grab
30-Jul-13	SP1VS17	benthos grab
30-Jul-13	SP1VS18	benthos grab
31-Jul-13	SP1VS19	benthos grab
30-Jul-13	SP1VS20	benthos grab + CTD and rosette
31-Jul-13	SP1VS21	benthos grab
30-Jul-13	SP1VS22	benthos grab
30-Jul-13	SP1VS23	benthos grab
31-Jul-13	SP1VS24	benthos grab
30-Jul-13	SP1VS25	benthos grab + CTD and rosette
31-Jul-13	SP1VS26	benthos grab
	Buoy - mooring site	
26-Jul-13	SP1GC15	benthos grab + CTD and rosette
26-Jul-13	SP1GC15	Recovery of MSI buoy
02-Aug-13	SP1GC15	Redeployment of MSI buoy

© NMP 2014

Table 2-2: Summary of the sampling of the monitoring sites:

Environmental survey of SP 1 (24th July - 4th August 2013).

	REFERENCE SITES (north)	
31-Jul-13	SP1RS01	5x benthos grab
31-Jul-13	SP1RS02	5x benthos grab
01-Aug-13	SP1RS03	5x benthos grab
01-Aug-13	SP1RS04	5x benthos grab
	IMPACT SITES	
01-Aug-13	SP1IS01	5x benthos grab
01-Aug-13	SP1IS02	5x benthos grab
02-Aug-13	SP1IS03	5x benthos grab
02-Aug-13	SP1IS04	5x benthos grab
	REFERENCE SITES (south)	
31-Jul-13	SP1RS05	5x benthos grab
02-Aug-13	SP1RS06	5x benthos grab
02-Aug-13	SP1RS07	5x benthos grab
03-Aug-13	SP1RS08	5x benthos grab

© NMP 2014

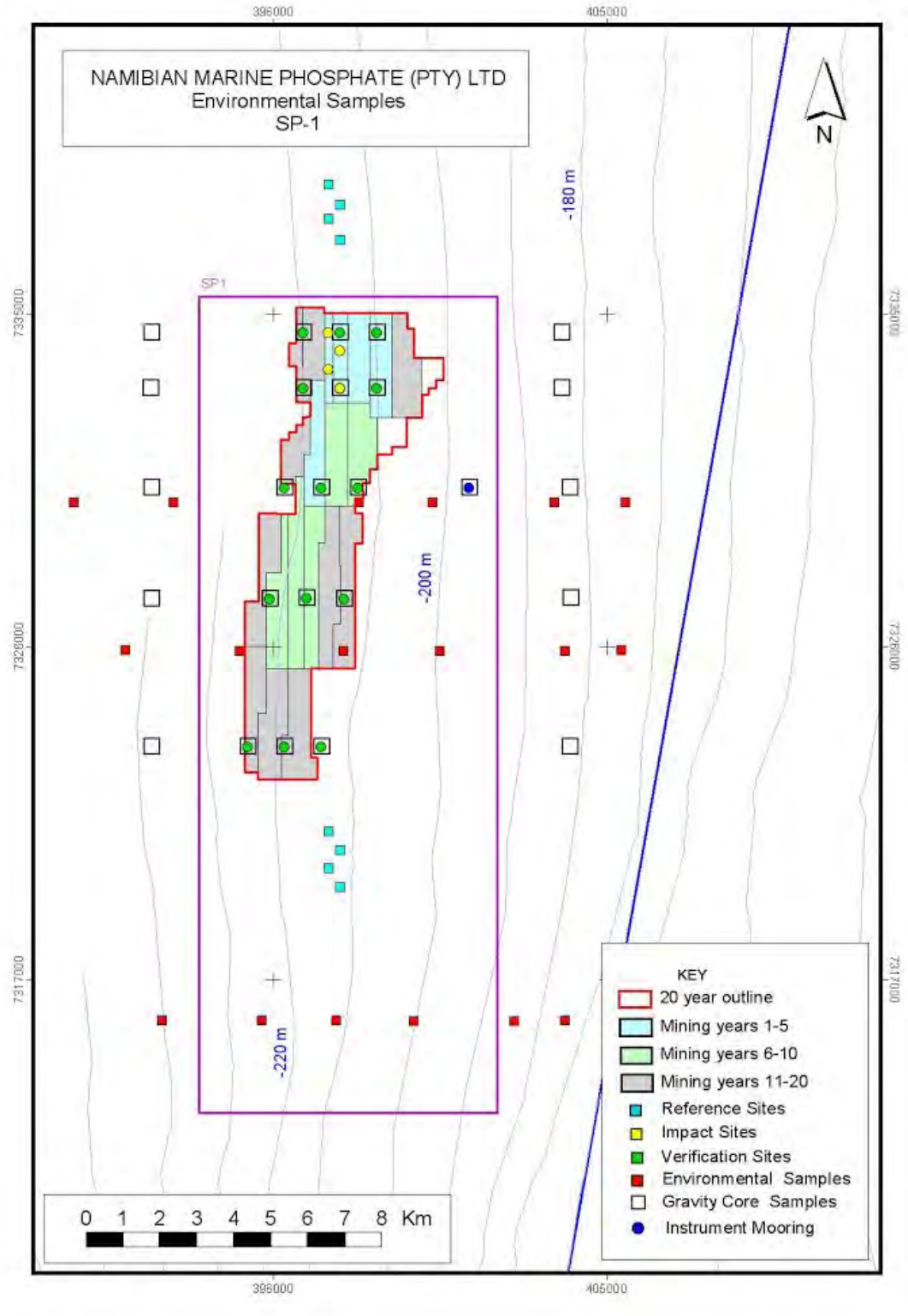


Figure 2.1: The verification sampling stations.

At the clear squares a single benthos grab was taken. The clear squares with green dots indicate sites where macrofauna samples were collected from single benthos grabs. The clear square with the blue dot represents the site where the mooring was recovered and redeployed. The light blue squares north and south of the verification sites represent the reference sites. The yellow dots at the north of the verification sites represent the impact sites. The reference and impact sites make up the monitoring sites that will be used in future surveys.

2.2 SAMPLING ROUTINE

Before each shift a toolbox meeting was held and the activities that needed to be completed in that shift were discussed. This included a handover discussion between the respective teams.

2.2.1 Sediment grabs

Following the failure of the GOMEX box corer to recovery samples, the Day grab was used at all sites to collect benthos samples. The grab was attached to a winch and was lowered down through the water column until the cable went slack, indicating that the grab had reached the bottom. The grab was then brought back onto the vessel. Grabs that were less than 40% full were regarded as failed. When a failed grab occurred the grab was redeployed at the same site until an adequate sized sample was collected. On retrieval of each grab, the following procedures were followed:

Physical analysis (on all grabs):
The fullness of the grab was estimated and the space remaining between the upper level of sediment and the lid of the grab was also noted. This number can be used to convert the fullness of the grab into actual volume of sediment, using the dimensions of the Day grab. A photograph was then taken of the surface of the sediment within the grab. This photograph included a detailed label (site number, date and where needed a replicate number) as well as a scale object (the label size remained the same throughout the survey). The label was written on white paper, which serves as a colour comparison between the different sediment samples. The colour of the sediment within the grab was noted. All necessary information was recorded on datasheets provided in Appendix 1.1, Annexure 3.



Figure 2.2: Example: Detail of site sample label
(site number, date and where needed a replicate number).

Chemical, metal and particle size analysis:
Two benthos samples, which would be later used to analyse the chemical, metal and particle size composition of the sediment, were taken at each of the verification, reference and impact sites.

Using a 50 mm plastic tube a core of the benthos was sampled and stored in a pre-labelled 375 ml glass jar, which was then placed in the freezer. This sample would be used for analysis of organic substances. The field team were careful to allow enough headspace in each of the glass bottles to ensure they did not crack when frozen.

The same method was used to collect a 750 g subsample to be used in the metal and particle size analysis. The first core for this sample was used to record the ORP (Oxygen Redox Potential) reading. This was done by using a 50 mm tube with a hole 8 cm from the bottom. Before the tube was inserted into the benthos the hole was covered with duct tape. When the core was recovered the tape was removed and a clean syringe was quickly inserted into the hole. The benthos that filled the syringe was removed and upon the syringe leaving the hole the ORP probe was inserted. The probe had a line of Vaseline petroleum jelly approximately 3 cm from the tip to create a seal when inserted into the tube. The reading was recorded on the data sheet. After 750 g of sample was collected, the sample was placed into a pre-labelled plastic Ziploc bag before being placed into the on-board freezer.

As soon as the sub-sampling from each grab was finished, the necessary details were recorded on the datasheets.

Meiofauna analysis:
A subsample of the sediment from each grab was taken with a 50 mm plastic tube and stored in a pre-labelled 250 ml honey jar. This sample was fixed in 10% neutralised formalin and stored in a black crate out of direct sunlight. The amount of formalin added to the container was equal to the volume of seawater already present in (or on top of) the sample, this then resulted in a final formalin concentration of ~4-5 %.

Note: A quarter of the grab was used to collect chemical, metal and particle size, and meiofauna samples. The other three quarters were used for the macrofauna sample.

Macrofauna analysis
A 5 ℓ subsample was taken from the grab using a series of 75 mm plastic tubes. These tubes were used as cores to subsample the benthos. This method ensured a controlled representative sample of the surface and the deeper layers of the sediment were collected. This method of sampling was problematic when the sediment was loose (watery) as the sediment moved into the areas that had already been sub-sampled.

The 5 ℓ subsample was then placed into the Wilsons autosiever (Figure 2.3). The autosiever had two tiers of sieves, which were placed above the incoming seawater jets. The top sieve had an aperture of 3 mm (Figure 2.4) and the bottom sieve had an aperture of 300 µm (Recommended by N. Steffani, as part of the evaluation of optimisation on subsequent monitoring assessment protocol). A hand held hosepipe was used to wash the sediment from above. At first the entire sample was place on the top sieve. It was soon noticed that this method caused the bottom sieve to clog. The sample was then added in small amounts to ensure that the bottom sieve did not clog.

© NMP 2014

Great care and time was taken to wash the sediment thoroughly. The shells in the sample were meticulously washed and only once all sediment had passed into the 300 µm were these discarded. The 3 mm sieve was then checked for any fauna that were stuck on the mesh.

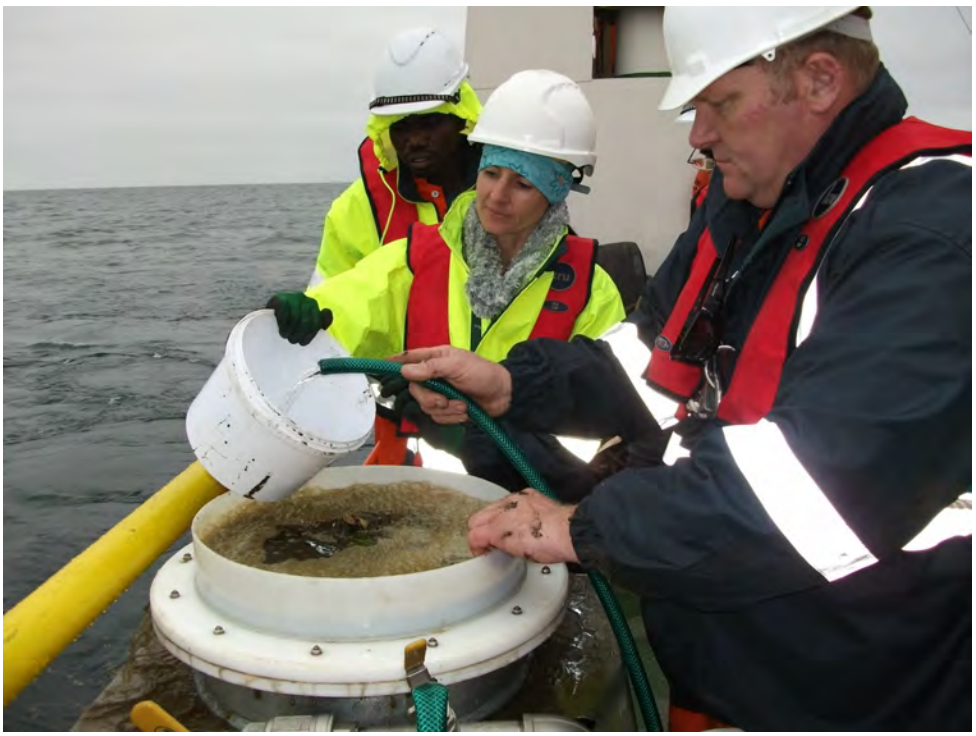


Figure 2.3: Wilsons autosiever used for sorting benthic samples.



Figure 2.4: Shell debris left over after sieving on the 3 mm sieve.

During sieving of the sediment used for the macrofauna sample any organisms that were found were placed in a separate container using forceps. 3 to 4 plastic containers were used to store each macrofauna sample. All macrofauna samples were fixed with 10% neutralised formalin. The amount of formalin added to the container was equal to the volume of seawater already present in (or on top of) the sample, this then resulted in a final formalin concentration of ~4-5 %.

© NMP 2014

2.2.2 Water column profiling and sampling

Sampling of the water column was achieved by using a Hydrobios multiple water sampler (rosette), which had a RBR CTD attached to it (Figure 2.5). This equipment was attached to the winch cable and lowered through the water column at a rate of ~5 $m.s^{-1}$ to a depth of approximately 200 m (the water depth varied between sites). It was brought up to the surface at ~5 $m.s^{-1}$ and only once it was stable and secured to the vessel, was the water collected from the Niskin bottles and the data downloaded.

Each time this equipment was used, the time and details of the equipment were recorded on recovery and deployment sheets, see Appendix 3.

Water sampling (Hydrobios multiple water sampler)
Before each deployment the on-board computer was programmed and the trigger depth for each individual Niskin bottle was set. The Niskin bottles were set and the taps were checked and closed.
The multiple water sampler was tracked on descent and ascent using a Fuduro fish finder transducer and a sonar bell transmitter. This allowed the Lwandle technician to know the depth of the sampler in real time. Once it had reached the unlocking pressure depth it was brought back up through the water column at ~5 $m.s^{-1}$.

On retrieval the multiple water sampler was securely set on the deck and the water from each Niskin bottle was sampled. After the dissolved oxygen and pH readings were taken the 1 ℓ, 250 ml, and 150 ml containers were filled (in that order). Each sample bottle was thoroughly rinsed with water from the associated Niskin before being filled with sampled water. The 1 ℓ bottles were stored in black crates out of direct sunlight, while the 250 ml and 150 ml bottles were stored in the freezer.

Once sampling was complete, the multiple water sampler was removed from the aft deck and placed close to the work station. It was then connected to the field laptop and the data were downloaded and saved. These data were later saved to an external hard drive.

Water column profiling (CTD)
The CTD was programmed, using Ruskin software, to sample the water column at a given frequency and for a set period. After deployment and recovery the data stored by the CTD was downloaded using the software Ruskin. This was later saved to an external hard drive.

All necessary information was recorded on datasheets provided in Appendix 1.1, Annexure 3.

© NMP 2014

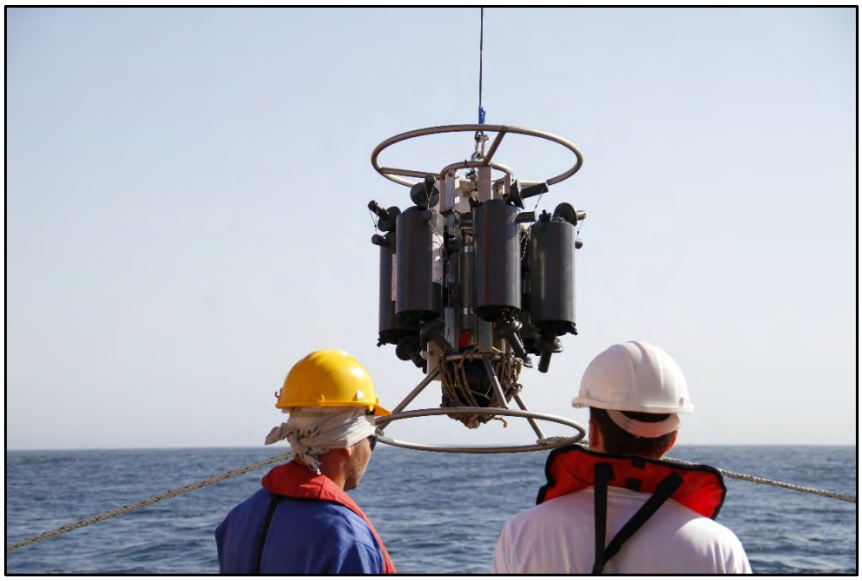


Figure 2.5: Hydrobios multiple water sampler and CTD deployment

2.3 VARIATION TO METHODS

Variations to the intended sampling methods had to be made to ensure completion and consistency of the sampling set across the target sampling area – SP-1. This was primarily due to the use of the Day grab, following the failure of the GOMEX box corer to penetrate the shell-rich marine sediments. It was found to be difficult to subsample using "vertical" cores from the Day grab when using the 75 mm tubes. To ensure that the recommended 5 ℓ of benthos was obtained the subsamples were taken at an angle so that at least ±10 cm of sediment could be collected at a time. In the case of very wet samples the tubes were used to scoop the sediment out of the grab. Even though there were variations in the benthos sampling method the surface and the bottom layers of the grab were always sampled.

2.4 LESSONS LEARNT

- The volume of sediment needed to be stored for macrofauna analysis was significantly more than estimated, this being due to the retention of sediment by the 300 µm sieve. This led to the plastic storage containers being used up very quickly. For the next cruise 1 ℓ - 1.5 ℓ containers should be used for storage of macrofuana samples.
- The lighting on deck was not sufficient to sieve at night. Fortunately we had a head torch that made it possible for us to work at the auto-siever throughout the night.
- The ORP reading varied between samples and because of this we feel that the reading may not have given a representative measurement of the oxygen redox potential. It is possible to measure the concentration of nitrates in the pore water of the samples at the CSIR laboratories. This information can then be used to indirectly calculate the concentrations of sulphide in the pore water.
- We had difficulty detecting the location of the multiple water sampler once it had been lowered past a depth of approximately 180 m. To ensure this problem does not occur again we have looked into using a stronger transducer head.

© NMP 2014

2.5 SAMPLE PROCUREMENT AND ANALYSIS

All collected samples were clearly labelled and stored in the appropriate storage containers. On arrival back into Walvis Bay the cargo was offloaded and stored at Manica Freight Services.

The equipment and unfrozen samples were transported back to the Lwandle offices on the 16th of August 2013. On the same day the frozen samples were delivered to the CSIR (Stellenbosch) where they were offloaded and stored in another freezer.

The samples have since been grouped according to importance of the associated analyses. The "Key samples" are those that need to be analysed first. This group is made up of the samples taken from the verification sites found in row 2 and column 4.

The balance of the verification sites make up the next most important group, while the monitoring sites (reference and impact sites) make up the final set and will be analysed last.

The macrofauna samples have been sorted, grouped and delivered to Professor Mark Gibbons of the University of the Western Cape for pre-analysis screening.



Figure 2.6: Scientific survey team

APPENDIX 1 - WATER COLUMN AND SEDIMENTARY ENVIRONMENT

1.3 Project Execution Plan: Thiobacteria Survey MV *Snowgoose*

NAMIBIAN MARINE PHOSPHATE

VERIFICATION SURVEY

THIOBACTERIA SAMPLING

PROJECT EXECUTION PLAN

Prepared for:
Namibian Marine Phosphate (Pty) Ltd.

Prepared by:
Lwandle Technologies (Pty) Ltd.
Report compiled by Andrew Russell



November 2013

Job no: 149

LWANDLE TECHNOLOGIES (PTY) LTD
The Old Warehouse, Black River Park, Fir Road, Observatory 7925, South Africa
Directors: C.P. Matthysen, B.J. Spolander
Co Reg. No. 2003/015524/07

MARINE SPECIALIST TEAM:

Robin Carter – Lwandle Technologies, Cape Town
Kate Munnik – Lwandle Technologies, Cape Town

Date	Version	Revised	Reviewed
28 October 2013	0.1	Jeremy Midgley	Robin Carter
01 November 2013	0.2	Jeremy Midgley	Robin Carter
05 November 2013	0.3	Kate Munnik	Robin Carter

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed “Attention: Administration Manager,” at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

contents

1 INTRODUCTION **1**

2 FIELD SURVEY **2**

2.1 LOCATION 2
2.2 TECHNICAL STAFF 4
2.3 SAMPLE COLLECTION EQUIPMENT 4

3 SAMPLE PRESERVATION, CURATION AND QUALITY CONTROL **4**

3.1 SAMPLING PROTOCOL 4
3.1.1 Prior to sailing 4
3.1.2 Sampling: Collecting a van Veen grab Sample 5
3.1.3 Sub sampling: 5
3.1.4 Transporting Samples 7
3.1.5 Quality Control 7
3.1.6 Analysis 8

ANNEXURE 1: SUMMARY OF SAMPLING PROTCOL 9
ANNEXURE 2: MOCK UP BOTTLE 10

figures

Figure 2-1: Regional location of the NMP Mining Licence 170. 2
Figure 2-2: Planned thiobacteria sampling location in the SP-1 primary mine target area 3

tables

Table 2-1: Co-ordinates of the planned thiobacteria sampling sites 4

© NMP 2014

1 INTRODUCTION

Namibian Marine Phosphate (NMP) is proposing to extract marine pelletal phosphate ore from deposits on the Namibian continental shelf. The phosphate will be extracted by dredging. The assessment of the environmental impacts associated with the project is therefore strongly reliant on a sound understanding of the sediment properties of the dredge area. The purpose of this verification survey is to confirm the sediment properties, water quality and local oceanographic processes of the seafloor and water column within the proposed dredge area. This information will then be used, in conjunction with previous scientific investigations of the region, to further inform the assessment of impacts on the marine environment as a result of the proposed dredging operations. This will aid in the final assessment of the impacts as detailed in the EIA / EMPR.

Following their review of the NMP Marine EIA for dredging of phosphate enriched sediments in ML 170, MFMR requested additions to the scope of work for the verification survey. One of the additions was to identify the presence or absence of thiobacteria within the mining licence area.

Thiobacteria, use hydrogen sulphide (H_2S) as fuel, effectively keeping the H_2S in the sediment and out of the water column. If the sediments are disrupted and the bacteria removed the H_2S may escape into the water column with (depending on scale and volumes) possibly significant impacts on the fauna and flora of the marine environment. Thiobacteria are ubiquitous on the Namibian continental shelf and generally in the world ocean. However, they have been shown to be temporally and spatially variable in the particulate organic matter (POM) enriched mud belt inshore of the proposed mining area (ML 170).

Although the presence of thiobacteria in ML 170 is suspected, given the sandy nature of the sediment (vertically and horizontally) compared to the H_2S-rich mud belt which is known to exist inshore of the mining area, the actual presence of the sulphur oxidising bacteria is questioned. Nonetheless, the detection of thiobacteria using the qPCR method, integrated with other Acid Volatile Source (AVS) assessments will provide a more robust indication of the potential presence and ecological importance of sulphur oxidizing bacteria in the survey area.

In order to determine the presence or absence of thiobacteria on the seafloor, the following survey is proposed:

Surface grab samples from 10 (ten) sample sites will be collected from the NMP licence area (ML 170). The samples will be recovered from the seabed with a van Veen grab deployed from the MV *Snowgoose*. 4 x 200ml sub-samples will be collected from each grab sample and these sub-samples (total 40) will then be stabilised and subsequently transferred to the University of the Western Cape, where they will be analysed for the presence of thiobacteria using the “real time Polymerase Chain Reaction” (qPCR) analysis procedure.

The samples are due to be collected during the last quarter of 2013.

© NMP 2014

2 FIELD SURVEY

2.1 LOCATION

The thiobacteria sampling sites are located within the NMP ML 170 Figure 2-1. These sites match those sampled during the NMP verification sampling programme, which focused on the northern enriched ore body called SP-1. 10 sample sites are targeted, these being the "T" [1]sites of the 26 verification sampling locations (SP-1). (Figure 2-2 and Table 2-1).

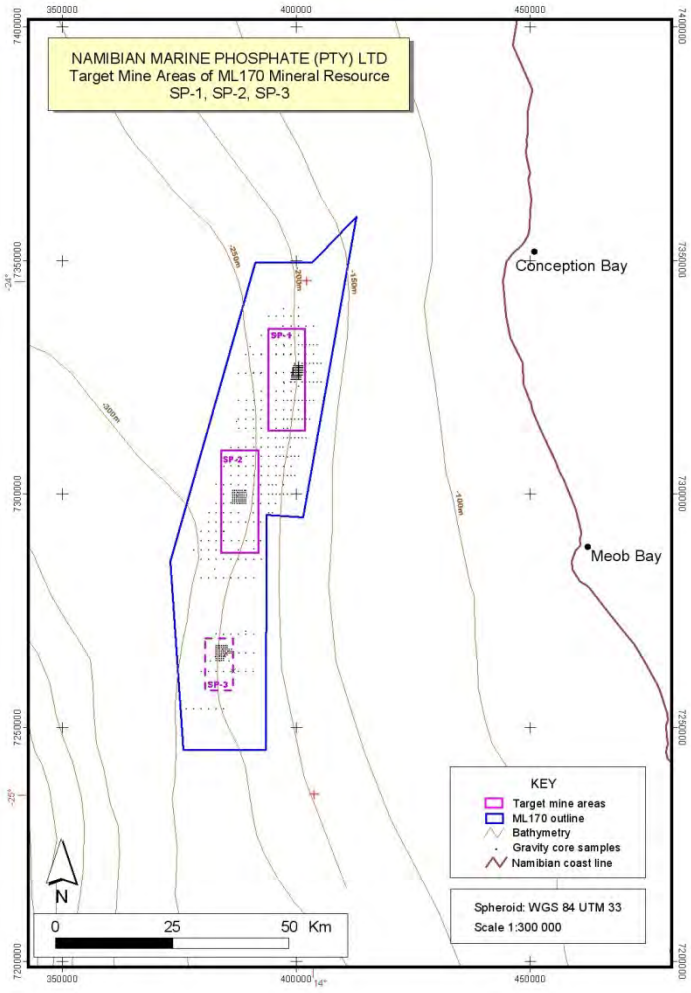


Figure 2-1: Regional location of the NMP Mining Licence 170.

[1] Provides for an east – west and north – south spatial assessment across the target mine site

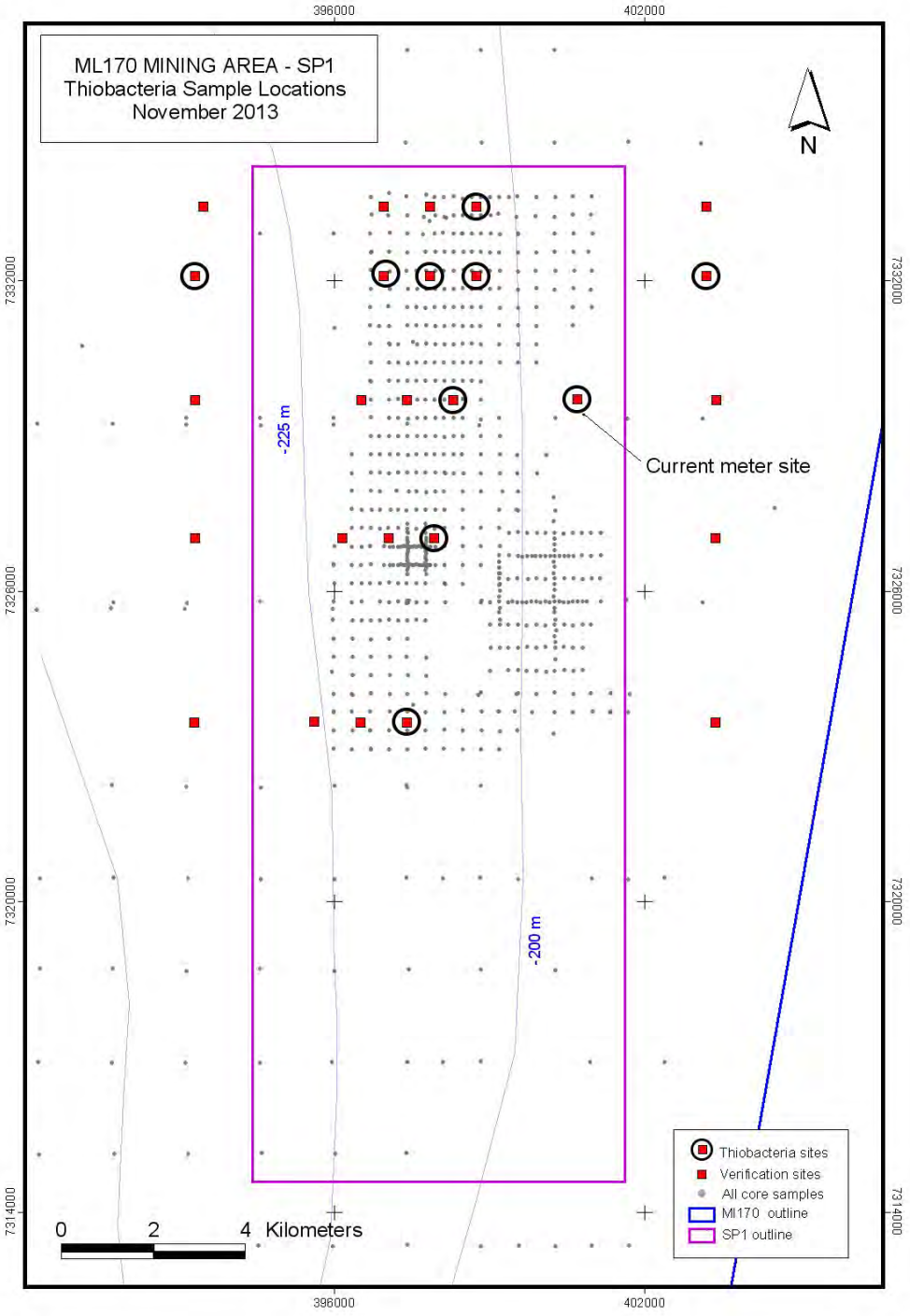


Figure 2-2: Planned thiobacteria sampling location in the SP-1 primary mine target area

Table 2-1: Co-ordinates of the planned thiobacteria sampling sites

Site	X	Y	Latitude	Longitude
1	397299	7323303	24°11.976'	13°59.324'
2	397888	7327305	24°09.810'	13°59.689'
3	398302	7330298	24°08.190'	13°59.946'
4	398802	7332998	24°06.729'	14°00.253'
5	397796	7332996	24°06.726'	13°59.659'
6	396803	7332998	24°06.721'	13°59.073'
7	392704	7332997	24°06.705'	13°56.653'
8	398800	7334498	24°05.916'	14°00.258'
9	403803	7332997	24°06.748'	14°03.205'
10	401016	7330084	24°08.316'	14°01.548'

2.2 TECHNICAL STAFF

The samples will be collected by the crew of the MV *Snowgoose*. Two of the crew (along with the NMP Representative) who normally collect the benthic samples will be familiarised with the thiobacteria sampling protocol.

2.3 SAMPLE COLLECTION EQUIPMENT

- Operational vessel (1) – MV *Snowgoose*
- Sampler (1 + spare) – van Veen Grab (of bite x m^2)
- Refrigeration (1) – chest deep freezer (-18 °C) with TidBits
- Bottles (50 units) – polypropylene (sterilised) (500 ml) – wide neck and cylindrical
- Sub sampler (4) – plastic scoop
- Hygiene (4 ℓ) – ethanol
- Fixing agent (1 ℓ) - RNAlater
- Gloves (box) – Nitrile
- Cloth (packet) – disposable cloth
- Temperature gauge – TidBit
- Photographic control – GoPro camera, with head strap mount and digital camera
- Waterproof marking paper and waterproof pens

3 SAMPLE PRESERVATION, CURATION AND QUALITY CONTROL

3.1 SAMPLING PROTOCOL

3.1.1 Prior to sailing

- Van Veen grab is to be tested and cleaned of any residual material (sea water wash).
- The freezer is to be operational for 48hrs prior to the collection of the samples.

© NMP 2014

- Temperate logging devices (TidBit) are to be placed in the freezer when it is first turned on.
- Sample collection equipment is to be verified against the list above (Section 2.3).

3.1.2 Sampling: Collecting a van Veen grab Sample

The standard van Veen grab sampling collection protocol is applied:

- One grab sample is collected at each of the stations.
- *Note*: For the van Veen grab sample to be acceptable for use the grab must be a minimum of 50 % full on recovery; otherwise another attempt on the site should be made before sub-samples are taken.

3.1.3 Sub sampling:

Please refer to:

1. The sampling protocol abbreviated list of sequential activities (This report, Annexure 1)
2. The Mock up bottle (This report, Annexure 2) and sample

3.1.3.1 Team

- The sub sampling team consists of two persons, Lead (LS) and Assistant (AS).

3.1.3.2 Preparation of the Equipment

- Technicians (AS & LS) are to be wearing a new pair or nitrile (disposable) gloves;
- The sub sampler (scoop) is to be cleaned with ethanol and disposable cloth before handling each sample;
- *Note*: the scoop may NOT come into contact with any item or person during the sampling process. Contact with human skin will contaminate the sample;
- 4 Nalgene bottles are required, inspect these to ensure that they have not been tampered with. Because they are sterile inside they should not be opened prior to use.
- 2 of the bottles are to have 50 ml of RNAlater poured in to them just before each grab sample is collected. The other 2 bottles remain dry.
- The bottles need to be labelled (Sample reference no.) with a permanent marker pen.

3.1.3.3 Collection of a Thiobacteria sub-sample

- Recover the grab to deck in a closed state.
- Open the inspection window and photograph the sediment in the recovered grab with station reference number label shown on the grab.
- Using the scoop the AS is responsible for collecting the 200 ml sample from the van Veen grab via the inspection window;
- LS is responsible for ensuring the that inspection window is open and that the sample bottles are prepared, this includes numbering and labelling;
- LS is responsible for sealing the bottles. Each bottle should be sealed immediately after the sample has been inserted;

© NMP 2014

- The 2 sample bottles containing the RNAlater (50 ml) and the sediment (200 ml), need to be shaken to distribute the liquid throughout the sediment sample;
- Upon a bottle being sealed it is to be placed in the freezer immediately;
- LS is responsible for ensuring that the bottles are sealed, correctly labelled and stored safely and securely (upright and do not roll around) in the freezer unit.

3.1.3.4 Photographing the Grab: Referencing the sample

- For each grab recovered from the sea bed, the sample number must be clearly written on waterproof paper, this number must be placed on the grab next to the inspection window and a photograph taken [DO NOT put the waterproof paper into the grab and on the sediment.]. Check the quality of the image to see if the sediment is recognisable as more than one attempt may be necessary to get a decent shot.

3.1.3.5 Bottle labelling & Marking

- Labels must be written on each bottle (and lid), these labels must correspond to the photograph and the datasheet entry (see example bottle in Annexure 2 of this report):
- e.g. for station No.1: T001-RNA-1 : T001-RNA-2
- e.g. for station No.1: T001-Non-1 : T001-Non-2
- The sample number, followed by RNA 1 – first bottle with RNAlater in it
- The sample number, followed by RNA 2 – second bottle with RNAlater in it
- The sample number, followed by Non 1 – first bottle with NO RNAlater in it
- The sample number, followed by Non 2 – second bottle with NO RNAlater in it

Bottles must be labelled by writing directly onto both the side and lid of the bottle with a permanent marker. The waterproof paper label (after a photograph has been taken of the grab sample) must be placed with the labelled bottle into a plastic bag (provided). Once the sample bottle has been filled, the plastic bag containing both the bottle and the waterproof paper label can then be placed into the freezer.

3.1.3.6 Filming

The collection of the thiobacteria samples is to be filmed by the party collecting the samples (GoPro camera is to be head mounted), General deck operations (GoPro camera to be mounted on the bridge). The camera must be activated as the grab comes out of the sea. The camera is to be deactivated once the thiobacteria subsamples have been packaged. Filming of at least 5 of the 10 stations is required.
The following are key aspects of the process to be filmed:

- Grab coming out of the sea and on to the deck;
- Nitrile gloves being put on;
- Sub sampling scoop being cleaned with ethanol;
- Sample bottles being prepared (50 ml RNAlater added, labelling, bottle marking);
- Sediment (200 ml) collected from the grab using the scoop. The sample is collected via the inspection window and subsequently put into the sample bottles;
- Sample bottles transferred to the freezer unit;

© NMP 2014

Two GoPros will be provided, one should cover the general activities on deck during the deployment of the grab. The other, as a head mount on the technical team leader / support technical person.

3.1.3.7 Position Control

The station sites are pre-selected to be aligned with the SP-1 verification sample site locations, with 10 of the 26 sites being targeted in this instance. Once the vessel comes on to station using the vessel positing system, the actual position of the vessel is recorded. This position is considered to be the location of the collected sample. There will be drift, however, this is not considered to be significant.

Positioning and depth is recorded by means of a Furuno Navigation system combining with a PS-8000 GPS, video echo-sounder and chart plotter. The positioning system is checked both before and after the cruise at a fixed reference point in Lüderitz harbour (the end of the Ministry of Sea Fisheries Jetty). A separate Garmin GPS linked up to the Maxsea Marine Software program is also used to confirm the accuracy of the main GPS on all samples and at the reference point.

3.1.4 Transporting Samples

The samples are to be transported to Cape Town in the same freezer unit as used on the MV *Snowgoose*. The freezer unit is to be kept in working condition at all times.

The freezer with the samples is to be delivered to:

Dr Bronwyn Kirby
Next Gen Sequencing Unit/Institute for Microbial Biotechnology and Metagenomics University of the Western Cape South Africa
Tel: + 27 (0) 21 9593033 Cell +27 0730498075

3.1.5 Quality Control

In order that quality controls are maintained, the following actions are to be adhered to:

- The technical team is to be familiarised with the sampling protocol;
- The NMP company representative is responsible for ensuring the quality management of the sampling procedure (Form 001- is to be completed for each sample site);
- Nitrile gloves are to be worn during the sub-sampling, A new pair of gloves is to be used per grab location;
- Only the provided nalgene 500 ml bottles are to be used;
- Do not use bottles that may have been contaminated: only use bottles where the seals are intact;
- The nalgene bottles are ONLY to be handled by persons wearing nitrile gloves;
- The sub-sampling scoop is to be cleaned with ethanol prior to use at each site, the scoop must NOT make contact with skin or clothing prior to use. If this should happen, re wash with ethanol;
- The freezer unit must be operating at full capacity for 48 hours prior to samples being stored within the unit;
- The collection of the thiobacteria samples is to be filmed by the party taking the sample, the GoPro camera is to be head mounted.

© NMP 2014

3.1.6 Analysis

This is to be carried out by Dr Bronwyn Kirby of the Next Generation Sequencing Facility/Institute for Microbial Biotechnology and Metagenomics, University of the Western Cape, South Africa.

© NMP 2014

ANNEXURE 1: SUMMARY OF SAMPLING PROTCOL

1. Sample labels are to be pre prepared on waterproof paper, and bottles are to be labelled as per Annexure 2 of this report.
2. Freezer unit to be activated 48 hrs before departure of vessel and temperature gauges (TidBit) to be inserted in the freezer
3. Van Veen grab to be checked and made ready for use at sea
4. Bottles to be kept in black storage containers prior to use
5. Both GoPro cameras to be activated (ensure they are charged prior to survey)
6. Van Veen grab to be deployed
7. Check that the recovered grab contains greater than 50% sediment
8. Recovered grab with station number to be photographed (referencing)
9. A new pair of nitrile gloves to be worn by the sampling team for each sample
10. 4 bottles to be prepared - labelled
11. Scoop to be cleaned with ethanol
12. Do not open the bottles before they are required for use
13. 50 ml RNAlater (fixing agent) to be added to each of 2 bottles
14. The other two bottles will only have sediment in them
15. 200 ml sediment to be put into each of the 4 sample bottles
16. Access the sediment through the inspection window, do not open the grab
17. The plastic scoops may need to be cut to fit the window of the grab.
18. The bottles with 50 ml RNAlater and sediment are to be shaken thoroughly
19. Ensure that all bottles are sealed and labeled correctly
20. Put each sediment filled bottle with its corresponding waterproof label into a transparent plastic bag
21. Put the plastic bag with the sample and its label immediately back in the freezer
22. All bottles (in their plastic bags) to be put into the black crates which must be in the freezer
23. Ensure that bottles are standing upright within the crates
24. Ensure that the freezer seals correctly
25. Dispose of nitrile gloves and any other waste products
26. Ensure that the sample record log is completed and signed off
27. Rinse out the grab prior to re-deployment
28. Turn off the GoPro cameras
29. Sail to the next station
30. Repeat the process.

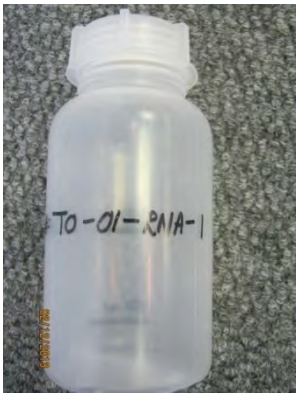
NOTE: It is imperative to ensure that human skin does not come into contact with sample.

NOTE: It is imperative to ensure that the scoop is cleaned with ethanol between stations and that the scoop does not come into contact with human skin

© NMP 2014

ANNEXURE 2: MOCK UP BOTTLE

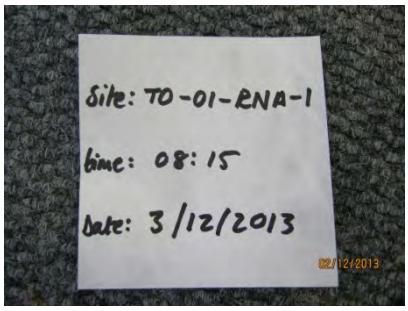
Graphic – *a mock up bottle will be provided to the technical sampling team.*



1. Bottle label (side): TO -01-RNA-1.



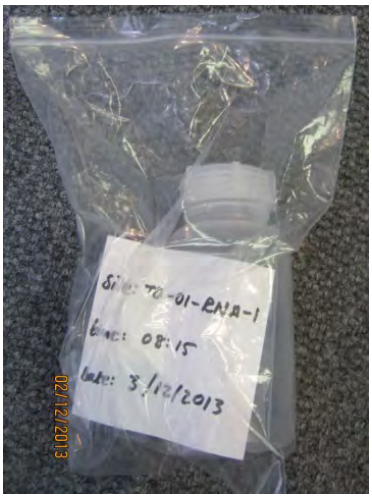
2. Bottle label (lid): TO -01-RNA-1



3. Waterproof Label: with site details (4 labels need to be written up per site, only 1 to be used in the photograph of the grab)



4. Sediment (250 ml) and RNA (50 ml) fill levels for each bottle.



5. Waterproof label and sample bottle placed in packet (once sample bottle is filled)

6. Bottle can now be placed in the freezer.

APPENDIX 1 - WATER COLUMN AND SEDIMENTARY ENVIRONMENT

1.4 Cruise Report: Thiobacteria Survey MV *Snowgoose*

ENVIRONMENTAL VERIFICATION

CRUISE REPORT

THIOBACTERIA SAMPLING

Prepared for:
Namibian Marine Phosphate (Pty) Ltd.

Prepared by:
Benjamin Bothma

24 February - 1 March 2014

Benjamin Bothma
PO Box 754, Lüderitz, NAMIBIA
Phone: +264 63 203 884 *Facsimile*: +264 63 203 878
Cell: +264 (0)81 128 7826

Email: benb@mweb.com.na

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed "Attention: Administration Manager," at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

ML 170

THIOBACTERIA SAMPLING PROGRAMME

CRUISE REPORT

for:

NAMIBIAN MARINE PHOSPHATE (PTY) LTD

VESSEL:	MV *Snowgoose*
CONTRACTOR:	Carpe Diem cc
OWNER/CAPTAIN:	Lukas Els
CONTACT:	+264 63 203358 crpediem@mweb.com.na
CLIENT:	Namibian Marine Phosphate (Pty) Ltd 127 Theo-Ben Gurirab Street, Walvis Bay, Namibia. +27 21 7150372 +264 64 278 150
CLIENT REPRESENTATIVE:	Benjamin Bothma +264 63 203884 +264 81128 7826 benb@mweb.com.na
DATES:	24th February to 1st March 2014

OBJECTIVE

To:

- Collect 10 grab samples from previously sampled sites in ML170, SP-1 area, intended for environmental lab analysis at the University of the Western Cape for thiobacteria.
- Collect 2 additional verification site cores intended for environmental laboratory analysis at the Council for Scientific and Industrial Research (CSIR), Stellenbosch. These fill earlier gaps.
- Obtain accurately positioned samples with QC /QA full integrity.

© NMP 2014

contents

1 INTRODUCTION **1**

2 HISTORICAL BACKGROUND **1**

3 SAMPLING VESSEL **1**

4 SAMPLING EQUIPMENT **2**

4.1 GRAVITY CORER 2

4.2 GRAB SAMPLER 3

5 SAMPLING METHOD **3**

5.1 GRAB DEPLOYMENT 3

5.2 GRAVITY CORER DEPLOYMENT 3

5.3 RECOVERED GRAB SAMPLES 4

5.4 RECOVERED GRAVITY CORE SAMPLES 4

6 SAMPLES **4**

7 POSITIONING **5**

8 SAMPLE HANDLING AND STORAGE **5**

9 CRUISE SUMMARY **5**

10 QC PROCEDURES SUMMARY **6**

Annexure 1: Thiobacteria Sample Locations 7

figures

Figure 1: Sampling vessel: MV *Snowgoose*. 2

Figure 2: Third generation gravity corer in use. 2

Figure 3: Grab sampler illustrating seawater venting mesh (left). Gravity corer and pipes lying on deck (right). 3

© NMP 2014

1 INTRODUCTION

Sampling Cruise # 29 was undertaken to complete an environmental verification programme in ML170. A set of bottled thiobateria samples was taken from 10 grab samples sites. Two gravity core samples were also taken from ML170 filling two gaps in the sampling grid of the environmental verification assessment of August 2013. The thiobacteria samples were required to be collected in a contamination free manner which meant that handling protocols precluded any contact with skin. The thiobacteria samples and the two environmental cores were to be cooled and kept frozen to -18 deg °C from time of collection and during delivery to UWC and CSIR in Cape Town.

2 HISTORICAL BACKGROUND

Phosphatic nodules were first recovered off the Agulhas Bank, South Africa in 1891. In 1978 Dr M. Bremner, of the Marine Geoscience Unit at the University of Cape Town, completed his PhD thesis on "*Sediments on the continental margin of South West Africa between Sylvia Hill and the Kunene River.",* for which a regional set of grab and core samples was collected along the coastal waters of Namibia. Since then there has been a steady stream of research on the marine sediments on the Namibian continental shelf including the research cruises of the R V *Benguela* and the R V *Professor Logachev*. In 1992 and 1994 Gencor drilled 50 vibrocorer holes, mainly in EPL 3414 and 3415 and at waters depths of between 200 and 300 m though some holes did stray into EPL 3323. Though data only exist for 38 of these holes, the results were very encouraging with grades between 15 and 22% P_2O_5 and thicknesses in 8 holes in EPL 3414 lying between 2.62 and 5.05 m, Peripheral areas displayed thicknesses of between 1 and 2.0 m. However, bulk sampling in 2004 by the Ocean Phosphate Consortium in EPL 3415 demonstrated the local continuity of grade and thickness in an area where grades lay between 16.66 and 18.35% P_2O_5 and thicknesses between 3.1 and 6.36 m. The above results provided sufficient evidence to support the view that the Sandpiper Project Area (ML170) could host significant quantities of phosphate, a view that was later confirmed by the 2008 to 2013 grab and core sampling programmes (Cruise Reports 1 to 28).

3 SAMPLING VESSEL

The MV *Snowgoose*, an 18.83 m wooden vessel with a gross tonnage of 63.63 tonnes owned by Carpé Diem Namibia cc. based in Lüderitz, was again used as a platform for the sampling program. The crew consisted of 12 people including the skipper/owner Lukas Els.

© NMP 2014



Figure 1: Sampling vessel: MV *Snowgoose*.

4 SAMPLING EQUIPMENT

4.1 GRAVITY CORER

The third generation 600 kg gravity corer was taken on this cruise (No. 29). Additional weights were also carried to bring the corer weight up to 750 kg if required. The gravity corer comprises a spooling head section and attached to the head section is a 3m or 4m long steel pipe section that carries a 3 m or 4 m long 75 mm or 90 mm internal diameter plastic sample tube. On this cruise a 100 mm steel pipe and 90 mm core tube setup was used for the two environmental cores, while the 75 mm tubes were used for the 100 EPL cores. The 75 mm tube provides about 6.3 kg of material per metre of core while the 90 mm tube provides about 9.2 kg per metre. The 75 mm core tubes are fitted with one-shot aluminium can core catchers riveted and glued in. For the 90 mm tubes core catchers are made from clean oil cans which have slightly thicker sheet metal.



Figure 2: Third generation gravity corer in use.

4.2 GRAB SAMPLER

Samples were to be taken with a modified Van Veen grab sampler. The grab was redesigned to recover samples without flushing the fine sediment out of the grab during recovery. The grab had a scoop volume of 20 litres, with a 425 x 400 mm bite footprint. The grab can take a bite into the sediment of approximately 20 cm depth. The grab was deployed over the side of the vessel by means of a 7 tonne Atlas crane and a free fall winch. The winch cable was fed through a pulley attached to the crane, which allowed the handling of the grab over the side of the vessel before and after deploying the grab to the seabed. The grab was modified to effectively trigger only on impact with the seabed.

5 SAMPLING METHOD

5.1 GRAB DEPLOYMENT

The grab sampler is primed on the vessel gunwale and readied for deployment using the vessels lighter winch (10 mm cable). After lifting the grab over the side, the winch is released, allowing the grab to free-fall to the seabed where it triggers. The GPS position of each grab is recorded when it lands on the seabed on two independent GPS units.



Figure 3: Grab sampler illustrating seawater venting mesh (left). Gravity corer and pipes lying on deck (right).

5.2 GRAVITY CORER DEPLOYMENT

The gravity corer is deployed using the vessels main winch. This winch is not a free fall winch. The gravity corer works with a lever controlled mechanical braking system. A 50 kg weight on a 5 m cable keeps the brake in a locked position while the gravity corer is lowered towards the sea bed on the main winch cable (16 mm). When the 50 kg weigh reaches the sea bed the weight on the lever goes slack, releasing the lever, which allows the brakes to release. The gravity corer then takes a controlled drop of up to 5 m to the seabed on a built in 13 mm wire spool that sits at the top of the corer.

The GPS position of each gravity core is recorded when it lands on the seabed on two independent GPS units.

© NMP 2014

5.3 RECOVERED GRAB SAMPLES

For the specific purpose of this programme each of the 10 grab samples was collected and recovered onto the vessel deck. At this point the grab is not opened in the usual manner. Instead the sediment was accessed through the sea water venting mesh on the top of the grab. In this manner a series of four sub-samples per grab were recovered and bottled in 500 ml Nalgene bottles in a sterile manner and preserved with RNALater (a specialised compound for preserving the thiobacteria in the sediment). The bottles were then stored in a chest freezer and kept frozen all through the transportation to Dr Bronwyn Kirby of the University of the Western Cape, Next Gen Sequencing Unit and Institute for Microbial Biotechnology and Metagenomics. The sampling process was filmed and photographed for audit purposes.

5.4 RECOVERED GRAVITY CORE SAMPLES

The core tube is unbolted and pulled free from the steel core barrel. The depth of the core penetration into the sediment is determined from the mud line on the outer core barrel. A retaining cap is immediately put on the catcher end and the extent of the core fill is determined by inserting a wooden pole into the inner tube to tag the top of the sediment and the internal length of core recovered is recorded. A hacksaw is used to cut the inner tube to the length of core fill so that the other retaining cap can be put on. It may need two cuts to get to a snug fit with the top of the sediment.

The sequential sample number is marked on the end cap of the core with a permanent marker and a corresponding sample tag goes inside the core. Samples are labeled with a sequential 4-digit number, which is logged with the temporal, positional, penetration and licence information on the master logging sheet. The top and bottom of the core is marked.

6 SAMPLES

The two ML 170 cores (90 mm barrel) were frozen and taken to Lüderitz for onwards transport in two deep freezers to CSIR Stellenbosch for environmental analysis. The 10 thiobacteria samples were frozen and delivered to UWC, Belville, Cape Town.

Cores:

Licence	Numbers	Water depth min	Max	Cores / Sites
ML170	2982 - 2983	195	200	2 / 2

Grab Samples:

Licence	Numbers	Water depth min	Max	Grabs / Sites
ML170	T 01 to T 10	195	227	1 / 10

© NMP 2014

7 POSITIONING

Positioning and depth was recorded by means of a Furuno Navigation system combining a PS-8000 GPS, video echo-sounder and chart plotter. The positioning system is checked both before and after the cruise at a fixed reference point in Lüderitz harbour (the end of the Ministry of Fisheries and Marine Resources jetty). A separate Garmin GPS linked up to the Maxsea Marine Software program was also used to confirm the accuracy of the main GPS on all samples and at the reference point.

The latitude and longitude positions of all planned sample sites (see this report Annexure 1) were uploaded onto the Maxsea system and the vessel then occupied each site following the simplest cruise pattern. Once on the target position the gravity corer is lowered over the side and the actual position recorded when the corer hits the seabed. This is to account for any drifting of the vessel after the corer was deployed over the side. Each sample is recorded with a sequential number starting at 2901 and ending on 3002, along with coordinate information, sample size and other pertinent information. Data were hand recorded on pre-prepared work sheets and then entered into a database after the cruise. Failed core sites were also recorded. The same procedure was followed when taking the ten thiobacteria grab samples.

8 SAMPLE HANDLING AND STORAGE

The environmental cores are cut to length (halved or thirds), capped at either end of each marked up section, then stored flat in a deep freezer. Once in port the diamond inspector inspected the cores before being released for storage. They were then transported to the Carpe Diem facilities for temporary storage in the freezer before onward transport to the CSIR, Stellenbosch. In transit he thiobacteria samples were also kept in the freezer and these were delivered to UWC, Bellville. During road transport the samples are kept frozen in the freezer which was carried on a trailer and kept working using a generator on the tow vehicle. Temperature gauges are installed in the freezer unit, which allows for monitoring of the freezer temperatures during transportation.

9 CRUISE SUMMARY

The vessel left Lüderitz at 17:15 on Monday the 24th February 2014 and set sail north to the northern end of ML170 with a strong SW wind (20 to 30 knots) and a 3 m swell. The vessel arrived at the concession area at 13:30 on Tuesday 25th February with a 20 knot SW wind and 2.5 m swell. The vessel had to wait for an improvement in the weather for the next few hours while starting to get ready for sampling at 23:00 with a 5 knot SW wind and 2 m swell. Thiobacteria grab sampling started at 00:13 on the 26th and was completed by 09:40 am. Problems were encountered with gloves (too small and easy to tear) and the GoPro cameras (various issues). Grabs filled reasonably well (20 kg plus) and consistently contained layer 1 shelly mud and phosphate.

Coring was completed at 02:45 on the 1st March and the vessel returned to Lüderitz arriving at 22:00 the same day. Cores and freezer samples were unloaded the following day.

© NMP 2014

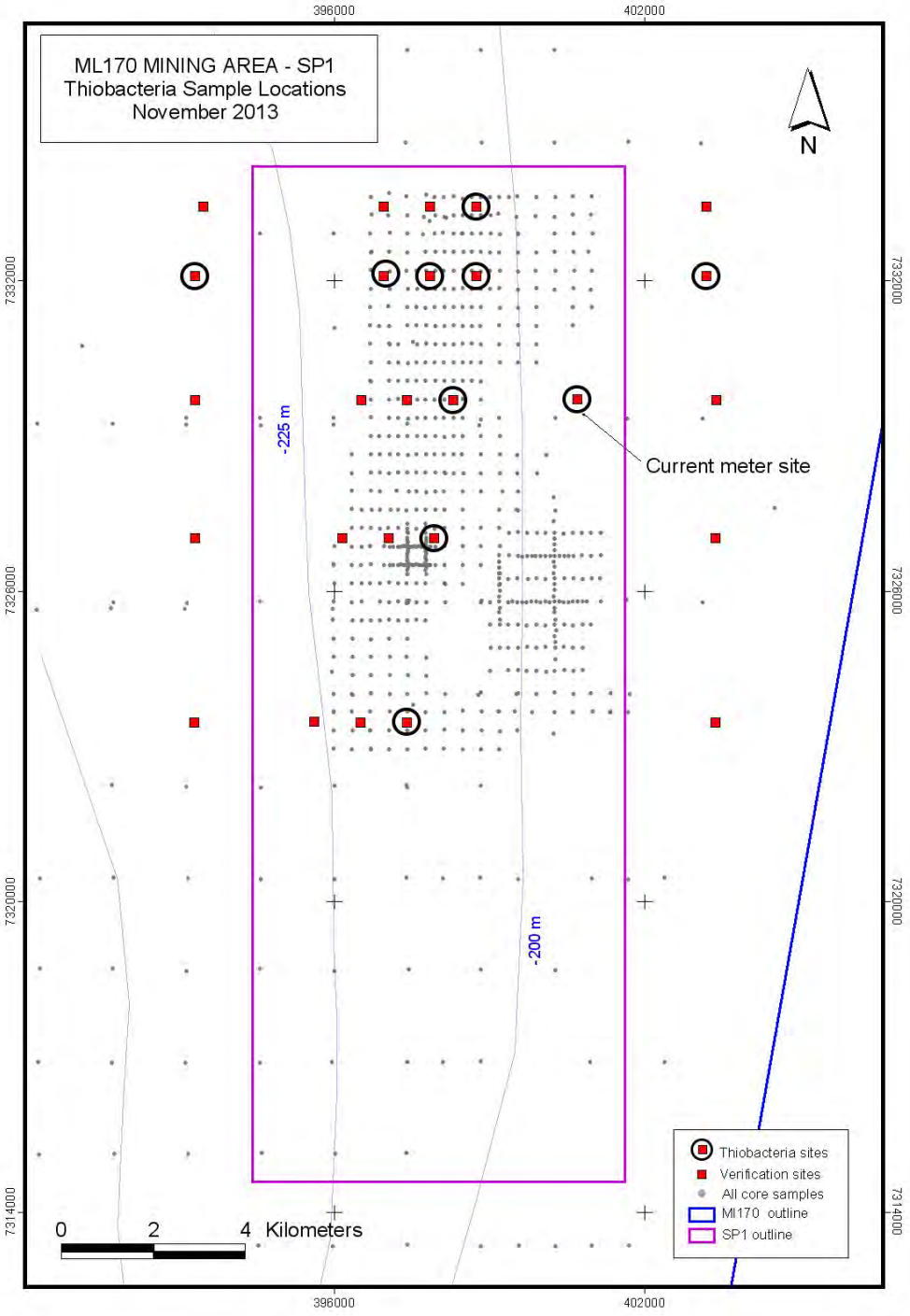
10 QC PROCEDURES SUMMARY

The client representative verified;

- The effectiveness of the GPS positioning system (by comparison with an independent GPS and reference to a fixed position);
- The quality of sample collected (by following sampling procedures and observation);
- The reliability of the record keeping (records attached and each page signed off);
- Correct labeling of the samples;
- Good storage of samples (no leakage, and careful handling of samples).

© NMP 2014

Annexure 1: Thiobacteria Sample Locations



APPENDIX 1 - WATER COLUMN AND SEDIMENTARY ENVIRONMENT

1.5 Project Execution Plan: Core Sampling MV *Snowgoose*

NAMIBIAN MARINE PHOSPHATE

VERIFICATION SURVEY

GRAVITY CORING

PROJECT EXECUTION PLAN

Prepared for:
Namibian Marine Phosphate (Pty) Ltd.

Prepared by:
Lwandle Technologies (Pty) Ltd.
Report compiled by Kate Munnik and Robin Carter

November 2013

Job no: 149

LWANDLE TECHNOLOGIES (PTY) LTD
The Old Warehouse, Black River Park, Fir Road, Observatory 7925, South Africa
Directors: C.P. Matthysen, B.J. Spolander
Co Reg. No. 2003/015524/07

MARINE SPECIALIST TEAM

Robin Carter – Lwandle Technologies, Cape Town
Kate Munnik – Lwandle Technologies, Cape Town

Date	Version	Revised	Reviewed
26/07/13	0.1	J Midgley	Kate Munnik

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed “Attention: Administration Manager,” at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

contents

1 PURPOSE AND SCOPE 1

2 WORK PROCEDURE 7

2.1 SURFICIAL SEDIMENT AND WATER COLUMN FEATURES 7
2.2 MOBILISATION 7
2.3 SAMPLING 7
2.3.1 Sediment Properties 7
2.4 BIOGEOCHEMICAL ANALYSIS 8

3 SAMPLE PRESERVATION AND CURATION 8

4 SAMPLING ANALYSIS 9

5 HEALTH AND SAFETY 9

5.1 PERSONAL PROTECTIVE EQUIPMENT 9
5.2 WORK ON DECK 9
5.3 RISK ANALYSIS 10
5.4 EMERGENCY PROCEDURES AND CONTACT NUMBERS 12
5.5 TOOLBOX MEETING TEMPLATE 13

figures

Figure 1-1: Location of Mining Licence Area (MLA) 170 offshore central Namibia. 2
Figure 1-2: Location of the proposed target dredging sites MLA 170. 3
Figure 1-3 : Gravity coring and Verification sampling sites in target dredge site SP-1. 4
Figure 1-4: The verification sites for SP-2. 5
Figure 1-5: The verification sites in SP-3. 6
Figure 5-1: Risk factor table taken from OGP HS&E guidelines for metocean surveys. 10

© NMP 2014

tables

Table 5-1: RA for the mobilisation of equipment and loading of ship 11
Table 5-2: RA for work on vessel deck 11
Table 5-3: RA for the handling and analysis of sediment samples 11
Table 5-4: RA for the deployment and recovery of Rosette and CTD 12
Table 5-5: RA for the packaging and unloading of samples 12
Table 5-6: Emergency contact details: 12

© NMP 2014

1 PURPOSE AND SCOPE

Namibian Marine Phosphate (NMP) is proposing to extract marine pelletal phosphate ore from deposits on the Namibian continental shelf. The phosphate will be extracted by dredging and the assessment of the environmental impacts associated with the project is therefore strongly reliant on a sound understanding of the sediment properties of the dredge area.

The purpose of the gravity coring survey is to confirm the sediment properties of the seafloor (to a maximum depth of ~ 2 m) within the proposed dredge area. This information will then be used, in conjunction with previous scientific investigations of the region as well as those from the verification survey, to further inform the assessment of impacts on the marine environment as a result of the proposed dredging operations. This will aid in the final assessment of the impacts as detailed in the EIA / EMPR.

The gravity coring survey will include the collection of seafloor sediments using a drop or gravity corer from aboard the MV *Snowgoose*. The collected sediment samples will be frozen on board the vessel and then transported in a frozen state back to South Africa for various analyses.

The focused survey area is defined as mine area SP-1, which is within MLA 170 (Figure 1-1), and is situated south west of Walvis Bay, directly offshore of Conception Bay and Meob Bay. The Sandpiper Phosphate licence area (MLA 170) includes mine target areas; SP-1, SP-2 and SP-3 (Figure 1-2). SP-1, where the verification survey will take place, is the primary dredging target area of the project (a 20-year mine plan is established for this site), while the dredging of SP-2 and SP-3 will take place subsequently. The gravity coring sites will match those to be sampled during the verification survey which will take place between 24 July and 8 August.

© NMP 2014

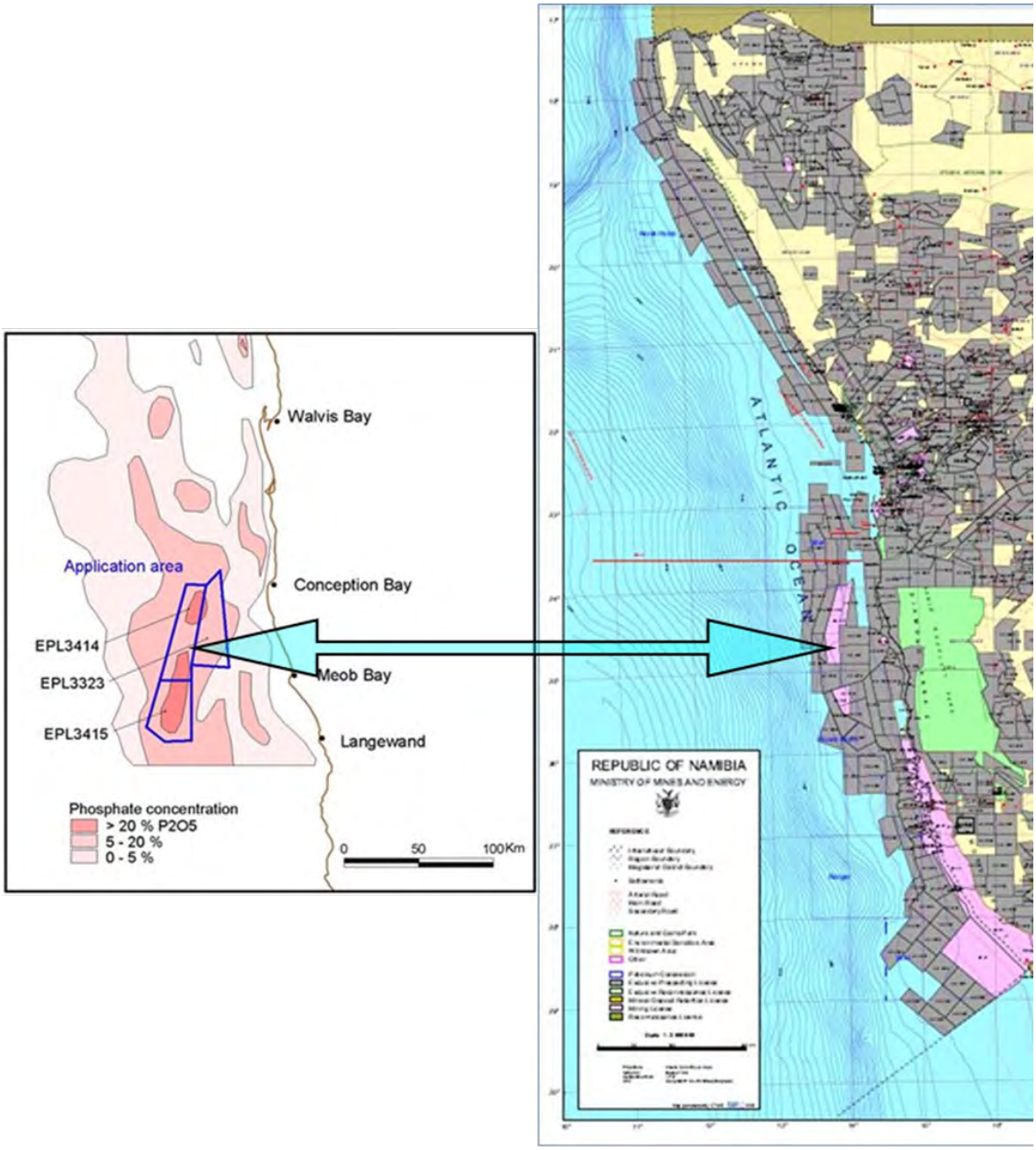


Figure 1-1: Location of Mining Licence Area (MLA) 170 offshore central Namibia.
MLA 170 is a consolidation of EPLs 3414 and portions of EPLs 3323 & 3415.

© NMP 2014

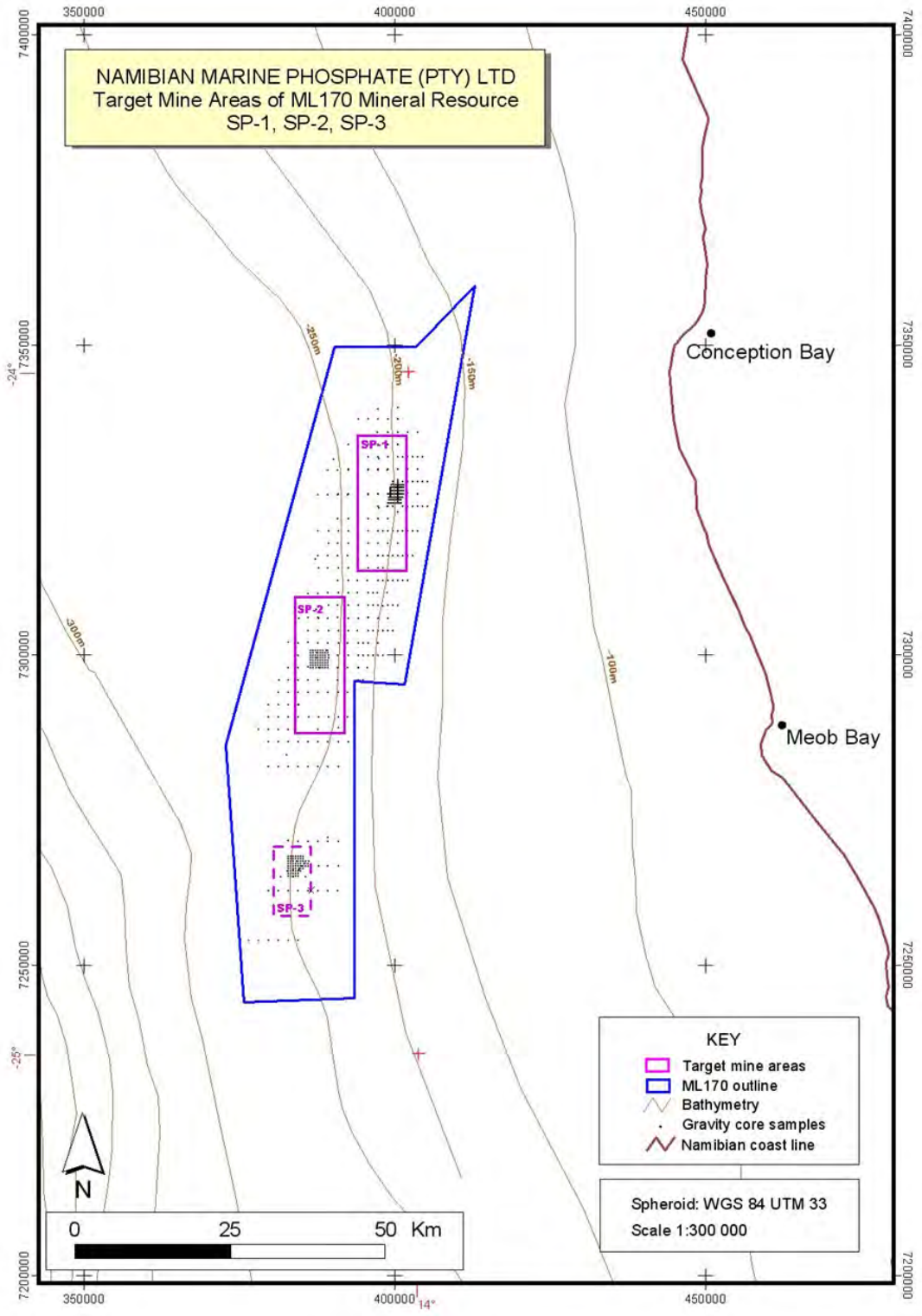


Figure 1-2: Location of the proposed target dredging sites MLA 170.
SP-1 (20 year mine plan established), SP-2 and SP-3 within the three resource areas of the Sandpiper Phosphate licence area.

© NMP 2014

A grid of sampling sites will be placed across SP-1 such that the broad distributions of sediment properties across the entire mine site can be determined. Figure 1-3 shows the sampling station layout (large black open squares).

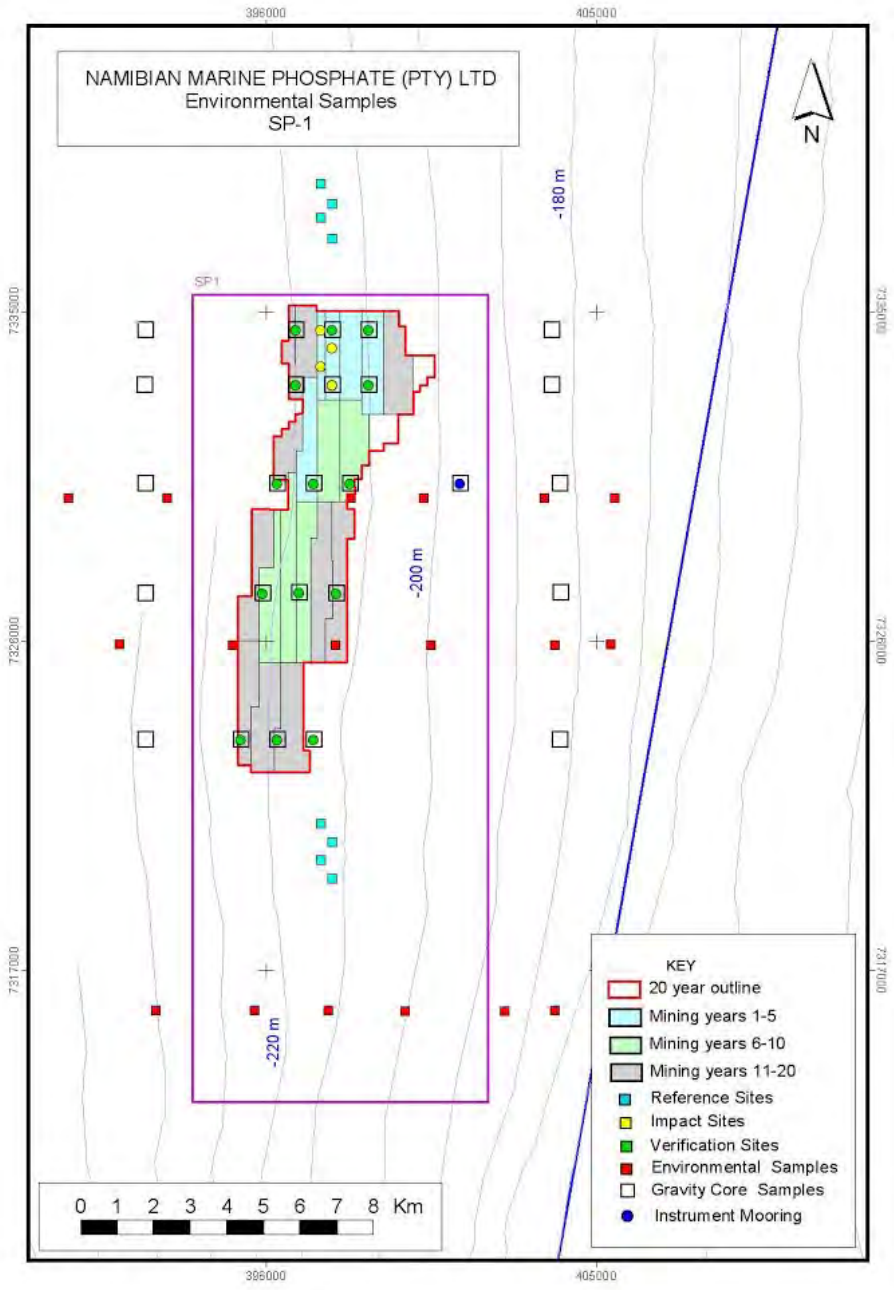


Figure 1-3 : Gravity coring and verification sampling sites in target dredge site SP-1. Note that the gravity coring/verification survey sites are represented by black open squares. Green squares represent sites identified for benthos verification sampling (Steffani); additional sampling sites for the macro benthos, meiofauna and sediment properties monitoring programme are shown in yellow (impact) and blue (reference). The blue square shows the provisional moored instrumentation site. Only the gravity coring/verification sites will be sampled during this survey.

© NMP 2014

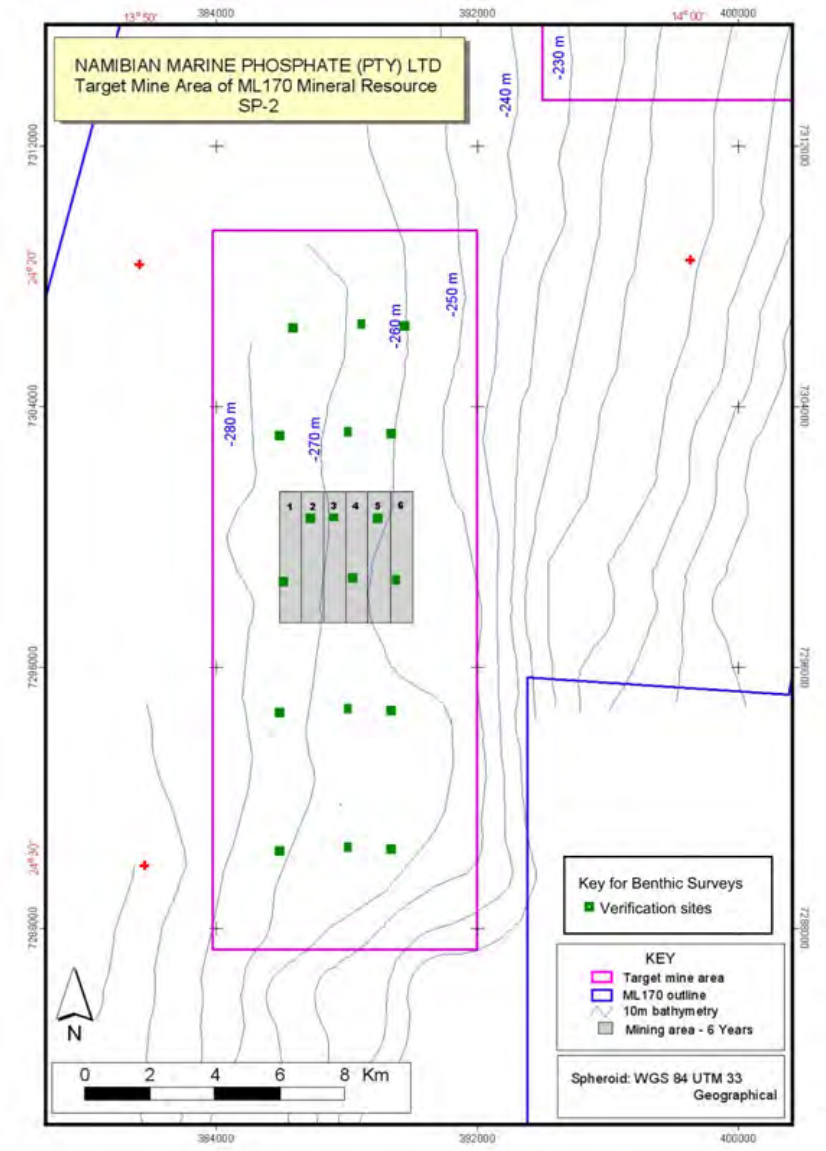


Figure 1-4: The verification sites for SP-2.

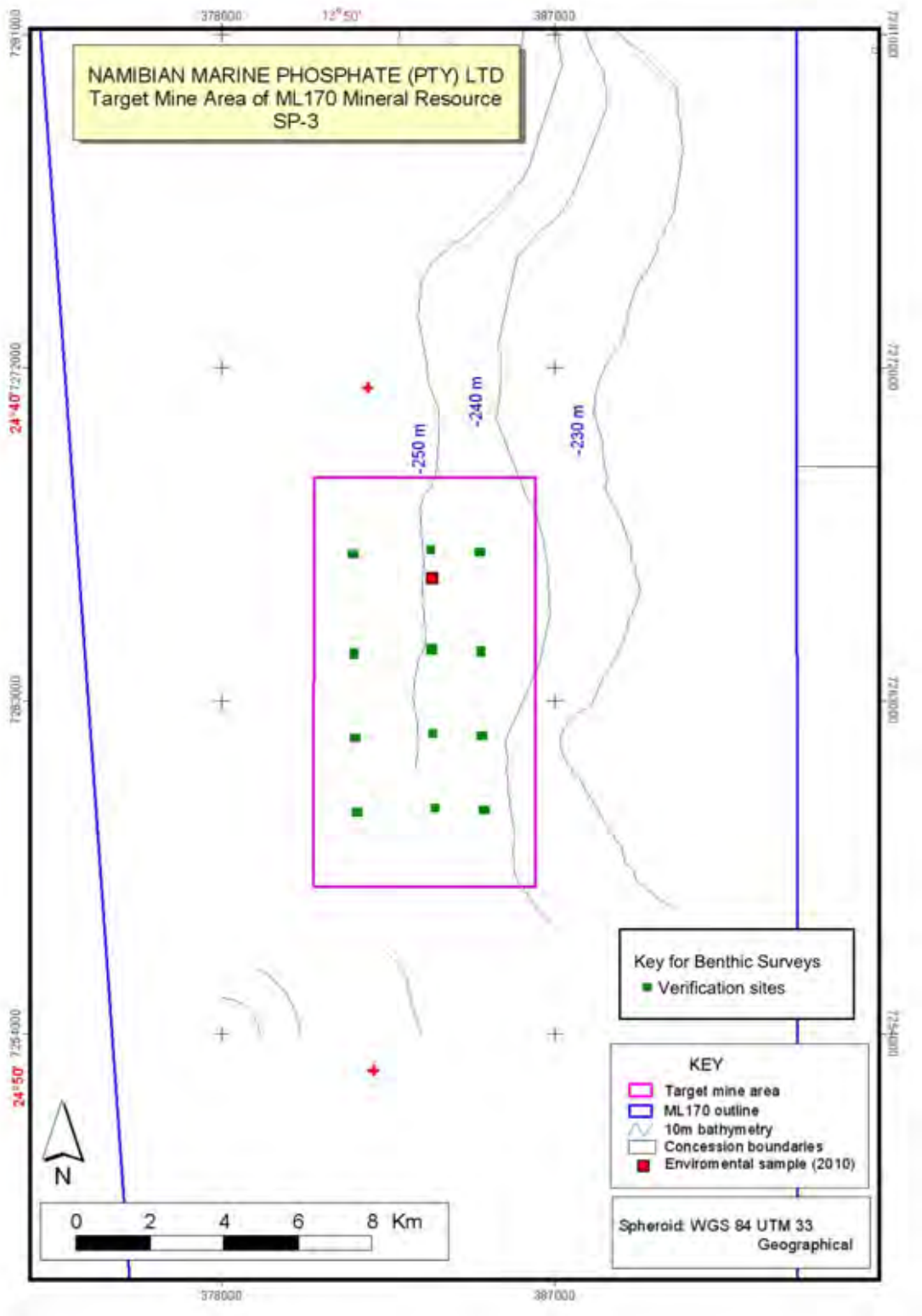


Figure 1-5: The verification sites in SP-3.

2 WORK PROCEDURE

2.1 SURFICIAL SEDIMENT AND WATER COLUMN FEATURES

Equipment and personnel will be mobilised to the port of embarkation (Walvis Bay). Following loading of the survey vessel, equipment will be carefully unpacked and assembled. Electronic equipment will be powered up and tested to determine whether any breakages have occurred during transit. Repairs or replacements will be made if and where necessary.

2.2 MOBILISATION

It is assumed that all coring equipment will be provided on board the MV *Snowgoose* and that this will be deployed by the ship's crew. The MV *Snowgoose* will mobilise out of Lüderitz, Namibia, for this survey.

2.3 SAMPLING

The ship's crew will conduct a test run of the sampling equipment before the vessel leaves the port area. This will allow the repair or modification of any equipment or deployment and recovery techniques before the cruise gets underway.

Once the testing has been completed; the vessel will progress to the relevant sampling locations and carry out the following procedures:

2.3.1 Sediment Properties

A gravity core is required to determine the subsurface particle size and texture distribution to a depth of ~3 m into the seabed, optimally terminating into footwall clay. Gravity core samples will be collected in similar locations to where box core samples are to be collected during the verification survey in the target dredge area SP-1.

All procedures are to be conducted by the officers and crew of the *Snowgoose*; there will be no Lwandle company representative on board during the survey.

There may be instances where the gravity core is unable to penetrate the surface of the seafloor, or where the core does not close correctly as a result of shelly bottom and/or debris becoming trapped in the sealing device. In such a case, the core attempt will be repeated a maximum of three times. In the event of no successful core being completed in any of the three attempts, the sampling site will be abandoned.

Following retrieval of the gravity core to deck the inner plastic liner (inner core tube) will be capped (top and bottom), cut in half and re capped at the open ends. The core reference number and sampling data are to be written on the subsample and these data logged on the data sheets. Each capped core section is to be directly placed in a chest freezer operating at -18 °C or lower. The core samples are to remain in the freezer until reaching CSIR Stellenbosch, where the analyses will take place.

© NMP 2014

2.4 BIOGEOCHEMICAL ANALYSIS

Analyses will be conducted under subcontract by CSIR, Stellenbosch. Variables will include AVS, POM, POC and PON, and particle size distributions.

Refer to: Gravity core analysis requirements (Appendix 1.6).

3 SAMPLE PRESERVATION AND CURATION

The preservation and curation of all samples collected while on board the vessel will be the responsibility of the ship's crew. It is very important that the samples are preserved and stored correctly to avoid any loss of data while the vessel is underway, or during transportation back to South Africa.

All permissions, authorisations and permits required for transporting the chemical/biological samples and any associated sampling equipment back into South Africa will need to be organized by NMP.

On board:

- All sample containers to be clearly labelled with the relevant station number, date etc. This information is to match that in the sample record data sheets.
- Check sample conditions in freezer daily. Ensure power connection to all fridges / freezers containing samples remains stable.
- Check integrity of biological samples daily (i.e. no leaks/drying etc.).

During transport back to South Africa:

- Ensure sufficiently inert packing material to safeguard samples and increase insulation.
- Add an operating temperature logging device (TidBit) to each of the freezers.
- Ensure the freezers are secured correctly and are not able to be opened.
- Ensure there is a continuous power source to the freezers so that the internal temperature remains below 18 °C.
- Clearly label the freezers with number and type of samples and destination.
- These samples must be transported back to South Africa overland via Swift Air or other courier to be arranged by the client.

© NMP 2014

4 SAMPLING ANALYSIS

Sediment samples will then be analysed back in Cape Town, the following analyses will be carried out:

- Organic content, POC and PON concentrations;
- Heavy metal concentrations;
- AVS and SEM;
- ORP.

5 HEALTH AND SAFETY

Mr Jeremy Midgley (NMP's representative) will be responsible for the overseeing of health and safety aspects for the duration of the trip.

5.1 PERSONAL PROTECTIVE EQUIPMENT

Personal protective equipment (PPE) must be worn on the vessel as directed by the vessel master.

The following general offshore PPE should be provided to personnel on board the MV *Snowgoose*:

- Bright Coveralls or at least long working pants with a reflective vest
- Safety footwear
- Safety helmet (as required during lift operations)
- Gloves
- Masks, safety glasses and nitrile gloves for working with formalin
- Self-inflatable life jackets
- Safety harnesses

5.2 WORK ON DECK

Particular care is required when handling any over-side equipment, each member of the field team is to ensure that the correct and safe procedures are understood and implemented for all work taking place on the deck of the vessel. The field team should ensure their safety harnesses are properly secured for any work undertaken near the gunwale of the vessel.

If the weather conditions begin to deteriorate, the field team should continually assess the situation and stop work whenever necessary. This is especially true in conditions where equipment becomes unstable, or instrumentation begins swaying excessively on the winch.

All the members on the field team will have the full authority to issue a "Stop work" command if anyone perceives a hazard during work operations. Most technical/manual activities are to be undertaken by trained boat crew.

A toolbox meeting should be held prior to any new tasks and or beginning of every shift being undertaken, and a refresher meeting should occur whenever necessary.

© NMP 2014

5.3 RISK ANALYSIS

A number of risk assessments have been carried out in alignment with the tasks that the field team will be carrying out. The risk assessments have been prepared on the basis of the risk factor table presented in Figure 5-1. The risk assessment tables should be read in conjunction with the associated deployment and recovery procedures.

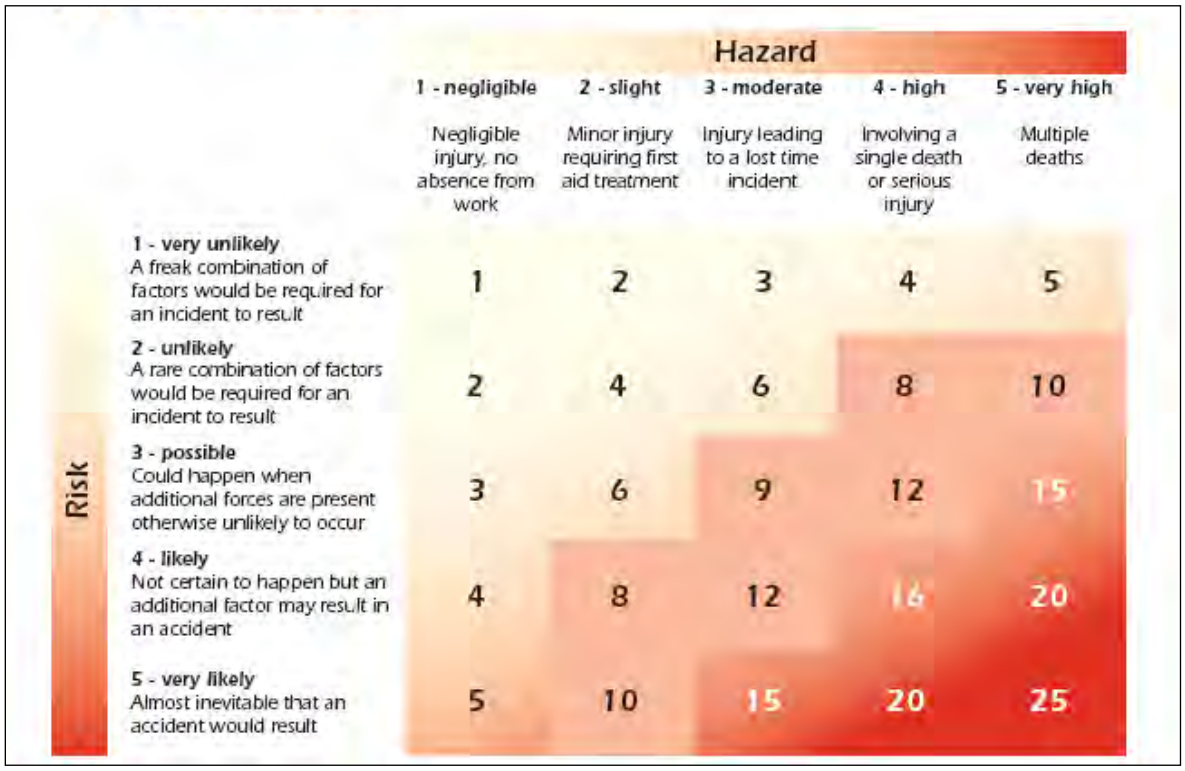


Figure 5-1: Risk factor table taken from OGP *HS&E Guidelines for Metocean Surveys*[1]..

[1] International Association of Oil and Gas Producers. http://www.ogp.org.uk/pubs/348.pdf

Table 5-1: RA for the mobilisation of equipment and loading of ship

Risk	H	R		Mitigation	H	R	
Theft/loss of valuables/ equipment/ personnel	4	3	12	• Keep all valuables out of sight while travelling. • Ensure equipment is securely packaged before transportation. • Be vigilant when travelling.	2	3	6
Scratches from securing equipment/moving/carrying boxes	2	3	6	• Use of PPE. • Ensure all boxes/crates are properly secured. • Ensure vessel crew is responsible for hoisting.	1	2	2
Injury to personnel and / or damage to equipment from uncontrolled lifting/dropping of boxes/equipment	4	3	12	• Use of PPE • Lift carefully, bend knees and not back.	1	2	2

Table 5-2: RA for work on vessel deck

Risk	H	R		Mitigation	H	R	
Personal injury due to Slips/trips/falls	4	3	12	• Use of PPE, especially safety shoes when on deck • Ensure deck is cleared of potential trip hazards	1	2	2
Personal injury due to falling over gunwale	5	3	15	• Use of PPE, especially life jackets and safety harnesses when working near the gunnel. • Work close to the gunnel only when it is safe to do so, if weather conditions are not favourable –Stop work.	3	2	6

Table 5-3: RA for the handling and analysis of sediment samples

Risk	H	R		Mitigation	H	R	
Injury to personnel/equipment from mishandling samples/grabs	4	3	12	• Use of PPE • Be vigilant when handling equipment and samples • Ensure no one puts their fingers close to the jaws of either grab.	1	2	2
Personal injury due to exposure to formalin	4	2	8	• Use of PPE • Use supplied gas mask • Only use formalin in well ventilated areas • Wash hands after work with formalin	3	1	3

© NMP 2014

Table 5-4: RA for the deployment and recovery of Rosette and CTD

Risk	H	R		Mitigation	H	R	
Personal (hands/head/feet)injury or damage to equipment due to mishandling of rosette	3	3	9	• Use of PPE, especially hardhats, safety boots • Ensure care is taken when setting up Niskin bottles, keep fingers away from the tops/bottoms of open bottles • Ensure care is taken when hoisting/lowering rosette unit.	3	2	6

Table 5-5: RA for the packaging and unloading of samples

Risk	H	R		Mitigation	H	R	
As per table 5-1	0	0	0		0	0	0

5.4 EMERGENCY PROCEDURES AND CONTACT NUMBERS

In the case of any emergency the following numbers are to be called either from a satellite phone, local sim card, or on board telephone (Table 5-6). Please ensure that this list of numbers is placed in an area visible to all field staff during work on board the vessel and while travelling.

Table 5-6: Emergency contact details:

Name	Position	Email	Phone number
Jeremy Midgley	NMP representative	mwjmidg@mweb.co.za	+ 27 21 7886212 +27 832649484
Bill Ludick	NMP representative	bludick@mweb.co.za	0814822386 (Namibian number)
Mike Woodborne	NMP land project coordinator	mike.woodborne@uclresources.com.au mike.woodborne@gmail.com	+61 410307205 / +37281054658
Hospital	Walvis Bay Medipark T/a Welwitchia Hospital	Street Address: Gertrude Rikumba Kandanga Hilukilwa Street, Walvis Bay	+26 464 21 8911
Police Station	Walvis Bay Police Station	Walvis Bay, Namibia	+264 64 21 9048 / 64 202 055 / 10111/
Sea Rescue	Namibian Sea Rescue		208 2221 or 081 129 6295

While on board, the vessel staff will be required to follow and adhere to all health and safety requirements/instructions given to them by the vessel captain.

© NMP 2014

5.5 TOOLBOX MEETING TEMPLATE

Toolbox Meetings

A toolbox meeting will be held prior to each operation, inclusive of Client rep, Party chief, technicians and divers discussing the following:

- Anticipated operations to be undertaken
- Any hazards that have not been actioned
- Individual concerns of employees

The toolbox meeting will be documented according in the following format:

Date & time of meeting		Date & time of report	
Location		Vessel	
List of attendees		Present weather conditions	

Matters for discussion

Scope of work summary		Comments	
Review and acceptance of JSA		Signed	

Signatures

Party Chief		Dive Master	
Client Rep			

APPENDIX 1 - WATER COLUMN AND SEDIMENTARY ENVIRONMENT

1.6 Gravity Core: Analysis Requirements

NAMIBIAN MARINE PHOSPHATE

CORE ANALYSIS REQUIREMENTS

METHOD STATEMENT

Prepared for:
Namibian Marine Phosphate (Pty) Ltd.

Prepared by:
Lwandle Technologies (Pty) Ltd.
Report compiled by Kate Munnik and Robin Carter

November 2013

Job no: 149

LWANDLE TECHNOLOGIES (PTY) LTD
The Old Warehouse, Black River Park, Fir Road, Observatory 7925, South Africa
Directors: C.P. Matthysen, B.J. Spolander
Co Reg. No. 2003/015524/07

MARINE SPECIALIST TEAM

Robin Carter – Lwandle Technologies, Cape Town
Kate Munnik – Lwandle Technologies, Cape Town

Date	Version	Revised	Reviewed
26/05/13	0.1	Kate Munnik	Robin Carter
08/05/13	0.2	Kate Munnik	Robin Carter

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed “Attention: Administration Manager,” at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

contents

1 GRAVITY CORE ANALYSIS 1

1.1 PRE-ANALYSIS CHECKS 1
1.2 IDENTIFYING CORE SECTIONS 1
1.3 COLLECTING SUB-SAMPLES AT VARIOUS DEPTHS 2
1.4 DESCRIBING SUB-SAMPLES 2
1.5 SEPARATING FOR FULL/PARTIAL ANALYSES 2
1.6 FULL ANALYSIS 3
1.7 PARTIAL ANALYSIS 3

tables

Table 1-1: Log sheet for gravity core collection, for NMP trial 1

© NMP 2014

1 GRAVITY CORE ANALYSIS

1.1 PRE-ANALYSIS CHECKS

Throughout the different phases of analyses and the preparation for these, detailed log sheets should be kept.

The first task will be to determine whether or not all the listed cores (Table 1-1) are present in the freezer, and how many sections each one has been divided into.

Table 1-1: Log sheet for gravity core collection, for NMP trial

Sample #	Date /Time	Depth	Penet.	Sections	General Comments	
	26/03/2013					
2735	12:30	215	0.75	1	90 mm pipe Enviro : 3 m swell / no wind	no clay
2735	12:30	215	1.55	2	2 attempts	no clay
2736	12:55	215	0.73	1	90 mm pipe Enviro : 5 kts wind : 2 attempts	no clay
2737	13:53	215	2.11	2	90 mm pipe Enviro : 3,5 m swell / 5 kts wind	clay
2738	14:13	216	0.91	1	90 mm pipe Enviro : 3,5 m swell / 8 kts wind	no clay
2738	14:13	216	2.39	2	2 attempts	no clay
2739	14:48	215	2.74	3	90 mm pipe Enviro : 3,5 m swell / 8 kts wind	no clay
2740	15:03	216	2.18	2	90 mm pipe Enviro : 3,5 m swell / 8 kts wind: (Duplicate)	no clay
2741	15:20	215	2.19	2	90 mm pipe Enviro : 3,5 m swell / 8 kts wind	no clay
2742	15:54	215	2.4	2	90 mm pipe Enviro : 3,5 m swell / 10 kts wind	no clay
2743	16:27	215	2.4	2	90 mm pipe Enviro : 3,5 m swell / 15 kts wind	no clay
2744	17:05	215	1.1	1	90 mm pipe Enviro : 3,5 m swell / 18 kts wind	no clay
2745	17:22	215	2.4	2	90 mm pipe Enviro : 3,5 m swell / 18 kts wind	no clay
2746	17:45	216	2.35	2	90 mm pipe Enviro : 3,5 m swell / 18 kts wind : (Duplicate)	no clay

1.2 IDENTIFYING CORE SECTIONS

Next all sections of each of the cores will need to be placed into the correct order (according to depth).

The full length (i.e. all sections) of the two duplicated cores (2740 and 2746) can then be handed over to Mr P. Morant, CSIR Stellenbosch, and he will provide the detailed instructions for their analysis.

© NMP 2014

1.3 COLLECTING SUB-SAMPLES AT VARIOUS DEPTHS

The full length (all sections) of the remaining 10 cores must then be divided into sub-samples at various depths along each core. In the case of cores 2735 and 2738, where two attempts at obtaining the cores were made, the first attempt will not be analysed. This means that sections 2735 (T1) and 2738 (T1) will remain whole and won't be analysed.

Dividing the remaining sections into sub-samples will be done by first heating the outer core casing and then attempting to push out the core sample using a rod. As the sample extrudes from the opposite end of the core casing, the required sections will be broken off from the main core. All sub-samples need to be purged with liquid nitrogen to restrict oxygenation and placed as quickly as possible into pre-labelled transparent, sealable plastic bags and appropriately stored for analysis. If it proves difficult to extrude the sediment cores for sub-sectioning the alternative of cutting the entire core (including the outer casing) into 'biscuits' can be followed. Cutting should be with a pipe-cutter which should not penetrate into the sediment sample. For this, it may be helpful to mark the exterior core casing with the following sub-sectioning depth intervals, as they will continue across different length sections of the various cores:

For all cores, sub-samples from the following lengths will need to be collected:

1. 0 - 10 cm
2. 20 – 30 cm
3. 50 – 60 cm
4. 100 – 110 cm
5. 200- 210 cm, or if shorter than 200 cm, the bottom 10 cm of the core.

1.4 DESCRIBING SUB-SAMPLES

Each packaged sub-sample will then need to be photographed and a description of the sample must be recorded on the appropriate log sheet. Ensure a detailed label (Sub-sample ID) as well as an object (for scale) are both visible in all of these photographs. Notes on the classification of the sediment should also be made at this time, the broad texture gradings are: mud, sand, or gravel. The presence of shells/shell fragments should be noted; it is expected that the samples will comprise mainly muddy sand and shell fragments with the latter in the gravel size range. Any bioturbation (biological activity as indicated by, eg, worm tubes) present in the sub-samples should too be noted.

1.5 SEPARATING FOR FULL/PARTIAL ANALYSES

The sub-samples from all the cores will then need to be separated into those that require full analysis and those that require only partial analysis:

- Full Analysis is required for all sub-samples from cores: 2735, 2739, 2745
- Partial Analysis is required for all sub-samples from cores: 2736, 2737, 2738, 2741, 2742, 2743, 2744.

© NMP 2014

1.6 FULL ANALYSIS

Sub-samples will need to be prepared for analysis in the appropriate manner after which the following analyses will be carried out:

- Heavy metals including Cd, Hg, Al, As, Ba, Cr, Cu, Co, Fe, Mn, Ni, Pb, V, Zn)
- Acid volatile sulphide (AVS) and simultaneously extracted metals test (SEM)
- Total organic matter
- Total organic carbon
- Total N
- Particle size analysis (including the sub 63 µm fraction)
- Redox state

1.7 PARTIAL ANALYSIS

Sub-samples will need to be prepared for analysis in the appropriate manner after which the following analyses will be carried out:

- Acid volatile sulphide (AVS)
- Total organic matter
- Total organic carbon
- Total N
- Particle size analysis (including the sub 63 µm fraction)
- Redox state.

© NMP 2014

APPENDIX 1 - WATER COLUMN AND SEDIMENTARY ENVIRONMENT

1.7 Cruise Report: Core Sampling MV *Snowgoose*

ENVIRONMENTAL VERIFICATION

CRUISE REPORT

CORE SAMPLING

Prepared for:
Namibian Marine Phosphate (Pty) Ltd.

Prepared by:
Benjamin Bothma

8 - 11 August 2013

Benjamin Bothma
PO Box 754, Lüderitz, NAMIBIA
Phone: +264 63 203 884 *Facsimile*: +264 63 203 878
Cell: +264 (0)81 128 7826

Email: benb@mweb.com.na

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed “Attention: Administration Manager,” at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

ML 170

PHOSPHATE CORE SAMPLING PROGRAMME

CRUISE REPORT

for:

NAMIBIAN MARINE PHOSPHATE (PTY) LTD

VESSEL:	MV *Snowgoose*
CONTRACTOR:	Carpe Diem cc
OWNER/CAPTAIN:	Lukas Els
CONTACT:	+264 63 203358 crpediem@mweb.com.na
CLIENT:	Namibian Marine Phosphate (Pty) Ltd 127 Theo-Ben Gurirab Street, Walvis Bay, Namibia. +27 21 7150372 +264 64 278 150
CLIENT REPRESENTATIVE:	Benjamin Bothma +264 63 203884 +264 81128 7826 benb@mweb.com.na
DATES:	8th to 11th August 2013

OBJECTIVE

To:

- Collect 26 cores in ML 170, SP-1 area, intended for laboratory analysis at the CSIR, Stellenbosch.
- Obtain accurately positioned samples with QC /QA full integrity.

© NMP 2014

contents

1 INTRODUCTION **1**

2 HISTORICAL BACKGROUND **1**

3 SAMPLING VESSEL **1**

4 SAMPLING EQUIPMENT **2**

5 SAMPLING METHOD **3**

5.1 GRAVITY CORER DEPLOYMENT 3

5.2 RECOVERED GRAVITY CORE SAMPLES 3

6 SAMPLES **3**

7 POSITIONING **4**

7.1 SAMPLE HANDLING AND STORAGE 4

7.2 CRUISE SUMMARY 4

8 QC PROCEDURES SUMMARY **5**

8.1 RECOMMENDATIONS 5

Annexure 1: Location map ML 170 – Waypoints / Core sample sites 6

figures

Figure 1: Sampling vessel: MV *Snowgoose*. 2

Figure 2: Third generation gravity corer in use. 2

© NMP 2014

1 INTRODUCTION

Sampling Cruise # 28 was undertaken to obtain and freeze 26 gravity core samples from ML 170 as part of the environmental verification assessment. The samples were required to be collected in a contamination fee manner and with the cores cooled and kept frozen to -18 deg °C from time of collection and during delivery to CSIR, Stellenbosch, South Africa.

2 HISTORICAL BACKGROUND

Phosphatic nodules were first recovered off the Agulhas Bank, South Africa in 1891. In 1978 Dr M. Bremner, of the Marine Geoscience Unit at the University of Cape Town completed his PhD thesis on "*Sediments on the continental margin of South West Africa between Sylvia Hill and the Kunene River.",* for which a regional set of grab and core samples were collected along the coastal waters of Namibia. Since then there has been a steady stream of research on the marine sediments on the Namibian continental shelf including the research cruises of the R V *Benguela* and the R V *Professor Logachev*. In 1992 and 1994 Gencor drilled 50 vibrocorer holes, mainly in EPL 3414 and 3415 and at waters depths of between 200 and 300 m though some holes did stray into EPL 3323. Though data only exists for 38 of these holes, the results were very encouraging with grades between 15 and 22% P_2O_5 and thicknesses in 8 holes in EPL 3414 lying between 2.62 and 5.05 m, Peripheral areas displayed thicknesses of between 1 and 2.0 m. However, bulk sampling in 2004 by the Ocean Phosphate Consortium in EPL 3415 demonstrated the local continuity of grade and thickness in an area where grades lay between 16.66 and 18.35% P_2O_5 and thicknesses between 3.1 and 6.36 m. The above results provided sufficient evidence to support the view that the Sandpiper Project Area (ML 170) could host significant quantities of phosphate, a view that was later confirmed by the 2008 to 2013 grab and core sampling programmes (Cruise Reports 1 to 27).

3 SAMPLING VESSEL

The MV *Snowgoose*, an 18.83 m wooden vessel with a gross tonnage of 63.63 tonnes owned by Carpé Diem Namibia cc. based in Lüderitz, was again used as a platform for the sampling program. The crew consisted of 12 people including the skipper/owner Lukas Els.

© NMP 2014



Figure 1: Sampling vessel: MV *Snowgoose*.

4 SAMPLING EQUIPMENT

The third generation 600 kg gravity corer was taken on this cruise (No. 28). Additional weights were also carried to bring the corer weight up to 750kg if required. The gravity corer comprises a spooling head section and attached to the head section is a 3m or 4m long steel pipe section that carries a 3 m or 4 m long 75 mm or 90 mm internal diameter plastic sample tube. On this cruise a 100mm steel pipe and 90mm core tube setup was used for the 26 environmental cores. The 75 mm tube provides about 6.3 kg of material per meter of core while the 90 mm tube provides about 9.2 kg per meter. The 75 mm core tubes are fitted with one-shot aluminium can core catchers riveted and glued in. For the 90mm tubes core catchers are made from clean oil cans which have slightly thicker sheet metal.



Figure 2: Third generation gravity corer in use.

© NMP 2014

5 SAMPLING METHOD

5.1 GRAVITY CORER DEPLOYMENT

The gravity corer is deployed using the vessel's main winch. This winch is not a free fall winch. The gravity corer works with a lever controlled mechanical braking system. A 50 kg weight on a 5 m cable keeps the brake in a locked position while the gravity corer is lowered towards the sea bed on the main winch cable (16 mm). When the 50 kg weight reaches the sea bed the weight on the lever goes slack, releasing the lever, which allows the brakes to release. The gravity corer then takes a controlled drop of up to 5 m to the seabed on a built-in 13 mm wire spool that sits at the top of the corer.

The GPS position of each gravity core is recorded when it lands on the seabed on two independent GPS units.

5.2 RECOVERED GRAVITY CORE SAMPLES

The core tube is unbolted and pulled free from the steel core barrel. The depth of the core penetration into the sediment is determined from the mud line on the outer core barrel. A retaining cap is immediately put on the catcher end and the extent of the core fill is determined by inserting a wooden pole into the inner tube to tag the top of the sediment and the internal length of core recovered is recorded. A hacksaw is used to cut the inner tube to the length of core fill so that the other retaining cap can be put on. It may need two cuts to get to a snug fit with the top of the sediment.

The sequential sample number is marked on the end cap of the core with a permanent marker and a corresponding sample tag goes inside the core. Samples are labeled with a sequential 4-digit number, which is logged with the temporal, positional, penetration and license information on the master logging sheet. The top and bottom of the core is marked.

6 SAMPLES

In total 26 core sites were attempted in which 25 gravity cores (in the number range 2875 to 2899) were recovered using the 90 mm core barrels, ranging in length from 0.60 to 2.90 m. The final site (2900, SP1GC21), at a water depth of 183 m, only produced enough material on the third attempt to make up a bottle sample. The ML 170 cores were frozen and taken to Lüderitz for onwards transport in two deep freezers to Stellenbosch for environmental analysis.

Licence	Numbers	Water depth min	Max	Cores
ML 170	2875 - 2900	181	237	25

© NMP 2014

7 POSITIONING

Positioning and depth was recorded by means of a Furuno Navigation system combining a PS-8000 GPS, video echo-sounder and chart plotter. The positioning system is checked both before and after the cruise at a fixed reference point in Lüderitz harbour (the end of the Ministry of Fisheries and Marine Resources jetty). A separate Garmin GPS linked up to the Maxsea Marine Software program was also used to confirm the accuracy of the main GPS on all samples and at the reference point.

The latitude and longitude positions of all planned sample sites were uploaded onto the Maxsea system and the vessel then occupied each site following the simplest cruise pattern. Once on the target position the gravity corer is lowered over the side and the actual position recorded when the corer hits the seabed. This is to account for any drifting of the vessel after the corer was deployed over the side. Each sample is recorded with a sequential number starting at 2875 and ending on 2900, along with coordinate information, sample size and other pertinent information. Data were hand recorded on pre prepared work sheets and then entered into a database after the cruise. Failed core sites were also recorded.

7.1 SAMPLE HANDLING AND STORAGE

The environmental cores are cut to length (halved), capped at either end of each marked up section, then stored flat in a deep freezer. Once in port the diamond inspector inspected the cores before being released for storage. They were then transported to the Carpe Diem premises for temporary storage in the two freezers before onward transport to the CSIR in Stellenbosch. During road transport the cores are kept cold in their freezers which are carried on a trailer and kept working using a generator on the tow vehicle. Temperature gauges (TidBits) are installed in each of the freezer units, which allows for monitoring of the freezer temperatures during transportation.

7.2 CRUISE SUMMARY

The vessel left Lüderitz at 14:30 on Thursday 8th of August 2013 and set sail north to the northern end of ML 170 with a strong SW wind (30 to 35 knots) and a 4 m swell. The vessel arrived at the concession at 07:00 on Friday 9th of August with a 20 knot SW wind and 3.5 m swell. The vessel had to wait for the next few hours for weather conditions to improve. Sampling started at 15:00 with a 15 knot SW wind and 3 m swell. By 18:28 the 6th site had been completed, but the wind had picked up to 18 knots and sampling was stopped pending a forecast drop in wind speed for the following morning. At 03:41 on Saturday 10th August sampling resumed with improved weather conditions (5 knot SW wind). Penetration was generally good although evidence of footwall clay was only present on one of the 26 core samples. The deeper water samples were not expected to reach clay (footwall), while the shallower samples, at water depths of less than 212 m, were in an area where the shell density makes penetration beyond 1 m difficult. Multiple attempts were made where necessary to obtain the optimal penetration. Three of the short cores taken during poorer weather were repeated in better conditions at the end cruise with much better results (Waypoints 12, 20 and 25). Waypoint 21 failed to retain much material from any penetration with 3 attempts and the limited material obtained was put in a plastic bottle. At 17:30 on 10th August sampling was completed and the vessel sailed back to Lüderitz arriving at 12:00 on Sunday the 11th August where cores and freezer were unloaded and stored at the workshop.

© NMP 2014

8 QC PROCEDURES SUMMARY

The client representative,

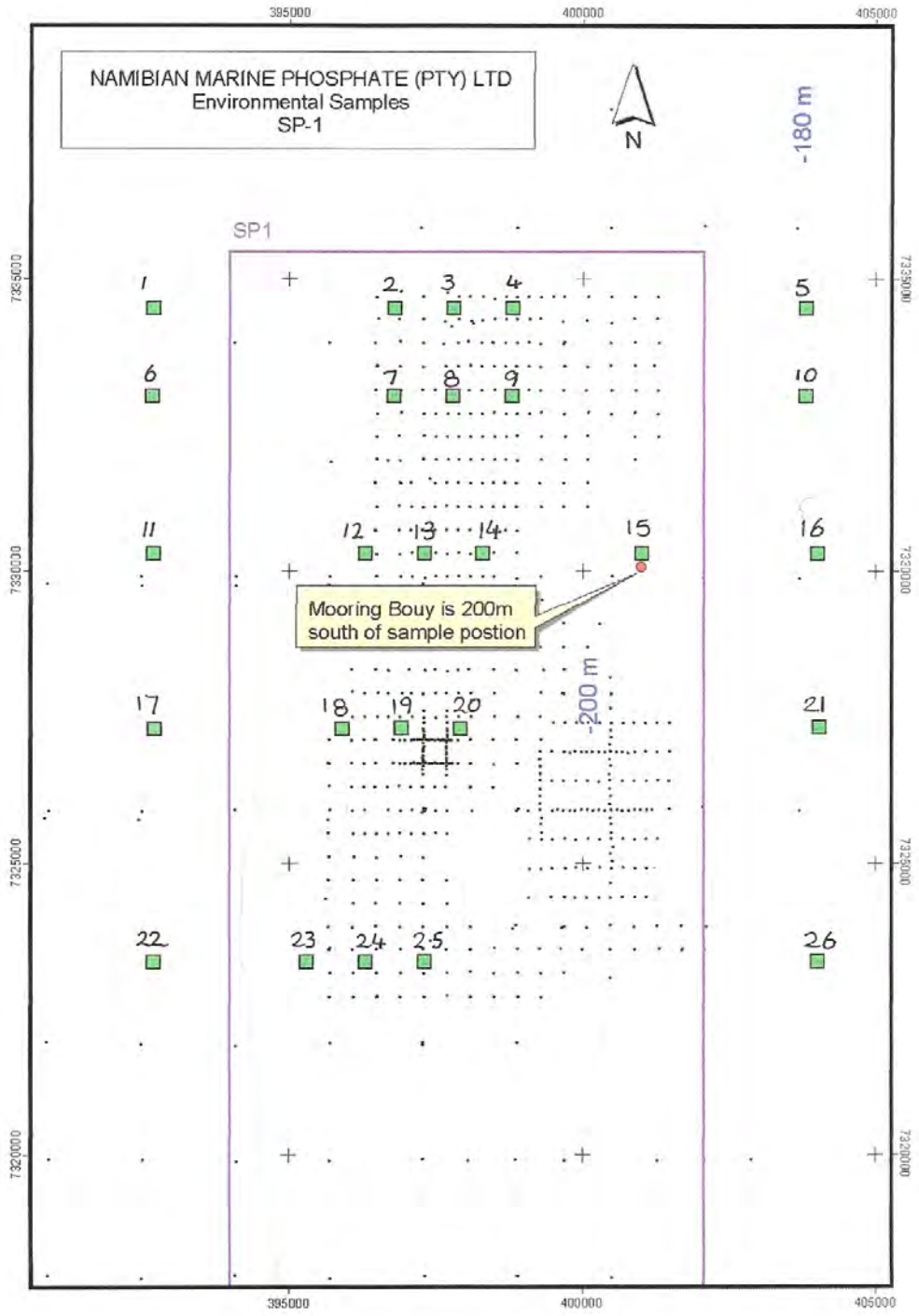
- Verified the effectiveness of the GPS positioning system (by comparison with an independent GPS and reference to a fixed position);
- The quality of samples collected (by observation);
- The reliability of the record keeping (records attached and each page signed off);
- Correct labeling of the samples;
- Good storage of samples (no leakage, and careful handling of samples).

8.1 RECOMMENDATIONS

For environmental sampling freezer capacity limits the number of cores that can be taken per freezer load. An extra freezer may be necessary.

© NMP 2014

Annexure 1: Location map ML 170 – Waypoints / Core sample sites



APPENDIX 1 - WATER COLUMN AND SEDIMENTARY ENVIRONMENT

1.8 Instrument Mooring Report: Day 0 to 45

NAMIBIAN MARINE PHOSPHATE

VERIFICATION SURVEY

DATA REPORT
Day 0 to 45

Prepared for:
Namibian Marine Phosphate (Pty) Ltd.

Prepared by:

October 2014

Project: 267

SOUTH AFRICA
Unit A4 Diep River Industrial Park, Greenville Road, Diep River, Cape Town
Directors: S.W. Bilski, B.J. Spolander, S.C. Stimson (British)
Co Reg. No. 2002/029886/07

AUSTRALIA
6a Magnet Court, Sandy Bay, Tasmania 7005, Australia
Directors: S.W. Bilski, B.J. Spolander S.C. Stimson (British)
ABN No. 87122 046 431

REVISION HISTORY

Date	Version	Originator	Checked	Approved
21 Aug 2013	0	C. Bloch	B. Spolander	B. Spolander
22 Jan 2013	1	C. Bloch	B. Spolander	B. Spolander



CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed “Attention: Administration Manager,” at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

contents

1 EXECUTIVE SUMMARY 1

2 INTRODUCTION 6

2.1 PROJECT DESCRIPTION 6
2.2 CONVENTIONS USED IN THIS REPORT 7
2.3 MEASUREMENT LOCATIONS 8
2.4 MOORING CONFIGURATION 9
2.5 EQUIPMENT CONFIGURATION 10

3 DATA QUALITY CONTROL 11

3.1 ADCP 11
3.2 AQUADOPPS 14
3.3 RBR CTD LOGGER 17

4 DATA PRESENTATION 18

4.1 ADCP 18
4.1.1 Current Data 18
4.1.1.1 Time series plots 18
4.1.1.2 Summary plots 22
4.1.1.3 Progressive vector plots 26
4.1.1.4 Tidal harmonic plots 30
4.1.1.5 Profile plots 34
4.1.2 Pressure and water temperature data 38
4.1.2.1 Time series plot 38
4.2 AQD 1 40
4.2.1 Current data 40
4.2.1.1 Time series plot 40
4.2.1.2 Summary plot 42
4.2.1.3 Progressive vector plot 44
4.2.1.4 Tidal harmonic data 46
4.2.2 Pressure and water temperature data 48
4.2.2.1 Time series plot 48
4.3 AQD 2 50
4.3.1 Current data 50
4.3.1.1 Time series plot 50
4.3.1.2 Summary plot 52
4.3.1.3 Progressive vector plot 54
4.3.1.4 Tidal harmonic data 56
4.3.2 Pressure and water temperature data 58
4.3.2.1 Time series plot 58
4.4 CTD 60

© NMP 2014

4.4.1 Water quality data *60*
4.4.1.1 Time series plot 60
4.4.1.2 Summary plot 62
4.4.2 Tide data *64*
4.4.2.1 Time series plot 64
4.4.2.2 Tidal harmonics table 66
4.4.2.3 Tidal harmonics plot 68

5 DISCUSSION 70

figures

Figure 1: Data return for the measurement period for each instrument. 1
Figure 2: Oceanographic measurement location offshore Namibia. 8
Figure 3: Mooring configuration. 9
Figure 4 : Quality control data from the ADCP. The upper panel shows the sensor attitude data (heading scaled to the left axis and pitch and roll to the right axis). 13
Figure 5: Quality control data from AQD 1. The upper panel shows the sensor attitude data (heading scaled to the left axis and pitch and roll to the right axis). 15
Figure 6: Quality control data from AQD 2. 16
Figure 7: Time series plots of current data at 7 m depth 19
Figure 8: Time series plots of current data at 51 m depth 20
Figure 9: Time series plots of current data at 94 m depth 21
Figure 10: Current data summary plots for 7 m depth 23
Figure 11: Current data summary plots for 51 m depth 24
Figure 12: Current data summary plots for 94 m depth 25
Figure 13: Current progressive vector plot for 7 m depth 27
Figure 14: Current progressive vector plot for 51 m depth 28
Figure 15: Current progressive vector plot for 94 m depth 29
Figure 16: Mean profile plot 34
Figure 17: Profile plot at the time of maximum current speed in the upper water column 35
Figure 18: Profile plot at the time of maximum current speed in the mid water column 36
Figure 19: Profile plot at the time of maximum current speed in the lower water column 37
Figure 20: Upper panel: time series plot of pressure. Lower panel: time series plot of temperature. 39
Figure 21: Time series plots of current data at 148 m depth 41
Figure 22: Current speed and direction plots for 148 m depth 43
Figure 23: Current progressive vector plot for 148 m depth 45
Figure 24: Time series plots of pressure (water level) and water temperature at 148 m depth 49
Figure 25: Time series plots of current data at 193 m depth 51
Figure 26: Current speed and direction plots of 193 m depth 53
Figure 27: Current progressive vector plot for 193 m depth 55
Figure 28: Time series plots of pressure (water level) and water temperature at 193 m depth 59
Figure 29: Water quality data for 192.33 m depth 61
Figure 30: Summary data for environmental parameters at 192.33 m depth 63
Figure 31: Time series of tidal height 65
Figure 32: Graphical representation of the tidal harmonic components presented in Table 15. 69

© NMP 2014

Figure 33: Overview of current directions recorded in the upper, mid and lower water column respectively. Current speeds are indicated by the colour scale. 71
Figure 34: Time series of hourly mean current velocity throughout the water column. 72
Figure 35: Time series of hourly mean temperature throughout the water column. White patches indicate missing data. 72

tables

Table 1: Current flow summary 2
Table 2: Temperature summary 6
Table 3 : Pressure summary 6
Table 4: CTD summary 6
Table 5: Glossary and conventions used in this report 7
Table 6: As deployed measurement location 8
Table 7: TRDI 300 kHz ACDCP configuration 10
Table 8: Aquadopp configuration 10
Table 9 : CTD configuration 11
Table 10 : Current harmonic data for 7 m depth 31
Table 11 : Current harmonic data for 51 m depth 32
Table 12 : Current harmonic data for 94 m depth 33
Table 13 : Current harmonic data for 148 m depth 47
Table 14 : Current harmonic data for 193 m depth 57
Table 15 : Tidal harmonic data for 192.33 m depth 67

© NMP 2014

1 EXECUTIVE SUMMARY

Metocean Services International (Pty) Limited (MSI) has been awarded a contract by Lwandle Technologies, under sub contract from Namibian Marine Phosphate (Pty) Ltd (NMP), to deploy an oceanographic mooring offshore Namibia. NMP intends dredging marine phosphate reserves at the site and requires verification of previous studies regarding the behaviour of the water column and sediment re-suspension events. Current measurements throughout the water column were undertaken with an ADCP and two single point current meters and water quality measurements were undertaken with a CTD near the seabed.

First order statistics of the data collected during the first measurement period (nominally from 8 June 2013 to 26 July 2013) are presented in this section, together with an indication of the data return achieved. Data return was good, however the upper AQD and CTD stopped logging data shortly before recovery as a result of depleted batteries.

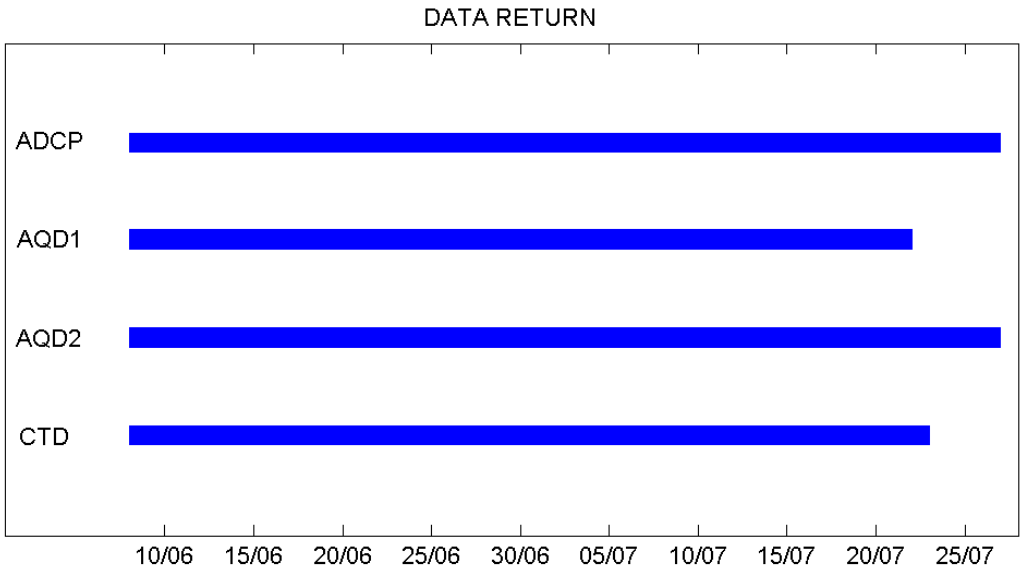


Figure 1: Data return for the measurement period for each instrument.
Every day for which a greater than 50% data return was achieved is marked in colour.

© NMP 2014

Table 1: Current flow summary

Instrument	Depth	Start	End	DR	Max speed	Max dir	Max date	Mean speed	STD speed	VM speed	VM Dir
	m	dd/mm/yy	dd/mm/yy	%	$cm.s^{-1}$	^{0}	dd/mm/yy	$cm.s^{-1}$	$cm.s^{-1}$	$cm.s^{-1}$	^{0}
ADCP	-5.7	08/06/13	26/07/13	23.38	56.94	316.38	21/07/13	22.06	9.06	14.40	331.38
ADCP	-6.7	08/06/13	26/07/13	95.54	56.73	326.88	15/06/13	17.08	9.30	10.85	327.73
ADCP	-7.7	08/06/13	26/07/13	98.16	54.31	336.80	15/06/13	15.10	9.02	8.90	309.86
ADCP	-8.7	08/06/13	26/07/13	98.90	46.50	345.38	15/06/13	14.77	8.19	8.20	294.70
ADCP	-9.7	08/06/13	26/07/13	99.33	43.80	275.96	16/06/13	14.46	7.67	7.78	289.23
ADCP	-10.7	08/06/13	26/07/13	99.58	42.40	269.02	04/07/13	14.27	7.58	7.61	288.56
ADCP	-11.7	08/06/13	26/07/13	99.68	40.15	275.48	16/06/13	14.11	7.48	7.47	288.73
ADCP	-12.7	08/06/13	26/07/13	99.74	40.80	267.40	04/07/13	13.99	7.40	7.32	288.68
ADCP	-13.7	08/06/13	26/07/13	99.72	39.72	274.18	16/06/13	13.86	7.37	7.18	288.62
ADCP	-14.7	08/06/13	26/07/13	99.72	39.85	271.40	16/06/13	13.74	7.31	7.05	288.92
ADCP	-15.7	08/06/13	26/07/13	99.81	39.83	268.43	16/06/13	13.65	7.24	6.90	289.14
ADCP	-16.7	08/06/13	26/07/13	99.84	39.83	266.37	04/07/13	13.51	7.22	6.77	289.29
ADCP	-17.7	08/06/13	26/07/13	99.88	39.85	272.90	16/06/13	13.38	7.12	6.64	289.14
ADCP	-18.7	08/06/13	26/07/13	99.88	40.29	274.80	16/06/13	13.26	7.06	6.53	289.49
ADCP	-19.7	08/06/13	26/07/13	99.91	39.69	266.86	04/07/13	13.16	7.04	6.38	289.89
ADCP	-20.7	08/06/13	26/07/13	99.97	37.36	272.50	16/06/13	12.98	6.99	6.20	290.19
ADCP	-21.7	08/06/13	26/07/13	99.96	37.56	270.82	16/06/13	12.89	6.94	6.07	290.52
ADCP	-22.7	08/06/13	26/07/13	99.99	39.41	275.10	16/06/13	12.77	6.91	5.91	291.03
ADCP	-23.7	08/06/13	26/07/13	99.99	42.76	303.22	20/06/13	12.65	6.85	5.78	291.19
ADCP	-24.7	08/06/13	26/07/13	99.99	42.48	303.24	20/06/13	12.57	6.81	5.63	292.30
ADCP	-25.7	08/06/13	26/07/13	99.97	43.19	304.79	20/06/13	12.43	6.76	5.49	292.93
ADCP	-26.7	08/06/13	26/07/13	99.97	40.89	305.53	20/06/13	12.28	6.70	5.37	293.75
ADCP	-27.7	08/06/13	26/07/13	99.97	40.14	305.94	20/06/13	12.18	6.68	5.23	295.06

© NMP 2014

Table 1 – continued...

Instrument	Depth	Start	End	DR	Max speed	Max dir	Max date	Mean speed	STD speed	VM speed	VM Dir
	m	dd/mm/yy	dd/mm/yy	%	$cm.s^{-1}$	^{0}	dd/mm/yy	$cm.s^{-1}$	$cm.s^{-1}$	$cm.s^{-1}$	^{0}
ADCP	-28.7	08/06/13	26/07/13	99.97	37.71	269.34	16/06/13	12.04	6.64	5.15	295.79
ADCP	-29. 7	08/06/13	26/07/13	99.97	37.13	274.40	16/06/13	11.96	6.59	5.03	296.56
ADCP	-30.7	08/06/13	26/07/13	100.00	37.43	281.53	04/07/13	11.85	6.53	4.94	297.83
ADCP	-31.7	08/06/13	26/07/13	100.00	37.03	334.79	21/07/13	11.72	6.51	4.85	299.31
ADCP	-32.7	08/06/13	26/07/13	100.00	35.70	271.48	16/06/13	11.63	6.48	4.78	300.41
ADCP	-33.7	08/06/13	26/07/13	100.00	35.78	271.94	16/06/13	11.51	6.48	4.71	301.65
ADCP	-34.7	08/06/13	26/07/13	100.00	36.00	335.78	10/07/13	11.43	6.41	4.63	302.43
ADCP	-35.7	08/06/13	26/07/13	100.00	35.46	338.41	10/07/13	11.35	6.44	4.61	303.90
ADCP	-36.7	08/06/13	26/07/13	100.00	35.60	339.25	21/07/13	11.24	6.37	4.57	305.46
ADCP	-37.7	08/06/13	26/07/13	100.00	34.79	282.38	16/06/13	11.20	6.32	4.53	306.46
ADCP	-38.7	08/06/13	26/07/13	100.00	35.99	334.97	21/07/13	11.15	6.30	4.49	307.85
ADCP	-39.7	08/06/13	26/07/13	99.97	34.27	336.99	21/07/13	11.08	6.29	4.50	309.16
ADCP	-40.7	08/06/13	26/07/13	99.99	34.52	340.56	21/07/13	11.02	6.26	4.51	310.57
ADCP	-41.7	08/06/13	26/07/13	99.99	34.65	340.08	21/07/13	10.99	6.28	4.49	311.71
ADCP	-42.7	08/06/13	26/07/13	99.94	34.26	339.85	21/07/13	11.01	6.28	4.46	313.04
ADCP	-43.7	08/06/13	26/07/13	99.94	35.57	300.94	20/07/13	10.97	6.28	4.48	313.71
ADCP	-44.7	08/06/13	26/07/13	99.96	34.67	305.99	20/07/13	11.02	6.22	4.49	314.99
ADCP	-45.7	08/06/13	26/07/13	99.94	35.56	26.96	21/06/13	11.00	6.25	4.52	316.26
ADCP	-46.7	08/06/13	26/07/13	99.99	37.62	15.01	21/06/13	11.06	6.25	4.58	316.71
ADCP	-47.7	08/06/13	26/07/13	100.00	38.40	17.29	21/06/13	11.04	6.26	4.62	317.73
ADCP	-48.7	08/06/13	26/07/13	100.00	39.70	22.39	21/06/13	11.06	6.26	4.62	318.34
ADCP	-49.7	08/06/13	26/07/13	100.00	36.09	315.83	21/07/13	11.04	6.28	4.62	319.08
ADCP	-50.7	08/06/13	26/07/13	99.94	37.15	315.15	21/07/13	11.03	6.28	4.62	319.33
ADCP	-51.7	08/06/13	26/07/13	99.94	37.75	314.80	21/07/13	11.04	6.29	4.70	319.51

© NMP 2014

Table 1 – continued...

Instrument	Depth	Start	End	DR	Max speed	Max dir	Max date	Mean speed	STD speed	VM speed	VM Dir
	m	dd/mm/yy	dd/mm/yy	%	$cm.s^{-1}$	^{0}	dd/mm/yy	$cm.s^{-1}$	$cm.s^{-1}$	$cm.s^{-1}$	^{0}
ADCP	-52.7	08/06/13	26/07/13	99.99	39.04	328.70	21/07/13	10.96	6.27	4.67	320.23
ADCP	-53.7	08/06/13	26/07/13	99.97	42.54	320.20	21/07/13	10.93	6.29	4.72	319.91
ADCP	-54.7	08/06/13	26/07/13	99.97	40.45	320.52	21/07/13	10.92	6.28	4.71	319.59
ADCP	-55.7	08/06/13	26/07/13	99.97	41.61	320.35	21/07/13	10.87	6.28	4.67	320.03
ADCP	-56.7	08/06/13	26/07/13	99.94	39.53	314.14	21/07/13	10.84	6.27	4.66	320.14
ADCP	-57.7	08/06/13	26/07/13	100.00	39.59	315.70	21/07/13	10.73	6.27	4.64	319.75
ADCP	-58.7	08/06/13	26/07/13	99.99	40.12	318.87	21/07/13	10.75	6.26	4.67	319.64
ADCP	-59.7	08/06/13	26/07/13	99.97	39.64	332.85	21/07/13	10.70	6.23	4.66	319.35
ADCP	-60.7	08/06/13	26/07/13	99.93	38.86	330.16	21/07/13	10.65	6.23	4.63	319.11
ADCP	-61.7	08/06/13	26/07/13	99.96	40.01	351.26	21/07/13	10.62	6.24	4.64	319.10
ADCP	-62.7	08/06/13	26/07/13	99.99	40.74	342.98	21/07/13	10.63	6.26	4.68	318.74
ADCP	-63.7	08/06/13	26/07/13	99.97	40.20	344.52	21/07/13	10.60	6.26	4.66	318.03
ADCP	-64.7	08/06/13	26/07/13	99.99	41.52	351.32	21/07/13	10.61	6.27	4.70	318.09
ADCP	-65.7	08/06/13	26/07/13	99.99	41.10	349.42	21/07/13	10.59	6.28	4.73	317.34
ADCP	-66.7	08/06/13	26/07/13	99.99	44.33	347.44	21/07/13	10.54	6.25	4.76	317.09
ADCP	-67.7	08/06/13	26/07/13	99.99	43.90	349.16	21/07/13	10.55	6.24	4.78	316.58
ADCP	-68.7	08/06/13	26/07/13	99.96	42.18	350.68	21/07/13	10.52	6.25	4.79	315.63
ADCP	-69.7	08/06/13	26/07/13	99.97	41.49	350.91	21/07/13	10.51	6.18	4.83	315.36
ADCP	-70.7	08/06/13	26/07/13	100.00	44.20	344.86	21/07/13	10.50	6.16	4.85	314.57
ADCP	-71.7	08/06/13	26/07/13	100.00	44.23	343.17	21/07/13	10.48	6.12	4.85	314.22
ADCP	-72.7	08/06/13	26/07/13	100.00	42.80	345.78	21/07/13	10.50	6.07	4.92	313.00
ADCP	-73.7	08/06/13	26/07/13	99.99	41.50	338.46	21/07/13	10.47	6.04	4.96	312.48
ADCP	-74.7	08/06/13	26/07/13	100.00	40.10	344.80	21/07/13	10.40	6.03	4.98	311.50
ADCP	-75.7	08/06/13	26/07/13	99.99	39.91	339.48	21/07/13	10.41	5.97	4.98	311.18

© NMP 2014

Table 1 – continued...

SECTION D, APPENDIX 1 - WATER COLUMN AND SEDIMENTARY ENVIRONMENT
1.8 Instrument Mooring Report: Day 0 to 45

Instrument	Depth	Start	End	DR	Max speed	Max dir	Max date	Mean speed	STD speed	VM speed	VM Dir
	m	dd/mm/yy	dd/mm/yy	%	$cm.s^{-1}$	^{0}	dd/mm/yy	$cm.s^{-1}$	$cm.s^{-1}$	$cm.s^{-1}$	^{0}
ADCP	-76.7	08/06/13	26/07/13	99.99	37.74	340.51	21/07/13	10.38	5.93	5.04	310.28
ADCP	-77.7	08/06/13	26/07/13	99.99	37.72	336.84	21/07/13	10.33	5.92	5.05	309.60
ADCP	-78.7	08/06/13	26/07/13	99.99	37.47	336.32	21/07/13	10.32	5.85	5.09	309.09
ADCP	-79.7	08/06/13	26/07/13	100.00	35.67	334.22	21/07/13	10.25	5.79	5.08	308.22
ADCP	-80.7	08/06/13	26/07/13	99.97	35.40	345.38	15/06/13	10.24	5.74	5.15	307.91
ADCP	-81.7	08/06/13	26/07/13	100.00	33.76	334.96	21/07/13	10.21	5.70	5.14	307.11
ADCP	-82.7	08/06/13	26/07/13	99.96	35.96	318.24	15/06/13	10.15	5.63	5.19	306.29
ADCP	-83.7	08/06/13	26/07/13	99.99	34.58	320.22	15/06/13	10.10	5.64	5.17	305.66
ADCP	-84.7	08/06/13	26/07/13	100.00	33.66	321.17	15/06/13	10.03	5.57	5.21	305.22
ADCP	-85.7	08/06/13	26/07/13	100.00	37.88	319.55	15/06/13	10.02	5.59	5.20	304.41
ADCP	-86.7	08/06/13	26/07/13	99.97	34.22	320.31	15/06/13	9.99	5.53	5.27	303.58
ADCP	-87.7	08/06/13	26/07/13	99.99	33.14	319.82	15/06/13	9.98	5.51	5.31	303.23
ADCP	-88.7	08/06/13	26/07/13	99.99	33.36	318.66	15/06/13	9.89	5.49	5.31	302.54
ADCP	-89.7	08/06/13	26/07/13	99.99	30.91	334.94	15/06/13	9.88	5.48	5.31	301.99
ADCP	-90.7	08/06/13	26/07/13	100.00	31.32	333.96	16/06/13	9.85	5.55	5.37	301.60
ADCP	-91.7	08/06/13	26/07/13	100.00	30.86	332.65	16/06/13	9.89	5.56	5.43	301.15
ADCP	-92.7	08/06/13	26/07/13	99.99	30.80	321.22	15/06/13	9.97	5.59	5.54	301.77
ADCP	-93.7	08/06/13	26/07/13	100.00	31.96	321.38	15/06/13	10.07	5.52	5.66	302.88
AQD1	-148.0	08/06/13	24/07/13	97.93	37.01	25.37	16/06/13	10.62	6.12	1.01	77.84
AQD2	-193.0	08/06/13	26/07/13	100.00	42.76	250.63	17/07/13	17.52	5.87	12.97	221.45

© NMP 2014

Table 2: Temperature summary

Instrument	Mean Depth (m)	Data Return (%)	Max (°C)	Mean (°C)	Min (°C)
ADCP	-97	100.00	13.54	12.31	11.71
AQD1	-148	97.89	12.59	11.77	11.13
AQD2	-193	99.96	11.85	11.20	10.03
CTD	-192	100.00	11.64	11.05	9.81

Table 3 : Pressure summary

Instrument	Mean Depth (m)	Data Return (%)	Max (Bar)	Mean (Bar)	Min (Bar)
ADCP	-97	100.00	9.82	9.72	9.63
AQD1	-148	97.93	14.97	14.86	14.78
AQD2	-193	100.00	19.43	19.34	19.26
CTD	-192	100.00	19.39	19.30	19.22

Table 4: CTD summary

Parameter	Unit	Data Return (%)	Max	Mean	Min
Temperature	˚C	100.00	11.64	11.05	9.81
Conductivity	$S.m^{-1}$	100.00	39.85	39.17	35.31
Salinity	psu	97.06	35.11	35.02	34.86
Depth	m	100.00	-191.53	-192.33	-193.22
Dissolved Oxygen	$\mu mol.l^{-1}$	99.94	34.31	9.15	1.35
Fluorescence	$\mu g.l^{-1}$	99.97	0.42	0.08	0.06
Turbidity	NTU	99.97	408.76	2.86	0.22
Height	m	100.00	0.89	0.00	-0.81

2 INTRODUCTION

2.1 PROJECT DESCRIPTION

Metocean Services International (Pty) Limited (MSI) has been awarded a contract by Lwandle Technologies, under sub contract from Namibian Marine Phosphate (Pty) Ltd (NMP), to deploy an oceanographic mooring offshore Namibia. NMP intends dredging marine phosphate reserves at the site and requires verification of previous studies regarding the behaviour of the water column and sediment re-suspension events. Current measurements throughout the water column were undertaken with an ADCP and two single point current meters and water quality measurements were undertaken with a CTD near the seabed.

This report details the quality control procedures and data presentation (Sections 3 and 4 for the first measurement period (nominally from 8 June 2013 to 26 July 2013).

© NMP 2014

2.2 CONVENTIONS USED IN THIS REPORT

A list of the conventions used in this report is presented in Table 5.

Table 5: Glossary and conventions used in this report

Term	Explanation
ADCP	Acoustic Doppler Current Profiler
AQD	Aquadopp
Bin	ADCP depth cell within which the measurement of current velocity is spatially averaged. The depth of the bin refers to the centre of the bin.
Bin length	Vertical distance over which ADCP data is spatially averaged into a single current velocity.
Conductivity	Conductivity is measured in Siemens per metre ($S.m^{-1}$)
CTD	Conductivity, temperature and depth meter
Current Speed	The speed of flow with units of centimetres per second ($cm.s^{-1}$)
Current Direction	The direction towards which the vector mean current is flowing and referenced to true north at 0^0 with a right handed convention.
Data Return	The data return reflects the percentage of good data coverage for the time period that the instrument was operational.
Density	Density is expressed as kilograms per cubic metre ($kg.m^{-3}$).
Depth	The water depth below mean sea level, with units of m.
Dissolved Oxygen	Dissolved oxygen is measured in micromoles per litre ($\mu mol.l^{-1}$).
Ensemble	Time interval over which ADCP pings are averaged into a single current velocity for each bin.
Fluorescence	Fluorescence is a measure of chlorophyll in micrograms per litre ($\mu g.l^{-1}$).
Height	Height is measured in meters (m) referenced to mean sea level.
Ping	Single acoustic pulse from the ADCP, which produces measurement of current velocity.
Pressure	Pressure is in Bars.
Salinity	Salinities are expressed in practical salinity units (psu)
Sound velocity	Sound velocity is expressed in meters per second ($m.s^{-1}$).
STD	The standard deviation of the current speed.
Temperatures	Temperatures are in degrees centigrade (°C).
Time	All times are presented in UTC.
VM	Vector mean.

© NMP 2014

2.3 MEASUREMENT LOCATIONS

The location of the measurements offshore Namibia, is given in Table 6 and indicated in Figure 2 below.

Table 6: As deployed measurement location

Location	Latitude	Longitude	Depth
MP1*	24° 08' 18.96" S	14° 01' 32.88" E	~ 193 m
*(Position calculated using slant-range position and depth information)			



Figure 2: Oceanographic measurement location offshore Namibia.

2.4 MOORING CONFIGURATION

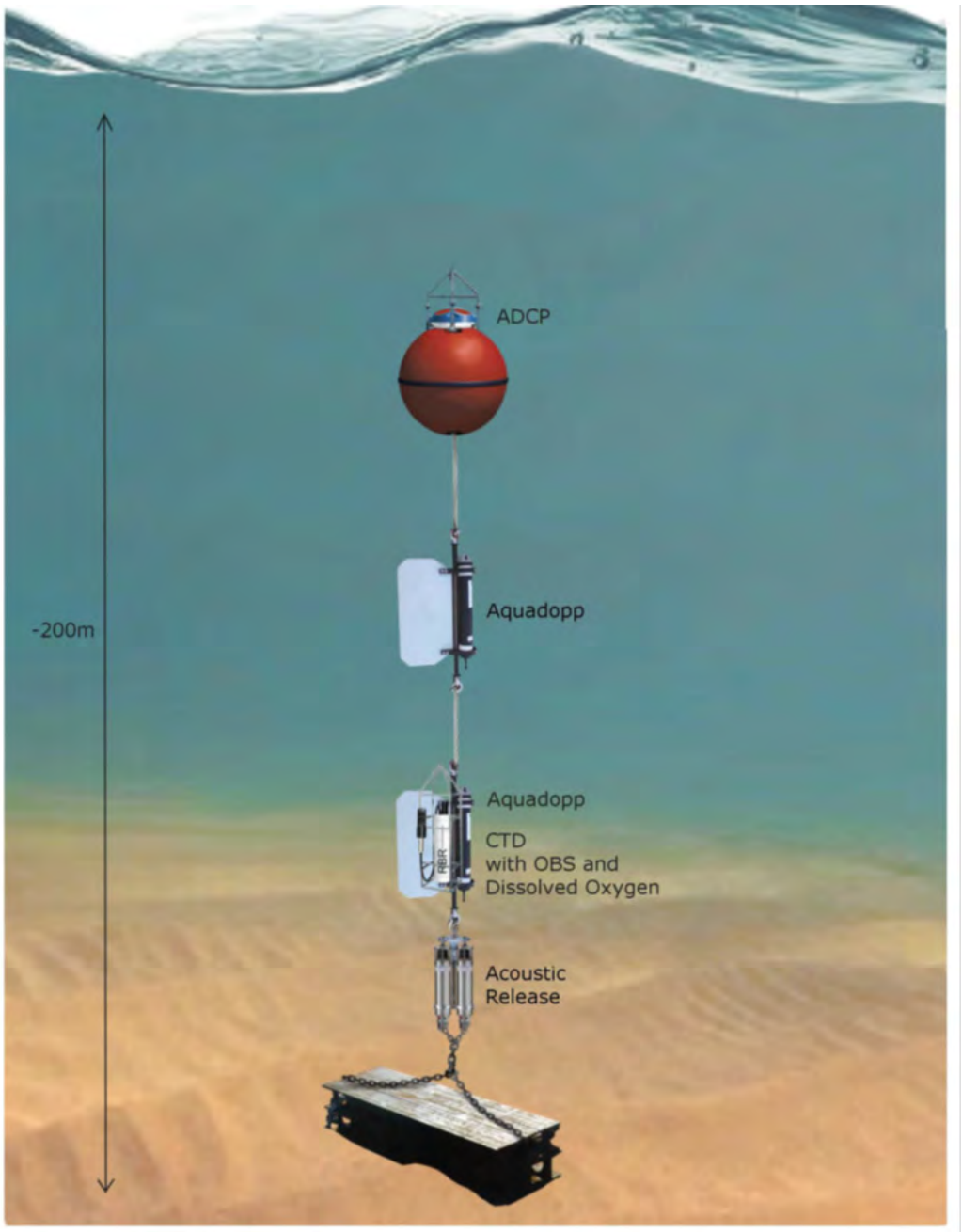


Figure 3: Mooring configuration.

2.5 EQUIPMENT CONFIGURATION

Table 7: TRDI 300 kHz ACDCP configuration

Parameter	Configuration
Planned water depth	~100 m (200 m total)
Assumed duration	90 days (~ 45 service)
Number of battery packs	1 x alkaline
Ensemble interval	10 minutes
Number of pings	110
Number of depth cells	175
Cellsize	1m
General	
Standard deviation	1.29 $cm.s^{-1}$
Battery utilisation	1.0
Memory required	23.46 mb

Table 8: Aquadopp configuration

Parameter	Configuration	
	Mid-water DW Aquadopp (s/n AQD 3011)	**Near-bottom Aquadopp (s/n AQD 2481)**
Planned water depth	~150 m (200 m total)	~195 m (200 m total)
Assumed duration	50 days	50 days
Number of battery packs	1 x alkaline (50Wh)	1 x alkaline (50Wh)
Measurement interval	30 seconds	30 seconds
Average interval	5 seconds	5 seconds
Measurement load	9 %	22 %
Blanking distance	0.50 m	0.35 m
Compass update rate Diagnostics Interval (min) Number of samples	1 second Enabled 60 16	1 second Enabled 60 16
General		
Vertical velocity precision	3.4 $cm.s^{-1}$	3.8 $cm.s^{-1}$
Horizontal velocity precision	2.3 $cm.s^{-1}$	2.3 $cm.s^{-1}$
Battery utilisation	97 %	97 %
Memory required	6.6 mb	6.6 mb

© NMP 2014

Table 9 : CTD configuration

Parameter	Configuration
Approximate water depth	~195 m (total 200 m)
Sampling period	00:10:00
Averaging period Maximum duration[1]	2 seconds battery
Memory required	3%
Battery required	100%

3 DATA QUALITY CONTROL

3.1 ADCP

The current data were imported from RD Instruments WinSc software into Matlab for further processing:

- The record was truncated to exclude times pre and post deployment.
- The depth of the instrument was determined from the pressure sensor.
- Directions were adjusted from magnetic to true north using a magnetic variation of -14.6247°. Magnetic variation was obtained from the NOAA website at http://www.ngdc.noaa.gov/geomag-web/#declination.
- A flag was imposed on all data within 6% of the ocean surface due to side lobe interference. The distance to the ocean surface was deduced from the pressure data.
- The ADCP attitude data (heading, pitch and roll) were then examined (see Figure 4). These parameters were well within the recommended operating range throughout the deployment.
- The ADCP beam correlation data were then examined. Adopting RDI recommended practice, when the correlation count for any of the 4 beams fell below 64 (RD Instruments recommended value) in a bin, all data from this bin to the end of the profile were flagged.
- Checks were then run on the percentage good data collected by the ADCPs. All ensembles where the number of two beam solutions exceeded 50% were flagged.
- Checks were then run on the error velocities. Examination of the error velocity distribution led to the selection of a cut off of –20 $cm.s^{-1}$ to +20 $cm.s^{-1}$. All data with error velocities beyond this range were flagged. This check mainly affected data in the uppermost valid bins.
- Checks were then run searching for any outliers in the speed data. This was automated within a routine that compared the median of 3 values to the centre point.

© NMP 2014

A tolerance of 50 $cm.s^{-1}$ was allowed. Outliers identified by this method were then visually examined and flagged. The same check was run on both the northward and eastward velocity components. As a final check, the data were visually examined and any remaining spikes flagged.

- Checks were then run searching for repeated values in the speed and direction data. This was automated within a routine that searched for 3 identical consecutive values.

- Finally, all flagged data were replaced with the Matlab NaN symbol, ensuring that they would be excluded from all further processing.

- As a result of the quality control measures applied, the data return in the uppermost bins of retained data was reduced. For this reason, the first data bin achieving over 95% data return was presented as representative of the near-surface currents.

- Quality control data from the ACDCP are presented visually in Figure 4.

© NMP 2014

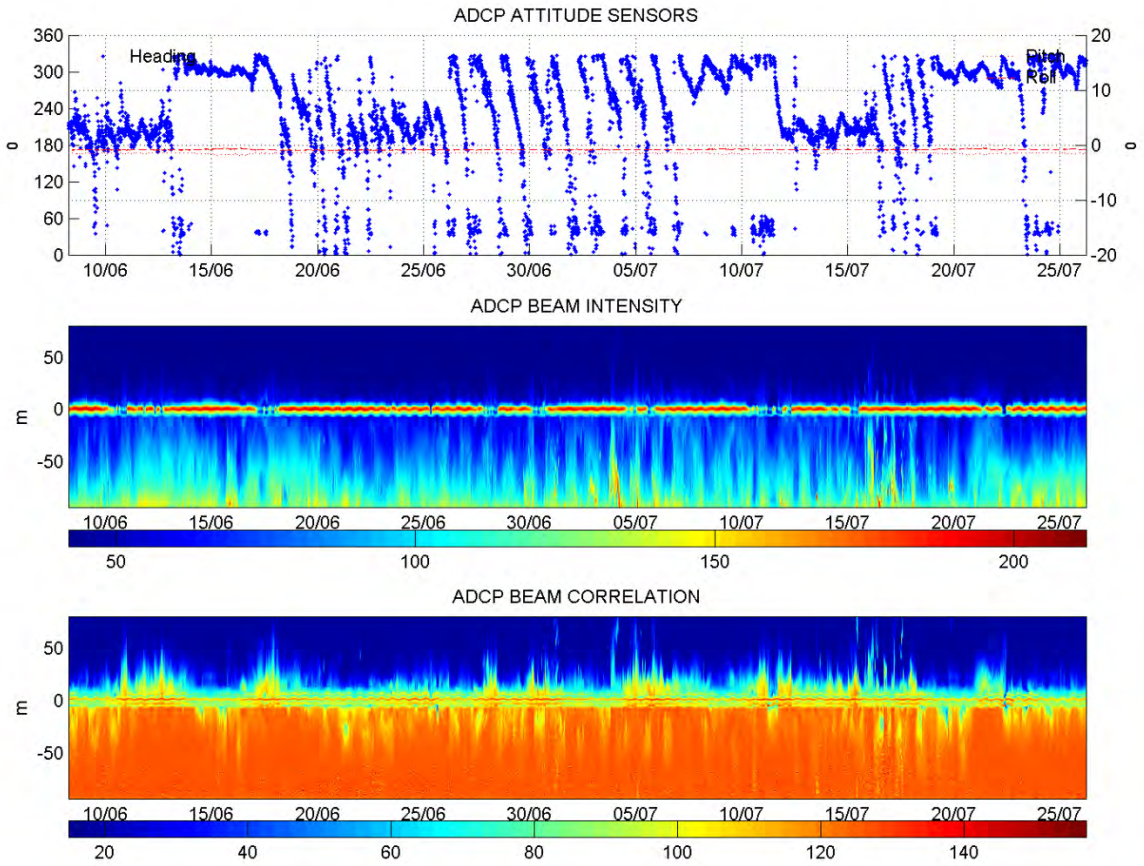


Figure 4 : Quality control data from the ADCP. The upper panel shows the sensor attitude data (heading scaled to the left axis and pitch and roll to the right axis). The middle panel shows the time-series of ADCP beam intensity through the water column, while the lower panel shows similar information for the beam correlation.

© NMP 2014

3.2 AQUADOPPS

The current data were exported to ascii text files from Nortek's Aquadopp software and then imported into Matlab for further processing:

- The record was truncated to exclude times pre and post deployment.
- The depth of the instrument was determined from the pressure sensor.
- A 10 minute data set was created from the 30 second data by finding the mean of all data recorded within each ten minute period. The mean u and v velocity components for each ten minute period were then converted to speed and direction. All data presented in this report are derived from the 10 minute data set.
- Directions were adjusted from magnetic to true north using a magnetic variation of -14.6247°. Magnetic variation was obtained from the NOAA website at http://www.ngdc.noaa.gov/geomag-web/#declination.
- The AQD attitude data (heading, pitch and roll) as well as the depth and vertical velocity were then examined (see Figure 5 and Figure 6). All instruments remained within the recommended operating range for pitch and roll (-30° to 30°) throughout the deployment.
- Checks were then run searching for any outliers in the speed data. This was automated within a routine that compared the median of 5 values to the centre point. A tolerance of 30 $cm.s^{-1}$ was allowed. Outliers identified by this method were then visually examined and flagged. The same check was run on both the northward and eastward velocity components. As a final check, the data were visually examined and any remaining spikes flagged.
- Checks were then run searching for repeated values in the speed and direction data. This was automated within a routine that searched for 3 identical consecutive values.
- Finally, all flagged data were replaced with the Matlab NaN symbol, ensuring that they would be excluded from all further processing.
- AQD 1 stopped logging data before recovery as a result of a depleted battery. Additionally, intermittent data loss occurred towards the end of the dataset as a result of low battery power.
- Quality control data from the Aquadopp 1(AQD 1) and the Aquadopp 2(AQD 2) instruments are presented in Figures 5 and 6 respectively.

© NMP 2014

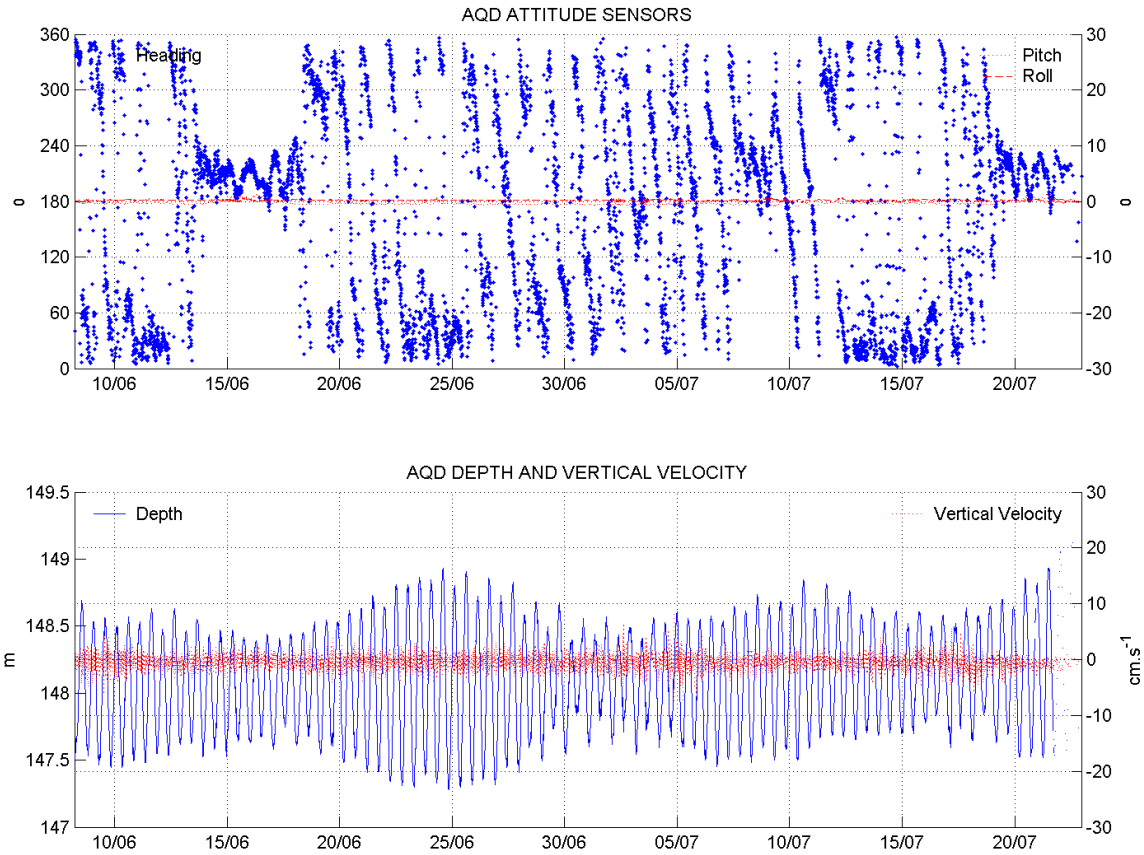


Figure 5: Quality control data from AQD 1. The upper panel shows the sensor attitude data (heading scaled to the left axis and pitch and roll to the right axis). The lower panel shows the depth (scaled to the left axis) and the vertical velocity (scaled to the right axis).

© NMP 2014

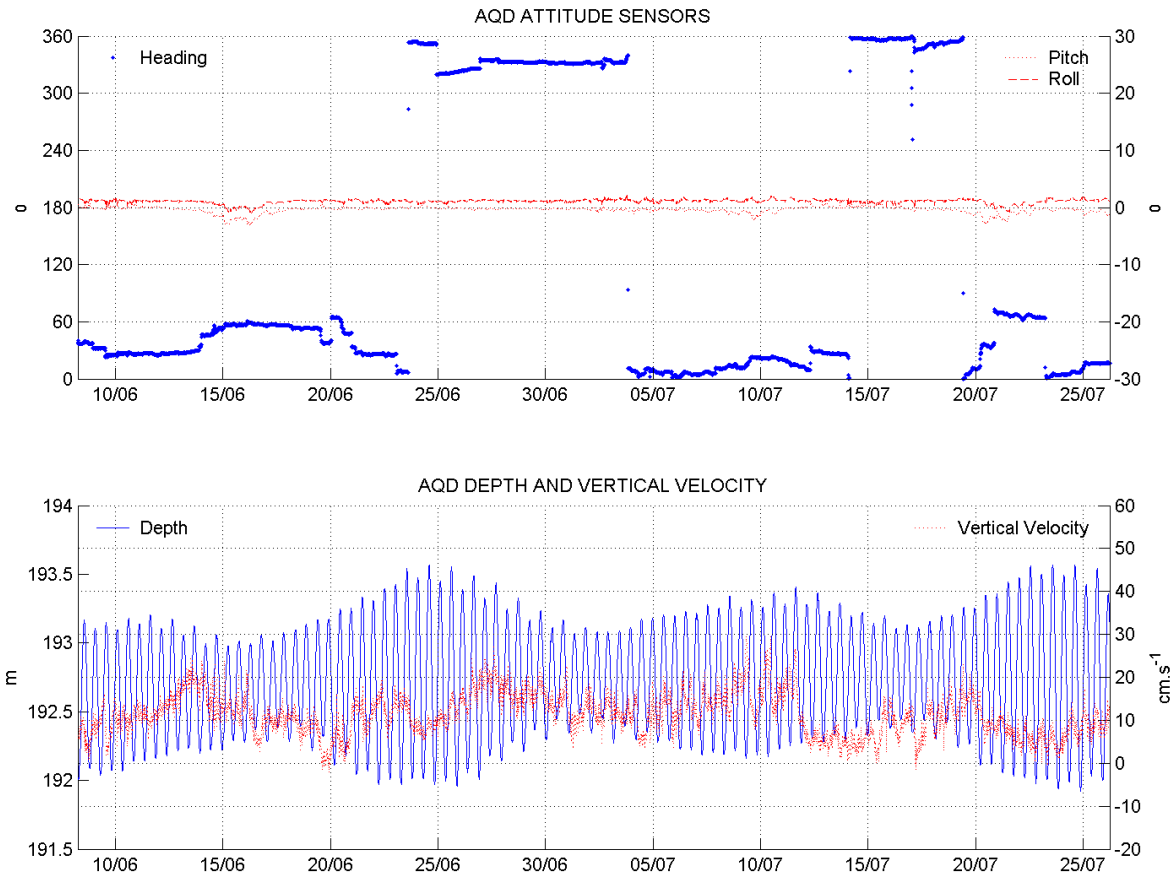


Figure 6: Quality control data from AQD 2.
The upper panel shows the sensor attitude data (heading scaled to the left axis and pitch and roll to the right axis). The lower panel shows the depth (scaled to the left axis) and the vertical velocity (scaled to the right axis).

© NMP 2014

3.3 RBR CTD LOGGER

The data were exported directly from the RBR software into Matlab for further processing:

- The record was truncated to exclude times pre and post deployment.
- Depth was derived using an assumed gravity value of 9.80 $m.s^{-2}$ and mean water density of 1024 $kg.m^{-3}$.
- The conductivity and temperature data were used to derive salinity according to the 1978 UNESCO algorithm.
- Checks were run searching for any outliers in the data. This was automated within a routine that compared the median of 5 values to the centre point. For salinity, a tolerance of 1 psu was allowed. For turbidity, a tolerance of 250 NTU was allowed. For fluorescence and dissolved oxygen, tolerances of 0.5 $\mu mol.l^{-1}$ and 5 $\mu g.l^{-1}$ were allowed respectively.
- Height was determined from the depth. Checks were then run searching for any outliers in the height data. This was automated within a routine that compared the median of 5 values to the centre point. A tolerance of 15 cm was allowed. Outliers identified by this method were then visually examined and flagged. As a final check, the data were examined visually and any remaining spikes flagged.
- Checks were then run searching for repeated values in the height data. This was automated within a routine that searched for 3 identical consecutive values.
- Finally, all flagged data were replaced with the Matlab NaN symbol, ensuring that they would be excluded from all further processing.
- The CTD stopped logging data prior to recovery as a result of a depleted battery.
- A number of low salinity spikes were noted in the dataset. These spikes were mostly observed during periods of elevated turbidity, which may have affected the conductivity measurements. These spikes were therefore removed from the dataset. An additional low salinity spike was observed when turbidity levels were not elevated, however this may have been the result of particles settling in the sensor. This spike was also removed from the dataset.

© NMP 2014

4 DATA PRESENTATION

4.1 ADCP

4.1.1 Current Data

4.1.1.1 Time series plots

Figures 7,8 and 9 on the following pages present time series plots for the depths; -7 m, -51 m and -94 m respectively. The time series plots consist of:

- The first (upper) panel is of the observed current speed against time.
- The second panel is of the observed current direction against time.
- The third panel is of the tidal current speed, calculated from the observed current speed and direction, against time. The entire data set of observations is used in the derivation of the tidal component. The tidal calculation follows the method of Foreman and uses the observed complex current vector as input (*R. Pawlowicz, B. Beardsley, and S. Lentz, "Classical tidal harmonic analysis including error estimates in MATLAB using T_TIDE", Computers and Geosciences 28 (2002), 929-937*)
- The fourth panel is of the tidal current direction, calculated as above, against time.
- The fifth panel is of the residual current speed against time. The residual has been calculated as north and east components (residual component = observed component – tidal component), which have then been converted into residual speed and direction.
- The sixth panel is of the residual current direction against time, calculated as above.
- The first day of each month is indicated visually by a thin red line on each of the plots.

© NMP 2014

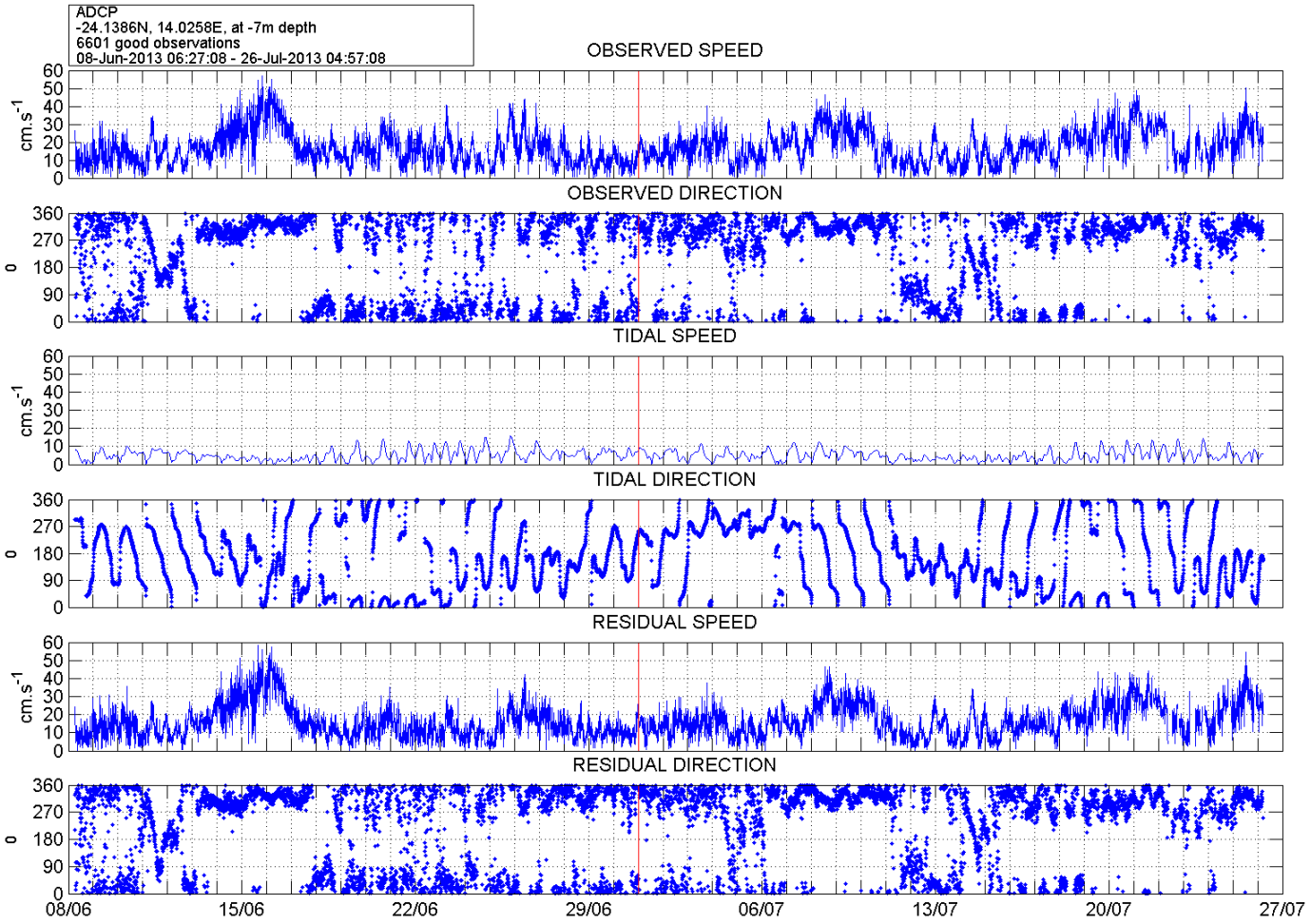


Figure 7: Time series plots of current data at 7 m depth

© NMP 2014

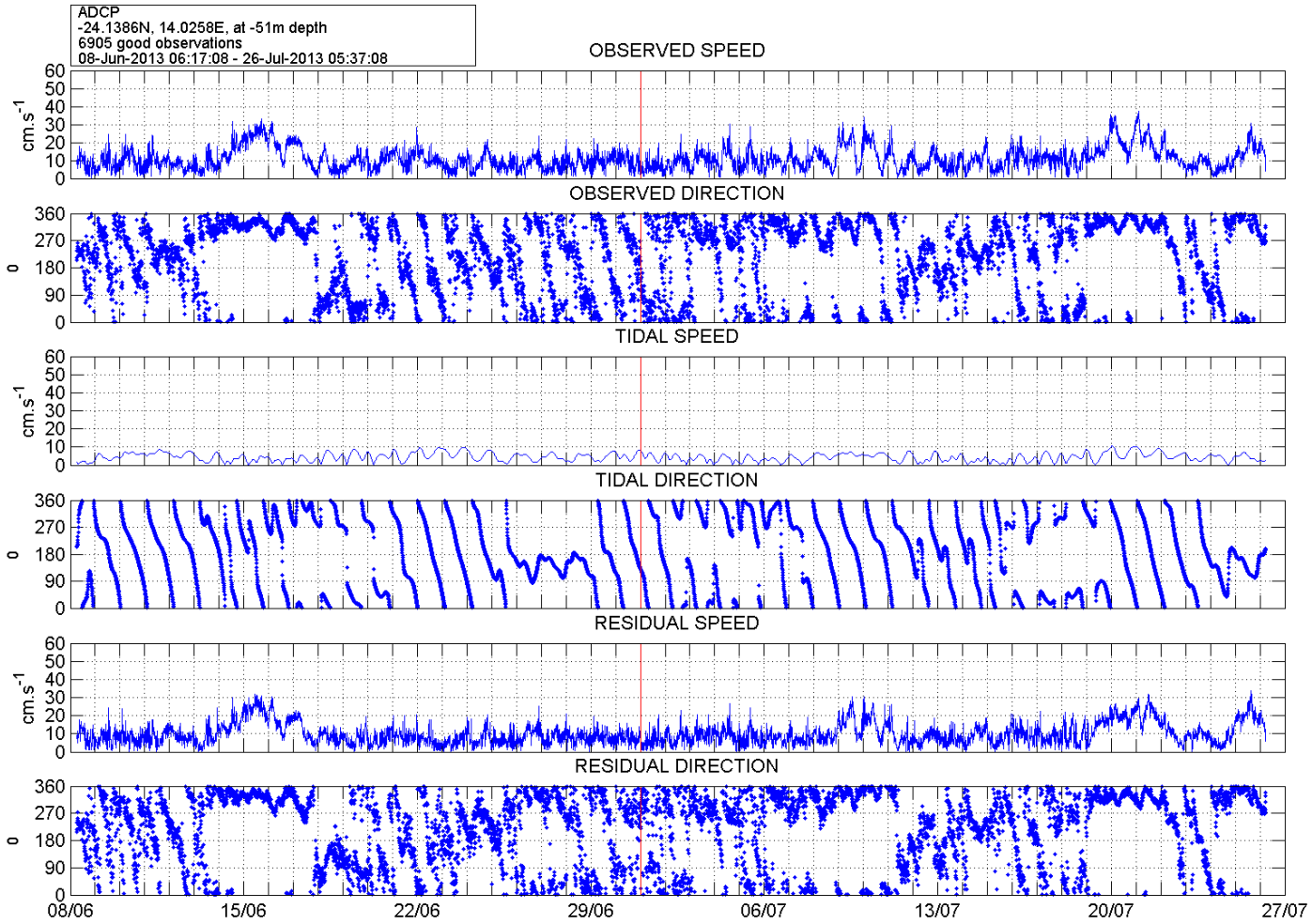


Figure 8: Time series plots of current data at 51 m depth

© NMP 2014

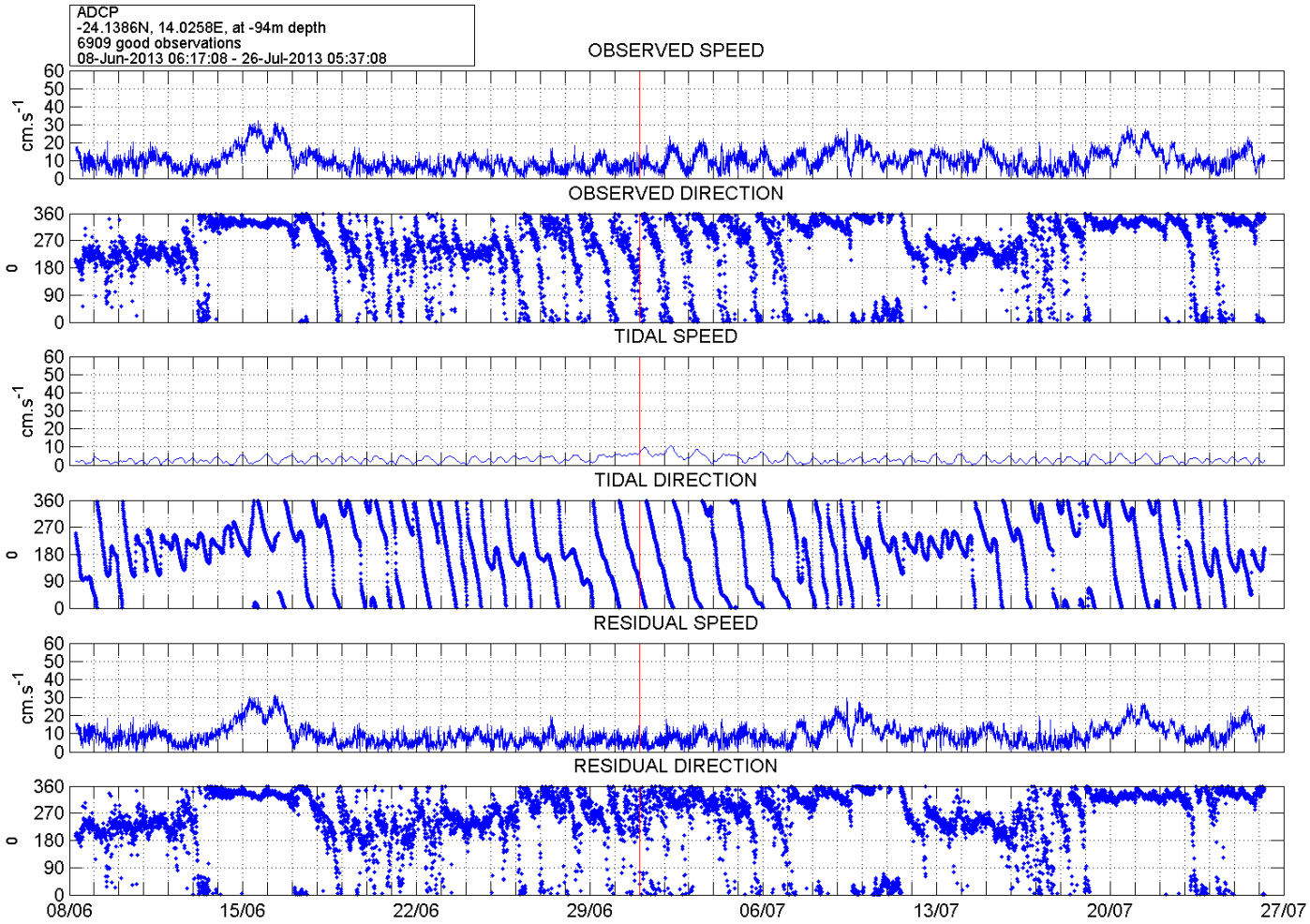


Figure 9: Time series plots of current data at 94 m depth

© NMP 2014

4.1.1.2 Summary plots

Figures 10, 11 and 12 on the following pages present summary plots for the depths; -7 m, -51 m and -94 m respectively. The summary plots consist of:

- The upper panel is a table of the joint distribution of 10 minute averaged current speed against direction. Columns of the table represent direction classes and rows the speed classes. The numbers in the table reflect the percentage of observations that fall within a particular speed interval and direction sector.
- The lower left hand panel is a rose of the 10 minute averaged current direction. This is a histogram of the directional distribution and reflects the percentage of observations that fall within each direction sector. The colour scale indicated the current speeds which are represented.
- The lower right hand panel is a histogram of the 10 minute averaged current speeds. This reflects the percentage of observations that fall within each speed interval. Included on the plot are basic statistics for the current speed distribution.

© NMP 2014

ADCP
-24.1386N, 14.0258E, at -7m depth
6601 good observations
08-Jun-2013 06:27:08 - 26-Jul-2013 04:57:08

JOINT DISTRIBUTION OF SPEED AND DIRECTION

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Σ
0-5	0.65	0.50	0.52	0.41	0.52	0.39	0.42	0.41	0.35	0.48	0.42	0.32	0.47	0.44	0.59	0.76	7.65
5-10	2.00	1.62	1.12	1.26	0.79	0.67	0.52	0.47	0.26	0.45	0.73	1.14	1.12	1.44	1.77	1.83	17.18
10-15	2.89	2.41	1.55	0.88	0.61	0.33	0.44	0.38	0.24	0.39	0.70	1.05	1.97	2.23	2.53	2.86	21.45
15-20	2.29	2.20	1.62	0.61	0.30	0.11	0.18	0.27	0.29	0.32	0.32	0.73	1.82	2.67	3.15	2.61	19.47
20-25	1.70	1.76	1.39	0.35	0.02	0.03	0.06	0.14	0.09	0.27	0.21	0.44	1.35	2.26	2.71	2.09	14.86
25-30	0.73	0.73	0.71	0.09					0.02	0.14	0.23	0.23	0.73	1.48	2.24	1.95	9.27
30-35	0.44	0.29	0.18	0.03					0.02	0.02	0.08	0.11	0.33	1.12	1.55	1.39	5.54
35-40	0.14	0.21										0.03	0.14	0.71	1.08	0.56	2.86
40-45	0.03	0.06	0.02										0.02	0.24	0.39	0.47	1.23
45-50	0.02													0.09	0.18	0.06	0.35
50-55														0.02	0.06	0.05	0.12
55-60																0.02	0.02
Σ	10.88	9.77	7.10	3.62	2.23	1.53	1.62	1.67	1.26	2.08	2.68	4.03	7.94	12.70	16.26	14.65	100.00

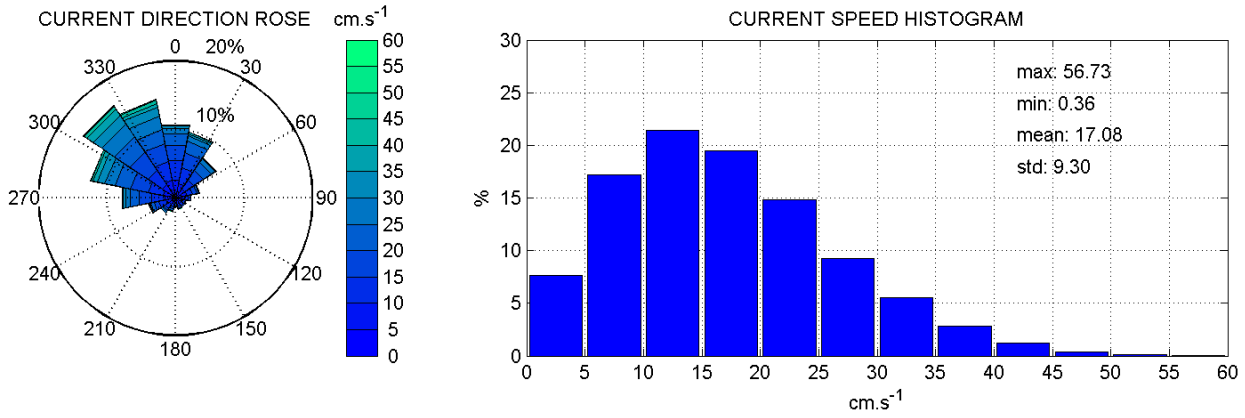


Figure 10: Current data summary plots for 7 m depth

ADCP
-24.1386N, 14.0258E, at -51m depth
6905 good observations
08-Jun-2013 06:17:08 - 26-Jul-2013 05:37:08

JOINT DISTRIBUTION OF SPEED AND DIRECTION

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Σ
0-5	0.96	0.85	0.93	0.91	0.98	0.83	0.84	0.77	0.88	0.88	0.90	0.98	1.01	1.40	1.32	1.58	16.03
5-10	2.10	1.71	1.52	1.68	1.68	1.38	1.96	1.51	1.80	2.11	2.06	2.30	2.42	3.50	2.91	2.88	33.51
10-15	2.49	1.65	1.59	1.07	1.00	0.98	0.97	1.01	1.22	1.49	1.58	2.22	2.48	2.68	3.13	2.97	28.53
15-20	1.25	0.74	0.52	0.43	0.23	0.17	0.32	0.04	0.29	0.23	0.39	1.04	0.91	1.14	2.32	2.04	12.08
20-25	1.06	0.28	0.07	0.06	0.01	0.03		0.01		0.01	0.01	0.22	0.25	0.61	1.56	1.98	6.17
25-30	0.30	0.12											0.03	0.41	0.65	1.23	2.74
30-35	0.04	0.01											0.01	0.06	0.32	0.43	0.88
35-40															0.04	0.01	0.06
40-45																	0.00
45-50																	0.00
50-55																	0.00
55-60																	0.00
Σ	8.20	5.36	4.63	4.16	3.91	3.39	4.08	3.35	4.19	4.74	4.94	6.76	7.11	9.80	12.25	13.14	100.00

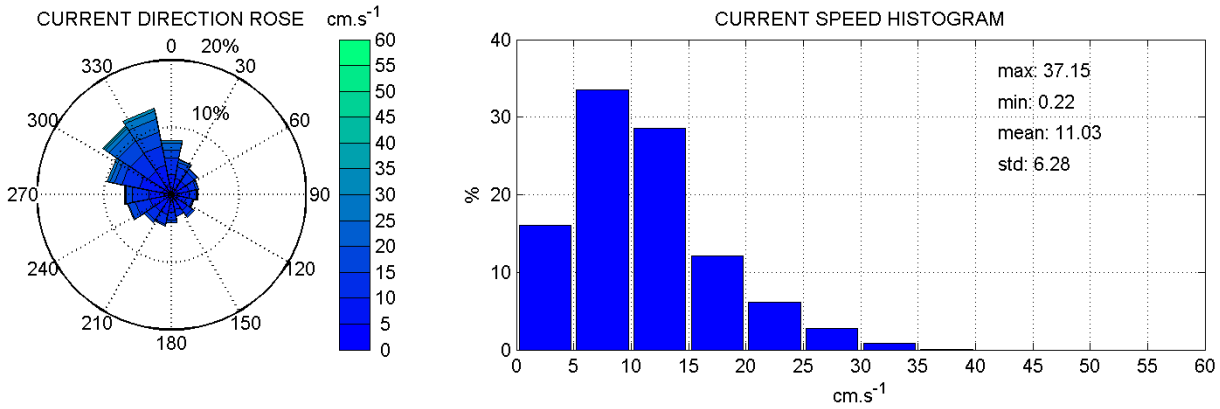


Figure 11: Current data summary plots for 51 m depth

ADCP
-24.1386N, 14.0258E, at -94m depth
6909 good observations
08-Jun-2013 06:17:08 - 26-Jul-2013 05:37:08

JOINT DISTRIBUTION OF SPEED AND DIRECTION

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Σ
0-5	0.85	0.90	0.64	0.58	0.54	0.61	0.74	0.65	1.00	1.36	1.49	1.68	1.38	1.65	1.24	1.40	16.70
5-10	3.17	1.94	1.10	0.88	0.48	0.32	0.52	0.98	2.06	3.43	5.09	4.96	3.84	3.79	3.65	3.78	39.99
10-15	2.40	1.14	0.41	0.12	0.03	0.04	0.09	0.14	0.61	1.77	4.13	3.04	1.62	1.94	3.79	4.60	25.86
15-20	1.23	0.16	0.07	0.01	0.01			0.03	0.03	0.42	0.61	0.97	0.20	0.33	3.01	4.50	11.59
20-25	0.07	0.03		0.01					0.01		0.01	0.04	0.01	0.03	1.10	2.69	4.02
25-30															0.48	1.22	1.69
30-35															0.01	0.12	0.13
35-40																	0.00
40-45																	0.00
45-50																	0.00
50-55																	0.00
55-60																	0.00
Σ	7.73	4.17	2.21	1.61	1.06	0.97	1.35	1.81	3.71	6.98	11.33	10.70	7.05	7.74	13.29	18.31	100.00

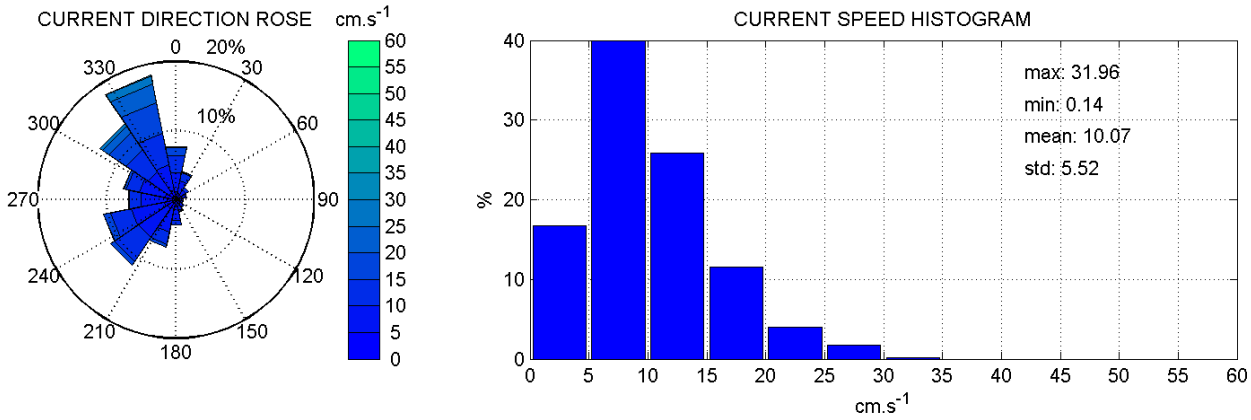


Figure 12: Current data summary plots for 94 m depth

4.1.1.3 Progressive vector plots

Figures 13, 15 and 15 on the following pages present progressive vector plots for the depths; -7 m, -51 m and -94 m respectively. The plots consist of:

- The solid line represents the displacement that a particle of water would undergo when subject to the currents that were observed.
- The start and end points of the observations are labelled.
- Each day is represented by a red cross.

© NMP 2014

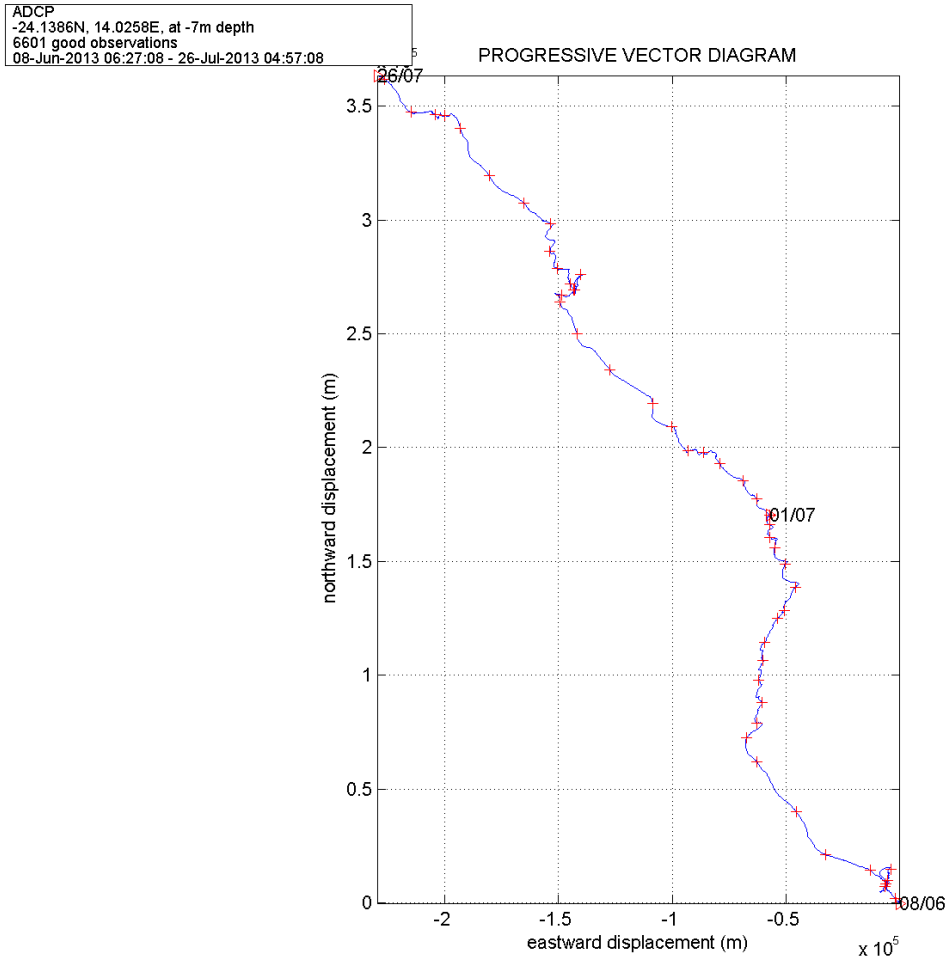


Figure 13: Current progressive vector plot for 7 m depth

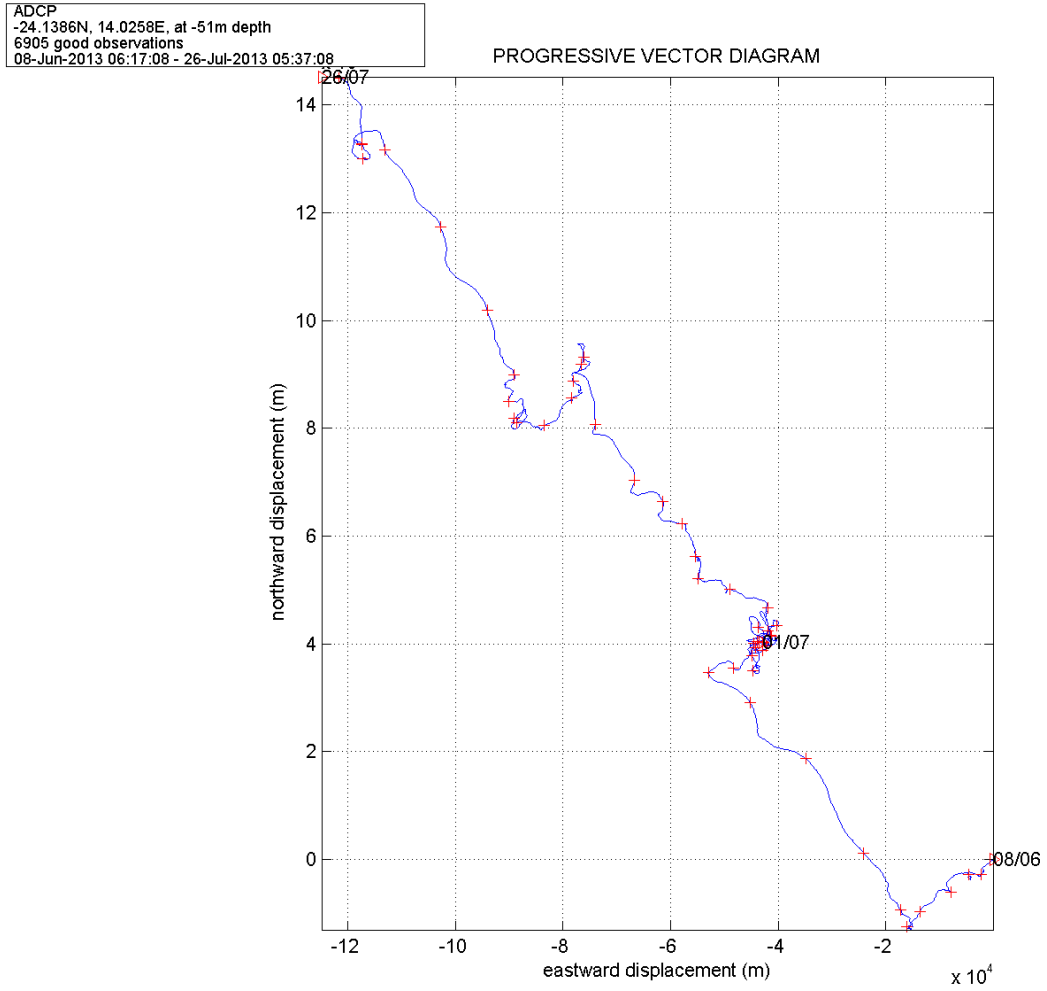


Figure 14: Current progressive vector plot for 51 m depth

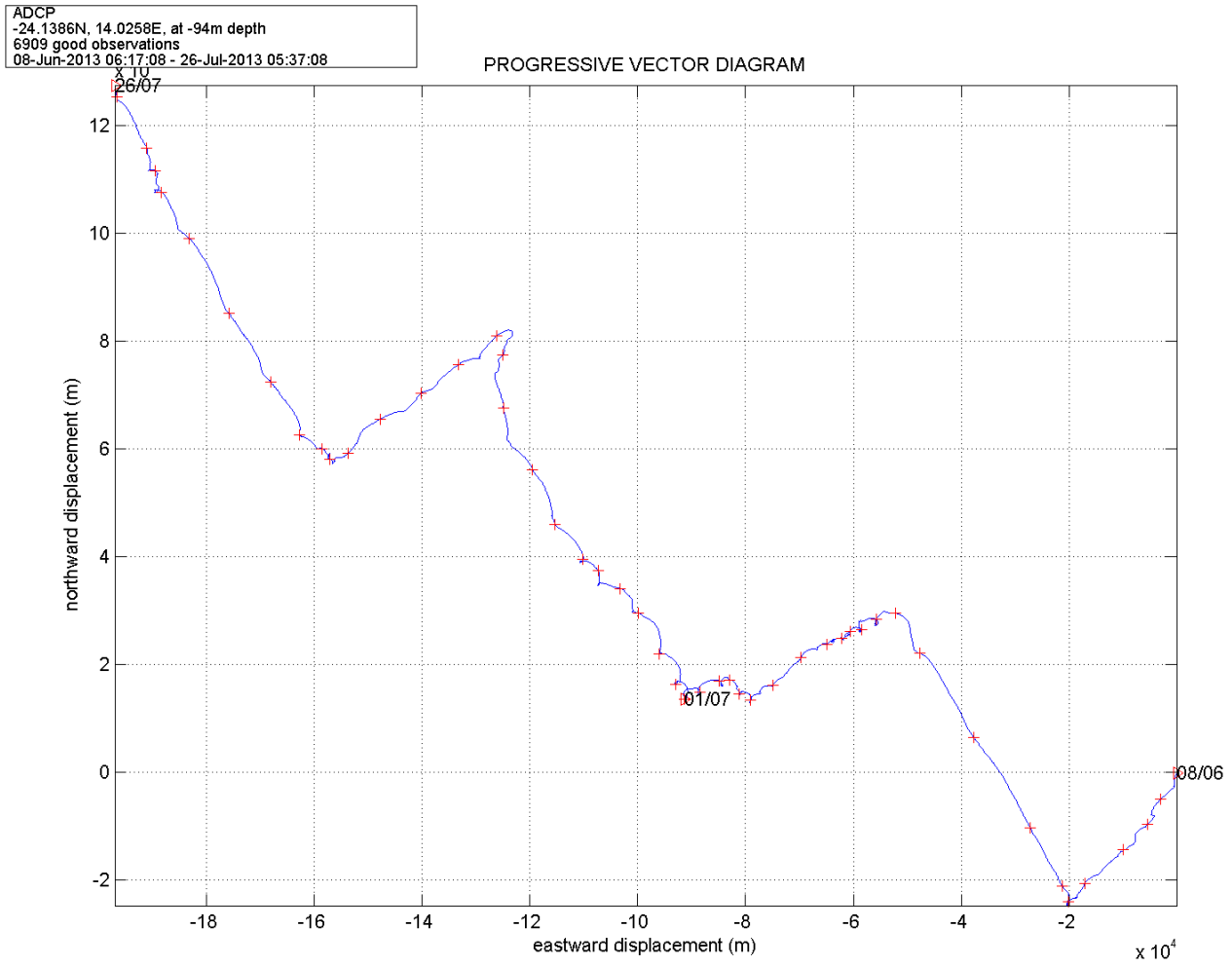


Figure 15: Current progressive vector plot for 94 m depth

4.1.1.4 Tidal harmonic plots

Tables 10, 11 and 12 on the following pages present current harmonic data for the depths; -7 m, -51 m and -94 m respectively. The harmonics consist of:

- The tidal calculation follows the method of Foreman and uses the observed complex current vector as input *(R. Pawlowicz, B. Beardsley and S. Lentz, "Classical tidal harmonic analysis including error estimates in Matlab using T_TIDE", Computers and Geosciences 28 (2002), 929-937*).
- The major and minor axis amplitudes are given in $cm.s^{-1}$.
- The ellipse orientation and Greenwich phase are given in degrees.

Table 10 : Current harmonic data for 7 m depth

ADCP
-24.1386N, 14.0258E, in -7m depth
6601 good observations
08-Jun-2013 06:27:08 - 26-Jul-2013 04:57:08

HARMONIC COMPONENTS

Component	Major	Minor	Ellipse	Phase
MM	3.16	-0.33	34.23	338.96
MSF	3.07	-0.73	126.04	293.69
ALP1	3.26	-0.96	43.29	263.41
2Q1	2.22	-0.52	1.14	20.44
Q1	1.71	0.58	14.69	147.97
O1	2.48	0.80	22.98	118.61
NO1	1.51	0.35	156.48	179.70
K1	2.81	1.56	178.24	299.04
J1	0.61	-0.25	147.90	145.15
OO1	3.15	2.37	172.01	221.48
UPS1	1.01	-0.04	58.72	55.19
EPS2	0.32	0.13	2.42	117.06
MU2	0.94	0.11	61.89	190.36
N2	1.87	-0.95	70.27	193.31
M2	2.23	-0.73	66.08	226.50
L2	0.81	0.05	22.65	27.51
S2	0.81	0.04	86.47	236.60
ETA2	0.27	-0.18	72.10	226.23
MO3	0.43	0.01	86.30	208.22
M3	0.59	0.28	89.61	155.82
MK3	0.73	-0.01	59.35	359.57
SK3	0.34	0.17	91.36	46.48
MN4	0.33	-0.09	80.23	3.67
M4	0.54	0.13	101.76	46.01
SN4	0.26	-0.04	3.42	48.15
MS4	0.71	-0.13	31.92	358.14
S4	0.26	0.14	50.62	242.03
2MK5	0.57	-0.29	26.67	157.50
2SK5	0.41	0.11	29.82	341.67
2MN6	0.18	0.02	35.64	263.26
M6	0.22	-0.06	146.32	157.42
2MS6	0.07	-0.04	120.79	191.96
2SM6	0.24	-0.04	156.03	296.35
3MK7	0.32	0.11	36.77	92.94
M8	0.36	0.15	36.98	192.53

© NMP 2014

Table 11 : Current harmonic data for 51 m depth

ADCP
-24.1386N, 14.0258E, in -51m depth
6905 good observations
08-Jun-2013 06:17:08 - 26-Jul-2013 05:37:08

HARMONIC COMPONENTS

Component	Major	Minor	Ellipse	Phase
MM	1.75	-0.61	159.02	223.51
MSF	2.73	0.14	100.06	266.50
ALP1	3.17	2.05	61.47	222.30
2Q1	1.89	1.21	161.70	279.85
Q1	2.11	1.54	145.51	343.48
O1	1.85	1.22	22.40	105.45
NO1	1.79	0.56	152.65	279.45
K1	1.95	0.72	122.73	309.73
J1	1.21	0.22	169.34	132.43
OO1	2.49	1.33	92.35	85.47
UPS1	0.99	0.42	36.26	24.98
EPS2	0.55	-0.07	40.32	294.30
MU2	0.33	0.09	112.33	78.69
N2	0.63	0.59	155.73	197.79
M2	1.24	1.12	172.52	102.49
L2	0.32	-0.19	140.65	258.35
S2	0.23	0.14	60.24	2.72
ETA2	0.59	0.00	77.25	228.73
MO3	0.40	0.17	29.78	134.87
M3	0.43	0.33	56.60	115.47
MK3	0.33	-0.03	89.13	357.22
SK3	0.35	0.03	50.34	285.77
MN4	0.16	0.00	40.99	159.71
M4	0.29	-0.06	124.66	358.65
SN4	0.28	-0.05	175.22	75.22
MS4	0.29	-0.15	16.19	343.93
S4	0.29	0.20	167.72	279.26
2MK5	0.27	0.06	99.92	103.56
2SK5	0.38	0.05	93.08	183.79
2MN6	0.14	-0.03	62.92	141.20
M6	0.16	0.04	53.80	292.02
2MS6	0.13	0.07	164.46	334.50
2SM6	0.12	0.11	71.13	342.55
3MK7	0.06	0.04	124.22	40.60
M8	0.27	0.10	74.57	182.49

© NMP 2014

Table 12 : Current harmonic data for 94 m depth

ADCP
-24.1386N, 14.0258E, in -94m depth
6909 good observations
08-Jun-2013 06:17:08 - 26-Jul-2013 05:37:08

HARMONIC COMPONENTS

Component	Major	Minor	Ellipse	Phase
MM	1.30	0.46	12.66	97.06
MSF	2.36	-0.37	90.09	273.74
ALP1	2.07	1.71	74.13	92.13
2Q1	1.14	0.94	79.05	190.87
Q1	2.56	1.65	76.22	321.19
O1	1.05	0.89	172.55	137.11
NO1	1.20	0.53	43.46	142.67
K1	0.53	0.22	58.86	348.70
J1	1.03	0.67	150.94	89.63
OO1	1.46	0.80	94.65	4.82
UPS1	0.32	-0.08	90.53	248.60
EPS2	0.30	0.03	131.95	284.13
MU2	0.51	0.32	79.26	54.19
N2	0.30	0.16	15.41	275.67
M2	1.41	1.15	36.63	339.07
L2	0.44	0.24	157.03	235.22
S2	0.50	0.23	156.72	170.84
ETA2	0.41	0.10	96.30	286.54
MO3	0.34	0.22	162.67	44.65
M3	0.13	-0.02	28.08	165.50
MK3	0.29	0.13	21.89	209.81
SK3	0.31	0.05	174.07	220.64
MN4	0.13	0.05	48.81	312.35
M4	0.23	-0.05	29.87	40.55
SN4	0.25	-0.07	5.95	187.65
MS4	0.27	-0.03	82.83	246.57
S4	0.10	-0.01	71.27	55.29
2MK5	0.24	0.01	50.10	308.57
2SK5	0.06	-0.00	73.84	252.08
2MN6	0.23	0.09	72.52	198.15
M6	0.17	0.02	33.12	172.41
2MS6	0.10	0.06	43.82	350.66
2SM6	0.12	-0.06	138.98	10.61
3MK7	0.07	0.03	46.48	225.70
M8	0.07	0.03	22.94	308.85

© NMP 2014

4.1.1.5 Profile plots

Figures 16, 17, 18 and 19 on the following pages display profile plots of the currents through the water column. The first plot displays the mean profile plot over the duration of measurements, while the following three plots display profile plots at selected times. The times selected were time of maximum current speed for bins 88, 44 and 1. These represent the flow for the depths -7 m, -51 m and -94 m respectively. These plots consist of:

- The left hand panel is a 3-dimensional illustration of the current vector through the water column, with depth on the vertical axis. The vector arrow indicates the direction towards which the current is flowing, with the length of the arrow proportional to the current speed.
- The middle panel is a plot of the current speed (x-axis) with depth (y-axis).
- The right hand panel is a plot of current direction (x-axis) with depth (y-axis).

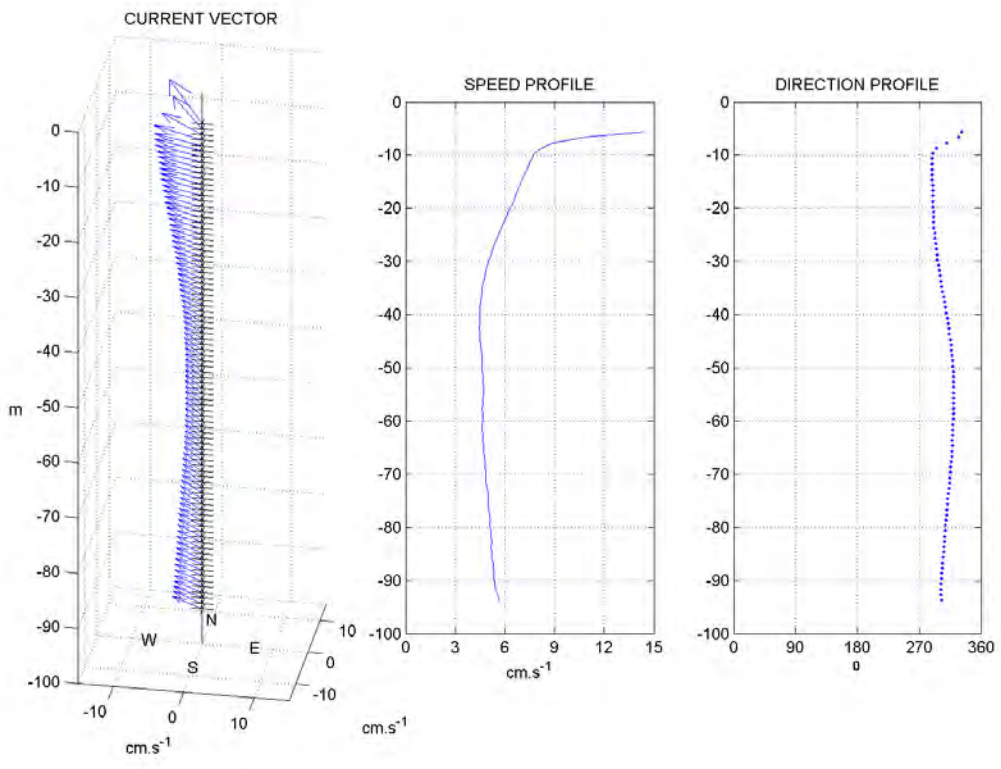


Figure 16: Mean profile plot

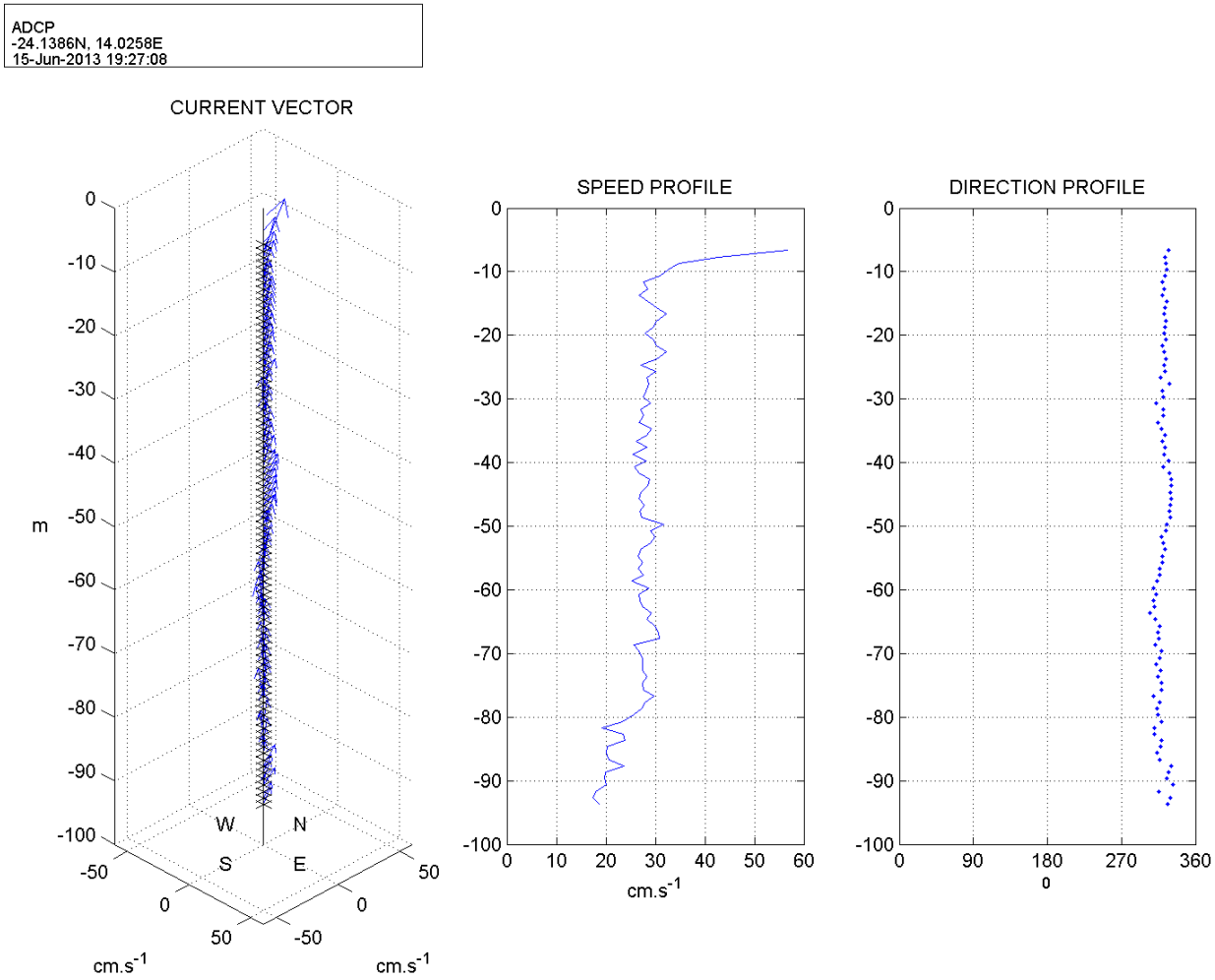


Figure 17: Profile plot at the time of maximum current speed in the upper water column

© NMP 2014

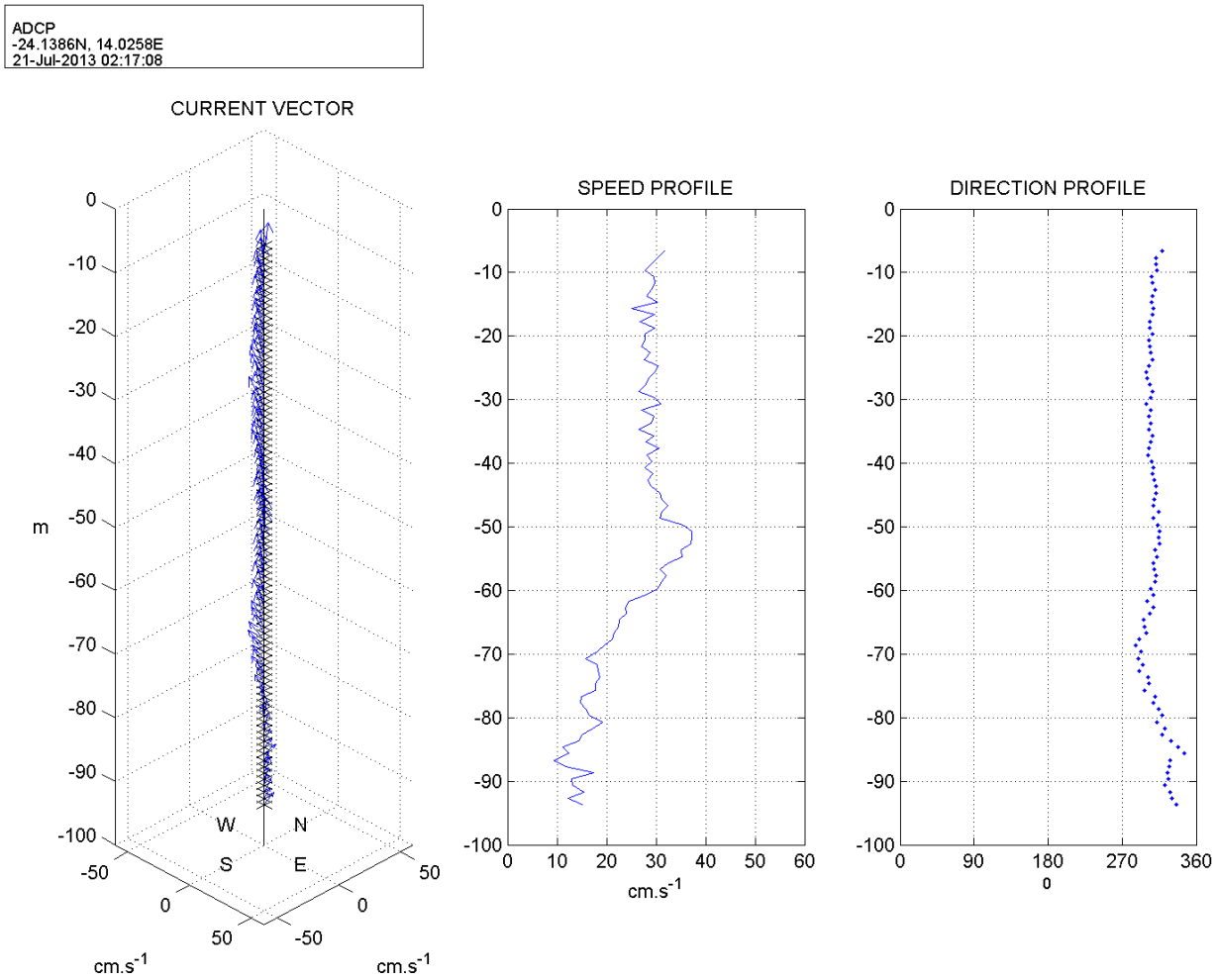


Figure 18: Profile plot at the time of maximum current speed in the mid water column

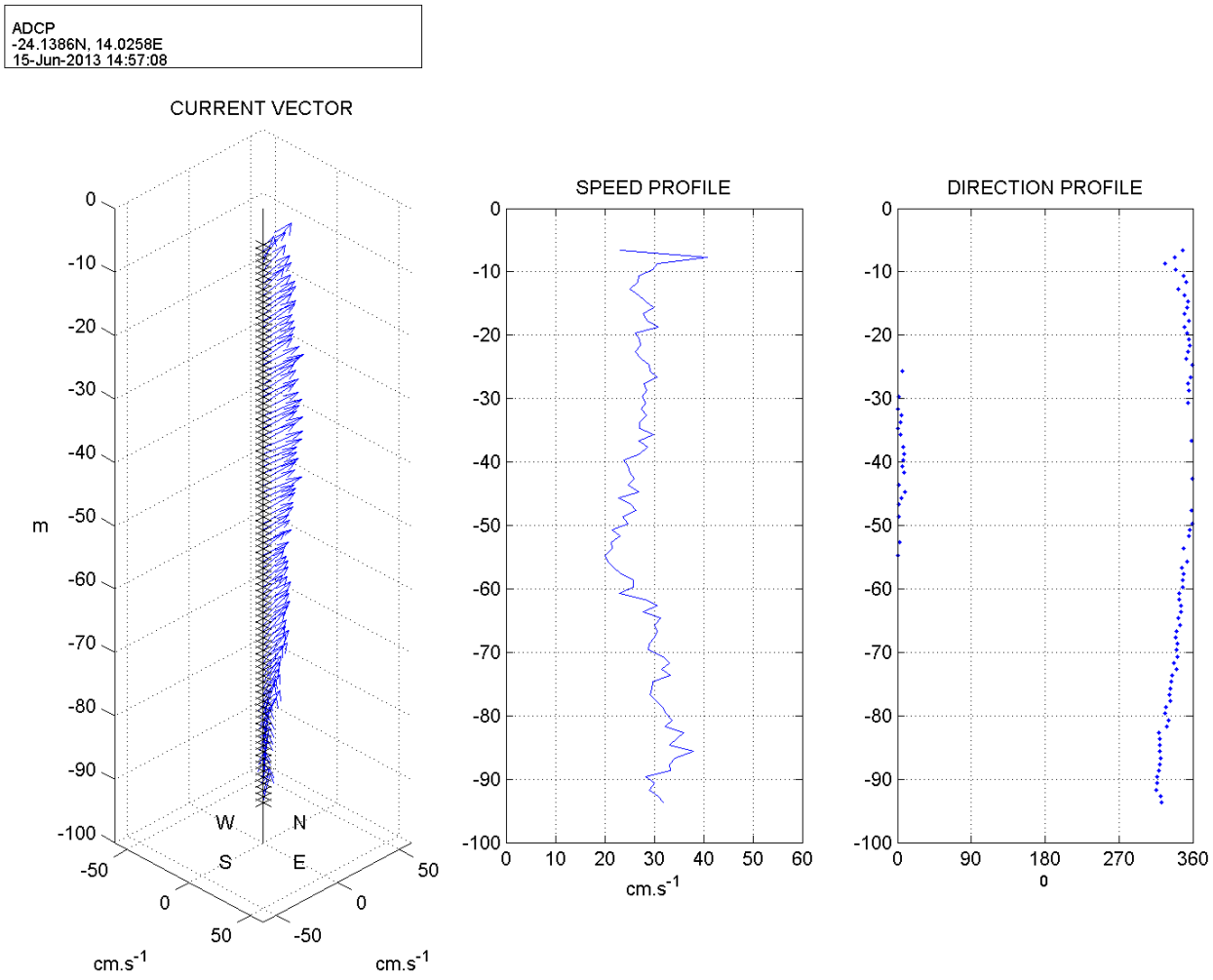


Figure 19: Profile plot at the time of maximum current speed in the lower water column

4.1.2 Pressure and water temperature data

4.1.2.1 Time **series plot**

Figure 20 on the following page displays a time series plot, which consists of:

- The first (upper) panel is of the observed pressure against time.
- The second panel is of the observed water temperature against time.
- The first day of each month is indicated visually by a thin red line on each of the plots.

© NMP 2014

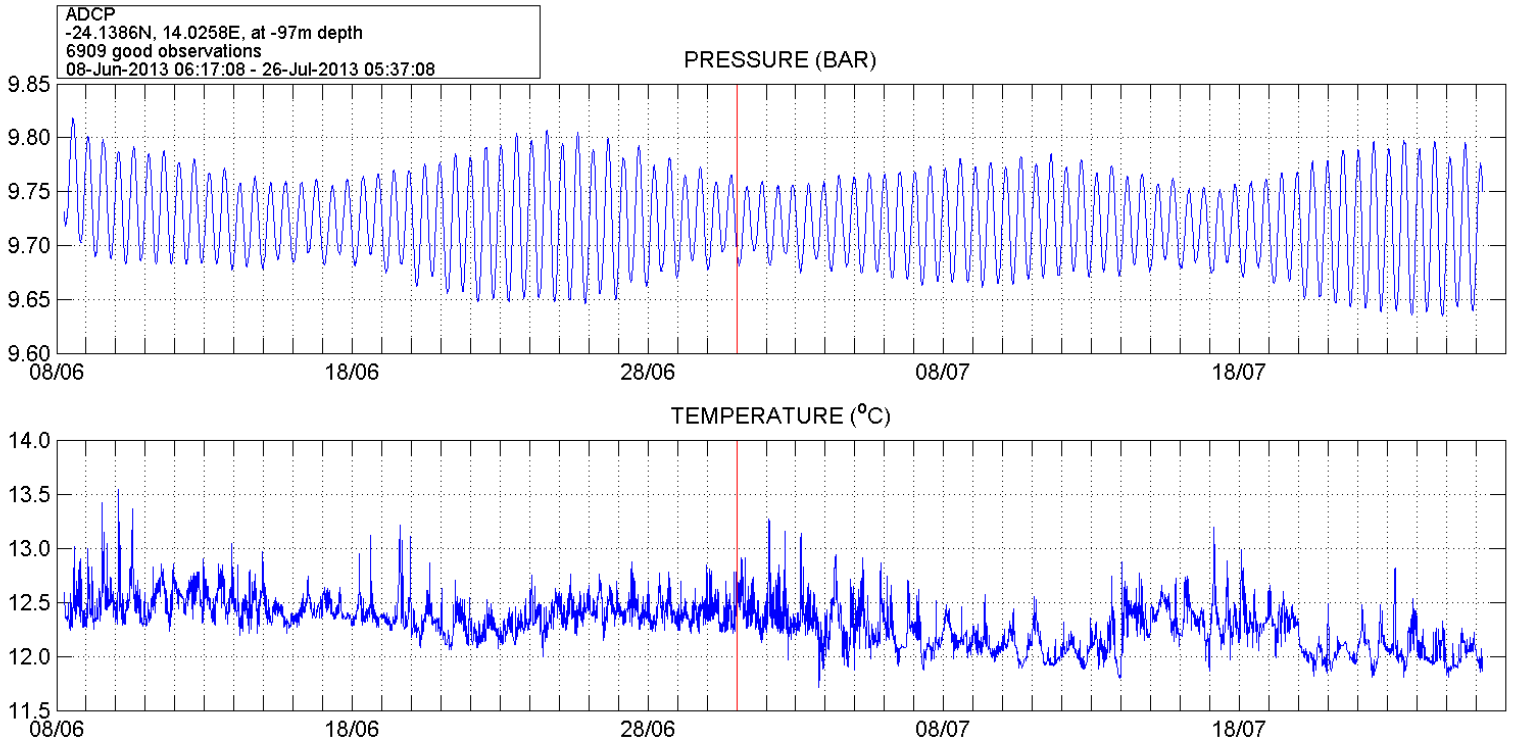


Figure 20: Upper panel: time series plot of pressure. Lower panel: time series plot of temperature.
Note: the first day of the month is indicated by a thin red line on each of the plots.

© NMP 2014

4.2 AQD 1

4.2.1 Current data

4.2.1.1 Time series plot

Figure 21 on the following page displays a time series plot which consists of:

- The first (upper) panel is of the observed current speed against time.
- The second panel is of the observed current direction against time.
- The third panel is of the tidal current speed, calculated from the observed current speed and direction, against time. The entire data set of observations is used in the derivation of the tidal component. The tidal calculation follows the method of Foreman and uses the observed complex current vector as input (*R. Pawlowicz, B. Beardsley, and S. Lentz, "Classical tidal harmonic analysis including error estimates in MATLAB using T_TIDE", Computers and Geosciences 28 (2002), 929-937*)
- The fourth panel is of the tidal current direction, calculated as above, against time.
- The fifth panel is of the residual current speed against time. The residual has been calculated as north and east components (residual component = observed component – tidal component), which have then been converted into residual speed and direction.
- The sixth panel is of the residual current direction against time, calculated as above.

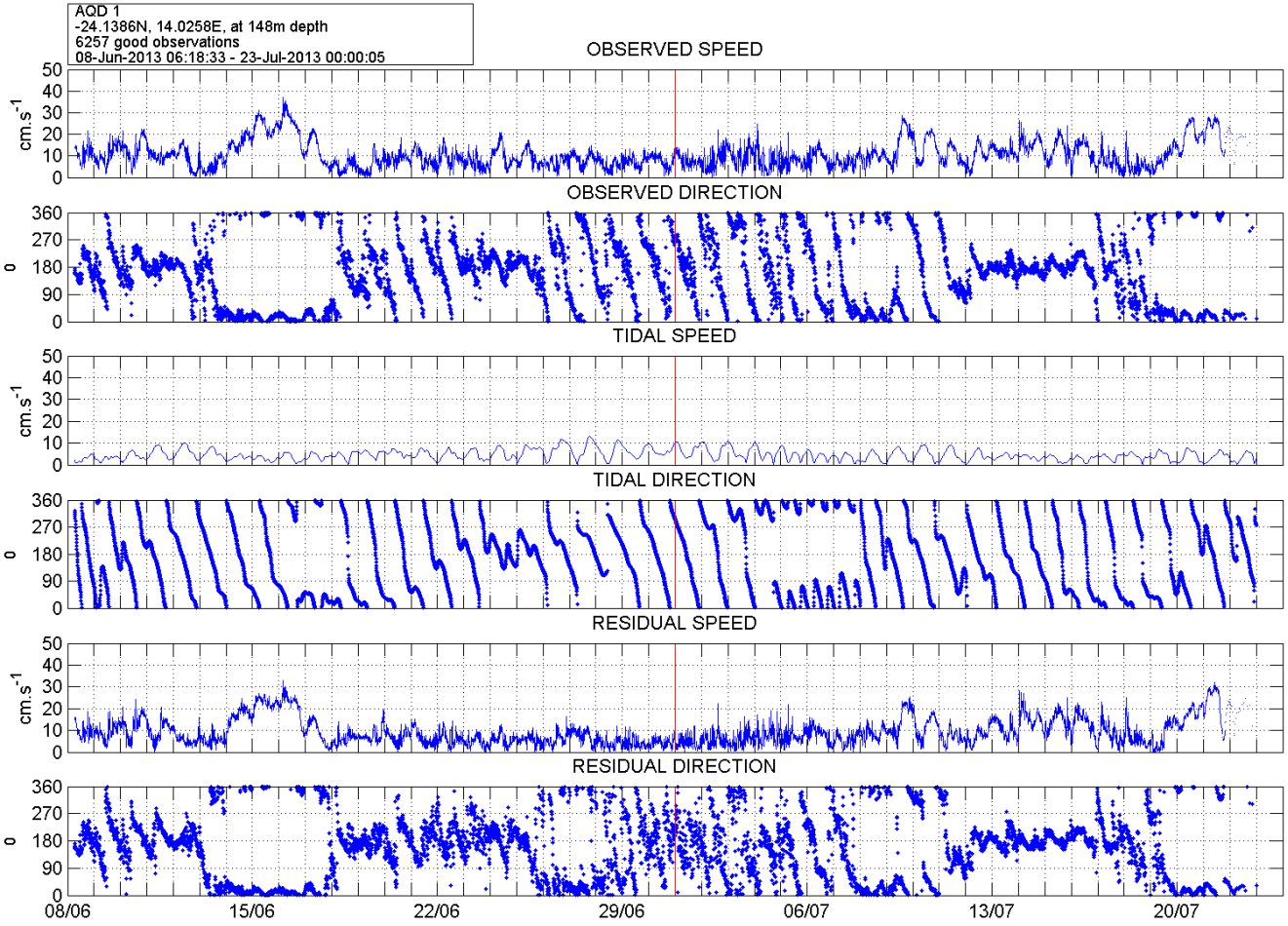


Figure 21: Time series plots of current data at 148 m depth

© NMP 2014

4.2.1.2 Summary plot

Figure 22 on the following page displays a summary plot which consists of:

- The upper panel is a table of the joint distribution of 10 minute averaged current speed against direction. Columns of the table represent direction classes and rows the speed classes. The numbers in the table reflect the percentage of observations that fall within a particular speed interval and direction sector.
- The lower left hand panel is a rose of the 10 minute averaged current direction. This is a histogram of the directional distribution and reflects the percentage of observations that fall within each direction sector.
- The lower right hand panel is a histogram of the 10 minute averaged current speeds. This reflects the percentage of observations that fall within each speed interval. Included on the plot are basic statistics for the current speed distribution.

© NMP 2014

AQD 1
-24.1386N, 14.0258E, at 148m depth
6257 good observations
08-Jun-2013 06:18:33 - 23-Jul-2013 00:00:05

JOINT DISTRIBUTION OF SPEED AND DIRECTION

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Σ
0-5	0.72	1.12	0.83	1.17	1.12	1.20	1.21	0.93	1.58	1.29	1.09	0.94	0.91	0.75	0.78	1.02	16.67
5-10	2.14	2.38	2.41	1.65	2.09	2.35	2.67	3.21	4.09	3.88	2.59	2.01	1.55	1.36	1.29	1.61	37.30
10-15	1.95	2.38	1.47	1.09	0.96	1.18	1.55	3.04	3.71	2.88	2.17	1.07	0.88	0.46	0.32	0.64	25.75
15-20	1.37	1.95	0.37	0.35	0.29	0.35	0.27	1.13	2.14	0.88	0.94	0.29	0.05	0.10	0.14	0.27	10.90
20-25	1.34	2.53	0.42	0.19	0.02			0.13	0.46	0.22	0.13	0.08	0.02		0.11	0.32	5.96
25-30	1.37	1.34	0.11						0.02	0.02						0.10	2.96
30-35	0.14	0.29															0.43
35-40		0.03															0.03
40-45																	0.00
45-50																	0.00
Σ	9.05	12.02	5.61	4.44	4.47	5.08	5.71	8.44	12.00	9.17	6.92	4.40	3.40	2.67	2.65	3.96	100.00

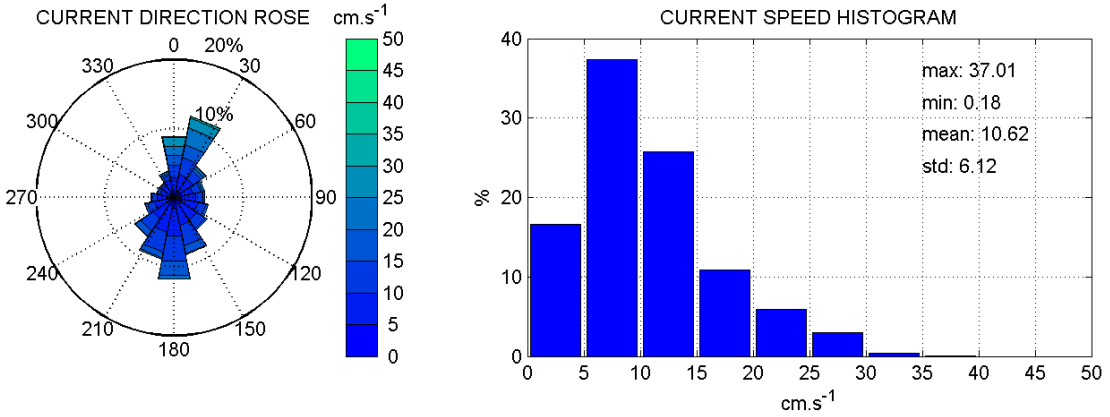


Figure 22: Current speed and direction plots for 148 m depth

4.2.1.3 Progressive vector plot

Figure 23 on the following page displays a progressive vector plot which consists of:

- The solid line represents the displacement that a particle of water would undergo when subject to the currents that were observed.
- The start and end points of the observations are labelled.
- Each day is represented by a red cross.

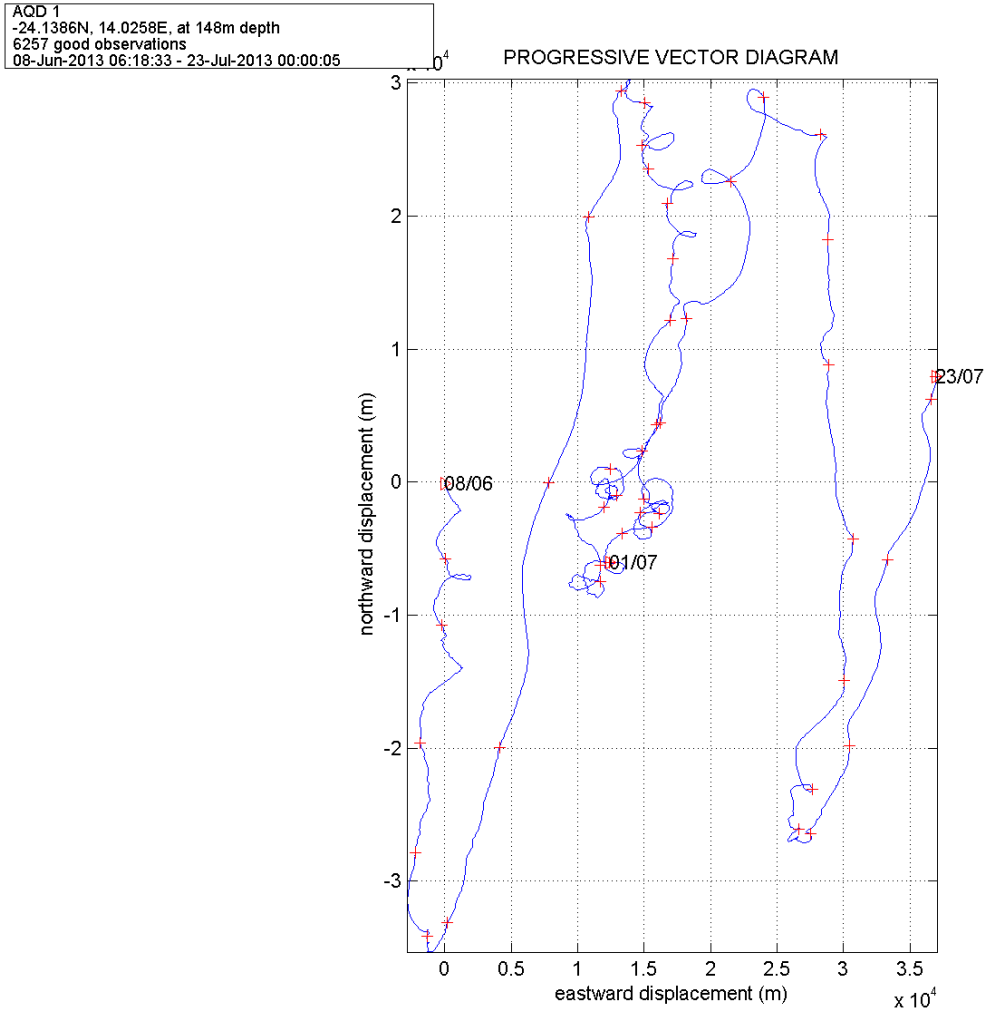


Figure 23: Current progressive vector plot for 148 m depth

4.2.1.4 Tidal harmonic data

Table 13 on the following page presents current harmonic data which consist of:

- The tidal calculation follows the method of Foreman and uses the observed complex current vector as input *(R. Pawlowicz, B. Beardsley and S. Lentz, "Classical tidal harmonic analysis including error estimates in Matlab using T_TIDE", Computers and Geosciences 28 (2002), 929-937*).
- The major and minor axis amplitudes are given in knots.
- The ellipse orientation and Greenwich phase are given in degrees.

© NMP 2014

Table 13 : Current harmonic data for 148 m depth

AQD 1
-24.1386N, 14.0258E, in 148m depth
6257 good observations
08-Jun-2013 06:18:33 - 23-Jul-2013 00:00:05

HARMONIC COMPONENTS

Component	Major	Minor	Ellipse	Phase
MM	2.01	-0.77	49.61	229.40
MSF	3.60	-0.55	85.11	258.30
ALP1	2.34	2.25	165.96	123.97
2Q1	2.40	1.70	23.62	345.67
Q1	3.16	2.46	16.85	72.86
O1	1.42	0.98	146.91	21.19
NO1	2.20	1.57	17.50	278.88
K1	0.58	0.26	101.17	183.84
J1	0.89	0.81	106.94	327.61
OO1	1.31	1.07	115.49	353.69
UPS1	0.80	0.43	71.56	251.23
EPS2	0.60	0.20	72.46	66.17
MU2	0.22	0.12	179.13	67.11
N2	0.51	0.35	4.41	279.39
M2	1.82	1.51	154.18	109.50
L2	0.57	0.27	104.25	102.51
S2	1.12	0.61	159.15	94.04
ETA2	0.48	0.33	110.89	38.60
MO3	0.35	0.14	64.37	142.28
M3	0.36	-0.10	21.20	127.95
MK3	0.39	0.07	18.68	351.98
SK3	0.36	-0.06	166.11	198.29
MN4	0.06	0.03	166.52	214.29
M4	0.27	0.05	11.22	264.57
SN4	0.26	0.12	163.56	171.64
MS4	0.22	0.15	12.98	99.68
S4	0.33	-0.08	21.78	340.08
2MK5	0.20	-0.04	149.63	186.02
2SK5	0.12	0.04	10.20	251.73
2MN6	0.13	0.06	111.43	105.87
M6	0.16	0.06	58.38	189.54
2MS6	0.16	-0.07	157.59	113.08
2SM6	0.14	0.06	78.69	103.49
3MK7	0.14	-0.08	10.18	97.50
M8	0.08	0.00	53.17	33.33

© NMP 2014

4.2.2 Pressure and water temperature data

4.2.2.1 Time series plot

Time series plots of water level and water temperature variations as a function of time over the recording period are presented in Figure 24.

- The first (upper) panel is of the observed 10 minute water level against time.
- The second panel is of the observed 10 minute water temperature against time.

© NMP 2014

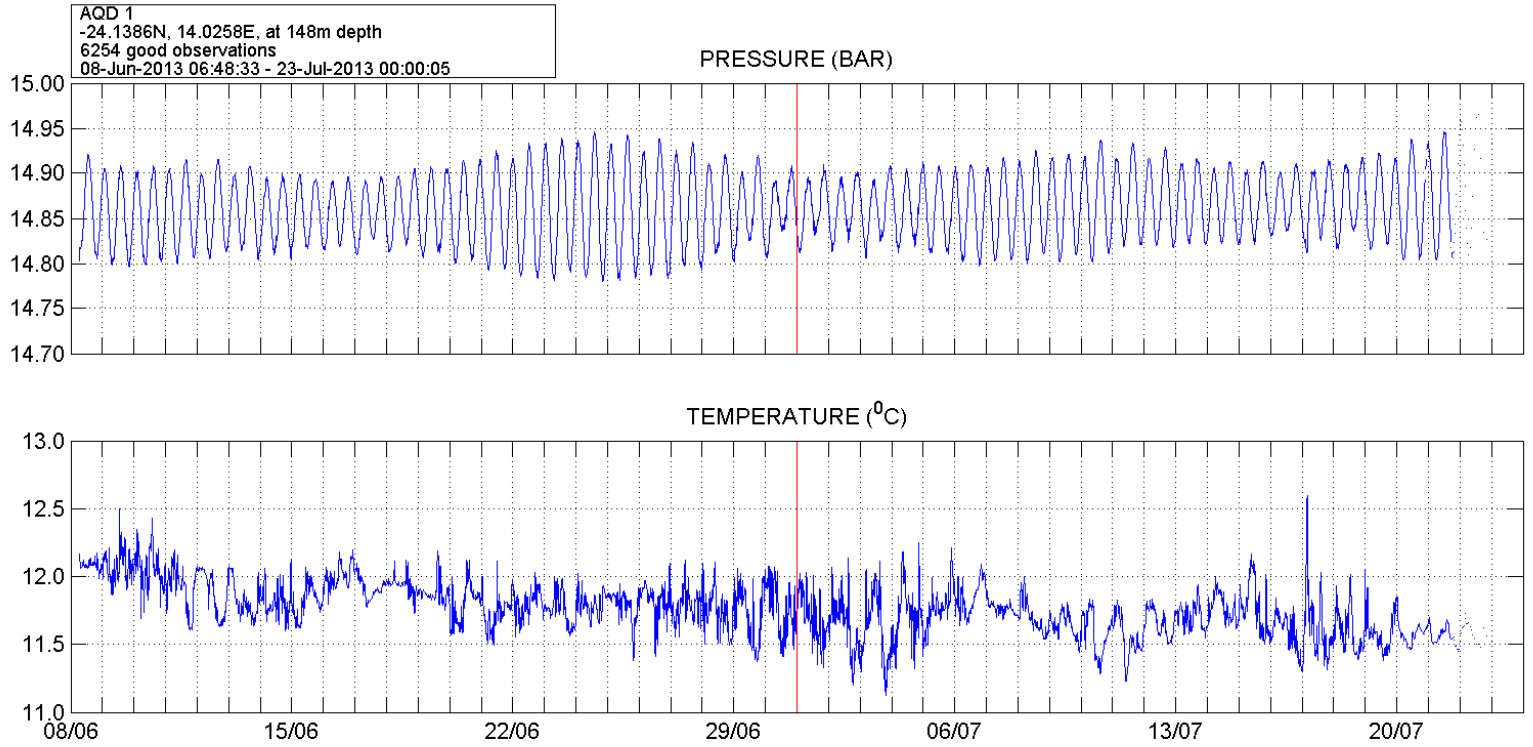


Figure 24: Time series plots of pressure (water level) and water temperature at 148 m depth

© NMP 2014

4.3 AQD 2

4.3.1 Current data

4.3.1.1 Time series plot

Figure 25 on the following page displays a time series plot which consists of:

- The first (upper) panel is of the observed current speed against time.
- The second panel is of the observed current direction against time.
- The third panel is of the tidal current speed, calculated from the observed current speed and direction, against time. The entire data set of observations is used in the derivation of the tidal component. The tidal calculation follows the method of Foreman and uses the observed complex current vector as input (*R. Pawlowicz, B. Beardsley, and S. Lentz, "Classical tidal harmonic analysis including error estimates in MATLAB using T_TIDE", Computers and Geosciences 28 (2002), 929-937*)
- The fourth panel is of the tidal current direction, calculated as above, against time.
- The fifth panel is of the residual current speed against time. The residual has been calculated as north and east components (residual component = observed component – tidal component), which have then been converted into residual speed and direction.
- The sixth panel is of the residual current direction against time, calculated as above.

© NMP 2014

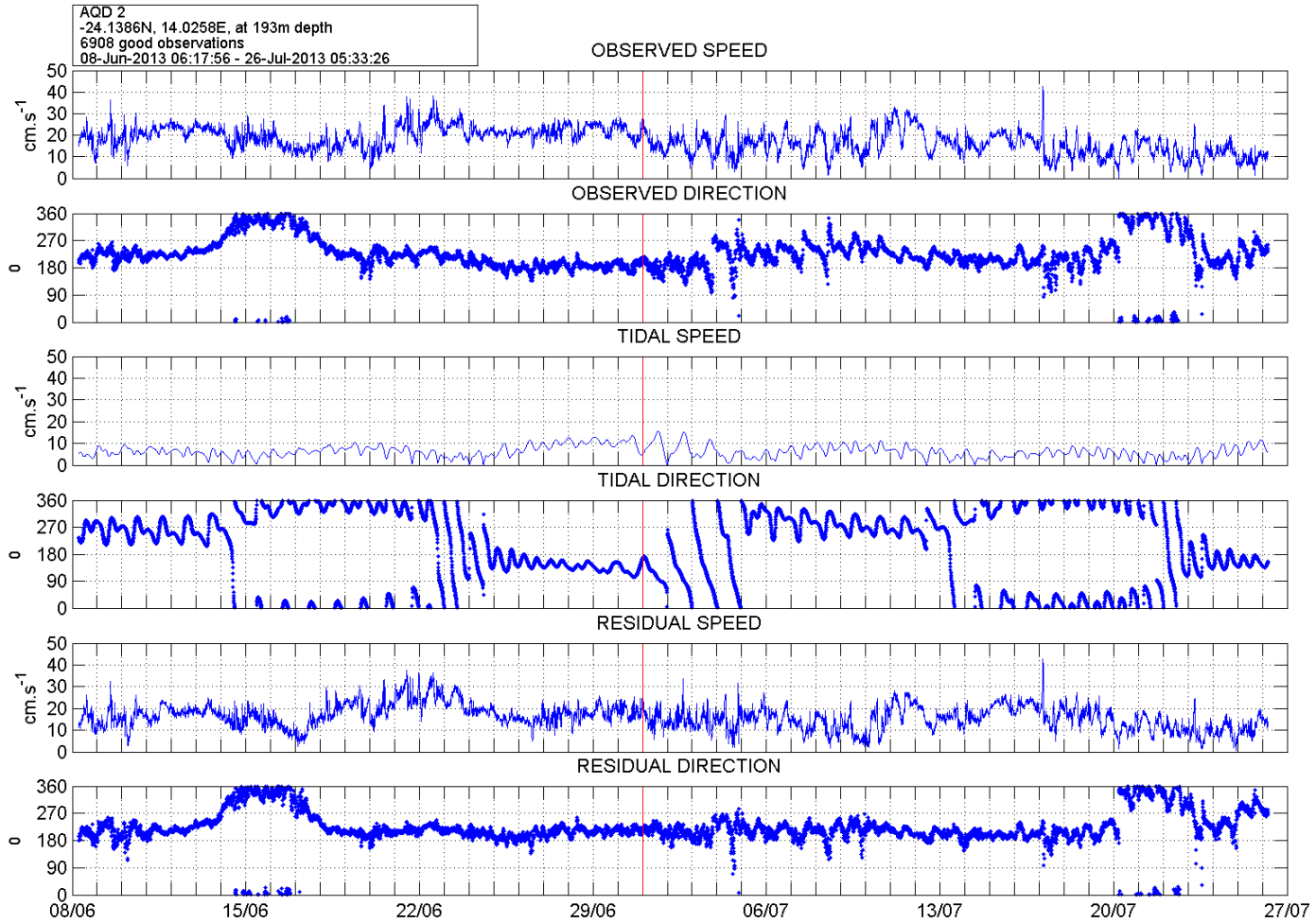


Figure 25: Time series plots of current data at 193 m depth

© NMP 2014

4.3.1.2 Summary plot

Figure 26 on the following page displays a summary plot which consists of:

- The upper panel is a table of the joint distribution of 10 minute averaged current speed against direction. Columns of the table represent direction classes and rows the speed classes. The numbers in the table reflect the percentage of observations that fall within a particular speed interval and direction sector.
- The lower left hand panel is a rose of the 10 minute averaged current direction. This is a histogram of the directional distribution and reflects the percentage of observations that fall within each direction sector.
- The lower right hand panel is a histogram of the 10 minute averaged current speeds. This reflects the percentage of observations that fall within each speed interval. Included on the plot are basic statistics for the current speed distribution.

© NMP 2014

AQD 2
-24.1386N, 14.0258E, at 193m depth
6908 good observations
08-Jun-2013 06:17:56 - 26-Jul-2013 05:33:26

JOINT DISTRIBUTION OF SPEED AND DIRECTION

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Σ
0-5	0.04	0.01				0.03	0.17	0.12	0.16	0.10	0.09	0.12	0.10	0.12	0.13	0.06	1.24
5-10	0.14	0.12			0.04	0.22	0.20	0.72	1.36	1.16	1.38	1.46	1.16	0.68	0.45	0.35	9.44
10-15	1.23	0.20			0.07	0.09	0.39	0.74	2.74	5.04	3.65	3.40	2.39	1.11	1.26	1.61	23.91
15-20	1.85	0.26	0.01			0.03	0.26	0.97	4.00	7.28	7.41	3.56	0.87	0.58	0.36	1.90	29.34
20-25	0.20	0.04			0.01		0.04	0.87	5.52	6.12	8.61	3.56	0.38	0.30	0.43	0.54	26.64
25-30								0.07	1.14	1.85	3.21	1.62	0.04		0.14	0.03	8.12
30-35										0.01	0.65	0.41					1.07
35-40												0.22					0.22
40-45												0.01					0.01
45-50																	0.00
Σ	3.47	0.64	0.01	0.00	0.13	0.36	1.07	3.49	14.91	21.57	25.00	14.36	4.94	2.79	2.78	4.47	100.00

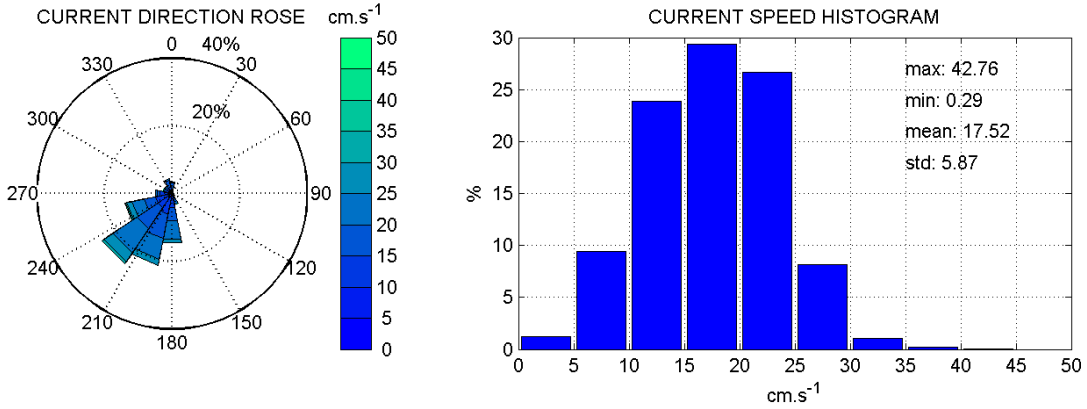


Figure 26: Current speed and direction plots of 193 m depth

4.3.1.3 Progressive vector plot

Figure 27 on the following page displays a progressive vector plot which consists of:

- The solid line represents the displacement that a particle of water would undergo when subject to the currents that were observed.
- The start and end points of the observations are labelled.
- Each day is represented by a red cross.

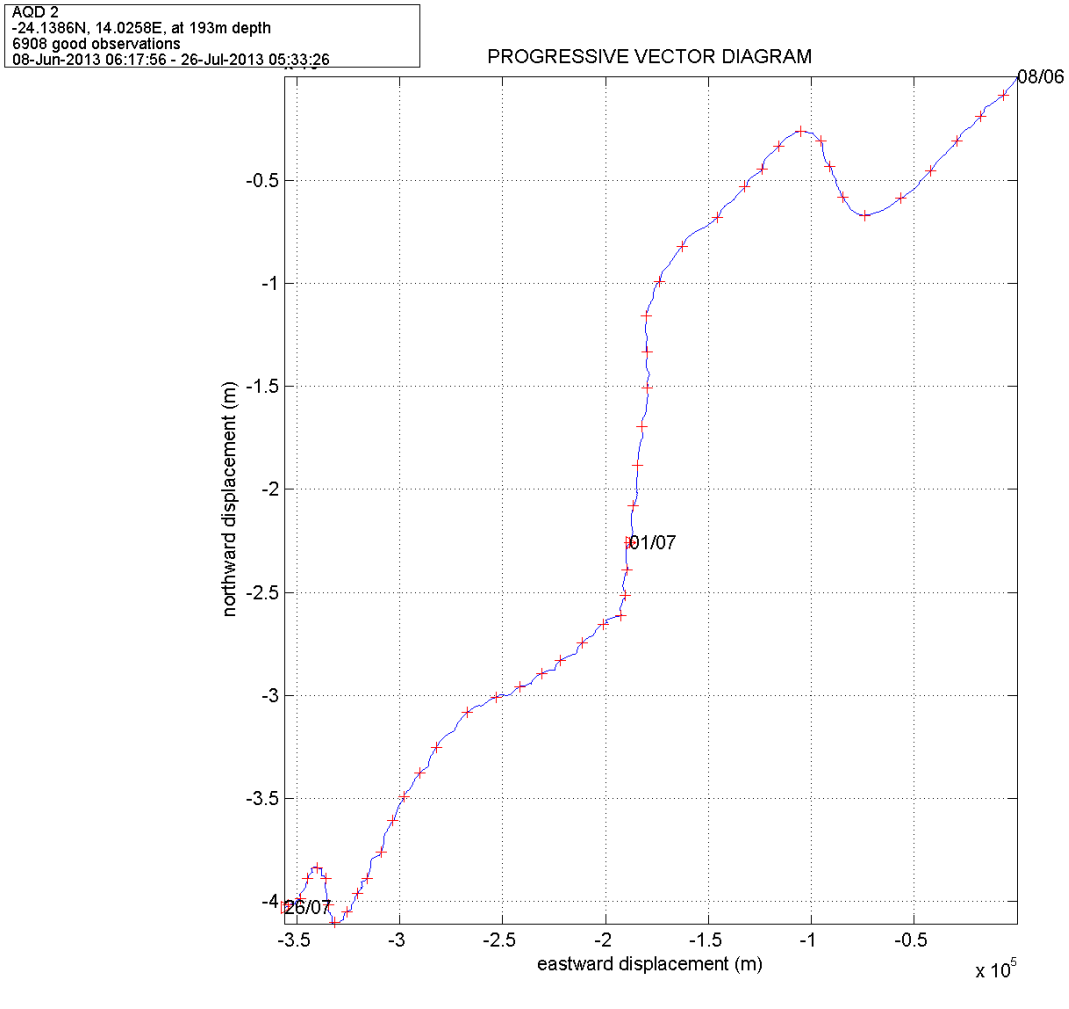


Figure 27: Current progressive vector plot for 193 m depth

4.3.1.4 Tidal harmonic data

Table 14 on the following page presents current harmonic data which consist of:

- The tidal calculation follows the method of Foreman and uses the observed complex current vector as input *(R. Pawlowicz, B. Beardsley and S. Lentz, "Classical tidal harmonic analysis including error estimates in Matlab using T_TIDE", Computers and Geosciences 28 (2002), 929-937*).
- The major and minor axis amplitudes are given in knots.
- The ellipse orientation and Greenwich phase are given in degrees.

© NMP 2014

Table 14 : Current harmonic data for 193 m depth

AQD 2
-24.1386N, 14.0258E, in 193m depth
6908 good observations
08-Jun-2013 06:17:56 - 26-Jul-2013 05:33:26

HARMONIC COMPONENTS

Component	Major	Minor	Ellipse	Phase
MM	6.91	-1.55	141.46	250.26
MSF	4.17	3.13	95.77	283.69
ALP1	1.38	0.73	176.29	7.69
2Q1	1.63	0.65	15.34	307.27
Q1	1.26	0.59	65.77	85.25
O1	2.24	0.69	173.53	358.43
NO1	0.88	0.58	35.11	297.07
K1	2.08	0.79	21.69	66.72
J1	1.39	0.75	92.50	297.55
OO1	2.05	0.87	129.74	354.06
UPS1	0.81	0.15	153.18	107.29
EPS2	0.41	0.09	76.11	353.68
MU2	0.46	0.06	120.74	55.13
N2	0.86	0.15	172.38	91.88
M2	1.63	1.29	126.69	53.31
L2	0.70	-0.40	3.39	159.69
S2	1.05	0.64	155.01	76.35
ETA2	0.65	0.10	59.75	120.74
MO3	0.48	-0.04	18.16	69.25
M3	0.31	-0.17	164.90	334.73
MK3	0.57	0.31	20.17	325.20
SK3	0.28	0.08	52.15	6.18
MN4	0.11	0.09	50.11	258.74
M4	0.25	-0.00	179.55	87.62
SN4	0.10	0.09	21.62	39.06
MS4	0.25	-0.01	19.09	148.90
S4	0.17	-0.11	29.86	277.55
2MK5	0.08	0.02	169.09	290.33
2SK5	0.28	0.02	4.58	301.12
2MN6	0.23	0.04	16.31	326.55
M6	0.08	0.06	16.53	256.56
2MS6	0.18	-0.09	20.25	271.25
2SM6	0.14	-0.02	147.07	69.65
3MK7	0.14	-0.07	156.10	310.00
M8	0.12	0.02	36.38	42.32

© NMP 2014

4.3.2 Pressure and water temperature data

4.3.2.1 Time series plot

Time series plots of water level and water temperature variations as a function of time over the recording period are presented in Figure 28:

- The first (upper) panel is of the observed 10 minute water level against time.
- The second panel is of the observed 10 minute water temperature against time.

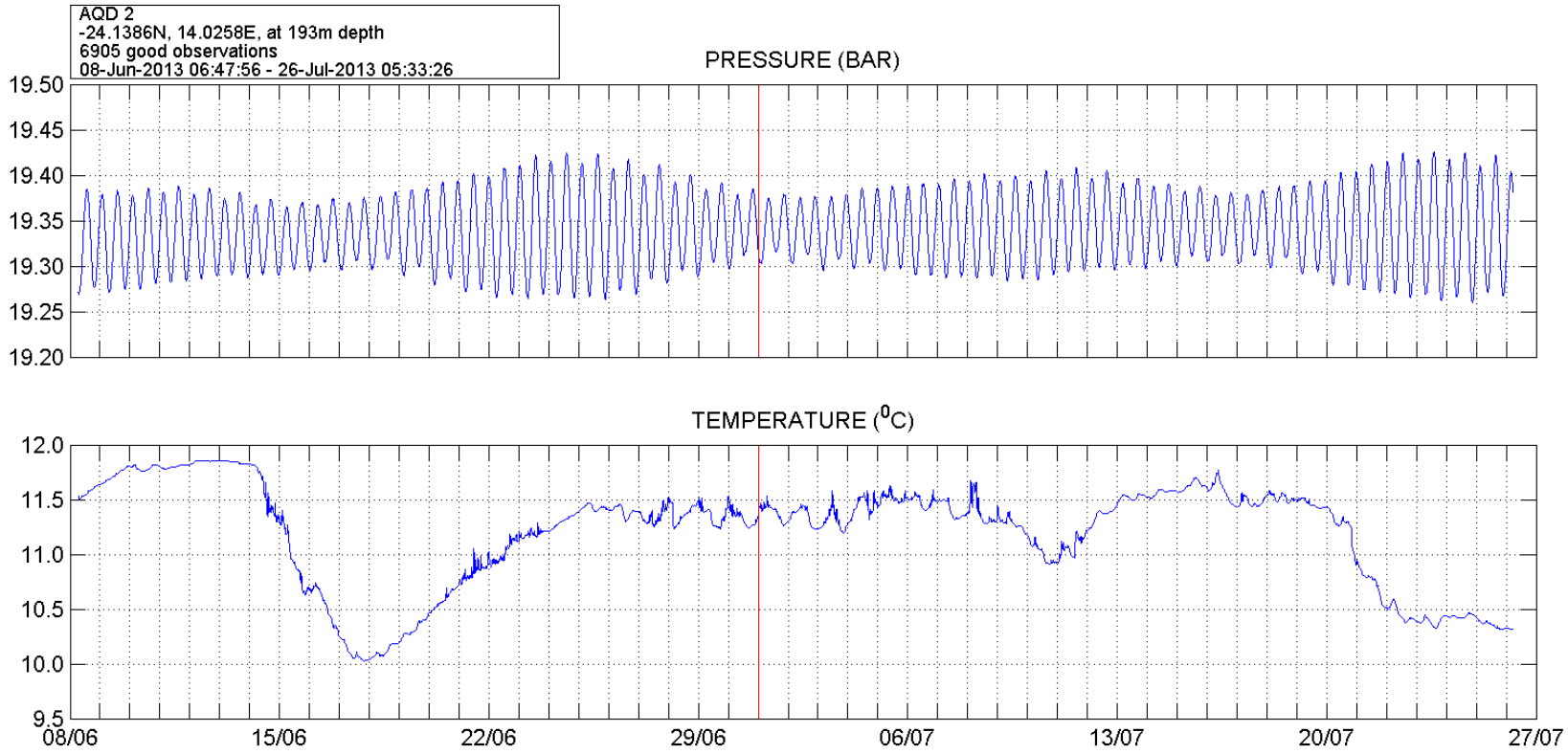


Figure 28: Time series plots of pressure (water level) and water temperature at 193 m depth

© NMP 2014

4.4 CTD

4.4.1 Water quality data

4.4.1.1 Time series plot

Figure 29 on the following page displays a set of time series plots, which consist of:

- The first (upper) panel is of the observed water temperature against time.
- The second panel is of the derived salinity against time.
- The third panel is of the observed depth against time.
- The fourth panel is of the observed dissolved oxygen against time.
- The fifth panel is of the observed fluorescence against time.
- The sixth panel is of the observed turbidity against time.

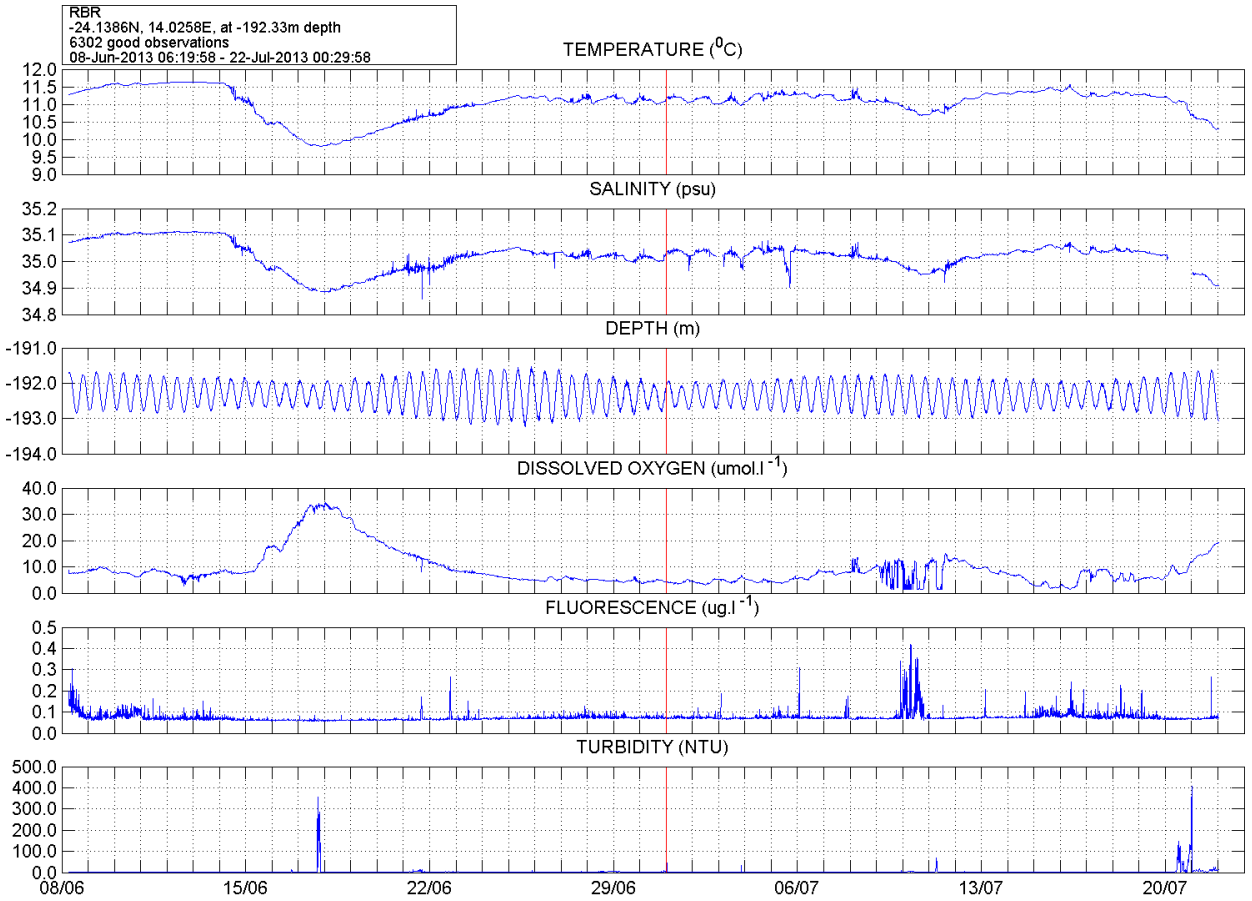


Figure 29: Water quality data for 192.33 m depth

© NMP 2014

4.4.1.2 Summary plot

Figure 30 on the following page displays frequency distributions of measurements of water temperature, depth, dissolved oxygen, fluorescence and turbidity at 192.33 m water depth.

- The upper left hand panel is a histogram of the water temperature. This reflects the percentage of observations that fall within each temperature interval. Included on the plot are basic statistics for the distribution.
- The upper middle panel is a histogram of the water salinity. This reflects the percentage of observations that fall within each salinity interval. Included on the plot are basic statistics for the distribution.
- The upper right hand panel is a histogram of the water depth. This reflects the percentage of observations that fall within each depth interval. Included on the plot are basic statistics for the distribution.
- The lower left hand panel is a histogram of the dissolved oxygen. This reflects the percentage of observations that fall within each sound velocity interval. Included on the plot are basic statistics for the distribution.
- The lower middle panel is a histogram of the fluorescence. This reflects the percentage of observations that fall within each density interval. Included on the plot are basic statistics for the distribution.
- The lower right hand panel is a histogram of the turbidity. This reflects the percentage of observations that fall within each turbidity interval. Included on the plot are basic statistics for the distribution.

© NMP 2014

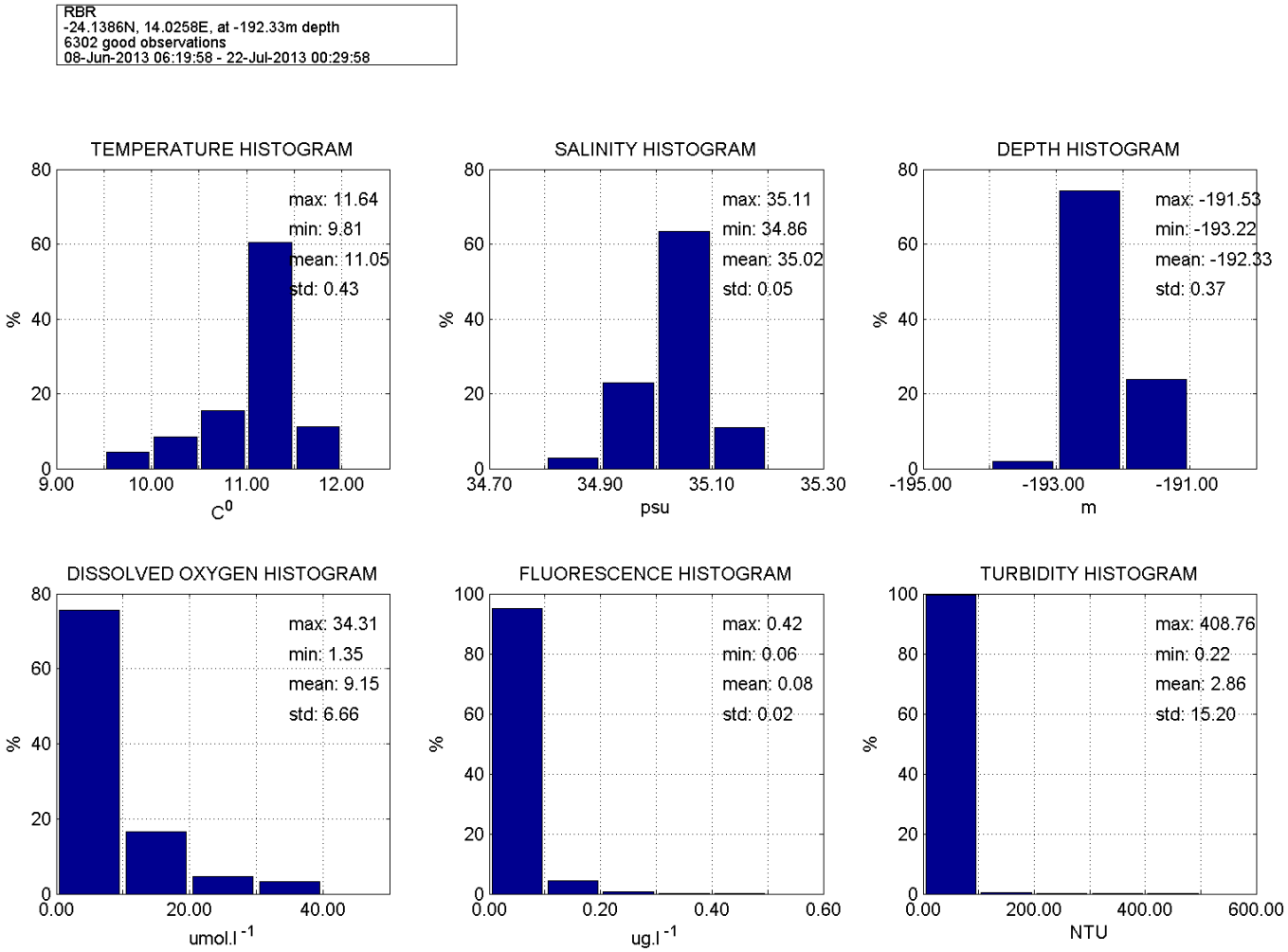


Figure 30: Summary data for environmental parameters at 192.33 m depth

© NMP 2014

4.4.2 Tide data

4.4.2.1 Time series plot

Figure 31 on the following page displays a time series plot of the tidal height. The time series plot consists of:

- The first (upper) panel is of the observed height against time.
- The second panel is of the tidal height, calculated from the observed height, against time. The tidal calculation follows the method of Foreman and uses the observed height as input (*R. Pawlowicz, B. Beardsley, and S. Lentz, "Classical tidal harmonic analysis including error estimates in MATLAB using T_TIDE", Computers and Geosciences 28 (2002), 929-937*)
- The third panel is of the residual height against time. The residual has been calculated as the observed height minus the tidal height.

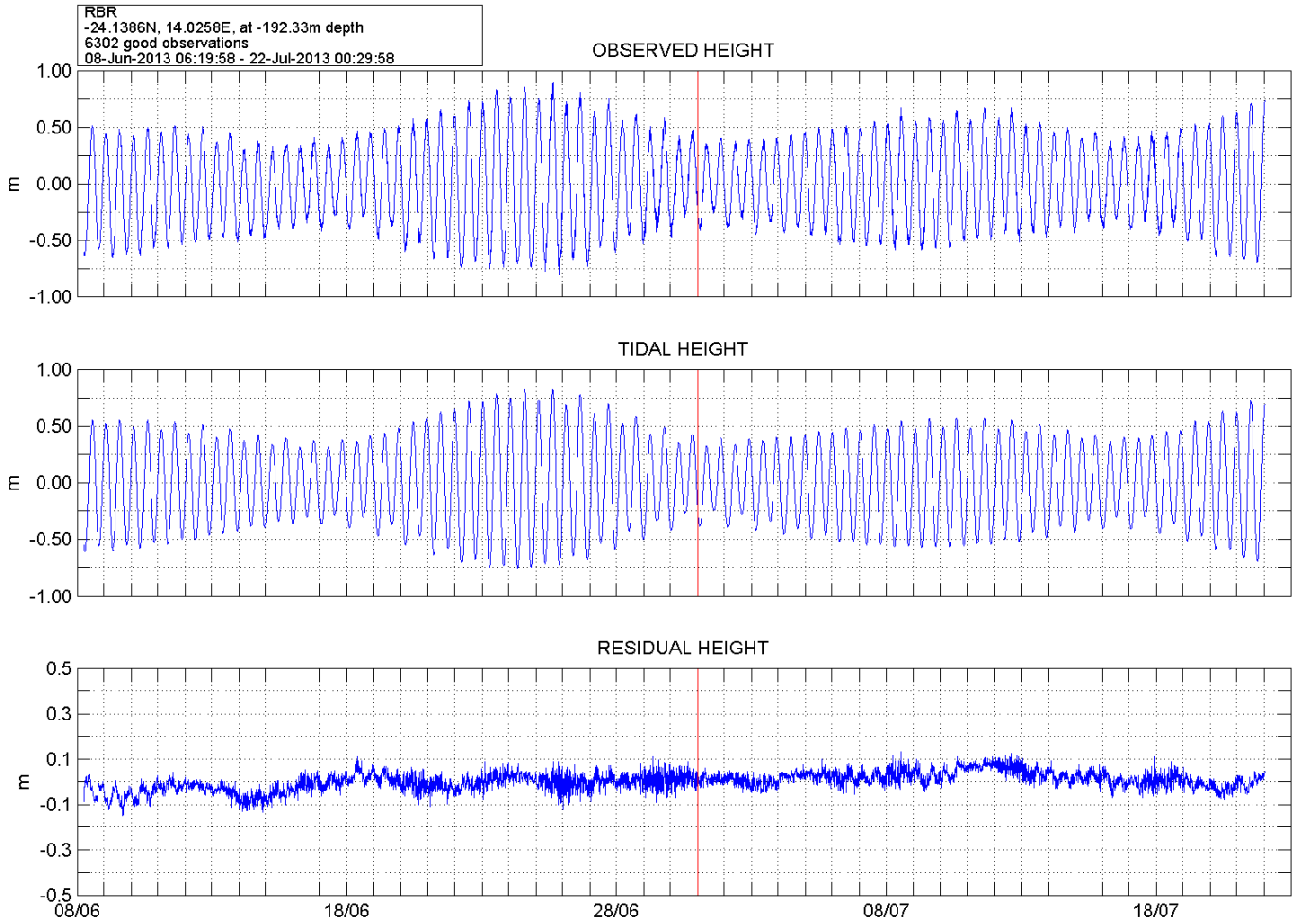


Figure 31: Time series of tidal height

4.4.2.2 Tidal harmonics table

The tidal harmonics resulting from the analysis are presented in Table 15. The tidal calculation follows the method of Foreman and uses the observed complex current vector as input (*R. Pawlowicz, B. Beardsley, and S. Lentz, "Classical tidal harmonic analysis including error estimates in MATLAB using T_TIDE", Computers and Geosciences 28 (2002), 929-937*).

© NMP 2014

Table 15 : Tidal harmonic data for 192.33 m depth

RBR
-24.1386N, 14.0258E, in -192.33m depth
6302 good observations
08-Jun-2013 06:19:58 - 22-Jul-2013 00:29:58

HARMONIC COMPONENTS

Component	Amplitude (m)	Phase (deg)
MM	0.014	19.690
MSF	0.012	148.287
ALP1	0.001	193.059
2Q1	0.001	182.746
Q1	0.012	182.008
O1	0.019	218.151
NO1	0.010	51.353
K1	0.053	66.993
J1	0.004	90.369
OO1	0.004	54.951
UPS1	0.001	21.737
EPS2	0.007	1.410
MU2	0.030	15.540
N2	0.120	23.785
M2	0.477	38.257
L2	0.016	43.947
S2	0.137	61.073
ETA2	0.006	351.679
MO3	0.003	75.746
M3	0.006	292.182
MK3	0.000	243.432
SK3	0.004	188.576
MN4	0.005	70.813
M4	0.009	117.790
SN4	0.001	185.676
MS4	0.004	234.380
S4	0.003	236.715
2MK5	0.003	88.039
2SK5	0.005	279.117
2MN6	0.002	262.996
M6	0.004	315.066
2MS6	0.003	67.264
2SM6	0.000	13.469
3MK7	0.001	349.214
M8	0.002	191.633

© NMP 2014

4.4.2.3 Tidal harmonics plot

Graphical representations of the tidal harmonic components presented in Table 15 are displayed in Figure 32:

- Components with periods between 0 to 10hours are displayed in the top panel, while the left and right bottom panels display components with periods of 10 to 14 hours and greater than 14 hours respectively.
- Amplitudes for each component are indicated by the bar graph, while the phase of each component is indicated by the pie chart above each amplitude bar.
- The period associated with each component is indicated below the amplitude bar.

© NMP 2014

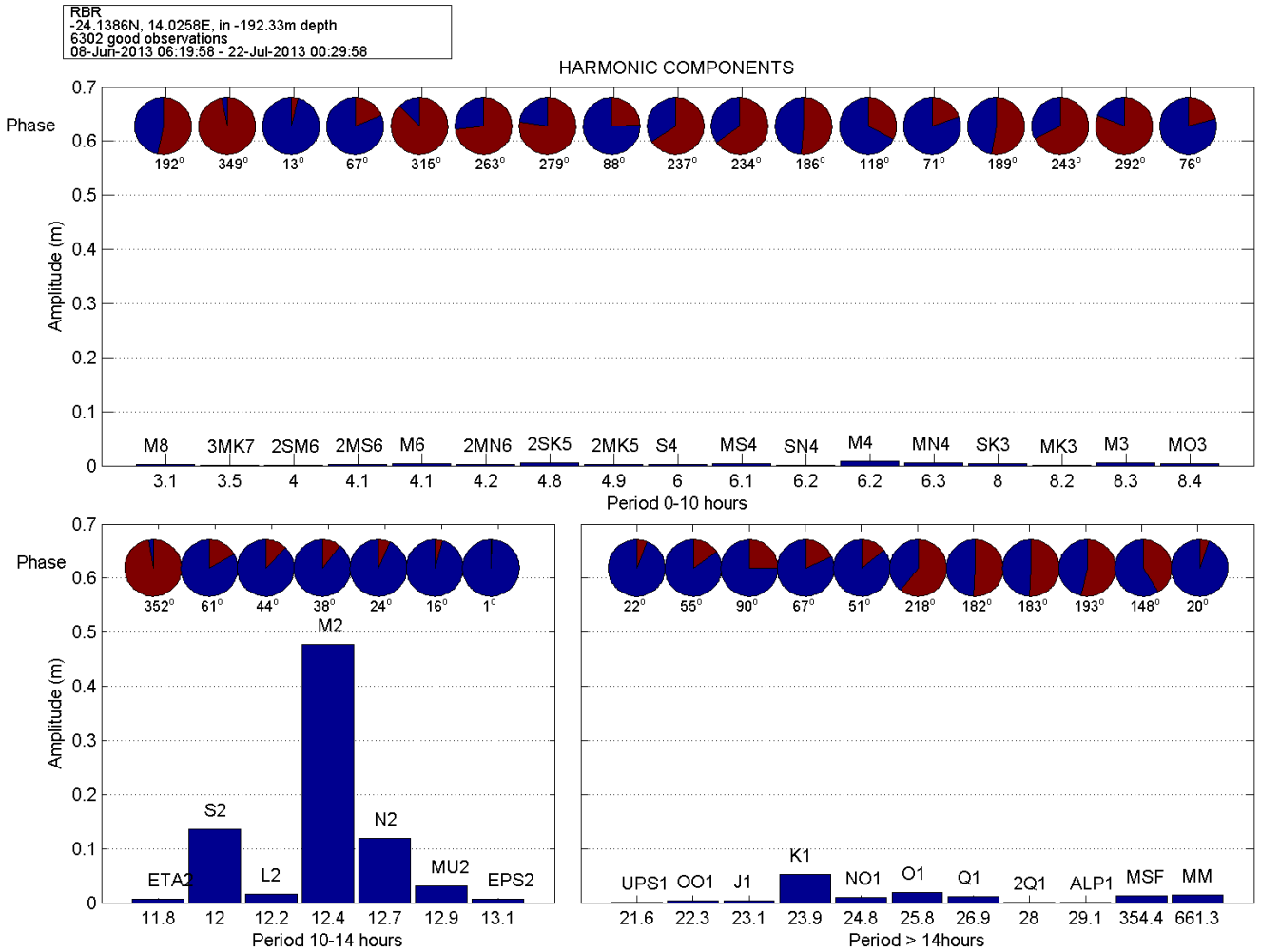


Figure 32: Graphical representation of the tidal harmonic components presented in Table 15.

5 DISCUSSION

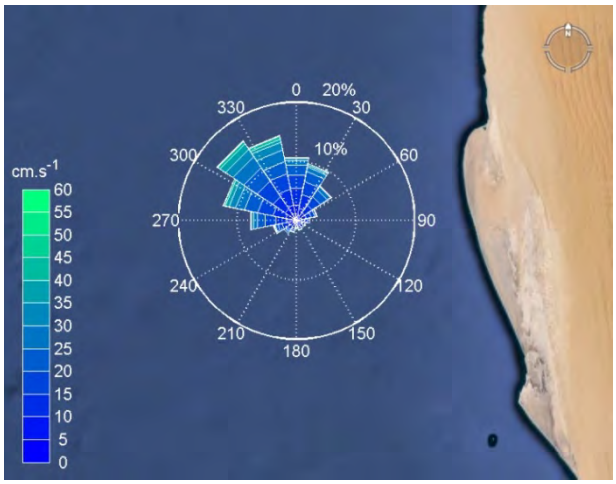
Metocean Services International (Pty) Limited (MSI) has been awarded a contract by Lwandle Technologies, under sub contract from Namibian Marine Phosphate (Pty) Ltd (NMP), to deploy an oceanographic mooring offshore Namibia. NMP intends dredging marine phosphate reserves at the site and requires verification of previous studies regarding the behaviour of the water column and sediment re-suspension events. Current measurements throughout the water column were undertaken with an ADCP and two single point current meters and water quality measurements were undertaken with a CTD near the seabed. Data collected during the first measurement period (nominally from 8 June 2013 to 26 July 2013) are presented in this report. Data return was good, however the upper AQD and CTD stopped logging data shortly before recovery as a result of depleted batteries.

Current speeds at the measurement location were low, with maximum speeds not exceeding 60 $cm.s^{-1}$ and maximum current speeds exceeding 50 $cm.s^{-1}$ above approximately 8m depth only. Near the seabed, a maximum current speed of 43 $cm.s^{-1}$ was recorded. Mean current speeds showed a general decrease with depth from a mean current speed of 17 $cm.s^{-1}$ at a depth of 7 m to mean speeds of approximately 10 $cm.s^{-1}$ in the mid water column. Near the seabed, mean current speeds show a significant increase with a mean speed of 18 $cm.s^{-1}$ determined at 193 m depth. Current flow was primarily towards the WNW to N sectors in the upper water column, with secondary SW to WSW flow apparent at a depth of 94 m. At a depth of 148 m, SSE to SSW flow was more prevalent with N to NNE flow becoming secondary. Near the seabed current flow was predominantly towards the S to WSW sectors. An overview of current directions at depths of 7 m, 148 m and 193 m is presented in Figure 33. A contour plot of the northward and eastward current velocity components throughout the water column is included in Figure 34 below. High current speed events occurred around 15 and 16 June and 21 July 2013, with increased speeds most notable in the northward velocity component. Maximum current speeds were recorded at most depths during these events.

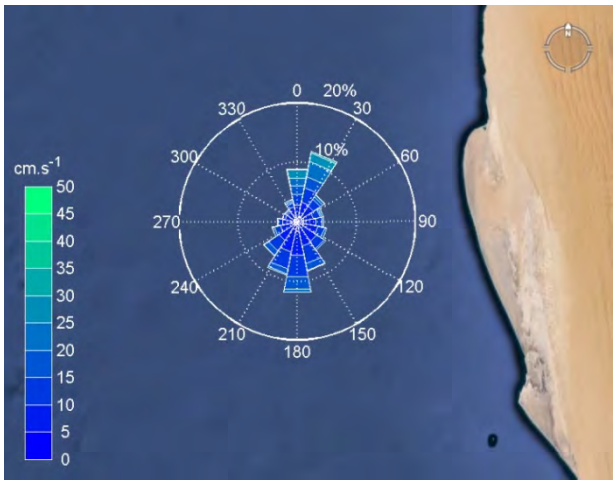
Water temperature at the measurement location ranged between a maximum of 14˚C at a depth of 97 m to a minimum of 10˚C near the seabed. The temperature records at 97 m depth and near the seabed showed temperature ranges of 1.8˚C, while the temperature range at 148 m was smaller, at 1.4˚C. Mean temperatures decreased from 12˚C at 100 m to 11˚C near the seabed. A contour plot of the temperature recorded throughout the water column is included as Figure 35 below. A significant cooling event occurred near the seabed between 14 June and 25 June 2013 which was evident in both the AQD and CTD data sets. This cooling event was associated with northward current flow near the seabed, in contrast to the predominantly southward currents at this depth. Dissolved oxygen concentration reached a maximum of 34.31 $\mu mol.l^{-1}$ during this event, while the mean over the measurement period was 9.15 $\mu mol.l^{-1}$. A maximum fluorescence of 0.42 $\mu g.l^{-1}$ was recorded during a period of low oxygen concentration in early July, with over 90% of values recorded below 0.1 $\mu g.l^{-1}$. Salinity ranged between 32.24 psu and 35.11 psu with a mean of 35 psu. Turbidity was low for much of the measurement period with a mean turbidity of 2.86 NTU, however intermittent increases were noted, with turbidity values exceeding 350NTU on two occasions. A tidal range of approximately 1.7 m was calculated for this location, with the height measured by the CTD ranging between -0.81 m and 0.89 m. The dominant tidal constituents were determined to be M_2, S_2 and N_2 with amplitudes of 0.48 m, 0.14 m and 0.12 m respectively.

© NMP 2014

NEAR SURFACE CURRENTS (-7m)



MID WATER COLUMN CURRENTS (-148m)



NEAR SEABED CURRENTS (-193m)

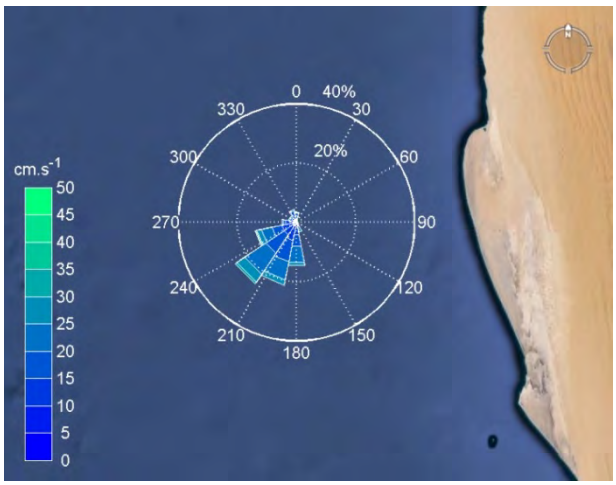


Figure 33: Overview of current directions recorded in the upper, mid and lower water column respectively. Current speeds are indicated by the colour scale.

© NMP 2014

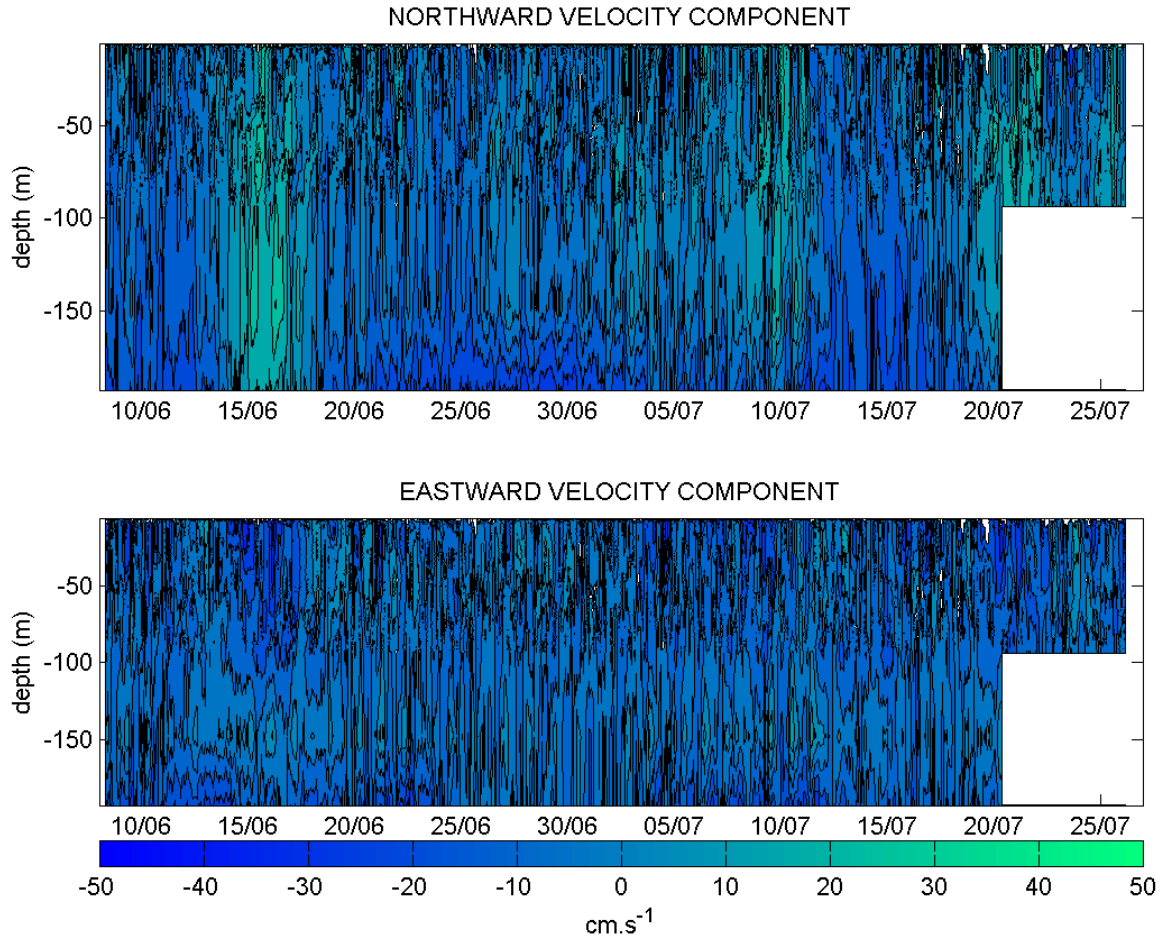


Figure 34: Time series of hourly mean current velocity throughout the water column. The upper panel is the northward velocity component in $cm.s^{-1}$ (negative blue values indicate southward flow and positive green values indicate northward flow) while the eastward component is in the lower panel. White patches indicate missing data.

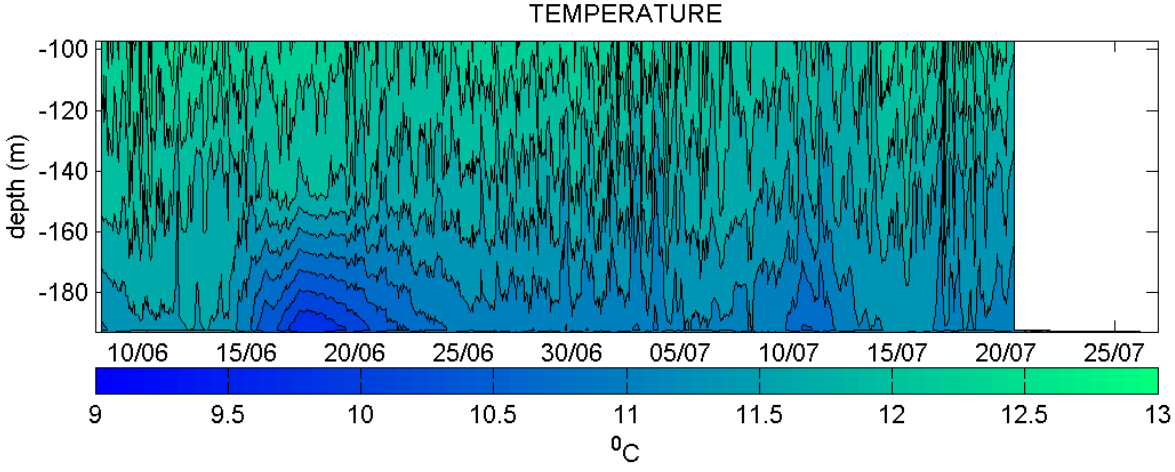


Figure 35: Time series of hourly mean temperature throughout the water column. White patches indicate missing data.

APPENDIX 1 - WATER COLUMN AND SEDIMENTARY ENVIRONMENT

1.9 Instrument Mooring Report: Day 45 to 90

NAMIBIAN MARINE PHOSPHATE

VERIFICATION SURVEY

DATA REPORT

Day 45 to 90

Prepared for:
Namibian Marine Phosphate (Pty) Ltd.

Prepared by:

October 2014

Project: 267

SOUTH AFRICA
Unit A4 Diep River Industrial Park, Greenville Road, Diep River, Cape Town
Directors: S.W. Bilski, B.J. Spolander, S.C. Stimson (British)
Co Reg. No. 2002/029886/07

AUSTRALIA
6a Magnet Court, Sandy Bay, Tasmania 7005, Australia
Directors: S.W. Bilski, B.J. Spolander S.C. Stimson (British)
ABN No. 87122 046 431

REVISION HISTORY

Date	Version	Originator	Checked	Approved
10 Oct 2013	0	C. Bloch	B. Spolander	B. Spolander
22 Jan 2013	1	C. Bloch	B. Spolander	B. Spolander

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed “Attention: Administration Manager,” at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

contents

1 EXECUTIVE SUMMARY 1

2 INTRODUCTION 6

2.1 PROJECT DESCRIPTION 6
2.2 CONVENTIONS USED IN THIS REPORT 7
2.3 MEASUREMENT LOCATIONS 8
2.4 MOORING CONFIGURATION 9
2.5 EQUIPMENT CONFIGURATION 10

3 DATA QUALITY CONTROL 11

3.1 ADCP 11
3.2 AQUADOPPS 14
3.3 RBR CTD LOGGER 19

4 DATA PRESENTATION 20

4.1 ADCP 20
4.1.1 Current Data 20
4.1.1.1 Time series plots 20
4.1.1.2 Summary plots 24
4.1.1.3 Progressive vector plots 28
4.1.1.4 Tidal harmonic plots 32
4.1.1.5 Profile plots 36
4.1.2 Pressure and water temperature data 40
4.1.2.1 Time series plot 40
4.2 AQD 1 42
4.2.1 Current data 42
4.2.1.1 Time series plot 42
4.2.1.2 Summary plot 44
4.2.1.3 Progressive vector plot 46
4.2.1.4 Tidal harmonic plot 48
4.2.2 Pressure and water temperature data 50
4.2.2.1 Time series plot 50
4.3 AQD 2 52
4.3.1 Current data 52
4.3.1.1 Time series plot 52
4.3.1.2 Summary plot 54
4.3.1.3 Progressive vector plot 56
4.3.1.4 Tidal harmonic plot 58
4.3.2 Pressure and water temperature data 60
4.3.2.1 Time series plot 60
4.4 CTD 62

© NMP 2014

4.4.1 Water quality data *62*
4.4.1.1 Time series plot 62
4.4.1.2 Summary plot 64
4.4.2 Tide data *66*
4.4.2.1 Time series plot 66
4.4.2.2 Tidal harmonics table 68
4.4.2.3 Tidal harmonics plot 69

5 DISCUSSION **71**

figures

Figure 1: Data return for the measurement period for each instrument. Every day for which greater than 50% data return was achieved is marked in colour. 1
Figure 2: Oceanographic measurement location offshore Namibia. 8
Figure 3: Mooring configuration. 9
Figure 4: Quality control data from the ADCP. 13
Figure 5: Quality control data from AQD 1. 15
Figure 6: Quality control data from AQD 2. 16
Figure 7: Plot exported from the Nortek Storm Software comparing the signal strength from each beam from AQD 2 during the deployment. 17
Figure 8: Comparison of speed and direction data from AQD 2. 18
Figure 9: Current time series data for 9 m depth 21
Figure 10: Current time series for 50 m depth 22
Figure 11: Current time series for 90 m depth 23
Figure 12: Summary of current data at 9 mm depth 25
Figure 13: Summary of current data at 50 mm depth 26
Figure 14: Summary of current data at 90 mm depth 27
Figure 15: Current progressive vector plot for 9 m depth 29
Figure 16: Current progressive vector plot for 50 m depth 30
Figure 17: Current progressive vector plot for 90 m depth 31
Figure 18: Mean profile plot 36
Figure 19: Profile plot at the time of maximum current speed in the upper water column 37
Figure 20: Profile plot at the time of maximum current speed in the mid water column 38
Figure 21: Profile plot at the time of maximum current speed in the lower water column 39
Figure 22: Pressure (water level) and temperature at 93 m depth 41
Figure 26: Current time series data for 142 m depth 43
Figure 24: Summary of current data at 142 depth 45
Figure 28: Current progressive vector plot at 142 m depth 47
Figure 30: Pressure (water level) and temperature at 142 m depth 51
Figure 27: Current time series data for 188 m depth 53
Figure 32: Summary of current data at 188 m depth 55
Figure 29: Current progressive vector plot at 188 m depth 57
Figure 30: Pressure (water level) and temperature at 188 m depth 61
Figure 31: Water quality data for 187.48 m depth 63
Figure 32: Summary data for environmental parameters at 187.48 m depth 65

© NMP 2014

Figure 33: Time series of tidal height at 187.48 m depth 67
Figure 34: Tidal harmonic components in 187.48 m depth 70
Figure 35: Overview of current directions recorded in the upper, mid and lower water column respectively. Current speeds are indicated by the colour scale. 72
Figure 36: Time series of hourly mean current velocity throughout the water column. 73
Figure 37: Time series of hourly mean temperature throughout the water column. White patches indicate missing data. 73

tables

Table 1: Current flow summary 2
Table 2: Temperature summary 6
Table 3: Pressure summary 6
Table 4: CTD summary 6
Table 5: Glossary and conventions used in this report 7
Table 6: As deployed measurement location 8
Table 7: TRDI 300 kHz configuration 10
Table 8: Aquadopp configuration 10
Table 9: RBR CTD configuration 11
Table 10: Current harmonic data for 9 m depth 33
Table 11: Current harmonic data for 50 m depth 34
Table 12: Current harmonic data for 90 m depth 35
Table 13: Current harmonic data for 142 m depth 49
Table 14: Current harmonic data for 188 m depth 59
Table 15: Tidal harmonic data at 187.48 m depth 68

© NMP 2014

1 EXECUTIVE SUMMARY

Metocean Services International (Pty) Limited (MSI) has been awarded a contract by Lwandle Technologies, under sub contract from Namibian Marine Phosphate (Pty) Ltd (NMP), to deploy an oceanographic mooring offshore Namibia. NMP intends dredging marine phosphate reserves at the site and requires verification of previous studies regarding the behaviour of the water column and sediment re-suspension events. Current measurements throughout the water column were undertaken with an ADCP and two single point current meters and water quality measurements were undertaken with a CTD near the seabed.

First order statistics of the data collected during the second and final measurement period (nominally from 2 August 2013 to 13 Sep 2013) are presented in this section, together with an indication of the data return achieved. Data return was good, with all instruments returning complete datasets, however no dissolved oxygen data was recorded by the CTD (Tables 1 – 4).

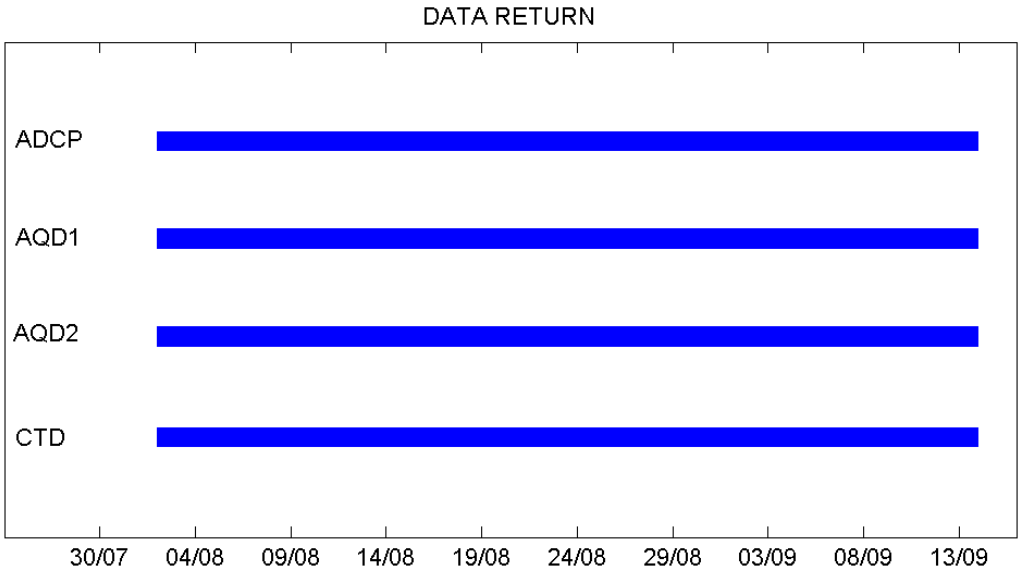


Figure 1: Data return for the measurement period for each instrument. Every day for which greater than 50% data return was achieved is marked in colour.

© NMP 2014

Table 1: Current flow summary

Instrument	Depth	Start	End	DR	Max speed	Max dir	Max date	Mean speed	STD speed	VM speed	VM Dir
	m	dd/mm/yy	dd/mm/yy	%	$cm.s^{-1}$	^{0}	dd/mm/yy	$cm.s^{-1}$	$cm.s^{-1}$	$cm.s^{-1}$	^{0}
ADCP	-6.2	02/08/13	13/09/13	72.00	68.38	325.94	04/09/13	22.29	9.60	14.34	334.22
ADCP	-7.2	02/08/13	13/09/13	86.91	56.59	284.52	06/09/13	19.25	9.08	11.79	332.03
ADCP	-8.2	02/08/13	13/09/13	89.21	66.09	322.92	05/09/13	18.33	9.02	10.77	323.81
ADCP	-9.2	02/08/13	13/09/13	91.22	54.17	340.78	15/08/13	16.63	8.40	8.99	316.31
ADCP	-10.2	02/08/13	13/09/13	93.03	53.45	272.75	06/09/13	16.03	8.09	8.47	314.10
ADCP	-11.2	02/08/13	13/09/13	94.69	51.58	273.87	06/09/13	15.77	7.89	8.24	313.66
ADCP	-12.2	02/08/13	13/09/13	96.12	53.48	276.72	06/09/13	15.56	7.75	8.12	313.74
ADCP	-13.2	02/08/13	13/09/13	97.30	52.83	275.14	06/09/13	15.32	7.58	7.93	314.19
ADCP	-14.2	02/08/13	13/09/13	97.76	52.35	272.56	06/09/13	15.13	7.46	7.82	314.89
ADCP	-15.2	02/08/13	13/09/13	98.21	50.75	275.62	06/09/13	15.00	7.38	7.75	315.18
ADCP	-16.2	02/08/13	13/09/13	98.60	49.54	270.55	06/09/13	14.86	7.29	7.67	315.68
ADCP	-17.2	02/08/13	13/09/13	98.83	49.52	274.06	06/09/13	14.76	7.21	7.59	316.50
ADCP	-18.2	02/08/13	13/09/13	99.01	47.37	273.15	06/09/13	14.60	7.18	7.51	316.91
ADCP	-19.2	02/08/13	13/09/13	99.21	47.60	268.20	06/09/13	14.53	7.17	7.43	317.49
ADCP	-20.2	02/08/13	13/09/13	99.29	45.98	273.45	06/09/13	14.40	7.12	7.33	317.84
ADCP	-21.2	02/08/13	13/09/13	99.36	45.32	268.08	06/09/13	14.26	7.06	7.22	318.68
ADCP	-22.2	02/08/13	13/09/13	99.46	47.68	269.66	06/09/13	14.15	7.02	7.09	319.36
ADCP	-23.2	02/08/13	13/09/13	99.51	45.60	266.72	06/09/13	14.01	6.98	7.05	319.78
ADCP	-24.2	02/08/13	13/09/13	99.62	46.45	269.67	06/09/13	13.90	6.97	6.97	320.60
ADCP	-25.2	02/08/13	13/09/13	99.79	44.94	265.72	06/09/13	13.73	6.97	6.84	320.99
ADCP	-26.2	02/08/13	13/09/13	99.85	42.93	272.12	06/09/13	13.57	6.94	6.76	321.87
ADCP	-27.2	02/08/13	13/09/13	99.88	43.48	266.87	06/09/13	13.44	6.94	6.68	322.12
ADCP	-28.2	02/08/13	13/09/13	99.90	43.99	273.89	06/09/13	13.29	6.89	6.59	322.44

© NMP 2014

Table 1 – continued...

Instrument	Depth	Start	End	DR	Max speed	Max dir	Max date	Mean speed	STD speed	VM speed	VM Dir
	m	dd/mm/yy	dd/mm/yy	%	$cm.s^{-1}$	^{0}	dd/mm/yy	$cm.s^{-1}$	$cm.s^{-1}$	$cm.s^{-1}$	^{0}
ADCP	-29.2	02/08/13	13/09/13	99.97	42.43	267.99	06/09/13	13.16	6.89	6.54	323.38
ADCP	-30.2	02/08/13	13/09/13	100.00	41.96	265.49	06/09/13	13.00	6.86	6.45	323.80
ADCP	-31.2	02/08/13	13/09/13	100.00	41.90	265.78	06/09/13	12.87	6.82	6.37	324.15
ADCP	-32.2	02/08/13	13/09/13	100.00	43.26	270.75	06/09/13	12.76	6.78	6.32	324.81
ADCP	-33.2	02/08/13	13/09/13	100.00	43.03	359.05	07/08/13	12.62	6.75	6.31	325.26
ADCP	-34.2	02/08/13	13/09/13	100.00	45.96	2.54	07/08/13	12.58	6.73	6.32	325.83
ADCP	-35.2	02/08/13	13/09/13	100.00	42.52	2.15	07/08/13	12.45	6.68	6.28	326.71
ADCP	-36.2	02/08/13	13/09/13	100.00	39.94	273.27	06/09/13	12.37	6.61	6.24	327.31
ADCP	-37.2	02/08/13	13/09/13	100.00	40.96	262.91	06/09/13	12.31	6.53	6.26	327.38
ADCP	-38.2	02/08/13	13/09/13	100.00	39.48	266.73	06/09/13	12.18	6.52	6.22	327.80
ADCP	-39.2	02/08/13	13/09/13	100.00	39.79	260.96	06/09/13	12.14	6.52	6.25	328.38
ADCP	-40.2	02/08/13	13/09/13	100.00	38.37	263.27	06/09/13	12.06	6.47	6.23	329.00
ADCP	-41.2	02/08/13	13/09/13	100.00	39.46	276.89	06/09/13	11.98	6.44	6.27	329.54
ADCP	-42.2	02/08/13	13/09/13	100.00	39.13	267.13	06/09/13	11.89	6.42	6.25	329.90
ADCP	-43.2	02/08/13	13/09/13	100.00	39.42	343.30	02/09/13	11.86	6.46	6.33	330.71
ADCP	-44.2	02/08/13	13/09/13	100.00	39.58	272.07	06/09/13	11.78	6.46	6.34	331.06
ADCP	-45.2	02/08/13	13/09/13	100.00	38.23	339.02	02/09/13	11.69	6.47	6.35	331.68
ADCP	-46.2	02/08/13	13/09/13	100.00	37.23	276.59	06/09/13	11.58	6.50	6.33	332.04
ADCP	-47.2	02/08/13	13/09/13	100.00	40.28	277.50	06/09/13	11.51	6.51	6.36	332.57
ADCP	-48.2	02/08/13	13/09/13	100.00	39.85	270.31	23/08/13	11.43	6.54	6.37	332.82
ADCP	-49.2	02/08/13	13/09/13	100.00	39.29	272.20	23/08/13	11.33	6.55	6.39	333.09
ADCP	-50.2	02/08/13	13/09/13	99.98	40.85	337.88	04/09/13	11.29	6.56	6.42	333.46
ADCP	-51.2	02/08/13	13/09/13	99.98	40.84	336.03	04/09/13	11.20	6.58	6.45	333.38
ADCP	-52.2	02/08/13	13/09/13	99.98	40.96	335.06	04/09/13	11.16	6.60	6.51	333.38

© NMP 2014

Table 1 – continued...

Instrument	Depth	Start	End	DR	Max speed	Max dir	Max date	Mean speed	STD speed	VM speed	VM Dir
	m	dd/mm/yy	dd/mm/yy	%	$cm.s^{-1}$	^{0}	dd/mm/yy	$cm.s^{-1}$	$cm.s^{-1}$	$cm.s^{-1}$	^{0}
ADCP	-53.2	02/08/13	13/09/13	99.98	40.94	335.20	04/09/13	11.12	6.57	6.51	332.74
ADCP	-54.2	02/08/13	13/09/13	99.98	40.29	341.49	04/09/13	11.09	6.59	6.49	332.45
ADCP	-55.2	02/08/13	13/09/13	99.98	39.10	332.33	04/09/13	11.08	6.56	6.55	332.58
ADCP	-56.2	02/08/13	13/09/13	99.98	41.57	330.56	04/09/13	11.05	6.54	6.56	332.37
ADCP	-57.2	02/08/13	13/09/13	99.97	41.80	346.15	04/09/13	11.05	6.55	6.56	331.98
ADCP	-58.2	02/08/13	13/09/13	100.00	42.03	343.15	04/09/13	11.03	6.54	6.59	331.59
ADCP	-59.2	02/08/13	13/09/13	100.00	42.45	348.03	04/09/13	10.99	6.56	6.56	331.76
ADCP	-60.2	02/08/13	13/09/13	100.00	41.20	352.30	04/09/13	11.00	6.54	6.62	331.39
ADCP	-61.2	02/08/13	13/09/13	100.00	44.22	347.15	04/09/13	10.99	6.50	6.58	331.31
ADCP	-62.2	02/08/13	13/09/13	100.00	44.07	348.58	04/09/13	10.94	6.51	6.55	330.90
ADCP	-63.2	02/08/13	13/09/13	100.00	44.93	349.67	04/09/13	10.95	6.54	6.57	330.30
ADCP	-64.2	02/08/13	13/09/13	100.00	44.06	354.47	04/09/13	10.92	6.53	6.58	330.17
ADCP	-65.2	02/08/13	13/09/13	100.00	43.92	347.03	04/09/13	10.93	6.49	6.57	329.66
ADCP	-66.2	02/08/13	13/09/13	100.00	44.95	354.29	04/09/13	10.90	6.49	6.55	328.92
ADCP	-67.2	02/08/13	13/09/13	100.00	45.05	352.47	04/09/13	10.86	6.48	6.52	328.53
ADCP	-68.2	02/08/13	13/09/13	100.00	44.54	342.89	04/09/13	10.87	6.47	6.47	327.96
ADCP	-69.2	02/08/13	13/09/13	99.98	46.00	345.95	04/09/13	10.85	6.42	6.46	327.26
ADCP	-70.2	02/08/13	13/09/13	99.97	45.51	346.72	04/09/13	10.83	6.41	6.42	326.54
ADCP	-71.2	02/08/13	13/09/13	99.97	44.30	344.69	04/09/13	10.78	6.38	6.36	325.80
ADCP	-72.2	02/08/13	13/09/13	99.97	43.71	346.38	04/09/13	10.79	6.39	6.34	325.00
ADCP	-73.2	02/08/13	13/09/13	99.97	44.44	347.78	04/09/13	10.74	6.37	6.30	324.18
ADCP	-74.2	02/08/13	13/09/13	99.97	44.35	340.68	04/09/13	10.68	6.35	6.28	323.28
ADCP	-75.2	02/08/13	13/09/13	99.98	44.92	343.67	04/09/13	10.69	6.31	6.25	322.58
ADCP	-76.2	02/08/13	13/09/13	100.00	43.79	349.00	04/09/13	10.67	6.31	6.22	321.17

© NMP 2014

Table 1 – continued...

Instrument	Depth	Start	End	DR	Max speed	Max dir	Max date	Mean speed	STD speed	VM speed	VM Dir
	m	dd/mm/yy	dd/mm/yy	%	$cm.s^{-1}$	^{0}	dd/mm/yy	$cm.s^{-1}$	$cm.s^{-1}$	$cm.s^{-1}$	^{0}
ADCP	-77.2	02/08/13	13/09/13	100.00	44.60	345.20	04/09/13	10.62	6.29	6.18	320.43
ADCP	-78.2	02/08/13	13/09/13	100.00	45.40	345.21	04/09/13	10.60	6.25	6.15	319.74
ADCP	-79.2	02/08/13	13/09/13	100.00	44.57	336.17	04/09/13	10.59	6.21	6.17	318.85
ADCP	-80.2	02/08/13	13/09/13	100.00	44.97	334.05	04/09/13	10.57	6.19	6.13	318.36
ADCP	-81.2	02/08/13	13/09/13	100.00	43.93	340.89	04/09/13	10.50	6.17	6.09	317.39
ADCP	-82.2	02/08/13	13/09/13	100.00	42.58	335.05	04/09/13	10.46	6.10	6.06	316.69
ADCP	-83.2	02/08/13	13/09/13	100.00	43.38	337.78	04/09/13	10.41	6.10	6.04	316.01
ADCP	-84.2	02/08/13	13/09/13	100.00	42.19	341.53	04/09/13	10.32	6.03	5.95	315.39
ADCP	-85.2	02/08/13	13/09/13	100.00	42.84	339.30	04/09/13	10.28	6.01	5.96	314.74
ADCP	-86.2	02/08/13	13/09/13	100.00	43.28	334.41	04/09/13	10.19	5.99	5.90	313.38
ADCP	-87.2	02/08/13	13/09/13	100.00	41.17	334.98	04/09/13	10.12	5.93	5.89	312.95
ADCP	-88.2	02/08/13	13/09/13	100.00	40.78	334.88	04/09/13	10.06	5.88	5.87	312.13
ADCP	-89.2	02/08/13	13/09/13	100.00	40.82	333.17	04/09/13	10.08	5.86	5.93	311.45
ADCP	-90.2	02/08/13	13/09/13	100.00	40.80	333.31	04/09/13	10.14	5.82	6.00	312.30
AQD1	-141.8	02/08/13	13/09/13	100.00	33.81	33.61	04/09/13	9.33	5.53	1.97	48.33
AQD2	-187.9	02/08/13	13/09/13	99.87	26.67	30.67	04/09/13	8.81	4.63	0.14	46.62

© NMP 2014

Table 2: Temperature summary

Instrument	Mean Depth (m)	Data Return (%)	Max (°C)	Mean (°C)	Min (°C)
ADCP	-93	99.95	12.71	11.72	10.92
AQD1	-142	99.93	12.00	11.23	10.72
AQD2	-188	99.92	11.43	10.94	10.51
CTD	-188	100.00	11.21	10.71	10.29

Table 3: Pressure summary

Instrument	Mean Depth (m)	Data Return (%)	Max (Bar)	Mean (Bar)	Min (Bar)
ADCP	-93	100.00	9.46	9.38	9.29
AQD1	-142	100.00	14.32	14.23	14.15
AQD2	-188	100.00	18.94	18.85	18.77
CTD	-188	100.00	18.91	18.81	18.73

Table 4: CTD summary

Parameter	Unit	Data Return (%)	Max	Mean	Min
Temperature	˚C	100.00	11.21	10.71	10.29
Conductivity	$S.m^{-1}$	100.00	39.93	39.27	31.23
Salinity	psu	96.51	35.62	35.53	35.43
Depth	m	100.00	-186.62	-187.48	-188.40
Dissolved Oxygen	$\mu mol.l^{-1}$	0.00	-	-	-
Fluorescence	$\mu g.l^{-1}$	99.84	0.78	0.01	0.00
Turbidity	NTU	99.90	1316.51	17.26	0.39
Height	m	100.00	0.92	0.00	-0.86

2 INTRODUCTION

2.1 PROJECT DESCRIPTION

Metocean Services International (Pty) Limited (MSI) has been awarded a contract by Lwandle Technologies, under sub-contract from Namibian Marine Phosphate (Pty) Ltd (NMP), to deploy an oceanographic mooring offshore Namibia. NMP intends dredging marine phosphate reserves at the site and requires verification of previous studies regarding the behaviour of the water column and sediment re-suspension events. Current measurements throughout the water column were undertaken with an ADCP and two single point current meters and water quality measurements were undertaken with a CTD near the seabed.

This report details the quality control procedures and data presentation (Sections 3 and 4 for the second and final measurement period (nominally from 2 August 2013 to 13 September 2013).

© NMP 2014

2.2 CONVENTIONS USED IN THIS REPORT

A list of the conventions used in this report is presented in Table 5.

Table 5: Glossary and conventions used in this report

Term	Explanation
ADCP	Acoustic Doppler Current Profiler
AQD	Aquadopp
Bin	ADCP depth cell within which the measurement of current velocity is spatially averaged. The depth of the bin refers to the centre of the bin.
Bin length	Vertical distance over which ADCP data is spatially averaged into a single current velocity.
Conductivity	Conductivity is measured in Siemens per metre ($S.m^{-1}$)
CTD	Conductivity, temperature and depth meter
Current Speed	The speed of flow with units of centimetres per second ($cm.s^{-1}$)
Current Direction	The direction towards which the vector mean current is flowing and referenced to true north at 0^0 with a right handed convention.
Data Return	The data return reflects the percentage of good data coverage for the time period that the instrument was operational.
Density	Density is expressed as kilograms per cubic metre ($kg.m^{-3}$).
Depth	The water depth below mean sea level, with units of m.
Dissolved Oxygen	Dissolved oxygen is measured in micromoles per litre ($\mu mol.l^{-1}$).
Ensemble	Time interval over which ADCP pings are averaged into a single current velocity for each bin.
Fluorescence	Fluorescence is a measure of chlorophyll in micrograms per litre ($\mu g.l^{-1}$).
Height	Height is measured in metres (m) referenced to mean sea level.
OBS	Optical back-scatter sensor
Ping	Single acoustic pulse from the ADCP, which produces measurement of current velocity.
Pressure	Pressure is in Bars.
Salinity	Salinities are expressed in practical salinity units (psu)
Sound velocity	Sound velocity is expressed in meters per second ($m.s^{-1}$).
STD	The standard deviation of the current speed.
Temperatures	Temperatures are in degrees centigrade (°C).
Time	All times are presented in UTC.
VM	Vector mean.

© NMP 2014

2.3 MEASUREMENT LOCATIONS

The location of the measurements, offshore Namibia, is given in Table 6 and indicated in Figure 2 below.

Table 6: As deployed measurement location

Location	Latitude	Longitude	Depth
MP1*	24° 08' 19.32" S	14° 01' 32.88" E	~ 193 m
*(Position calculated using slant-range position & depth information)			



Figure 2: Oceanographic measurement location offshore Namibia.

2.4 MOORING CONFIGURATION

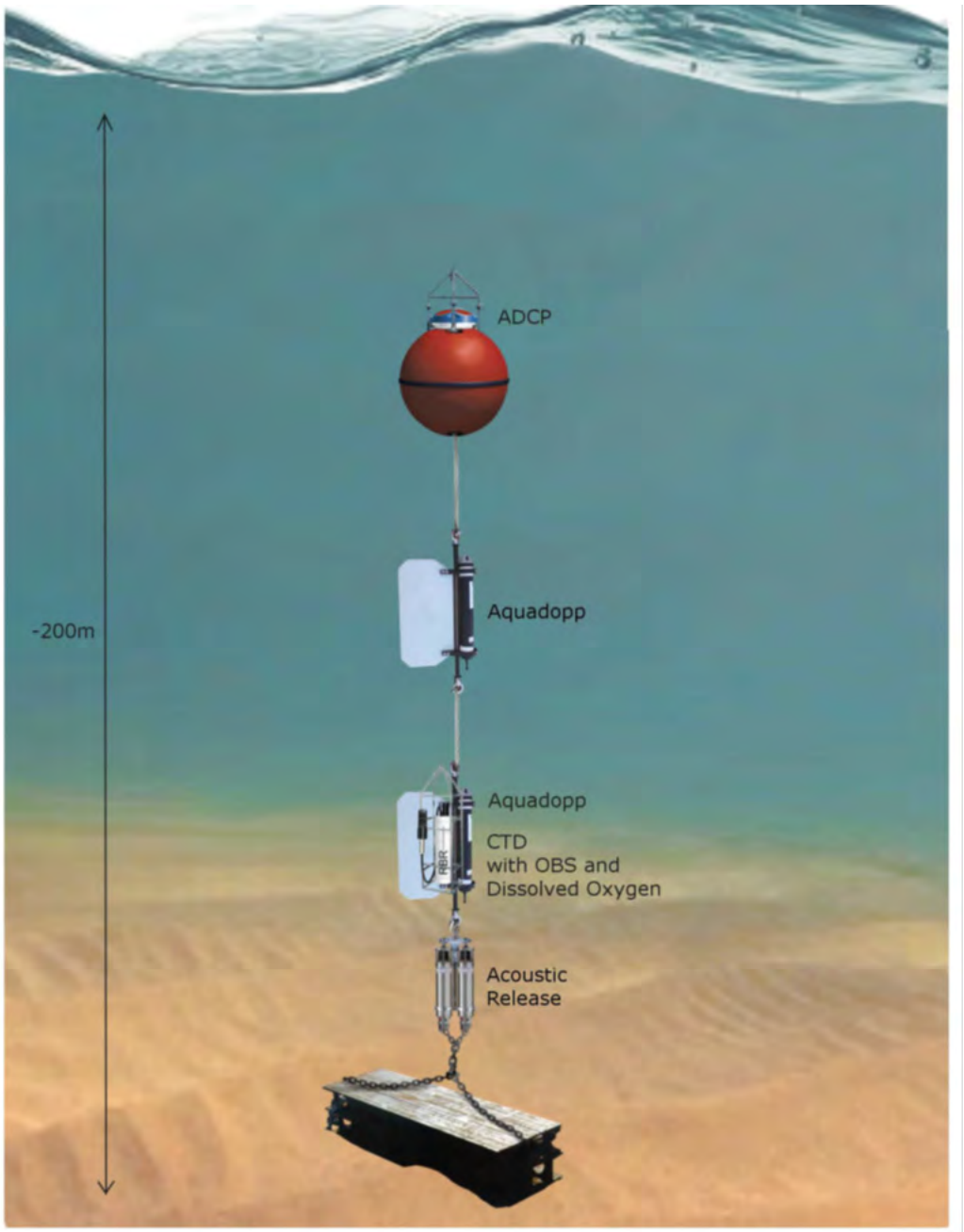


Figure 3: Mooring configuration.

2.5 EQUIPMENT CONFIGURATION

Table 7: TRDI 300 kHz configuration

Parameter	**Configuration**
Planned water depth	~100 m (200 m total)
Assumed duration	90 days (~ 45 service)
Number of battery packs	1 x alkaline
Ensemble interval	10 minutes
Number of pings	110
Number of depth cells	175
Cellsize	1 m
General	
Standard deviation	1.29 $cm.s^{-1}$
Battery utilisation	1.0
Memory required	23.46 mb

Table 8: Aquadopp configuration

Parameter	**Configuration**	
	Mid-water DW Aquadopp (s/n AQD 3011)	**Near-bottom Aquadopp (s/n AQD 2481)**
Planned water depth	~150 m (200 m total)	~195 m (200 m total)
Assumed duration	50 days	50 days
Number of battery packs	1 x alkaline (50Wh)	1 x alkaline (50Wh)
Measurement interval	30 seconds	30 seconds
Average interval	5 seconds	5 seconds
Measurement load	9 %	22 %
Blanking distance	0.50m	0.35m
Compass update rate Diagnostics Interval (min) Number of samples	1 second Enabled 60 16	1 second Enabled 60 16
General		
Vertical velocity precision	3.4 $cm.s^{-1}$	3.8 $cm.s^{-1}$
Horizontal velocity precision	2.3 $cm.s^{-1}$	2.3 $cm.s^{-1}$
Battery utilisation	97 %	97 %
Memory required	6.6 mb	6.6 mb

© NMP 2014

Table 9: RBR CTD configuration

Parameter	Configuration
Approximate water depth	~195 m (total 200 m)
Sampling period	00:10:00
Averaging period Maximum duration[1]	2 seconds battery
Memory required	3%
Battery required	100%

3 DATA QUALITY CONTROL

3.1 ADCP

The current data were imported from RD Instruments WinSc software into Matlab for further processing:

- The record was truncated to exclude times pre and post deployment.
- The depth of the instrument was determined from the pressure sensor.
- Directions were adjusted from magnetic to true north using a magnetic variation of -14.6682°. Magnetic variation was obtained from the NOAA website at http://www.ngdc.noaa.gov/geomag-web/#declination.
- A flag was imposed on all data within 6% of the ocean surface due to side lobe interference. The distance to the ocean surface was deduced from the pressure data.
- The ADCP attitude data (heading, pitch and roll) were then examined (see Figure 4). These parameters were well within the recommended operating range throughout the deployment.
- The ADCP beam correlation data were then examined. Adopting RDI recommended practice, when the correlation count for any of the 4 beams fell below 64 (RD Instruments recommended value) in a bin, all data from this bin to the end of the profile were flagged. Beam correlation dropped below the threshold intermittently throughout the measurement period in the uppermost bins which resulted in reduced data return for these bins.
- Checks were then run on the percentage good data collected by the ADCPs. All ensembles where the number of two beam solutions exceeded 50% were flagged.
- Checks were then run on the error velocities. Examination of the error velocity distribution led to the selection of a cut off of –20 $cm.s^{-1}$ to +20 $cm.s^{-1}$. All data with error velocities beyond this range were flagged. This check mainly affected data in the uppermost valid bins.
- Checks were then run searching for any outliers in the speed data. This was automated within a routine that compared the median of 3 values with the centre

© NMP 2014

point. A tolerance of 50 $cm.s^{-1}$ was allowed. Outliers identified by this method were then examined visually and flagged. The same check was run on both the northward and eastward velocity components. As a final check, the data were visually examined and any remaining spikes flagged.

- Checks were then run searching for repeated values in the speed and direction data. This was automated within a routine that searched for 3 identical consecutive values.

- Finally, all flagged data were replaced with the Matlab NaN symbol, ensuring that they would be excluded from all further processing.

- As a result of the quality control measures applied, the data return in the uppermost bins of retained data was reduced. For this reason, the first data bin achieving over 90% data return was presented as representative of the near-surface currents.

© NMP 2014

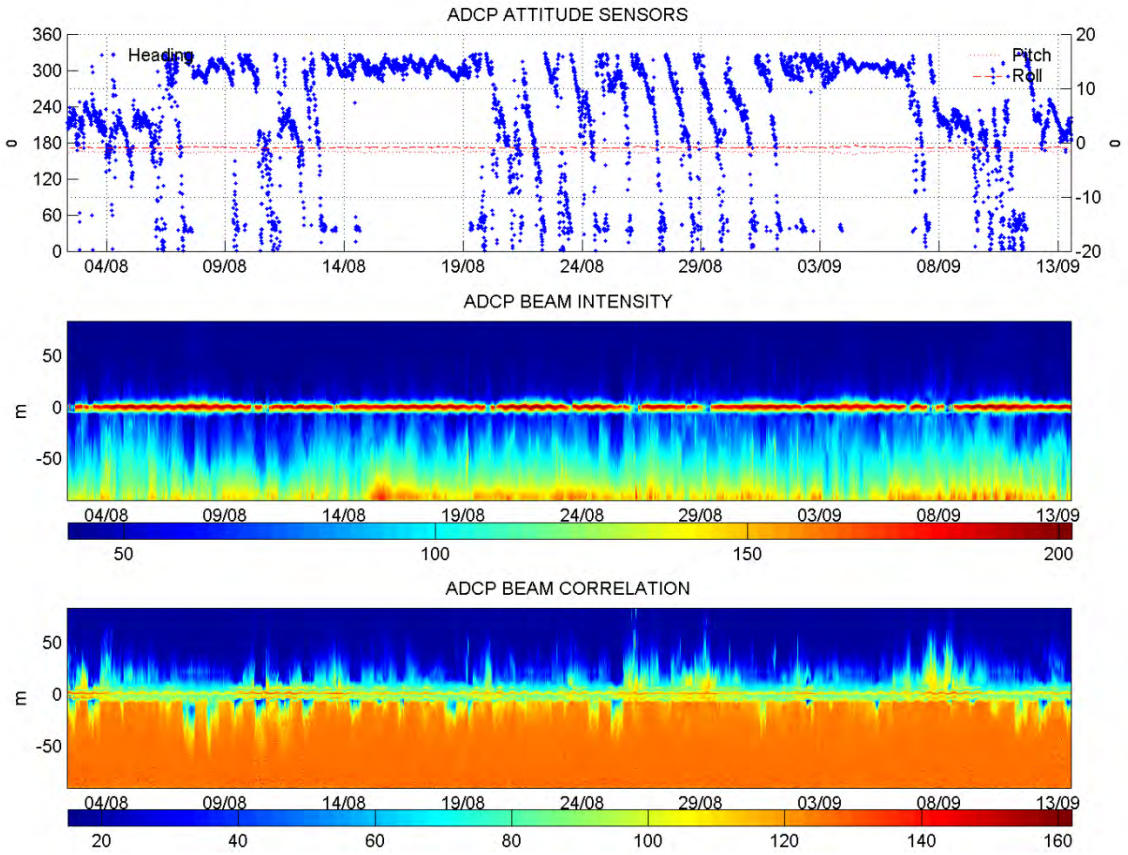


Figure 4: Quality control data from the ADCP.
The upper panel shows the sensor attitude data (heading scaled to the left axis and pitch and roll to the right axis). The middle panel shows the time-series of ADCP beam intensity through the water column, while the lower panel shows similar information for the beam correlation.

© NMP 2014

3.2 AQUADOPPS

The current data were exported to ascii text files from Nortek's Aquadopp software and then imported into Matlab for further processing:

- The record was truncated to exclude times pre and post deployment.
- The depth of the instrument was determined from the pressure sensor.
- A 10 minute data set was created from the 30 second data by finding the mean of all data recorded within each ten minute period. The mean u and v velocity components for each ten minute period were then converted to speed and direction. All data presented in this report are derived from the 10 minute data set.
- Directions were adjusted from magnetic to true north using a magnetic variation of -14.6682°. Magnetic variation was obtained from the NOAA website at http://www.ngdc.noaa.gov/geomag-web/#declination.
- The AQD attitude data (heading, pitch and roll) as well as the depth and vertical velocity were then examined (see Figure 5 and Figure 6). All instruments remained within the recommended operating range for pitch and roll (-30° to 30°) throughout the deployment.
- Checks were then run searching for any outliers in the speed data. This was automated within a routine that compared the median of 5 values to the centre point. A tolerance of 30 $cm.s^{-1}$ was allowed. Outliers identified by this method were then visually examined and flagged. The same check was run on both the northward and eastward velocity components. As a final check, the data were examined visually and any remaining spikes flagged.
- Checks were then run searching for repeated values in the speed and direction data. This was automated within a routine that searched for 3 identical consecutive values.
- Finally, all flagged data were replaced with the Matlab NaN symbol, ensuring that they would be excluded from all further processing.
- AQD 2 showed unusual data which did not compare well to data recorded during the previous deployment. Visual inspection of the signal strength from the individual beams showed some unusual characteristics in the data from beam 1 (please see Figure 7). This may have been caused by a fault in the transducer. As a result, the data was re-processed using the Nortek Storm software using a two-beam solution which excluded Beam 1 from the calculation. The data were then imported into Matlab and the quality control measures outlined above were applied. Note that the calculation of velocity using a two-beam solution requires the assumption that the vertical velocity is zero. As the instrument was moored, this assumption may have incorrectly influenced the calculated velocities for some data records. The velocity data from AQD 2 should therefore be viewed with caution. A comparison of the speed and direction data calculated using the two-beam and three-beam solutions is included as Figure 8.)

© NMP 2014

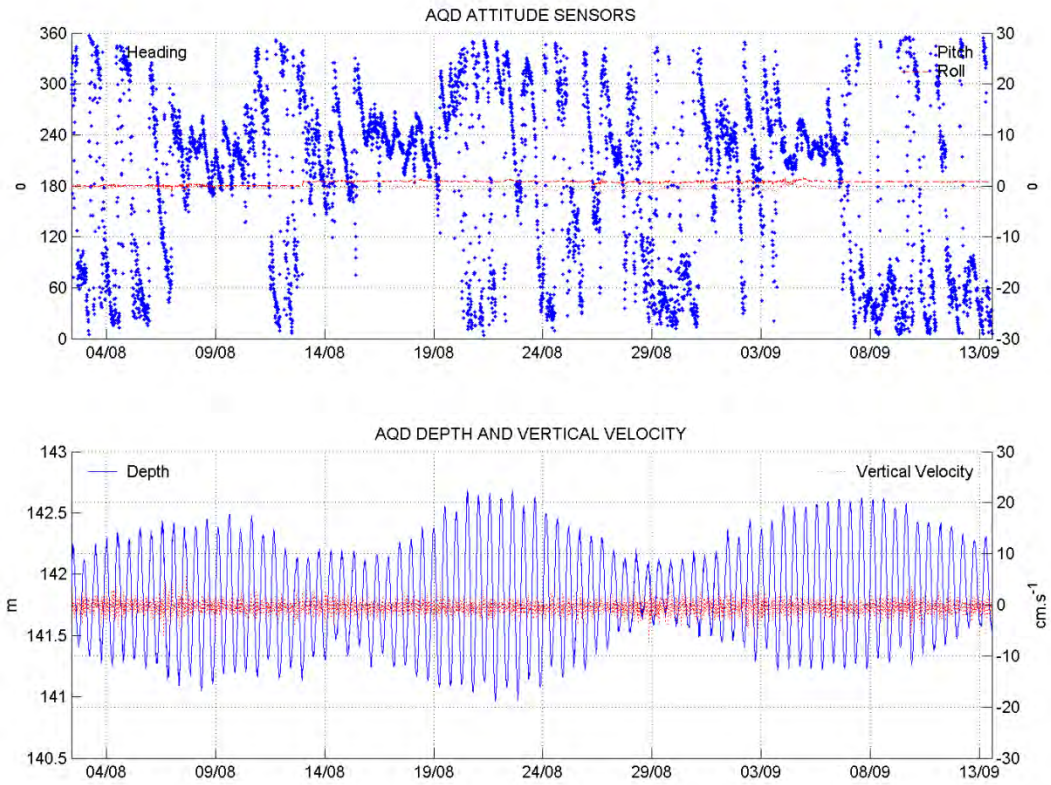


Figure 5: Quality control data from AQD 1.
The upper panel shows the sensor attitude data (heading scaled to the left axis and pitch and roll to the right axis). The lower panel shows the depth (scaled to the left axis) and the vertical velocity (scaled to the right axis).

© NMP 2014

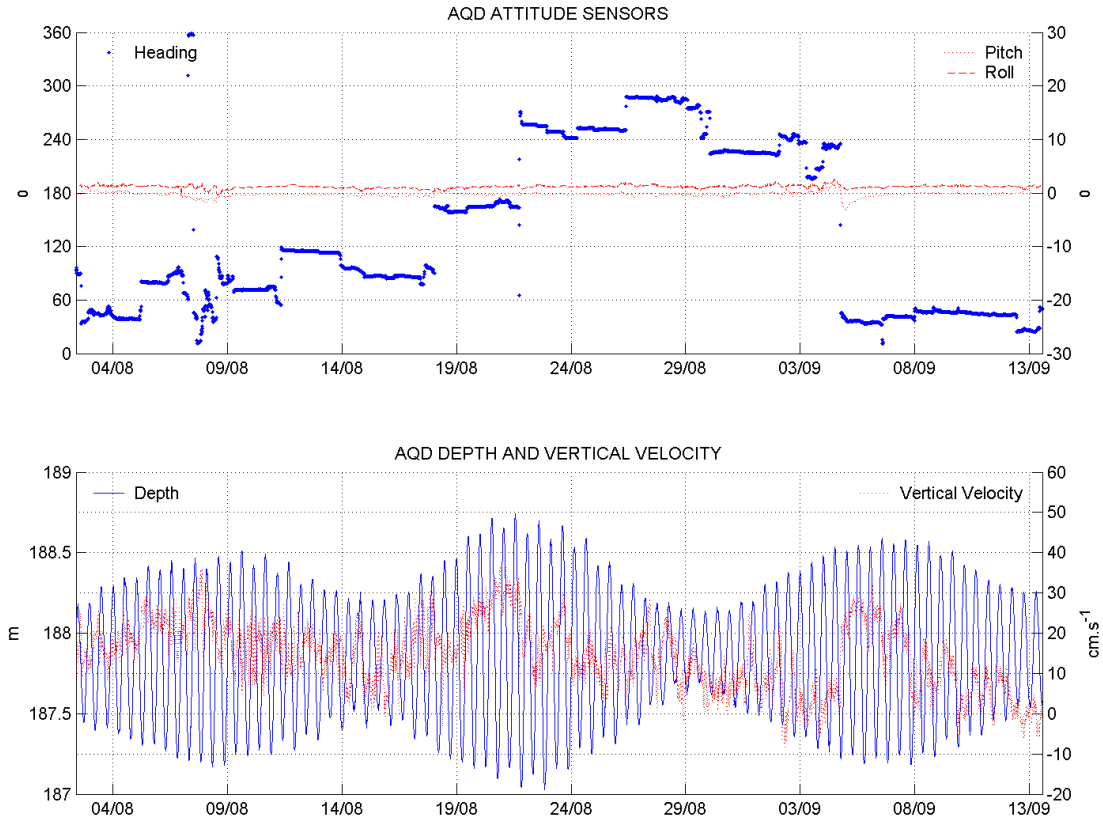


Figure 6: Quality control data from AQD 2.
The upper panel shows the sensor attitude data (heading scaled to the left axis and pitch and roll to the right axis). The lower panel shows the depth (scaled to the left axis) and the vertical velocity (scaled to the right axis).

© NMP 2014

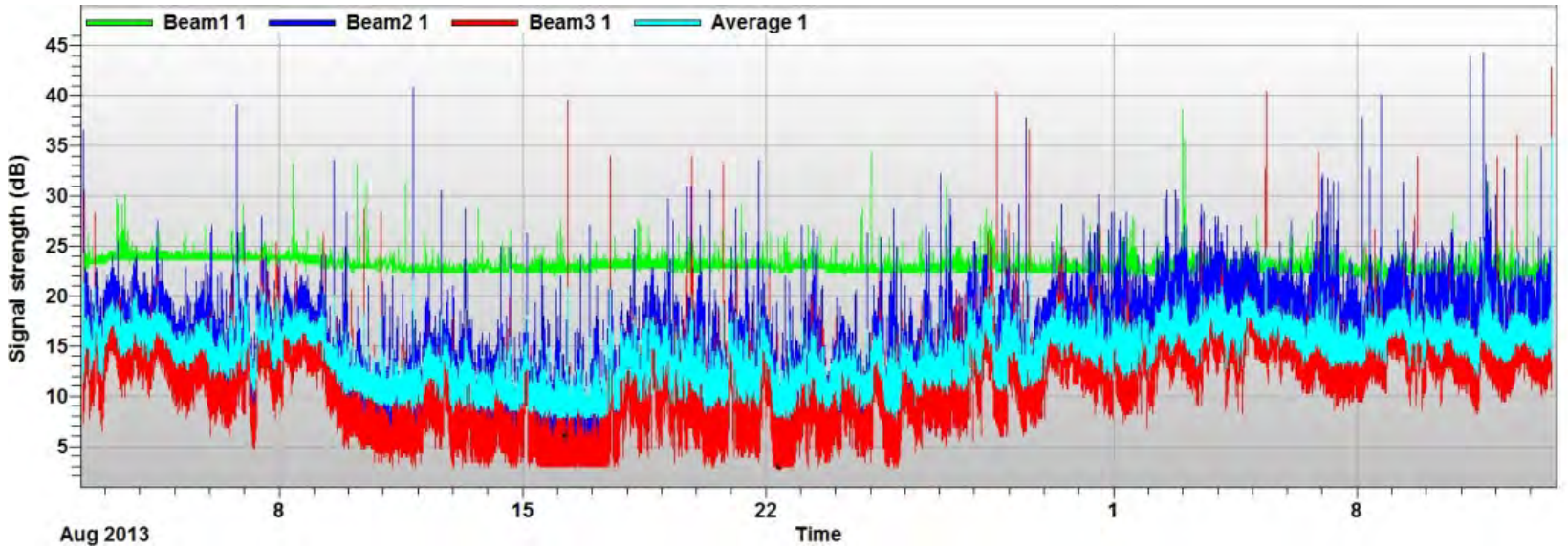


Figure 7: Plot exported from the Nortek Storm Software comparing the signal strength from each beam from AQD 2 during the deployment.

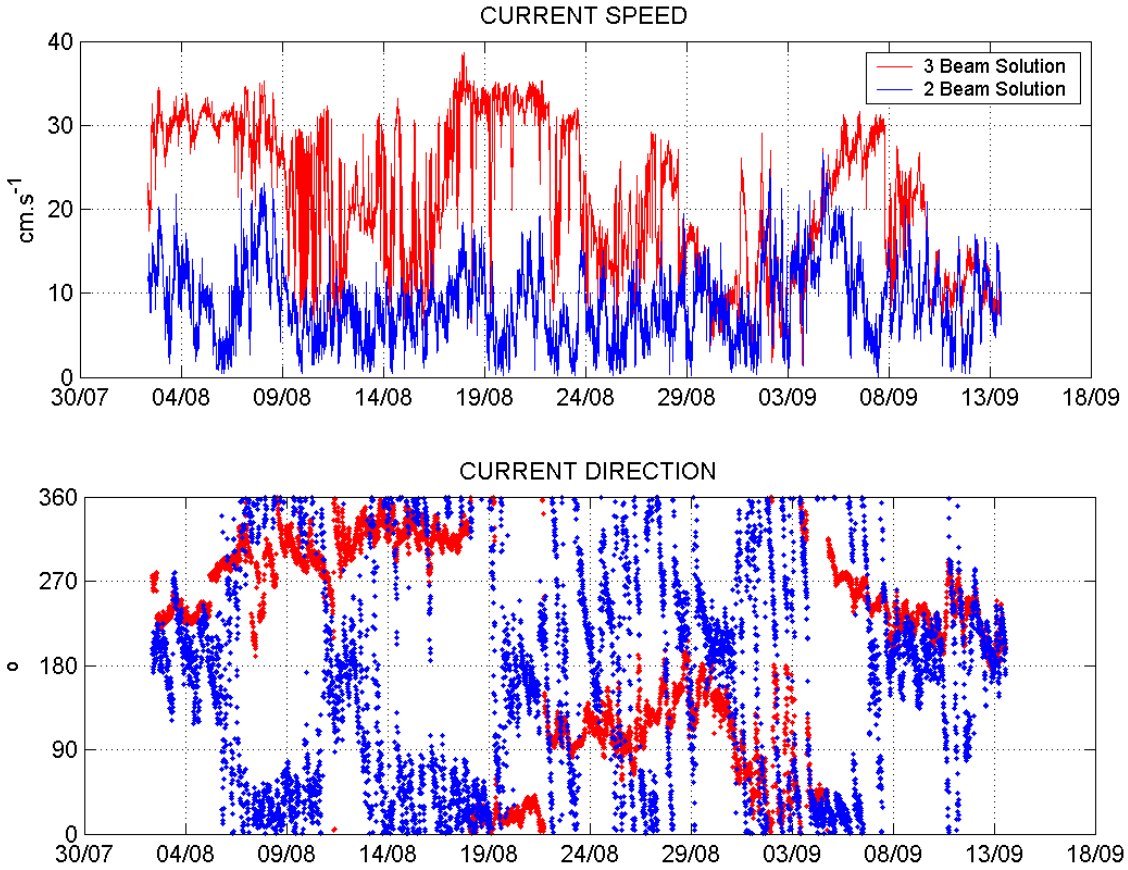


Figure 8: Comparison of speed and direction data from AQD 2.
Data processed using the standard three-beam solution (plotted in red) and a two-beam solution which excluded Beam 1 (plotted in blue).

© NMP 2014

3.3 RBR CTD LOGGER

The data were exported directly from the RBR software into Matlab for further processing:

- The record was truncated to exclude times pre and post deployment.
- Depth was derived using an assumed gravity value of 9.80 $m.s^{-2}$ and mean water density of 1024 $kg.m^{-3}$.
- The conductivity and temperature data were used to derive salinity according to the 1978 UNESCO algorithm.
- Checks were run searching for any outliers in the data. This was automated within a routine that compared the median of 5 values to the centre point. For salinity, a tolerance of 1psu was allowed. For turbidity, a tolerance of 250 NTU was allowed.
- Height was determined from the depth. Checks were then run searching for any outliers in the height data. This was automated within a routine that compared the median of 5 values to the centre point. A tolerance of 15 cm was allowed. Outliers identified by this method were then examined visually and flagged. As a final check, the data were examined visually and any remaining spikes flagged.
- Checks were then run searching for repeated values in the height data. This was automated within a routine that searched for 3 identical consecutive values.
- Finally, all flagged data were replaced with the Matlab NaN symbol, ensuring that they would be excluded from all further processing.
- No dissolved oxygen data were recorded by the RBR CTD. This may be the result of a failure of the oxygen sensor.
- A number of low salinity spikes were noted in the dataset. These spikes were mostly observed during periods of elevated turbidity, which may have affected the conductivity measurements. These spikes were therefore removed from the dataset.

© NMP 2014

4 DATA PRESENTATION

4.1 ADCP

4.1.1 Current Data

4.1.1.1 Time series plots

Figures 9 to 11 display time series plots for the depths: -9 m, -50 m and -90 m respectively. The time series plots consist of:

- The first (upper) panel is of the observed current speed against time.
- The second panel is of the observed current direction against time.
- The third panel is of the tidal current speed, calculated from the observed current speed and direction, against time. The entire data set of observations is used in the derivation of the tidal component. The tidal calculation follows the method of Foreman and uses the observed complex current vector as input (*R. Pawlowicz, B. Beardsley, and S. Lentz, "Classical tidal harmonic analysis including error estimates in MATLAB using T_TIDE", Computers and Geosciences 28 (2002), 929-937*)
- The fourth panel is of the tidal current direction, calculated as above, against time.
- The fifth panel is of the residual current speed against time. The residual has been calculated as north and east components (residual component = observed component: tidal component), which have then been converted into residual speed and direction.
- The sixth panel is of the residual current direction against time, calculated as above.
- The first day of each month is indicated visually by a thin red line on each of the plots.

© NMP 2014

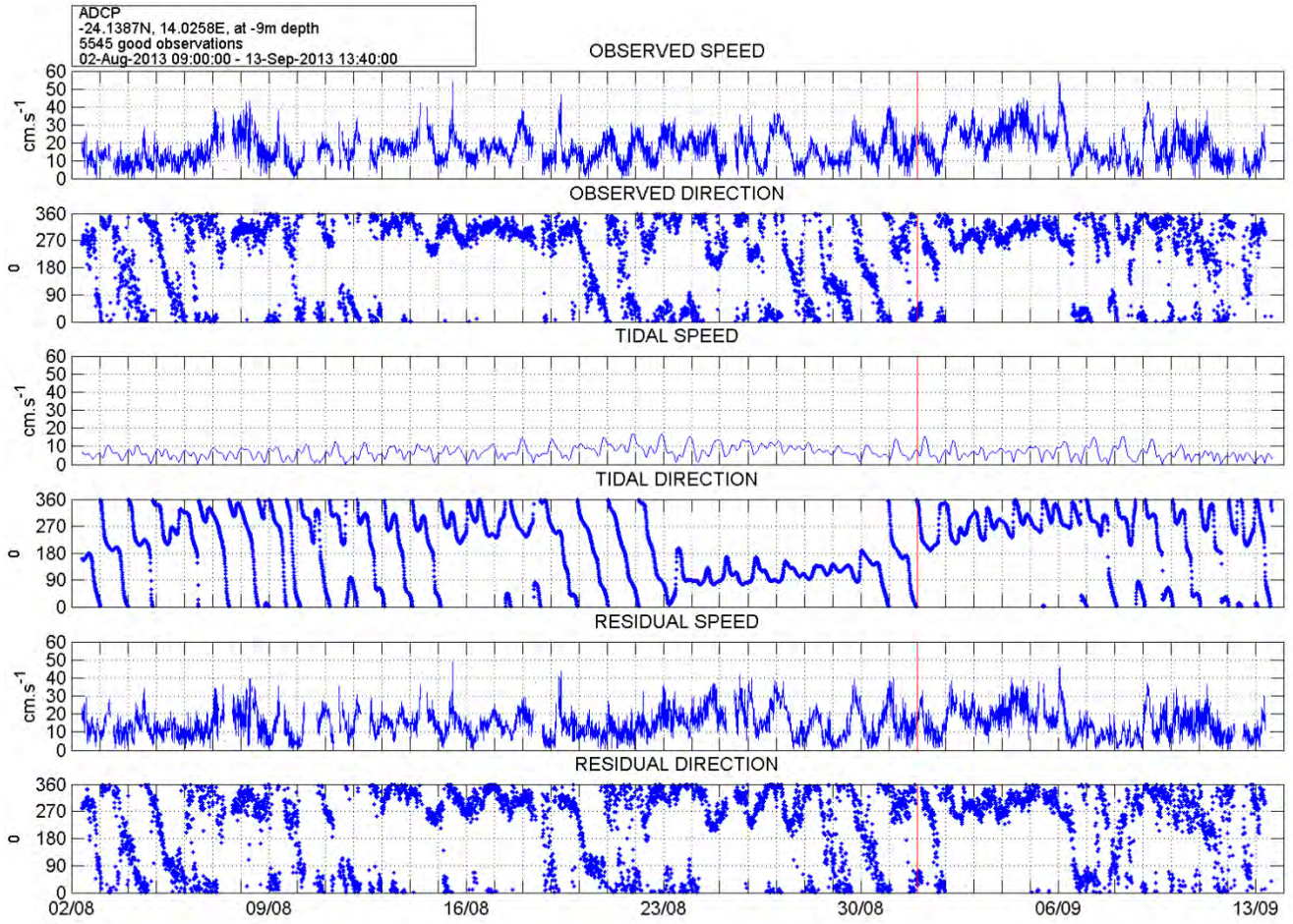


Figure 9: Current time series data for 9 m depth

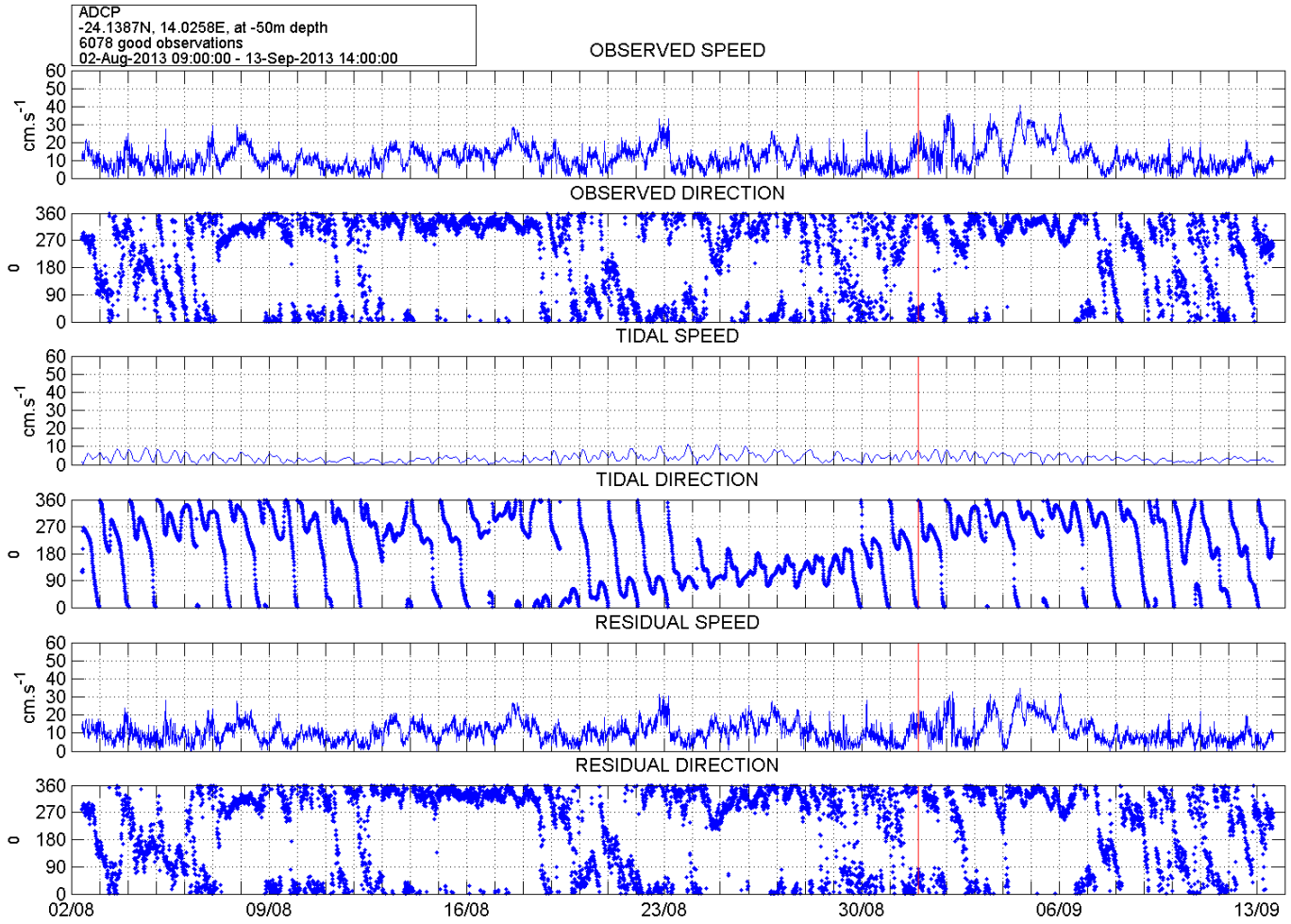


Figure 10: Current time series for 50 m depth

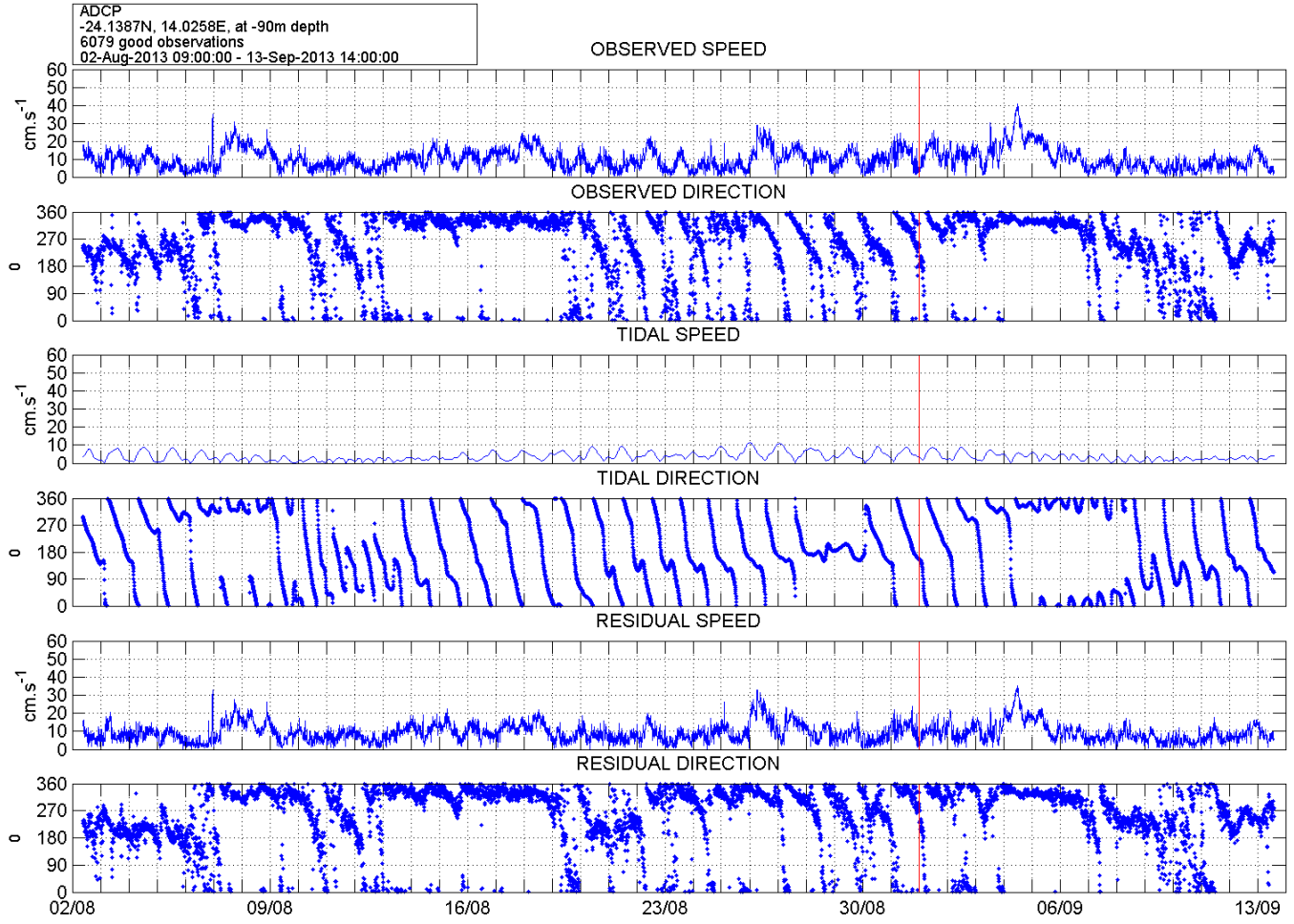


Figure 11: Current time series for 90 m depth

© NMP 2014

4.1.1.2 Summary plots

Figures 12 to 14 display summary plots of the current depths at: -9 m, -50 m and -90 m respectively. The summary plots consist of:

- The upper panel is a table of the joint distribution of 10 minute averaged current speed against direction. Columns of the table represent direction classes and rows the speed classes. The numbers in the table reflect the percentage of observations that fall within a particular speed interval and direction sector.
- The lower left hand panel is a rose of the 10 minute averaged current direction. This is a histogram of the directional distribution and reflects the percentage of observations that fall within each direction sector. The colour scale indicates the current speeds which are represented.
- The lower right hand panel is a histogram of the 10 minute averaged current speeds. This reflects the percentage of observations that fall within each speed interval. Included on the plot are basic statistics for the current speed distribution.

© NMP 2014

ADCP
-24.1387N, 14.0258E, at -9m depth
5545 good observations
02-Aug-2013 09:00:00 - 13-Sep-2013 13:40:00

JOINT DISTRIBUTION OF SPEED AND DIRECTION

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Σ
0-5	0.40	0.38	0.29	0.27	0.47	0.20	0.25	0.36	0.29	0.38	0.34	0.36	0.41	0.34	0.49	0.41	5.64
5-10	1.55	1.30	1.15	0.81	0.76	0.79	0.74	0.76	0.58	0.72	0.96	1.24	1.28	1.95	1.91	1.44	17.94
10-15	2.47	1.86	0.97	0.92	0.61	0.96	0.83	0.65	0.50	0.43	0.76	1.57	2.31	2.80	3.41	2.71	23.75
15-20	2.09	1.82	1.12	0.99	0.27	0.32	0.27	0.27	0.23	0.43	0.70	1.23	1.79	2.47	3.77	3.05	20.83
20-25	1.21	1.42	1.12	0.50	0.25	0.02		0.02	0.13	0.52	1.01	0.97	1.41	2.18	2.81	1.95	15.53
25-30	0.63	0.87	0.34	0.20		0.02	0.02		0.11	0.32	0.31	0.81	1.03	1.84	1.48	1.15	9.13
30-35	0.31	0.41	0.04						0.02	0.07	0.11	0.31	0.49	1.01	0.96	0.54	4.26
35-40	0.31	0.18								0.04	0.02	0.16	0.32	0.38	0.49	0.34	2.24
40-45	0.02											0.04	0.14	0.04	0.14	0.13	0.50
45-50													0.04	0.04			0.07
50-55													0.07	0.02		0.02	0.11
55-60																	0.00
Σ	8.98	8.24	5.03	3.70	2.36	2.31	2.11	2.06	1.86	2.92	4.20	6.69	9.29	13.06	15.46	11.74	100.00

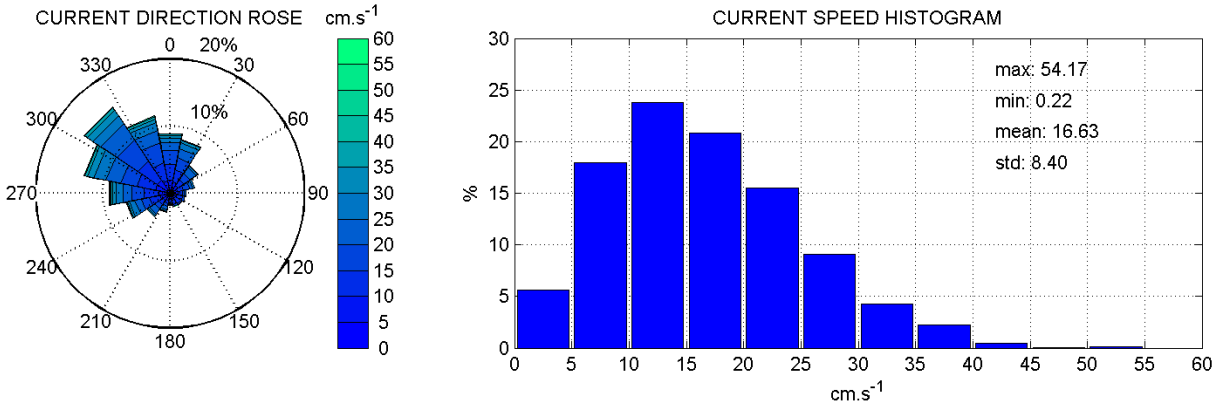


Figure 12: Summary of current data at 9 mm depth

ADCP
-24.1387N, 14.0258E, at -50m depth
6078 good observations
02-Aug-2013 09:00:00 - 13-Sep-2013 14:00:00

JOINT DISTRIBUTION OF SPEED AND DIRECTION

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Σ
0-5	1.33	1.17	0.66	0.63	0.76	0.59	0.71	0.79	0.97	0.71	0.77	0.87	1.09	1.50	1.53	1.60	15.66
5-10	3.47	2.57	1.66	1.25	1.18	0.97	0.81	0.92	0.82	1.20	1.50	1.97	2.58	3.36	4.71	4.13	33.10
10-15	3.46	2.07	1.46	1.53	1.18	0.67	0.56	0.36	0.58	0.43	0.66	1.05	1.84	3.24	4.79	3.95	27.84
15-20	1.96	1.28	1.07	0.51	0.26	0.30	0.08	0.08	0.07		0.07	0.31	0.86	1.40	2.44	2.76	13.44
20-25	0.48	0.61	0.30	0.05	0.05	0.05	0.03	0.02			0.02	0.10	0.28	0.71	1.37	1.38	5.43
25-30	0.23	0.26	0.15			0.02						0.02	0.28	0.35	0.61	0.99	2.90
30-35	0.15	0.02											0.10	0.08	0.26	0.76	1.37
35-40	0.02												0.05	0.02	0.02	0.15	0.25
40-45																0.02	0.02
45-50																	0.00
50-55																	0.00
55-60																	0.00
Σ	11.09	7.98	5.30	3.97	3.44	2.60	2.19	2.17	2.44	2.34	3.01	4.33	7.07	10.64	15.71	15.73	100.00

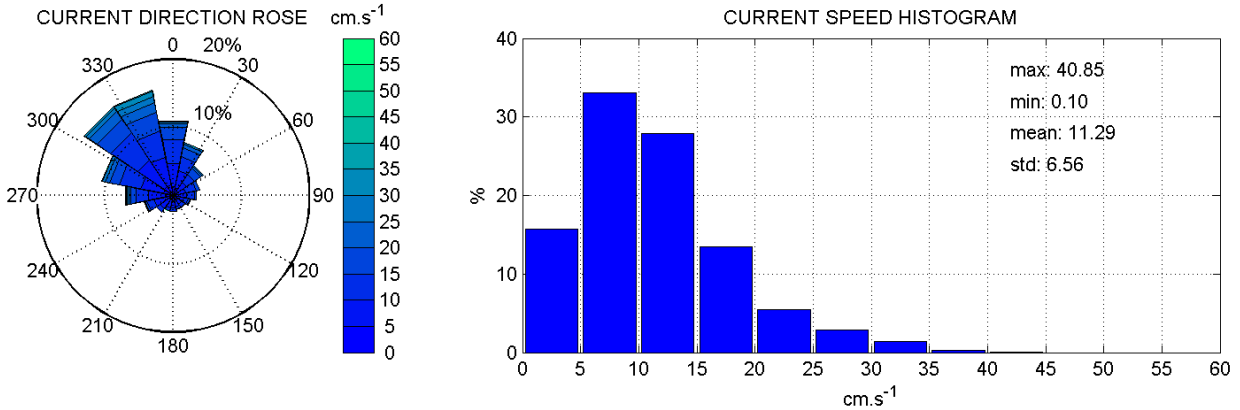


Figure 13: Summary of current data at 50 mm depth

ADCP
-24.1387N, 14.0258E, at -90m depth
6079 good observations
02-Aug-2013 09:00:00 - 13-Sep-2013 14:00:00

JOINT DISTRIBUTION OF SPEED AND DIRECTION

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Σ
0-5	1.27	1.18	1.05	0.82	0.79	0.74	0.92	1.00	1.32	1.48	1.15	1.61	1.43	1.55	1.83	1.65	19.79
5-10	2.93	1.55	0.76	0.53	0.44	0.41	0.86	1.20	2.09	3.06	3.04	3.42	3.39	2.81	4.34	4.39	35.22
10-15	2.48	0.76	0.43	0.07	0.23	0.12	0.20	0.31	0.64	1.65	2.35	2.35	1.10	1.50	5.40	6.53	26.11
15-20	1.56	0.07	0.05	0.02		0.03	0.02	0.07	0.16	0.18	0.51	0.71	0.20	0.58	3.64	4.87	12.65
20-25	0.41	0.02											0.05	0.20	1.41	2.63	4.72
25-30	0.07													0.02	0.36	0.53	0.97
30-35															0.08	0.20	0.28
35-40																0.23	0.23
40-45																0.03	0.03
45-50																	0.00
50-55																	0.00
55-60																	0.00
Σ	8.72	3.57	2.29	1.43	1.46	1.30	1.99	2.58	4.21	6.37	7.06	8.09	6.17	6.65	17.06	21.06	100.00

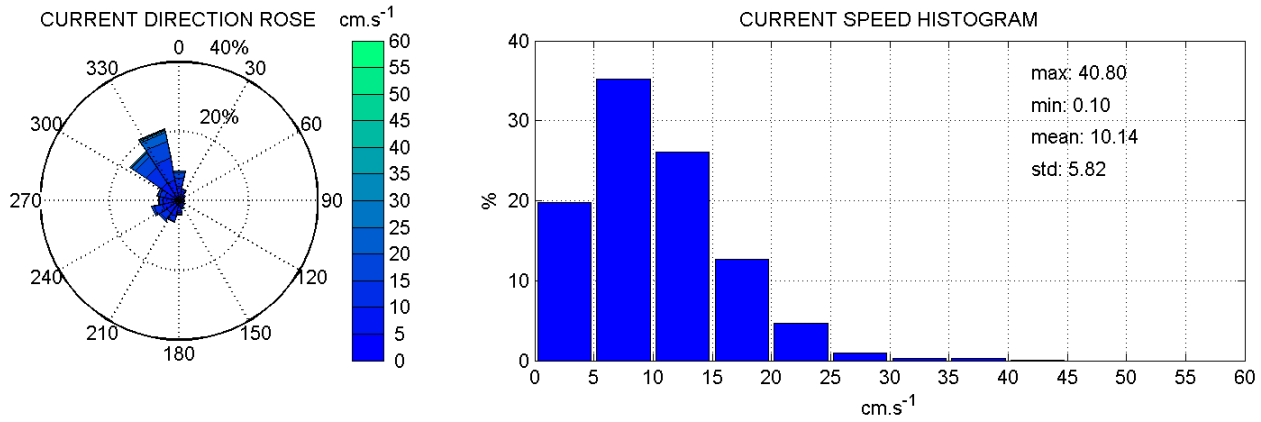


Figure 14: Summary of current data at 90 mm depth

4.1.1.3 Progressive vector plots

Figures 15 to 17 display progressive vector plots for the depths: -9 m, -50 m and -90 m respectively. The plots consist of:

- The solid line represents the displacement that a particle of water would undergo when subject to the currents that were observed.
- The start and end points of the observations are labelled.
- Each day is represented by a red cross.

© NMP 2014

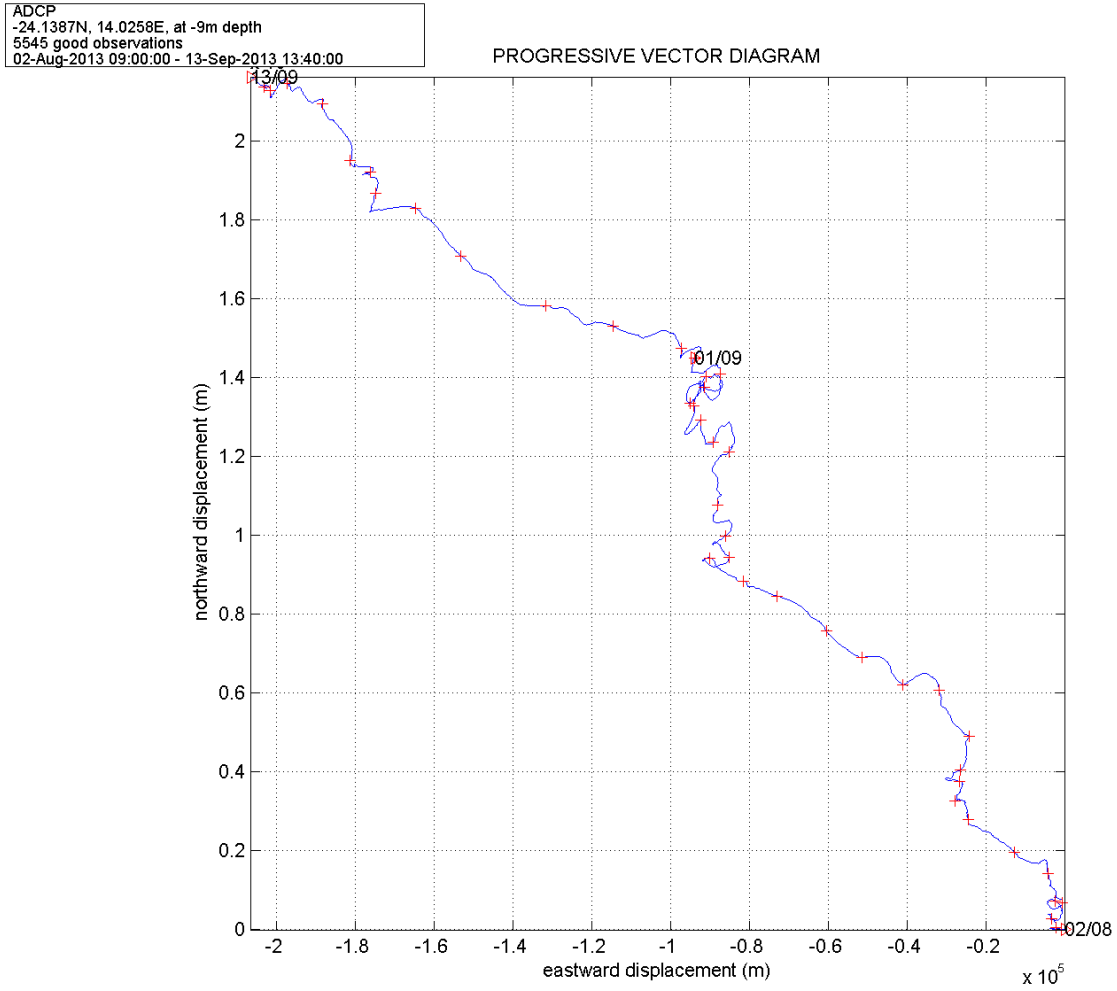


Figure 15: Current progressive vector plot for 9 m depth

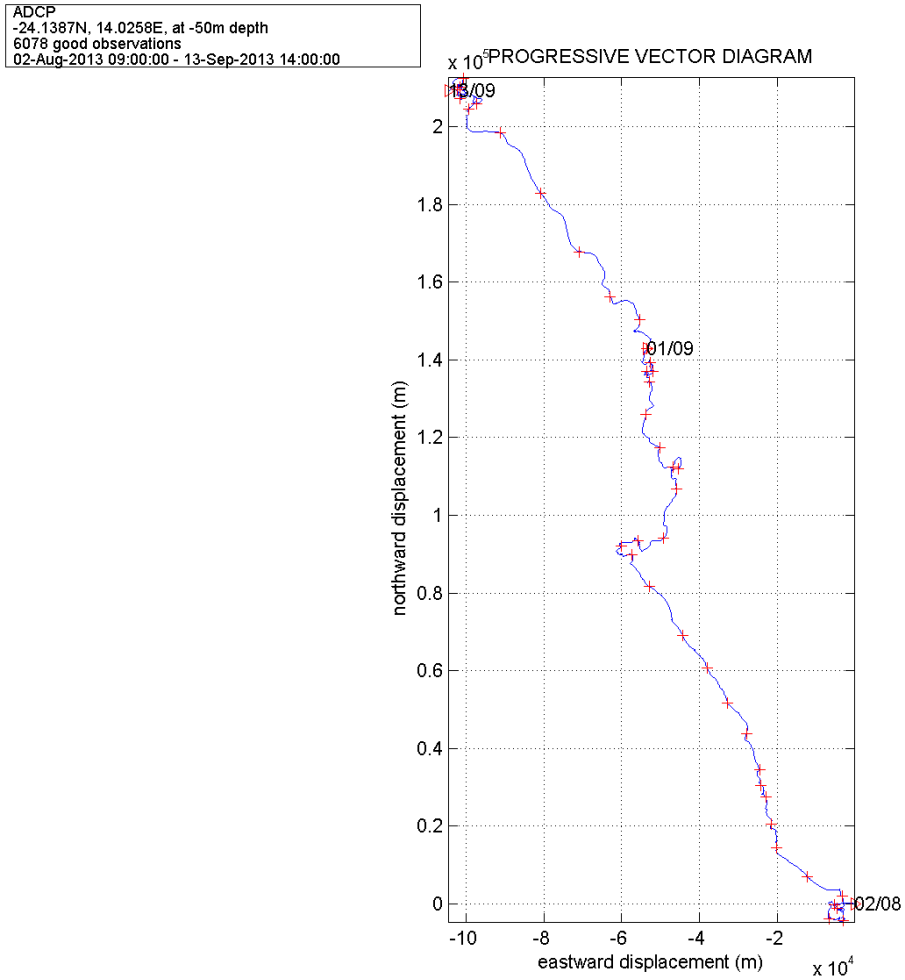


Figure 16: Current progressive vector plot for 50 m depth

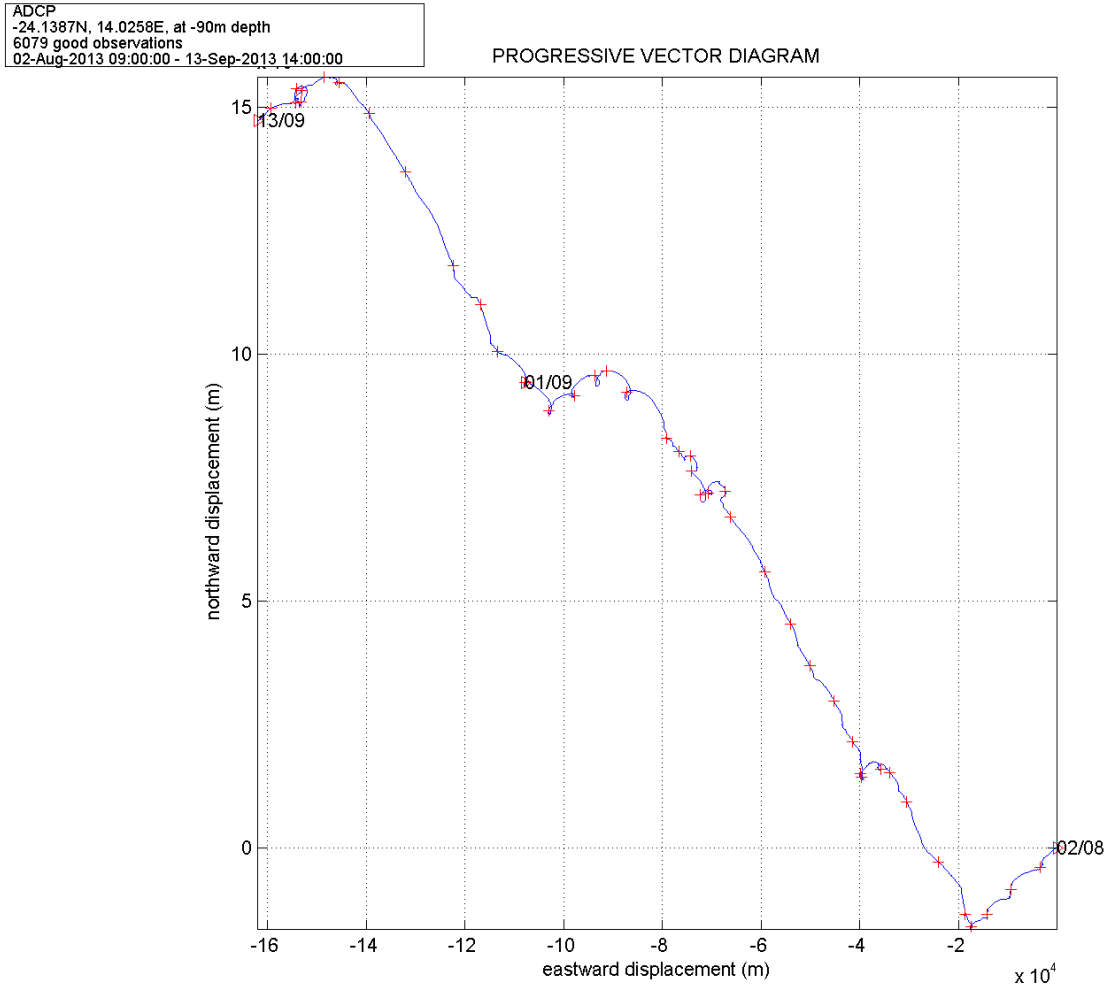


Figure 17: Current progressive vector plot for 90 m depth

4.1.1.4 Tidal harmonic plots

Tables 10 – 12 present current harmonic data for the depths: -9 m, -50 m and -90 m respectively. The harmonics consist of:

- The tidal calculation follows the method of Foreman and uses the observed complex current vector as input *(R. Pawlowicz, B. Beardsley and S. Lentz, "Classical tidal harmonic analysis including error estimates in Matlab using T_TIDE", Computers and Geosciences 28 (2002), 929-937*).
- The major and minor axis amplitudes are given in $cm.s^{-1}$.
- The ellipse orientation and Greenwich phase are given in degrees.

© NMP 2014

Table 10: Current harmonic data for 9 m depth

ADCP
-24.1387N, 14.0258E, in -9m depth
5545 good observations
02-Aug-2013 09:00:00 - 13-Sep-2013 13:40:00

HARMONIC COMPONENTS

Component	Major	Minor	Ellipse	Phase
MM	5.90	-0.77	159.24	293.08
MSF	3.62	-1.99	0.13	120.08
ALP1	3.26	1.65	60.55	87.79
2Q1	1.82	0.93	62.74	48.09
Q1	3.05	1.65	21.84	13.84
O1	3.05	2.05	170.65	181.43
NO1	1.63	-0.73	138.74	23.47
K1	3.63	2.17	31.23	203.53
J1	2.03	0.33	99.13	359.99
OO1	2.17	0.21	170.48	114.27
UPS1	2.43	1.27	37.03	288.01
EPS2	1.20	0.39	57.32	23.59
MU2	0.78	0.18	155.14	31.04
N2	1.40	0.50	62.57	203.55
M2	1.23	-0.14	139.52	109.25
L2	0.87	0.11	59.72	70.65
S2	1.60	0.29	31.00	336.04
ETA2	1.53	-0.70	59.74	248.30
MO3	0.75	-0.34	51.09	4.27
M3	1.12	0.71	143.21	108.99
MK3	0.88	0.39	60.60	199.88
SK3	0.77	-0.27	19.90	40.20
MN4	0.29	-0.22	100.24	163.41
M4	0.29	0.01	98.76	357.19
SN4	0.37	0.04	14.85	43.26
MS4	0.27	-0.13	27.05	179.39
S4	0.55	0.19	92.58	336.08
2MK5	0.42	-0.10	52.73	207.33
2SK5	0.46	0.11	6.19	62.77
2MN6	0.36	-0.24	24.51	345.71
M6	0.28	0.14	108.90	267.21
2MS6	0.21	-0.10	96.95	109.26
2SM6	0.20	0.00	48.22	347.13
3MK7	0.41	-0.09	57.54	14.23
M8	0.27	-0.01	175.22	209.78

© NMP 2014

Table 11: Current harmonic data for 50 m depth

ADCP
-24.1387N, 14.0258E, in -50m depth
6078 good observations
02-Aug-2013 09:00:00 - 13-Sep-2013 14:00:00

HARMONIC COMPONENTS

Component	Major	Minor	Ellipse	Phase
MM	3.14	-0.69	158.92	271.19
MSF	2.04	-1.04	139.85	308.77
ALP1	1.47	0.81	39.78	84.52
2Q1	0.99	0.91	158.98	358.46
Q1	1.08	0.55	50.93	355.89
O1	1.31	-0.20	176.29	168.22
NO1	2.14	-1.28	31.80	106.16
K1	1.78	0.20	36.35	197.73
J1	0.63	-0.06	21.81	205.04
OO1	1.18	0.90	7.57	71.21
UPS1	1.90	0.73	76.80	24.26
EPS2	0.57	0.23	72.21	350.54
MU2	0.22	0.15	140.88	26.07
N2	0.77	0.70	73.49	262.04
M2	1.55	0.97	90.59	36.12
L2	0.49	0.14	65.33	81.43
S2	1.31	0.95	170.62	101.57
ETA2	0.88	-0.27	179.07	109.64
MO3	0.44	-0.10	47.36	54.18
M3	0.60	0.17	25.78	13.50
MK3	0.35	0.12	166.09	201.81
SK3	0.45	-0.09	147.31	254.47
MN4	0.18	0.02	65.30	169.83
M4	0.36	0.10	24.48	54.33
SN4	0.32	-0.06	18.82	18.35
MS4	0.43	0.23	13.18	136.29
S4	0.20	0.08	72.97	298.91
2MK5	0.28	0.14	91.91	3.86
2SK5	0.17	-0.01	171.33	257.13
2MN6	0.15	-0.11	168.68	249.64
M6	0.26	0.16	35.64	188.77
2MS6	0.12	0.00	74.67	290.75
2SM6	0.27	-0.05	140.47	315.34
3MK7	0.07	0.03	147.28	144.40
M8	0.11	0.01	28.63	109.04

© NMP 2014

Table 12: Current harmonic data for 90 m depth

ADCP
-24.1387N, 14.0258E, in -90m depth
6079 good observations
02-Aug-2013 09:00:00 - 13-Sep-2013 14:00:00

HARMONIC COMPONENTS

Component	Major	Minor	Ellipse	Phase
MM	2.17	-1.16	86.04	308.81
MSF	3.06	-0.96	106.86	325.67
ALP1	1.92	1.20	96.51	279.86
2Q1	1.62	1.22	112.73	283.18
Q1	1.81	1.33	106.44	169.40
O1	1.78	1.16	103.87	262.28
NO1	1.47	0.29	134.41	343.51
K1	1.76	1.12	135.95	103.44
J1	1.50	0.78	134.42	215.59
OO1	0.66	0.46	66.17	103.46
UPS1	0.56	-0.06	125.20	185.65
EPS2	0.37	-0.24	55.98	276.43
MU2	0.23	0.10	144.79	238.40
N2	0.25	0.05	61.83	55.19
M2	1.37	1.15	73.62	349.75
L2	0.18	-0.06	158.48	285.05
S2	0.48	0.22	179.07	121.49
ETA2	0.48	-0.18	176.47	190.72
MO3	0.44	0.32	4.47	106.87
M3	0.20	0.11	46.40	69.26
MK3	0.33	0.15	11.79	332.93
SK3	0.34	0.01	95.17	202.55
MN4	0.31	-0.02	59.34	21.68
M4	0.11	0.01	121.57	51.00
SN4	0.19	-0.04	31.34	241.02
MS4	0.25	0.05	118.15	301.11
S4	0.11	0.03	31.79	111.47
2MK5	0.21	-0.10	76.41	217.14
2SK5	0.24	0.01	119.22	63.47
2MN6	0.12	-0.07	20.15	197.42
M6	0.17	0.00	118.67	240.38
2MS6	0.15	-0.06	31.43	273.57
2SM6	0.04	-0.00	112.01	289.02
3MK7	0.24	0.09	120.74	136.42
M8	0.13	-0.01	178.22	8.21

© NMP 2014

4.1.1.5 Profile plots

Figures 19 to 21 display profile plots of the currents through the water column. The first plot displays the mean profile plot over the duration of measurements, while the following three plots display profile plots at selected times. The times selected were time of maximum current speed for bins 82, 41 and 1. These represent the flow for the depths -9 m, -50 m and -90 m respectively. These plots consist of:

- The left hand panel is a 3-dimensional illustration of the current vector through the water column, with depth on the vertical axis. The vector arrow indicates the direction towards which the current is flowing, with the length of the arrow proportional to the current speed.
- The middle panel is a plot of the current speed (x-axis) with depth (y-axis).
- The right hand panel is a plot of current direction (x-axis) with depth (y-axis).

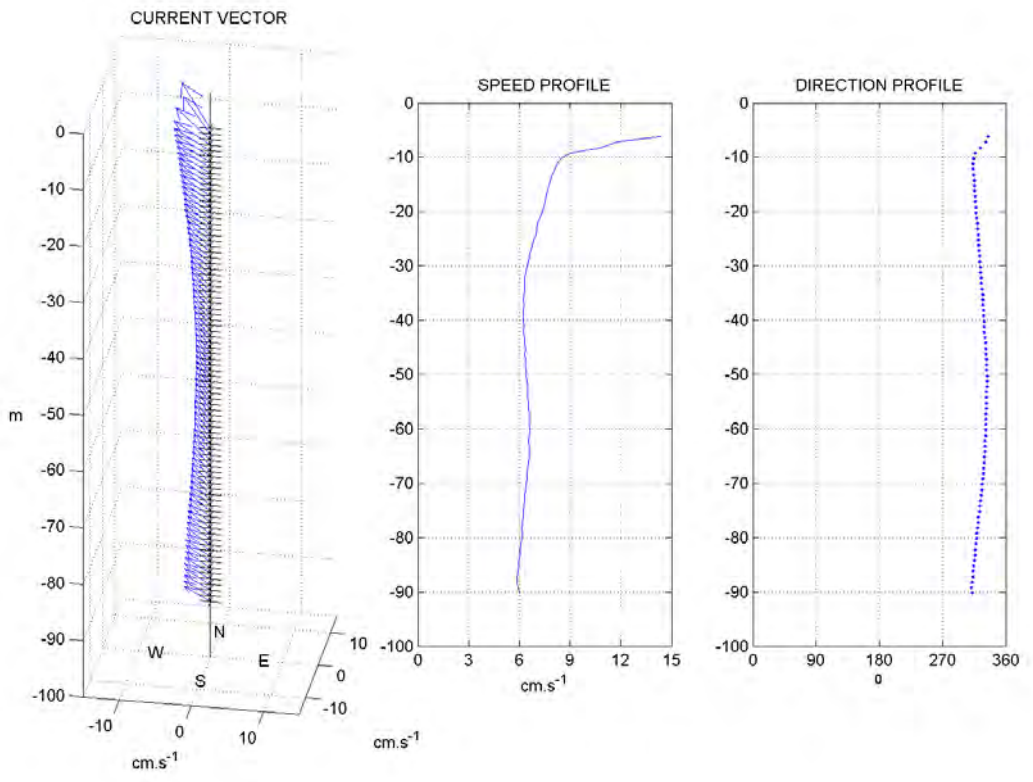


Figure 18: Mean profile plot

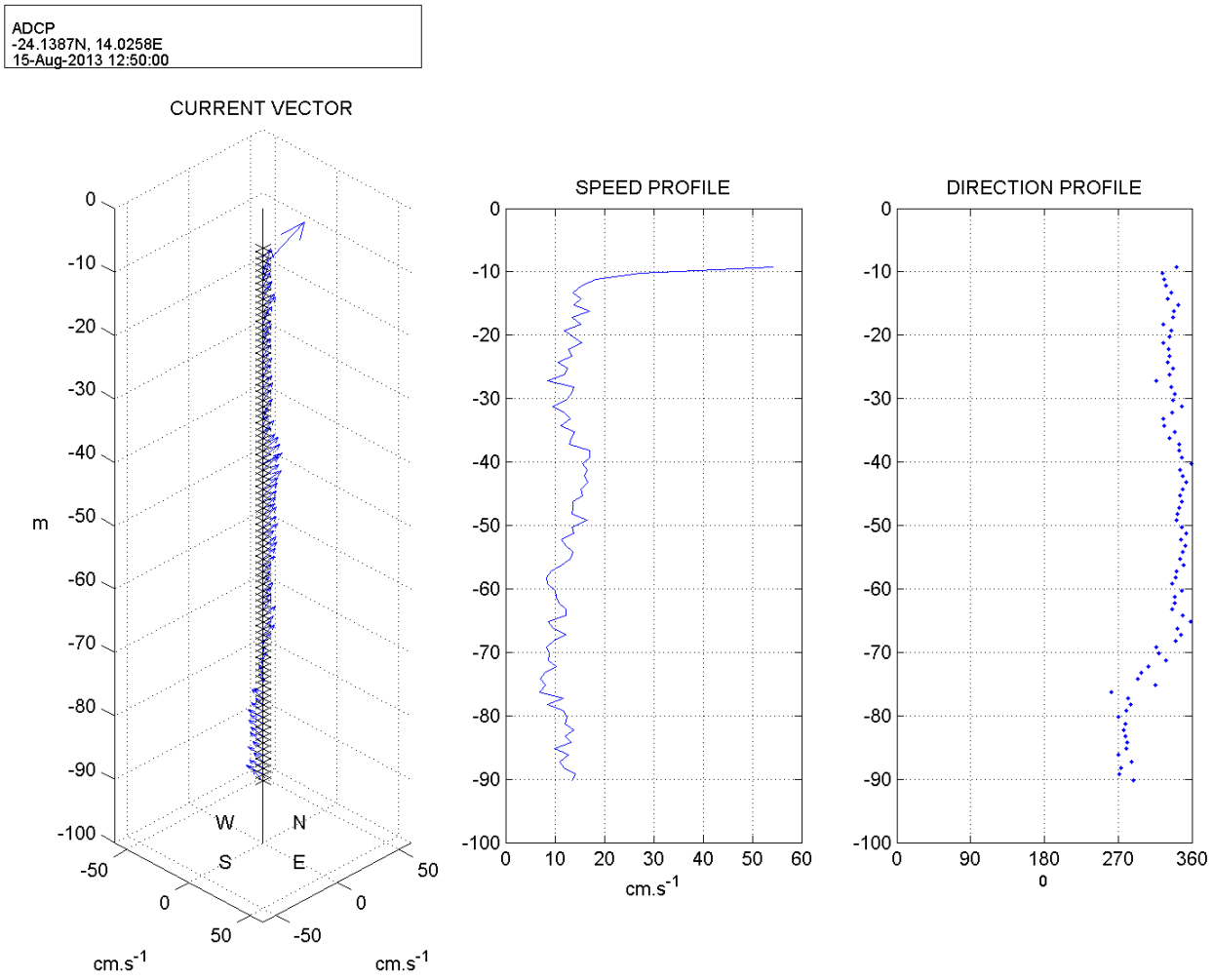


Figure 19: Profile plot at the time of maximum current speed in the upper water column

© NMP 2014

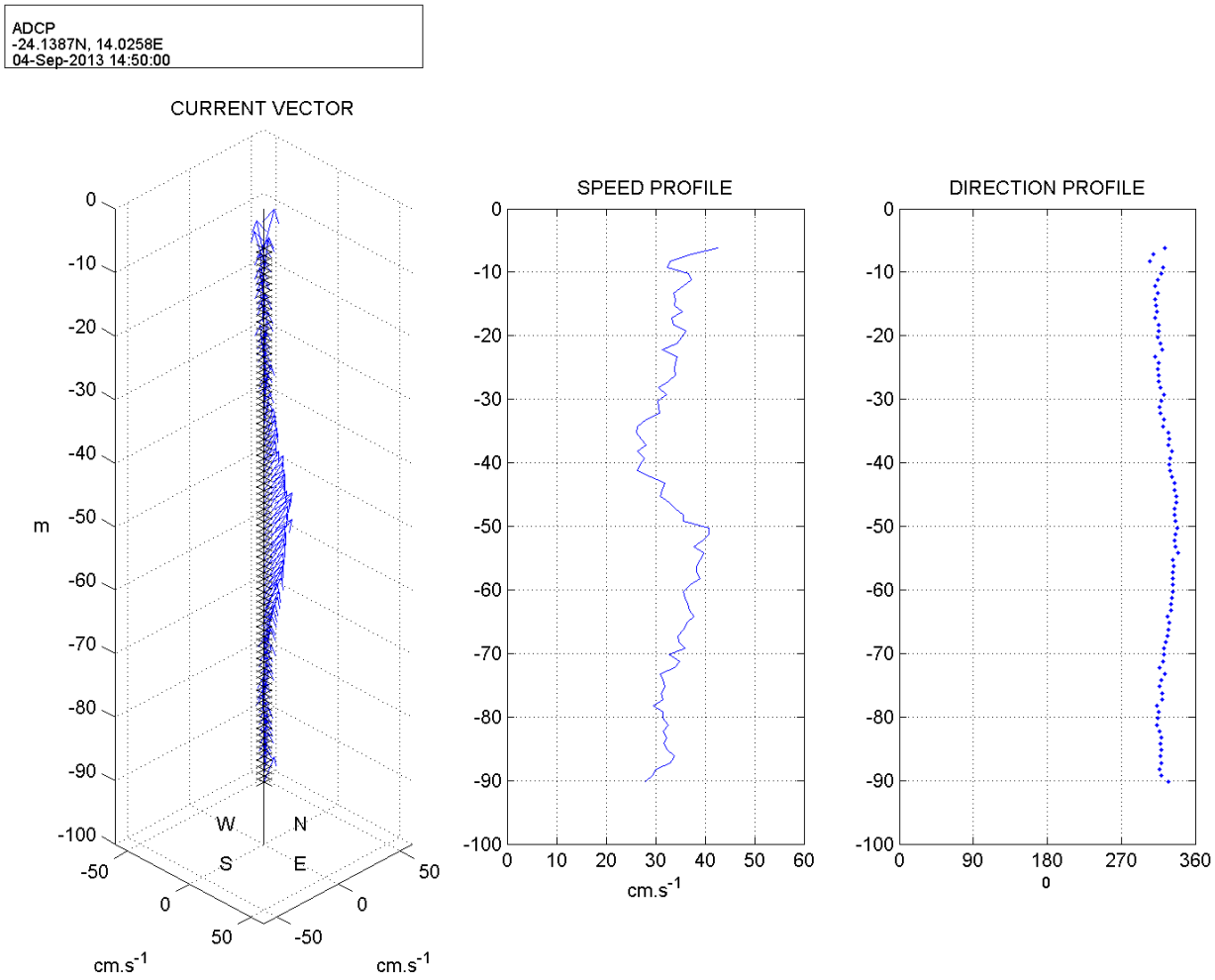


Figure 20: Profile plot at the time of maximum current speed in the mid water column

© NMP 2014

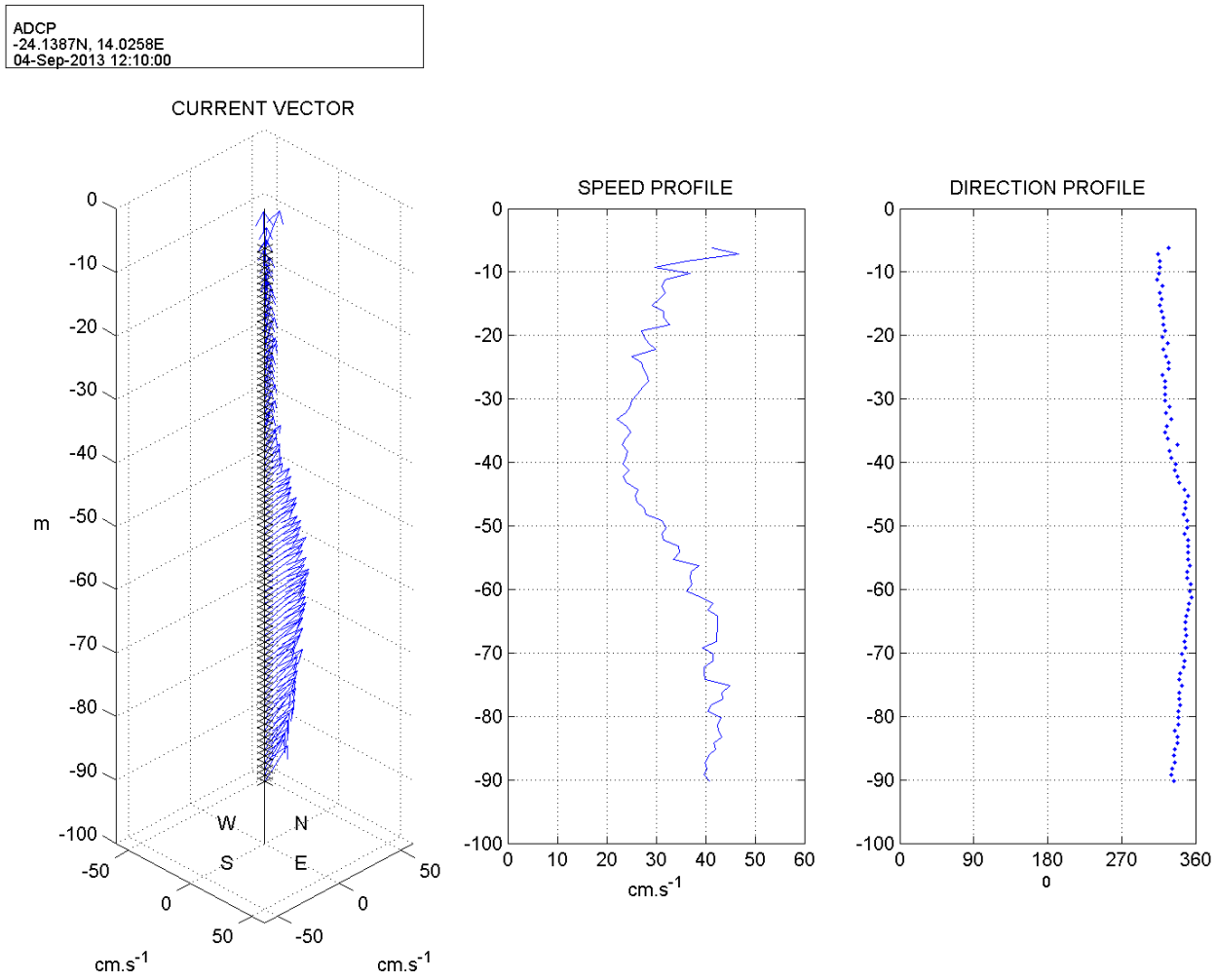


Figure 21: Profile plot at the time of maximum current speed in the lower water column

© NMP 2014

4.1.2 Pressure and water temperature data

4.1.2.1 Time series plot

Figure 22 displays a time series plot, which consists of:

- The first (upper) panel is of the observed pressure (water level) against time.
- The second panel is of the observed water temperature against time.
- The first day of each month is indicated visually by a thin red line on each of the plots.

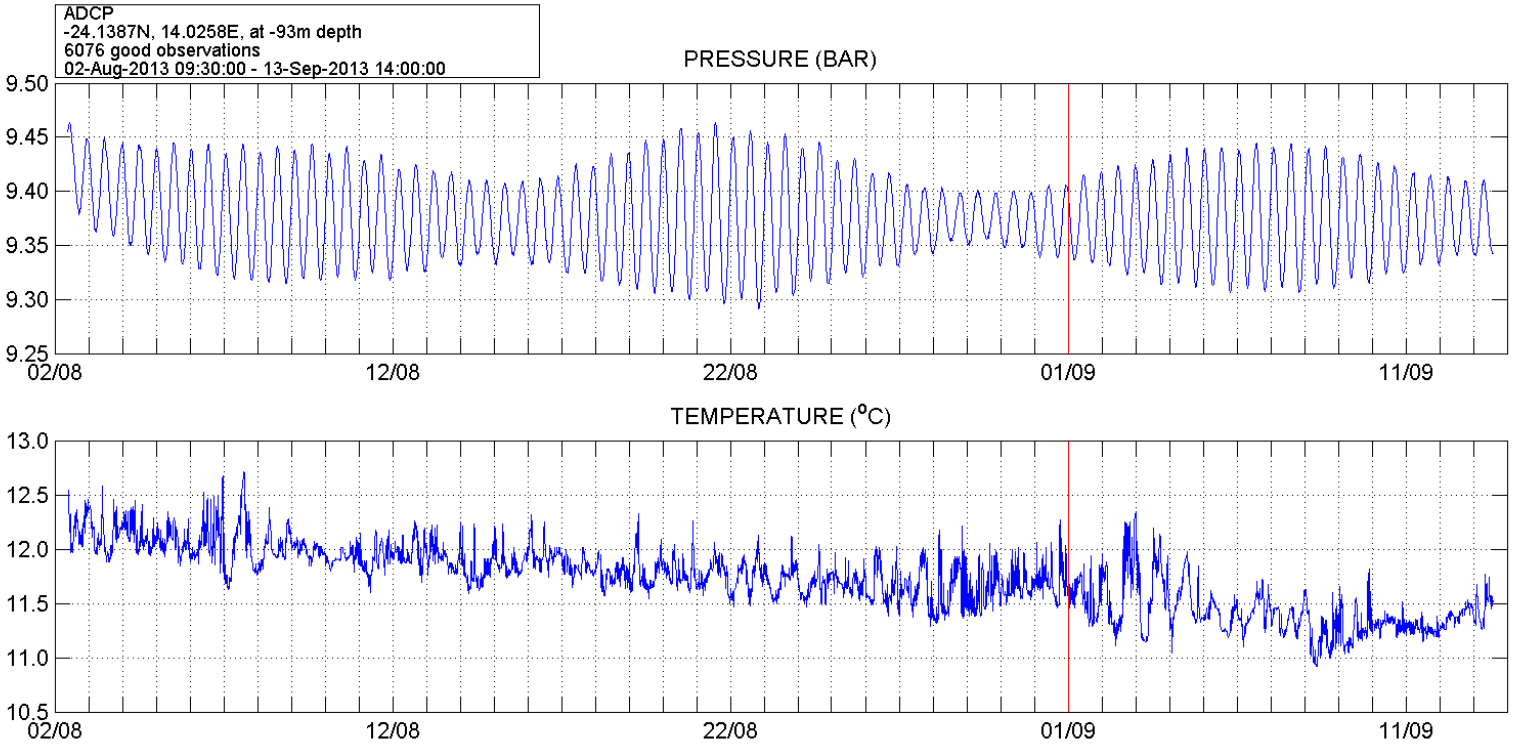


Figure 22: Pressure (water level) and temperature at 93 m depth

© NMP 2014

4.2 AQD 1

4.2.1 Current data

4.2.1.1 Time series plot

Figure 23 displays a time series plot which consists of:

- The first (upper) panel is of the observed current speed against time.
- The second panel is of the observed current direction against time.
- The third panel is of the tidal current speed, calculated from the observed current speed and direction, against time. The entire data set of observations is used in the derivation of the tidal component. The tidal calculation follows the method of Foreman and uses the observed complex current vector as input (*R. Pawlowicz, B. Beardsley, and S. Lentz, "Classical tidal harmonic analysis including error estimates in MATLAB using T_TIDE", Computers and Geosciences 28 (2002), 929-937*)
- The fourth panel is of the tidal current direction, calculated as above, against time.
- The fifth panel is of the residual current speed against time. The residual has been calculated as north and east components (residual component = observed component – tidal component), which have then been converted into residual speed and direction.
- The sixth panel is of the residual current direction against time, calculated as above.

© NMP 2014

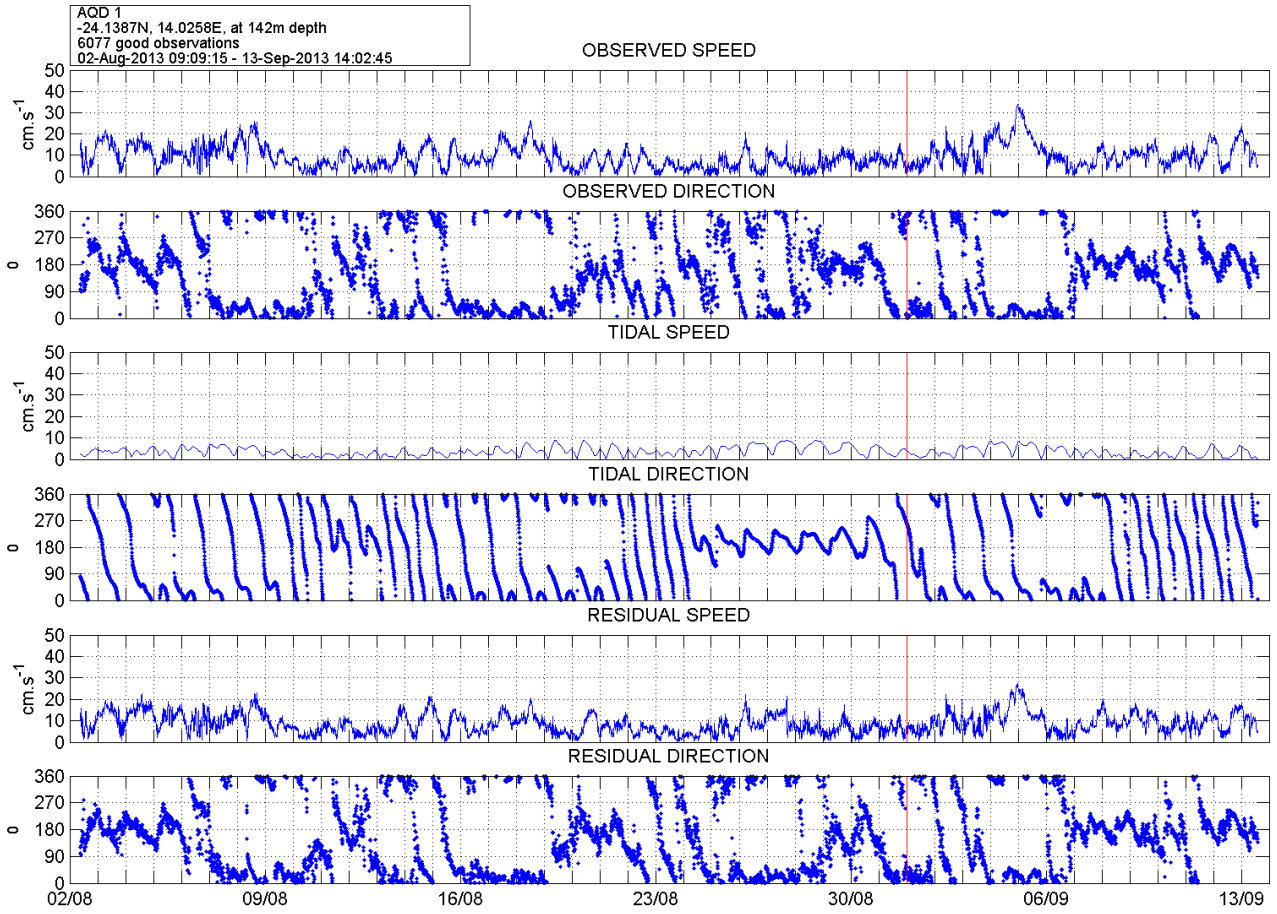


Figure 23: Current time series data for 142 m depth

4.2.1.2 Summary plot

Figure 24 displays a summary plot which consists of:

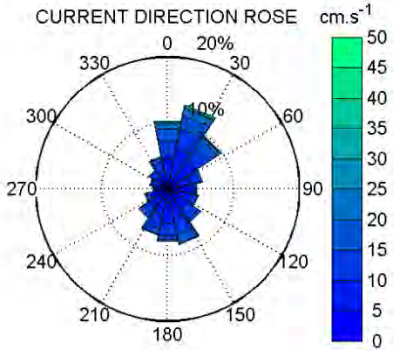
- The upper panel is a table of the joint distribution of 10 minute averaged current speed against direction. Columns of the table represent direction classes and rows the speed classes. The numbers in the table reflect the percentage of observations that fall within a particular speed interval and direction sector.
- The lower left hand panel is a rose of the 10 minute averaged current direction. This is a histogram of the directional distribution and reflects the percentage of observations that fall within each direction sector.
- The lower right hand panel is a histogram of the 10 minute averaged current speeds. This reflects the percentage of observations that fall within each speed interval. Included on the plot are basic statistics for the current speed distribution.

© NMP 2014

AQD 1
-24.1387N, 14.0258E, at 142m depth
6077 good observations
02-Aug-2013 09:09:15 - 13-Sep-2013 14:02:45

JOINT DISTRIBUTION OF SPEED AND DIRECTION

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Σ
0-5	1.17	1.69	1.91	1.56	1.76	1.43	1.97	1.93	1.94	1.71	1.40	1.35	1.00	1.25	1.02	1.14	24.24
5-10	3.47	4.51	3.31	1.99	2.02	2.37	1.79	2.60	3.32	2.40	1.97	1.33	0.76	0.86	1.37	1.69	35.77
10-15	2.81	3.19	2.27	1.48	0.64	0.76	1.78	2.58	1.96	2.07	1.07	0.63	0.41	0.46	0.87	1.38	24.37
15-20	1.78	1.99	1.60	0.38	0.12	0.15	0.48	1.27	0.61	0.81	0.82	0.30	0.07	0.21	0.08	0.66	11.30
20-25	0.94	1.14	0.49	0.02				0.16	0.23	0.15					0.07	0.16	3.36
25-30	0.26	0.08	0.07													0.02	0.43
30-35		0.38	0.15														0.53
35-40																	0.00
40-45																	0.00
45-50																	0.00
Σ	10.43	12.98	9.79	5.43	4.54	4.71	6.02	8.54	8.06	7.14	5.27	3.60	2.24	2.78	3.41	5.05	100.00



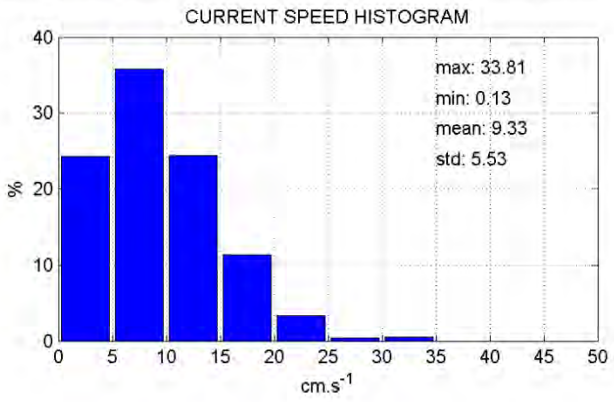


Figure 24: Summary of current data at 142 depth

4.2.1.3 Progressive vector plot

Figure 25 displays a progressive vector plot which consists of:

- The solid line represents the displacement that a particle of water would undergo when subject to the currents that were observed.
- The start and end points of the observations are labelled.
- Each day is represented by a red cross.

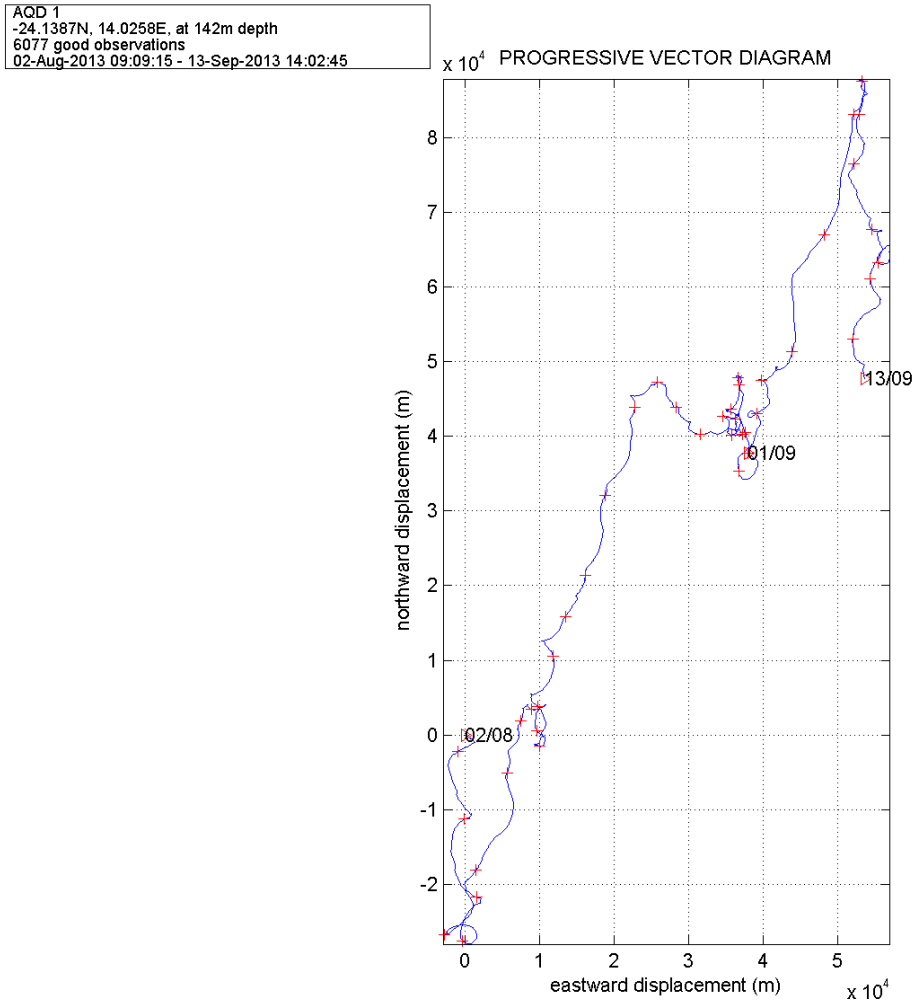


Figure 25: Current progressive vector plot at 142 m depth

4.2.1.4 Tidal harmonic plot

Table 13 presents a current harmonic data which consists of:

- The tidal calculation follows the method of Foreman and uses the observed complex current vector as input *(R. Pawlowicz, B. Beardsley and S. Lentz, "Classical tidal harmonic analysis including error estimates in Matlab using T_TIDE", Computers and Geosciences 28 (2002), 929-937*).
- The major and minor axis amplitudes are given in knots.
- The ellipse orientation and Greenwich phase are given in degrees.

Table 13: Current harmonic data for 142 m depth

AQD 1
-24.1387N, 14.0258E, in 142m depth
6077 good observations
02-Aug-2013 09:09:15 - 13-Sep-2013 14:02:45

HARMONIC COMPONENTS

Component	Major	Minor	Ellipse	Phase
MM	2.44	-0.67	76.26	303.08
MSF	3.73	-0.11	65.51	333.28
ALP1	1.06	0.91	41.55	332.28
2Q1	1.25	1.13	87.72	128.42
Q1	1.42	0.85	168.32	39.40
O1	1.11	0.68	112.80	106.45
NO1	1.25	0.56	44.95	116.45
K1	1.49	0.81	17.12	341.03
J1	0.65	0.41	44.70	111.07
OO1	1.76	0.93	173.81	94.02
UPS1	1.02	0.44	18.40	127.06
EPS2	0.26	0.07	5.05	133.61
MU2	0.52	0.27	34.40	17.55
N2	0.81	0.57	174.15	137.37
M2	1.67	1.37	44.24	342.62
L2	0.34	0.17	172.55	16.88
S2	0.58	0.32	126.75	117.87
ETA2	0.42	0.20	43.27	109.81
MO3	0.34	0.19	30.55	228.30
M3	0.19	0.05	156.28	323.19
MK3	0.36	0.16	1.78	273.08
SK3	0.18	-0.07	137.87	181.28
MN4	0.18	0.04	168.60	97.34
M4	0.17	0.03	150.83	257.96
SN4	0.11	-0.11	42.65	49.24
MS4	0.09	-0.00	156.47	23.29
S4	0.09	0.04	159.81	101.14
2MK5	0.14	-0.04	130.81	259.89
2SK5	0.36	0.03	20.73	290.82
2MN6	0.13	0.09	154.85	299.65
M6	0.13	0.02	48.05	20.04
2MS6	0.27	0.00	77.16	251.31
2SM6	0.18	0.04	22.72	336.29
3MK7	0.20	0.01	169.76	12.11
M8	0.09	0.01	57.77	149.31

© NMP 2014

4.2.2 Pressure and water temperature data

4.2.2.1 Time series plot

Figure 26 displays a time series plot of pressure (water level) and water temperature variations as a function of time over the recording period.

- The first (upper) panel is of the observed 10 minute water level against time.
- The second panel is of the observed 10 minute water temperature against time.

© NMP 2014

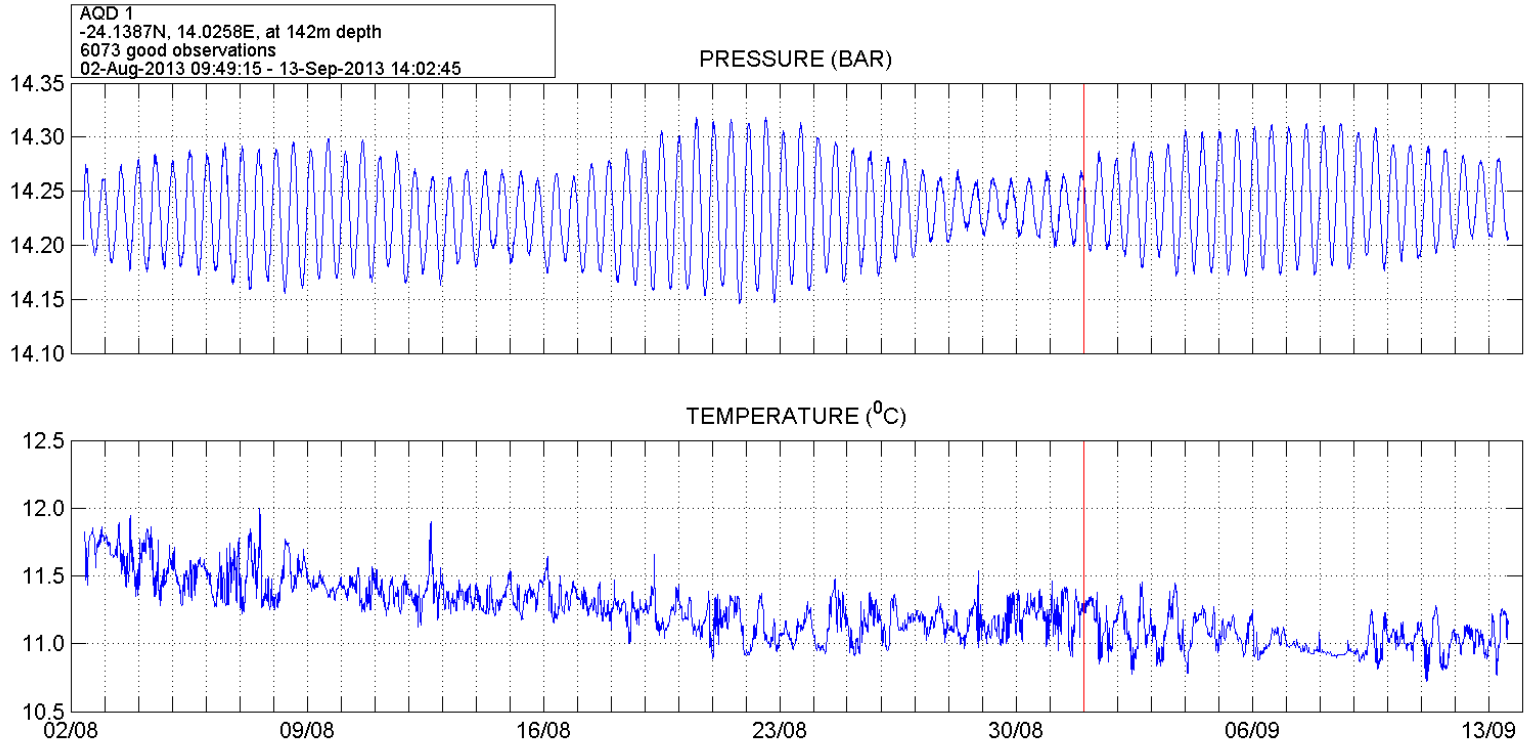


Figure 26: Pressure (water level) and temperature at 142 m depth

© NMP 2014

4.3 AQD 2

4.3.1 Current data

4.3.1.1 Time series plot

Figure 27 displays a time series plot which consists of:

- The first (upper) panel is of the observed current speed against time.
- The second panel is of the observed current direction against time.
- The third panel is of the tidal current speed, calculated from the observed current speed and direction, against time. The entire data set of observations is used in the derivation of the tidal component. The tidal calculation follows the method of Foreman and uses the observed complex current vector as input (*R. Pawlowicz, B. Beardsley, and S. Lentz, "Classical tidal harmonic analysis including error estimates in MATLAB using T_TIDE", Computers and Geosciences 28 (2002), 929-937*)
- The fourth panel is of the tidal current direction, calculated as above, against time.
- The fifth panel is of the residual current speed against time. The residual has been calculated as north and east components (residual component = observed component – tidal component), which have then been converted into residual speed and direction.
- The sixth panel is of the residual current direction against time, calculated as above.

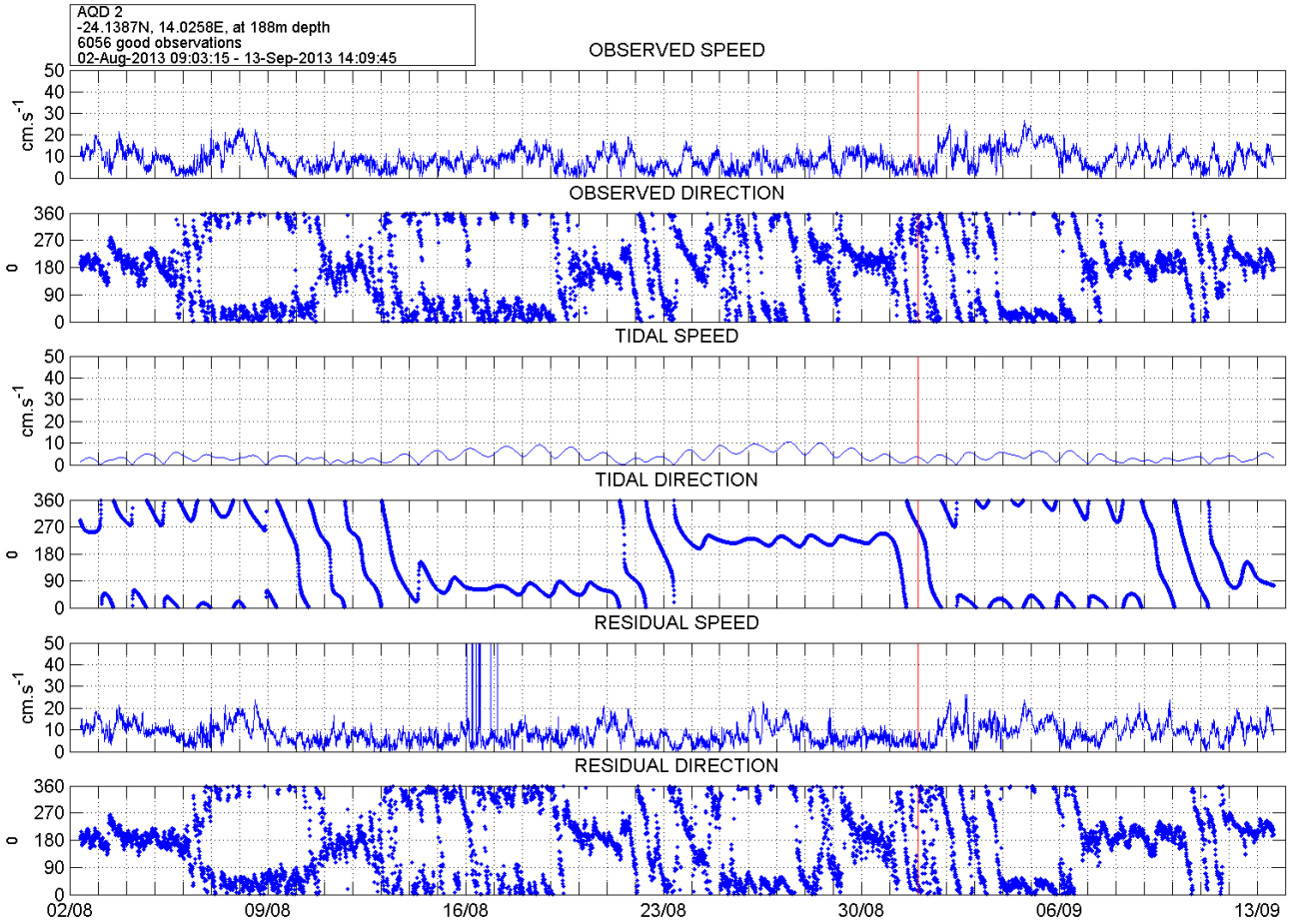


Figure 27: Current time series data for 188 m depth

4.3.1.2 Summary plot

Figure 28 displays a summary plot which consists of:

- The upper panel is a table of the joint distribution of 10 minute averaged current speed against direction. Columns of the table represent direction classes and rows the speed classes. The numbers in the table reflect the percentage of observations that fall within a particular speed interval and direction sector.
- The lower left hand panel is a rose of the 10 minute averaged current direction. This is a histogram of the directional distribution and reflects the percentage of observations that fall within each direction sector.
- The lower right hand panel is a histogram of the 10 minute averaged current speeds. This reflects the percentage of observations that fall within each speed interval. Included on the plot are basic statistics for the current speed distribution.

© NMP 2014

AQD 2
-24.1387N, 14.0258E, at 188m depth
6056 good observations
02-Aug-2013 09:03:15 - 13-Sep-2013 14:09:45

JOINT DISTRIBUTION OF SPEED AND DIRECTION

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Σ
0-5	1.72	1.62	1.40	1.54	1.42	1.34	1.37	1.42	1.57	1.52	1.49	1.29	1.30	1.25	1.22	1.21	22.67
5-10	3.27	3.52	3.63	2.34	1.44	1.21	2.23	3.34	4.05	4.18	3.22	2.15	1.47	1.16	1.30	1.78	40.27
10-15	2.16	3.76	2.05	1.24	0.40	0.23	0.56	1.80	2.96	4.16	3.09	1.47	0.88	0.31	0.63	1.09	26.78
15-20	0.83	2.20	1.49	0.30	0.07	0.03	0.05	0.25	0.40	0.88	0.79	0.35	0.13	0.23	0.30	0.21	8.49
20-25	0.20	0.73	0.36							0.03	0.18	0.15	0.02	0.02		0.05	1.73
25-30		0.05															0.05
30-35																	0.00
35-40																	0.00
40-45																	0.00
45-50																	0.00
Σ	8.17	11.87	8.93	5.42	3.32	2.81	4.21	6.80	8.97	10.77	8.77	5.40	3.80	2.97	3.45	4.34	100.00

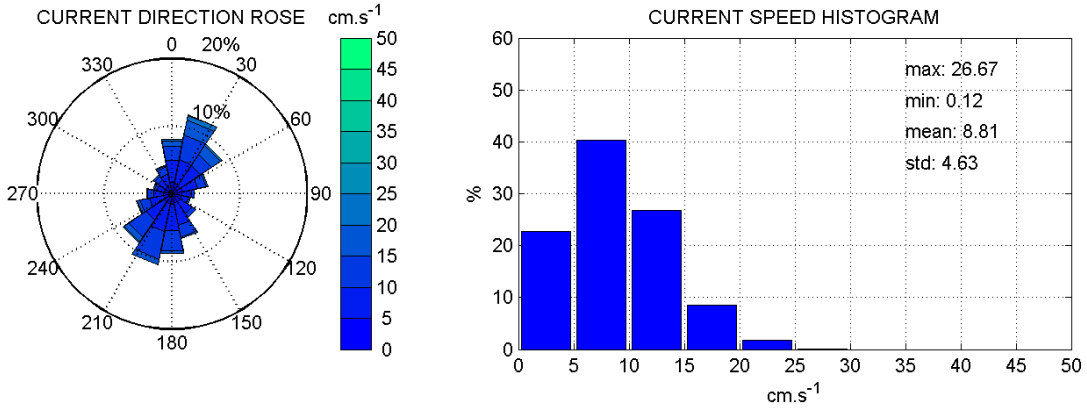


Figure 28: Summary of current data at 188 m depth

4.3.1.3 Progressive vector plot

Figure 29 depicts a progressive vector plot which consists of:

- The solid line represents the displacement that a particle of water would undergo when subject to the currents that were observed.
- The start and end points of the observations are labelled.
- Each day is represented by a red cross.

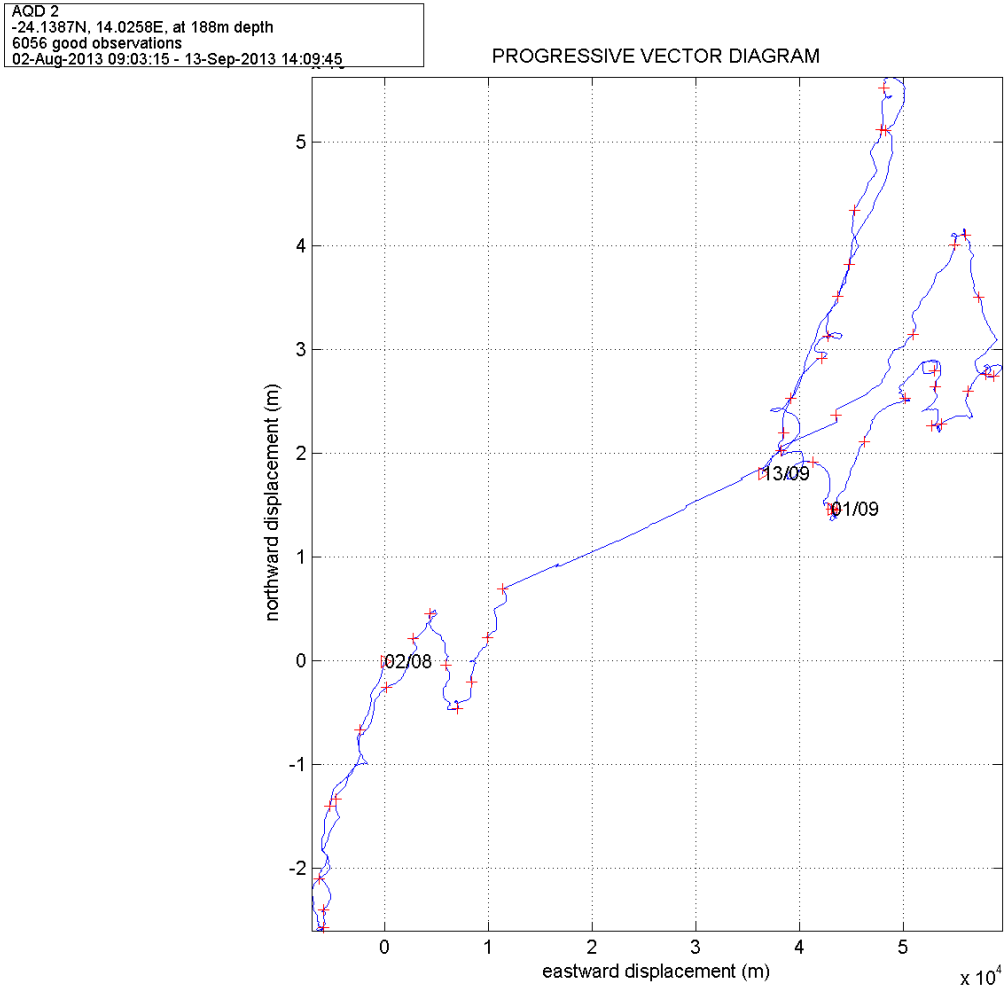


Figure 29: Current progressive vector plot at 188 m depth

4.3.1.4 Tidal harmonic plot

Table 14 presents a current harmonic data which consists of:

- The tidal calculation follows the method of Foreman and uses the observed complex current vector as input *(R. Pawlowicz, B. Beardsley and S. Lentz, "Classical tidal harmonic analysis including error estimates in Matlab using T_TIDE", Computers and Geosciences 28 (2002), 929-937*).
- The major and minor axis amplitudes are given in knots.
- The ellipse orientation and Greenwich phase are given in degrees.

Table 14: Current harmonic data for 188 m depth

AQD 2
-24.1387N, 14.0258E, in 188m depth
6056 good observations
02-Aug-2013 09:03:15 - 13-Sep-2013 14:09:45

HARMONIC COMPONENTS

Component	Major	Minor	Ellipse	Phase
MM	4.35	-1.64	35.94	319.59
MSF	3.84	0.97	49.25	305.48
ALP1	0.59	-0.03	36.35	66.53
2Q1	2.91	1.67	30.94	348.61
Q1	0.82	0.47	159.90	252.89
O1	0.32	0.06	150.67	313.82
NO1	1.04	0.63	81.41	218.90
K1	1.57	0.37	26.45	301.76
J1	0.87	0.36	11.80	346.95
OO1	1.80	0.74	102.22	59.20
UPS1	1.50	-0.24	178.13	304.52
EPS2	1.09	0.60	30.66	131.63
MU2	0.21	-0.13	108.77	5.27
N2	0.47	0.39	144.51	65.86
M2	1.19	0.72	43.22	303.47
L2	0.83	0.52	45.65	190.67
S2	0.56	0.49	59.63	306.84
ETA2	0.85	0.51	49.55	343.70
MO3	0.47	-0.39	173.10	324.50
M3	0.44	0.01	42.05	290.00
MK3	0.62	0.13	170.33	329.19
SK3	1.17	0.39	22.10	17.45
MN4	0.59	0.16	34.28	255.70
M4	0.64	-0.05	21.27	280.32
SN4	0.73	0.18	34.84	136.95
MS4	0.63	0.26	17.11	134.02
S4	0.59	-0.04	32.58	359.33
2MK5	1.55	-0.09	23.85	189.53
2SK5	1.48	-0.10	18.50	302.61
2MN6	0.57	-0.02	13.67	126.57
M6	0.68	-0.02	23.70	139.50
2MS6	0.64	0.09	32.54	356.75
2SM6	0.60	0.02	8.36	195.87
3MK7	0.40	0.04	22.11	38.83
M8	0.58	-0.02	22.99	336.52

© NMP 2014

4.3.2 Pressure and water temperature data

4.3.2.1 Time series plot

Figure 30 depicts a time series plot of pressure (water level) and water temperature variations as a function of time over the recording period.

- The first (upper) panel is of the observed 10 minute water level against time.
- The second panel is of the observed 10 minute water temperature against time.

© NMP 2014

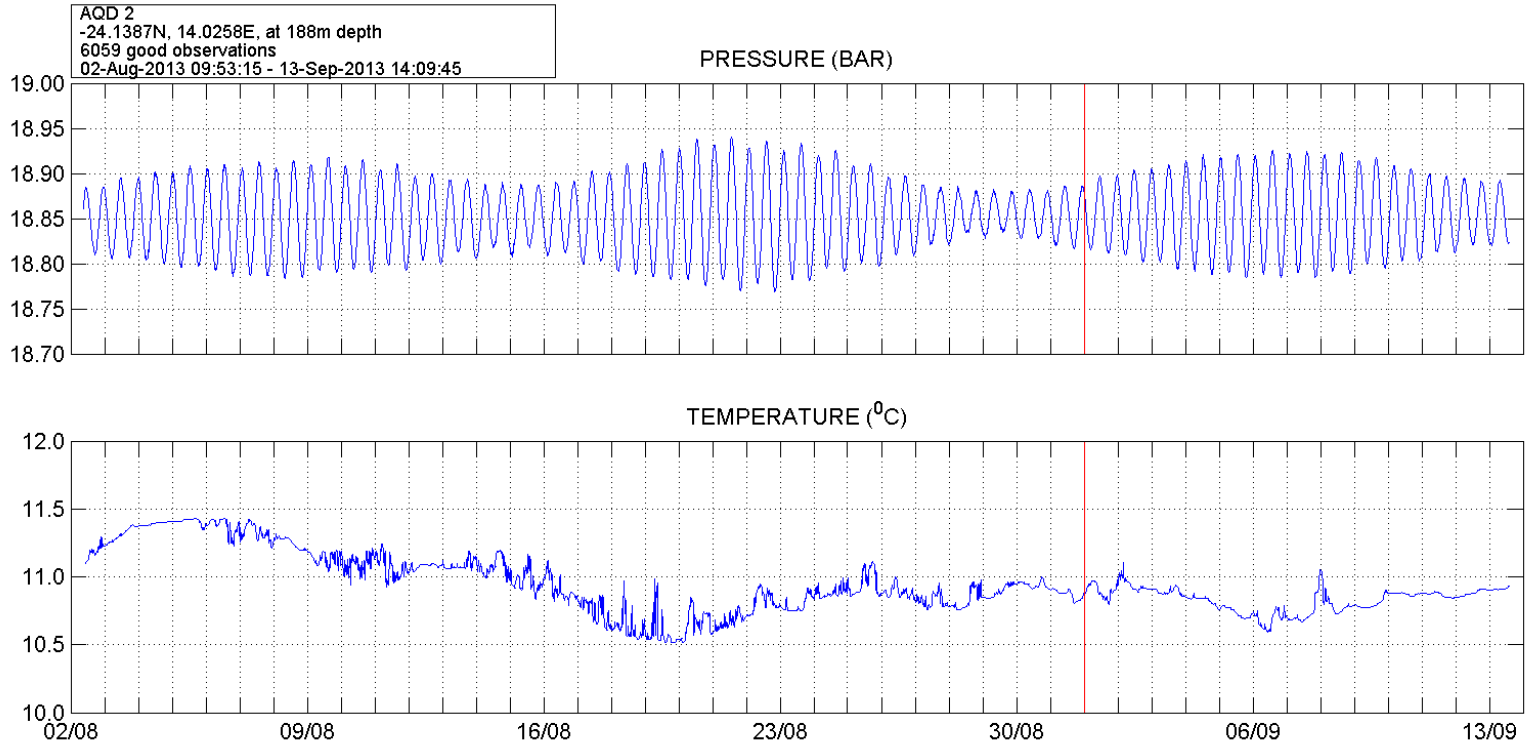


Figure 30: Pressure (water level) and temperature at 188 m depth

4.4 CTD

4.4.1 Water quality data

4.4.1.1 Time series plot

Figure 31 depicts a time series plot, which consists of:

- The first (upper) panel is of the observed water temperature against time.
- The second panel is of the derived salinity against time.
- The third panel is of the observed depth against time.
- The forth panel is of the observed fluorescence against time.
- The fifth panel is of the observed turbidity against time.

© NMP 2014

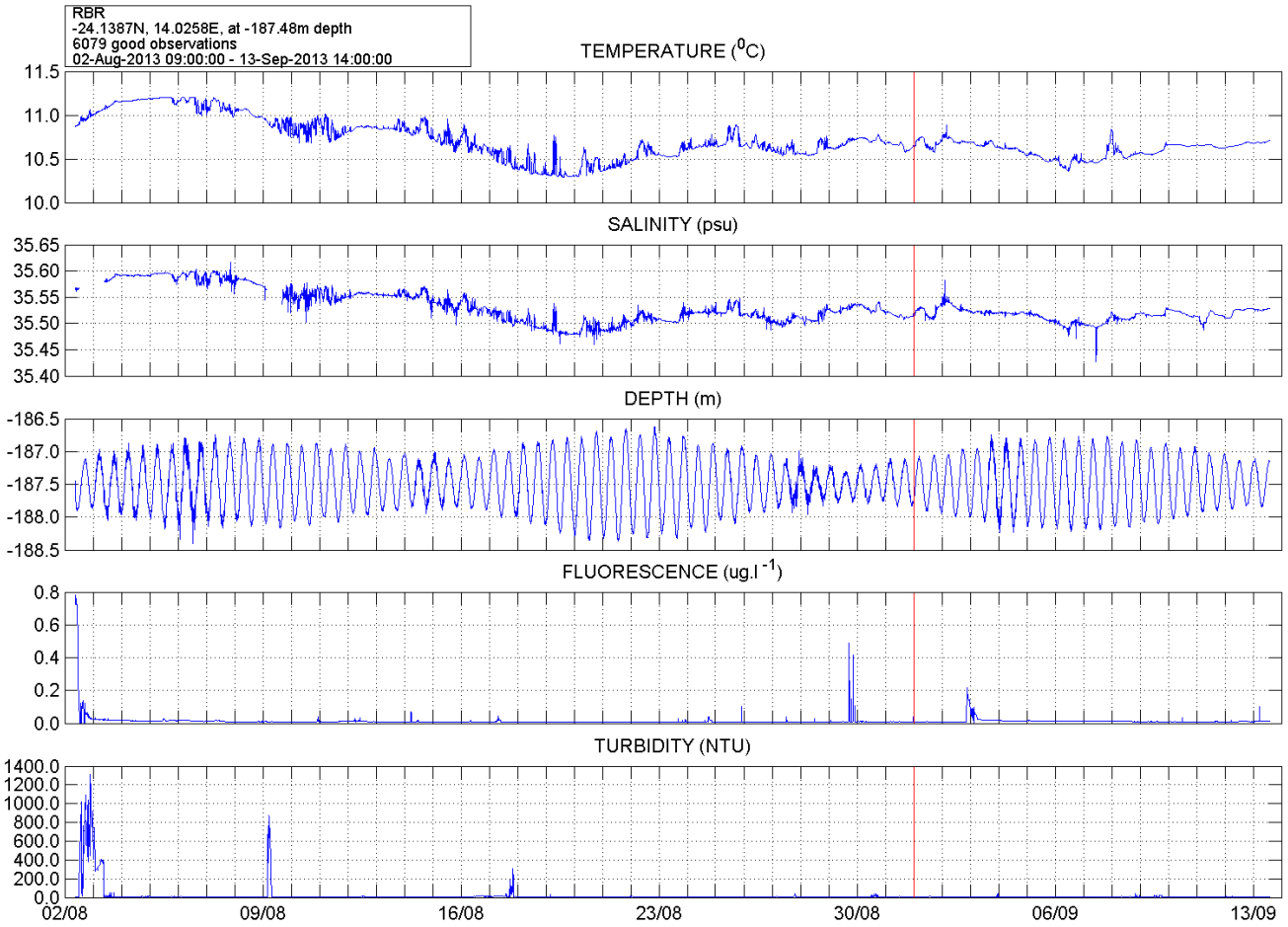


Figure 31: Water quality data for 187.48 m depth

© NMP 2014

4.4.1.2 Summary plot

Figure 32 depicts a summary plot, which consists of:

- The upper left hand panel is a histogram of the water temperature. This reflects the percentage of observations that fall within each temperature interval. Included on the plot are basic statistics for the distribution.
- The upper middle panel is a histogram of the water salinity. This reflects the percentage of observations that fall within each salinity interval. Included on the plot are basic statistics for the distribution.
- The upper right hand panel is a histogram of the water depth. This reflects the percentage of observations that fall within each depth interval. Included on the plot are basic statistics for the distribution.
- The lower middle panel is a histogram of the fluorescence. This reflects the percentage of observations that fall within each density interval. Included on the plot are basic statistics for the distribution.
- The lower right hand panel is a histogram of the turbidity. This reflects the percentage of observations that fall within each turbidity interval. Included on the plot are basic statistics for the distribution.

© NMP 2014

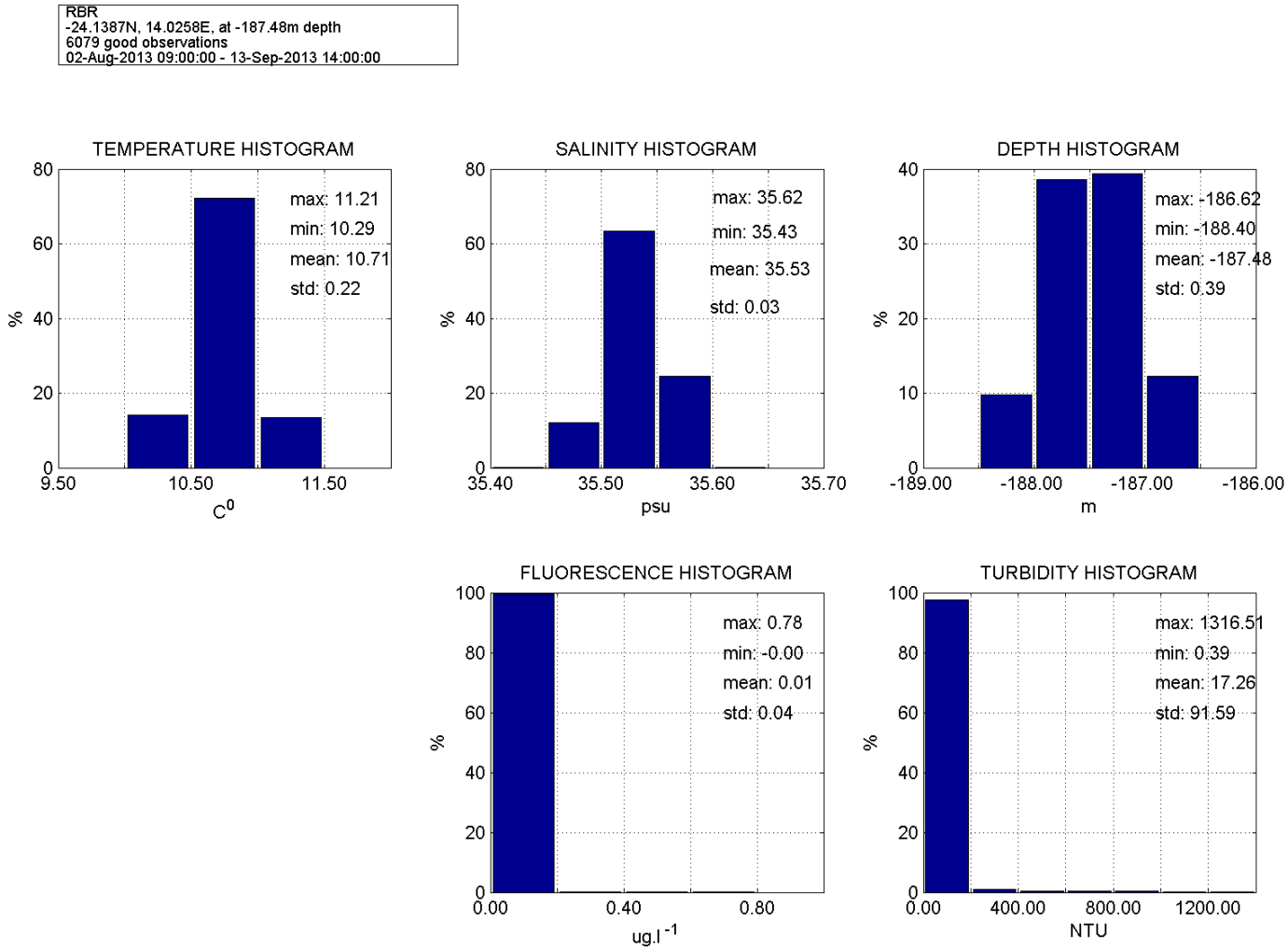


Figure 32: Summary data for environmental parameters at 187.48 m depth

© NMP 2014

4.4.2 Tide data

4.4.2.1 Time series plot

Figure 33 depicts a time series plot of the tidal height. The time series plot consists of:

- The first (upper) panel is of the observed height against time.
- The second panel is of the tidal height, calculated from the observed height, against time. The tidal calculation follows the method of Foreman and uses the observed height as input (*R. Pawlowicz, B. Beardsley, and S. Lentz, "Classical tidal harmonic analysis including error estimates in MATLAB using T_TIDE", Computers and Geosciences 28 (2002), 929-937*)
- The third panel is of the residual height against time. The residual has been calculated as the observed height minus the tidal height.

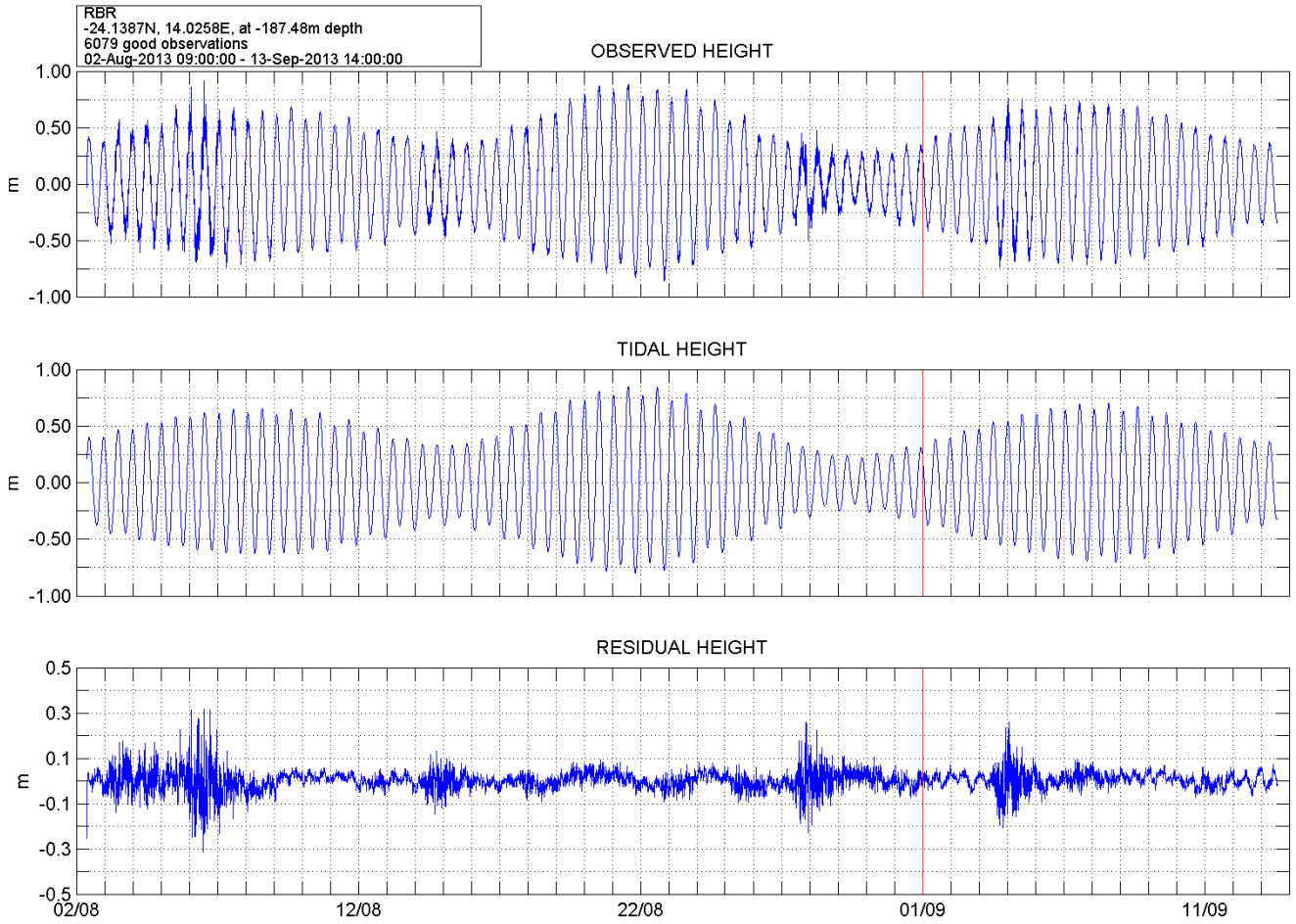


Figure 33: Time series of tidal height at 187.48 m depth

4.4.2.2 Tidal harmonics table

Table 15 displays the tidal harmonics resulting from the analysis. The tidal calculation follows the method of Foreman and uses the observed complex current vector as input (*R. Pawlowicz, B. Beardsley, and S. Lentz, "Classical tidal harmonic analysis including error estimates in MATLAB using T_TIDE", Computers and Geosciences 28 (2002), 929-937*).

Table 15: Tidal harmonic data at 187.48 m depth

RBR
-24.1387N, 14.0258E, in -187.48m depth
6079 good observations
02-Aug-2013 09:00:00 - 13-Sep-2013 14:00:00

HARMONIC COMPONENTS

Component	Amplitude (m)	Phase (deg)
MM	0.014	93.194
MSF	0.010	46.972
ALP1	0.002	104.851
2Q1	0.003	79.356
Q1	0.010	184.144
O1	0.014	198.044
NO1	0.003	57.382
K1	0.039	75.061
J1	0.003	105.814
OO1	0.005	99.532
UPS1	0.003	99.910
EPS2	0.004	15.755
MU2	0.022	52.981
N2	0.101	16.563
M2	0.479	38.398
L2	0.013	61.329
S2	0.198	57.690
ETA2	0.002	346.943
MO3	0.002	86.385
M3	0.007	290.554
MK3	0.003	335.692
SK3	0.004	229.034
MN4	0.003	94.496
M4	0.009	120.102
SN4	0.002	196.553
MS4	0.004	207.228
S4	0.003	58.615
2MK5	0.003	145.274
2SK5	0.006	355.997
2MN6	0.001	267.704
M6	0.005	324.281
2MS6	0.005	32.882
2SM6	0.001	215.995
3MK7	0.001	239.196
M8	0.001	142.209

© NMP 2014

4.4.2.3 Tidal harmonics plot

Figure 34 depicts a graphical representation of the harmonic components presented in the previous table.

- Components with periods between 0 to 10 hours are displayed in the top panel, while the left and right bottom panels display components with periods of 10 to 14 hours and greater than 14 hours respectively.
- Amplitudes for each component are indicated by the bar graph, while the phase of each component is indicated by the pie chart above each amplitude bar.
- The period associated with each component is indicated below the amplitude bar.

© NMP 2014

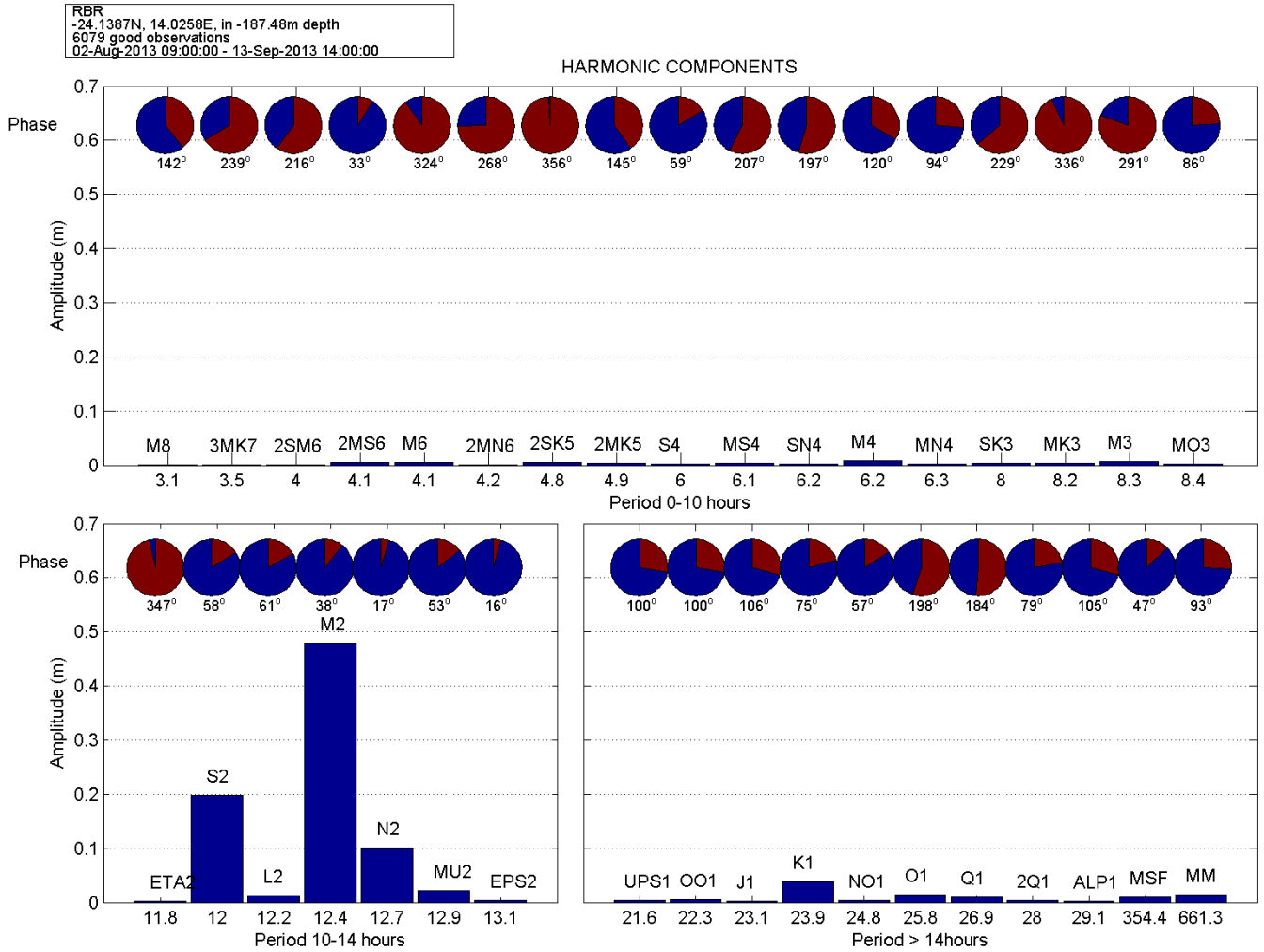


Figure 34: Tidal harmonic components in 187.48 m depth

5 DISCUSSION

Metocean Services International (Pty) Limited (MSI) has been awarded a contract by Lwandle Technologies, under sub-contract from Namibian Marine Phosphate (Pty) Ltd (NMP), to deploy an oceanographic mooring offshore Namibia. NMP intends dredging marine phosphate reserves at the site and requires verification of previous studies regarding the behaviour of the water column and sediment re-suspension events. Current measurements throughout the water column were undertaken with an ADCP and two single point current meters and water quality measurements were undertaken with a CTD near the seabed. Data collected during the second and final measurement period (nominally from 2 August 2013 to 13 September 2013) are presented in this report. Data return was good with all instruments returning complete datasets, however no dissolved oxygen data was recorded by the CTD. This may have been the result of a failure of the oxygen sensor.

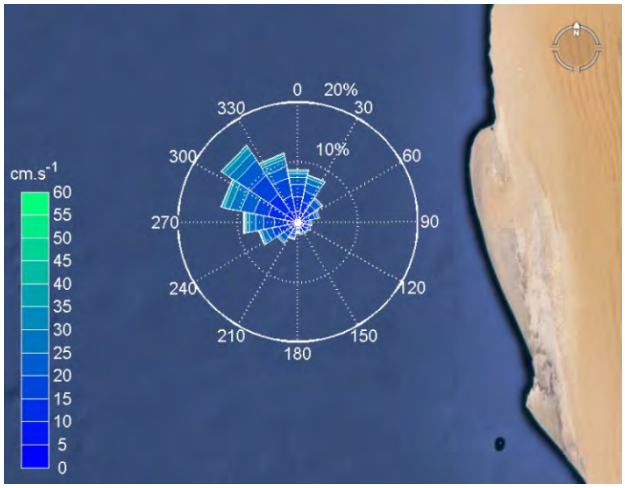
Current speeds at the measurement location were low, with maximum current speeds exceeding 50 $cm.s^{-1}$ above approximately 15 m depth only. Near the seabed, a maximum current speed of 26.67 $cm.s^{-1}$ was recorded. Mean current speeds showed a general decrease with depth from a mean current speed of 17 $cm.s^{-1}$ at a depth of 9 m to mean speeds of approximately 9$cm.s^{-1}$ in the mid and lower water column. Current flow was primarily towards the WNW to NNW sectors in the upper water column. At a depth of 142 m, current flow was more strongly aligned to the N to NNE sectors, while near the seabed, current flow became polarised, with flow directions mostly recorded between N to NE and S to SW sectors. An overview of current directions at depths of 9 m, 142 m and 188 m is presented in Figure 35. A high current speed event was noted throughout the water column in early September. The maximum current speeds at most depths were recorded during this period. A contour plot of the northward and eastward current velocity components throughout the water column is included in Figure 36 below.

The water temperature was lower than the previous measurement period, with temperatures ranging between a maximum of 13˚C at a depth of 93 m to a minimum of 10˚C near the seabed. The temperature records show a decrease in temperature ranges from 1.8˚C at 93m depth to 0.9˚C near the seabed. Mean temperatures decreased from 12˚C at 93 m to 11˚C near the seabed. A contour plot of the temperature recorded throughout the water column is included as Figure 37 below.

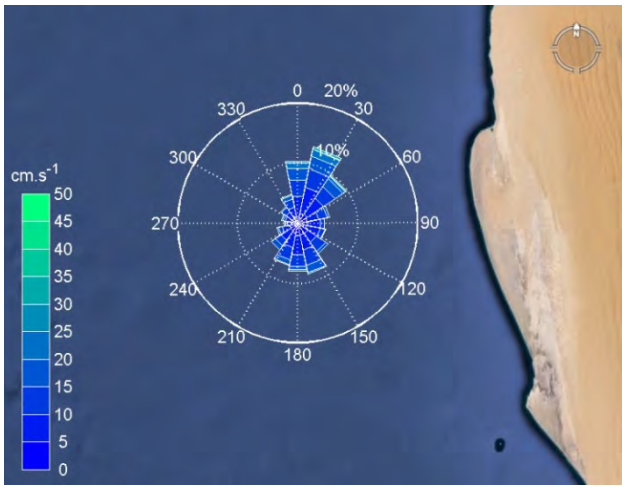
Temperatures showed a general cooling trend at 93 m, with a cooling event occurring near the seabed between 17 and 19 August. This event was visible in both the CTD and AQD data records and is associated with increased current speeds recorded during this period. A maximum fluorescence of 0.78 $\mu g.l^{-1}$ was recorded near the beginning of the measurement period, with fluorescence values exceeding 0.45 $\mu g.l^{-1}$ once more during the data record, while the majority of fluorescence values were recorded between 0 and 0.2 $\mu g.l^{-1}$. The salinity range was small, varying between a maximum of 35.62 psu and a minimum of 35.43 psu with a calculated mean of 35.53 psu. Turbidity was low for much of the measurement period with a mean turbidity of 17.26 NTU, however intermittent increases were noted, with turbidity values exceeding 200 NTU on three occasions. A prolonged period of increased turbidity was noted at the beginning of the measurement period with a maximum value exceeding 1300 NTU. A tidal range of approximately 1.8m was calculated for this location, with the height measured by the CTD ranging between -0.86 m and 0.92 m. The dominant tidal constituents were determined to be M_2, S_2 and N_2 with amplitudes of 0.48 m, 0.20 m and 0.10 m respectively.

© NMP 2014

NEAR SURFACE CURRENTS (-9m)



MID WATER COLUMN CURRENTS (-142m)



NEAR SEABED CURRENTS (-188m)

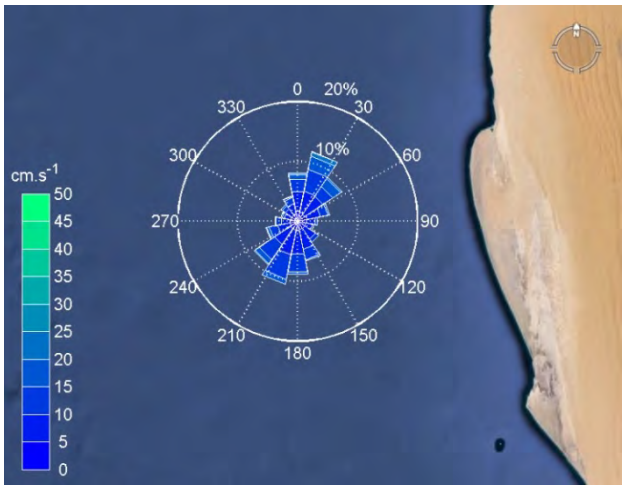


Figure 35: Overview of current directions recorded in the upper, mid and lower water column respectively. Current speeds are indicated by the colour scale.

© NMP 2014

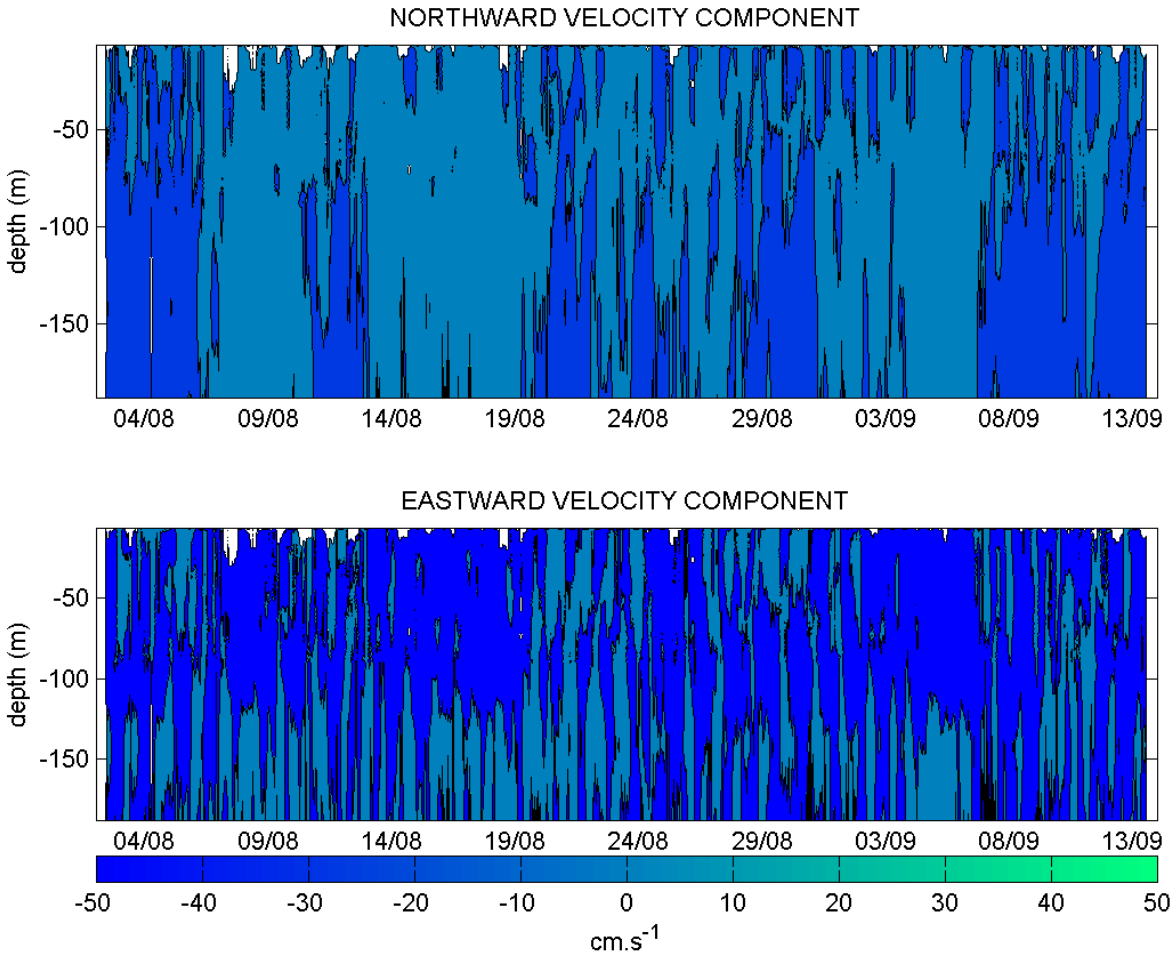


Figure 36: Time series of hourly mean current velocity throughout the water column. The upper panel is the northward velocity component in cm.s^{-1} (negative blue values indicate southward flow and positive green values indicate northward flow) while the eastward component is in the lower panel. White patches indicate missing data.

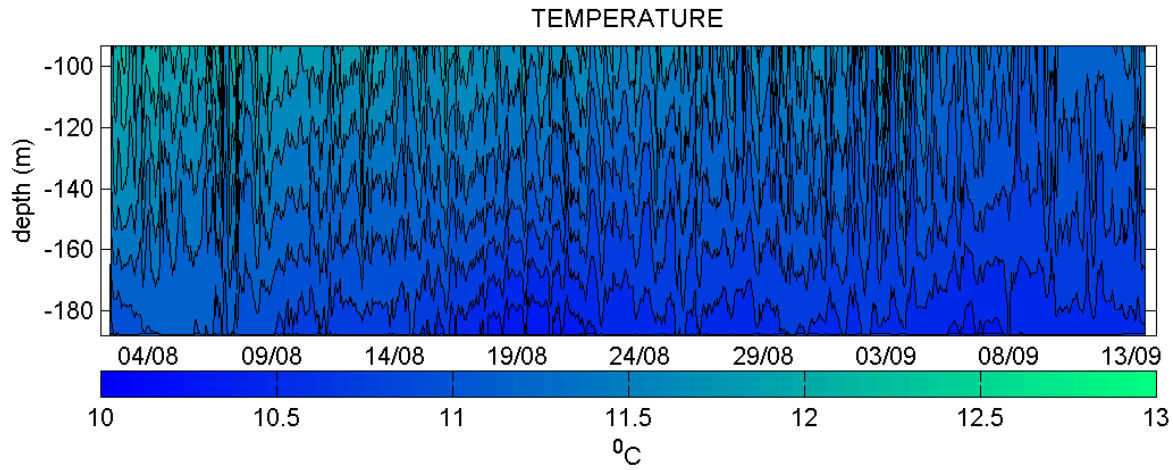


Figure 37: Time series of hourly mean temperature throughout the water column. White patches indicate missing data.

© NMP 2014

APPENDIX 1 - WATER COLUMN AND SEDIMENTARY ENVIRONMENT

1.10 Chemical Analysis Method Statement

METHODOLOGY FOR SEDIMENT ANALYSIS OF NAMIBIAN MARINE PHOSPHATE

VERIFICATION SURVEY

Prepared for:
Namibian Marine Phosphate (Pty) Ltd.

Prepared by:
CSIR
Report compiled by Sebastian Brown



June 2014

SANAS Accredited laboratory analyses:
CSIR Stellenbosch Analytical Laboratory T0093

Tel: +27 21 888-2436
Fax: +27 21 888-2693
Email: sbrown@csir.co.za

Document number:
I:\CAS\Stellenbosch Analytical Laboratory\Reports\Namibian Marine Phosphate\SALM CM 1.0

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed “Attention: Administration Manager,” at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

contents

1 INTRODUCTION 1

1.1 BACKGROUND 1
1.2 OBJECTIVES 1

2 ANALYTICAL METHODS SUMMARY 1

2.1 METHOD STEPS FOR SUB-SURFACE CORE SEDIMENTS 1
2.2 METHOD STEPS FOR SURFICIAL GRAB SEDIMENTS 2
2.3 SCHEMATIC FLOW DIAGRAM OF SUB-SURFACE CORES METHOD PROTOCOL 3
2.4 SCHEMATIC FLOW DIAGRAM OF SURFICIAL GRAB SEDIMENTS 4

3 SAMPLE PRE-PREPARATION FOR SUB-SURFACE CORES 5

3.1 EQUIPMENT 5
3.2 PROCEDURE 5

4 OXIDATION REDUCTION POTENTIAL FOR SUB-SURFACE CORES 8

4.1 EQUIPMENT & CHEMICALS 8
4.2 PROCEDURE 8

5 ACID VOLATILE SULPHIDE AND SIMULTANEOUSLY EXTRACTED METALS FOR SUB-SURFACE CORES AND SURFICIAL GRAB SEDIMENTS 8

5.1 EQUIPMENT & CHEMICALS 8
5.2 PROCEDURE 9

6 INTERSTITIAL WATER-SOLUBLE NUTRIENTS FOR SUB-SURFACE CORES 10

6.1 EQUIPMENT & CHEMICALS 10
6.2 PROCEDURE 10

7 %MOISTURE AND ORGANIC MATTER DETERMINATION FOR SUB-SURFACE CORES AND SURFICIAL SEDIMENTS 10

7.1 EQUIPMENT 10
7.2 PROCEDURE 11

8 %TOTAL ORGANIC CARBON AND NITROGEN DETERMINATION FOR SUB-SURFACE CORES AND SURFICIAL SEDIMENTS 12

8.1 EQUIPMENT & CHEMICALS 12
8.2 PROCEDURE 12

9 TOTAL HEAVY METAL DETERMINATION FOR SUB-SURFACE CORES AND SURFICIAL SEDIMENTS 13

9.1 EQUIPMENT & CHEMICALS 13
9.2 PROCEDURE 13

10 PARTICLE SIZE ANALYSIS BY LASER DIFFRACTION AND WET SIEVING FOR SUB-SURFACE CORES AND SURFICIAL SEDIMENTS 14

© NMP 2014

10.1 EQUIPMENT 14
10.2 PROCEDURE 14

11 SEAWATER ELUTRIATION TESTING 15

11.1 EQUIPMENT & CHEMICALS 15
11.2 PROCEDURE 15

12 LABORATORY ACCREDITATION 16

13 REFERENCES 19

1 INTRODUCTION

1.1 BACKGROUND

Namibian Marine Phosphate (NMP) is developing the world's first marine phosphate project which will establish Namibia as a premier rock phosphate producer in the global market. There is potential to establish future downstream processing of NMP's beneficiated phosphate into higher value phosphorus and compound fertilisers. Local production of phosphate will help to secure agricultural productivity and food security in Namibia and the region, as well as elsewhere in the world. The project will contribute to national and regional growth through employment, royalties and tax revenues. Direct permanent employment will be created, as well as indirect jobs in supporting services. These will include short-term employment during construction and the opportunity for capacity development and training.

NMP has commissioned a detailed Environmental Impact Assessment (EIA) Report to establish the degree to which its operations may affect the environment and in particular the marine environment. The EIA consists of three phases: Scoping, Specialist Studies and Assessment of Impacts. The primary environmental impacts which the EIA is examining include the following:

- Potential loss of marine habitat
- Potential effects on the marine benthic fauna
- Potential impact on marine food chain functionality
- Potential creation of new habitat colonised by as yet unknown fauna

1.2 OBJECTIVES

Lwandle Technologies (Pty) Ltd was commissioned to undertake a Verification Survey of the sediment properties and water column features of the proposed mining area. Lwandle in turn sub-contracted the CSIR CAS Analytical Laboratory in Stellenbosch to conduct all the chemical analyses for surficial grab sediments and sub-surface core sediments.

The document is a compilation of all analytical methods employed by the CSIR CAS Analytical Laboratory to provide the sediment quality data required by Lwandle for its verification survey.

2 ANALYTICAL METHODS SUMMARY

2.1 METHOD STEPS FOR SUB-SURFACE CORE SEDIMENTS

- Cut cores into sections: *0-10 cm, A , *20-30 cm, B, *50-60 cm, C, *100-110 cm
- Remove sections* and store in nitrogen-purged Ziploc bags.
- Intermediate sections A, B and C stored in plastic bags.
- The centre of nitrogen-purged sections* is sub-sampled into small Ziploc plastic bags and nitrogen-purged. These samples are for AVS/SEM (acid volatile sulphide/simultaneously extracted metals) analysis.
- A second sub-sample taken from the centre of nitrogen-purged sections* will immediately be used for ORP (Oxidation Reduction Potential) measurement.
- The remainder of section* is split into a specimen jar (%moisture, %loss on ignition, total heavy metals, organic carbon and nitrogen) and a large plastic bag (Particle size analysis).

© NMP 2014

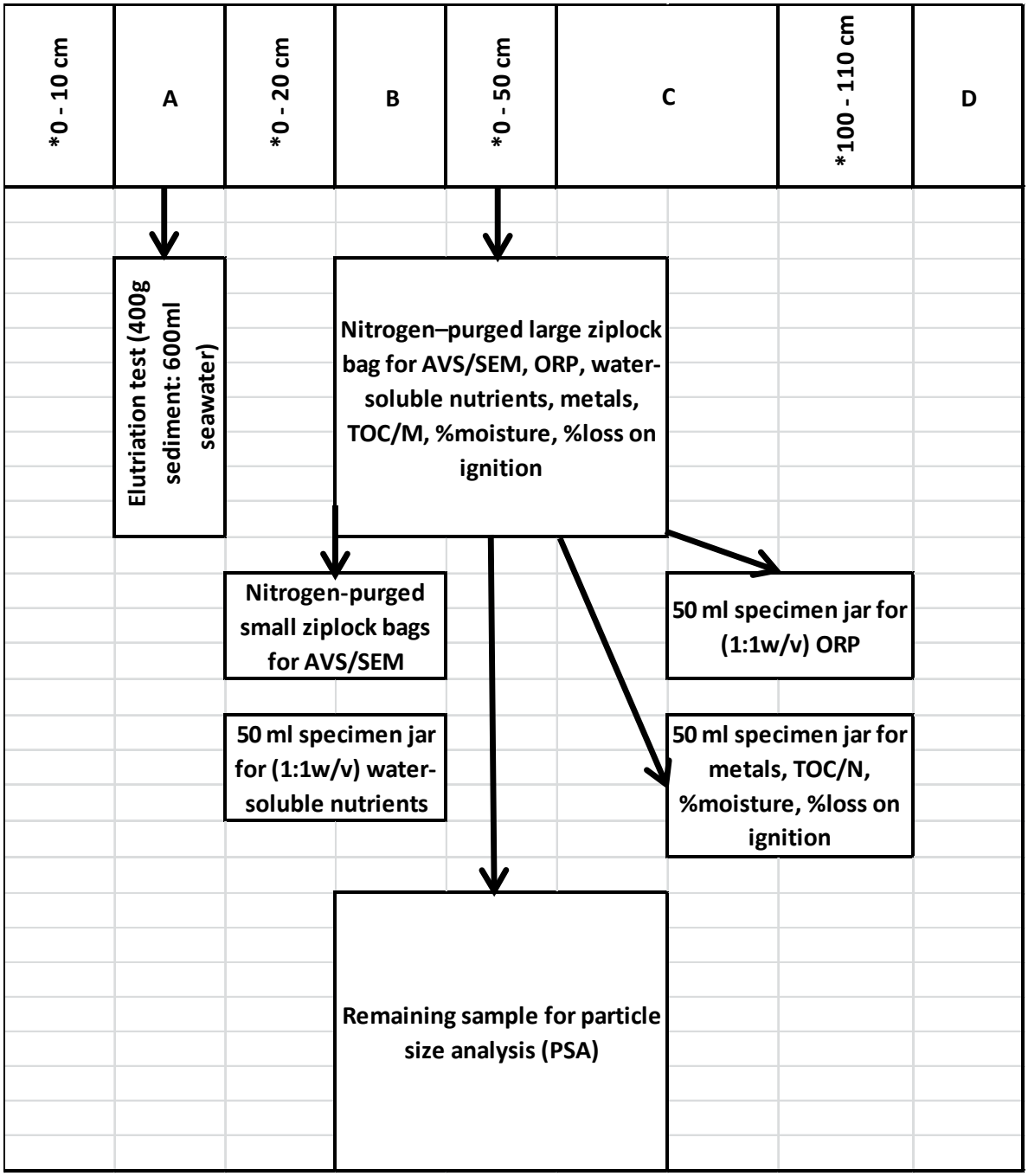
- The specimen jar is pre-weighed, filled with sample, re-weighed, freezedried and re-weighed (%moisture).
- Dried sample is ball-milled.
- A homogenised dried sub-sample is microwave digested and analysed by ICP OES and ICP MS (total heavy metals, total phosphorus and total sulphur).
- A second homogenised dried sub-sample is weighed into a pre-weighed foil dish, ignited at 450°C and re-weighed (%loss on ignition).
- A third homogenised sub-sample is acidified, washed with Milli-Q doubly de-ionised water, oven-dried and analysed by Vario Elementar for total organic carbon/ nitrogen.
- An AVS/SEM sub-sample is extracted with HCl, titrated for AVS and residual acid extract analysed by ICP OES for SEM.
- A second AVS/SEM sub-sample is water-extracted (1:1 w/v) and analysed by FIA (Flow injection analyser for nutrients (nitrate, ammonia, phosphate)
- Sections A and B are used for metal elutriation with filtered seawater (400:600 w/v) and analysed by ICP MS for dissolved heavy metals.
- Sections C and D are stored.

2.2 METHOD STEPS FOR SURFICIAL GRAB SEDIMENTS

- Surficial grab sediment samples are received frozen in 375 mℓ glass jars and plastic Ziploc bags.
- Samples contained in the Ziploc bags were used for particle size analysis.
- First sub-sample is taken from the glass jar for %moisture, %loss on ignition, total heavy metals, organic carbon and nitrogen analyses.
- The specimen jar is pre-weighed, filled with sample, re-weighed, freezedried and re-weighed (%moisture).
- Dried sample is ball-milled. A homogenised dried sub-sample is microwave digested and analysed by ICP OES and ICP MS for total heavy metals, total phosphorus and total sulphur).
- A second homogenised dried sub-sample is weighed into a pre-weighed foil dish, ignited at 450°C and re-weighed (%loss on ignition).
- A third homogenised sub-sample is acidified, washed with Milli-Q doubly de-ionised water, oven-dried and analysed by Vario Elementar for total organic carbon/ nitrogen.
- The second sub-sample is taken from the inner core of the glass jar under anoxic conditions created by nitrogen purging for acid volatile sulphide/simultaneously extracted metals analyses.
- An AVS/SEM sub-sample is extracted with HCl, titrated for AVS and residual acid extract analysed by ICP OES for SEM.
- The remaining samples in the glass jars and Ziploc bags are kept frozen.

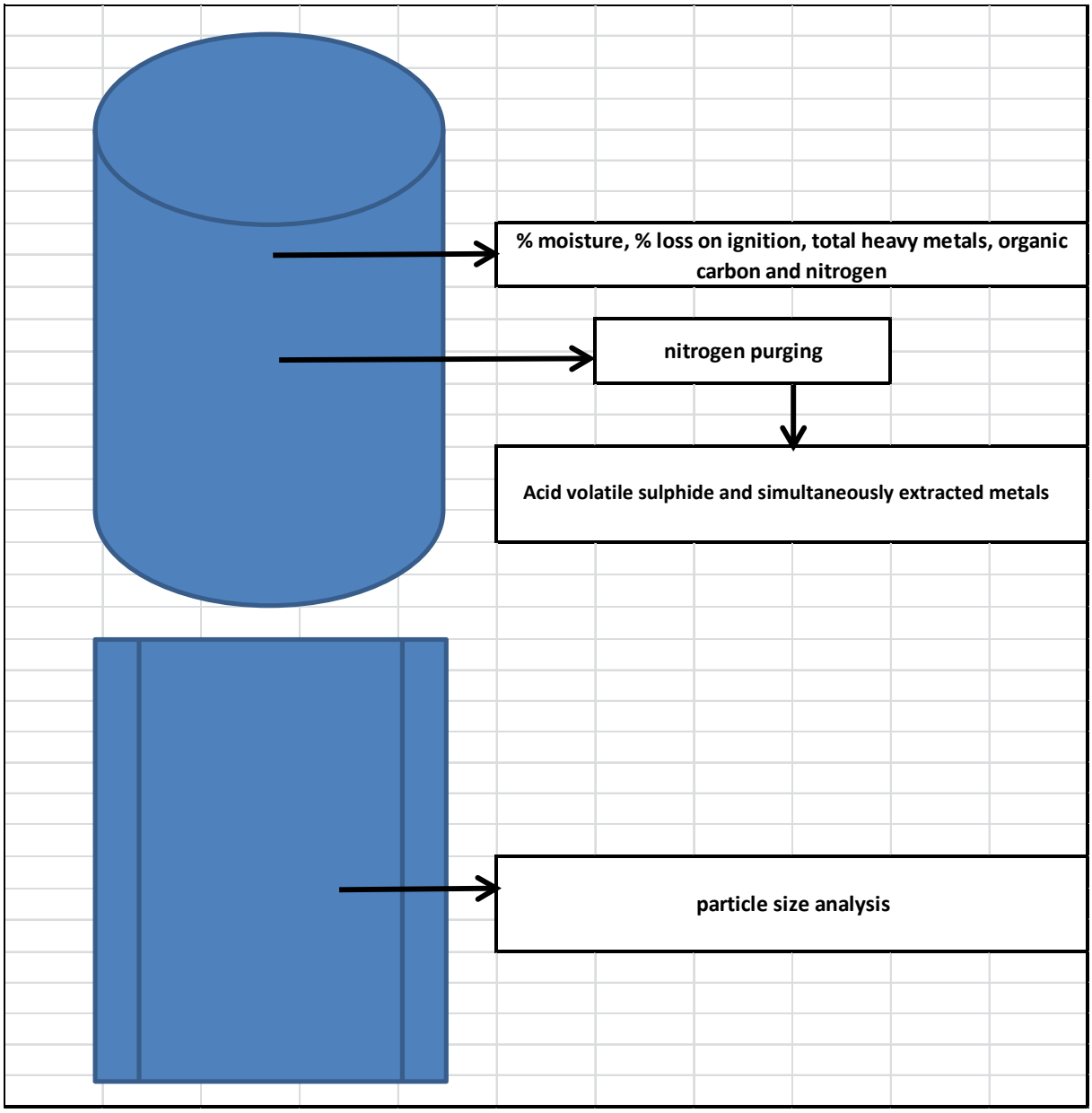
© NMP 2014

2.3 SCHEMATIC FLOW DIAGRAM OF SUB-SURFACE CORES METHOD PROTOCOL



© NMP 2014

2.4 SCHEMATIC FLOW DIAGRAM OF SURFICIAL GRAB SEDIMENTS



© NMP 2014

3 SAMPLE PRE-PREPARATION FOR SUB-SURFACE CORES

3.1 EQUIPMENT

- Freezers
- Pre-measured and marked workbench
- Camera
- Angle Grinder
- Protective gear (heavy-duty gloves, goggles, visors, heavy-duty overalls and safety boots)
- Nitrogen cylinder
- Large Ziploc plastic bags
- Small Ziploc plastic bags
- Pre-calibrated ORP meter
- 50 mℓ plastic specimen jars
- Calibrated and Verified top-loader 2 decimal place balance
- Freezedrier
- Ball-mill

3.2 PROCEDURE

- The frozen PVC core is removed from the freezer and placed onto a plastic covered pre-marked workbench with the caps at each end removed to record the sample identity (id).
- A picture of the core is taken.



© NMP 2014

- An angle grinder is carefully used to cut the outer cover.



- The outer cover is carefully removed to expose the frozen sediment core.



© NMP 2014

- The frozen sediment core is then cut into Sections (*0-10 cm, A , *20-30 cm, B, *50-60 cm, C, *100-110 cm, D) dependent on the length of the sample core.



- Sections (*0-10 cm, *20-30 cm, *50-60 cm, *100-110 cm) are immediately placed into nitrogen-purged Ziploc plastic bags ad allowed to defrost.
- Sections (A, B, C, D) are placed in a separate Ziploc plastic bag.
- The centre of the sections (*0-10 cm, *20-30 cm, *50-60 cm, *100-110 cm) are swiftly removed under a nitrogen-filled atmosphere to ensure that the sub-sample is not exposed to atmospheric oxygen.
- The centre sub-sample is placed in a nitrogen-purged small Ziploc bag for analysis of acid volatile sulphide and simultaneously extracted metals (AVS/SEM).
- A second sub-sample of 20 mℓ volume taken from the centre of this section is placed in a nitrogen-purged 50 mℓ plastic specimen jar and immediately measured for oxidation reduction potential (ORP) with the addition of 20 mℓ double – deionised Milli Q water after a single inversion of the sealed specimen jar.
- From the remaining sections (*0-10 cm, *20-30 cm, *50-60 cm, *100-110 cm) a 50 mℓ pre-weighed specimen jar is filled with sediment, freezedried, re-weighed and homogenised by ball-milling with zirconium balls. This homogenised sample will be analysed for %moisture, %organic matter/ loss on ignition, total heavy metals and total organic carbon and nitrogen.
- The remainder of the sample in the large plastic Ziploc bag is kept for particle size analysis.
- Sections A and B are combined for seawater elutriation testing.

© NMP 2014

4 OXIDATION REDUCTION POTENTIAL FOR SUB-SURFACE CORES

4.1 EQUIPMENT & CHEMICALS

- Eutech Instruments pH700 mV Bench Meter
- Doubly de-ionised Milli Q water
- ORP Pretreatment 475 solution
- ORP Quinhydrone 263 standard solution
- ORP Quinhydrone 86 standard solution

4.2 PROCEDURE

- The ORP meter is pre-treated as per instrument manual with pre-treatment solution and allowed to stabilise for 30 minutes.
- The ORP meter is calibrated with the above standards as per instrument manual.
- The electrode is thoroughly rinsed with Milli Q water before the quality control (QC) solution is measured.
- If the QC measurement is within specifications the electrode is rinsed with doubly de-ionised Milli Q water and the ORP measurements of the samples commence.
- The electrode is rinsed between each sample measurement and the QC solution is measured after every 12 samples to ensure instrument and electrode response and accuracy.

5 ACID VOLATILE SULPHIDE AND SIMULTANEOUSLY EXTRACTED METALS FOR SUB-SURFACE CORES AND SURFICIAL GRAB SEDIMENTS

5.1 EQUIPMENT & CHEMICALS

- AVS extraction apparatus
- Nitrogen cylinder
- Plastic weighing boats
- Pre-verified calibrated two decimal place toploader balance
- Doubly de-ionised Milli Q water
- 6M Hydrochloric Acid
- 20 g/l Zinc Acetate
- 100 mℓ measuring cylinder
- 250 mℓ Erlenmeyer Flasks
- Standard Iodine solution, 0.025N
- Standard Sodium Thiosulfate solution, 0.025N
- Starch Indicator Solution
- 50 mℓ A grade Burette
- 10 mℓ A grade Pipette
- 200 mℓ A grade Volumetric flask
- Thermo ICap Inductively Coupled Plasma Optical Emission Spectrometer

© NMP 2014



5.2 PROCEDURE

- Purge the AVS system with nitrogen for 30 minutes with a flowrate of 1l/min to ensure all atmospheric oxygen is removed.
- From the centre of the frozen AVS/SEM small sample Ziploc plastic bag snap off pieces of sediment and transfer to a tared weighing boat on the balance.
- Accurately weigh out between 20 – 25 g of frozen sediment and record mass on worksheet.
- Swiftly transfer the sample into the AVS reactor vessel. Ensure the sample is quantitatively transferred to the vessel by spraying the sample with Milli Q water through a squeeze bottle from the weighing boat and removing all residual sample.
- Add 50 mℓ of doubly de-ionised Milli Q water, close the reactor vessel and allow nitrogen purge for 3 minutes with a flowrate of 1ℓ/min.
- From the acid reservoir connected to the top of the reactor dispense 30 mℓ of 6M HCl while continuously purging with nitrogen.
- Slowly start the magnetic stirrer to allow the stirrer bar inside the reactor to agitate the sediment/water/acid mixture.
- After extraction for 2 hrs, the Fritz bubblers are carefully removed from the zinc acetate reservoirs and rinsed with doubly de-ionised Milli Q water.
- The zinc acetate/ zinc sulphide mixture is combined and quantitatively transferred to a 100 mℓ measuring cylinder. The mixture is made up to 100 mℓ with Milli Q water and transferred to a 250 mℓ Erlenmeyer flask.
- 10 mℓ of standard iodine 0.025N is pipetted into the zinc acetate/ zinc sulphide mixture in the Erlenmeyer flask and mixed.
- The excess iodine which has not reacted to the available sulphide is back titrated with standard sodium thiosulphate 0.025N with 0.5 mℓ soluble starch solution added as indicator just before the blue endpoint is reached.
- $mgS^{2-}/L = \{[(m\ell\ I_2 \times I_2\ Normality) – (m\ell\ Na_2S_2O_3 \times Na_2S_2O_3\ Normality)] \times 16000\} / m\ell\ sample$
- $mgS^{2-}/kg = (mgS^{2-}/L \times g\ original\ sample\ mass) / 100\ m\ell$
- The acid extractant remaining in the reactor is quantitatively removed and transferred to 200 mℓ volumetric flask.

© NMP 2014

- The volumetric flask is made up to the mark with Milli Q water and the extract is analysed by inductively coupled plasma optical emission spectrometry (ICP OES) for the simultaneously extracted metals (SEM) Al, As, Cd, Cr, Cu, Fe, Pb, Mn, Ni, V, Zn.

6 INTERSTITIAL WATER-SOLUBLE NUTRIENTS FOR SUB-SURFACE CORES

6.1 EQUIPMENT & CHEMICALS

- 50 mℓ plastic specimen jar
- Doubly de-ionised Milli Q water
- 20 mℓ A grade Pipette
- Horizontal shaker
- 20 mℓ syringe
- 0.45 µm hydrophilic syringe filter
- Lachat flow injection analyser

6.2 PROCEDURE

- From the centre of the frozen AVS/SEM small sample Ziploc plastic bag snap off fragments of sediment and transfer into a tarred 50 mℓ plastic specimen jar containing 20 mℓ of Milli Q water.
- Weigh 30 g of frozen sediment sample into the specimen jar and seal tightly with screw cap lid.
- Vigorously shake the jar on a horizontal shaker for 30 minutes.
- Allow particulate fraction to settle for 1 – 2 minutes.
- Remove the supernatant aqueous phase with a 20 mℓ syringe.
- Fit the 0.45 µm filter to the syringe and filter the dissolved fraction into the pre-labelled flow injection analyser (FIA) sample cups.
- Soluble nitrate, ortho-phosphate and ammonia are colorimetrically analysed by accredited validated internal FIA Methods (SALM6.0 & SALM7.0).

7 %MOISTURE AND ORGANIC MATTER DETERMINATION FOR SUB-SURFACE CORES AND SURFICIAL SEDIMENTS

7.1 EQUIPMENT

- 50 mℓ specimen jar
- Calibrated and verified top-loader 2 decimal balance
- Defy chest freezer
- Virtis freezedrier
- Retsch PM 400 planetary ball mill
- Aluminium foil dishes
- Calibrated and verified 4 decimal analytical balance
- Naber 2804 furnace
- Desiccator

© NMP 2014

7.2 PROCEDURE

- The empty specimen jar with lid is weighed on the balance.
- Mass of empty jar is recorded on worksheet.
- The wet sediment is transferred into the specimen jar, sealed with the lid and reweighed on the balance.
- Mass of jar and wet sample is recorded on worksheet.
- The jar is transferred into the freezer and frozen overnight.
- The lid is removed and the frozen jar with sample is placed into the freezedrier and dried for up to 3 days depending on the number of samples and anticipated sample moisture to be removed.
- After the dried sample is removed from the freezedrier it is reweighed on the balance.
- Mass of jar and dry sample is recorded on worksheet.
- % moisture = 100 x (g mass of wet sample & jar – g mass of dry sample & jar) / (g mass of wet sample & jar – g mass empty jar)
- The dried sample is removed from the jar and transferred into the planetary mill bowls with zirconium balls.
- The sample is homogenised by milling at 400 rpm for 5 minutes and returned to the specimen jar.
- Weigh an empty aluminium foil dish on an analytical balance.
- Mass of empty dish is recorded on worksheet.
- Add approximately 1 – 3 g of dried sample to the dish and accurately reweigh on the analytical balance.
- Mass of dry sample and dish is recorded on worksheet.
- Transfer the sample and dish into the furnace and heat the furnace to 450°C for 4 hrs.
- Allow the furnace to cool overnight and transfer the sample and dish to a desiccator.
- Weigh the sample ash and dish on the analytical balance.
- Mass of sample ash and dish is recorded on worksheet.
- % organic matter = 100 x (g mass of dry sample & dish – g mass of sample ash & dish) / (g mass of dry sample & dish – g mass empty dish)

© NMP 2014

8 %TOTAL ORGANIC CARBON AND NITROGEN DETERMINATION FOR SUB-SURFACE CORES AND SURFICIAL SEDIMENTS

8.1 EQUIPMENT & CHEMICALS

- 10 mℓ plastic centrifuge tube with screw cap
- 1M hydrochloric acid
- Vortex mixer
- Doubly de-ionised Milli Q water in squeeze bottle
- Centrifuge
- Oven proof centrifuge tube rack
- Laboratory oven
- Round tipped Teflon rod
- Desiccator
- Vario Elementar

8.2 PROCEDURE

- Transfer approximately 2 g of dried homogenised sample into a 10 mℓ centrifuge tube.
- Slowly add drop-wise 2 mℓ of 1M HCl to the sample. Make sure that the initial effervescence does not cause the sample froth to overflow from the tube.
- The acid/sample slurry is then agitated on the vortex mixer for 30 – 60 seconds to ensure that the all inorganic carbon reacts with the HCl to liberate CO_2 gas.
- The slurry is then washed by adding Milli Q water to top of the tube, capped, inverting the tube several times and further mixing on the vortex mixer.
- Place the sample and tube into the centrifuge and spin for 1 minute at 300 rpm.
- Remove the tube from the centrifuge and discard the supernatant aqueous phase.
- Place the tube on an ovenproof rack and in the oven at 100°C for 8 hrs.
- Cool the sample in a desiccator.
- Grind the sample with a round tipped Teflon rod inside the tube.
- The sample is then analysed for total organic carbon by thermocatalytic combustion in the Vario Elementar MALS3.1.
- An unacidified dried homogenised sample is analysed for total nitrogen thermocatalytic combustion in the Vario Elementar MALS3.1.

© NMP 2014

9 TOTAL HEAVY METAL DETERMINATION FOR SUB-SURFACE CORES AND SURFICIAL SEDIMENTS

9.1 EQUIPMENT & CHEMICALS

- Calibrated & verified top-loader 2 decimal place balance
- MARS XP1500dDigestion vessels
- MARS X Microwave digestion system
- Certified reference material PACS-2 Marine Sediment
- Fume cupboard
- 65% GR nitric acid
- 70% GR perchloric acid
- 50% GR hydrogen peroxide
- Doubly de-ionised Milli Q water in squeeze bottle
- Calibrated and verified bottle dispenser
- Calibrated and verified 1 mℓ Socorex Pipetman
- 50 mℓ A grade verified volumetric flasks
- 50 mℓ plastic specimen jars with screw cap lids
- 20 mℓ syringe
- 0.45 µm syringe filters
- Thermo ICap Inductively Couple Plasma Optical Emission Spectrometer
- Agilent 4500Cx Inductively Couple Plasma Mass Spectrometer

9.2 PROCEDURE

- Place a clean digestion vessel on the balance and tare.
- Accurately weigh between 0.25 – 0.5 g of dried homogenised sample into the vessel.
- Record the sample mass on the worksheet.
- The digestion carousel will contain 1 reagent blank, 1 certified reference material, duplicate sediment sample and 8 more single samples.
- Transfer the vessels to a fume cupboard.
- Dispense 5 mℓ of HNO_3 into each vessel.
- Pipette 1 mℓ of $HClO_4$ and H_2O_2 respectively into each vessel.
- Close the vessels and torque with the microwave system wrench n the digestion carousel.
- Insert the carousel into the microwave cavity and connect the pressure and temperature sensors before closing the door.
- Digest the samples as per the pre-defined microwave programme settings adapted from the EPA Method SW 5010, internal method reference MALS4.5.
- After the digestion vessels have cooled to room temperature remove the digestion carousel and place in the fume cupboard.
- Loosen the vessels with the torque wrench and quantitatively decant the digestate into 50 mℓ volumetric flasks.
- Make up to the mark with Milli Q water.
- Transfer the digestate into pre-labelled specimen jars and clean the volumetric flasks.
- Remove 20 mℓ of digestate from the specimen jar using a syringe and place a 0.45 µm filter on the syringe tip.
- Filter the sample into pre-labelled ICP sample cups.

© NMP 2014

- The sample is analysed for pseudo-total heavy metals Al, As, Ba, Cd, Cr, Co, Cu, Fe, Pb, Mn, Ni, V, Zn by the accredited ICP OES Method MALS 6.2A. Mercury is analysed by ICP MS Method SALM20.

10 PARTICLE SIZE ANALYSIS BY LASER DIFFRACTION AND WET SIEVING FOR SUB-SURFACE CORES AND SURFICIAL SEDIMENTS

10.1 EQUIPMENT

- Calibrated and Verified Top loader Balance (max 11 kg)
- Fritsch Pulversette sieve shaker
- Stacked variable mesh size sieves
- Lab oven
- 5 ℓ Erlenmeyer Flask
- Mastersizer 2000 Malvern laser diffraction particle size analyser

10.2 PROCEDURE

- Particle size analyses were sub-contracted to EMS* in Durban.
- The Mastersizer 2000 uses laser diffraction to measure the size of particles. It does this by measuring the intensity of light scattered as a laser beam passes through a dispersed particulate sample. These data are then analyzed to calculate the size of the particles that created the scattering pattern.
- In the event where the sample has no measureable fraction <63µ (coarse sediment) wet sieving with stacked variable mesh sized sieves are employed.
- Sieves are pre-weighed on a balance.
- Sieve masses are recorded on worksheet.
- The sieves are stacked in a regressively decreasing mesh size on top of the sieve shaker.
- A wet sub-sample of approximately 150 – 200 g is introduced at the top of the stack and closed with the waterspray lid.
- Switch on the shaker and open the tap to allow water to spray the sample for 10 minutes.
- Once the sieving is complete remove the sieves containing the residual fractions and place in the oven at 100°C overnight or at least 4hrs.
- Allow the sieves to cool off for 15 minutes and re-weigh each individual sieve on the balance.
- Sieve + residual sample masses are recorded on worksheet.
- Quantitatively remove the residual fractions from the sieves into a composite sample.
- Re-weigh the composite sample and record on worksheet.
- The sample mass retained (g) on each sieve is calculated as the difference in post mass (g) – pre mass (g).
- Size distribution is calculated as the % fraction sample mass retained: total mass recovered.

* Environmental Mapping &Surveying, P.O. Box 201155, Durban North, KwaZulu-Natal, 4016

© NMP 2014

11 SEAWATER ELUTRIATION TESTING

11.1 EQUIPMENT & CHEMICALS

- Plastic bucket
- Plastic jar
- Calibrated & verified top loader balance
- Filtered seawater
- Horizontal industrial paint shaker
- 50 mℓ plastic syringe
- 0.45 µm syringe filters
- 70% Ultra-pure nitric acid
- Agilent 4500Cx Inductively Coupled Plasma Mass Spectrometer

11.2 PROCEDURE

- A composite from sections A and B with an approximate mass of 1-2 kg is thoroughly mixed in a clean plastic bucket.
- 400 g of the homogenised sediment sample is weighed into a second clean plastic jar and 600 mℓ of filtered seawater is added to the bucket and sealed.
- The sample is then vigorously shaken for 15 minutes on a horizontal industrial paint shaker.
- After removing the jar from the shaker it is allowed to settle for 30 seconds before extracting the supernatant seawater with a 50 mℓ syringe.
- A 0.45 µm syringe filter is attached to the tip of the syringe and the eluent filtered into a pre-labelled ICP sample cup.
- The extract is acidified with HNO_3 before it is analysed by inductively coupled plasma mass spectroscopy (ICP MS) for trace metals leached into the filtered seawater.
- The background trace metal concentrations of the filtered seawater was also analysed by ICP MS.
- Quality control on seawater analysis includes internal quality control (QC) –solutions and spiked seawater samples with laboratory criteria set at 90% - 110% recovery range.

© NMP 2014

12 LABORATORY ACCREDITATION



sanas
South African National Accreditation System

CERTIFICATE OF ACCREDITATION

In terms of section 22(2) (b) of the Accreditation for Conformity Assessment, Calibration and Good Laboratory Practice Act, 2006 (Act 19 of 2006), read with sections 23(1), (2) and (3) of the said Act, I hereby certify that:-

COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH
ANALYTICAL LABORATORY

STELLENBOSCH

Facility Accreditation Number: **T0093**

is a South African National Accreditation System accredited Testing laboratory provided that all SANAS conditions and requirements are complied with

This certificate is valid as per the scope as stated in the accompanying schedule of accreditation Annexure "A", bearing the above accreditation number for

CHEMICAL ANALYSIS

The facility is accredited in accordance with the recognised International Standard

ISO/IEC 17025:2005

The accreditation demonstrates technical competency for a defined scope and the operation of a laboratory quality management system

While this certificate remains valid, the Accredited Facility named above is authorised to use the relevant SANAS accreditation symbol to issue facility reports and/or certificates

Mr R Josias
Chief Executive Officer

Effective Date: 01 August 2013
Certificate Expires: 31 July 2018

ANNEXURE A

SCHEDULE OF ACCREDITATION

Facility Number: T0093

Permanent Address of Laboratory: CSIR Analytical Services Stellenbosch Jan Celliers Street Stellenbosch 7600 Tel: (021) 888- 2400/2433 Fax: (021) 888-2630 E-mail: sbrown@csir.co.za	**Management Signatory:** **Technical Signatories:** **Nominated Representative:** Issue No.: Date of Issue: Expiry Date:	Mr A Pascall Mr S Brown Ms C Anderson Mr E Fieland Mr S Brown 13 21 June2013 31 July 2018
Materials / Products Tested	**Type of Tests / Properties Measured, Range of Measurement**	**Standard Specifications, Equipment / Technique Used**
Sediment & Soils (dry mass basis)	Cadmium as Cd, Cobalt as Co, Copper as Cu, Manganese as Mn, Nickel as Ni, Zinc as Zn, 0.5 -> 500mg/kg Arsenic as As, Lead as Pb 1.0 ->500mg/kg Iron as Fe in mg/kg 50 -> 100 000mg/kg	Microwave Digestion & ICP OES Detection MALS 4.5 & MALS 6.2 A
Aquatic Biota (dry mass basis)	Cobalt as Co, Nickel as Ni, Manganese as Mn, Zinc as Zn, 0.1 -> 500mg/kg Arsenic as As, Cadmium as Cd0.25 ->500mg/kg Copper as Cu, Iron as Fe, Selenium as Se, Vanadium as V, 0.5->500mg/kg	Microwave Digestion & ICP OES Detection MALS 4.7 & MALS 6.3 A
Potable Ground & Wastewater (Dissolved)	Aluminium as Al, Antonomy as Sb, Arsenic as As, Barium as Ba, Beryllium as Be, Cadium as Cd, Chromium as Cr, Cobalt as Co, Copper as Cu, Iron as Fe, Lead as Pb, Manganese as Mn, Molybdenum as Mo, Nickel as Ni, Strontium as Sr, Selenium as Se,Vanadium as V, Zinc as Zn 0.105 - >100mg	ICP OES Detection MALS 64.A
	Boron as B, 0.02->100mg/L	ICP OES Detection MALS 4.A
	Calcium as Ca, Sodium as Na, Potassium as K, Magnesium as Mg, Sulphate as SO_4 in mg/L 0.1 - >100000	ICP OES Detection MALS 5A.4

Original Date of Accreditation: 01 August 1998

Page 1 of 2

Field Manager

ANNEXURE A

Facility No.: T0093
Date of Issue: 21 June 2013
Expiry Date: 31 July 2018

Materials / Products Tested	Type of Tests / Properties Measured, Range of Measurement	Standard Specifications, Equipment / Technique Used
Potable, Ground & Wastewater (Dissolved)	Chloride as Cl in mg/L 0.5 - >300mg/L	SALM.1.0 Flow Injection Colorimetry
Potable Ground & Wastewater	pH 2 – 12	SALM.2.0 Electrometic
	Alkalinity as $CaCO_3$ If pH > 4.5 : 0.5 -> 100mg/L	SALM.5.0 Potentiometric
	Electrical Conductivity in mS/m 1 - >5000 ms/m	SALM.3.0 Electrometric
Potable Ground & Wastewater (Dissolved)	Ammonia as NH4-N, OrthoPhosphate as PO4-P 0.05mg/L -> 5mg/L	SALM 6.0 Flow Injection Colorimetry
Potable Ground & Wastewater	Dissolved and Total Organic Carbon 0.5-> 100mg/L	SALM 26 Themocatalytic Oxidation + Combustion
Potable Ground & Wastewater (Dissolved)	Arsenic as As, Cadmium as Cd, Colbat As Co, Antimony as Sb,	ICPMS Detection SALM 2.0
	Borylium as Be, Selenium as Se, Lead as Pb,	
	Manganese as Mn, Nickel Ni, Vanadium as V, Uranium as U 0.5->100µg/L Copper as Cu, Mercury as Hg1.0ug/L-> 100-ug/L Zinc as Zn 2.0ug/L -> 100-ug/L	

Original Date of Accreditation: 01 August 1998

Page 2 of 2

ISSUED BY THE SOUTH AFRICAN NATIONAL ACCREDITATION SYSTEM

Field Manager

13 REFERENCES

Loring, D.H. and Rantala, R.T.T. 1992. Manual for the geochemical analyses of marine sediments and suspended particulate matter. *Earth Science Reviews* **32**: 235 -283.

Monteiro, P.M.S and Scott, D. 2000. Sediment Assessment Programme for the Port of Cape Town: 1999. Stellenbosch, CSIR Report ENV-S-C2000-117, CSIR, South Africa.

Windt, C.N and Visser, E. 1997.Analytical Methods Manual Estuarine and Marine Waters, Sediments and Biological Tissue. Stellenbosch, CSIR Report ENV-S-I97011

http://www.legis.state.wi.us/rsb/code/nr/nr149.pdf Procedures for Handling and Chemical Analysis of Sediment and Water Samples., Technical Report **EPA**/**CE**.**81**.**1**, Environmental Laboratory, U.S

http://www.fao.org/sediments/GIPMESQGReport:pdf GIPME,1999. Guidance on Assessment of Sediment Quality.

American Public Health Association 2012., *Standard Methods for the examination of water and wastewater* 22nd Edition, 2012. American Water Works Association, Water Environment Federation.

SANDPIPER PROJECT

Verification Programme Report:
Mining Licence Area No. 170

SECTION D : APPENDICES

APPENDIX 2

Fisheries and Biodiversity

2.1: PEP Biodiversity Survey FV *Zeerarend*
2.2: Cruise Report Biodiversity Survey FV *Zeearend*
2.3: CTD Deployment Report FV *Zeearend*
2.4: Sailing Orders Biodiversity Survey FV *Zeearend*
2.5: Biodiversity Induction Module FV *Zeearend*

APPENDIX 2 – FISHERIES AND BIODIVERSITY

2.1 PEP Biodiversity Survey FV *Zeearend*

NAMIBIAN MARINE PHOSPHATE

BIODIVERSITY SURVEY

PROJECT EXECUTION PLAN

Prepared for:
Namibian Marine Phosphate (Pty) Ltd.

Prepared by:
Capricorn Fisheries Monitoring cc
Report compiled by Melanie Smith.

June 2014

CAPFISH (Pty) LTD
Unit 15, Foregate Square. Table Bay Boulevard, 8002, South Africa
Directors: Japp, Wissema, Heinecken, Wilkinson, Ncongo
Co Reg. No. 2004 / 004844 / 07

MARINE SPECIALIST TEAM

Melanie Smith – CapFish, Cape Town
Kate Munnik – Lwandle Technologies, Cape Town
Timothy Mc Clurg - CapFish, Cape Town
Victor Ncongo - CapFish, Cape Town
Robert Willamson - CapFish, Cape Town
Ester Nangolo, MFMR Namibia
Malakia Shimhanda, MFMR Namibia

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed “Attention: Administration Manager,” at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

contents

1 PURPOSE AND OBJECTIVES 1

2 WORK PROCEDURE 6

2.1 INSTALLATION AND SAMPLING 6
2.2 TRAWL AND SAMPLING EQUIPMENT 6
2.3 SURVEY DESIGN 9
2.4 ONBOARD SAMPLING 9
2.4.1 Fish sampling 10
2.4.2 Benthic sampling 10
2.4.3 Marine mammal and seabird sampling 10
2.4.4 Hydrological and environmental sampling 11
2.5 DATA AND ANALYSIS 11

3 SAMPLE PRESERVATION AND CURATION 11

4 HEALTH AND SAFETY 12

4.1 PERSONAL PROTECTIVE EQUIPMENT 12
4.2 WORK ON DECK 12
4.3 RISK ANALYSIS 12
4.4 EMERGENCY PROCEDURES AND CONTACT NUMBERS 15

Annexure 1: Approval letter from MFMR 17
Annexure 2: Ship requirements for samples and their storage 18
Annexure 3: Equipment list 19
Annexure 4: Pre-sailing safety inspection form 20
Annexure 5: Data sheets 22

© NMP 2014

figures

Figure 1: Location of the proposed target dredging sites SP-1 (20-year mine plan established), SP-2 and SP-3 within the three resource areas of the Sandpiper phosphate licence area. 3
Figure 2: Position of the 24 biodiversity survey stations randomly selected to cover the area within and in close proximity to the target mine area SP-1. Note all stations are in water deeper than 200 m. 4
Figure 3. Configuration of the double belly monkfish trawl net 7
Figure 4: Portable multi probe internal CTDs (left) and stainless steel casing (above) 8
Figure 5: Large scale up to 50kg 8

tables

Table 1: Randomly selected start and end positions (decimal degrees) for the 24 biodiversity survey stations. Station codes are also included with D = day time trawl and N = night time trawl. 5
Table 2: The daily sampling routine 9
Table 3: RA for the mobilisation of equipment and loading of ship 13
Table 4: RA for work on vessel deck 14
Table 5: RA for the handling of sampling equipment 14
Table 6: RA for the deployment and recovery CTD 14
Table 7: RA for the packaging and unloading of samples 14
Table 8: Emergency contact details 15
Table 9: Personal Emergency information 16

© NMP 2014

1 PURPOSE AND OBJECTIVES

Namibian Marine Phosphate (NMP) is proposing to extract marine phosphate from deposits on the Namibian continental shelf. The deposits lie approximately 40-60 km offshore from Conception Bay in water depths of 190 to 300 m and cover an area of 2233 km^2 (Figure 1). Within the context of increasing international demand for phosphates, the company has been granted a 20-year mining licence (ML 170), subject to the issue of an Environmental Clearance Certificate following the completion of an Environmental Impact Assessment (EIA) and Environmental Management Plan (EMP). The phosphate will be extracted by dredging in the target mine areas described as Sandpiper 1 (SP-1), 2 (SP-2) and 3 (SP-3). It is currently estimated that a total resource of 2443 Mt at 15 % P_2O_5 exists in these areas. SP-1 is within ML 170 and is situated south west of Walvis Bay, directly offshore of Conception Bay and Meob Bay (Figure 1). SP-1 (176 km^2) is the target dredge area for proposed project, approximately one third of this area would be dredged during the 20 year mining licence approval period.

The purpose of the verification assessment programme is to collect in-situ marine fauna and epibenthic data from SP-1 in order to confirm the results detailed in the EIA specialist report; (*Japp and Smith 2012: Appendix 1a on fish resources, fisheries, marine mammals and birds*). Five primary impacts were identified in the EIA report:

1) the likely impact of mining on commercial fisheries;
2) the likely impact of mining on the main commercial fish species;
3) the likely impact of mining on the recruitment of commercially important species;
4) the likely impact of mining on fish biodiversity and
5) the likely impact of mining on seabirds and marine mammals.

Responses to the EIA from NatMIRC were outlined in a letter dated 16 June 2012 and discussed with NatMIRC in a meeting (facilitated by the Governor of Erongo Region, The Honourable Cleophas Mutjavikua) on 10 September 2012 in Swakopmund. NatMIRC raised 13 concerns and issues which they felt needed to be addressed. Of these, four related to the component of the EIA relating to fish resources, mammals and seabirds.

Summarised these concerns were:

1. Turbidity affecting marine predators that use visual cues to forage for prey;
2. Spawning activities of fish in the mining area was relatively unknown;
3. The importance of the proposed mining area as a nursery ground for juvenile hake;
4. Impacts of the proposed mining on the ecosystem were uncertain – in particular trophic (feeding) interactions.

As part of the original verification assessment programme of the EIA assessment (*Japp, 2012: Namibian Marine Phosphate – Environmental Impact Assessment of Fish, mammals and seabirds: Proposed monitoring and verification of Impacts in the proposed Mining Area*) it was recommended that a structured biomass survey of the proposed mining area – in particular the area proposed to be dredged in the first phase (SP-1), be undertaken. However, following biomass estimate modelling of demersal survey data by Dr James Gaylard (*Gaylard, 2013: Biomass and stock estimates of Hake and Monk in the mining lease areas of Namibian Phosphates*) and spawning and recruitment statistical

© NMP 2014

data assessment by Dr Hillka Ndjaula (*Ndjaula, 2014: Fish Recruitment and Stock Dynamics Study with respect to a Proposed Development of Phosphate Deposits in the Sandpiper Phosphate Licence Area off the Coast of Central Namibia*), it was recommended that a biodiversity (as opposed to biomass) survey was of more value to the fishery assessment requirements and that information outputs will provide more substantive information to assist in refining the assessments of impacts made to date.

It was thus decided to undertake a biodiversity survey to verify the current assumed baseline for biodiversity, fish abundance (density), recruitment (size distribution) and other biological aspects (spawning state of main commercial species etc). An industry owned monkfish trawler, FV *Zeearend,* will be used to carry out the biodiversity survey. The main objectives are to:

- Estimate the abundance (density) of the main commercial species such as hake, monk and horse mackerel etc.;
- Collect biological information (length, sex, maturity stage, stomach content) from the commercially important/exploited species;
- Identify, collect and photograph epibenthic species and at the same time the nature of the substrate and bottom profile;
- Collect environmental data (using visual observations and a CTD) to establish linkages between the environment and species distribution, recruitment and abundance;
- Record/identify the occurrence of surface species such as marine mammals and seabirds in the area; and
- Collect baseline data for future monitoring.

Essentially, the survey will be designed to quantify the biodiversity of the area and compare this with the known information on the region, i.e. a biodiversity verification assessment. The survey will also obtain full commercial data on target catch (monk), hake and the other bycatch species. This will allow for a crude estimate of spawner biomass and recruitment that can then form a baseline for future surveys in the area.

The biodiversity survey will involve sampling the marine species and the water column in the target mining area SP-1. A grid of sampling sites was placed across SP-1 such that a broad distribution of stations was randomly selected across the entire SP-1 and target dredge site of SP-1. Figure 2 shows the sampling station layout. The locations of the environmental reference sites (for a companion investigation) are also shown. The coordinates in decimal degrees of the start and end positions of each trawl are presented in Table 1. Of the 24 stations 12 will be sampled during the day (D) and 12 during the night (N). Four stations will be sampled in a 24 hour period and stations are limited to waters deeper than the 200 m bathymetry contour as per the approval letter from MFMR (Annexure 1).

© NMP 2014

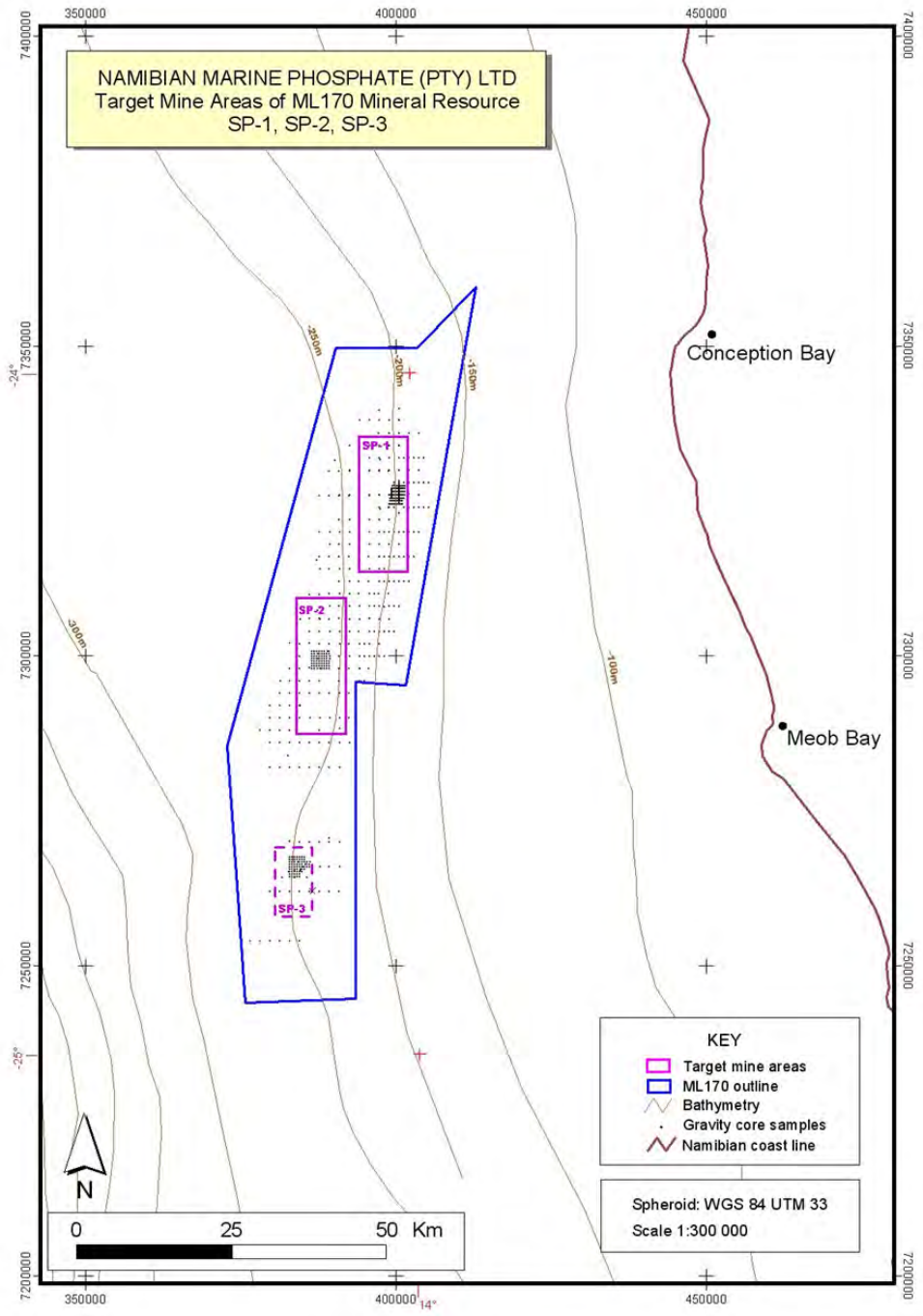


Figure 1: Location of the proposed target dredging sites SP-1 (20-year mine plan established), SP-2 and SP-3 within the three resource areas of the Sandpiper phosphate licence area.

© NMP 2014

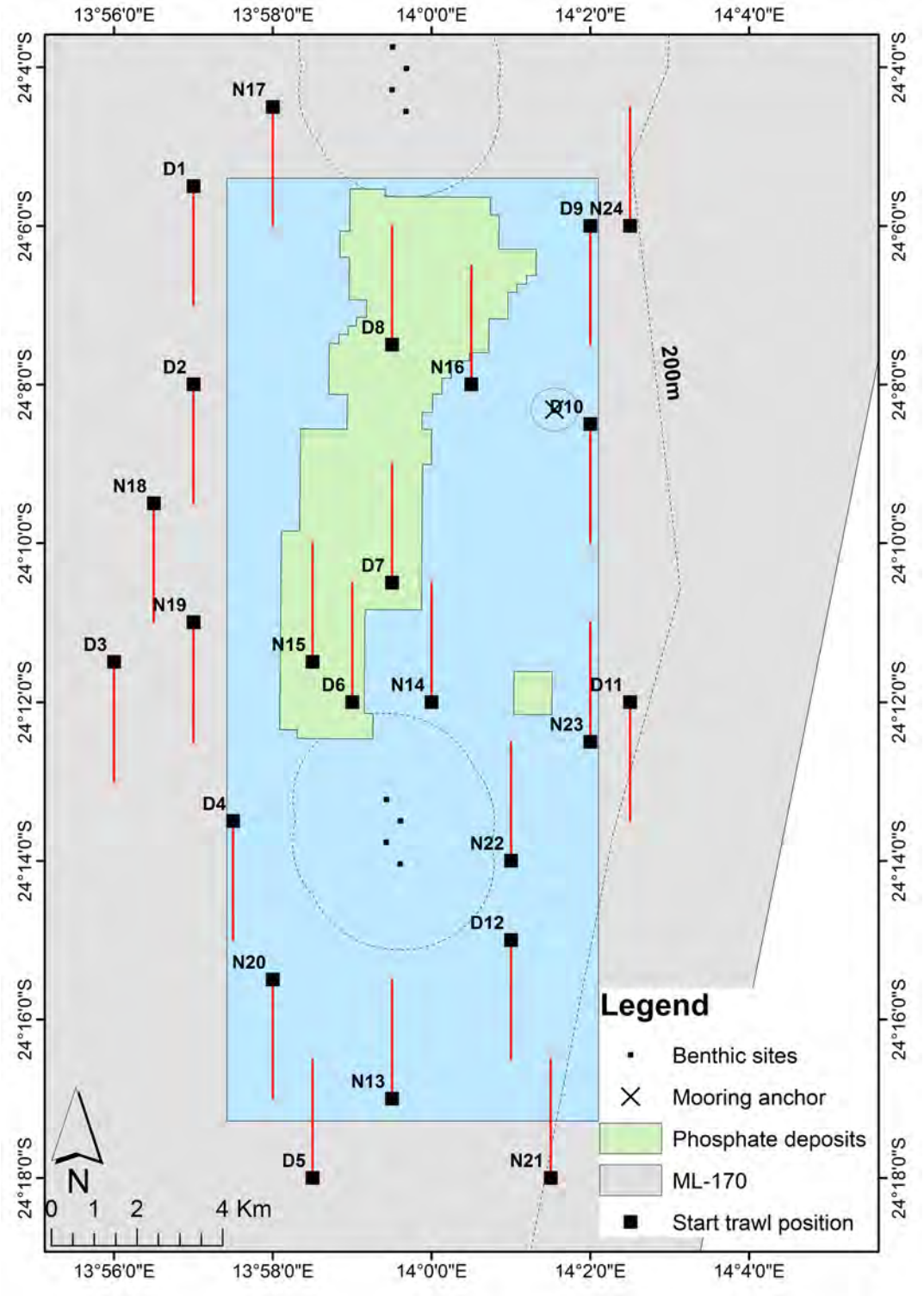


Figure 2: Position of the 24 biodiversity survey stations randomly selected to cover the area within and in close proximity to the target mine area SP-1. Note all stations are in water deeper than 200 m.

Table 1: Randomly selected start and end positions (decimal degrees) for the 24 biodiversity survey stations. Station codes are also included with D = day time trawl and N = night time trawl.

Station code	Start Latitude	Start Longitude	End Latitude	End Longitude
D1	-24.0917	13.9500	-24.1167	13.9500
D2	-24.1333	13.9500	-24.1583	13.9500
D3	-24.1917	13.9333	-24.2167	13.9333
D4	-24.2250	13.9583	-24.2500	13.9583
D5	-24.3000	13.9750	-24.2750	13.9750
D6	-24.2000	13.9833	-24.1750	13.9833
D7	-24.1750	13.9917	-24.1500	13.9917
D8	-24.1250	13.9917	-24.1000	13.9917
D9	-24.1000	14.0333	-24.1250	14.0333
D10	-24.1417	14.0333	-24.1667	14.0333
D11	-24.2000	14.0417	-24.2250	14.0417
D12	-24.2500	14.0167	-24.2750	14.0167
N13	-24.2833	13.9917	-24.2583	13.9917
N14	-24.2000	14.0000	-24.1750	14.0000
N15	-24.1917	13.9750	-24.1667	13.9750
N16	-24.1333	14.0083	-24.1083	14.0083
N17	-24.0750	13.9667	-24.1000	13.9667
N18	-24.1583	13.9417	-24.1833	13.9417
N19	-24.1833	13.9500	-24.2083	13.9500
N20	-24.2583	13.9667	-24.2833	13.9667
N21	-24.3000	14.0250	-24.2750	14.0250
N22	-24.2333	14.0167	-24.2083	14.0167
N23	-24.2083	14.0333	-24.1833	14.0333
N24	-24.1000	14.0417	-24.0750	14.0417

© NMP 2014

2 WORK PROCEDURE

Sampling equipment and personnel will be mobilised to the port of embarkation, the Benguella Fishing Company (Walvis Bay). Following loading of the fishing/survey vessel, equipment will be carefully unpacked and assembled. Electronic equipment will be powered up and tested to determine whether any breakages have occurred during transit. Repairs or replacements will be made if and where necessary.

2.1 INSTALLATION AND SAMPLING

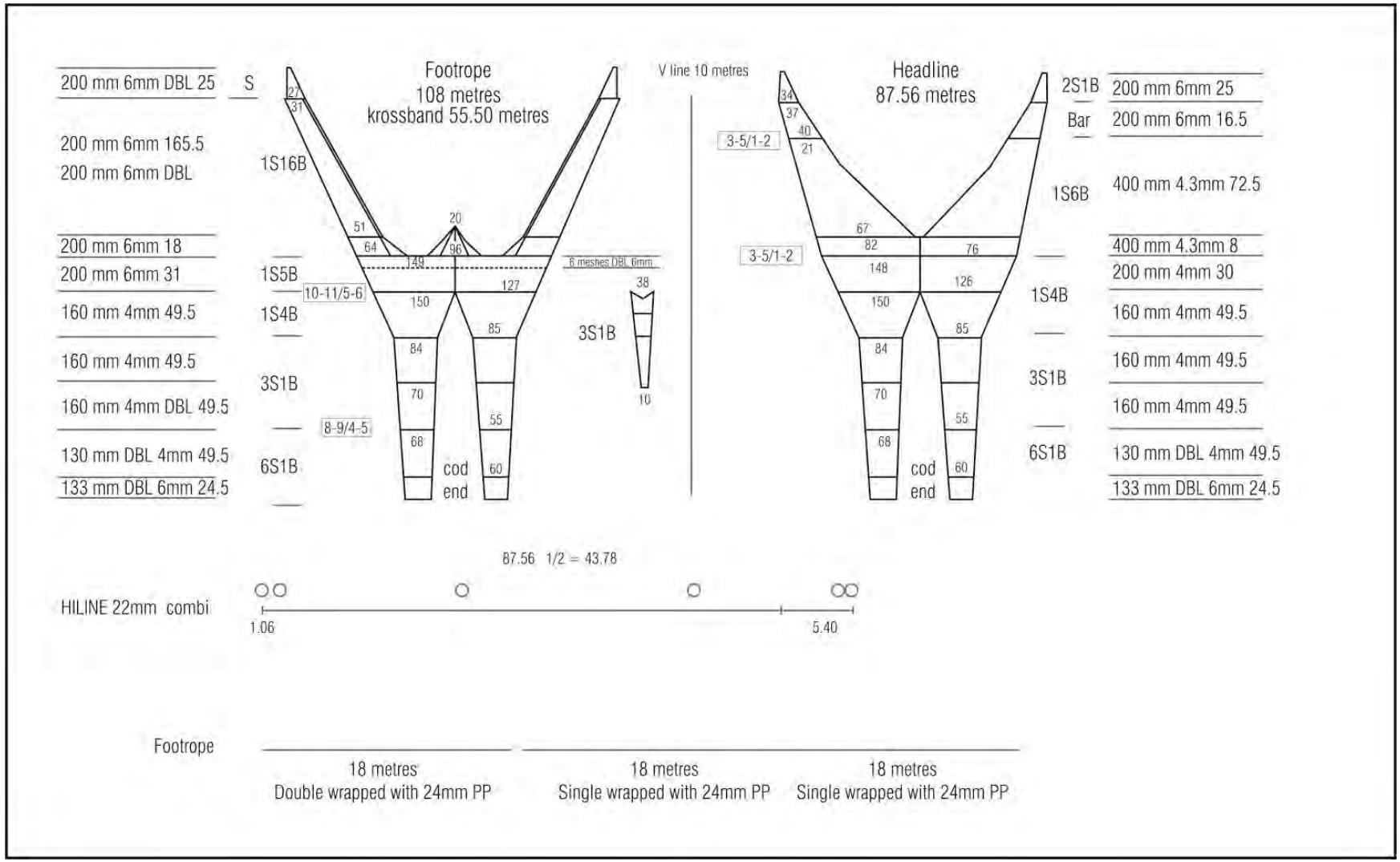
Prior to the vessel steaming to the survey area a test run of the sampling equipment will be carried out in Walvis Bay. This will involve a run through of all the procedures outlined below. All sea safety protocols will be advised and demonstrated to the scientific team at this time, under the instruction of the Master of the vessel. After the test deployment of the relevant equipment, the data will be downloaded and quality checked. At this stage any problems that may have emerged during the sampling procedures or with the quality of the captured data can be resolved through adjustments to the instrumentation or the deployment procedures. Should any changes to the deployment procedures be necessary, they must be noted in detail and the procedures described below should be amended accordingly.

The sampling procedures, which will be coordinated and conducted with the cooperation of the marine crew will be explained to the scientific team and the crew that will be involved before the test run commences and each participant should understand their roles and responsibilities during the sampling activities. The importance of following these procedures and of maintaining the integrity of all samples collected during the survey must be emphasised. The importance of ensuring that all work areas are kept clean free from any oil/grease contamination should too be made clear.

2.2 TRAWL AND SAMPLING EQUIPMENT

A commercial Viking Double-Belly monkfish bottom trawl with a head length 88 m, footrope 47 m and vertical net opening 30 – 40 m will be used. The distance between the wings during towing will be approximately 40 m. The trawl will be rigged with tickler chains along the footrope. The “Thyborun” trawl doors will be 4.2 m squared in size, weighing approximately 800 kg. The codend mesh size will be 120 mm but in order to avoid small fish and epibenthic fauna being lost through the meshes, a 20 mm mesh inner-liner will be installed inside the codend. No SCANMAR sensors are onboard, only trawl out will be measured.

© NMP 2014


200 mm 6mm DBL 25
S
200 mm 6mm 165.5
200 mm 6mm DBL
200 mm 6mm 18
200 mm 6mm 31
160 mm 4mm 49.5
160 mm 4mm 49.5
160 mm 4mm DBL 49.5
130 mm DBL 4mm 49.5
133 mm DBL 6mm 24.5
Footrope
108 metres
krossband 55.50 metres
1S16B
1S5B
1S4B
3S1B
6S1B
10-11/5-6
8-9/4-5
6 meshes DBL 6mm
3S1B
V line 10 metres
Headline
87.56 metres
3-5/1-2
3-5/1-2
2S1B
Bar
1S6B
1S4B
3S1B
6S1B
200 mm 6mm 25
200 mm 6mm 16.5
400 mm 4.3mm 72.5
400 mm 4.3mm 8
200 mm 4mm 30
160 mm 4mm 49.5
160 mm 4mm 49.5
160 mm 4mm 49.5
130 mm DBL 4mm 49.5
133 mm DBL 6mm 24.5
cod end
cod end
87.56 1/2 = 43.78
HILINE 22mm combi
1.06
5.40
Footrope
18 metres
Double wrapped with 24mm PP
18 metres
Single wrapped with 24mm PP
18 metres
Single wrapped with 24mm PP

A Multi-probe internal logging Conductivity, Temperature and Depth (CTD) recorder will be encased inside a stainless steel protective casing and specially designed net bag, this will be attached, using shackles and cable ties, to the head rope of the trawl net. The CTD will be lowered at every station with the trawl net through the water column to within 5 m of the seafloor. The CTD will be fitted with temperature, conductivity and dissolved oxygen. The CTD will be removed after each trawl to download the data and change batteries whenever necessary.





Figure 4: Portable multi probe internal CTDs (left) and stainless steel casing (above)

A net scale will be attached to the net crane to weigh the entire catch before the catch is released on board. Two digital scales, tested and calibrated, will be used for measuring fish and epibenthic quantities from 1g to 50 kg.

Hourly measurements from coastal weather stations as well as daily SST imagery will be used to discuss the wind and surface temperature conditions during the survey.



Figure 5: Large scale up to 50kg

2.3 SURVEY DESIGN

The monkfish bottom trawler, FV *Zeearend* will be used to sample 24 stations within and in close proximity to the target dredge area SP-1. Stations are randomly selected by dividing the survey area into grid blocks (2.5 nm x 3 nm). In each grid block two stations were randomly selected (Figure 2) using Excel. Where possible, the first random position was selected. If not, the next position on the list was selected, and this continued until two stations were selected per grid block[1]. Stations that were not suitable for trawling include those in water shallower than 200 metres [2], those inside the environmental reference site areas and within 500 m of the oceanographic mooring anchor.

Trawl speed will be three knots on average with a trawling time of 30 minutes, this being the time the net will spend in contact with the seabed. The fishing operation will be in a north/south direction and the trawl distance covered at each station will be approximately 1.5 nm. The length of the trawl wire will be recorded.

Four stations will be sampled per 24 hour period for six days. Therefore two days will be available in the event of "down-time" due to adverse weather conditions and/or gear damage (torn net).Half the stations will be sampled during the day (07h00 - 17h30) and the other half during the night (20h00 – 07:00) hours. During daytime trawls the net will not be deployed before sunrise and will be raised approximately 30 minutes before sunset. In foggy or overcast conditions, these time restrictions will be extended to 60 minutes after sunrise and 60 minutes before sunset. During night time trawls the net will not be deployed before sunset and will be raised 30 minutes before sunrise.

2.4 ONBOARD SAMPLING

Once the captain/party chief has confirmed the correct position of the vessel, deployment of the sampling equipment will begin. One of the scientific crew members will record the time and GPS coordinates when the trawl settles on the ocean bottom and when it begins its ascent. This person will also drop a way point to ensure that the correct position will be recorded. For each trawl station visual weather observations will be made and the presence of marine mammals and seabirds will be recorded. Subject to sea condition the daily sampling routine will be as follows:

Table 2: The daily sampling routine

Visual environment, marine mammal and bird observations	Fish and benthic sampling Stations D1-D12	Fish and benthic sampling Stations N13 – N24
Day time trawls only	**Day time trawls**	**Night time trawls**
07:00 – 08:00	07:00 – 07:30	20:00 – 20:30
11:00 - 12:00	11:00 – 11:30	23:00 – 23:30
14:00 – 15:00	14:00 – 14:30	02:00 – 02:30
17:00 – 18:00	17:00 – 17:30	05:00 - 05:30

[1] Note that two stations per grid block were selected to allow for one day and one night trawl per grid block.
[2] Related to the survey permit conditions as issued by MFMR – Letter MFMR to NMP 060614

© NMP 2014

2.4.1 Fish sampling

The entire catch (or a subsample in the case of large catches) will be sorted into species. Monk, hake, horse mackerel and chondrichthyans will be further sorted by sex. The total catch weight (kg) of each species (and sex where applicable) will be recorded. Length frequency (total length) data will be collected for all commercial species (measured by sex if split). For non-commercial species (such as rat tails), only the weight and number of fish raised to the total catch will be used.

If the catch is > 1 tonne, it will be split into two (approximately 50%) and one half will be sampled as above. If the catch is > 5 tonnes then 25% of the catch will be sampled as above. This will be done by estimating the catch in the stocker pond and splitting the catch into the desired proportions e.g. 50 or 25%.

In both cases, biological sampling (individual weight and length measurements, sex, maturity stage, stomach contents) of about 15 – 20 fish will be done for hake and monk per station.

All fish caught during the survey will be handled and disposed off as per routine NatMIRC [3]surveys.

2.4.2 Benthic sampling

All invertebrate species retained by the net and landed as part of the catch will be recorded. All invertebrate species will be identified to the lowest possible taxon, counted and weighed. All large, whole epibenthic species retained in the wings of the net will be included in the data counts. A sub-sample of small, abundant epibenthic organisms (e.g. small sea pens and shrimps) from the wings of the net will be counted and weighed with the remainder being estimated.

Photographs of the invertebrate assemblage will be taken for each trawl. This includes a representative individual of each invertebrate occurring within that trawl and, to provide an overview, a snapshot image of all invertebrates occurring at each station. Where possible, species information will be recorded in a draft identification guide by making use of taxonomic keys and live specimens.

Additional photographs will be taken of all invertebrate species, where possible, to show key identification features. All specimens for which identification to at least genus level is not possible will be appropriately preserved and retained for identification by relevant taxonomic experts.

2.4.3 Marine mammal and seabird sampling

Marine mammal sightings (strategy taken from the Marine Mammal Observation[4] standard procedures) and seabird observations will be carried out during the day by one of the scientific crew members. The person will visually record and identify the number of species within a 500 m radius of the vessel. Sixty minute observations will be conducted at the start of each trawl.

[3] Related to the survey permit conditions as issued by MFMR – Letter MFMR to NMP 060614
[4] JNCC (2010). Marine mammals recording forms (Detailed sighting records) Joint Nature Conservation Committee

© NMP 2014

2.4.4 Hydrological and environmental sampling

The CTD will be attached to the head rope (top rope) of the trawl net using shackles and rope and data will be recorded throughout the entire net deployment. The CTD will be removed from the net before it is bought onboard to protect it from any damage. Data will be downloaded and saved onto external hard drives.

At the start of the trawl, air pressure, wind direction, Beaufort scale (wind speed), cloud cover, sea surface colour, sea surface temperature, bottom temperature and depth will be recorded using the equipment on the bridge and by visual observations.

2.5 DATA AND ANALYSIS

All data will be recorded on data sheets (Annexure 5) and entered electronically in an Access (and Excel) database. Hard copies of the data sheets will subsequently be retained by NMP. Three integrated reports; the Cruise Report, the Verification Report and Epibenthic Report will be submitted to NMP approximately three months after the completion of the survey.

3 SAMPLE PRESERVATION AND CURATION

The preservation and curation of all samples collected while on board the research vessel will be the responsibility of the scientific crew carrying out each activity with the assistance of the ship's crew. It is very important that the samples are preserved and stored correctly to avoid any loss of data while the vessel is underway, or during transportation.

All permissions, authorisations and permits required for transporting the chemical/biological samples any associated sampling equipment will need to be organized by NMP.

On board:

- All sample containers to be clearly labelled with the relevant station number, date etc. This information is to match that in the sample record data sheets.
- Check sample conditions in container fridge and freezers daily. Ensure power connection to all fridges / freezers containing samples remains stable.
- Check integrity of biological samples daily (i.e. no leaks/drying etc.).

During transport:

- Benthos
    - Ensure that the biological sample containers are tightly sealed and are stored upright.
    - Use inert packing material to add support to containers.
    - Seal the lid of the sample crate with cable ties.
    - Clearly label the crates with number and type of samples and destination.
    - Samples are to be transported by road.
- Data
    - After each CTD download data and store copies on laptop and portable hard drive.
    - Carry laptop and portable hard drive separately when travelling.
- Gear

© NMP 2014

- Repack all gear into the original crates that they were delivered in. Ensure that these are numbered and have inventory lists with them.

4 HEALTH AND SAFETY

The Master (FV *Zeearend*), Melanie Smith (Chief scientist) and the relevant vessel authorities will be responsible for overseeing health and safety aspects for the duration of the trip. There will be a Pre-Sea inspection conducted by one of the scientific crew of all the safety equipment.

4.1 PERSONAL PROTECTIVE EQUIPMENT

Personal protective equipment (PPE) must be worn on the vessel as directed by the vessel master.

The following general offshore PPE is provided by CapFish to offshore personnel:

- Oil-skins
- Safety footwear (boots)
- Safety hard hat (as required during lift operations)
- Gloves
- Self-inflatable life jackets

4.2 WORK ON DECK

Particular care is required when working on the deck, each member of the scientific team is to ensure that the safety procedures are understood and implemented for all work taking place on the deck of the vessel.

If the weather conditions begin to deteriorate, the scientific team in conjunction with the Master should continually assess the situation and stop work whenever necessary. This is especially true in conditions where sampling equipment (i.e., baskets, bins) becomes unstable.

All the members of the scientific team will have the full authority to issue a “Stop work” command if anyone perceives a hazard during work operations. Most technical/manual activities are to be undertaken by the trained vessel crew.

A toolbox meeting should be held prior to any new tasks being undertaken, and a refresher meeting should occur whenever necessary.

4.3 RISK ANALYSIS

A number of risk assessments have been carried out in alignment with the tasks that the scientific team will be carrying out. The risk assessments have been prepared on the basis of the risk factor table presented in Figure 3.

© NMP 2014

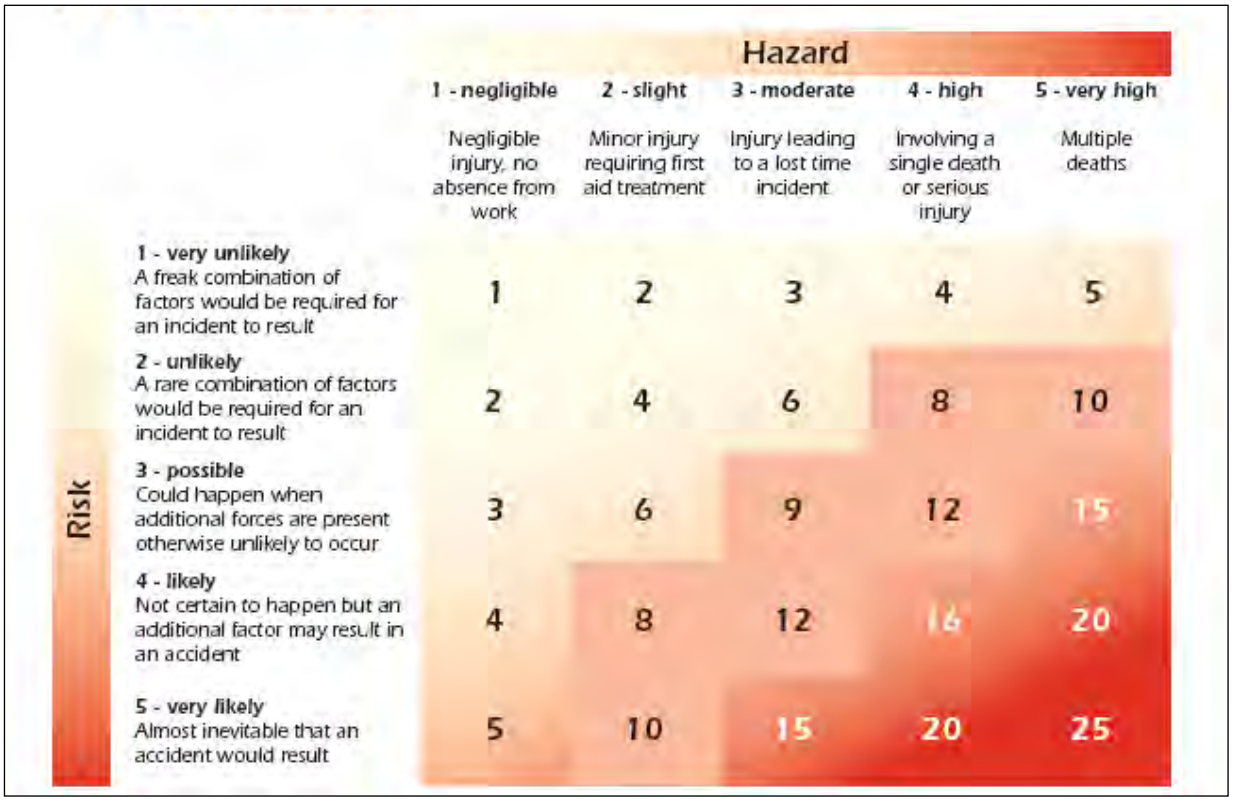


Figure 6: Risk factor table taken from OGP *HS&E Guidelines for Metocean Surveys*[5].

Table 3: RA for the mobilisation of equipment and loading of ship

Risk	H	R		Mitigation	H	R	
Theft/loss of valuables/ equipment/ personnel	4	3	12	• Keep all valuables out of sight while travelling. • Ensure equipment is securely packaged before transportation. • Be vigilant when travelling.	2	3	6
Injury to personnel and / or damage to equipment from uncontrolled lifting/dropping of boxes/equipment	4	3	12	• Use of PPE • Lift carefully, bend knees and not back.	1	2	2

[5] International Association of Oil and Gas Producers. http://www.ogp.org.uk/pubs/348.pdf

© NMP 2014

Table 4: RA for work on vessel deck

Risk	H	R		Mitigation	H	R	
Personal injury due to slips/trips/falls	4	3	12	• Use of PPE, especially safety shoes when on deck • Ensure deck is cleared of potential trip hazards	1	2	2
Personal injury due to fishing gear failure	4	3	12	• Use PPE, especially hardhats when on deck • Keep first aid kit near the work station	2	2	4
Personal injury due to cuts/ stab wounds from fish spines and sampling knives/scissors	4	3	12	• Use PPE, especially gloves, overalls and oil skins • Keep first aid kit near the work station	1	2	2
Personal injury due to falling over gunnel	5	3	15	• Use of PPE, especially life jackets and safety harnesses when working near the gunnel. • Work close to the gunnel only when it is safe to do so, if weather conditions are not favourable –Stop work.	3	2	6

Table 5: RA for the handling of sampling equipment

Risk	H	R		Mitigation	H	R	
Injury to personnel/equipment from mishandling samples	4	3	12	• Use of PPE • Be vigilant when handling equipment and samples	1	2	2

Table 6: RA for the deployment and recovery CTD

Risk	H	R		Mitigation	H	R	
Personal (hands/head/feet) injury or damage to equipment due to mishandling of CTD	3	3	9	• Use of PPE, especially hardhats, safety boots • Ensure care is taken when attaching the CTD, keep fingers away from the cables/warps.	3	2	6

Table 7: RA for the packaging and unloading of samples

Risk	H	R		Mitigation	H	R	
As per Table 3	0	0	0		0	0	0

© NMP 2014

4.4 EMERGENCY PROCEDURES AND CONTACT NUMBERS

In the case of any emergency the following numbers are to be called either from a satellite phone, local sim card, or on board telephone (Tables 8 and 9). Please ensure that this list of numbers is placed in an area visible to all field staff during work on board the vessel and while travelling.

Table 8: Emergency contact details

Name	Position	Email	Phone number
CapFish Team			Satellite phone number 87 077 645 8726
FV *Zeearend*	Vessel Call sign: V5ZD Licence No: L - 1298	Easy mail no: 581465935911 A.Olivier@benguella.com	+870764905196
Dave Japp	Director, CapFish	dave@capfish.co.za	+ 27 21 4252161 +27 827886737
Melanie Smith	Project manager, CapFish	melanie@capfish.co.za	+ 27 21 4252161 +27 727729876
Jeremy Midgley	NMP representative	mwjmidg@mweb.co.za	+ 27 21 7886212 +27 832649484
Rachel Misika	NMP representative	Rachel.misika@namphos.com	+264 817929047
Mike Woodborne	NMP land project coordinator	mike.woodborne@uclresources.com.au mike.woodborne@gmail.com	+61 410307205 / +37281054658 /+61 893414969
Robin Carter	Lwandle Director	robin@lwandle.co.za	+27 829223504
Hospital	Walvis Bay Medipark T/a Welwitchia Hospital	Street Address: Gertrude Rikumba Kandanga Hilukilwa Street, Walvis Bay	+26 464 21 8911
Police Station	Walvis Bay Police Station	Walvis Bay, Namibia	+264 64 21 9048 / 64 202 055 / 10111/
Sea Rescue	Namibian Sea Rescue		208 2221 or 081 129 6295
SOS international emergency number (for Discovery clients)			+27 11 541 1222

Table 9: Personal Emergency information

Name	Medical aid number	Emergency Contact	Phone number
Melanie Smith Victor Ngcongo Robert Williamson	Griffin Risk Management cc 03GPA505572	Dave Japp (CapFish director)	+27 21 425 2161 + 27 82 788 6737
Timothy McClurg (Scientific Officer)	Discovery number: 223996381	Helen McClurg (wife)	+27 31 762 1356 +27 83 681 67 66
Kate Munnik	Discovery, Coastal Saver. Number: 403004690	Michael Munnik (father) Lynne Munnik (Mother)	+27 (0) 83 6427492 +27 (0) 83 6407600
Ester Nangolo	PSEMAS 134831	Victoria Nangolo (mother)	+264 81215 2809
Malakia Shimhanda	PSEMAS 11600	Anna Shimhanda (wife)	+264 81826 9702

While on board, all scientific crew will be required to follow and adhere to all health and safety requirements/instructions given to them by the vessel captain.

Annexure 1: Approval letter from MFMR

14-20001

REPUBLIC OF NAMIBIA

MINISTRY OF FISHERIES AND MARINE RESOURCES

Tel (00 264 61) 205 3007
Fax (00 264 61) 22 45 66

OFFICE OF THE PERMANENT SECRETARY

Brendan Simbwaye Square
Uhland Street
Private Bag 13355
WINDHOEK

6 June 2014

Michael Woodborne
Chief Operations Officer
Namibia Marine Phosphate (Pty) Ltd
Private Bag 5018
Walvis Bay

Dear Mr Woodborne,

SUBJECT: AUTHORIZATHION FOR BIOMASS/BIODIVERSITY SAMPLING IN ML170 (SP1)

With reference to your letter dated 5 June 2014, on the abovementioned request and your earlier communication on 31 March 2014 on the requirements for the environmental verification programme. The Ministry has considered your request and grants you permission to conduct a biodiversity survey on board of the MV Zeearend.

The following conditions are to be strictly adhered to:

- The survey plan to be agreed with the relevant scientists at NatMIRC prior to commencement of the cruise.
- Two NatMIRC scientists are to fully participate in the survey.
- An inner cod end lining of 20 mm to be used to limit escapements in the cod-end.
- All fish caught during the survey are to be handled and disposed off as per routine NatMIRC surveys.
- All other relevant fishing regulations are to be complied with.

Yours sincerely

MINISTRY OF FISHERIES
PERMANENT SECRETARY
2014 -06- 06
MARINE RESOURCES

Ms Ulitala Hiveluah
PERMANENT SECRETARY

Cc : Hon. Bernhard Esau, Minister
Ms Graca D'Almeida, Director : Resource Management
Mr Chris Bartholomae, Deputy Director : NATMIRC

Annexure 2: Ship requirements for samples and their storage

Deployment of sampling equipment

- Power supply for laptops
- GPS system, with relatively accurate depth reading/echo sounder
- Full safety specifications/certifications

Sample preparations

- Deck space for sampling catch
- Sampling table
- 1 x net bag for CTD
- 4 x spades
- Net scale (10 tonnes)
- Small portable scale(50 kg)
- Digital Scale (5 g)
- Portable spot lights
- 10 x large bins (30 kg)
- 10 x blue baskets (25 kg)
- 10 x basins (5 kg)
- Sea water and freshwater supply.
- Ethanol storage area (safety)

Sample storage

- Fridge space
- Freezer space
- Power supply requirements for fridge and freezer.

© NMP 2014

Annexure 3: Equipment list

Deployment of sampling equipment

- GPS
- Laptops
- 2 x CTD
- 2 x stainless steel casing
- Sonar bell and echo sounder
- Deployment datasheets
- Sampling/deployment species identification guidelines and hand books (all sheets laminated)

Sample preparation

- Stationary (pen, pencils, erasers, markers)
- 8 x knives
- 4 x scissors
- 14 x protective gloves
- 2 x Digital cameras
- 3 x GoPro
- 3 x clip board
- 2 x ring binder files
- 3 x large measuring boards (1.5 m)
- 2 x small measuring board (50 cm)
- 4 x slates
- 7 x head torches
- Binoculars
- Ethanol
- Data sheets
- Water proof paper
- Sample jars/containers
- Storage (lunch box size) for samples
- Plastic bags (sandwich bags/Zip-loc bags)

Sample storage

- Boxes/ crates/drums
- Storage (large boxes) for transport
- Rope/strapping
- External hard drive to duplicate logged memory

© NMP 2014

Annexure 4: Pre-sailing safety inspection form

PRE-SEA INSPECTION CHECKLIST I

Fill in fields where possible and comments where necessary.

Carrier Vessel Details

Inspected by:

Observer / Co-ordinator		Date		Signature	
Vessel Agent		Date		Signature	
Port / Position					

Vessel Details:

Vessel Name		
Captain Name		
Call Sign		
Flag		
Size GRT		
LOA		
Number of Crew		
Vessel contact Number	Telephone	
	Fax	
	Inmarsat (A/C/M) & No.	
	Email:	
Vessel Agents	Name	
	Telephone	
	Fax	
	Mobile	

Safety Equipment:

Valid Safety Certificate (Y/N)		Issuing Authority	
Life Boats			
Type	Number	Capacity	Launch method Gravity Davit or Free Fall
Life Rafts			
Type	Number	Capacity	Hydrostatic release Yes / No	Date Service Due
Life Jackets			
Type Inflatable/Packed	Number	Location Cabin /Muster Station/ Both	SOLAS Approved Yes/ No

© NMP 2014

Immersion Suits			
	Number	Location Cabin/Muster Station/ Both	SOLAS Approved Yes/ No
Life Buoys			
	Number	Free Release Yes / No	Light/SART Attached

Flares: Location		If checked No. / Exp Date	
First Aid Materials Location		Certified Medical Officer	
Fire Extinguishers			
Positioned in main corridor's (Y/N)		Charge seals intact (Y/N)	
Positioned on bridge (Y/N)		Charge seals intact (Y/N)	

GMDSS Requirements:

Radio Equipment	HF Operational yes or no	MF Operational yes or no	VHF Operational yes or no	INMARSAT Operational yes or no	NAVTEX Operational yes or no

EPIRB's			
Type	Number	Location	Release manual / float free
SART's	Number	Location	Release manual / float free

Accommodation:

Single Cabin or Sharing	Comment
Vessel Emergency Evacuation and Muster Stations Lists – Displayed (Y/N)	

General Comments:

Annexure 5: Data sheets

TRAWL FORM 1. **TRIP SHEET**

Vessel name			
Call sign			
Skipper name		Sign:	
Skipper phone			
Permit No			
Rights holder			

Cruise Itinerary			
Embarkation		**Disembarkation**	
Port		Port	
Date		Date	
Time		Time	
Sailing		**Landing**	
Date		Date	
Time		Time	
Days in transit			
Days in fishing area			
Days fishing			
Days lost to weather			
Days lost to gear and equipment failure			

21. Comments
General

TRAWL FORM # 2 **VESSEL DATA SHEET**

Vessel name	

Vessel Details		
Call sign		
Vessel type		
Hull material		
Owners		
Port of registration		
Flagged state		
Fishing Master		
Captain		
Number of crew		
Length overall (LOA)		
Gross tonnage (GRT)		
Main engines	Make/	Power/
Hold capacity - volume (m^3)		
Hold capacity – mass (t)		

Electronic Equipment Details			
Plotters			
GPS			
Radar	12 Mile	24 Mile	48+mile
Radios	VHF	HF	
Echo Sounder			
Sonar			
Temp. recorders			

TRAWL FORM #3	**TRAWL GEAR DETAILS**		
Net #	1	2	3
Trawl Type			
Top rope length			
Foot rope length			
Vertical opening			
Horizontal opening			
Codend circumference			
Codend mesh orientation			
Mesh size (mm)			
Trawl door type			
Trawl door weight			
Warp diameter (mm)			
Net sounder (yes/no)			
Footrope bobbins fitted			
Footrope bobbins diameter			
Footrope bobbins spacing			

Random mesh measurements (mm)				

Comments

TRAWL FORM #4 **LOG FORMS**

Vessel				
Station number				
Net Number				
Barometric pressure				
Wind direction				
Beaufort scale (0 – 12)				
Sea surface colour				
Sea surface temp. (ºC)				
Cloud Cover (0 – 8)				
Echo profile retained? Y/N				
Tori lines deployed Y/N				
Shooting away: Date Start	/ /	/ /	/ /	/ /
Shooting away: Time Net Deployed	:	:	:	:
Shooting away: Fishing Time Start	:	:	:	:
Shooting away: Start Latitude (start fish)	° .	° .	° .	° .
Shooting away: Start Longitude (start fish)	° .	° .	° .	° .
Shooting away: Start Bottom Depth				
Trawl: Start Bottom Temperature				
Trawl: Trawl Speed (knots)				
Trawl: Vertical Opening				
Hauling net: End Bottom Depth				
Hauling net: End Bottom Temperature				
Hauling net: Fishing Time End	:	:	:	:
Hauling net: End Latitude (end fish)	° .	° .	° .	° .
Hauling net: End Longitude (end fish)	° .	° .	° .	° .
Hauling net: Time net on board	:	:	:	:
Hauling net: Date, net on board	/ /	/ /	/ /	/ /
Skippers Total Catch Weight (Tons)				
Net scale Total Catch Weight (Tons)				

© NMP 2014

SECTION D, APPENDIX 2 – FISHERIES AND BIODIVERSITY
2.1 PEP Biodiversity Survey FV *Zeearend*

TRAWL FORM #5 **SPECIES COMPOSTION FORMS**

Station Number:	Date:	
Species Composition	Weight (kg)	Number
Total		

TRAWL FORM #6 Females COMMERCIAL SPECIES LENGTH FREQUENCY

Vessel:				Station No:					Date:				
Species													
Weight (kg)													
Stage:	F1	F2	F3	F4	F5			F1	F2	F3	F4	F5	
0							0						
1							1						
2							2						
3							3						
4							4						
5							5						
6							6						
7							7						
8							8						
9							9						
0							0						
1							1						
2							2						
3							3						
4							4						
5							5						
6							6						
7							7						
8							8						
9							9						
0							0						
1							1						
2							2						
3							3						
4							4						
5							5						
6							6						
7							7						
8							8						
9							9						
0							0						
1							1						
2							2						
3							3						
4							4						
5							5						
6							6						
7							7						
8							8						
9							9						
0							0						
1							1						
2							2						
3							3						
4							4						
5							5						
6							6						
7							7						
8							8						
9							9						
Total:							Total:						

TRAWL FORM #6 Males **COMMERCIAL SPECIES LENGTH FREQUENCY**

Vessel:				Station No:				Date:					
Species													
Weight (kg)													
Stage:	M1	M2	M3	M4	M5			M1	M2	M3	M4	M5	
0							0						
1							1						
2							2						
3							3						
4							4						
5							5						
6							6						
7							7						
8							8						
9							9						
0							0						
1							1						
2							2						
3							3						
4							4						
5							5						
6							6						
7							7						
8							8						
9							9						
0							0						
1							1						
2							2						
3							3						
4							4						
5							5						
6							6						
7							7						
8							8						
9							9						
0							0						
1							1						
2							2						
3							3						
4							4						
5							5						
6							6						
7							7						
8							8						
9							9						
Total:							Total:						

TRAWL FORM #7 **RETAINED BYCATCH SPECIES LENGTH-FREQUENCY**

Vessel:							Station No:							Date:					
Species:																			
Weight (Kg):																			
0							0												
1							1												
2							2												
3							3												
4							4												
5							5												
6							6												
7							7												
8							8												
9							9												
0							0												
1							1												
2							2												
3							3												
4							4												
5							5												
6							6												
7							7												
8							8												
9							9												
0							0												
1							1												
2							2												
3							3												
4							4												
5							5												
6							6												
7							7												
8							8												
9							9												
0							0												
1							1												
2							2												
3							3												
4							4												
5							5												
6							6												
7							7												
8							8												
9							9												
Total:							Total:												

TRAWL FORM # 8 **BIRD OBSERVERATIONS**

Observer		Station No		Start time	
Vessel		Date		End time	

SETTING PERIOD (observe the entire setting period)					
Wind direction relative to vessel		Discarding (Y/N)		Time doors deployed	
Bird approach relative to vessel		Discards (port/starboard)		Time tori line deployed	
Net cleaned (Y/N)		Tori lines deployed (Y/N)		% tori line covering warps	

Species (including adults and juveniles)	Maturity (Juvenile or Adult)	Interactions/collisions		Impact (H,M,L)	Outcome
		Surface	Flying		
1.					
2.					
3.					
4.					
5.					
6.					
7.					
8.					
9.					
10.					
11.					
12.					

BIRD COUNT (Count birds for 10 minutes)			
Species (including adults and juveniles)	Total number of birds	Species (including adults and juveniles)	Total number of birds
Shy Albatross (adult)		*Giant petrel (southern or northern)*	
Shy Albatross (juvenile)		*Great Shearwater*	
Black-browed Albatross (adult)		*Sooty Shearwater*	
Black-browed Albatross (juvenile)		*Cory's Shearwater*	
Indian Yellow-nosed Albatross		*Sub-Antarctic Skua*	
Atlantic Yellow-nosed Albatross			
Cape Gannet (adult)			
Cape Gannet (juvenile)			
Kelp Gull (Adult)			
Kelp Gull (Juvenile)			
Storm Petrel			
White-chinned Petrel			
Pintado Petrel			

© NMP 2014

HAULING – NET INTERACTIONS (record bird interaction with net)				
29. Date:	30. Time:	31. Species	32. Where caught (wings, belly, codend):	33. Outcome (sample taken)
1.				
2.				
3.				
4.				
5.				
6.				
7.				

Comments **(i.e. tori lines not set; lots of seals)**

Impact	**Outcome**
H = Heavy (dragged under)	D = Dead, P = Possibly dead, I = injured, U = Uninjured
M = Medium (collide, flight path changed)	I = injured, U = Uninjured
L = Light (just touched)	U = Uninjured

© NMP 2014

TRAWL FORM #9 EPI-BENTHIC DATASHEET

Station number:	Date:		Vessel:		
Species ID	Count (number)	Weight (g)	Comments/descriptions and ID guidebook reference	Photo number	Retained reference number

TRAWL FORM #10 **MARINE MAMMAL DATASHEET**

<table>
<tr><td>Date</td><td>Start time:
End time:
Time of sighting:</td><td>Station No</td><td>Sighting no.</td></tr>
<tr><td colspan="4">How did this sighting occur? (please tick box)
While you were keeping a continuous watch for marine mammals ☐
Spotted incidentally by you or someone else
Other (please specify) ☐</td></tr>
<tr><td colspan="2">Vessel</td><td colspan="2">Observer</td></tr>
<tr><td colspan="3">Ship's position (latitude and longitude)</td><td>Water depth (metres)</td></tr>
<tr><td colspan="2">Species</td><td colspan="2">Certainty of identification</td></tr>
<tr><td colspan="2">Total number</td><td colspan="2">Number of adults
Number of juveniles</td></tr>
<tr><td colspan="3" rowspan="2">Description (include features such as
•</td><td>Photograph or video taken</td></tr>
<tr><td>Direction of travel of animals in relation to vessel (draw arrow)</td></tr>
<tr><td colspan="3">Behaviour</td><td>Direction of travel of animals (compass points)</td></tr>
<tr><td>Activity of ship</td><td colspan="2">Closest distance of animals from the vessel(metres)</td><td>Comments</td></tr>
</table>

TRAWL FORM #11 BIOLOGICAL FORM

Station number:						Date:				
Species	Length (cm)	Weight (g)	Maturity stage	Stomach state	Prey spp name)	Prey spp length	Digest state	Photo number	Retained reference no	Comments

Stomach State	Digest state
E = Everted	0 = Trawl caught
R = Regurgitated	1 = Very fresh
0 = Empty	2 = Possibly digested
1 - 4 = Fullness	3 = Well digested
	4 = Only traces left

APPENDIX 2 – FISHERIES AND BIODIVERSITY

2.2 Cruise Report Biodiversity Survey FV *Zeearend*

NAMIBIAN MARINE PHOSPHATE

NMP BIODIVERSITY VERIFICATION SURVEY

CRUISE: NMP Biodiversity Verification Survey
SAILING: Walvis Bay - 06:00 Wednesday 18th June 2014
RETURN: Walvis Bay – 09:00 Friday 27th June 2014

Prepared for:
Namibian Marine Phosphate (Pty) Ltd.

Prepared by:
Capricorn Fisheries Monitoring cc

August 2014

CAPFISH (Pty) LTD
Unit 15, Foregate Square. Table Bay Boulevard, 8002, South Africa
Directors: Japp, Wissema, Heinecken, Wilkinson, Ncongo
Co Reg. No. 2004 / 004844 / 07

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed "Attention: Administration Manager," at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

contents

1 SUMMARY **1**

2 PERSONNEL **1**

3 OBJECTIVES **2**

4 SURVEY DESIGN **3**

5 TRAWLING GEAR AND SAMPLING EQUIPMENT **6**

6 METHODS **6**

7 RESULTS **7**

8 CRUISE NARRATIVE **10**

9 REFERENCES **13**

Annexure 1. Coordinates for the original and actual trawl stations. trawl duration (decimal hours) and depth are also shown. 14
Annexure 2. Summary of weight per species per station. 15
Annexure 3. Summary of numbers per species per station. 17
Annexure 4. Length frequency graphs for the main commercial species 19

figures

Figure 1. Location of the proposed target dredging sites SP-1 (20-year mine plan established), SP-2 and SP-3 within the Sandpiper phosphate licence area (ML 170). 4
Figure 2. Location of the 24 stations (trawl lanes) within and surrounding SP-1. 5
Figure 3. Total catch weight (kg) per 30 minute trawl and per swept area. 8

tables

Table 1. Number (and where applicable weight) for all the species identified and recorded during the biodiversity survey 9

© NMP 2014

1 SUMMARY

The FV *Zeearend* sailed from Walvis Bay, Namibia on 18th June 2014 to conduct a Biodiversity Verification Survey in the proposed marine phosphate target dredge area, Sandpiper - 1 (SP-1), which is located in the Mining Licence Area (MLA), ML 170. The survey was successfully completed on 27th June 2014. The primary objective of the cruise was to conduct a bottom trawl survey to assess the abundance, biodiversity and distribution of commercial and other demersal fish species, epifauna, seabirds and marine mammals. The duration of the survey was eight days, during which 24 stations were completed. Each station was sampled using a double codend monk trawl net with a 20 mm codend liner net (so that the smaller epifauna organisms were retained).

A total of 28 tonnes was caught in the trawl net with an average of 1.2 tonnes per station. A total of 48 species (fish, epifauna, seabirds and mammals) was identified during the survey, of which 31 comprised fish and epifauna species, 15 seabirds and 2 marine mammals. In terms of total numbers, the fish comprised 38 421 specimens, the epifauna 131 423, seabirds 2196 and marine mammals 323. These figures excluded red jellyfish (*Chrysaora fulgida*), which were not counted. Water column characteristics were found to be consistent with those expected in the region. South Atlantic Central Water was present throughout the survey and relatively low oxygen conditions were experienced near the bottom. In general throughout the survey the bottom water layers averaged 10.68 °C, which was 2.5-4 °C cooler than the surface water.

Objectives met during the survey included:

- Estimation of the abundance (density) of the main commercial species such as hake, monk, sole and horse mackerel;
- Collection of biological information (length, weight, sex, maturity stage, stomach content) on the commercial species;
- Collection, identification, weighing and photographing of epi-benthic species;
- Collection of environmental and hydrological data using visual observations and a CTD;
- Identification and recording of marine mammals and seabirds in the area; and
- Collection of baseline data (establishment of site information base)for future monitoring;

2 PERSONNEL

There was a team of six scientists and professional staff and support from the vessels crew. Professional samplers included specialists on epifauna (benthic), fish, environmental (CTD) and mammals and birds. In addition the team included two Namibian NatMIRC scientists who provided local knowledge and experience relating to Namibian species and conditions.

© NMP 2014

PERSONNEL	ROLE	NATIONALITY
Melanie Smith	Chief scientist	SA
Victor Ngcongo	Chief technician	SA
Dr Robert Williamson	Data manager	SA
Tim McClurg	Epifauna specialist	SA
Kate Munnik	CTD scientist	SA
Ester Nangolo	Scientist	NAM
Malakia Shimhanda	Technician	NAM

3 OBJECTIVES

To address the numerous questions and issues raised by the reviewers and other responses to the Namibian Marine Phosphate (NMP) Environmental Impact Assessment (EIA, 2012) (*Japp, 2012: Appendix 1a. Namibian Marine Phosphate – Environmental Impact Assessment of Fish, mammals and seabirds: Proposed monitoring and verification of Impacts in the proposed Mining Area*), a Biodiversity Verification Survey of the proposed area to be dredged (SP-1) was carried out. The survey design was aligned with standard scientific biomass surveys with randomly selected stations. The biodiversity survey, which investigated a very small part of the broader Namibian EEZ, responded to the concerns expressed by NMP specialist consultants (detailed in the EIA, Midgley 2012) and independent reviewers of the EIA, including MFMR. A primary concern raised being that the data provided by NatMIRC for the EIA had few historical data points inside the primary target dredge area of SP-1. The biodiversity survey served to augment the limited original baseline information significantly, allowing for improved confidence in the assessments of the impacts. The survey has provided comparative data to address the following issues:

- The biodiversity indicated in the EIA;
- Size structure of the main commercial fish species of the target dredge site and MLA compared with areas outside;
- Biological information on the main commercial species to verify if there are any notable deviations from the information and assumptions made in the EIA;
- To verify the spatial distribution and possible differences in the fauna in, and adjacent to, SP-1;
- Determine a recruitment index based on size and sex structure of the main species caught using a bottom trawl in, and adjacent to, SP-1 and to test whether the results deviated significantly from those determined by the EIA.

Essentially, the survey and verification report, (*CapFish 2014, Impact Assessment - Verification Phase: Fish , Mammals and Seabirds*) were designed primarily to quantify the biodiversity of the area and to compare this with the known information for the region. The survey also obtained commercial data on the target catch (monk), hake and bycatch species. This allowed for a rough estimate of spawner biomass and recruitment, creating a baseline for future surveys in the area if dredging proceeded.
Specific objectives were to:

© NMP 2014

- Estimate the abundance (density) of the main commercial species such as hake, monk and horse mackerel;
- Collect biological information (length, sex, maturity stage, stomach content) from the commercially important/exploited species;
- Collect, identify and photograph epifauna species identify, collect and photograph epifauna species and at the same time determine the nature of the substrate and bottom profile;
- Collect environmental data using visual observations and a CTD;
- Record/identify the occurrence of surface species such as marine mammals and seabirds in the area;
- Collect baseline data for future monitoring.

4 SURVEY DESIGN

Mining Licence Area (MLA), ML 170 lies approximately 60 km offshore from Conception Bay in water depths of 190 to 300 m and covers an area of 2233 km^2. The phosphate deposits will be extracted by dredging up to 3 km^2 annually for the duration of the mining licence (20 years) in the target mine area described as Sandpiper-1 (SP-1). Subsequently with further approvals, mining could take place in the future in SP-2 and SP-3 (Figure 1).

The monkfish bottom trawler, FV *Zeearend* was used to sample 24 stations within, and in close proximity to, the target dredge area SP-1 (Figure 1). Stations were randomly selected by dividing the survey area into grid blocks (2.5 nm x 3 nm). In each grid block two stations were randomly selected using Microsoft Excel. Where possible, the first random position was selected and if there was a limitation then the next position on the list was selected. This process was continued until two stations were selected per grid block[1]. Stations that were not suitable for trawling included those in water shallower[2] than 200 m, those inside the environmental reference site areas, and within 500 m of the oceanographic instrument mooring anchor.

The original locations of the stations were randomly selected such that a broad distribution of the entire SP-1, and just outside SP-1, would be sampled. However, given that trawling is limited to waters deeper than the 200 m isobath, most of the stations on the eastern side of SP-1 had to be relocated westward to deeper water. The survey coordinates in decimal degrees of the original and actual start and end trawl positions is given in Annexure 1.

[1] Note that two stations per grid block were selected to allow for one day and one night trawl per grid block
[2] Related to the survey permit conditions as issued by MFMR – Letter MFMR to NMP 060614

© NMP 2014

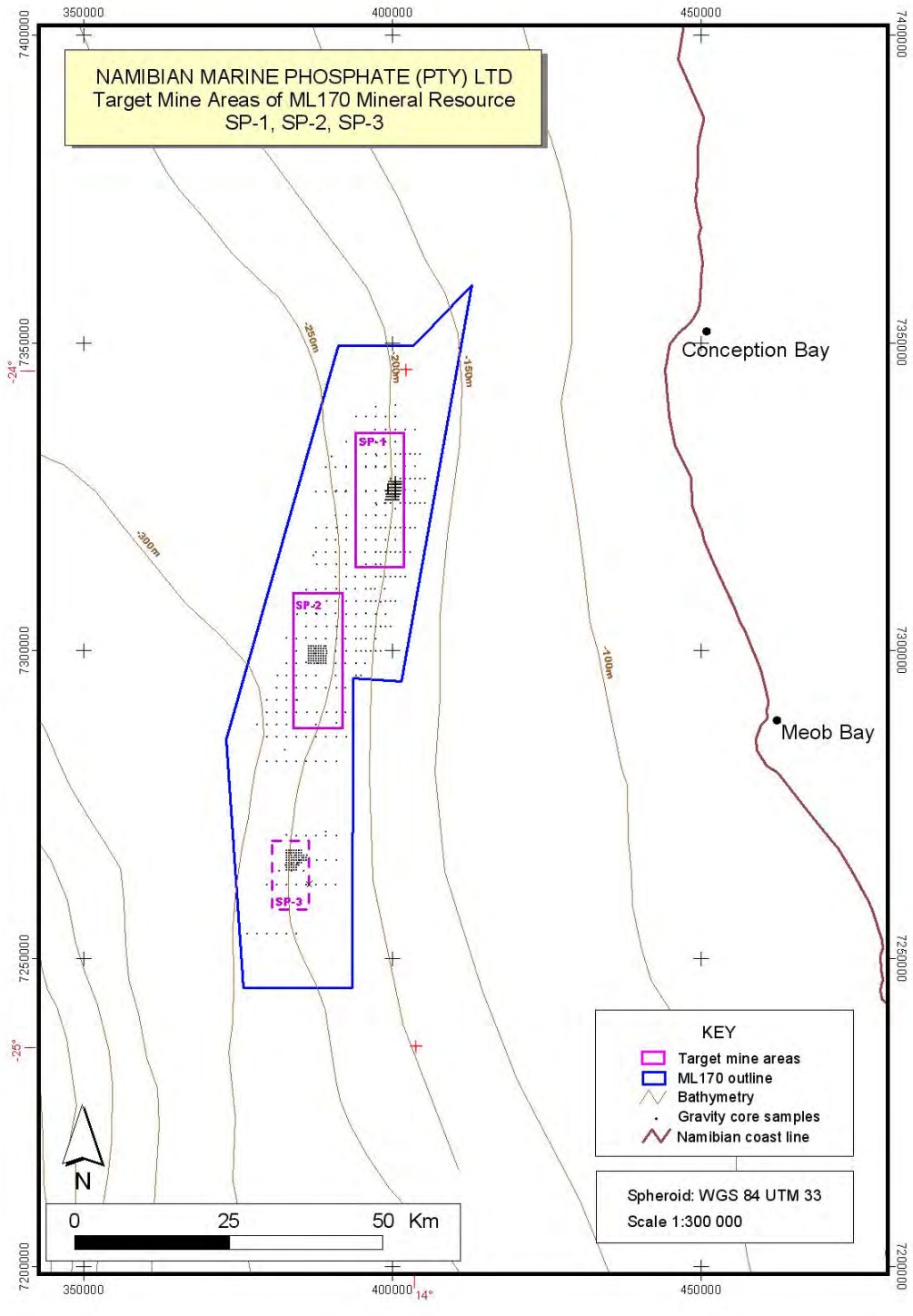


Figure 1. Location of the proposed target dredging sites SP-1 (20-year mine plan established), SP-2 and SP-3 within the Sandpiper phosphate licence area (ML 170).

© NMP 2014

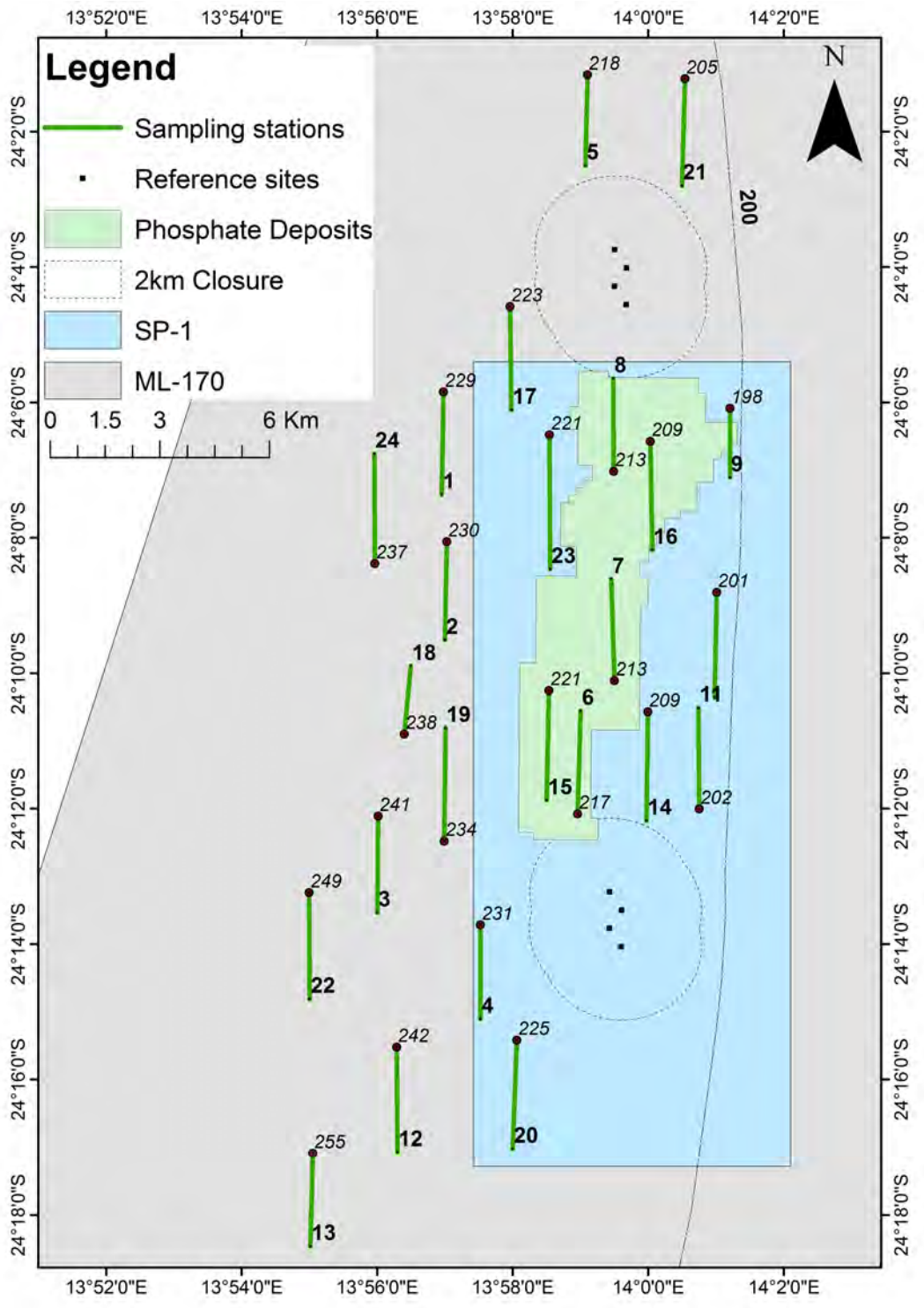


Figure 2. Location of the 24 stations (trawl lanes) within and surrounding SP-1.
Benthic sites refer to the environmental sample sites, which was closed (2 km around the sites) to survey trawling. Note all the stations were in water deeper than 200 m.

© NMP 2014

Trawl speed averaged three knots with trawl duration of 30 minutes, this being the time the net was in contact with the seabed. The trawls were orientated in a north/south direction and the distance covered at each station was approximately 1.5 nm. The length of the trawl wire was also recorded.

On average four stations were sampled per 24 hour period for the eight day survey period. Adverse weather conditions prevented sampling on one day. Twelve stations were sampled during the day between 07h00 - 17h30 and the remaining twelve during the night between 20h00 – 07h00. For daytime trawls the net was not deployed before sunrise and was raised approximately 30 minutes before sunset. In foggy or overcast conditions, these time restrictions were increased to 60 minutes after sunrise and 60 minutes before sunset. For night trawls the net was not deployed before sunset and was raised 30 minutes before sunrise. Time, location and depth were recorded per station.

5 TRAWLING GEAR AND SAMPLING EQUIPMENT

A commercial type Viking double-belly monkfish bottom trawl with a head length 86 m, footrope 108 m and vertical net opening 45 m was used. The distance between the wings during towing was approximately 40 - 50 m. The trawl was rigged with tickler chains along the footrope. The “Thyborun” trawl doors were 4.2 m square in size, weighing around 800 kg each. The codend mesh size was 120 mm but in order to retain small fish and epifauna fauna, a 20 mm inner-liner was integrated into the codend.

A Multi-probe internal logging conductivity, temperature and depth (CTD) recorder was encased inside a stainless steel protective housing and specially-designed net bag, which was attached to the head rope of the trawl net using shackles and cable ties. The CTD was lowered at every station with the trawl net through the water column to within 1 m of the seafloor. The CTD was fitted with temperature, conductivity and dissolved oxygen sensors. The CTD was removed after each trawl to download the data and check the unit.

Two digital scales tested and calibrated, were used in the onboard factory for measuring the quantities of the catch (fish and epifauna) and were calibrated to measure catch weight from 1 g to 50 kg.

6 METHODS

Processing of the catches was achieved through team work by all scientists and crew. Key components (principally fishes and jellyfish) were extracted first and the remaining material was then transferred to a sorting table where it was rigorously screened for epifauna.

The entire catch (or a subsample in the case of large catches) was sorted into species. Monk, hake, and sole were further sorted by sex. The total catch weights (kg) and number of each species (and sex where applicable) were recorded (Annexure 2 and 3). Length frequency (total length) data were collected for all commercial species (Annexure 4). For non-commercial species such as rat tails, only the weight and number of fish were recorded. If the catch was > 1.5 tonnes, the main fish species (hake, monk, sole and horse mackerel) were removed from the catch and the rest was sub-sampled by randomly selecting and measuring approximately 100 kg. Biological sampling of 15 fish per species

© NMP 2014

(individual weight and length measurements, sex, maturity stage, stomach contents) was done for hake and monk per station.

All invertebrate species retained by the net and landed as part of the catch were identified to the lowest possible taxon, counted and weighed. All large, whole epifauna species retained in the wings of the net were also included in the data counts. Photographs of invertebrates were taken for each trawl to provide an overview and a snapshot image of invertebrates occurring at each station

Density was calculated for each species per station using the swept area method. The swept area per hour at station, ***SA***, was calculated by:

© NMP 2014

A total of 48 species (fish, epifauna, seabirds and mammals) was identified during the survey, of which 31 were fish and epifauna species, 15 were seabirds and 2 were marine mammals. In terms of total numbers the fish comprised 38 421 specimens, the epifauna 131 423, seabirds 2196 and marine mammals 323. These figures excluded red jellyfish (*Chrysaora fulgida,*) which were not counted.

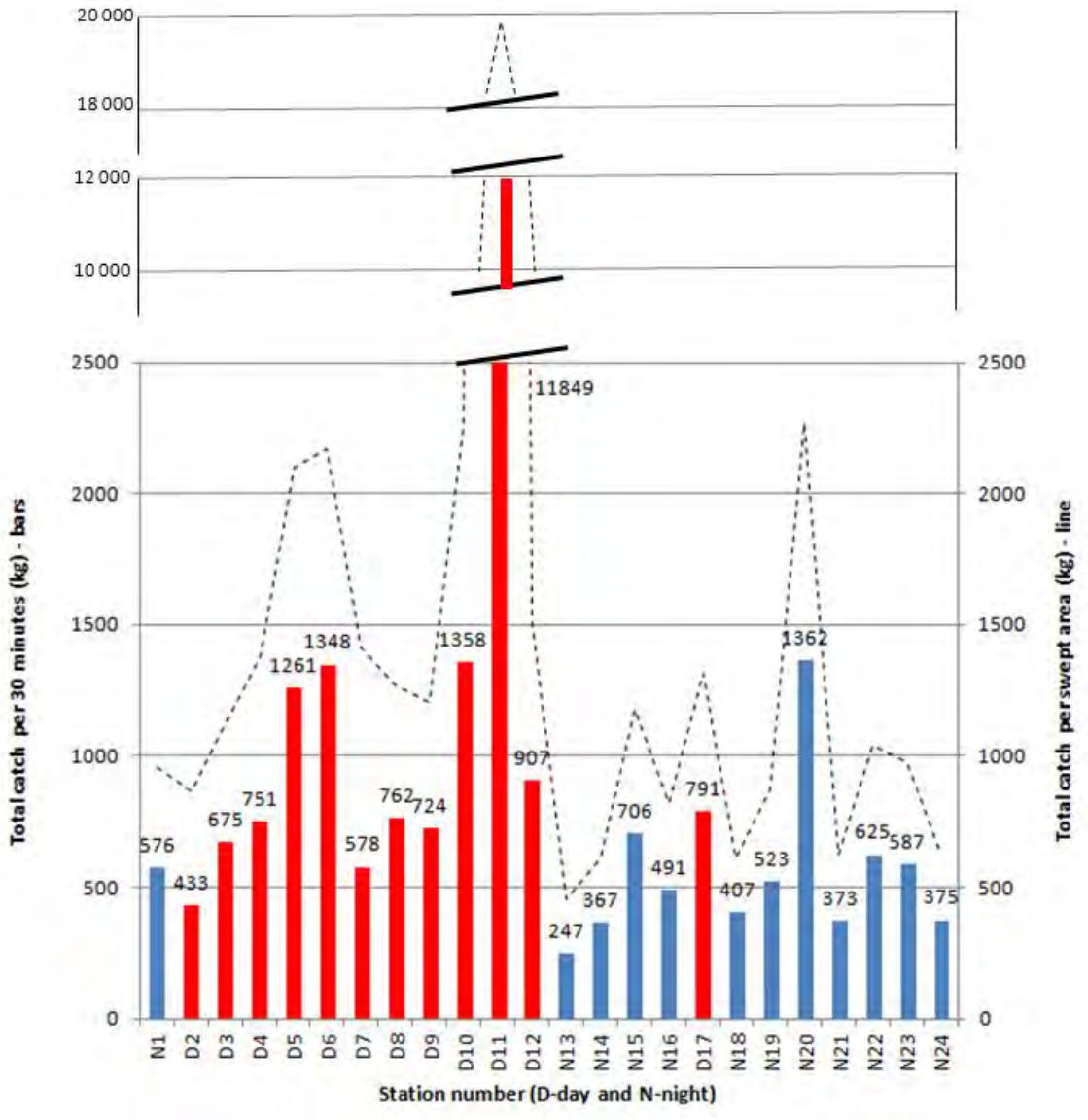


Figure 3. Total catch weight (kg) per 30 minute trawl and per swept area.
Note: Average catch per station is 1.2 tonnes per half hour and the average catch per swept area is 0.7 tonnes. Station 11 was dominated by jellyfish and thus the maximum extent is not shown.

Table 1. Number (and where applicable weight) for all the species identified and recorded during the biodiversity survey

No	Common name	Scientific name	Weight (kg)	Number
Fish and Pelagic Component				
1	Angelfish	*Brama brama*	3.06	2
2	Bonefish (long fin)	*Pterothrissus belloci*	3.23	17
3	Shallow water hake	*Merluccius capensis*	1920.89	13791.95
4	Goby (pelagic)	*Sufflogobius bibarbatus*	56.20	6564
5	Gurnard Capensis	*Chelidonichthys capensis*	0.60	2
6	Jacopever	*Helicolenus dactylopterus*	54.42	928
7	Jellyfish (purple)	*Chrysaora africana*	0.05	1
8	Jellyfish (red)	*Chrysaora fulgida*	17722.98	0
9	Jellyfish (white)	*Aequorea forskalea*	405.24	1959
10	Maasbanker	*Trachurus trachurus*	21.42	143
11	Mackerel	*Scomber japonicus*	8.38	4
12	Monk	*Lophius vomerinus*	1703.56	3565.76
13	Rat Tail Short Nose Rough	*Coelorinchus simorhynchus*	672.48	9530
14	Shark (bluntnose sixgill)	*Hexanchus griseus*	2.79	2
15	Squid (Angola flying)	*Todarodes angolensis*	174.29	1058
16	Squid (flying)	*Toderopsis sagittatus*	0.05	1
17	West Coast sole	*Austroglossus microlepis*	157.26	316.85
Epifauna Component				
18	Hermit crab	*Parapaguridae* sp.	4.81	7
19	Mantis shrimp	*Squilla* sp.	19.64	853
20	Prawn	*Funchalia woodwardi*	0.06	6
21	Prawn (Solenocera)	*Solenocera africana*	0.22	70
22	Sea cucumber (white)	*Pseudocnus thandari*	0.20	43
23	Sea pen	*Verellidae* sp.	28.37	76612
24	Ascidians	*Molgula* sp.	4616.91	108813
25	Sponge (brown)	*Porifera* sp.	376.63	1334
26	Starfish (long armed)	*Astropecten* sp.	0.03	5
27	Starfish (short armed)	*Odontaster australis*	0.05	15
28	Swimming crab	*Bathynectus piperitus*	113.36	2613
29	Whelk (dog)	*Nassarius wolfii*	0.01	7
30	Whelk (sponge)	Faciolariidae (plus sponge) sp.	2.82	25
31	Whelk (tulip)	Fasciolariidae *lugubra*	7.23	188
Seabird Component				
32	Sub Antarctic skua	*Catharacta antarctica*		436
33	Kelp gull	*Larus dominicanus*		1
34	Tern	Sternidae		1
35	Cape Gannet	*Morus capensis*		13
36	Cape cormorant	*Phalacrocorax capensis*		1
37	Storm petrel	Hydrobatidae		75
38	Albatross	Diomedeidae		33
39	Shy albatross	*Thalassarche cauta*		160
40	Black browed albatross	*Thalassarche melanophrys*		253
41	Yellow nosed albatross	*Thalassarche chlororhynchos/carteri*		9
42	Pintado petrel	*Daption capense*		19
43	Petrel	Procellaridae		10
44	White chinned petrel	*Procellaria aequinoctialis*		999
45	Shearwater	*Puffinus*		8
46	Sooty shearwater	*Puffinus griseus*		104
Marine mammal Component				
47	Cape fur seal	*Arctocephalus pusillus pusillus*		73
48	Dusky Dolphin	*Lagenorhynchus obscurus*		250

© NMP 2014

The CTD with the attached temperature, salinity and oxygen sensors was attached to the trawl net to allow recordings to be collected simultaneously with trawling. The complete CTD report (CTD deployment report FV *Zeearend*. Lwandle 2013) can be found in Appendix 2: 2.3. In summary 22 of the 24 trawls undertaken during the biomass verification survey provided acceptable results for temperature and 19 trawls yielded reasonable salinity results (with exceptions being: Trawls 13, 14, 17, 20 and 21). The trawls where successful temperature and/or salinity data were recorded can be compared to the fisheries and biomass data from the respective trawls. Temperature profiles showed a well-mixed upper water column in most cases, with slight stratification occurring from Trawl 10 onwards. This is to be expected as the survey took place just after an extended period of rough seas and considerable wave action in the survey area. The weather conditions calmed significantly from Trawl 5 onwards and this may have allowed slight stratification of the upper layers of the water column. In general the upper water column was approximately 2.5 – 4 °C warmer than the near seafloor temperatures (>200 m). Temperature on or near the sea floor throughout the survey averaged 10.68°C. This is within the range of expected winter values for the region (Shannon and Nelson 1996).

Salinity and temperature data indicated the presence of South Atlantic Central Water (SACW) for the majority of the survey. SACW upwells from approximately 200 m below the surface with a salinity of 34.7-35.65 PSU and temperatures between 8 and 16°C (Shannon and Nelson 1996, Mohrholz *et al*. 2001, Duncombe Rae 2005). The dissolved oxygen levels near the seafloor for most of the trawls were low (approx. 3-10 %) as can be expected in the continental shelf zone offshore of Namibia (Monteiro and van der Plas, 1996).

8 CRUISE NARRATIVE

Wednesday 18 June 2014

All scientific personnel were on board FV *Zeearend* by 07h00 on Wednesday 18 June 2014. Emergency drills were conducted at 10h00. The vessel set sail at 07h40 rounding Pelican Point and heading southwards to the survey area. Winds were in a southerly direction (19+ knots) and sea conditions were moderate (1.8 m). It took seven hours to sail to the survey area - **Station 1**. The net was deployed at 17h50 and the entire operation including sampling took five hours to complete. Initially the CTD and frame were attached to the head rope of the trawl net above its mouth. In theory this was the safest place for the CTD to be positioned as it was clear from most of the metal tickler chains, bobbins and steel cabling. However, due to the configuration of the net setting gear and associated stern rollers, attaching the CTD to this position proved problematic. During the first deployment the CTD frame was rolled back onto one of the stern rollers as the net was being set. This caused damage to the steel frame but did not damage the CTD itself. For subsequent trawls the CTD was place higher up the top rope.

Station 1: Night trawl , depth 229 m.

Thursday 19th June 2014

No stations were conducted today due to unfavourable weather and sea conditions. Southerly winds reached 35 knots and waves were moderately high at 5.5 m. The CTD frame was bent back into shape and reinforced with steel rods.

© NMP 2014

Friday 20th June 2014

Favourable weather conditions - wind direction south, light breeze (11 knots) and small wavelets (0.2 m) therefore sampling resumed at **Station 2.** Operations were delayed for about 30 minutes to resolve problems with the calibration of the oxygen sensor on the CTD. In the end the CTD was deployed but the oxygen sensor was not working. Sampling was slow but thorough. The entire catch was weighed, counted and, for the commercial fish length frequency was measured. Hake and monk were staged and stomach content data collected. For **Station 3** the oxygen sensor on the CTD was repaired and calibrated. For subsequent trawls the CTD successfully collected temperature, salinity, oxygen and depth. Bag weight was relatively small (650 kg) and sampling was completed in 1.5 hours. A small six gilled cow shark *Hexanchus griseus* weighing 1.15 kg was caught. **Station 4** was dominated by ascidians (350 kg) thus hake, monk, sole, rat tails, squid and jellyfish were removed from the stocker pond first before the rest of the catch was subsampled i.e. 5 out of 19 bins[4] were sorted and sampled.

Station 2: Day trawl, depth 230 m.
Station 3: Day trawl, depth 241 m.
Station 4: Day trawl, depth 231 m.

Saturday 21st June 2014

Very calm sea conditions with a light breeze from the west. It was decided that Station 5 would be conducted near the end of the survey if time permitted since we had already lost a sample day due to unfavourable weather conditions. All the stations sampled today therefore fell inside the phosphate deposit area within SP-1 (Figure 1). **Station 6** was a large catch >1.3 tonnes thus monk, hake, sole and jellyfish were removed first before the rest of the catch was subsampled i.e. 7/22 bins were sorted and sampled. White sea cucumbers (*Pseudocnus thandari*) were recorded at this station. For **Station 7** hake, monk, jellyfish, squid and sole were removed before 4/9 baskets were subsampled. This station had the highest abundance of gobies (*Sufflogobius bibarbatus*) and a single cape gurnard (*Chelidonichthys capensis*) was caught and measured. A large pod (about 150 individuals) of dusky dolphins (*Lagenorhynchus obscurus*) was sighted while the observer was keeping a continuous watch for marine mammals. They were leaping and swimming next to the bow of the vessel. **Station 8** was completed successfully; hake, monk and jellyfish were removed before the rest of the catch was subsampled.

Station 6: Day trawl, depth 217 m.
Station 7: Day trawl, depth 213 m.
Station 8: Day trawl, depth 13 m.

[4] Note a full bin was approximately 30 kg.

© NMP 2014

Sunday 22nd June 2014

Sea conditions were glassy and very calm with no wind. The entire catch at **Station 9** was sorted and sampled (i.e. no subsamples were taken). Adult horse mackerel (*Trachurus capensis*) were caught at this station as well as several small starfish (*Odontaster australis*). During the mammal observations 100 dusky dolphins were sighted about 1700 m from the vessel. For **Station 10** the entire catch was also sorted and sampled. A decomposed dead seal was caught in the net and a large whale vertebra bone. **Station 11** was completely dominated by the red jellyfish (*Chrysaora fulgida*) with 11.8 tonnes caught while the net descended to the seafloor and therefore does not show a true reflection of the catch composition for that station. Nevertheless, the rest of the catch (50 kg) was sampled entirely and included two angel fish (*Brama brama*). **Station 12** was subsampled after removing hake, monk, rat tails, gobies, squid and jacopever from the catch.

Station 9: Day trawl, depth 217 m.
Station 10: Day trawl, depth 198 m.
Station 11: Day trawl, depth 202 m.
Station 12: Day trawl, depth 242 m.

Monday 23rd June 2014

Sea conditions were very calm and water surface was like a mirror. No wind and no swell. For **Station 17** the hake, monk, jellyfish, squid and sole were removed and 4/12 bins were sorted and sampled. Two bonefish (*Pterothrissus belloci*) were found at this station. **Station 15 was** also subsampled after monk, hake, jellyfish and sole were removed and 4/16 bins sorted and sampled. For **Station 16** sea temperatures were warm with a CTD reading of 10 °C at the sea floor. To reduce the time spent removing the CTD from the net bag and frame a small hole was made for ease of access to the data port of the unit. 4/10 bins were subsampled for this station.

Station 17: Day trawl, depth - 223 m.
Station 15: Night trawl, depth - 221 m.
Station 16: Night trawl, depth - 209 m.

Tuesday 24th June 2014

Sea conditions were calm and glassy with a light breeze from the south-west. **Station 23** was subsampled and 4/13 bins were sorted. One prawn species (*Solenocera africana*) was found at this station. **Station 5** was a relatively large catch (>1.2 tonnes) dominated by ascidians and hake. Three adult chub mackerel (*Scomber japonicus*) greater than 50 cm were also found at this station. The entire catch was sorted at **Station 21**. A single lantern fish (*Lampanyctodes hectoris*) was found at this station but was not recorded given that it belonged to the unsorted sample. For **Station 14** the entire catch was sampled since night trawls appear to be smaller than day trawls. A different but not unique purple coloured jellyfish (*Chrysaora africana*) was found at this station.

Station 23: Night trawl, depth - 221 m.
Station 5: Day trawl, depth - 218 m.
Station 21: Night trawl, depth - 205 m.
Station 14: Night trawl, depth - 209 m.

Wednesday 25th June 2014

Weather conditions picked up slightly with a gentle south-westerly wind (7 knots) and larger wavelets (0.7 m). **Station 13** was a particularly small catch (270 kg) thus the entire catch was sampled. The substrate was dominated by dead clam shells. 19/30 bins were subsampled for **Station 20** due to the

© NMP 2014

large amount of ascidians. **Station 19** was similar in biodiversity and abundance but 4/11 bins were sampled.

Station 13: Night trawl, depth - 255 m.
Station 20: Day trawl, depth - 225 m.
Station 19: Night trawl, depth - 234 m.

Thursday 26th June 2014

There was a switch in the wind direction from a gentle north-west breeze (7 knots) to a strong southerly wind (22+ knots) with 3 m waves. **Station 18** catch was fairly small and therefore the entire catch was sampled. During **Station 22** the oxygen readings on the CTD were recording unusual values, which could have been a result of being bumped slightly during deployments. Jacopever (*Helicolenus dactylopterus*) dominated this station. For **Station 24** the oxygen sensor was re-calibrated and working well for the last station of the survey. Catch was fairly small but a subsample was taken.

Station 18: Night trawl, depth - 238 m.
Station 22: Day trawl, depth - 249 m.
Station 24: Night trawl, depth - 237 m.

9 REFERENCES

Duncombe Rae 2005 - Duncombe Rae CM. 2005. A demonstration of the hydrographic partition of the Benguela upwelling ecosystem at 26°40'S. *African Journal of Marine Science* **27**(3):617–628.

JNCC (2010) Marine mammal recording forms (Detailed sighting records).Joint Nature Conservation Committee.

Mohrholz *et al*. 2001 - Mohrholz V, Schmidt M, Lutjeharms JRE. 2001. The hydrography and dynamics of the Angola Benguela Frontal Zone and environment in April 1999. *South African Journal of Science* **97**:199–210.

Monteiro PMS, van der Plas AK. 1996. Low Oxygen Water (LOW) variability in the Benguela System: Key processes and forcing scales relevant to forecasting. In: Wefer G, Berger WH, Siedler G, Webb DJ (eds) *The south Atlantic: Present and past circulation.* Spinger-Verlag Berlin, Germany, pp 163–210.

Shannon and Nelson 1996 - Shannon LV, Nelson G. 1996. The Benguela: Large scale features and processes and system variability. In: Wefer G, Berger WH, Siedler G, Webb DJ (eds) *The south Atlantic: Present and past circulation.* Spinger-Verlag Berlin, Germany, pp 163–210.

© NMP 2014

Annexure 1. Coordinates for the original and actual trawl stations. trawl duration (decimal hours) and depth are also shown.

Station Number	Date Start	Time Start	Day or Night	Start Bottom Depth	End Bottom Depth	Trawl time (hr)	Original start latitude	Original start longitude	Original end latitude	Original end longitude	*Actual start latitude*	*Actual start longitude*	*Actual end latitude*	*Actual end longitude*
1	18-Jun-14	18:05	N	229	231	0.5	-24.09	13.95	-24.12	13.95	-24.10	13.95	-24.12	13.95
2	20-Jun-14	07:35	D	230	235	0.5	-24.13	13.95	-24.16	13.95	-24.13	13.95	-24.16	13.95
3	20-Jun-14	12:35	D	241	244	0.5	-24.19	13.93	-24.22	13.93	-24.20	13.93	-24.23	13.93
4	20-Jun-14	16:12	D	231	232	0.5	-24.23	13.96	-24.25	13.96	-24.23	13.96	-24.25	13.96
5	24-Jun-14	15:05	D	218	216	0.5	-24.30	13.98	-24.28	13.98	-24.02	13.99	-24.04	13.98
6	21-Jun-14	07:13	D	217	219	0.5	-24.20	13.98	-24.18	13.98	-24.20	13.98	-24.18	13.98
7	21-Jun-14	11:56	D	213	214	0.7	-24.18	13.99	-24.15	13.99	-24.17	13.99	-24.14	13.99
8	21-Jun-14	16:00	D	213	213	0.5	-24.13	13.99	-24.10	13.99	-24.12	13.99	-24.09	13.99
9	22-Jun-14	07:05	D	198	198	0.5	-24.10	14.03	-24.13	14.03	-24.10	14.02	-24.12	14.02
10	22-Jun-14	10:22	D	201	202	0.5	-24.14	14.03	-24.17	14.03	-24.15	14.02	-24.17	14.02
11	22-Jun-14	13:45	D	202	203	0.5	-24.20	14.04	-24.23	14.04	-24.20	14.01	-24.18	14.01
12	22-Jun-14	17:00	D	242	244	0.5	-24.25	14.02	-24.28	14.02	-24.26	13.94	-24.28	13.94
13	25-Jun-14	00:55	N	255	255	0.6	-24.28	13.99	-24.26	13.99	-24.28	13.92	-24.31	13.92
14	24-Jun-14	21:55	N	209	210	0.5	-24.20	14.00	-24.18	14.00	-24.18	14.00	-24.20	14.00
15	23-Jun-14	19:00	N	221	222	0.5	-24.19	13.98	-24.17	13.98	-24.17	13.98	-24.20	13.98
16	23-Jun-14	22:20	N	209	209	0.5	-24.13	14.01	-24.11	14.01	-24.11	14.00	-24.14	14.00
17	23-Jun-14	12:55	D	223	224	0.5	-24.08	13.97	-24.10	13.97	-24.08	13.97	-24.10	13.97
18	26-Jun-14	00:55	N	238	238	0.5	-24.16	13.94	-24.18	13.94	-24.18	13.94	-24.16	13.94
19	25-Jun-14	21:55	N	234	233	0.5	-24.18	13.95	-24.21	13.95	-24.21	13.95	-24.18	13.95
20	25-Jun-14	17:40	N	225	225	0.5	-24.26	13.97	-24.28	13.97	-24.26	13.97	-24.28	13.97
21	24-Jun-14	18:55	N	205	205	0.5	-24.30	14.03	-24.28	14.03	-24.02	14.01	-24.05	14.01
22	26-Jun-14	18:52	N	249	252	0.5	-24.23	14.02	-24.21	14.02	-24.22	13.92	-24.25	13.92
23	24-Jun-14	01:35	N	221	221	0.5	-24.21	14.03	-24.18	14.03	-24.11	13.98	-24.14	13.98
24	26-Jun-14	22:15	N	237	235	0.5	-24.10	14.04	-24.08	14.04	-24.14	13.93	-24.11	13.93

© NMP 2014

Annexure 2. Summary of weight per species per station.

Station Number		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Sampling Time (Day/Night)		**N**	**D**	**D**	**D**	**D**	**D**	**D**	**D**	**D**	**D**	**D**	**D**	**N**	**N**	**N**	**N**	**D**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
Water Depth at start (m)		**229**	**230**	**241**	**231**	**218**	**217**	**213**	**213**	**198**	**201**	**202**	**242**	**255**	**209**	**221**	**209**	**223**	**223**	**238**	**234**	**205**	**249**	**221**	**237**
Fish and Pelagic Component	**Common name**																								
Aequorea forskalea	Jellyfish (white)			15	4		13	17	25	39	53		32	61	6	29	13	10	13	29	11	5	30	5	3
Austroglossus microlepis	West Coast sole (female)	11	4	4	3	7	6	5	4	1	2	1	6		7	6	7	2	7	21	9	4	4	7	
Austroglossus microlepis	West Coast sole (male)	1		1	1	2	1	1	1		1	1	2		1	2	2	1	0	1	9	1	0	1	
Austroglossus sp.	Sole															0									
Brama brama	Pomfret											3													
Chelidonichthys capensis	Cape gurnard							0		0															
Chrysaora africana	Jellyfish (purple)										0														
Chrysaora fulgida	Jellyfish (red)	180	132	123	243	113	673	480	232	567	1165	11800	463	96	101	122	161	311	105	112	56	215	169	144	110
Coelorinchus simorhynchus	Rattail (short nose rough)	18	44	34	20	77	14	6	11	4	4		39	8	12	52	17	54		55	16	25	79	44	42
Helicolenus dactylopterus	Jacopever			5									7	5									35		3
Hexanchus griseus	Shark (bluntnose sixgill)			1														1							
Lophius vomerinus	Monk	37																							
Lophius vomerinus	Monk (female)	44	62	39	40	38	49	27	35	31	19	14	52	7	31	33	19	60	36	45	23	34	58	39	47
Lophius vomerinus	Monk (juvenile)					1	1	1	1				2		3	1	1	1	1	4	2	2	1	2	2
Lophius vomerinus	Monk (male)	46	63	34	32	37	31	21	29	14	15	8	52	10	13	36	15	39	24	42	21	20	87	39	44
Merluccius capensis	Hake	104	37		14	197																0			
Merluccius capensis	Hake (female)	14	38	33	48	56	66	51	73	32	41	7	87	12	42	35	31	57	17	26	41	26	33	42	31
Merluccius capensis	Hake (male)	15	30	32	35	46	39	38	43	17	21	2	57	7	36	30	20	46	8	16	23	25	31	32	17
Pterothrissus belloci	Bonefish (long fin)				0	1										1	0	0					0	0	
Scomber japonicus	Mackerel					6															2				
Sufflogobius bibarbatus	Pelagic goby	3	1	2	1	2	1	7	3	1	2	0	4	1	3	3	6	2	4	3	2	4	1	0	2
Todarodes angolensis	Squid (Angola flying)	3	20	9	31	6	22	7	14	3	2	2	19	1	2	5	2	13		3	2	2	8		3
Toderopsis sagittus	Squid (flying)																		0						
Trachurus trachurus	Maasbanker							0		3	10	8	0												

© NMP 2014

Station Number		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Sampling Time (Day/Night)		**N**	**D**	**D**	**D**	**D**	**D**	**D**	**D**	**D**	**D**	**D**	**D**	**N**	**N**	**N**	**N**	**D**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
Water Depth at start (m)		**229**	**230**	**241**	**231**	**218**	**217**	**213**	**213**	**198**	**201**	**202**	**242**	**255**	**209**	**221**	**209**	**223**	**223**	**238**	**234**	**205**	**249**	**221**	**237**
Epifaunal Component																									
Astropecten sp.	Starfish (long armed)													0											
Bathynectus piperitus	Swimming crab	3	3	2	5	12	9	4	5	3	5	1	3	5	8	7	6	4	2	3	9	8	3	5	3
Callianassa africana	Mud prawn								0																
Fasciolaria lugubris	Whelk (tulip)	0	0	0	0			3						6	0	0	0	0	0	0	0	0	0	0	
Funchalia woodwardi	Prawn												0					0							
Molgula sp.	Ascidians	69	56	317	347	644	368	175	280	6	17		62		100	324	185	162	146	131	1101		8	211	23
Nassarius wolffi	Whelk (dog)													0											
Odontaster australis	Starfish (cushion star)									0	0														
Paguridae	Hermit crab													5											
Porifera	Sponge (brown)	26	28	22		12	10	2	3	0	1		20	45	1	20	3	25		26	32	3	73	12	46
Pseudocnus thandari	Sea cucumber					0	0	0								0	0				0				
Pterygosquilla armata capensis	Mantis shrimp	1	1	1	1	1	1	1	1	0	0		1	2	1	1	1	1	1	3	1	0	3	2	0
Solenocera africana	Prawn													0					0	0					0
Veretellidae	Sea pen	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Total Biomass (kg)		**576**	**522**	**675**	**826**	**1261**	**1303**	**847**	**762**	**724**	**1358**	**11849**	**907**	**272**	**367**	**706**	**491**	**791**	**366**	**523**	**1362**	**373**	**625**	**587**	**375**

© NMP 2014

Annexure 3. Summary of numbers per species per station.

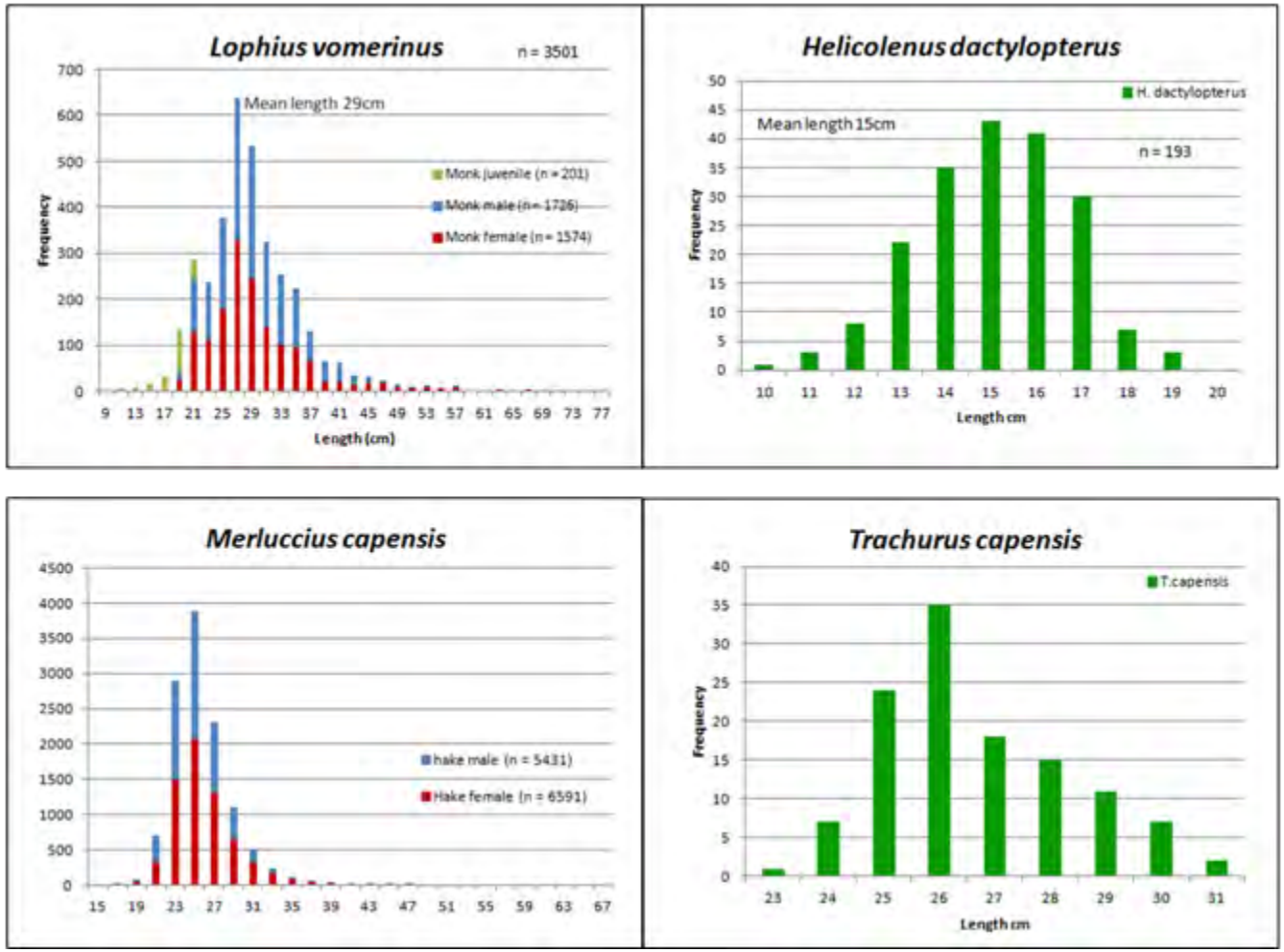
Station Number		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Sampling Time (Day/Night)		**N**	**D**	**D**	**D**	**D**	**D**	**D**	**D**	**D**	**D**	**D**	**D**	**N**	**N**	**N**	**N**	**D**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
Water Depth at start (m)		**229**	**230**	**241**	**231**	**218**	**217**	**213**	**213**	**198**	**201**	**202**	**242**	**255**	**209**	**221**	**209**	**223**	**223**	**238**	**234**	**205**	**249**	**221**	**237**
Fish and Pelagic Component	**Common name**																								
Aequorea forskalea	Jellyfish (white)			215	4		29	26	55	86	114		69	116	14	64	28	21	31	64	25	71	908	12	6
Austroglossus microlepis	West Coast sole (female)	16	6	7	5	15	11	6	13	4	5	3	7		17	15	19	5	13	31	20	12	6	15	
Austroglossus microlepis	West Coast sole (male)	1		1	4	6	2	3	2		2	3	3		2	5	5	2	1	2	13	4	1	2	
Austroglossus sp.	Sole															1									
Brama brama	Pomfret											2													
Chelidonichthys capensis	Cape gurnard							1		1															
Chrysaora africana	Jellyfish (purple)										1														
Chrysaora fulgida	Jellyfish (red)																								
Coelorinchus simorhynchus	Rattail (short nose rough)	165	441	427	284	1068	234	105	251	127	41		510	94	376	783	490	57		940	344	593	874	925	402
Helicolenus dactylopterus	Jacopever			83									108	83									615		39
Hexanchus griseus	Shark (bluntnose sixgill)			1														1							
Lophius vomerinus	Monk	94																							
Lophius vomerinus	Monk (female)	68	105	69	75	92	83	27	64	45	33	13	102	18	46	58	33	93	83	88	51	57	110	68	82
Lophius vomerinus	Monk (juvenile)					12	7	8	17				11		21	8	13	7	11	25	11	17	10	11	10
Lophius vomerinus	Monk (male)	86	127	81	73	90	71	33	62	26	42	15	133	24	34	72	41	91	67	94	52	45	176	85	90
Merluccius capensis	Hake	763	310		213	730																1			
Merluccius capensis	Hake (female)	79	287	254	322	347	586	264	566	272	350	43	513	63	307	275	206	434	87	156	286	149	176	297	149
Merluccius capensis	Hake (male)	112	250	260	234	329	385	234	385	163	230	17	470	44	285	251	163	376	57	115	206	166	209	271	98
Pterothrissus belloci	Bonefish (long fin)				2	6										3	1	2					1	2	
Scomber japonicus	Mackerel					3															1				
Sufflogobius bibarbatus	Pelagic goby	139	149	173	98	309	131	462	263	74	232	1	397	53	354	350	573	270	590	424	223	459	324	340	175
Todarodes angolensis	Squid (Angola flying)	52	134	70	174	18	148	24	99	16	18	12	115	4	9	26	14	66		11	9	5	25		10
Toderopsis sagittus	Squid (flying)																		1						
Trachurus trachurus	Maasbanker							1		24	67	50	1												

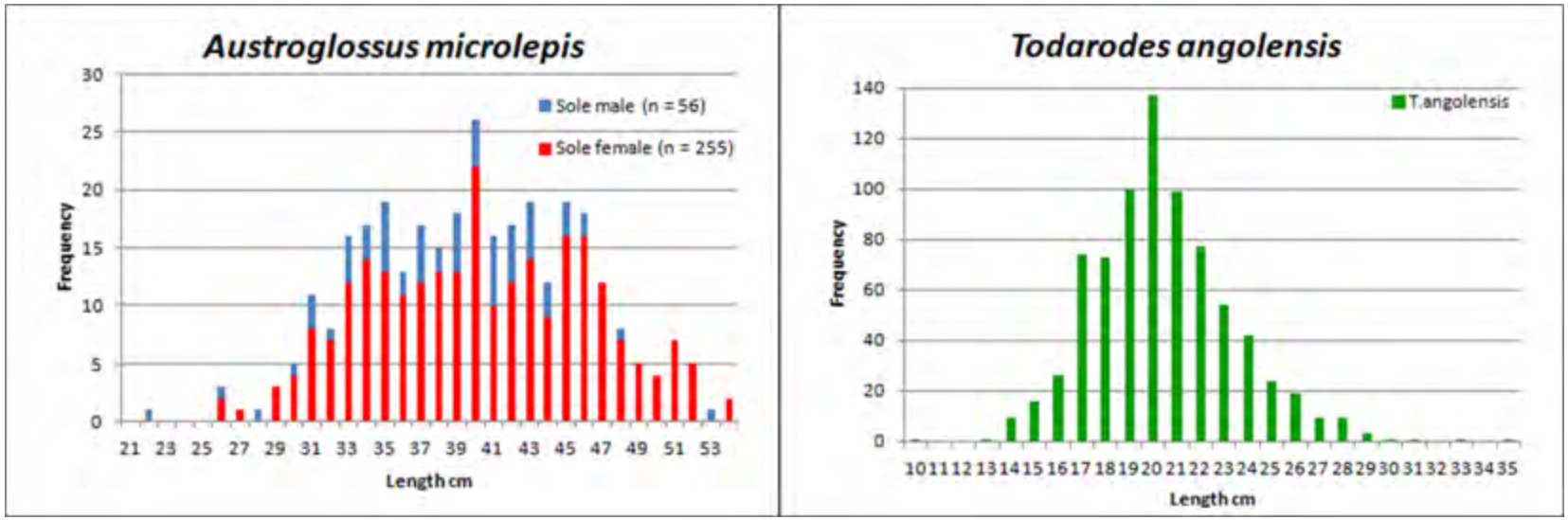
© NMP 2014

Station Number		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Sampling Time (Day/Night)		**N**	**D**	**D**	**D**	**D**	**D**	**D**	**D**	**D**	**D**	**D**	**D**	**N**	**N**	**N**	**N**	**D**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
Water Depth at start (m)		**229**	**230**	**241**	**231**	**218**	**217**	**213**	**213**	**198**	**201**	**202**	**242**	**255**	**209**	**221**	**209**	**223**	**223**	**238**	**234**	**205**	**249**	**221**	**237**
Epifaunal Component	**Common species**																								
Astropecten sp.	Starfish (long armed)													5											
Bathynectus piperitus	Swimming crab	92	88	41	117	143	204	64	145	73	107	31	87	108	172	175	156	98	66	73	176	212	68	126	79
Callianassa africana	Mud prawn								1																
Fasciolaria lugubris	Whelk (tulip)	9	3	5	10			14						89	1	15	12		6	5	3	1	8	16	10
Funchalia woodwardi	Prawn												3					3							
Molgula sp.	Ascidians	3226	7760	1275	40371	9207	5435	10939	4001	89	242		884		209	4622	2638	2308	2314	1873	15728		109	3014	328
Nassarius wolffi	Whelk (dog)													7											
Odontaster australis	Starfish (cushion star)									10	5														
Paguridae	Hermit Crab													7											
Porifera	Sponge (brown)	219	285	46		97	22	11	7	1	1		42	85	5	41	23	51		164	165	17	151	91	95
Pseudocnus thandari	Sea cucumber					6	10	1								10	12				3				
Pterygosquilla armata capensis	Mantis shrimp	54	50	39	24	34	26	18	19	2	4		39	48	12	20	40	80	44	67	36	3	124	101	18
Solenocera africana	Prawn													3					31	32					4
Veretellidae	Sea pens	3240	3240	3240	2945	3240	3352	2209	3240	3240	3240	3240	3240	2945	3240	3240	3240	3240	3600	3240	3240	3240	3240	3240	3240
Total Counts		**8415**	**13235**	**6287**	**44953**	**15752**	**10736**	**14450**	**9190**	**4253**	**4734**	**3430**	**6734**	**3795**	**5104**	**10034**	**7707**	**7205**	**7002**	**7404**	**20592**	**5052**	**7135**	**8616**	**4835**
Numbers of Taxa		**17**	**15**	**18**	**17**	**19**	**17**	**20**	**17**	**17**	**18**	**12**	**19**	**18**	**17**	**20**	**19**	**19**	**16**	**18**	**19**	**17**	**19**	**17**	**17**

Annexure 4. Length frequency graphs for the main commercial species

© NMP 2014


Lophius vomerinus
n = 3501
Mean length 29cm
Monk juvenile (n = 201)
Monk male (n = 1726)
Monk female (n = 1574)
Frequency
Length (cm)
Helicolenus dactylopterus
H. dactylopterus
Mean length 15cm
n = 193
Frequency
Length cm
Merluccius capensis
hake male (n = 5431)
Hake female (n = 6591)
Trachurus capensis
T.capensis
Frequency
Length cm


Austroglossus microlepis
Sole male (n = 56)
Sole female (n = 255)
Frequency
Length cm
Todarodes angolensis
T.angolensis
Frequency
Length cm

APPENDIX 2 – FISHERIES AND BIODIVERSITY

2.3 CTD Deployment Report FV *Zeearend*

NAMIBIAN MARINE PHOSPHATE

BIODIVERSITY VERIFICATION SURVEY

CTD REPORT

Prepared for:
Namibian Marine Phosphate (Pty) Ltd.

Prepared by:
Lwandle Technologies (Pty) Ltd.

30 July 2014

Job no. 204

LWANDLE TECHNOLOGIES (PTY) LTD
The Old Warehouse, Black River Park, Fir Road, Observatory 7925, South Africa
Directors: C.P. Matthysen, B.J. Spolander
Co Reg. No. 2003/015524/07

CTD DEPLOYMENT AND INTERPRETATION TEAM:

Dr. Robin Carter – Lwandle Technologies
Kate Munnik – Lwandle Technologies

BIODIVERSITY VERIFICATION SURVEY TEAM:

Kate Munnik – Lwandle Technologies
Melanine Smith – CapFish CC
Victor Ngcongo - CapFish CC
Robert Williamson - CapFish CC
Timothy McClurg –CapFish CC
Ester Nangolo – MFMR Namibia
Malakia Shimhanda- MFMR Namibia
Jeremy Midgley – Client Representative

Date	Version	Revised	Reviewed
30/07/2014	0.1	Kate Munnik	Erich Koch

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed “Attention: Administration Manager,” at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

SUMMARY

Namibian Marine Phosphate (NMP) proposes to recover pelletal phosphate from the Sandpiper ore body situated in Mining Licence Area (MLA) 170, offshore of Namibia. An Environmental Impact Assessment (EIA) for the marine component of this project was submitted in 2012. A biodiversity verification survey was conducted to investigate concerns raised during the production of the review of the EIA report. This report details the water column characteristics during the fisheries biodiversity verification survey. This report should be viewed as a supplement to the detailed fisheries biodiversity verification report. Water column characteristics were found to be consistent with those expected of the region. South Atlantic central water was present throughout the survey and relatively low oxygen conditions were experienced near the bottom. In general the bottom water layers were 2.5 to 4 °C cooler than the surface water.



Above: Field Team pictured in front of FV *Zeearend*. From left to right: Kate Munnik, Tim McClurg, Melanie Smith, Victor Ngcongo, Ester Nangolo, Malakia Shimhanda and Robert Williamson.

© NMP 2014

contents

SUMMARY ii

1 INTRODUCTION 1

2 SCOPE 1

3 METHODS 1

4 RESULTS 5

5 DISCUSSION AND RECOMMENDATIONS 6

5.1 RECOMMENDATIONS FOR FUTURE SAMPLING EFFORTS: 6

6 REFERENCES 7

Annexure 1: CTD Profiles 8
Annexure 2: Detailed statistics from all trawls 20

figures

Figure 1: a), b) and c) show the damaged caused to the CTD frame after Trawl 1. 2
Figure 2: a).b) and c) depict crew members of the *Zeearend* securing the CTD onto the trawl net. 3
Figure 3: Schematic showing the division of each trawl into sections. 4

tables

Table 1: Summary statistics of the 'Trawl section' (excluding up and down casts) of each trawl. 5

© NMP 2014

1 INTRODUCTION

Namibian Marine Phosphate (NMP) is investigating the possibility of extracting pelletal marine phosphate from the seabed on the continental shelf offshore of Namibia. An environmental impact assessment (EIA) was previously carried out to determine the possible effects of this development on the marine environment and a specialist biodiversity assessment was carried out as part of this process. Concerns as to the confidence of the results of the EIA as reported in the specialists studies of the EIA, along with reviewer concerns, raised a number of issues which are addressed through a series of verification surveys. The biodiversity verification survey, reported on here, was carried out by Capricorn Fisheries Monitoring cc (CapFish) with Lwandle Technologies (Pty) Ltd supplying and operating a CTD (conductivity, temperature and depth meter) instrument in order to conduct water column profiling in conjunction with the biodiversity trawls. This report describes the water column characteristics present during the biodiversity verification survey.

2 SCOPE

Lwandle supplied a CTD (RBR XR 420 and RBR XR 620) instrument with the following sensors for use during the trawl-based biodiversity survey:

- Pressure;
- Temperature;
- Conductivity; and
- Dissolved oxygen

The CTD was attached to the trawl net in order to allow under-way sampling during trawling. This meant the vessel did not have to stop before or after each trawl in order to deploy the CTD. Due to the potential 'hostility' of the survey environment a robust oxygen sensor (OXYGUARD by RBR) was used during the survey.

3 METHODS

The biodiversity verification survey was carried out in the SP-1 within the ML 170 licence area, offshore of Namibia as this is the stated target area for the first 20 years of mining (NMP 2012). A total of 24 trawls was undertaken during the survey with half being carried out at night and the other half in the day time hours.

The CTD was placed in a steel frame and covered with a rope-mesh bag for protection before being attached to the trawl net for each trawl. Initially the field team attempted to attach the CTD and frame to the head rope of the trawl net above its mouth. In theory this was the safest place for the CTD to be positioned as it was clear from most of the metal tickler chains, bobbins and steel cabling. However, due to the configuration of the net setting gear and associated stern rollers, attaching the CTD to this position proved very difficult. During the first deployment the CTD frame was rolled back onto one of the stern rollers as the net was being set. This caused damage to the steel frame as well as possible damage to the RBR unit itself (Figure 1).

© NMP 2014

a)



b)



c)



Figure 1: a), b) and c) show the damaged caused to the CTD frame after Trawl 1.
Most of the damage is expected to have been caused when the frame was rolled back onto the stern rollers.

A revised position for the CTD was identified further up the head rope, closer to the stern of the vessel. In this position the CTD could easily be attached prior to a trawl and detached as the trawl net was retrieved (Figure 2). Even in this revised position there were still occasions where the CTD and frame were subjected to collisions with other metal elements of the net. Recommendations for avoiding damage to the CTD and ensuring the best possible data return in any future work are provided at the end of this report.

© NMP 2014

a)



b)



c)



Figure 2: a).b) and c) depict crew members of the *Zeearend* securing the CTD onto the trawl net. The CTD had been placed in a protective steel frame and this frame had been covered with a mesh bag prior to securing it on the trawl net in order to prevent snags on the CTD sensors.

© NMP 2014

Before each trawl the CTD was switched on and set up using RBR's RUSKIN software. The instrument was set to sample at a frequency of 6 Hz (6 times per second). This was the case for all trawls except Trawl 2 (D4) as the RBR XR 420 was used for this trawl and this instrument's maximum sampling frequency is one sample every 10 seconds. Additionally dissolved oxygen data were missing from Trawl 2 (D4) as the XR 420 does not have an oxygen sensor. Trawl 2 was the only trawl for which this instrument configuration was used.

During each trawl the CTD was in logging mode from the moment it was activated by the Lwandle technician until the instrument was recovered and turned off after each trawl. For processing purposes each trawl was divided into three sections (Figure 3) the down cast (A), trawl (C) and up cast (B) sections. All data was processed using RBR's RUSKIN software as well as Mathworks' MATLAB. Salinity values greater than 40 and less than 30 and dissolved oxygen concentrations greater than 110 % were considered erroneous and were removed from the data.

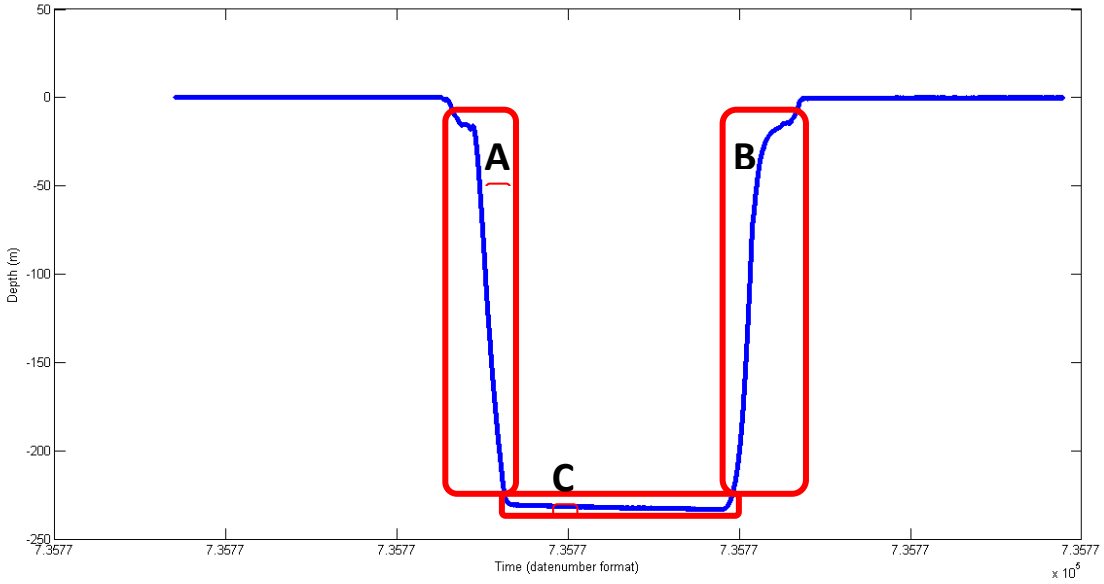


Figure 3: Schematic showing the division of each trawl into sections.
A: Down cast section, B: Up cast section and C: Trawl section.

The CTD did not function properly during the last two trawls (Trawl 23 (N22) and Trawl 24 (N24)) possibly due to previous damage to the unit during trawls. The data from both of these trawls has been discarded.

© NMP 2014

4 RESULTS

A summary table of results from the Trawl section (Figure 3: C – Trawl Section) excluding the up and down casts) of each trawl is shown below, and the profile images as well as the full results tables from each trawl are presented in Annexures 1 and 2.

A total of 24 trawls was carried out, half were performed during the daylight hours and the remainder at night (Table 1). The trawls are labelled chronologically with Trawl 1 being the first in the survey and Trawl 24 being the last. The salinity, depth and temperature data was within the expected ranges for the majority of the trawls (exceptions are trawls 23 and 24). The dissolved oxygen data however should be viewed with caution as the OXYGAURD sensor did appear to drift (in terms of accuracy) during the survey, likely due to impact of the logger/ sensor in the initial deployments. Trawl 2 does not have oxygen data as the RBR 420 CTD was used for that deployment.

Table 1: Summary statistics of the 'Trawl section' (excluding up and down casts) of each trawl.

Name	Station	Date	Time	Temperature (°C)		Dsvl. Oxygen (%)		Salinity (PSU)	
				Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Trawl 1	N1	18-Jun-14	18:05	10.85	0.05	18.49	0.53	35.12	0.01
Trawl 2	D2	20-Jun-14	07:35	10.01	0.03	N/A	N/A	34.29	0.79
Trawl 3	D3	20-Jun-14	12:35	10.25	1.14	19.48	8.83	35.11	0.21
Trawl 4	D4	20-Jun-14	16:12	10.08	1.07	19.63	6.79	34.99	0.61
Trawl 5	D6	21-Jun-14	07:13	9.86	0.01	2.59	0.16	34.26	1.31
Trawl 6	D7	21-Jun-14	11:56	9.97	0.01	5.14	0.11	34.45	1.27
Trawl 7	D8	21-Jun-14	16:00	10.18	0.02	4.16	0.17	34.99	0.49
Trawl 8	D9	22-Jun-14	07:05	10.57	0.01	5.39	0.16	34.83	0.69
Trawl 9	D10	22-Jun-14	10:22	10.54	0.01	5.34	1.08	34.76	0.75
Trawl 10	D11	22-Jun-14	13:45	10.49	0.01	4.01	0.92	35.18	0.05
Trawl 11	D12	22-Jun-14	17:00	9.72	0.03	2.36	1.70	34.11	1.48
Trawl 12	D17	23-Jun-14	12:55	10.58	0.04	3.45	0.76	34.78	0.82
Trawl 13	N15	23-Jun-14	19:00	10.65	0.02	3.24	0.59	32.68*	1.53
Trawl 14	N16	23-Jun-14	22:20	11.40	0.06	8.20	5.99	33.03*	1.71
Trawl 15	N23	24-Jun-14	01:35	11.36	0.15	1.08	2.10	34.90	0.31
Trawl 16	D5	24-Jun-14	15:05	11.20	0.03	2.51	0.71	34.44	0.87
Trawl 17	N21	24-Jun-14	18:55	11.39	0.02	3.86	2.68	34.00*	1.21
Trawl 18	N14	24-Jun-14	21:55	11.47	0.02	N/A	9.66	34.35	1.05
Trawl 19	N13	25-Jun-14	00:55	10.63	0.05	N/A	10.40	34.84	0.54
Trawl 20	N20	25-Jun-14	17:40	11.38	0.02	N/A	10.00	33.71*	1.47
Trawl 21	N19	25-Jun-14	21:55	11.49	0.66	N/A	17.27	33.31*	1.70
Trawl 22	N18	26-Jun-14	00:55	10.92	0.02	N/A	21.70	34.26	1.24
Trawl 23	N22	26-Jun-14	18:52	N/A	N/A	N/A	N/A	N/A	N/A
Trawl 24	N24	26-Jun-14	22:15	N/A	N/A	N/A	N/A	N/A	N/A

* These values are outside of the salinity range for SACW, and are associated with very high standard deviation values which indicates that they should be viewed with caution.

© NMP 2014

5 DISCUSSION AND RECOMMENDATIONS

Twenty two of the 24 trawls undertaken during the biomass verification survey provided acceptable results for temperature and 19 trawls yielded reasonable salinity results (with exceptions being: Trawls 13, 14, 17, 20 and 21). The trawls where successful temperature and/or salinity data were recorded can be compared to the fisheries and biomass data from the respective trawls.

Temperature profiles show a well-mixed upper water column in most cases, with slight stratification occurring from Trawl 10 onwards. This is to be expected as the survey took place just after an extended period of rough seas and considerable wave action in the survey area. The weather conditions calmed significantly from trawl 5 onwards and this may have allowed slight stratification of the upper layers of the water column. In general the upper water column was approximately 2.5 – 4 °C warmer than the near seafloor temperatures (> 200 m). Temperature on or near the sea floor throughout the survey averaged at 10.68 °C. This is within the range of expected winter values for the region.

Salinity and temperature data indicated the presence of South Atlantic Central Water (SACW) for the majority of the survey, which is the major water mass present in the region (5 to 18.01 °C, 34.3 to 35.8 PSU, (Emery and Meincke 1986)). The questionable salinity values highlighted in Table 2 above could be a result of the interference of suspended particles or direct interaction with the ocean floor, both of which could occur during trawling. However, the errors could also have been caused by damage to the RBR unit.

The oxygen data from all the trawls should be viewed as general guidance values in the deeper water layers, and mid to upper water column values should be regarded with extreme caution. The dissolved oxygen levels near the seafloor for most of the trawls were reasonably low (~3 to 10%) as can be expected in the continental shelf zone offshore of Namibia.

5.1 RECOMMENDATIONS FOR FUTURE SAMPLING EFFORTS:

Attaching a CTD to the trawl net allows the unique opportunity of collecting temperature, salinity and oxygen data at exactly the same time as biomass information from trawls. The alternative being static profiles at a location either directly before or after each trawl. As each trawl spans a distance of ~ 1.5 nm, static point data would not provide accurate information on the water quality characteristics present during the trawl. Alternative CTD mounting options or an entirely different CTD logging system need to be considered in the future so as to avoid issues with bulky and vulnerable units that can easily be damaged by tickler chains and/or trawl cabling. The most promising solution appears to be using three separate, single channel RBR units which are considerably smaller. These units could be individually housed to ensure complete protection of each sensor, which would still allow easy attachment to (and detachment from) the trawl net. It is recommended that these three units be placed in the same location that was used for the majority of the biomass survey.

© NMP 2014

6 REFERENCES

Emery W.J, Meincke J. 1986. Global water masses: Summary and review. Department of Oceanography, University of British Columbia, Vancouver, B.C., V6T 1W5, Canada.

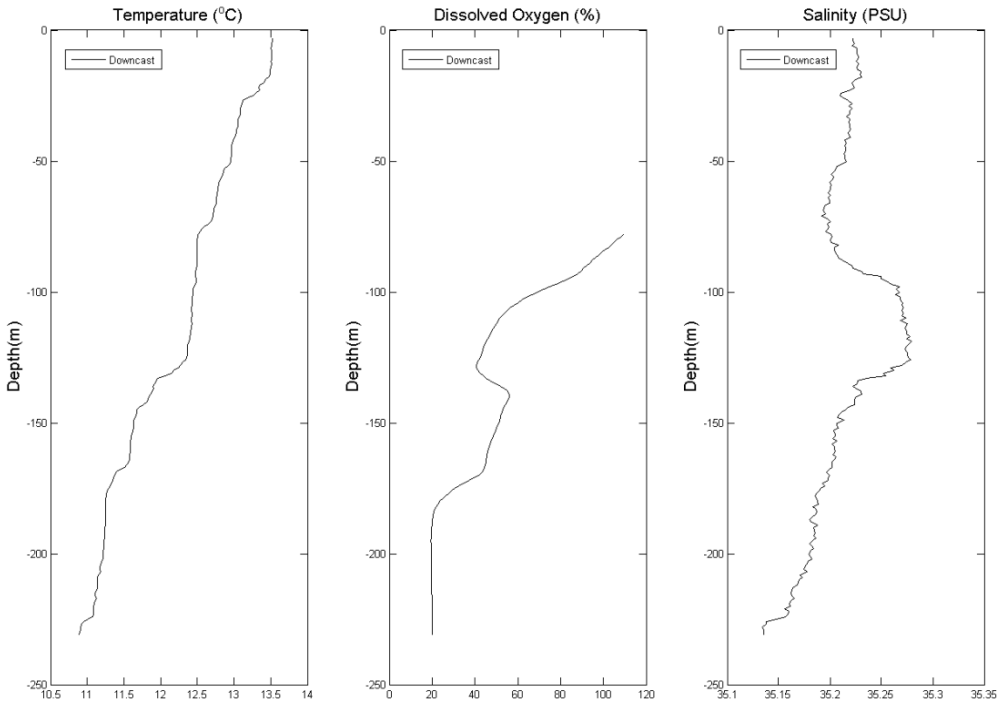
NMP 2012 – Environmental Impact Assessment for the proposed dredging of phosphate enriched sediments from Marine Licence Area No. 170. Namibian Marine Phosphate (PTY) Ltd. Namibia.

© NMP 2014

Annexure 1: CTD Profiles

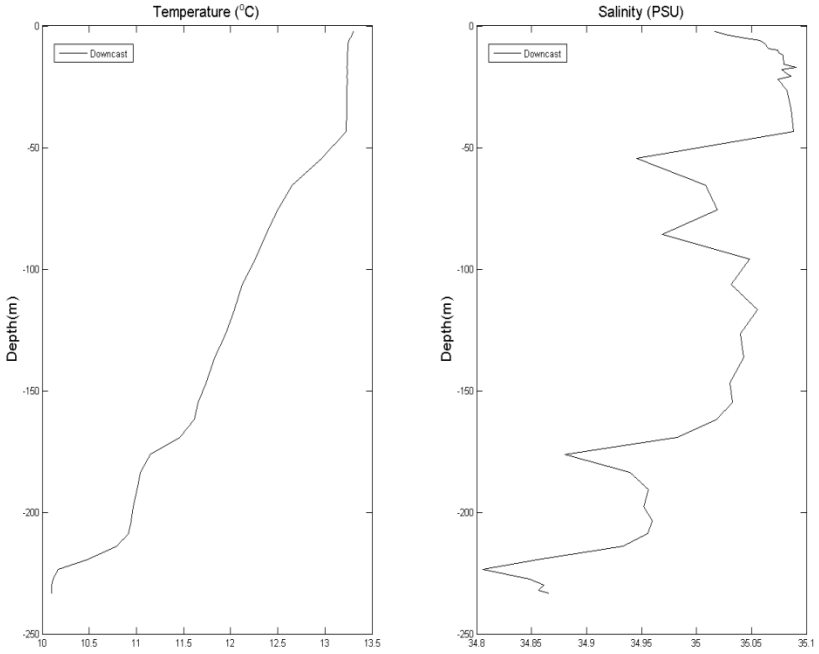
Down cast data are presented for each trawl in a cross-section view, temperature, dissolved oxygen and salinity data are shown.

Trawl 1 (N1)

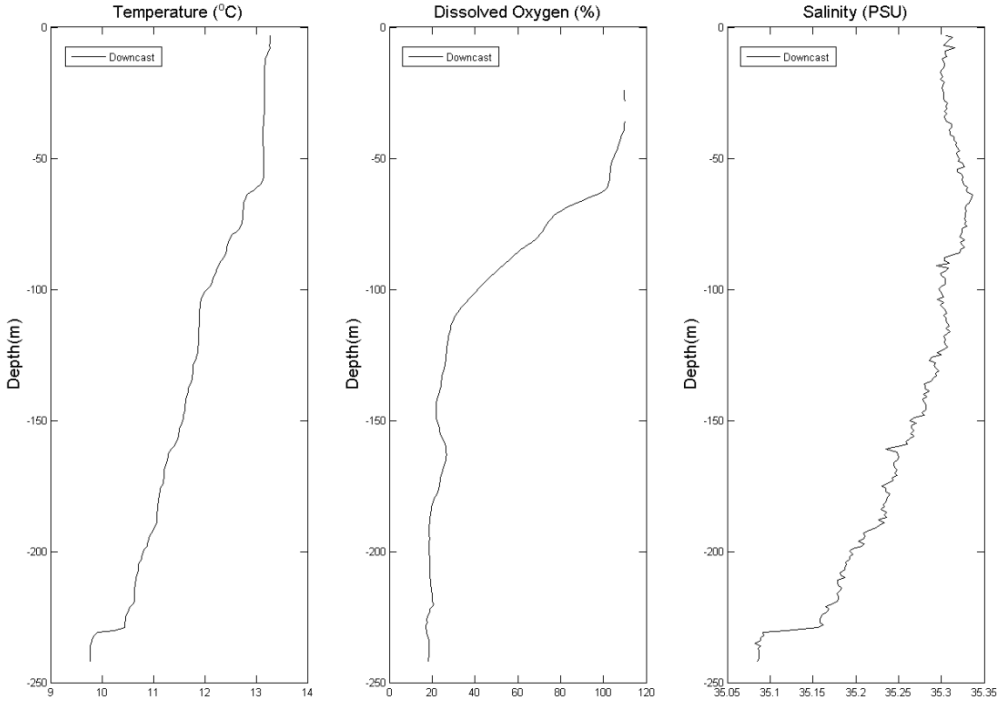


ANNEXURE 1: CTD PROFILES – continued...

Trawl 2 (D2)

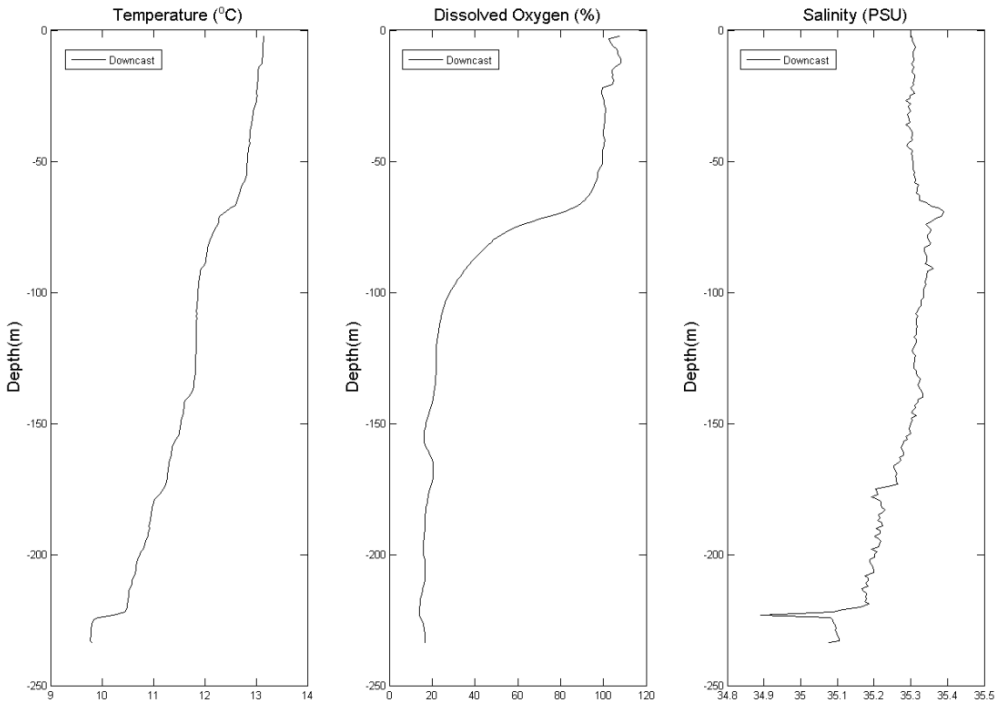


Trawl 3 (D3)

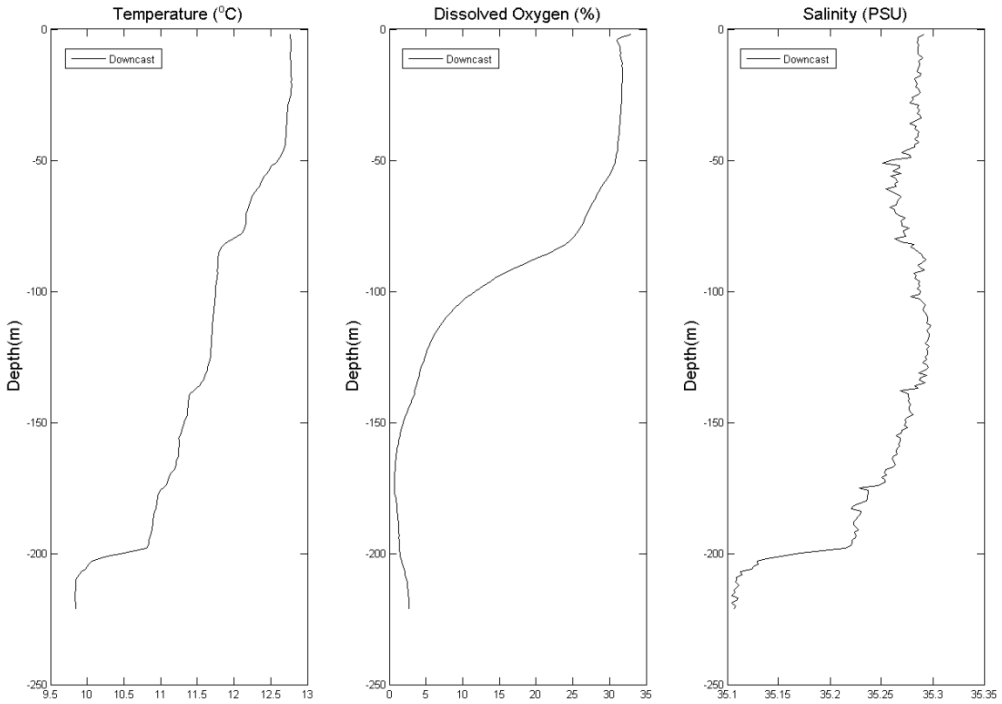


ANNEXURE 1: CTD PROFILES – continued...

Trawl 4 (D4)

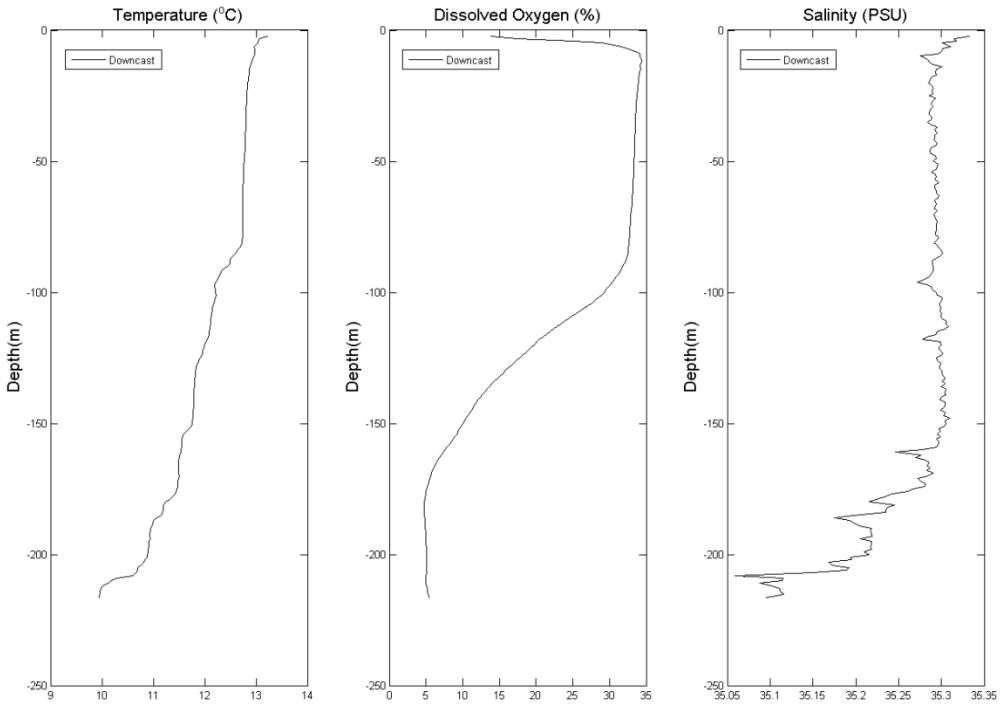


Trawl 5 (D6)

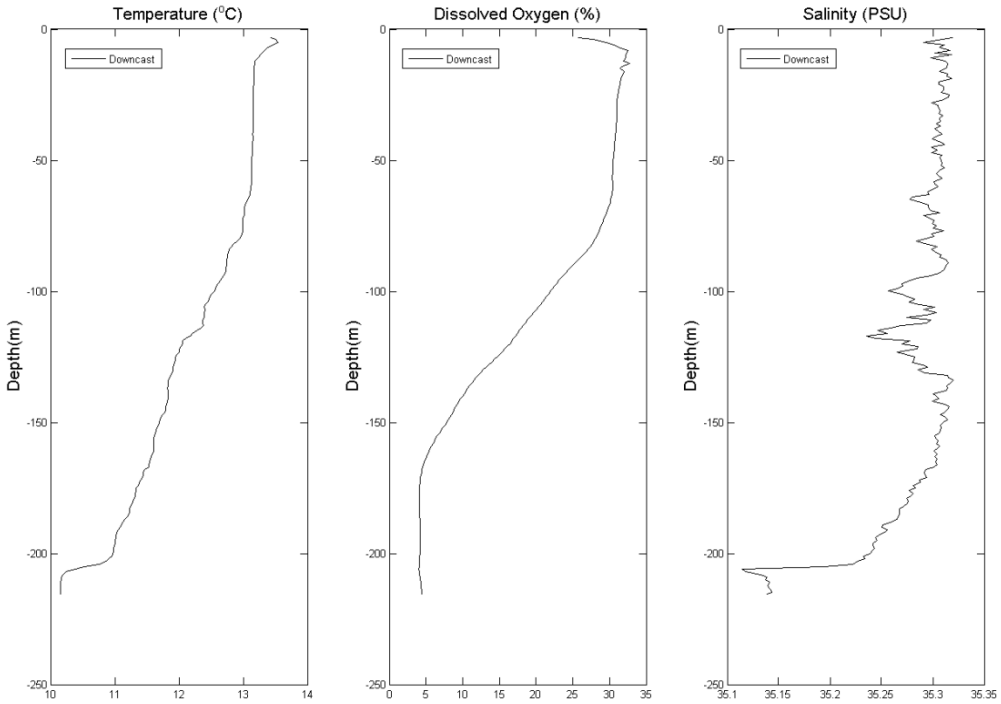


ANNEXURE 1: CTD PROFILES – continued...

Trawl 6 (D7)

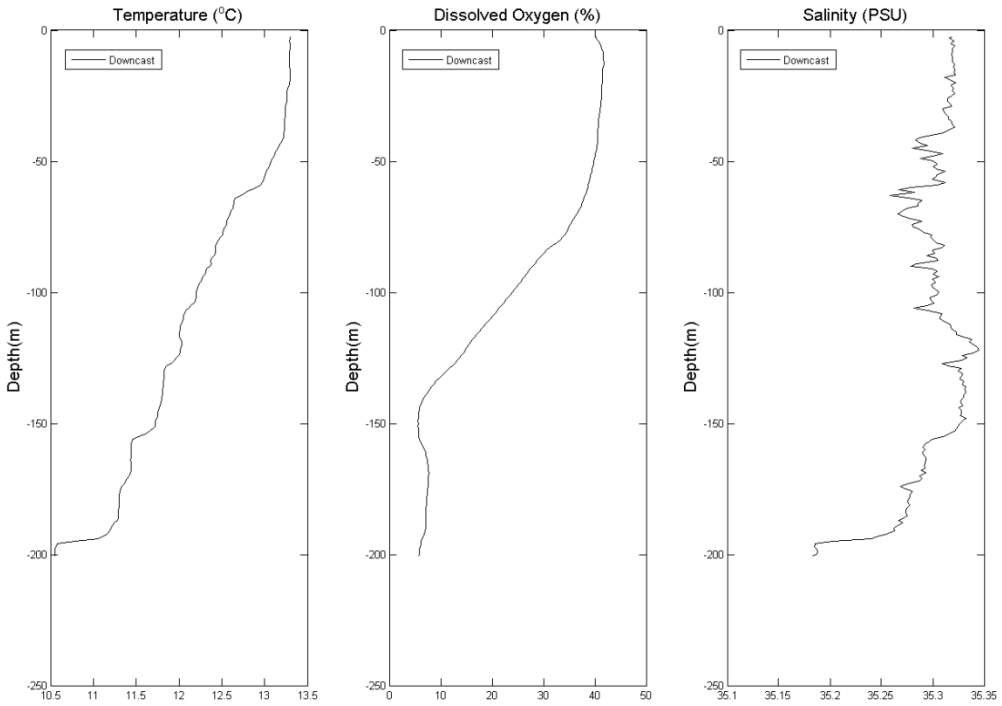


Trawl 7 (D8)

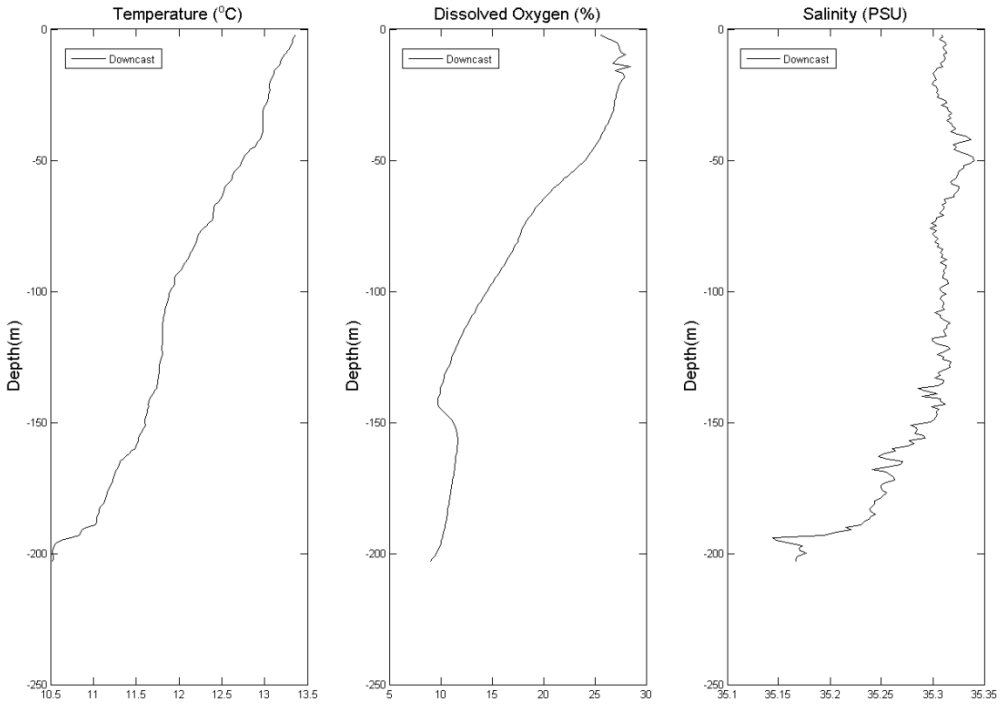


ANNEXURE 1: CTD PROFILES – continued...

Trawl 8 (D9)

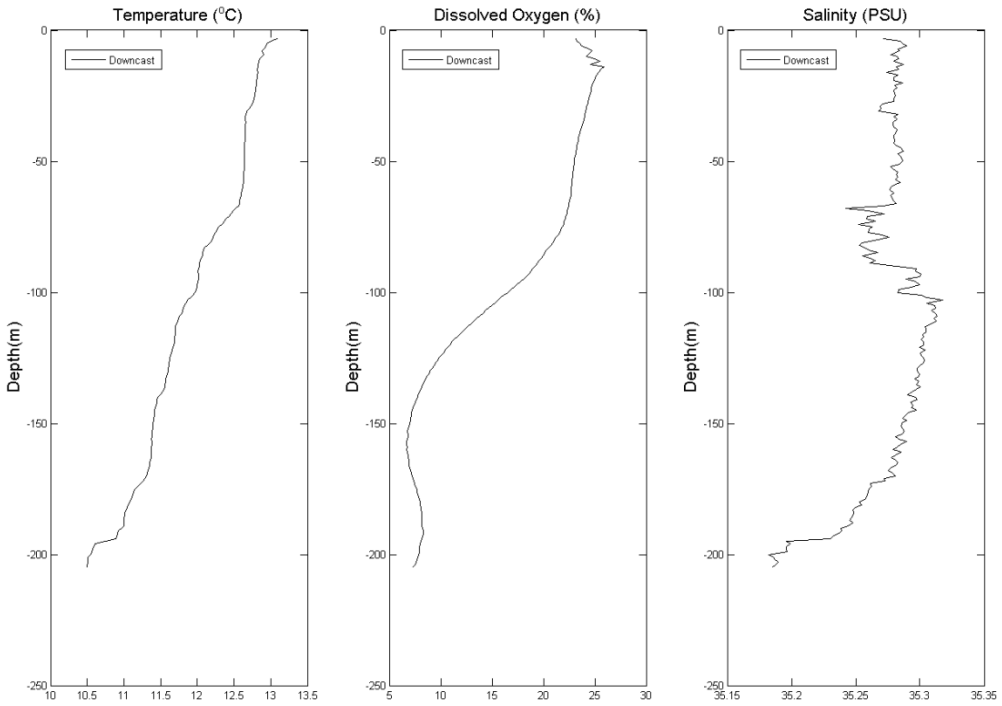


Trawl 9 (D10)

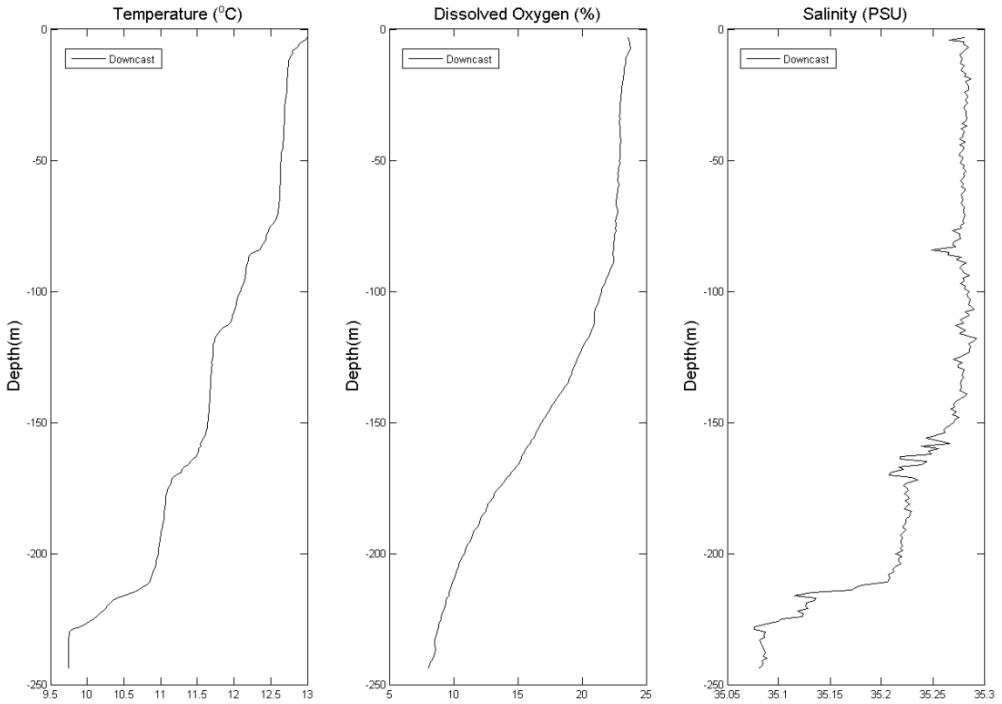


ANNEXURE 1: CTD PROFILES – continued...

Trawl 10 (D11)

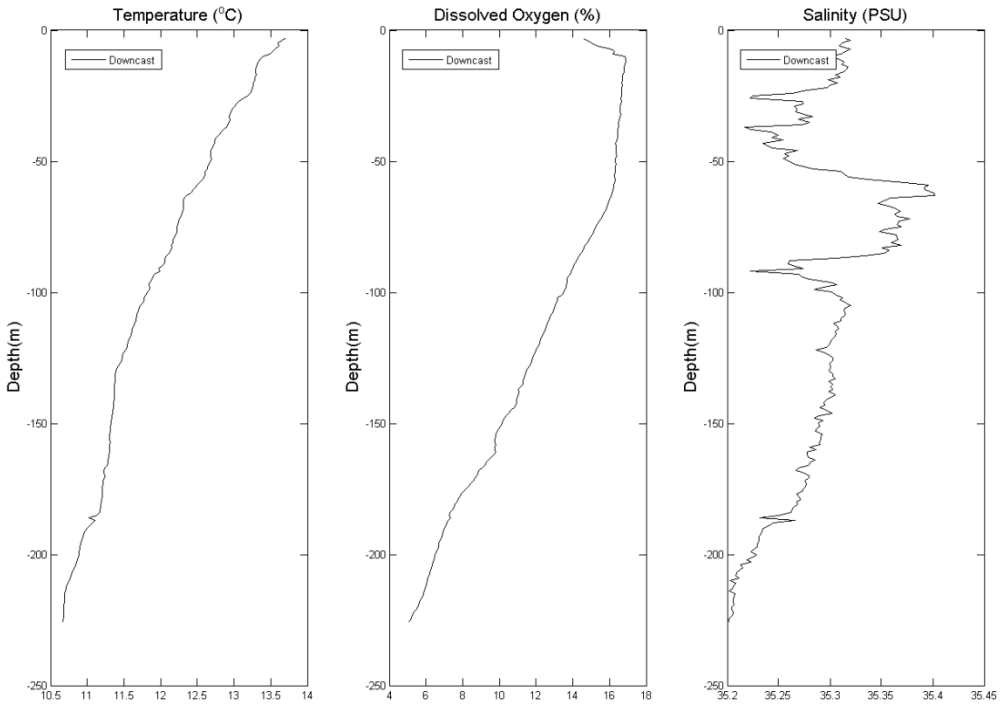


Trawl 11 (D12)

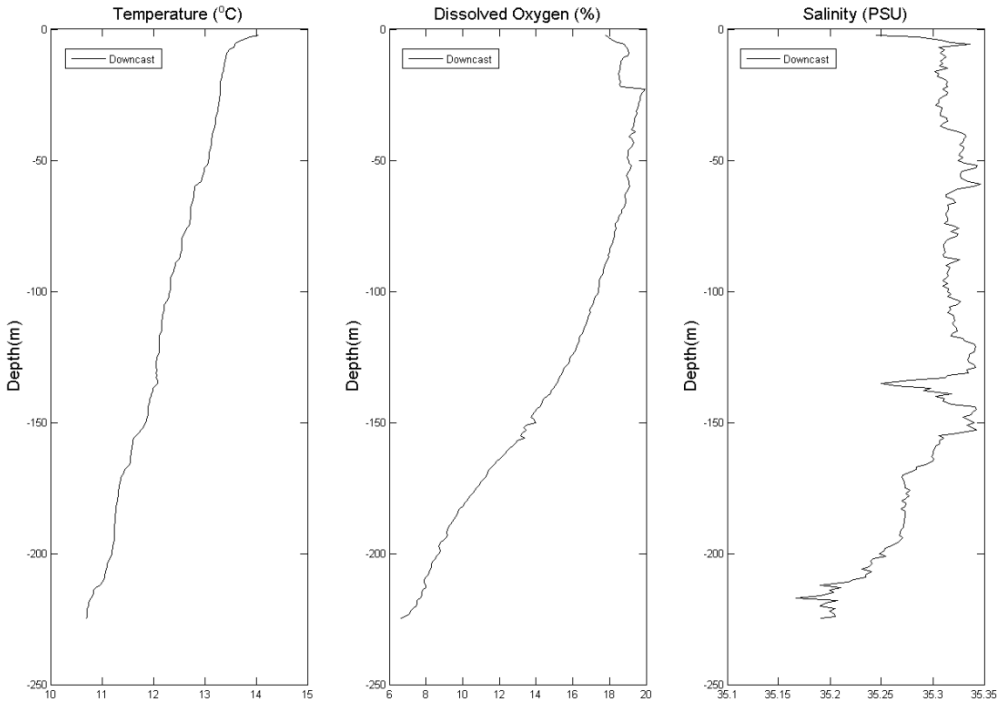


ANNEXURE 1: CTD PROFILES – continued...

Trawl 12 (D17)

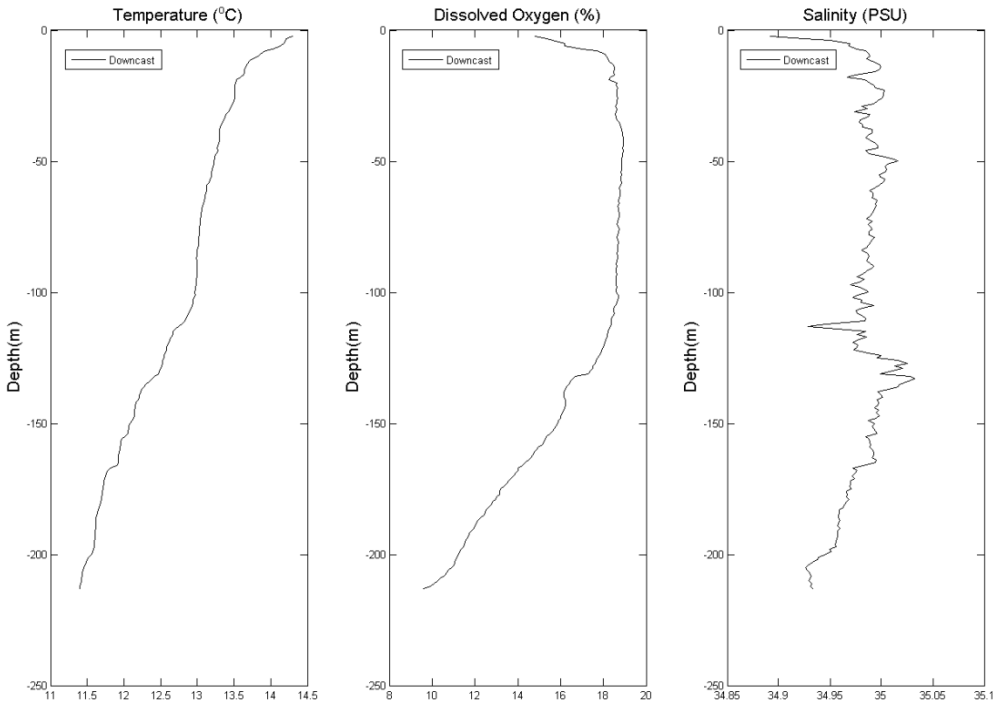


Trawl 13 (N15)

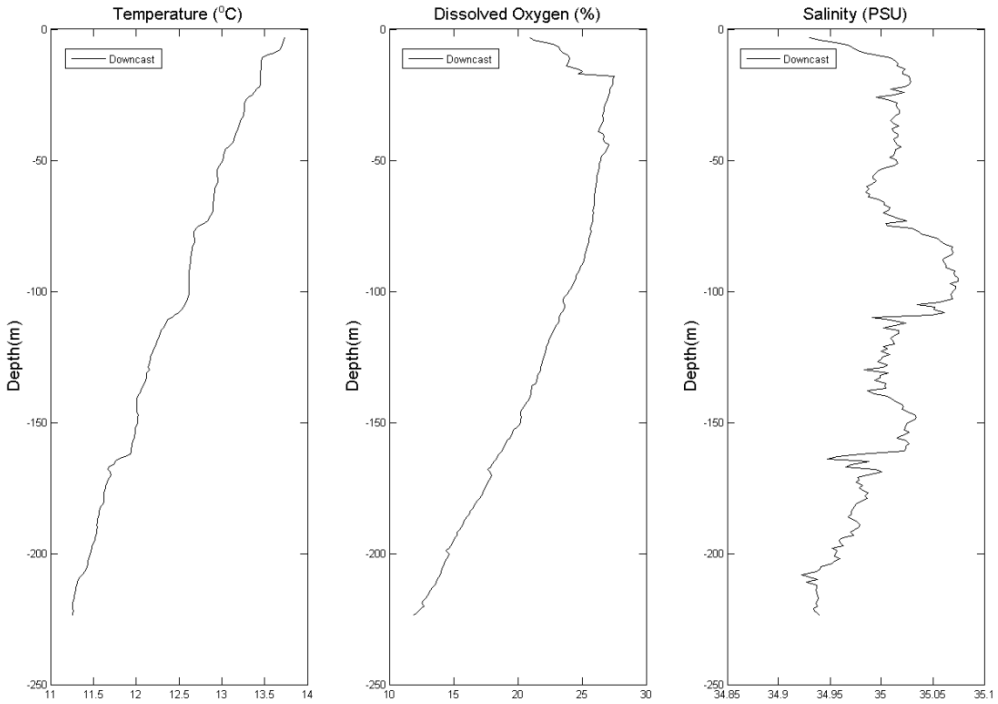


ANNEXURE 1: CTD PROFILES – continued...

Trawl 14 (N16)

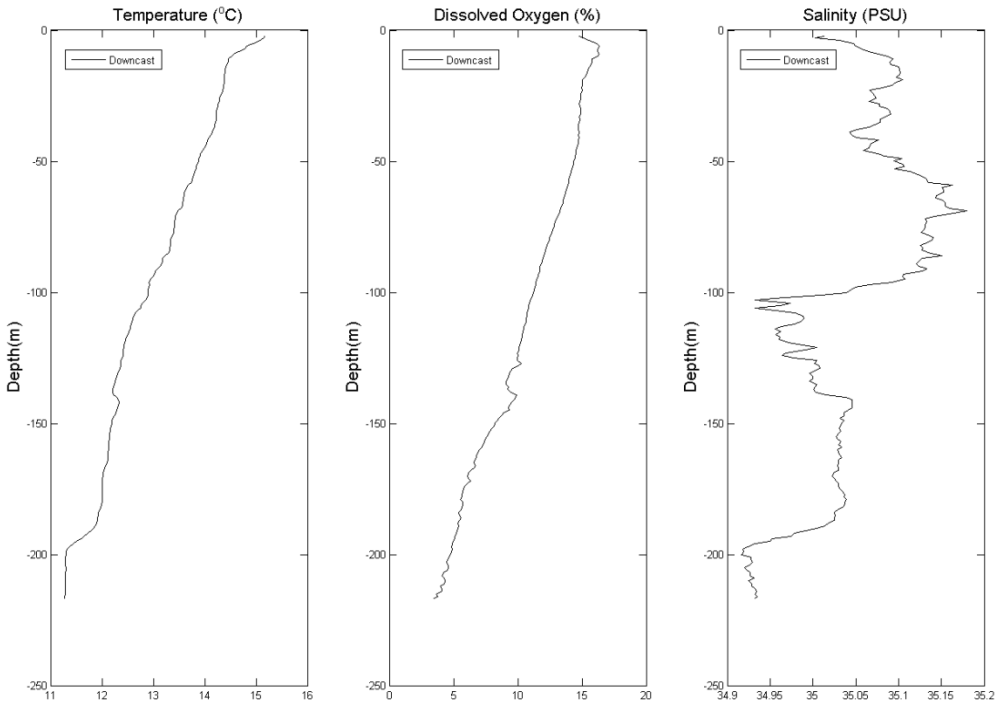


Trawl 15 (N23)

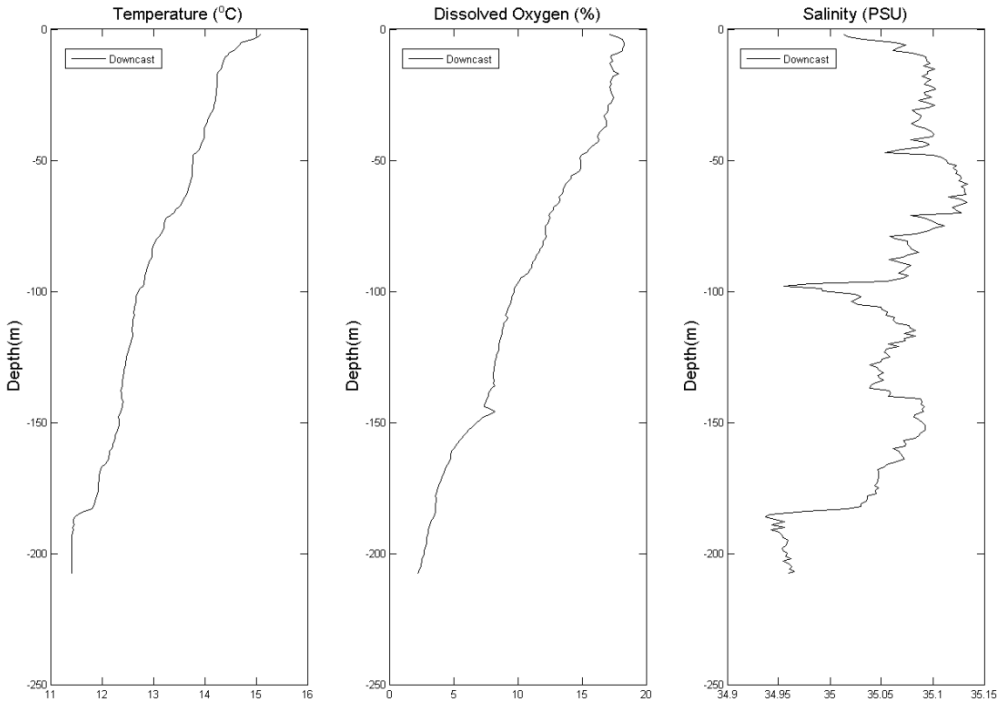


ANNEXURE 1: CTD PROFILES – continued...

Trawl 16 (D5)

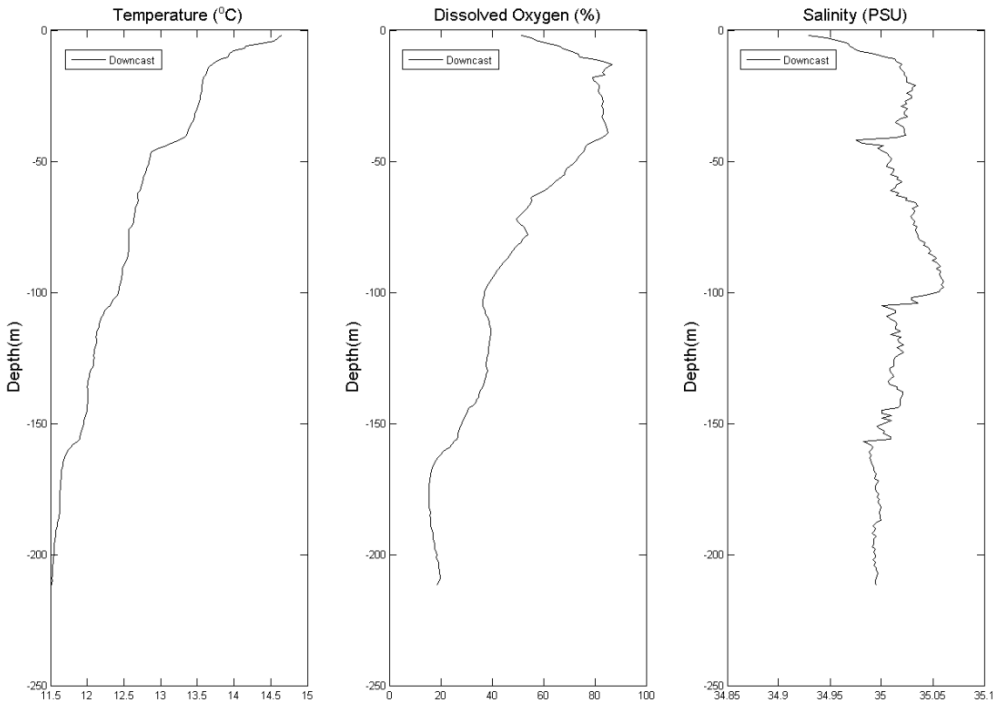


Trawl 17 (N21)

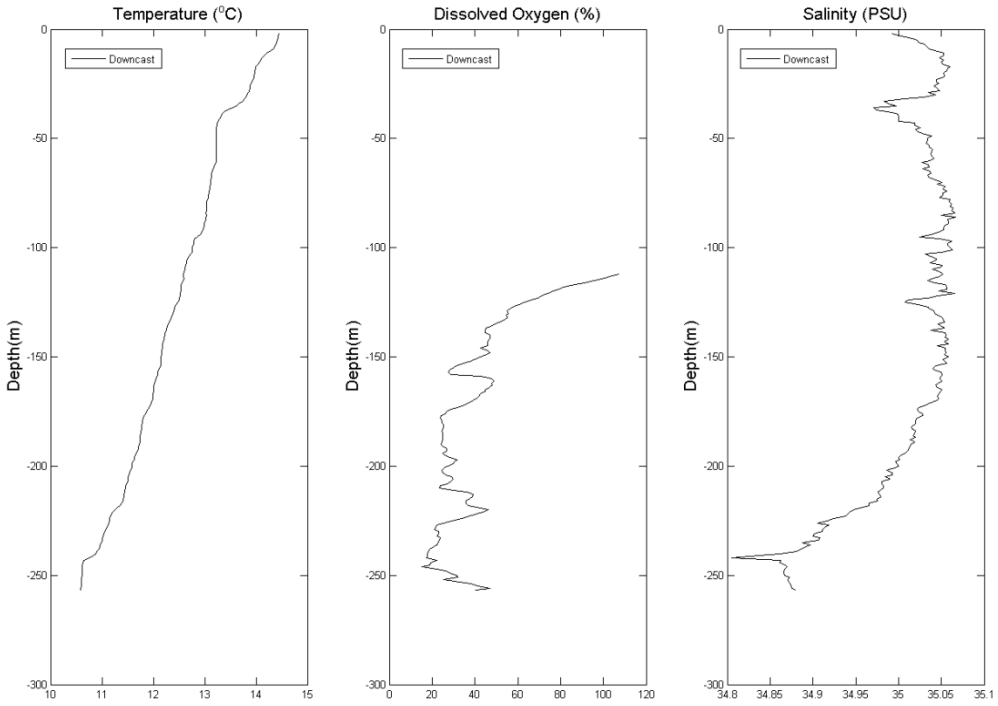


ANNEXURE 1: CTD PROFILES – continued...

Trawl 18 (N14) [Don't use O2 data]

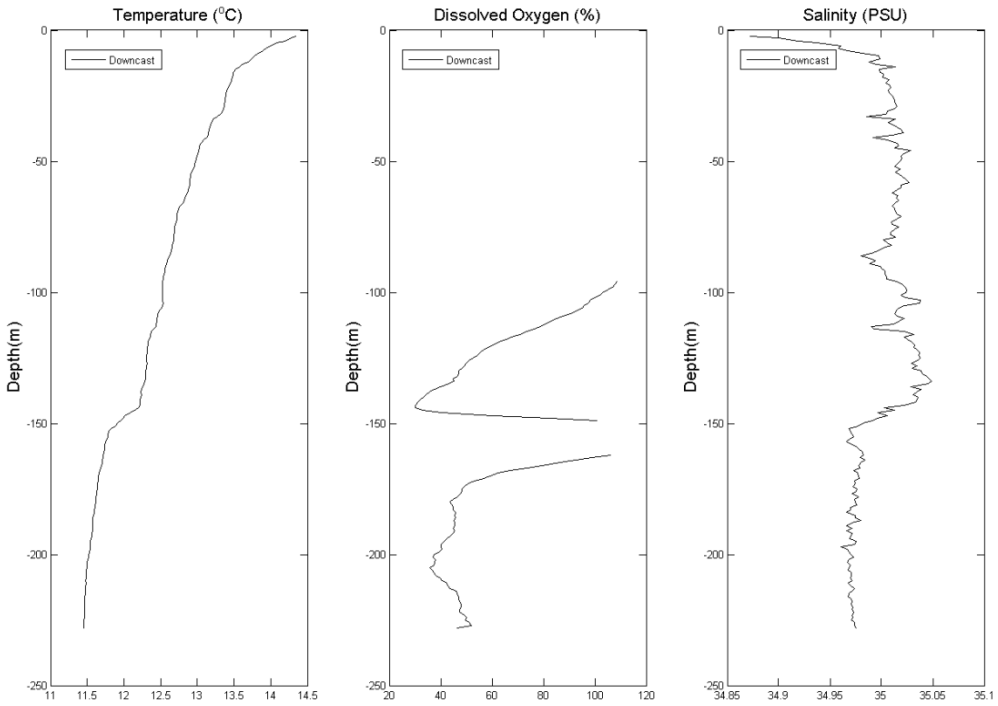


Trawl 19 (N13) [Don't use O2 data]

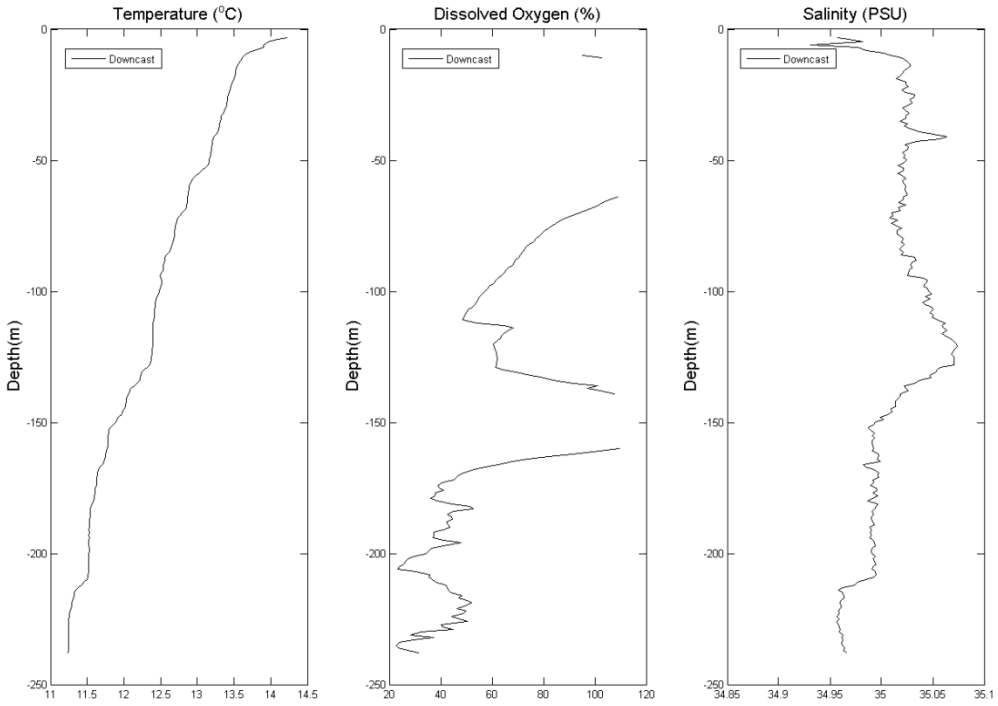


ANNEXURE 1: CTD PROFILES – continued...

Trawl 20 (N20) [Don't use O2 data]



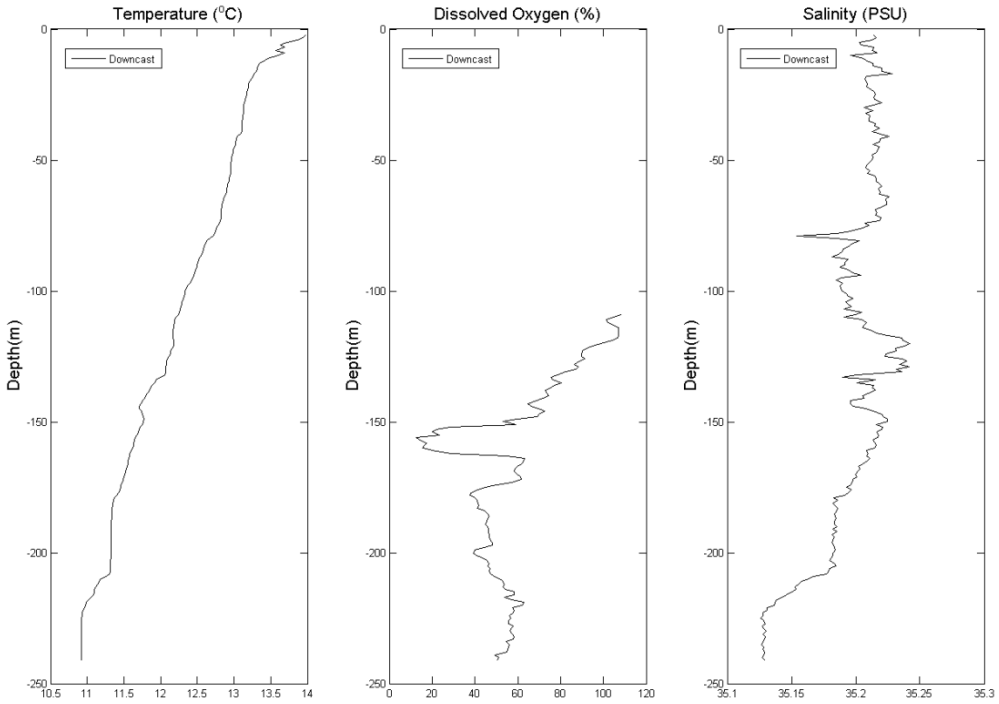
Trawl 21 (N19) [Don't use O2 data]



© NMP 2014

ANNEXURE 1: CTD PROFILES – continued...

Trawl 22 (N18) [Don't use O2 data]



Trawl 23 (N22)

DATA OF POOR QUALITY

Trawl 24 (N24)

DATA OF POOR QUALITY

© NMP 2014

Annexure 2: Detailed statistics from all trawls

Detailed statistics of all processed trawls are provided in tabular format below. The trawls are each divided into three sections (down cast, up cast and trawl) as per Figure 3.

Trawl 1 - Stats	**Profile**	**Max**	**Min**	**Mean**	**Std dev.**	**n**
	Down cast	13.52	10.89	12.17	0.79	229
	Up cast	13.67	10.75	12.15	0.85	233
	Trawl	10.94	10.75	10.85	0.05	13124
Dissolved Oxygen (%)	Down cast	109.44	19.49	44.74	24.54	154
	Up cast	104.70	17.84	48.37	29.91	188
	Trawl	20.06	17.73	18.49	0.53	13124
Salinity (PSU)	Down cast	35.28	35.13	35.21	0.03	229
	Up cast	35.27	35.11	35.20	0.03	233
	Trawl	35.15	35.10	35.12	0.01	13124
Trawl 2- Stats	**Profile**	**Max**	**Min**	**Mean**	**Std dev.**	**n**
	Down cast	13.30	10.10	12.12	1.15	44
	Up cast	13.22	9.97	12.02	1.25	48
	Trawl	10.10	9.97	10.01	0.03	237
Dissolved Oxygen (%)	Down cast	N/A	N/A	N/A	N/A	N/A
	Up cast	N/A	N/A	N/A	N/A	N/A
	Trawl	N/A	N/A	N/A	N/A	N/A
Salinity (PSU)	Down cast	35.09	34.81	35.00	0.08	44
	Up cast	35.27	34.93	35.13	0.09	48
	Trawl	34.94	31.06	34.29	0.79	212
Trawl 3- Stats	**Profile**	**Max**	**Min**	**Mean**	**Std dev.**	**n**
	Down cast	13.28	9.77	11.87	1.01	240
	Up cast	13.13	9.66	11.75	0.94	246
	Trawl	13.15	9.66	10.25	1.14	15461
Dissolved Oxygen (%)	Down cast	109.99	17.10	43.37	32.20	212
	Up cast	108.16	15.77	41.48	24.49	172
	Trawl	109.43	12.96	19.48	8.83	13491
Salinity (PSU)	Down cast	35.34	35.08	35.27	0.06	240
	Up cast	35.39	35.04	35.28	0.07	246
	Trawl	35.46	30.16	35.11	0.21	15438
Trawl 4- Stats	**Profile**	**Max**	**Min**	**Mean**	**Std dev.**	**n**
	Down cast	13.15	9.78	11.80	0.91	233
	Up cast	12.86	9.44	11.75	0.90	234
	Trawl	12.87	9.42	10.08	1.07	15859
Dissolved Oxygen (%)	Down cast	108.20	14.12	46.06	36.28	233
	Up cast	109.00	16.63	36.55	22.07	167
	Trawl	109.67	14.42	19.63	6.79	14101
Salinity (PSU)	Down cast	35.39	34.89	35.28	0.07	233
	Up cast	35.42	35.08	35.28	0.06	234
	Trawl	35.46	30.01	34.99	0.61	15388

© NMP 2014

Annexure 2 – continued...

Trawl 5- Stats	**Profile**	**Max**	**Min**	**Mean**	**Std dev.**	**n**
	Down cast	12.78	9.84	11.67	0.84	220
	Up cast	13.04	9.84	11.82	0.83	221
	Trawl	9.90	9.84	9.86	0.01	12251
Dissolved Oxygen (%)	Down cast	32.83	0.70	14.12	12.95	220
	Up cast	28.85	2.21	7.42	6.04	221
	Trawl	3.00	1.83	2.59	0.16	12251
Salinity (PSU)	Down cast	35.30	35.10	35.26	0.05	220
	Up cast	35.33	35.11	35.28	0.04	221
	Trawl	35.13	30.00	34.26	1.31	11624
Trawl 6- Stats	**Profile**	**Max**	**Min**	**Mean**	**Std dev.**	**n**
	Down cast	13.23	9.95	12.04	0.79	216
	Up cast	13.35	9.95	11.96	0.87	217
	Trawl	9.99	9.94	9.97	0.01	12209
Dissolved Oxygen (%)	Down cast	34.39	4.75	20.90	12.11	216
	Up cast	31.53	4.31	9.55	7.01	217
	Trawl	5.62	4.85	5.14	0.11	12209
Salinity (PSU)	Down cast	35.33	35.06	35.27	0.05	216
	Up cast	35.38	35.10	35.30	0.05	217
	Trawl	35.14	30.00	34.45	1.27	10936
Trawl 7- Stats	**Profile**	**Max**	**Min**	**Mean**	**Std dev.**	**n**
	Down cast	13.55	10.15	12.22	0.91	214
	Up cast	13.66	10.15	12.16	0.90	215
	Trawl	10.23	10.15	10.18	0.02	11911
Dissolved Oxygen (%)	Down cast	32.78	4.04	18.26	11.20	214
	Up cast	24.84	4.18	8.30	5.04	215
	Trawl	5.41	3.32	4.16	0.17	11911
Salinity (PSU)	Down cast	35.32	35.11	35.28	0.04	214
	Up cast	35.36	35.14	35.30	0.04	215
	Trawl	35.17	30.04	34.99	0.49	11779
Trawl 8- Stats	**Profile**	**Max**	**Min**	**Mean**	**Std dev.**	**n**
	Down cast	13.30	10.55	12.24	0.77	200
	Up cast	13.26	10.56	12.08	0.78	201
	Trawl	10.59	10.54	10.57	0.01	12141
Dissolved Oxygen (%)	Down cast	41.83	5.60	23.48	14.57	200
	Up cast	32.02	5.41	10.38	5.54	201
	Trawl	6.39	4.81	5.39	0.16	12141
Salinity (PSU)	Down cast	35.34	35.18	35.30	0.03	200
	Up cast	35.36	34.53	35.25	0.19	201
	Trawl	35.21	30.01	34.83	0.69	12055
Trawl 9- Stats	**Profile**	**Max**	**Min**	**Mean**	**Std dev.**	**n**
	Down cast	13.35	10.52	12.04	0.75	202
	Up cast	12.91	10.54	11.85	0.71	202
	Trawl	10.55	10.52	10.54	0.01	12660
Dissolved Oxygen (%)	Down cast	28.49	9.00	16.69	6.54	202
	Up cast	21.56	4.13	6.48	4.47	202

© NMP 2014

Annexure 2 – continued...

	Trawl	8.94	4.00	5.34	1.08	12660
Salinity (PSU)	Down cast	35.34	35.14	35.29	0.04	202
	Up cast	35.32	35.17	35.28	0.04	202
	Trawl	35.19	30.07	34.76	0.75	12556
Trawl 10- Stats	**Profile**	**Max**	**Min**	**Mean**	**Std dev.**	**n**
	Down cast	13.09	10.50	11.91	0.69	203
	Up cast	13.32	10.47	11.80	0.72	204
	Trawl	10.53	10.47	10.49	0.01	13390
Dissolved Oxygen (%)	Down cast	25.90	6.69	15.48	7.20	203
	Up cast	20.11	3.39	5.25	3.78	204
	Trawl	7.33	3.22	4.01	0.92	13390
Salinity (PSU)	Down cast	35.32	35.18	35.28	0.03	203
	Up cast	35.36	35.18	35.29	0.04	204
	Trawl	35.21	33.92	35.18	0.05	13390
Trawl 11- Stats	**Profile**	**Min**	**Mean**	**Std dev.**	**n**	**Max**
	Down cast	13.00	9.74	11.71	0.90	242
	Up cast	14.11	9.80	11.70	0.96	245
	Trawl	9.80	9.68	9.72	0.03	12899
Dissolved Oxygen (%)	Down cast	23.75	8.04	17.78	5.39	242
	Up cast	22.08	1.90	5.75	4.59	245
	Trawl	8.10	0.54	2.36	1.70	12899
Salinity (PSU)	Down cast	35.29	35.08	35.24	0.06	242
	Up cast	35.34	35.10	35.26	0.06	245
	Trawl	35.11	30.00	34.11	1.48	4136
Trawl 12- Stats	**Profile**	**Max**	**Min**	**Mean**	**Std dev.**	**n**
	Down cast	13.70	10.67	11.84	0.83	224
	Up cast	13.59	10.54	11.96	0.83	227
	Trawl	10.67	10.53	10.58	0.04	12511
Dissolved Oxygen (%)	Down cast	16.88	5.08	12.05	3.84	224
	Up cast	29.50	4.15	8.73	6.64	227
	Trawl	5.21	1.78	3.45	0.76	12511
Salinity (PSU)	Down cast	35.40	35.20	35.28	0.05	224
	Up cast	35.33	33.97	35.19	0.16	227
	Trawl	35.22	30.02	34.78	0.82	12088
Trawl 13- Stats	**Profile**	**Max**	**Min**	**Mean**	**Std dev.**	**n**
	Down cast	14.03	10.70	12.20	0.83	224
	Up cast	14.03	10.62	12.20	0.88	224
	Trawl	10.70	10.61	10.65	0.02	12501
Dissolved Oxygen (%)	Down cast	19.94	6.64	15.05	4.10	224
	Up cast	19.07	2.74	5.87	4.43	224
	Trawl	6.58	2.66	3.24	0.59	12501
Salinity (PSU)	Down cast	35.35	35.17	35.30	0.04	224
	Up cast	35.38	35.20	35.31	0.04	224
	Trawl	35.22	30.00	32.68	1.53	9853
Trawl 14- Stats	**Profile**	**Max**	**Min**	**Mean**	**Std dev.**	**n**
	Down cast	14.30	11.40	12.64	0.74	212

© NMP 2014

	Up cast	14.09	11.40	12.46	0.78	212
	Trawl	11.58	11.30	11.40	0.06	13003
Dissolved Oxygen (%)	Down cast	18.93	9.59	16.54	2.74	212
	Up cast	44.88	6.47	13.08	8.66	212
	Trawl	34.50	2.31	8.20	5.99	13003
Salinity (PSU)	Down cast	35.03	34.89	34.98	0.02	212
	Up cast	35.13	34.31	35.07	0.16	25
	Trawl	34.94	30.00	33.03	1.71	101
Trawl 15- Stats	**Profile**	**Max**	**Min**	**Mean**	**Std dev.**	**n**
	Down cast	13.74	11.25	12.37	0.70	222
	Up cast	13.87	11.13	12.36	0.78	224
	Trawl	11.61	11.10	11.36	0.15	13768
Dissolved Oxygen (%)	Down cast	27.56	11.89	21.60	4.55	222
	Up cast	33.92	1.19	8.29	7.20	224
	Trawl	11.91	0.00	1.08	2.10	13040
Salinity (PSU)	Down cast	35.07	34.92	35.00	0.04	222
	Up cast	35.28	32.33	35.09	0.20	224
	Trawl	34.95	30.48	34.90	0.31	217
Trawl 16- Stats	**Profile**	**Max**	**Min**	**Mean**	**Std dev.**	**n**
	Down cast	15.17	11.28	12.88	1.03	216
	Up cast	15.00	11.18	12.54	0.85	216
	Trawl	11.29	11.17	11.20	0.03	13971
Dissolved Oxygen (%)	Down cast	16.34	3.45	10.42	3.79	216
	Up cast	33.95	2.02	7.48	7.12	216
	Trawl	5.82	1.26	2.51	0.71	13971
Salinity (PSU)	Down cast	35.18	34.92	35.04	0.07	216
	Up cast	35.28	34.97	35.13	0.07	216
	Trawl	35.00	30.00	34.44	0.87	13604
Trawl 17- Stats	**Profile**	**Max**	**Min**	**Mean**	**Std dev.**	**n**
	Down cast	15.08	11.41	12.89	0.96	207
	Up cast	14.94	11.38	12.56	0.85	207
	Trawl	11.49	11.37	11.39	0.02	13199
Dissolved Oxygen (%)	Down cast	18.30	2.20	10.09	5.02	207
	Up cast	62.56	2.20	14.62	13.88	207
	Trawl	11.89	0.54	3.86	2.68	13199
Salinity (PSU)	Down cast	35.13	34.94	35.06	0.05	207
	Up cast	35.26	34.96	35.09	0.07	207
	Trawl	35.01	30.01	34.00	1.21	10148
Trawl 18- Stats	**Profile**	**Max**	**Min**	**Mean**	**Std dev.**	**n**
	Down cast	14.64	11.52	12.43	0.75	211
	Up cast	13.68	11.49	12.34	0.66	211
	Trawl	11.52	11.44	11.47	0.02	12472
Dissolved Oxygen (%)	Down cast	N/A	N/A	N/A	N/A	211
	Up cast	N/A	N/A	N/A	N/A	34
	Trawl	N/A	N/A	N/A	N/A	12412
Salinity (PSU)	Down cast	35.06	34.93	35.01	0.02	211

© NMP 2014

	Up cast	35.15	34.91	35.09	0.04	211
	Trawl	35.05	30.00	34.35	1.05	11871
Trawl 19- Stats	**Profile**	**Max**	**Min**	**Mean**	**Std dev.**	**n**
	Down cast	14.45	10.59	12.41	1.00	256
	Up cast	13.73	10.59	12.24	0.88	255
	Trawl	10.86	10.57	10.63	0.05	13421
Dissolved Oxygen (%)	Down cast	N/A	N/A	N/A	N/A	146
	Up cast	N/A	N/A	N/A	N/A	132
	Trawl	N/A	N/A	N/A	N/A	13421
Salinity (PSU)	Down cast	35.07	34.81	35.01	0.06	256
	Up cast	35.18	31.15	35.00	0.56	255
	Trawl	34.95	30.00	34.84	0.54	10837
Trawl 20- Stats	**Profile**	**Max**	**Min**	**Mean**	**Std dev.**	**n**
	Down cast	14.34	11.45	12.39	0.72	227
	Up cast	13.64	11.35	12.15	0.72	228
	Trawl	11.45	11.35	11.38	0.02	12423
Dissolved Oxygen (%)	Down cast	N/A	N/A	N/A	N/A	121
	Up cast	N/A	N/A	N/A	N/A	206
	Trawl	N/A	N/A	N/A	N/A	12423
Salinity (PSU)	Down cast	35.05	34.87	35.00	0.03	227
	Up cast	35.23	34.98	35.10	0.05	228
	Trawl	35.03	30.01	33.71	1.47	10778
Trawl 21- Stats	**Profile**	**Max**	**Min**	**Mean**	**Std dev.**	**n**
	Down cast	14.22	11.24	12.33	0.76	236
	Up cast	13.93	11.24	12.34	0.73	238
	Trawl	-	11.23	11.49	0.66	16149
Dissolved Oxygen (%)	Down cast	N/A	N/A	N/A	N/A	157
	Up cast	N/A	N/A	N/A	N/A	180
	Trawl	N/A	N/A	N/A	N/A	14750
Salinity (PSU)	Down cast	35.07	34.93	35.01	0.03	236
	Up cast	35.33	34.96	35.11	0.05	238
	Trawl	35.42	30.00	33.31	1.70	12582
Trawl 22- Stats	**Profile**	**Max**	**Min**	**Mean**	**Std dev.**	**n**
	Down cast	13.97	10.92	12.14	0.81	240
	Up cast	13.89	10.92	12.04	0.86	240
	Trawl	10.97	10.89	10.92	0.02	10850
Dissolved Oxygen (%)	Down cast	N/A	N/A	N/A	N/A	133
	Up cast	N/A	N/A	N/A	N/A	162
	Trawl	N/A	N/A	N/A	N/A	10850
Salinity (PSU)	Down cast	35.24	35.13	35.20	0.03	240
	Up cast	35.29	35.10	35.20	0.04	240
	Trawl	35.15	30.01	34.26	1.24	9461
Trawl 23- Stats	**Profile**	**Max**	**Min**	**Mean**	**Std dev.**	**n**
	Down cast	N/A	N/A	N/A	N/A	232
	Up cast	N/A	N/A	N/A	N/A	238
	Trawl	N/A	N/A	N/A	N/A	241

© NMP 2014

Dissolved Oxygen (%)	Down cast	N/A	N/A	N/A	N/A	249
	Up cast	N/A	N/A	N/A	N/A	225
	Trawl	N/A	N/A	N/A	N/A	228
Salinity (PSU)	Down cast	N/A	N/A	N/A	N/A	217
	Up cast	N/A	N/A	N/A	N/A	39
	Trawl	N/A	N/A	N/A	N/A	42
Trawl 24- Stats	Profile	Max	Min	Mean	Std dev.	n
	Down cast	N/A	N/A	N/A	N/A	0
	Up cast	N/A	N/A	N/A	N/A	0
	Trawl	N/A	N/A	N/A	N/A	0
Dissolved Oxygen (%)	Down cast	N/A	N/A	N/A	N/A	176
	Up cast	N/A	N/A	N/A	N/A	180
	Trawl	110.00	16.98	66.55	24.66	10983
Salinity (PSU)	Down cast	N/A	N/A	N/A	N/A	0
	Up cast	N/A	N/A	N/A	N/A	0
	Trawl	N/A	N/A	N/A	N/A	0

© NMP 2014

APPENDIX 2 – FISHERIES AND BIODIVERSITY

2.4 Sailing Orders Biodiversity Survey *FV Zeearend*

CRUISE:	Namibian Phosphate Biodiversity Verification Survey
VESSEL:	FV *Zeearend*, Benguella Fishing Company Pty (LTD)
START UP MEETING:	NMP Offices. 127 Theo-Ben Gurigab Street. Walvis Bay +264 (64) 27 8150 Tuesday 17/6/2014 14:00
SAILING:	*From*: Benguella Fishing Company, Walvis Bay Wednesday: 18/06/2014 (Time TBA) *To*: Benguella Fishing Company, Walvis Bay Saturday: 28/06/2014 (Time TBA)

PERSONNEL	**PERSONNEL**	**ROLE**	**NATIONALITY**
	Melanie Smith	*Chief Scientist /fish sampler*	SA
	Victor Ngcongo	*Chief technician / fish sampler*	SA
	Robert Williamson	*Data manager/ fish sampler*	SA
	Tim McClurg	*Epibenthic specialist / benthic sampler*	SA
	Kate Munnik	*CTD technician / fish sampler*	SA
	Ester Nangolo	*Scientist / fish sampler*	NAM
	Malakia Shimhanda	*Technician / fish sampler*	NAM

AREA OF OPERATION:	ML 170 – SP-1. Between Conception Bay and Meob Bay in Namibia, approximately 60 km offshore in water depths from 200 – 300 m. There will be 24 stations and general direction of trawls will be from north to south.
GEAR:	1. Viking double belly monkfish trawl net (with tickler chains) 2. Codend liner 20mm 3. Digital scales 4. CTD and stainless steel casing 5. Digital cameras

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed "Attention: Administration Manager," at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

contents

1 DATA TO BE COLLECTED 1

2 GENERAL CRUISE PLAN 1

2.1 BOTTOM TRAWLING 1
2.2 FISH SAMPLING 2
2.3 HYDROLOGY 2
2.4 STATION NUMBER ALLOCATION 2
2.5 PROGRESS MEETINGS 2
2.6 GENERAL 2

© NMP 2014

OBJECTIVES

- Estimate the abundance (density) of the main commercial species such as hake, monk and horse mackerel etc.,
- Collect biological information (length, sex, maturity stage, stomach content) from the commercially important/exploited species,
- Identify, collect and photograph epibenthic species and at the same time record the nature of the substrate and bottom profile,
- Collect environmental data (using visual observations and a CTD) to establish linkages between the environment and species distribution, recruitment and abundance, and
- Record/identify the occurrence of surface species such as marine mammals and seabirds in the area
- Collect baseline data for future monitoring

1 DATA TO BE COLLECTED

- The entire catch will be identified and sorted into species and the weight and numbers recorded.
- Hake, monk, horse mackerel and other target species will be differentiated by sex and lengths measured.
- Representative sub-samples of hake and monk will be measured for biological information such as individual length, weight, sex, maturity stage, and stomach fullness
- Two days will be available in the event of weather down time or gear damage (torn net).
- CTD data (vertical hydrographic profiles) will be collected at all stations. Data will include temperature, salinity (conductivity) and oxygen at a one metre depth resolution.
- Seabirds and marine mammal will be identified and counted (during the day) within a 500 m radius of the vessel.

2 GENERAL CRUISE PLAN

2.1 BOTTOM TRAWLING

Trawl duration will be 30 minutes, this being the time the net actually spends on the bottom, at a speed of 3 knots. Fishing will take place during day and night hours. The gear should not be deployed until the trawl deck has been cleared, or before the scientific processing of the previous catch is sufficiently advanced.

A commercial type Viking double-belly_monkfish bottom trawl with a head length 88 m, footrope 47 m and vertical net opening 30 – 40 m will be used. The distance between the wings during towing will be around approx 40 m. The trawl will be rigged with tickler chains along the footrope. The “Thyborun” trawl doors will be 4.2 m square in size and weigh around 800 kg. The codend mesh size will be 120 mm but in order to avoid small fish and epibenthic fauna being lost through the meshes, a 20 mm inner-liner will be installed inside the codend. No SCANMAR sensors are onboard, only trawl out will be measured

© NMP 2014

2.2 FISH SAMPLING

The entire catch (or a subsample in the case of large catches) will be sorted into species. Monk, hake, horse mackerel and chondrichthyans (sharks) will be further sorted by sex. The total catch weights (kg) of each species (and sex where applicable) will be recorded. Length frequency (total length) data will be collected for all commercial species (measured by sex if split). For non-commercial species (such as rat tails), only the weight and number of fish will be used.

If the catch is > 1 tonne, it will be split into two (approximately 50%) and one half will be sampled as above. If the catch is > 5 tonnes then 25% of the catch will be sampled as above. This will be done by estimating the catch in the stocker pond and splitting the catch into the desired proportions e.g. 50 or 25%.

In both cases, biological sampling (individual weight and length measurements, sex, maturity stage, stomach contents) of about 15 – 20 fish will be done for hake and monk per station

2.3 HYDROLOGY

A CTD will be deployed to acquire environmental research data.

2.4 STATION NUMBER ALLOCATION

Stations were randomly selected by dividing the survey area into grid blocks (2.5 nm x 3 nm). In each grid block two stations were randomly selected using Excel. Where possible, the first random position was selected. If not, the next position on the list was selected, and this continued until two stations were selected per grid block. Stations that were not suitable for trawling include those in water shallower than 200 m, those inside the environmental reference site areas and within 500 m of the oceanographic mooring anchor.

2.5 PROGRESS MEETINGS

Initial and final meetings will be held to inform everybody about the objectives of and progress made during and after the trip.

2.6 GENERAL

All scientific staff are advised to study the standing instructions regarding safety measures. A detailed guide covering all aspects of shipboard procedures is available in each cabin. All scientists are advised that casual attire should be worn for meals (i.e. NO work clothes/boots/shoes please).

© NMP 2014

DATA MANAGEMENT AND CRUISE REPORT

All data will be recorded on data sheets and entered electronically in an Access (and Excel) database. Hard copies of the data sheets will be retained by NMP. Three integrated reports; the Cruise Report, the Verification Report and Epibenthic Report will be submitted to NMP approximately three months after the completion of the survey.

© NMP 2014

APPENDIX 2 – FISHERIES AND BIODIVERSITY

2.5 Biodiversity Induction Module FV *Zeearend*

NAMIBIAN MARINE PHOSPHATE

NAMIBIAN BIODIVERSITY VERFICATION SURVEY

INDUCTION MODULE

Prepared for:
Namibian Marine Phosphate (Pty) Ltd.

Prepared by:
Capricorn Fisheries Monitoring cc

CAPFISH (Pty) LTD
Unit 15, Foregate Square. Table Bay Boulevard, 8002, South Africa
Directors: Japp, Wissema, Heinecken, Wilkinson, Ncongo
Co Reg. No. 2004 / 004844 / 07

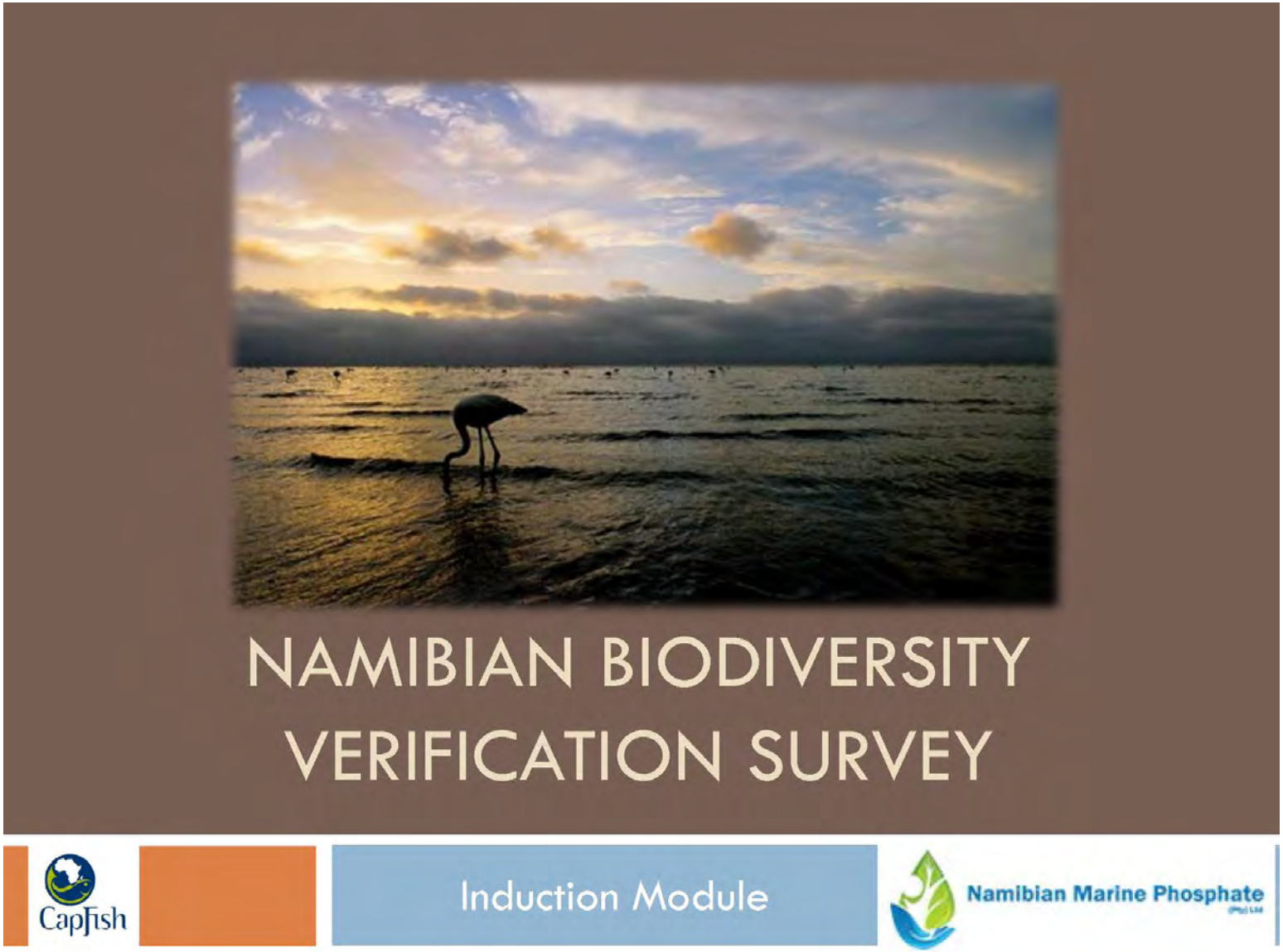
CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

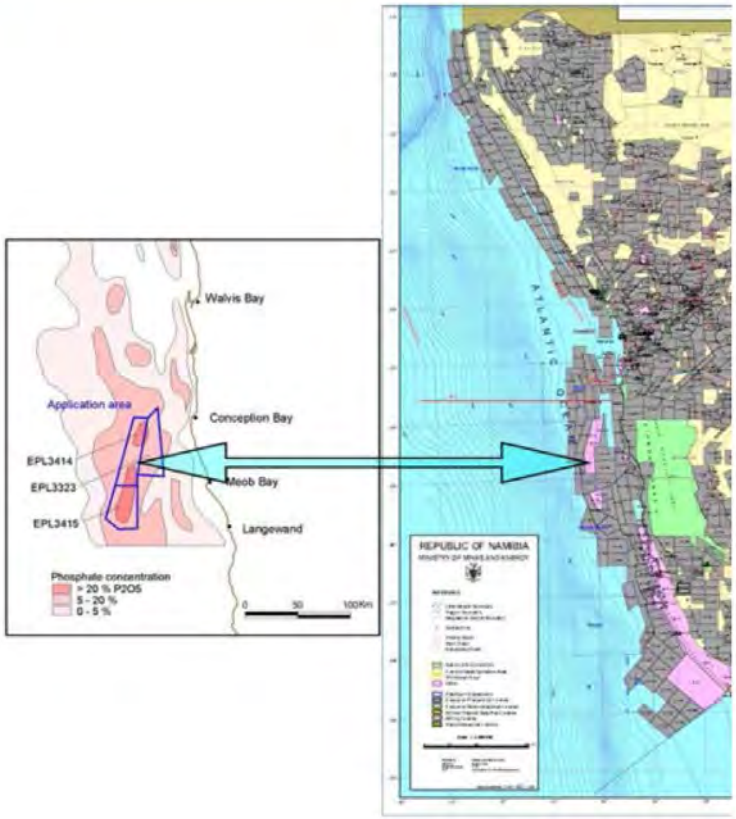
© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed "Attention: Administration Manager," at the address below.

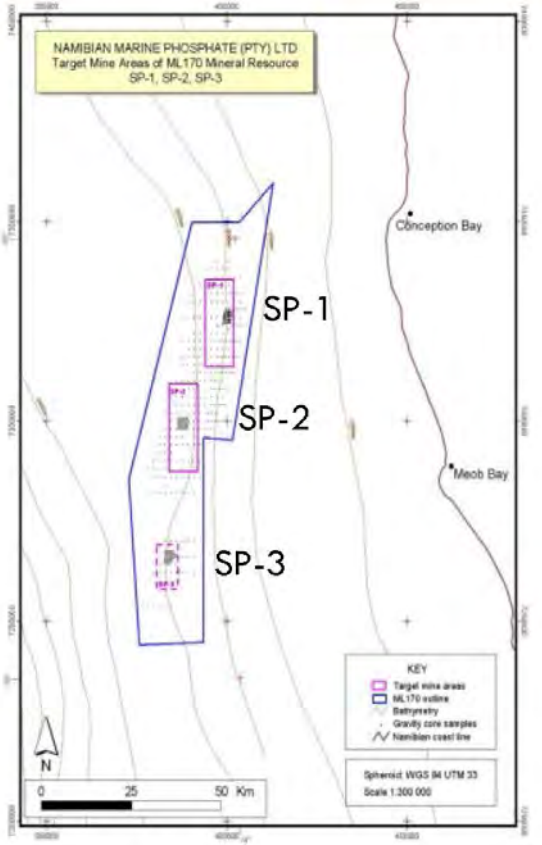
Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia


NAMIBIAN BIODIVERSITY
VERIFICATION SURVEY
CapFish
Induction Module
Namibian Marine Phosphate

© NMP 2014

Location of ML 170 & Sandpiper Deposit





Primary Objective

The purpose of the verification assessment program is to collect in-situ marine fauna and epibenthic data from SP-1 in order to confirm the results detailed in the EIA specialist report; (*Japp and Smith 2012: Appendix 1a on fish resources, fisheries, marine mammals and birds*). Five primary impacts were identified in the EIA report:

- the likely impact of mining on commercial fisheries;
- the likely impact of mining on the main commercial fish species;
- the likely impact of mining on the recruitment of commercially important species;
- the likely impact of mining on fish biodiversity and
- the likely impact of mining on seabirds and marine mammals.

© NMP 2014

Specific Objectives

- Estimate the abundance (density) of the main commercial species such as hake, monk and horse mackerel etc.,
- Collect biological information (length, weight, sex, maturity stage, stomach content) from the commercial species,
- Identify, collect and photograph epi-benthic species and at the same time the nature of the substrate,
- Collect environmental data (using visual observations and a CTD),
- Record/identify the occurrence marine mammals and seabirds in the area
- Collect baseline data for future monitoring

© NMP 2014

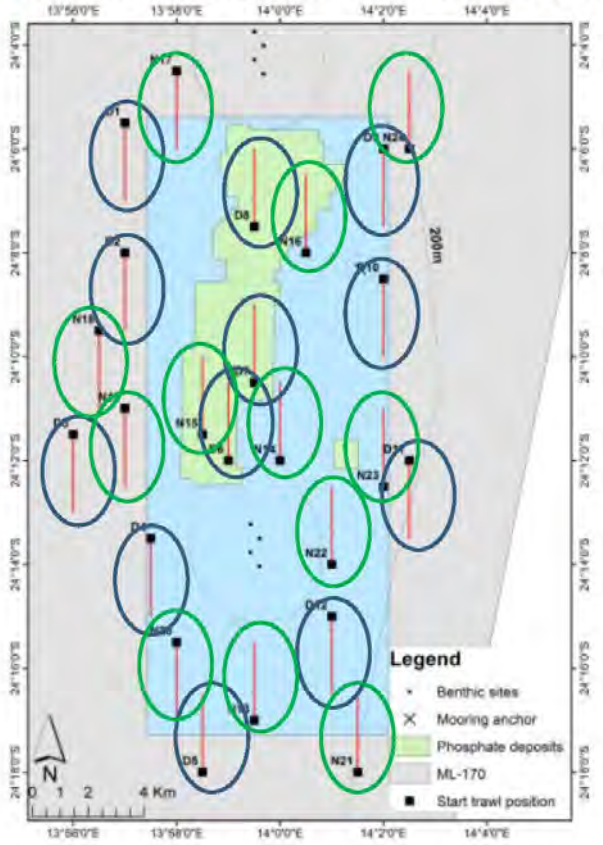
The Schedule

Day	Date	Time	Activity
Wednesday	18th June	06:00	Embark/sail
Thursday	19th June	07:00 – 17:30	Station D1 – D4
Friday	20th June	07:00 – 17:30	Station D5 – D8
Saturday	21st June	07:00 – 17:30	Station D9 – D12
Sunday	22nd June	20:00 – 05:30	Station N13 – N16
Monday	23rd June	20:00 – 05:30	Station N17 – N20
Tuesday	24th June	20:00 – 05:30	Station N21 – N24
Wednesday	25th June	*Contingency day*	
Thursday	26th June	*Contingency day*	
Friday	27th June	18:00	Return sail
Saturday	28th June	06:00	Disembark

© NMP 2014

Biodiversity Verification Survey

Location of stations within & surrounding SP-1



Cruise date: 18th – 28th June 2014

- 24 stations in 6 days (4 stations/day)
- 12 stations - day (D1 – D12)
- 12 stations - night (N13 – N24)
- 30 minute trawls at 3 knots (1.5nm)
- All stations deeper than 200m depth

© NMP 2014

Daily Sampling Routine

Visual environment, marine mammal and bird observations Stations D1-D12	Fish and benthic sampling Stations D1-D12	Fish and benthic sampling Stations N13 – N24
07:00 – 08:00	07:00 – 07:30	20:00 – 20:30
11:00 - 12:00	11:00 – 11:30	23:00 – 23:30
14:00 – 15:00	14:00 – 14:30	02:00 – 02:30
17:00 – 18:00	17:00 – 17:30	05:00 - 05:30

© NMP 2014

The Vessel – FV *Zeearend*

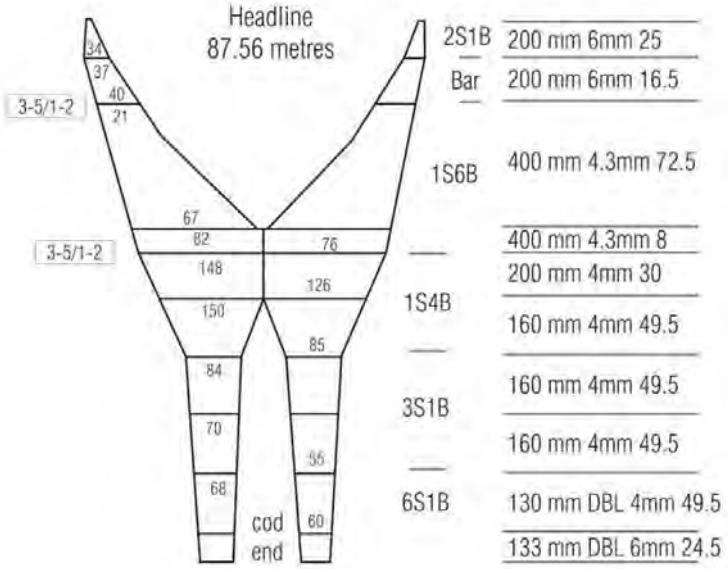


FV *Zeearend* – Benguella Fishing Company (BFC)

- Side trawler
- Skipper
- 16 people
- 7 scientists/9 fishing crew
- Cabins

© NMP 2014

Viking Double Belly Monk Trawl Net



Double codend net

- Codend liner - 20mm
- Distance between doors - 40m
- Vertical mouth opening – 1m
- Tickler chains

© NMP 2014

CTD (Salinity, Temperature, Depth)



Multi-probe internal logging CTD

- Protected by stainless steel casing & net bag
- Attached to the top rope of the trawl net with shackles, rope and cable ties

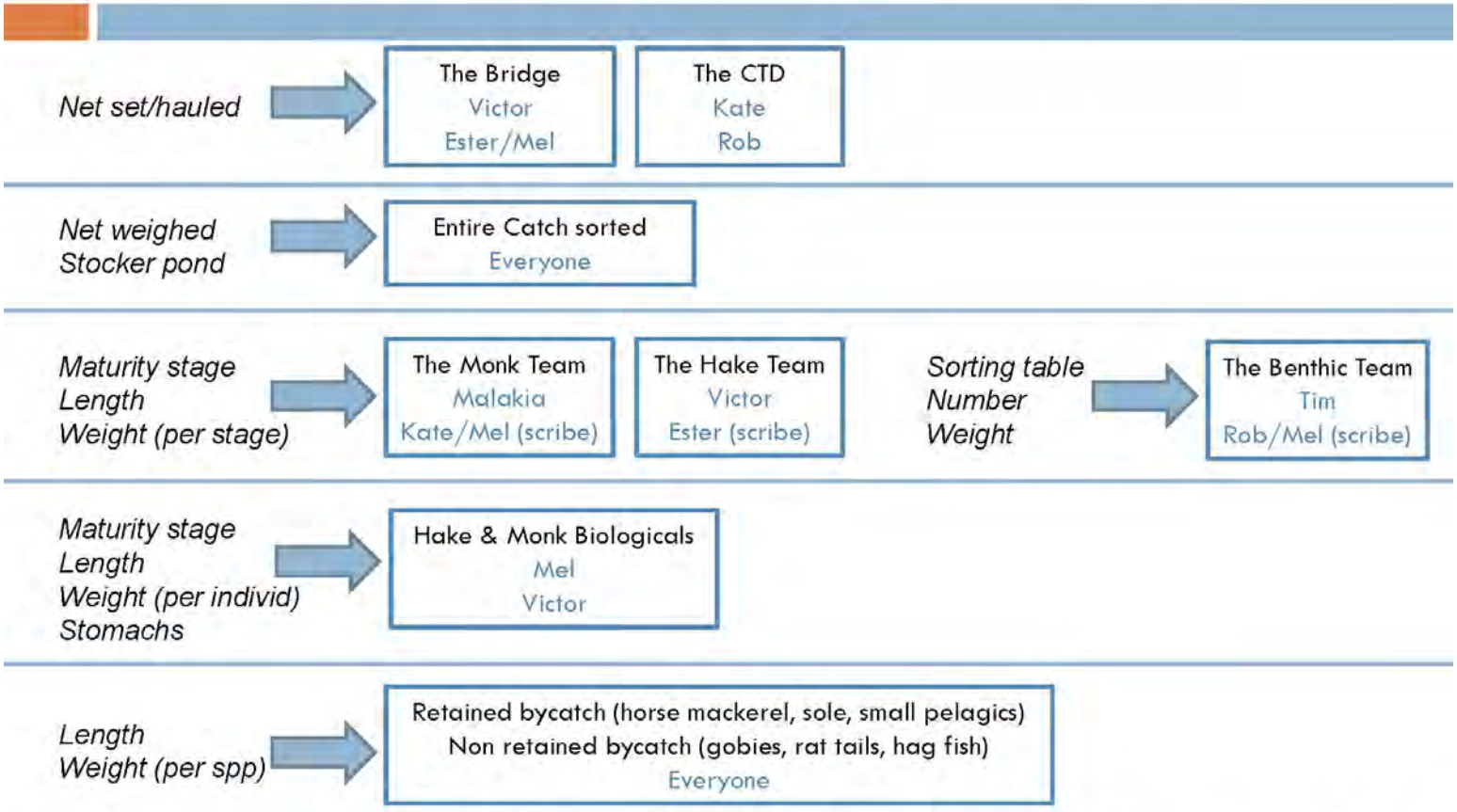
© NMP 2014

The Scientific Team

PERSONNEL	ROLE / RESPONSIBILITIES (Fish samplers)
Melanie Smith	Chief scientist
Ester Nangolo	Scientist/mammals & birds observer
Victor Ngcongo	Chief technician / mammals & birds observer
Tim McClurg	Epibenthic specialist / epibenthic sampler
Robert Williamson	Data manager/ epibenthic sampler
Malakia Shimhanda	Technician/Namibian species ID specialist
Kate Munnik	CTD technician

© NMP 2014

Roles & Responsibilities (in pairs)



If the catch is > 1 ton, it will be split into two (approximately 50%) and one half will be sampled as above.

Sampling Strategy



Catch weight measured

- Catch released into stocker pond
- Entire catch sorted into bins (50 kg), baskets (25 kg) and basins (5 kg)

© NMP 2014

Monk



Lophius vomerinus

For each fish measure

- Maturity Stage (1-5)
- Length
- Weight per stage



Lophius vaillanti

Hake

Merluccius capensis



Meluccius paradoxus



For each fish measure

- Maturity Stage (1-5)
- Length
- Weight per stage

© NMP 2014

Monk Maturity Stages - Females

Female
1 Immature **White**, relatively small, ribbon-like, **appear empty**, no blood vessels
2 Developing White, ribbon-like, blood vessels **begin**
3 **Active** **Turning orange**, small eggs begin to form inside the tissue
4 Ripe Ovary is **full of gelatinous egg mass.** Eggs approximately 2 mm in diameter. **Ovaries fill body cavity**
5 Spent **Highly vascularised (blood vessels)**, tissue appears very **granular**



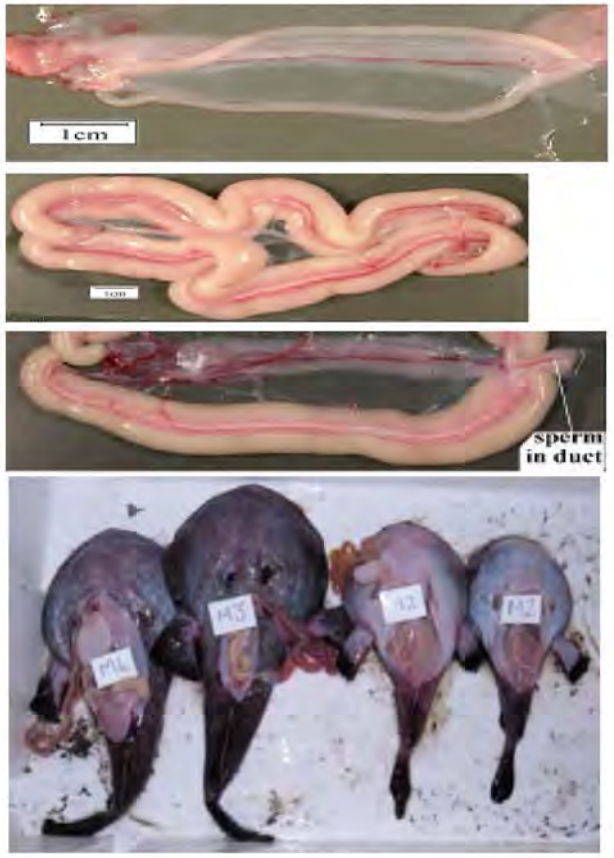






Monk Maturity Stages - Males

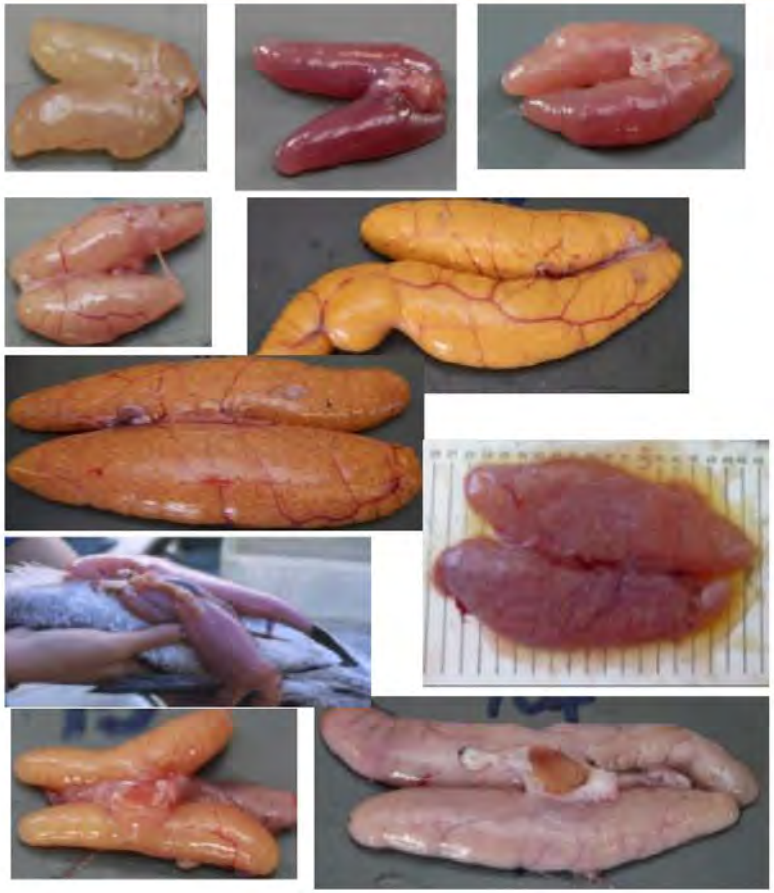
Male
1 Immature Small and white, very soft, distinct groove along dorsal edge
2 Developing Creamy-white, large and firm, blood vessels begins.
3 Active **Cream.** Sections of testis become **blotchy & bloody**, small amount of sperm present when testis is dissected
4 Ripe **Dark cream.** Tested distorted in shape, like an **over-filled sausage.** Highly vascularised, copious amount of sperm present
5 Spent **Dark cream**, highly vascularised. Small amount of **sperm present**



© NMP 2014

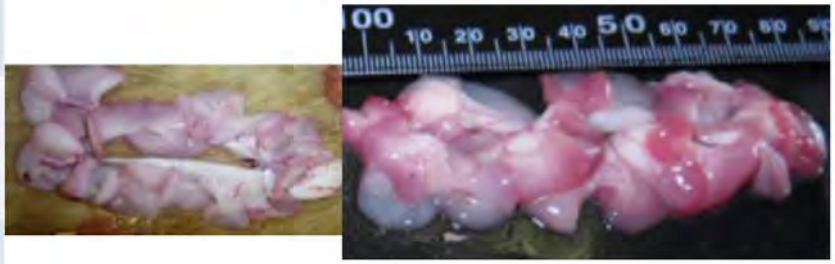
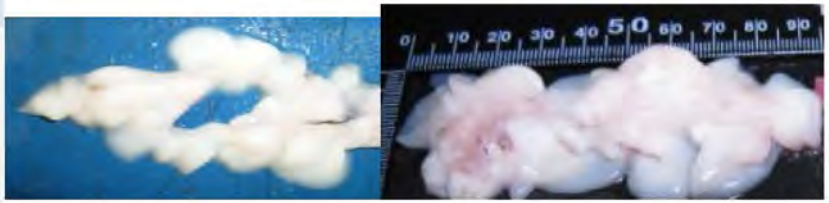
Hake Maturity Stages - Females

Females
1 Immature Never spawned
2 Developing Visible eggs. Blood vessels visible
3 Ripe Starting to turn bright orange, bright orange Signs of hydration.
4 Ripe & Running Fully hydrated ovaries and/or running eggs with little pressure
5 Spent Sexually mature, reproductively inactive Some eggs, partially spent



© NMP 2014

Hake Maturity Stages - Males

Males	
1 Immature Never spawned	
2 Developing Visible eggs. Blood vessels visible	
3. Ripe	
3 Ripe & Running Oozing sperm from the vent	
5 Spent No sperm	

Hake/Monk Biologicals (15 fish per spp)





For each fish measure

- Maturity Stage (1-5)
- Length
- Weight per fish
- Stomach contents (digest state, prey ID, number of prey spp, length)

© NMP 2014

Epibenthic



For each species

- Weight (per spp)
- Number
- Sub-sample
  - ✓ Count out 20 individuals
- Photo
- Preserve/100% alcohol

© NMP 2014

Forms (LF – Commercial Females)

TRAWL FORM # 6: COMMERCIAL SPECIES LENGTH FREQUENCY - FEMALES

Vessel:				**Station No:**					**Date:**				
Species													
Weight (kg)													
Stage:	F1	F2	F3	F4	F5			F1	F2	F3	F4	F5	
0							0						
1							1						
2							2						
3							3						
4							4						
5							5						
6							6						
7							7						
8							8						
9							9						
Total:							**Total:**						

Forms (LF Commercial Males)

TRAWL FORM # 6: COMMERCIAL SPECIES LENGTH FREQUENCY - MALES

Vessel:				Station No:					Date:				
Species													
Weight (kg)													
Stage:	M1	M2	M3	M4	M5		M1	M2	M3	M4	M5		
0							0						
1							1						
2							2						
3							3						
4							4						
5							5						
6							6						
7							7						
8							8						
9							9						
Total:							Total:						

Forms (LF – Bycatch)

TRAWL FORM # 7: RETAINED BYCATCH SPECIES LENGTH - FREQUENCY

Vessel:							Station No:						Date:					
Species:																		
Weight (Kg):																		
0							0											
1							1											
2							2											
3							3											
4							4											
5							5											
6							6											
7							7											
8							8											
9							9											
Total:							Total:											

Health and Safety

ALWAYS APPLY

LPSA

Loss Prevention Self Assessment

Before beginning any activity / task / job, after nay loss or near miss, any unusual circumstances:



Assess the risk!

- What could go wrong?
- What is the worst thing that could happen if something goes wrong?

Analyse the risk!

- Do I have all the necessary Training and Knowledge to do this job properly?
- Do I have all the proper Tools and Personal Protective equipment?

ACT to ensure loss-free operations!

- Take necessary Action to ensure the job is done properly!
- Follow written procedures!
- Ask for assistance if needed!

© NMP 2014

Acknowledgements



© NMP 2014

SANDPIPER PROJECT

Verification Programme Report:
Mining Licence Area No. 170

SECTION D : APPENDICES

APPENDIX 3
Geophysics

3.1: Geophysical Processing Procedures
3.2: Geophysical Habitat Mapping

APPENDIX 3 – GEOPHYSICS

3.1 Geophysical Processing Procedures

FLEDERMAUS AND GEOCODER TOOLKIT PROCESSING PROCEEDURES FOR HABITAT MAPPING FOR NMP VERIFICATION PROGRAMME

AREA 1, SANDPIPER PHOSPHATE PROJECT

Prepared for:
Namibian Marine Phosphate (Pty) Ltd.

Prepared by:
Marine Data Consultants



September 2014

Marine Data Consultants www.MarineDataConsultants.co.za
1A Carlton Close, Sun Valley 7975, Cape Town, South Africa
Tel +(27) (21) 7853825 Fax +(27) (21) 7853981 *Mobile* +(27) (0) 83 257 0731
Email Gordon.Rigg@MarineDataConsultants.co.za

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed “Attention: Administration Manager,” at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

contents

1 BACKGROUND 1

2 PROCESSING SOFTWARE USED 1

3 EM710 BATHY PROCESSING PROCEDURE 1

4 DIGITAL DATA DELIVERABLES 1

4.1 BACKSCATTER MOSAICS 1

4.2 EM710 MULTIBEAM BATHY DATA 2

© NMP 2014

1 BACKGROUND

MDC was commissioned by Namibian Marine Phosphate (NMP) on 06 August 2014 to post-process Kongsberg EM710 Multi Beam Echo Sounder (MBES) Bathymetry, EM710 Snippets and EdgeTech Side Scan Sonar Data which were acquired by a third-party. Data supplied to MDC were original raw Kongsberg (*.all) files and raw *.xtf EdgeTech files.

2 PROCESSING SOFTWARE USED

Fledermaus V7.4.0d, 64 bit Edition. Build17 May 2014
QINSy V8.10 Build 2014.03.06.1

3 EM710 BATHY PROCESSING PROCEDURE

1) The Kongsberg *.all files were imported into Fledermaus DMagic and re-projected to WGS84, UTM33S.
2) SANHO 10min predicted tides were applied (co-tidal solution using liner interpolation from Lüderitz and Walvis Bay tide stations. All soundings reduced to MSL.
3) A 1m Combined Uncertainty and Bathymetry Estimator (CUBE) surface was built in DMagic to IHO Order-1 (S44).
4) Blatant “fliers” (noise) were flagged as deleted in Fledermaus 3D Editor and the 1m CUBE updated.
5) An automated filter was applied 1m above and below the CUBE surface and all soundings outside1m from the CUBE surface were flagged as rejected.
6) The final 1mCUBEsurface was checked for sounding density and standard deviated and exported to ASCII (E,N,Z) for DTM creation and contouring.
7) The ASCII (E,N,Z) file was imported into QINSy Sounding Grid Utility for contouring (DXF) and Geotiff/KML Raster file creation.

A final 5mx5m bathy DTM grid was produced from the processed bathymetry and color-shaded by water depth.

4 DIGITAL DATA DELIVERABLES

4.1 BACKSCATTER MOSAICS

- NMP_Edgetech_SSS_Mosaic_30cm_Copper.tiff
- NMP_Edgetech_SSS_Mosaic_30cm_Grey.tiff
- NMP_Edgetech_SSS_Mosaic_30cm_Grey_crop.tif
- NMP_EM710_Snippets_Mosaic_50cm_Copper.tiff
- NMP_EM710_Snippets_Mosaic_50cm_Grey.tiff
- NMP_EM710_Snippets_Mosaic_50cm_Grey_crop.tif

© NMP 2014

4.2 EM710 MULTIBEAM BATHY DATA

- NMP_5m_Bathy_CUBE_edit_Area1.xyz
- DTM Geotiff -190 to -225m Delivery SG 5x5m.tif
- DTM Geotiff -190 to -225m Delivery SG 5x5m.tfw
- DTM Geotiff -190 to -225m Delivery SG 5x5m.kml
- Contours 1m.dxf
- Colour Bar -190 to -225m.jpg
- Bathymetry_20140807100844.dxf

© NMP 2014

APPENDIX 3 – GEOPHYSICS
3.2 Geophysical Habitat Mapping

Prepared for:
Namibian Marine Phosphate (Pty) Ltd.

Prepared by:
Jeremy Midgley

September 2014

Mr Jeremy Midgley Pr.Sci.Nat
J. Midgley & Associates
PO Box 110
Constantia 7806
South Africa
Email: mwjmidg@mweb.co.za

Report Preparation and Approval

Date	Version	Revised	Reviewed
1 August 2014	Draft 1	J. Midgley	B. Ludick
30 September 2014	Draft 2	Midgley	B. Ludick
17 October 2014	Final	Midgley	B. Ludick
APPROVED	Final	Midgley	

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed “Attention: Administration Manager,” at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

SUMMARY

The interpreted geophysical data reveals a flat, smooth seafloor with a homogeneous surficial sediment cover across the entire survey block, with no protruding obstacles (natural or artificial).

The sediment surficial sediment of the deposit consists of a mixture of silty sand particles, typically with dense shell. This has been confirmed from grab and core samples collected from in and around the target dredge site SP-1.

The geophysical information was collected using integrated multi beam echo sounder and side-scan sonar equipment.

© NMP 2014

contents

1 SURVEY AREA **1**

2 SURVEY EQUIPMENT AND DATA CAPTURING **4**

2.1 MULTI BEAM ECHO SOUNDER (MBES) 4
2.2 SIDE-SCAN SONAR 4

3 DATA PROCESSING **4**

3.1 GEODETIC PARAMETERS USED 4
3.2 EM710 BATHY PROCESSING PROCEDURE 4
3.3 EM710 SNIPPETS (PSEUDO BACKSCATTER) MOSAIC PROCESSING PROCEDURE 5
3.4 EDGETECH 4200 SIDE-SCAN SONAR (SSS) MOSAIC PROCESSING PROCEDURE 5

4 RESULTS **5**

4.1 MULTI BEAM ECHO SOUNDER (MBES) BATHYMETRY 5
4.2 PSEUDO BACKSCATTER MOSAIC 8
4.3 SIDE-SCAN SONAR (SSS) IMAGE 9

5 MACROFAUNA AND MEIOFAUNA **12**

5.1 MACROFAUNA AND SURFACE SEDIMENT CHARACTERISATION 12
5.2 MULTIVARIATE ANALYSES OF MEIOFAUNAL COMMUNITY DATA 14

6 SUMMARY **15**

figures

Figure 1a. Multibeam echo sounder and side-scan Sonar coverage within SP-1 2
Figure 1b: Side-scan sonar coverage within SP-1 3
Figure 2: MBES bathymetry data 7
Figure 3: Pseudo backscatter image 8
Figure 4: Side-scan sonar mosaic 9
Figure 5: Consolidated sampling locations, SP-1: NMP verification survey 11
Figure 6: Sediment grain size distribution at the verification survey sites. 12
Figure 7: Sample groups as identified by the dendrogram, MDS and PCO plots overlain on the macrofauna survey verification sites 13
Figure 8: Distributions of structurally – related meiofaunal nematode communities (SP-1, of MLA 170) 14

© NMP 2014

1 SURVEY AREA

A geophysical survey trial, to map the seafloor surficial sediments in support of habitat distribution, was undertaken over a period of 5 days during September 2013 from the MV *DP Star* with Side-scan-Sonar (SSS) and multibeam echo sounder (MBES) equipment. The purpose was to characterise the seafloor of the target dredge area SP-1 and also to test the effectiveness of the different geophysical technics for optimisation of equipment to assess seafloor conditions for the planned dredging operations.

A block of 4 x 5 km², covering the first 10 years of dredging inside SP-1, was selected as the survey location. A series of parallel NS-lines were run with side-scan sonar and/or multibeam echo sounder equipment although full coverage with both were not achieved due to adverse weather conditions (Figure 1a & 1b).

© NMP 2014

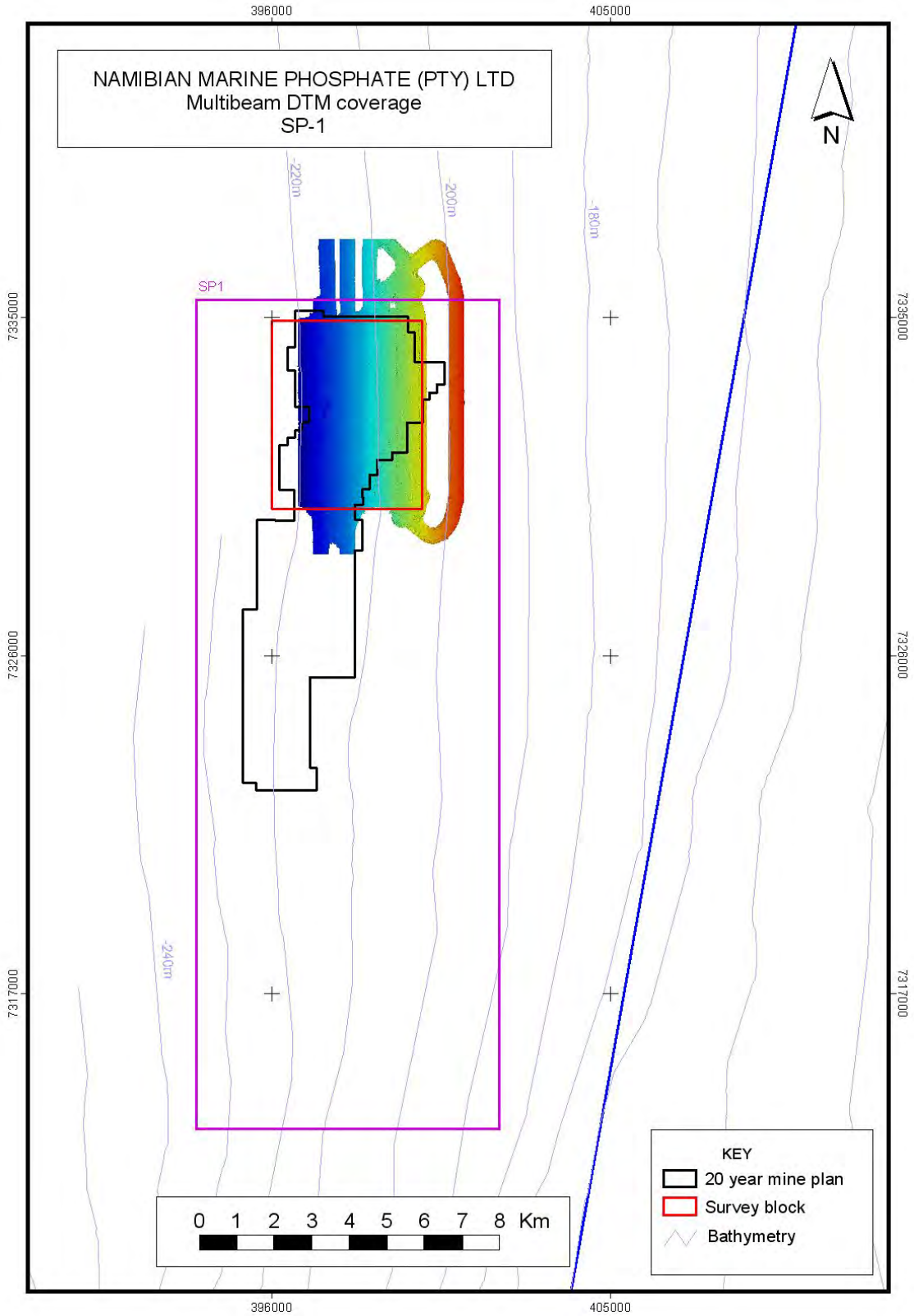


Figure 1a. Multibeam echo sounder and side-scan sonar coverage within SP-1

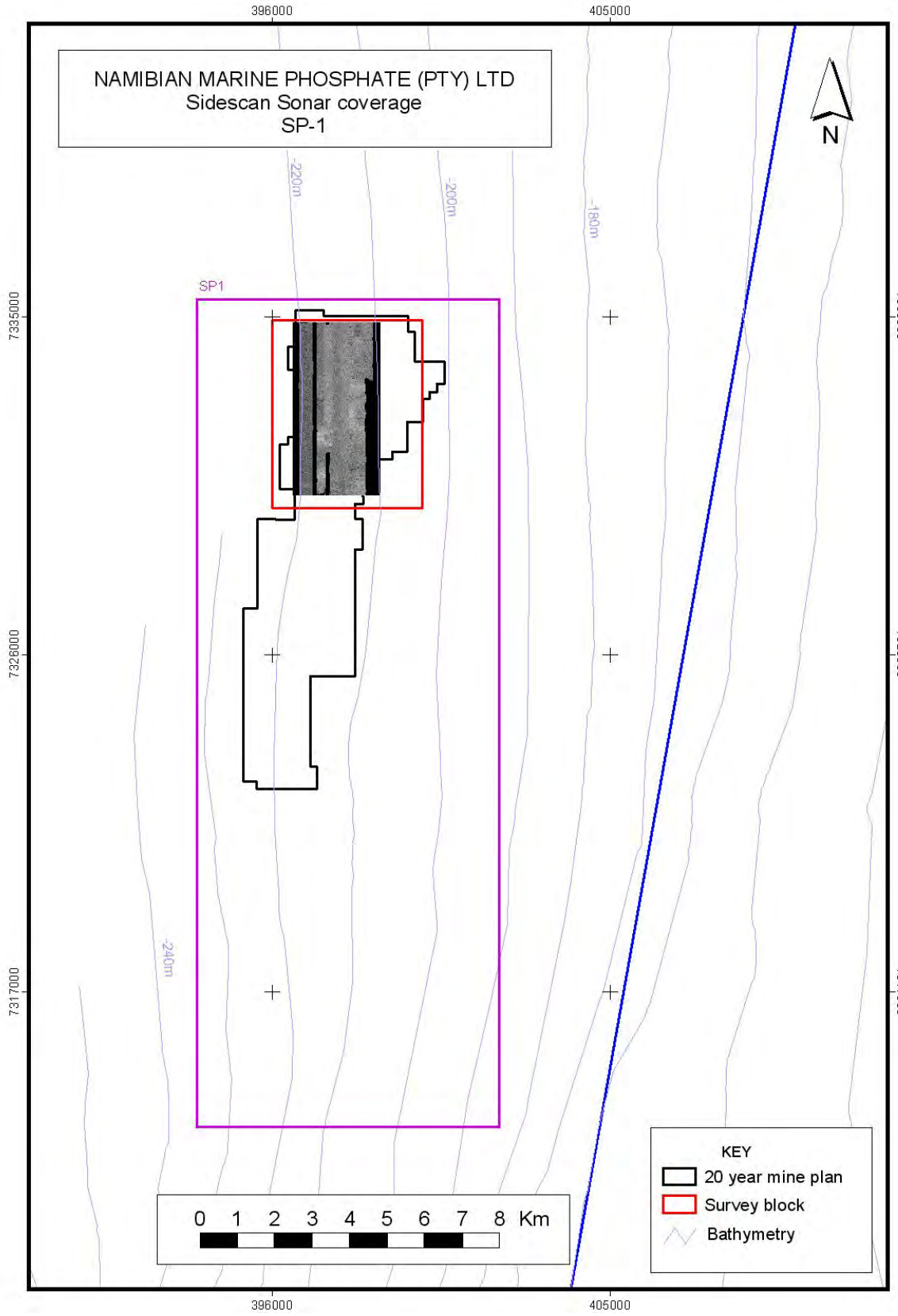


Figure 1b: Side-scan sonar coverage within SP-1

2 SURVEY EQUIPMENT AND DATA CAPTURING

The equipment selected for the geophysical survey consisted of the following:

2.1 MULTI BEAM ECHO SOUNDER (MBES)

- Kongsberg EM170, hull mounted on the MV *DP Star*, connected to MRU (type Seatex MRU5) and DGPS (type C-Nav3050)

2.2 SIDE-SCAN SONAR

- Dual simultaneous (Edgetech 2000-DSS) with combined SSS-SBP fish towed from winch and A-frame combination

Jan De Nul (an international dredging company) operated the SSS configuration and managed the data capture, with support from a marine surveyor, a marine geologist and a marine geophysicist. The MBES was operated by marine hydrographers from NUTAM (PYT) Ltd (a marine mining and exploration company).

3 DATA PROCESSING

Marine Data Consultants (MDC) (Appendix 3.1) was commissioned by Namibian Marine Phospahte (NMP) (PTY) Ltd to post-process the Kongsberg EM710 Multi Beam Echo Sounder (MBES) Bathymetry EM710 Snippets and the EdgeTech side-scan sonar data. Data supplied to MDC were original raw Kongsberg (*.all) files and raw *.xtf EdgeTech files.

3.1 GEODETIC PARAMETERS USED

Kongsberg *.all files and EdgeTech Discover *.xtf files are by definition, Geographic. All data were imported in Fledermaus DMagic (V7.4.0d) and re-projected with the following Geodetic Setup Parameters:

Horizontal Grid Coordinates: WGS 84, UTM Zone 33S
Vertical Datum: Mean Sea Level (MSL)

3.2 EM710 BATHY PROCESSING PROCEDURE

1) SANHO 10 min predicted tides were applied (co-tidal solution using linear interpolation from Lüderitz and Walvis Bay tide stations. All soundings reduced to mean sea level (MSL).
2) A 1 m Combined Uncertainty and Bathymetry Estimator (CUBE) surface was built in DMagic to IHO Order-1 (S44).
3) Blatant “fliers” (noise) were flagged as deleted in Fledermaus 3D Editor and the 1m CUBE updated.
4) An automated filter was applied 1 m above and below the CUBE surface and all soundings outside 1 m from the CUBE surface were flagged and rejected.

© NMP 2014

5) The final 1 m CUBE surface was checked for sounding density and standard deviation, with subsequent exported to ASCII (E,N,Z) for DTM creation and contouring.
6) The ASCII (E,N,Z) file was imported into QINSy (V8.10) Sounding Grid Utility for contouring (DXF) and Geotiff/KML Raster file creation.

3.3 EM710 SNIPPETS (PSEUDO BACKSCATTER) MOSAIC PROCESSING PROCEDURE

1) The *.all files were imported into Fledermaus Geocoder Toolkit (FMGT) and re-projected to WGS84, UTM33S.
2) Processing Sonar Defaults were applied for Simrad EM710 MBES model 710.
3) The cleaned (processed) EM710 bathymetry data were loaded into FMGT, mosaic resolution set to 50 cm, and mosaicked to 50 cm pixel resolution using the DTM bathy data for range and angle corrections (no flat-bottom assumption).
4) Final geotiff mosaics (*.tiff) were exported from FMGT at 50 cm pixel resolution using Grey scale and Copper colour palates.
5) An automated surficial seabed classification Angle versus Range Analysis (ARA) was performed on the dataset, revealing “Medium Muddy Sand” throughout the mosaicked survey area with no noticeable variation in the surficial sediment type.

3.4 EDGETECH 4200 SIDE-SCAN SONAR (SSS) MOSAIC PROCESSING PROCEDURE

1) The *.XTF files were imported into Fledermaus Geocoder Toolkit (FMGT) and re-projected to WGS84, UTM33S.
2) Processing Sonar Defaults were applied for Edgetech 4200.
3) The cleaned (processed) EM710 bathymetry data were loaded into FMGT, mosaic resolution set to 30 cm, and mosaicked to 30 cm pixel resolution using the DTM bathy data for range and angle corrections (no flat-bottom assumption).
4) Final geotiff mosaics (*.tiff) were exported from FMGT at 30 cm pixel resolution using Grey scale and Copper colour palates.
5) An automated surficial seabed classification Angle versus Range Analysis (ARA) was performed on the dataset, revealing “Medium Sand” throughout the mosaicked survey area with no noticeable variation in the surficial sediment type (consistent with the ARA results for the EM710 Snippets data over the same survey site).

4 RESULTS

4.1 MULTI BEAM ECHO SOUNDER (MBES) BATHYMETRY

A 5 m x 5 m bathy digital terrain model (DTM) grid was produced from the processed bathymetry and colour-shaded by water depth (Figure 2).

The clipped MBES DTM image shows an overall flat seafloor with depths ranging between -204 to -220 m. The 1 m isobaths contoured from the data, to a vertical resolution of 20 cm, strikes north-south with an eastward dip of around 0.3 degrees.

© NMP 2014

A single, shallow depression in the sediment, noticed in the DTM, is less than 1 m deep and seems to be an exception to the rule. No positive relief features in the form of reef outcrops or shipwrecks of any kind is present in the data.

Weather conditions were less than desirable during the survey, with the pitch and roll of the vessel causing some artefacts as can be seen (spikes) in the data. Nevertheless, the data overall confirmed the expected flatness of the seafloor.

© NMP 2014

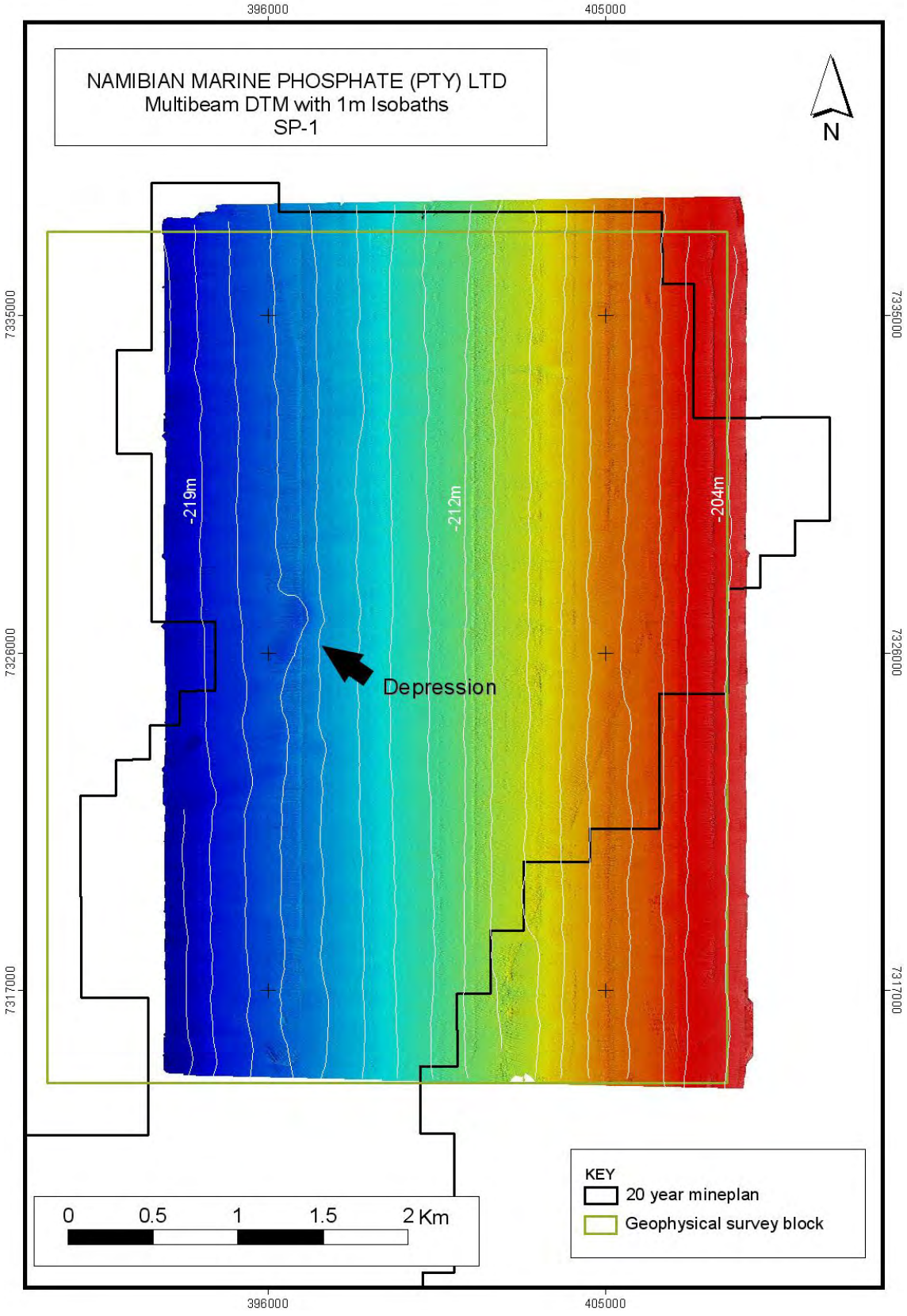


Figure 2: MBES bathymetry data

4.2 PSEUDO BACKSCATTER MOSAIC

The backscatter image (Figure 3) with a 50 cm pixel resolution produced from the MBES data shows a featureless, homogeneous surficial seafloor, indicated as a medium muddy sand surface by applying the automated surficial seabed classification Angle versus Range Analysis (ARA).

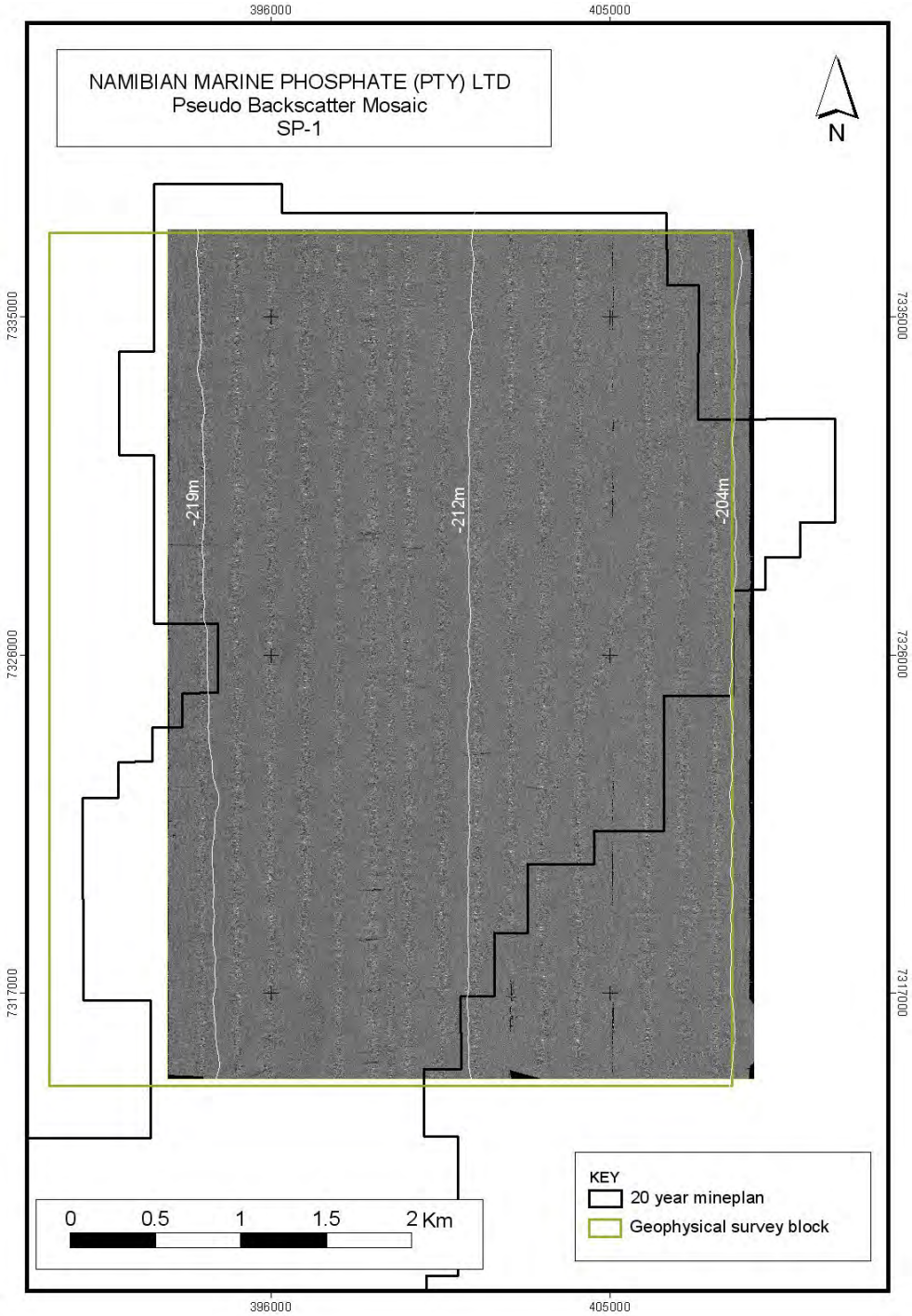


Figure 3: Pseudo Backscatter image

4.3 SIDE-SCAN SONAR (SSS) IMAGE

The side-scan sonar image (Figure 4) also confirms a smooth seafloor with an absence of any features or variance. The ARA result indicates a medium sand surface for all of the mosaic, which is consistent with the backscatter result.

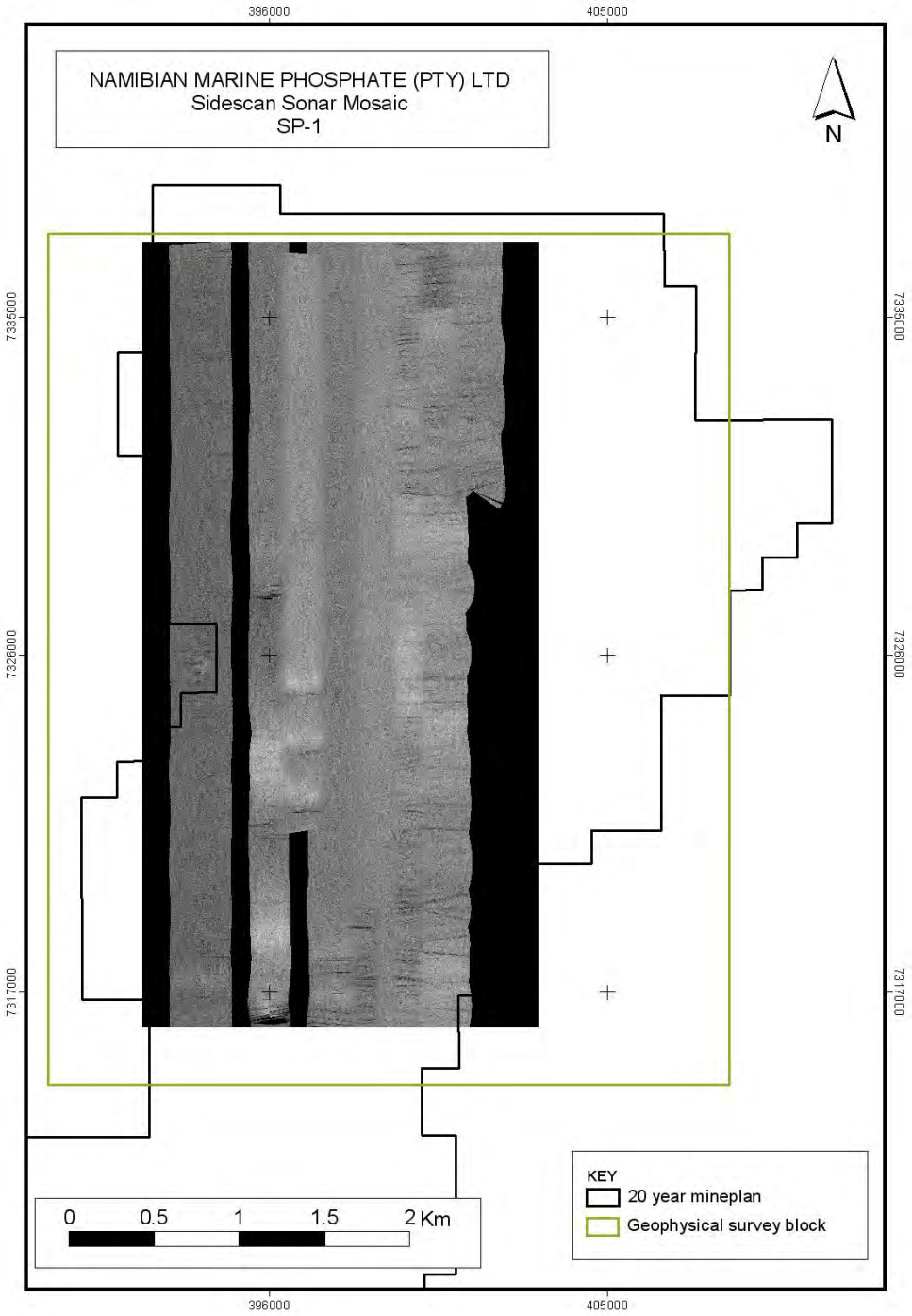


Figure 4: Side-scan Sonar Mosaic

For the NMP 2013 and 2014 Verification Survey, the information collected from in around the SP-1 target dredge site for the verification survey is extensive, from these surveys and data analysis the habitat has been assessed. The data coverage of the SP-1 target dredge site (Figure 5) consists of:

- A 90 day long instrument deployment, measuring: turbidity, current velocity, oxygen, conductivity, temperature and salinity
- 26 surficial sediment grab sites, from which, sediment characteristics were determined, macro and meio fauna samples were subsampled and analysed
- Collection of sediments for macrofauna impact sites referencing, and collection of 2 sets of reference sites (4 north and 4 south of the target dredge site). These sites together constitute the benthic macrofauna monitoring suite of samples
- Five samples sites, with CTD measurements and water samples recovered from depths of: 10 m, 20 m, 100 m, and ~ 200 m
- 25 cores of 90 mm were collected, each core of maximum length up to 3.0 m, these were subsequently analysed for sediment characterisation
- 10 surficial sample samples for the determination of bacterial content
- 24 monk demersal trawls (12 night and 12 day) of ~ 0.5 nm (30 minute trawl duration) over 8 days, with corresponding CTD deployments, full fisheries analysis of the catch, analysis of epifauna assemblage, and mammal and bird observations
- Geophysical survey, using, side-scan sonar, and multibeam equipment, with a total of 235 km line coverage.

© NMP 2014

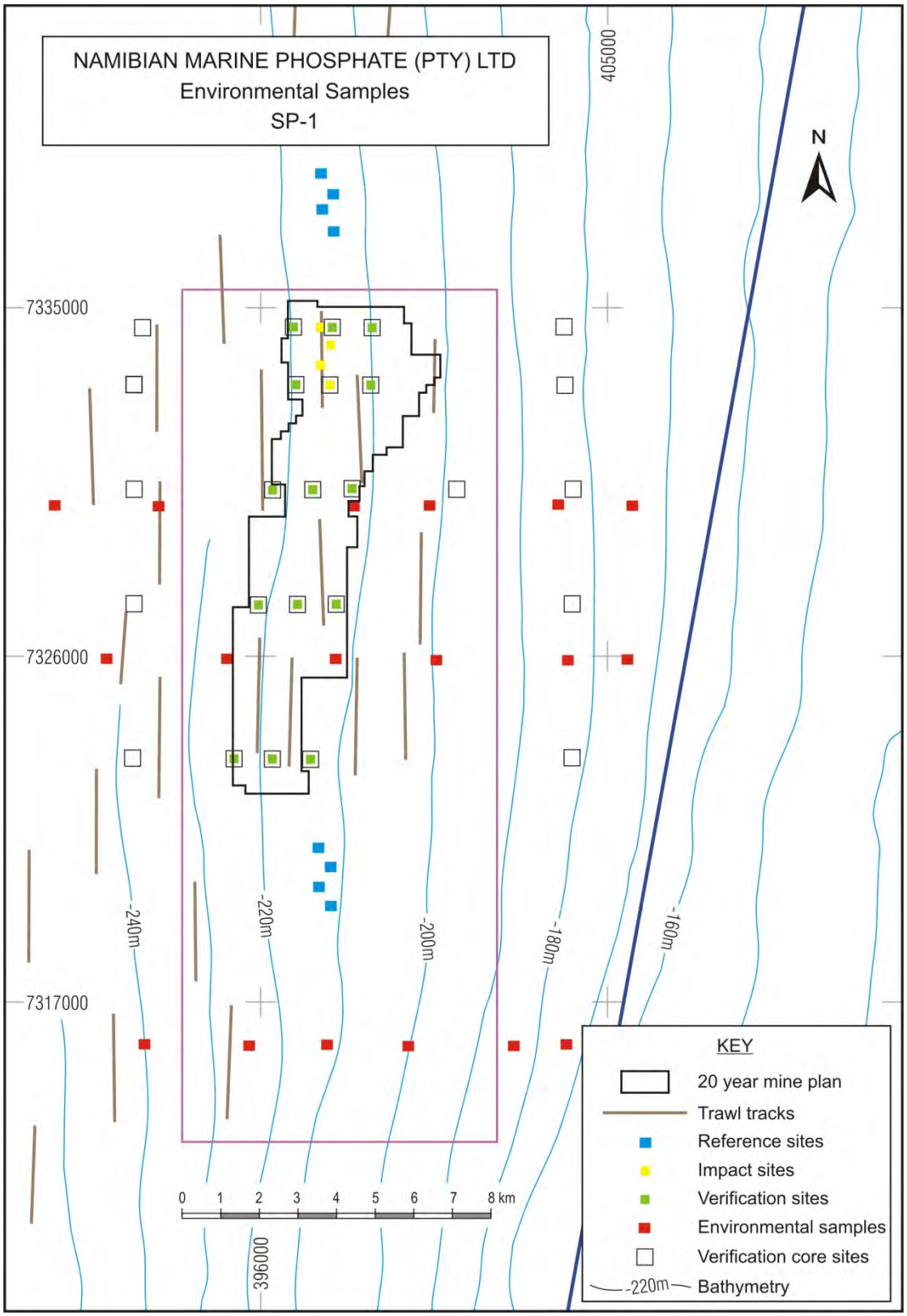


Figure 5: Consolidated sampling locations, SP-1: NMP verification survey

5 MACROFAUNA AND MEIOFAUNA

5.1 MACROFAUNA AND SURFACE SEDIMENT CHARACTERISATION

Sediment characteristics are discussed in detail in Section C, Chapter 2.1, here only a short description is provided. Surficial sediments in SP-1 can generally be classed as silty sand with an average median (D_{50}) sediment particle size of 114.39 µm and low porosity implying a firmly packed sediment with low pore water volumes. Surficial sediment layers frequently included dense shell layers, which were denser on the eastern boundary of the survey area than further to the west. With the exception of one site (SP1VS18), the measured particle size distributions were relatively similar at all the sites being dominated by medium and fine sand with a steady decline towards the smaller grain size (Figure 6). The combined fractions of <63 micron, *i.e.* the mud fraction, yielded around 30% while clay generally contributed <2%. In contrast to all other sites, SP1VS18 was highly dominated by very coarse sand (>70%).

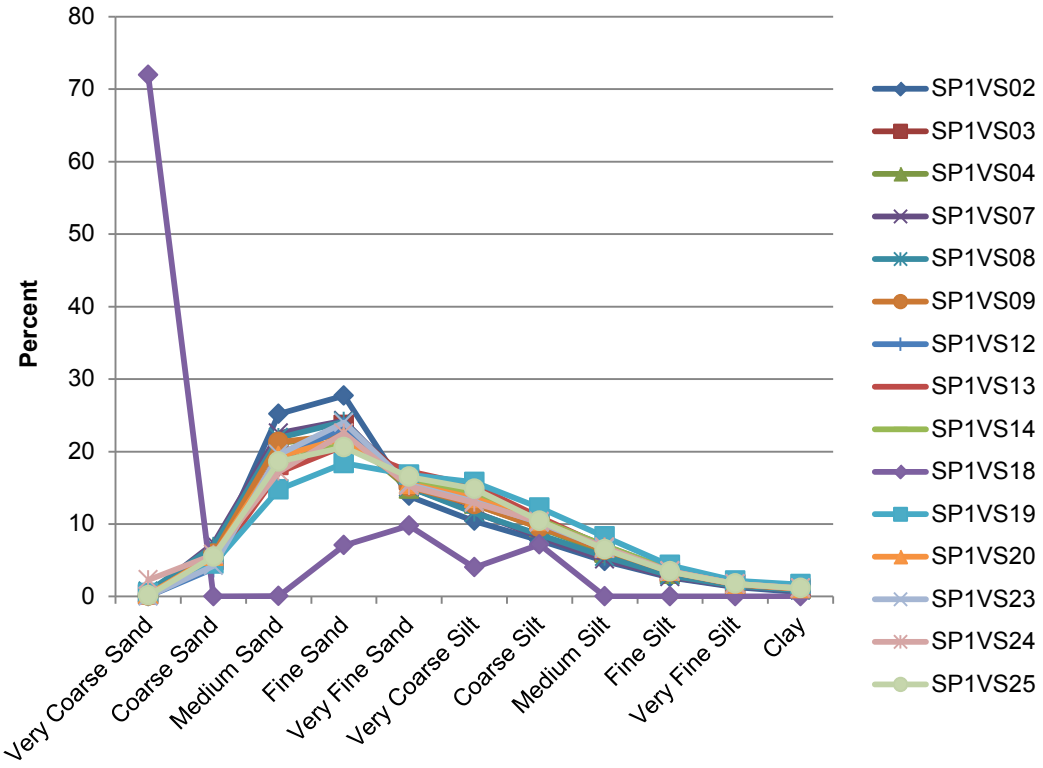


Figure 6: Sediment grain size distribution at the verification survey sites.

Macrofauna characteristics are discussed in detail in Section C, Chapter 2.5, here only a short description is provided. Figure 7 illustrates the sample clusters overlain onto the map of the verification survey sites, showing that Group A contains mostly the slightly shallower sites in the east of the survey grid with the exception of site SP1VS09. Sites SP1VS07 and SP1VS08 also fall into this group. Group B encompasses the western sites and SP1VS09. This information suggests a homogeneous sedimentary environment, with an east – west environmental gradient.

© NMP 2014

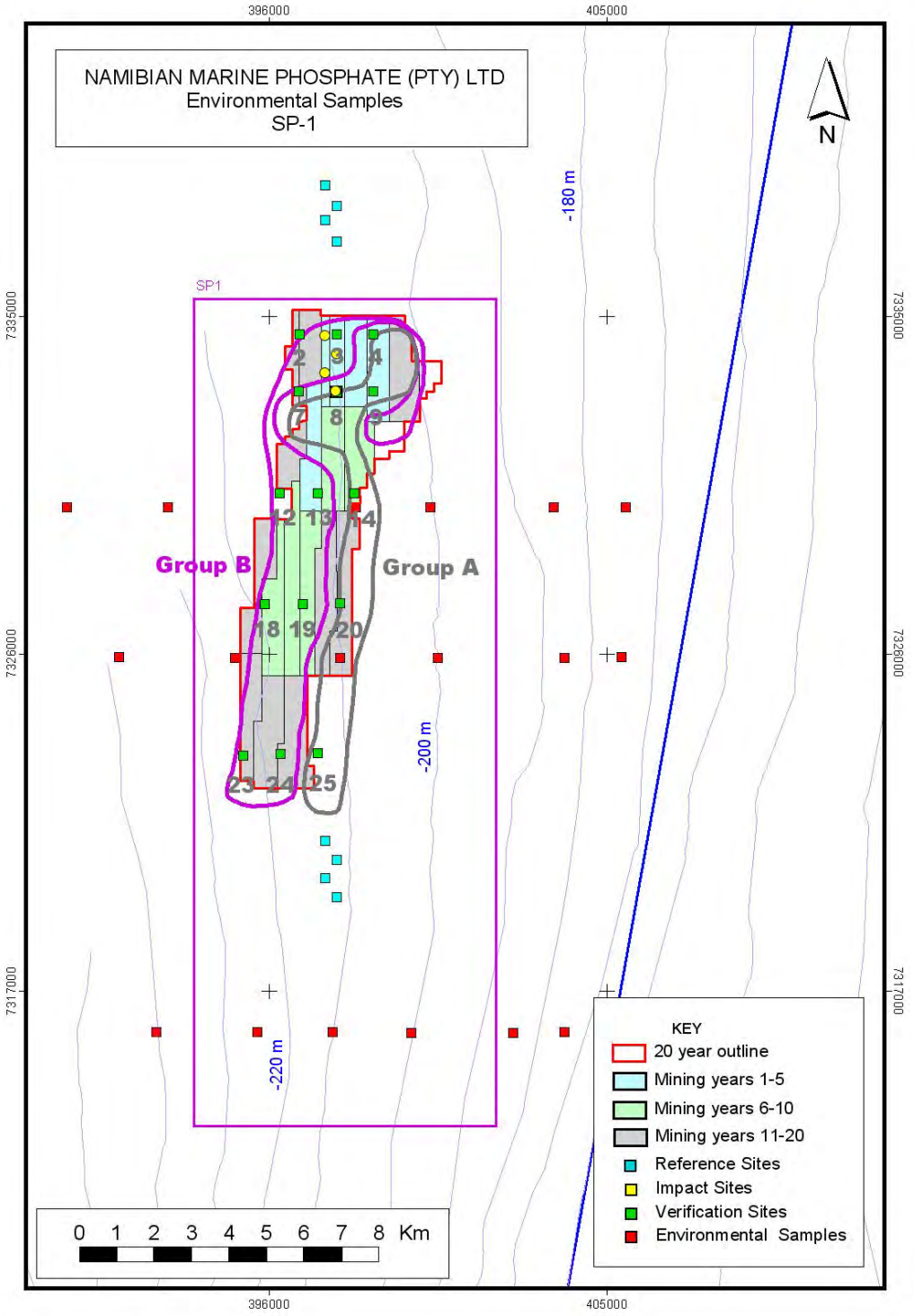


Figure 7: Sample groups as identified by the dendrogram, MDS and PCO plots overlain on the macrofauna survey verification sites

5.2 MULTIVARIATE ANALYSES OF MEIOFAUNAL COMMUNITY DATA

Meiofaunal characteristics are discussed in detail in Section C, Chapter 2.4, here only a short description is provided. The six clusters of structurally-related nematode assemblages identified by the classification analyses and corroborated by the ordination studies have been transposed onto the survey area chart (Figure 8). This reveals a nematode community distribution pattern *that is consistent with the presence of an environmental gradient*. The closely-related Cluster D, E and F meiofaunal assemblages were present at sites located on the eastern side of the verification survey area. Amongst these, the Cluster F communities were confined to the five sampling stations that extended along the eastern side of the grid. The remaining nematode assemblages, i.e. those belonging to Clusters A, B and C, were identified at sites located in the western half of the survey area (Figure 8).

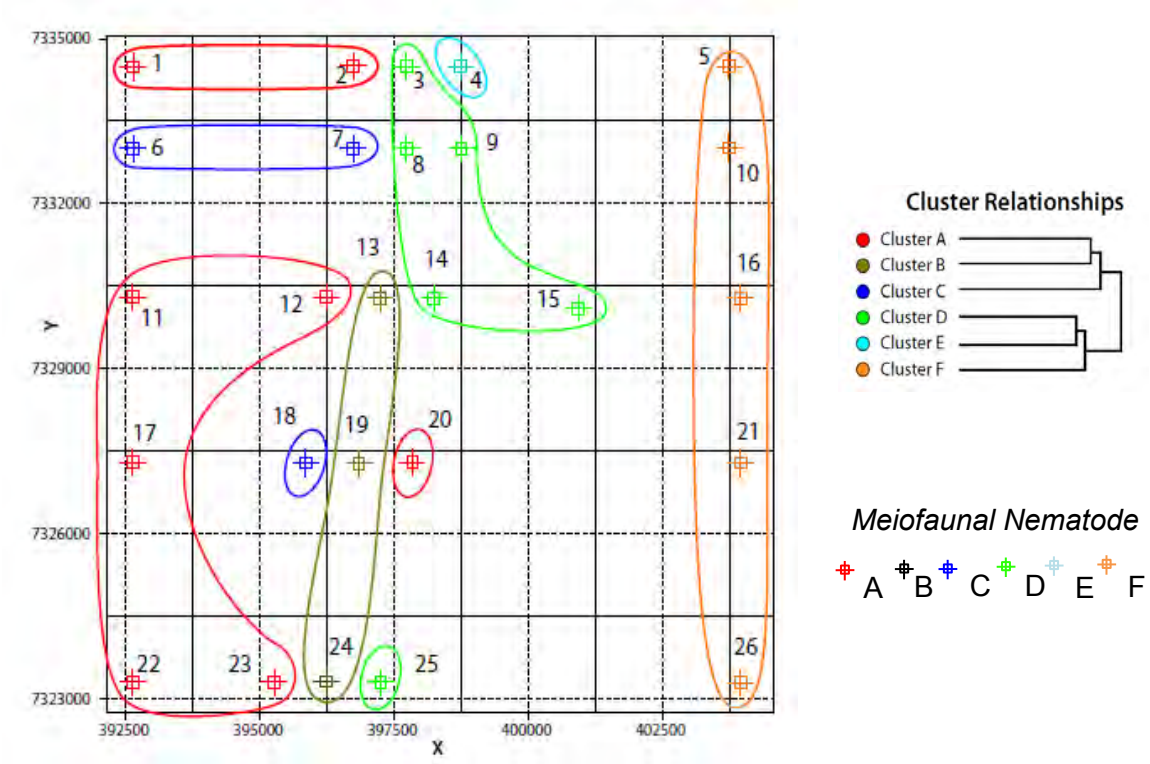


Figure 8: Distributions of structurally – related meiofaunal nematode communities (SP-1, of MLA 170)

6 SUMMARY

The geophysical data conclusively indicates a flat, smooth seafloor with a homogeneous surficial sediment cover across the entire survey block. No protruding obstacles were observed.

The surficial sediment composition of the area is well known from a large number of gravity cores and surficial grab samples that were collected across SP-1 for the purpose of phosphate resource development and environmental characterisation. The top few centimetres of the deposit consists of a mixture of silty sand particles, typically with dense shell. This site-based information confirms the muddy medium sand conclusion reached with the various images produced for, the geophysical survey and is further supported by the multivariate analyses of the macro and meiofaunal communities.

The multibeam echo sounder will be the geophysical tool of choice for dredging extraction control as well as pre - and post - dredging seafloor mapping.

© NMP 2014

SANDPIPER PROJECT

Verification Programme Report:
Mining Licence Area No. 170

SECTION D : APPENDICES

APPENDIX 4

Process Documentation

4.1: Verification Programme Activities
4.2: MFMR Response to the 2012 EIA
4.3: Final Scope of the Verification Programme submitted to the authorities

APPENDIX 4 – PROCESS DOCUMENTATION

4.1 Verification Programme Activities

4.2 MFMR Response to the 2012 EIA

4.3 Final Scope of the Verification Programme submitted to the Authorities

Prepared for:
Namibian Marine Phosphate (Pty) Ltd.

Prepared by:
Jeremy Midgley and Associates

Reviewed by:
Patrick Morant, CSIR

November 2014

Primary Contributing Parties:

Dr R Carter	Lwandle Technologies (Pty) Ltd
Dr N Steffani	Steffani Marine Environmental Consultant
Mr D Japp	Capricorn Fisheries Monitoring cc
Mr J Midgley	J Midgley and Associates cc

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed "Attention: Administration Manager," at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

contents

4.1 VERIFICATION PROGRAMME ACTIVITIES 2

4.2 MFMR RESPONSE TO THE 2012 EIA 6

4.3 FINAL SCOPE OF THE VERIFICATION PROGRAMME SUBMITTED TO THE AUTHORITES – NOVEMBER 2012 9

NMP Consolidated Verification Survey – Sediment Properties and Water Column Features 9

4.3.1 NEED FOR VERIFICATION SURVEY 9
4.3.1.1 Proposed Verification Survey 10
4.3.1.1.1 Scope 10
4.3.1.2 Survey area 13
4.3.1.3 Survey temporal coverage 15
4.3.1.3.1 Moored instrumentation 15
4.3.1.4 Reporting and deliverables 15

NMP Consolidate Verification Survey – Benthos 16

4.3.2 INTRODUCTION AND SCOPE 16
4.3.2.1 Benthic Habitat 16
4.3.2.2 Objectives and Key Questions 18
4.3.2.3 Survey Method and Design 19
4.3.2.3.1 General Sampling Design 19
4.3.2.3.2 Sampling Layout 20
4.3.2.3.3 Monitoring Programme 20

NMP Consolidated Verification Study - Fish, Mammals and Seabirds 26

4.3.3 INTRODUCTION 26
4.3.3.1 Actions to Address the Identified Issues 27
4.3.3.1.1 Terms of reference for proposed activities 27
4.3.3.2 Survey Design 28
4.3.3.2.1 Key elements of the survey 29
4.3.3.3 Expected Outputs 29
4.3.3.4 Time Frames 29
4.3.3.5 Conclusions 29

Amended Scope of Fish, Mammals and Seabirds Verification Survey, following discussions with MFMR – July 2013. 31

© NMP 2014

figures

Figure 1: Schematic representation of ADCP, Aquadopp and CTD+DO+turbidity mooring to be deployed as part of the NMP verification survey. 12
Figure 2: Sedimentation velocity for a range of fine grained sediment particle sizes as predicted by Stoke's Law. 13
Figure 3: Provisional verification sampling sites in Dredge Area SP-1. Note that the verification survey sites are represented by black open squares. Green squares represent sites identified for benthos sampling (Steffani); additional sampling sites for the benthos monitoring programme are shown in yellow (impact) and blue (reference). The blue square shows the provisional moored instrumentation site. 14
Figure 4 (a): Layout of macrofauna sampling stations for the verification and monitoring survey in SP-1. 23
Figure 4 (b): Layout of macrofauna sampling stations for the verification survey in SP-2. 24
Figure 4 (c): Layout of macrofauna sampling stations for the verification survey in SP-3. 25
Figure 5: Location of survey stations in SP-1 28

© NMP 2014

4.1

VERIFICATION PROGRAMME ACTIVITIES

© NMP 2014

4.1 VERIFICATION PROGRAMME ACTIVITIES

Activities relating to the development and execution of the Verification Programme (2012 – 2014)	
1	**EIA Submission**
2	NMP EIA submitted to MET for consideration for issue of Environmental Clearance certificate (Date 11 April 2012)
3	Environmental Commissioner requires further consultations (Letter dated 23 Apr 2012)
4	The Environmental Commissioner submits the NMP EIA to external independent review
5	1. SAIEA (Namibia), assessment undertaken by Ms. B. Walmsley (RSA) and Dr M. O'Toole (Ireland) 2. Professor L. Levin of Scripts Institute of Oceanography (USA). Professor J. Davis, University of Florida, Gainesville (USA)
6	**Additional consultation**
6	Governor of the Erongo Region, Honourable Cleophas Mutjavikua. Facilitates meeting between NMP and representatives of the Fishing Industry, NatMIRC and IA&Ps in attendance (Meeting date: 04 July 2012)
7	Respective parties issues presented and discussed. Fishing industry requested NMP engage with NatMIRC /MFMR to closeout on matters
8	Governor of the Erongo Region, Honourable Cleophas Mutjavikua. Facilitates meeting between NMP and NatMIRC (Meeting Date: 10 Sept 2012)
9	Approaches and considerations to the scientific content NMP of the verification programme (described in the 2012 EMP) discussed, in consideration of the (expanded) requirements of MFMR and I&APs.
10	**Verification Programme Commissioned**
11	In accordance with recommendations of the SAIEA report of the scientific content (2012 EIA) NMP initiates an expanded verification Programme. The scope is inclusive of 2012 EMP, MFMR requirements, and of the MET appointed independent reviewing parties. (November 2012)
12	NMP board allocates funding of N$ 20 m for the verification study
13	Expanded verification work programme forwarded to MFMR, MET, MME (letter dated 15 November 2012)
14	**Appointments**
15	J Midgley & Associates. Project manage the environmental process (November 2012)
16	CSIR, Mr P. Morant. Independent Programme Reviewer and Process Advisor, (November 2012)
17	Under CSIR guidance, the appointment of specialist consultants: CapFish, Lwandle, Metocean, Steffani Environmental Consultant to undertake the verification assessments identified in the expanded survey

© NMP 2014

	scope (November 2012)
18	University of Namibia, Dr S. Mafwila, external independent assessment of the *processes* (analytical and technical) of the Verification Programme (22 May 2013)
19	**Phase 1 of the Verification Programme: Instrument Mooring**
20	Instrument mooring deployment: 09 June 2013 deployed, 16 September recovered: 100 days. Metocean processes the recovered data, Lwandle analyses the data
21	**Phase 2 of the Verification Programme: Marine Biogeochemical Survey**
22	MME, MET, MFMR and UNAM representatives invited to participate in the surveys. UNAM representative join survey. 2 UNAM students and 6 scientists participate: CSIR analyses the sediments and water samples, Lwandle interprets the results
23	2a: - 10 day cruise (July / August 2013). Collecting: seabed surface sediment samples, water column samples, macrofauna and meiofauna from primary target dredge site SP-1 (ML 170)
24	2b: - 4 day cruise (August 2013). Collecting cores from the primary target. CSIR analyses the sediments and water samples, Lwandle interprets the results dredge site SP-1 (ML 170)
25	2c: - 5 day cruise (February / March 2014). Collecting thiobacteria samples from the primary target dredge site SP-1 (ML 170). UWC (Department of Biotechnology) analyses the sediments, Lwandle interprets the results
26	**Phase 3 of the Verification Programme: Geophysical Survey**
27	7 day (September 2013), Geophysical survey: 55 km line length in SP-1, and 175 km line length survey over the route of the intended fisheries biomass survey (ML 170)
28	Technical survey team of 5 persons, supported by 2 technicians to recover the instrument mooring
29	Geophysical data interpretation provided by Marine Data Consultants
30	**Phase 4 of the Verification Programme: Fisheries Survey Biomass / Biodiversity**
31	Survey managed by CapFish
32	CapFish meet, discuss and confirm the scope and methods of survey with NatMIRC/MFMR
33	MFMR advises (July 2013) that their survey vessel FRV *Welwitchia* is available for a biomass survey in November 2013.
Announcement of moratorium on marine mining of phosphate – September 2013	
34	MFMR advises that their survey vessel FRV *Welwitchia* is not available for private charter (September 2013)
35	Biomass survey, reconfigured to biodiversity survey following consultations with MFMR NMP charters commercial monk trawler
36	MFMR issues permit for the biodiversity survey to NMP (06 June 2014)
37	8-day biodiversity trawl survey in June 2014 over SP-1. CTD deployments per station. 12 day and 12 night stations trawled.

© NMP 2014

38	NatMIRC/MFMR technician and scientist, accompany the 5 CapFish scientists
39	CapFish analyses the biodiversity survey data, subsequently providing report. KZN Coastal Impact Consultants report on the epifauna. Lwandle report on the water column character
40	**Phase 5 of the Verification Programme: Auxiliary studies to the Fisheries Assessment**
41	Commissioned by CapFish
42	CapFish meet, discuss and confirm the scope of the supporting studies with NatMIRC/MFMR. MFMR approve provision of relevant data.
43	Biomass and Stock estimates: Monk and Hake: Mr. J. Gaylard
44	Reproductive dynamics assessment: Dr H. Ndjaula
45	Ecosystem assessment statement: Dr K. Chocrane
46	**Phase 6 of the Verification Programme: Independent Peer Review of Specialist Verification Studies**
47	CSIR manage the selection and appointment of International recognised peer review team: Dr A. Payne, Dr M. O'Toole, Dr B. Clark, Prof. A. Roychoudhury
48	Key documents issued to review time prior to workshop June - July - August 2014 Documents for review: Specialist reports, supporting text, scope of verification programme, external review reports (of the EIA 2012), MFMR communications
49	August: 2 day workshop in Cape Town CSIR, UNAM / UCCB in attendance as independent observer to the workshop process. Workshop: Specialists presentations, peer interviews of specialist consultants, and initial peer review assessment statements
50	Independent Peer review report Issued with recommendations, August 2014
51	NMP specialists, recommended work completed September - October 2014
52	UNAM: Report issued, September 2014: Independent Review of the NMP Verification Programme Process. Dr S Mafwila.
53	CSIR: Report issued: Independent Review of the NMP Verification Programme Report (November 2014)
54	**Integrated Report Compilation**
55	Compilation of the Verification Programme Report November 2014
56	**Report Submission to MET**
57	Verification Report submitted to MET, December 2014.

4.2

MFMR RESPONSE TO THE 2012 EIA

4.2 MFMR RESPONSE TO THE 2012 EIA

The Ministry of Fisheries and Marine Resources responded to the Minister of Environment and Tourism on the NMP 2012 EIA in a letter dated 15 June 2012. This letter contained 13 bullet points that required amendments to the Verification Programme as originally detailed in the 2012 EMP. The following 13 bullet points have been extracted verbatim from the letter and are presented below:

- The exact concentrations of hydrogen sulphide in the sediment (sampled fresh) need to be determined before any statement of the effect of H_2S can be made in the MLA. Also the effect of sulphides being possibly released to cause low oxygen in the water needs to be studied.
- The secondary effects of the possible release of hydrogen sulphide into the benthic layer (lowering of dissolved oxygen) must be assessed, because oxygen levels are critical in Oxygen Minimum Zones such as the central Benguella region.
- Dissolved nutrient inputs from sediments need to be quantified as these can be substantial, with cascade effects in the water column. Dissolved nutrients (pore water and water column) in the sediment properties or sediment plume behaviour study need to be measured. A sediment properties survey should also look at methane concentrations in the gravity cores because methane may be released when dredging to 3m depth. At least four surveys at three month intervals should be done at different times of the year to cover the seasonality.
- Trace metals and other potential noxious compounds released into the water column must be evaluated. Over and beyond the long term (>5 years) elevated trace metals incorporated into the food chain will have serious implications to the marketing of this products such as hake, monk and shellfish, as food quality regulations for export are stringent.
- Baseline information on Thio-bacteria must be collected in order to evaluate the possible impacts of disturbing these during mining operations.
- Faunal studies in Oxygen Minimum Zones must include animals to a minimum size of 300µm, not only >1mm as was the case in the studies on which the assessments were based, therefore base-information is incomplete and additional studies need to be conducted.
- A once-off survey to measure the *in situ* currents with an ADCP is not sufficient to cover the temporal variability. From literature it is established that there is strong seasonal variability in current speed and direction. Therefore at least four surveys would need to be done at three month intervals to capture the seasonality. A current meter should be moored near the MLA for a 12 month period.
- The behaviour of plumes needs to be modelled using current, sediment particle characteristics, nutrient, heavy metal and trace metal data from the site collected during different seasons.
- Changes in Redfield ratio in surface waters (due to release of overspill water from dredging) leading to preferential phytoplankton blooms of species other than diatoms in surface waters, and therefore a change in the food web as well as the possibility of harmful algal bloom problems, need to be measured and assessed.

© NMP 2014

- Most marine predators, including hakes and African penguins are relying on visual clues to forage, and increased turbidity affects their ability to feed in a drastic way. Field studies and *in situ* turbidity measurements need to be done in order to quantify the extent of the potential mining sediment plume and importance of the mining sites for foraging of predators.
- Very little information on spawning activities in the mining area is available. This information therefore needs to be collected before the effects of the project on recruitment of any species can be assessed.
- The area needs assessment as a nursery area for juvenile hakes, inferred patters of size frequency distribution of hake in the seal diet over the seasonal cycle for the last 15 years point to a nursery area in the vicinity of Walvis/Conception (at mid shelf) for fish 3 to 7cm total length (TL) and a shift further south for fish 8 to 16 cm TL. As the hake surveys are not designed to find juvenile hakes of these sizes (acoustic need to be used in addition to bottom trawls as these fish are monthly in their pelagic phase) and because the timing of the surveys carried out by the MFMR is not covering the seasonal changes, we do not have any direct information on the importance of this area for hake pre-recruits but this area could be a very important nursery area, so that changes in oxygen, sulphide and or turbidity could have major implications on recruitment. Surveys for juvenile fish covering the full annual period, must be undertaken.
- Ecosystem-functioning impacts must be assessed: these include food web interactions.

© NMP 2014

4.3

FINAL SCOPE OF THE VERIFICATION PROGRAMME SUBMITTED TO THE AUTHORITES – NOVEMBER 2012

4.3 FINAL SCOPE OF THE VERIFICATION PROGRAMME SUBMITTED TO THE AUTHORITES – NOVEMBER 2012

NMP Consolidated Verification Survey – Sediment Properties and Water Column Features

Prepared by Dr R. Carter
Lwandle Technologies (Pty) Ltd

4.3.1 NEED FOR VERIFICATION SURVEY

The conclusions and predictions of the environmental effects of dredging marine pelletal phosphate ore reserves on the Namibian continental shelf are primarily based on the sediment properties in the dredging areas. We consider that the information on this is robust as it is drawn from the seminal work conducted by Bremner (1978), direct surveys of sediment properties across one of the dredging areas by Rogers (2008) and because it is consistent with adduced distributions of turbulent energy across the shelf which control sediment texture distributions. All of this indicates that the sediments in the dredging areas are predominantly muddy sand. Hydrogen sulphide, methane and other chemical flux rate measurements conducted by, *inter alia*, Namibian and South African marine scientists indicate that these are low as sedimenting pelagically produced particulate organic matter (POM) does not accumulate on these sediments. Further, the phosphate ore body is considered to be derived from estuarine deposition in the Pliocene (2.6—1.0 MA, Compton 2012) so any organic material incorporated in the ore body would be extremely refractory. This implies that the only sources of sulphur in the ore body itself would be pyrites which have low dissolution rates.

On the basis of the above the water quality and associated environmental risks associated with the dredging process, were considered to be predominantly physical as opposed to biogeochemical. Consequently the conclusions on sediment textures in the mine licence area are of pivotal importance in the environmental assessment.

It is clear from comments received from interested parties in Namibia especially that this is a contentious issue as, although no data or analyses (peer reviewed or not) are presented in support of alternative views, there is a persistent concern that sulphidic sediments will be exposed during dredging with important consequences for water quality.

In our view the only practical response to this is to conduct a verification survey in the identified dredging areas on sediment properties, water quality and local oceanographic processes prior to the commencement of any dredging operations.

© NMP 2014

4.3.1.1 Proposed Verification Survey

4.3.1.1.1 Scope

The verification survey will focus on:

A) Sediment properties including:

- Surficial particle size and sediment texture distributions (box core). This is to confirm conclusions reached in the EIA studies that sediments in the proposed dredging areas are mainly fine and medium sands with minimal mud. Although this has been done via analyses of sediment core samples from the dredging areas post the EIA, which have shown 80-90% sand, the companion measurements on sediment properties that will be made (below) can only be properly understood in terms of the host sediment environment (**NatMIRC bullet points 1, 2 & 8**);
- Subsurface sediment particle size and texture distributions to ~2.5 m depth in the sediment (gravity core) (indirectly **NatMIRC bullet points 1,2 & 8**);
- Surficial and deep sediment organic content, POC and PON concentrations (indirectly **NatMIRC bullet point 1&2**);
- Surficial and deep sediment trace metal concentrations **(NatMIRC bullet point 4)**
- Surficial and deep sediment trace metal elutriation measurements to show the proportion of trace metals held in the particulate phase in the sediment that may be released into the dissolve phase and thereby become bioavailable (**NatMIRC bullet point 4**);
- Sediment pore water inorganic nutrient (N, P & Si) concentrations to demonstrate risks of departures from Redfield ratios when translocated to the upper water column during dredging (**NatMIRC bullet point 9**);
- Sediment pore water hydrogen sulphide concentrations to show potential fluxes to the water column when disturbed by dredging (**NatMIRC bullet point 1 & 2**);
- Methane detection of methane concentrations in sediment pore water will also be measured (**NatMIRC bullet point 3**).

NatMIRC (**bullet point 5**) express a need for the collection of baseline information on Thio-bacteria. There are no regional distribution data that we would be able to match whatever was found. The presence and role of these organisms depends on H_2S flux which requires organic matter supply and its incorporation in the sediments. We will be able to see this from sediment properties and the turbulence estimates from the moored Aquadopp current meter. Therefore from the acquired sediment property data we will be able to make probability statements on the presence and roles of this class of bacteria.

B) Water column properties including:

- Vertical profiles of the distributions of temperature, conductivity, dissolved oxygen (DO), chlorophyll fluorescence (Chl) and turbidity measured by a multi-probe internal logging CTD extending from the sea surface to within 5 m of the sea bed (partially addresses **NatMIRC bullet point 2**);
- Near sea bed temperature, conductivity, DO and turbidity time series measurements to elucidate background concentrations and possible variations linkable to internal tide generated turbulence (**NatMIRC bullet point 2**);
- Near sea bed high frequency current measurements (Aquadopp – see Figure 1) to determine turbulence and sediment resuspension events linkable to internal tide generated turbulence. This will be complementary to the DO and turbidity time series

© NMP 2014

(**NatMIRC bullet point 2** and confirmatory data for the internal tide generated turbulence control of POM capture in Namibian continental shelf sediments hypothesis), and

- Currents and indirect measurements (beam attenuation) of suspended sediments (equivalent to turbidity) through the upper water column (<100 m depth) measured by upward looking ADCP (Figure 1) (partially addresses **NatMIRC bullet points 7 & 8**).

In their commentary NatMIRC expresses a need for 'site specific' simulation modelling of dredge plume behaviour 'using current, heavy metal and trace metal data[1] from the site collected during different seasons' (**NatMIRC bullet point 8**). This requirement appears to be based on some misconceptions of the effectiveness of simulation modelling in providing unique, 'site specific' predictions on dredge plume and constituents of dredge plume behaviour.

Dredge turbidity plume simulations in commonly applied modelling platforms, (e.g. Delft 3D, DHI's Mike 21) primarily utilise currents, water column density structure and sediment particle sedimentation (sinking) velocity. The latter is an important determinant of plume distributions and is well established theoretically (Stoke's Law) and through direct measurement in, e.g., settling tubes. This to the point that standardised coefficients are employed with the main caveat being whether the particles will behave individually or cohesively. The latter is more characteristic of clay sized sediments and has the net result of accelerating sedimentation for these smaller and lighter particles. Figure 2 summarises settling velocity for a range of fine grained sediments. This figure ignores cohesive behaviour and therefore represents minimal velocities. Currents obviously advect the sinking sediment particles down the current path but also play a role in plume dispersion as dispersion is proportional to current velocity. The higher the velocity the higher the model coefficient for plume dispersion will be. This is also a predetermined relationship and is independent of the site being modelled.

Consequently two of the important determinants of turbidity plume behaviour are treated generically in modelled simulations. It is this and the broad similarity of measured plume behaviour between sites with wide ranges of sediment types and hydrodynamics that allow the extrapolation of modelled and real plume metrics and behaviour to the NMP case. The reliability of the extrapolation is enhanced by the very good investigation conducted by CSIR into dredge plumes from the bulk dredging of sediments for diamond recovery in southern Namibia where the upper water column at least is similar to that of the NMP licence area.

Therefore unless NatMIRC has information that shows that sediment properties in the dredge area are such that vastly different dynamic behaviour will arise or that the upper water column deviates from that described by Boyd and summarised by Shannon I see no value, but quite some cost, in conducting simulation modelling. Note that this also applies to heavy metals as these would be modelled as a conservative tracer, i.e. dilution alone will predict their concentrations, making their behaviour similar to that predicted for the sediment plume.

[1] In common usage these are the same group of elements comprising the transition metals, metallic elements such as arsenic and cadmium and lanthanides.

© NMP 2014

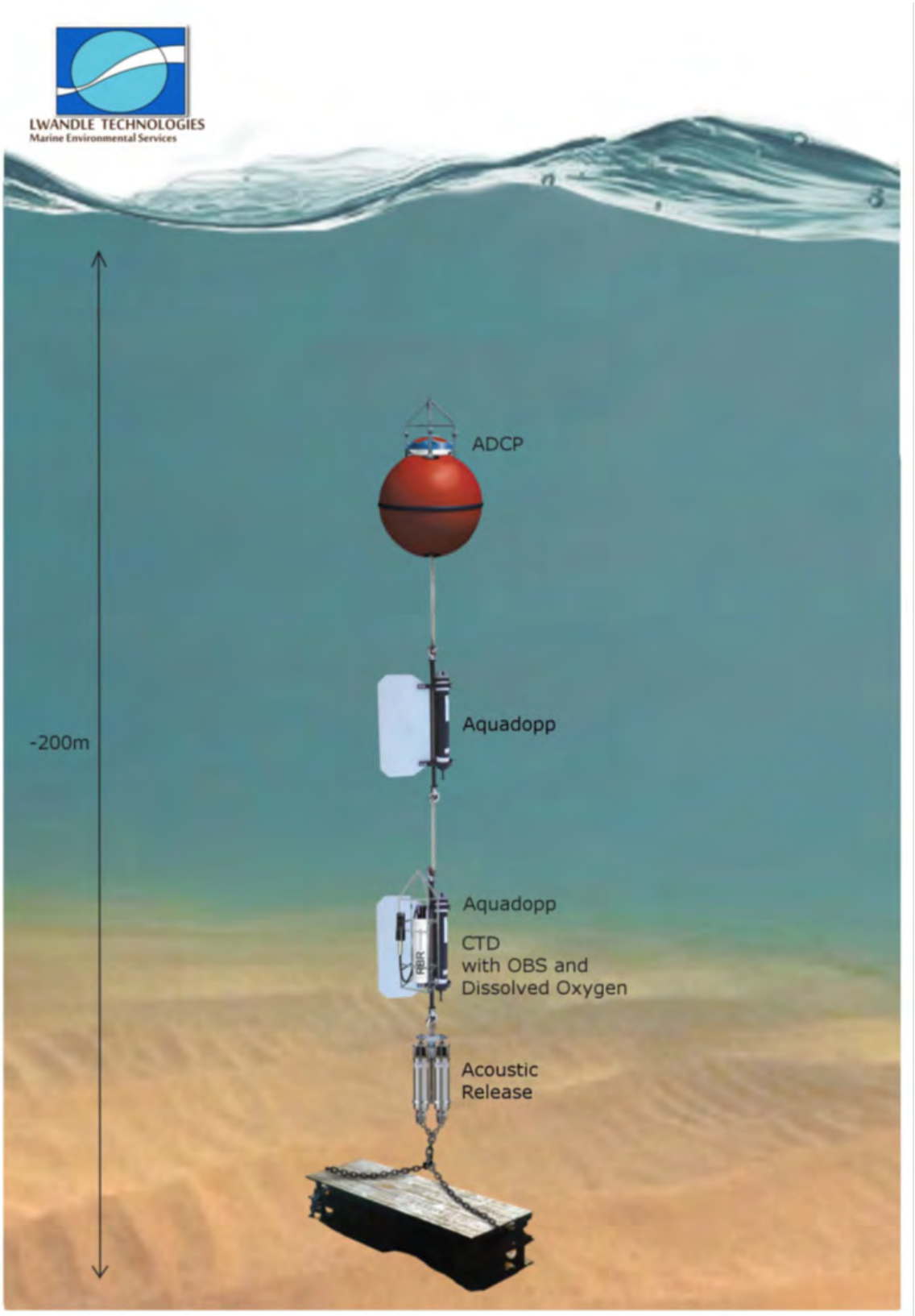


Figure 1: Schematic representation of ADCP, Aquadopp and CTD+DO+turbidity mooring to be deployed as part of the NMP verification survey.

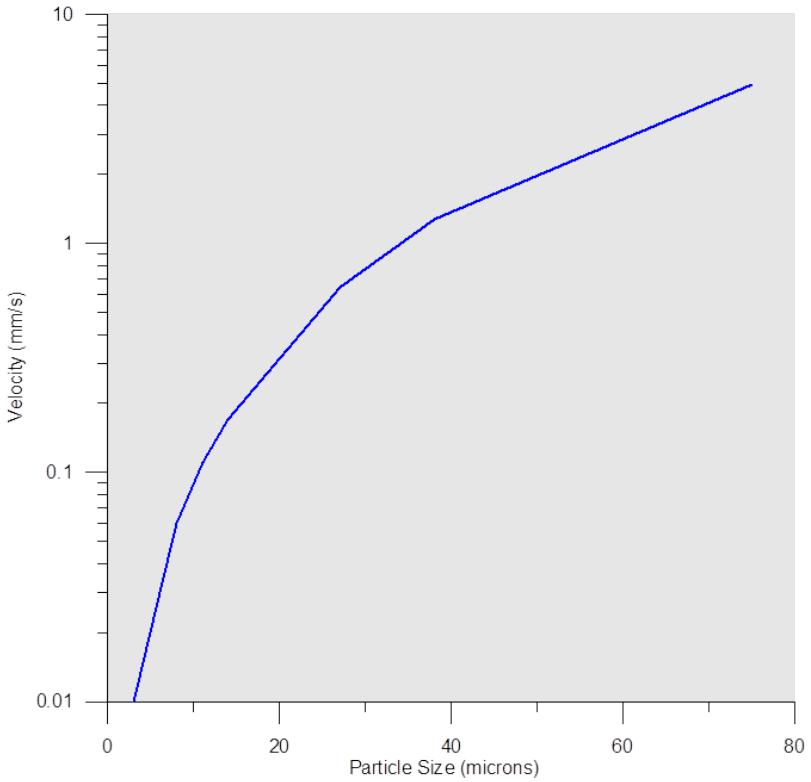


Figure 2: Sedimentation velocity for a range of fine grained sediment particle sizes as predicted by Stoke's Law.

4.3.1.2 Survey area

The survey area is defined as dredge area SP-1. A grid of sampling sites will be placed across SP-1 such that the broad distributions of sediment properties can be determined. Figure 3 shows the provisional sampling station layout (Black open squares). These are planned to coincide with the benthos sampling sites where possible. The provisional location of the moored instrumentation is shown.

The provisional sampling grids will generate 26 box core samples in SP-1 in a configuration of 5 transects of 5 stations each plus the additional sample at the moored instrumentation site. Samples on the transects will be aligned with the stations identified by Dr Nina Steffani. In a separate survey gravity core samples will be taken from these sites. In addition to the above, sediment samples will be obtained from the benthos verification sites in SP-2 and SP-3 (Steffani) and analysed for particle size, organic C and N content.

CTD profiling (6 Hz) and water sampling will be conducted at one site on each of the transects. One of these will be at the mooring location. Water sample depths will be 0 m, 10 m, 20 m, 50 m, 100 m, 150 m and 200 m.

© NMP 2014

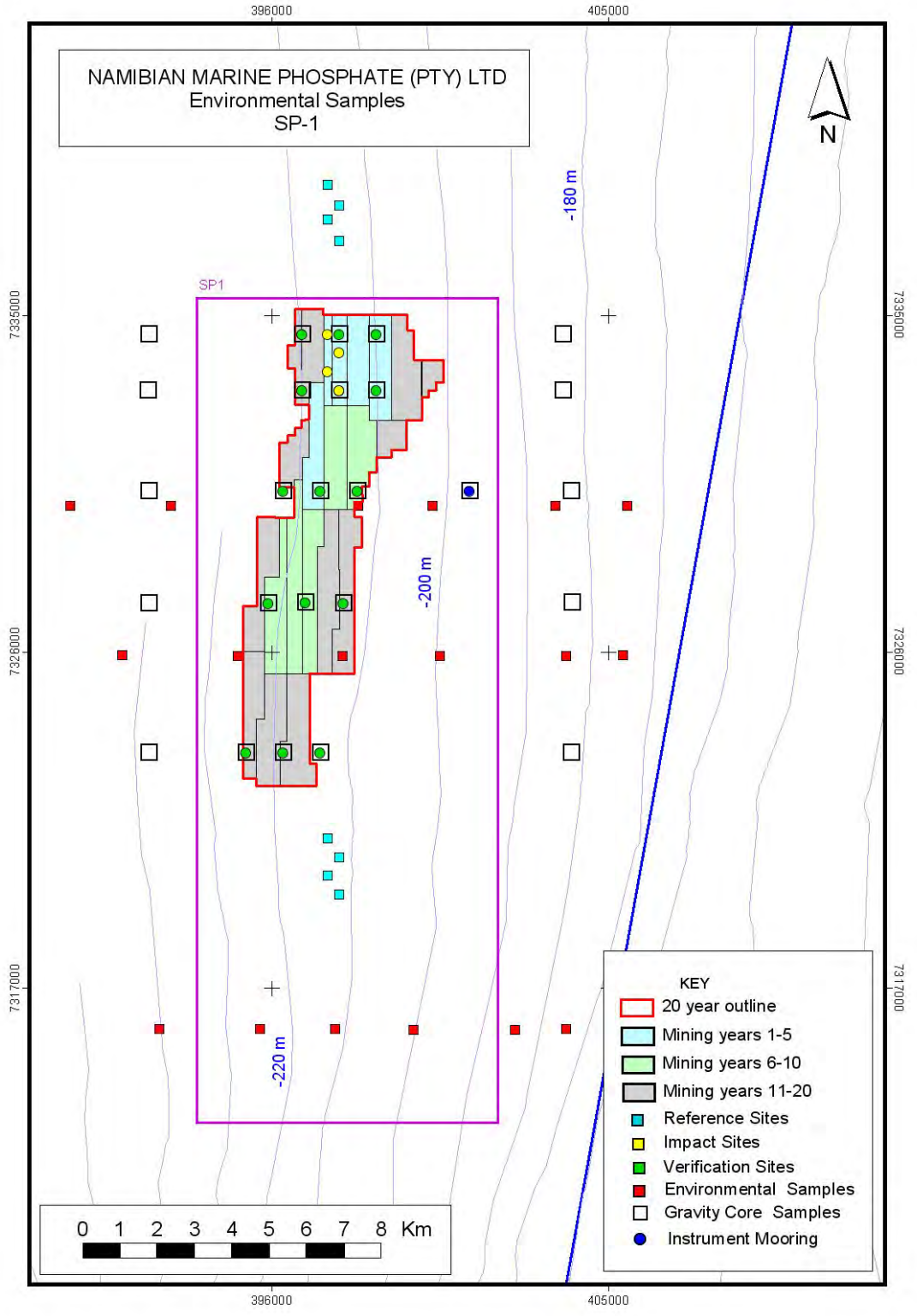


Figure 3: Provisional verification sampling sites in Dredge Area SP-1. Note that the verification survey sites are represented by black open squares. Green squares represent sites identified for benthos sampling (Steffani); additional sampling sites for the benthos monitoring programme are shown in yellow (impact) and blue (reference). The blue square shows the provisional moored instrumentation site.

© NMP 2014

4.3.1.3 Survey temporal coverage

4.3.1.3.1 Moored instrumentation

The planned duration for the moored instrumentation deployment (ADCP, Aquadopp, CTD+DO+Turbidity) is 90 days[2] within which will be a service interval at ~45 days. The 90 day period is predicated on the frequency of lunar barotropic internal tides and associated sediment resuspension events (Monteiro et al 2005). The intention of the mooring is to capture a number of these events (~6) and link concurrent variability in near sea bed oxygen and turbidity levels. The reason for the mid-deployment service interval is that the mooring recovery record for the Namibian continental shelf is not good (similar to South Africa and Mozambique) and the relatively short service interval will ensure that at least 50% of the planned measurements will be obtained. I.e. if the mooring is lost post service the initial measurement period data would have been downloaded at the end of the 1st measurement period, if the mooring is not recovered at the service visit a duplicate set will be deployed giving coverage for the 2nd measurement period.

Water column profiling and sediment sampling
The water, sediment and benthos verification survey will be a once-off event with a duration of 8-10 days at sea. The survey will be conducted in conjunction with the service visit for the moored instrumentation. Seabed coring will be conducted during a separate survey of the dredging areas (date and duration to be determined).

4.3.1.4 Reporting and deliverables

The following reports will be issued:

- An installation report immediately prior to survey commencement with equipment specifications and calibration and method statements for each of the procedures to be employed
- A mooring deployment report
- A preliminary field survey report listing measurements and sampling with commentary on the water quality, sediment properties and benthos survey
- A mooring recovery and redeployment report
- A final mooring recovery report, and
- A draft final verification report to be delivered in paper and electronic copies to the Namibian Marine Phosphate (Pty) Ltd within three weeks of the completion of sample processing (physical, chemical and biological). This report will be a fully referenced, scientific document.

[2] NatMIRC suggest a 12 month deployment period for the ADCP to show seasonal variation. The area is highly variable on a range of space and time scales and to properly constrain seasonal variability would require at least a multi-year deployment programme. This is beyond the scope of the verification measurements.

© NMP 2014

NMP Consolidate Verification Survey – Benthos

Prepared by Dr N. Steffani
Steffani Marine Environmental Consultant

4.3.2 INTRODUCTION AND SCOPE

Namibian Marine Phosphate (Pty) Ltd (NMP) has been awarded a 20-year mining licence (ML 170), which is located on the Namibian continental shelf offshore Conception Bay in water depths ranging from 180 to 300 m covering a total area of 2233 km^2. Within the mineralized resource zones of the licence area, also named Sandpiper licence area, three target areas have been identified, i.e. Sandpiper-1 (SP-1), 2 (SP-2), and 3 (SP-3). SP-1 is in the north of ML 170 in water depth from 190-235 m, SP-2 is in the centre in depth 245-285 m and SP-3 is in the south at 235-270 m depth.

With the exception of a benthic macrofauna and sediment property survey derived from 20 stations in SP-1, information on the physical and biological environment specific to the ML 170 is very sparse. Most of the impact assessments discussed in the Benthic Specialist Study are thus based on assumptions that are arrived from publicly available data from areas outside the Sandpiper licence area. The assumptions drawn from these data are deemed robust, but nonetheless it is recommended that an initial 'verification' survey to confirm these. An important aspect of this verification survey is the sampling of the macrofauna communities in all three dredging target areas. Continuing from this initial verification survey, the severity of the removal and destruction of benthic communities by the dredging process and the subsequent recovery (functional recovery) process need to be ascertained. A post-dredging benthic monitoring programme thus needs to be established.

4.3.2.1 Benthic Habitat

Dredging for offshore marine phosphate deposits is destructive by nature and thus inevitably affects the benthic communities of the receiving environment. The sea bed disturbed by the dredging activity is home to many communities, living on (epifauna) or in (infauna) the superficial sediments of the sea floor, with the greatest abundance to a depth of ~20 cm. The fauna is typically divided by size into megafauna (>10 cm), macrofauna (large enough to be retained on a 1-mm sieve, while some researchers also use a 500-micron sieve), meiofauna (0.1-1 mm) and microfauna (<0.1 mm). The macrofauna usually constitute the dominant biomass or organisms within marine sediments and typical taxa include polychaete annelids, smaller crustaceans (e.g. amphipods, isopods, shrimps, crabs), and molluscs (gastropods and bivalves) besides many other phyla. Megafauna include large crustaceans, molluscs, and echinoderms, and are often associated with the surface of the sea floor. The meiofauna is dominated by the large and diverse groups of nematodes and harpacticoid copepods, while microfauna include bacteria and protists. Macrofauna and other benthic fauna are a major food source for fish and other benthic predators, and play important roles in ecosystem processes such as nutrient cycling, pollutant metabolism, and dispersion and burial of organic matter.

© NMP 2014

The northern and central Benguela regions are characterised by the occurrence of natural shelf hypoxia, which is referred to as Oxygen Minimum Zone (OMZ) (Monteiro *et al.* 2011). OMZs have dissolved oxygen concentrations of ≤0.5ml/ℓ and typically impinge upon the continental margins of upwelling regions. Off Namibia, this layer extends between at least 18°S and 28°S and up to 60 km from the shore. The hypoxic conditions depict seasonal variation, locally shifting to anoxic conditions in late summer-autumn (Monteiro *et al.* 2008). A further significant feature of the central Namibian middle shelf is an extensive mud belt comprising organically rich diatomaceous oozes originating from planktonic detritus from the high productivity in the upwelled waters. The diatomaceous mud belt with a thickness of up to 14 m extends over 700 km in an N-S direction and 100 km in an E-W direction. Depending on the local bathymetry and dynamic current intensity, the landward flank of the mud belt is found at 15-104 m water depth, and the seaward flank from 45-151 m (Bremner 1983). The mud belt is characterised by often anoxic bottom water conditions and high H_2S fluxes, occasionally resulting in H_2S eruptions with devastating effects on the local fauna. These natural events can spread over 20 000 km^2 (Weeks *et al.* 2004).

The Sandpiper Mining Licence Area lies offshore from the mud belt at the fringe of the central Namibian OMZ and is thus affected by variable dissolved oxygen conditions with bottom-water oxygen concentrations probably below 0.5 ml/ℓ, but it is likely to be less affected by high H_2S concentrations in the surficial sediments or near-bottom waters, or severe anoxic conditions. Despite oxygen depletion, benthic assemblages can thrive in OMZs as many organisms have developed highly efficient ways to extract oxygen from oxygen-depleted water (e.g. small bodies, enhanced respiratory surface area, blood pigments, and specialised enzymes) (Levin 2003). Within OMZs, foraminiferans, meiofauna, and macrofauna typically exhibit high dominance and relatively low species richness (Levin 2003). In contrast to meiofauna, macrofauna and megafauna often have depressed densities and low diversity in the cores of OMZs, where the oxygen concentration is lowest, but they can form dense aggregations at the OMZ edges (Levin 2003, Levin *et al.* 2009).

Very little is known about the Namibian OMZ benthic infauna (see Arntz *et al.* 2006, Zettler *et al.* 2009). In May 2010, a macrofauna baseline survey was conducted by NMP in SP-1 as this is the initial priority area for proposed dredging operations (Steffani 2010a). Overall species richness of the benthic macrofauna assemblages was relatively low and strongly dominated by polychaetes (64% of species), followed by crustaceans, and molluscs. Most species found in the study area have a larger geographical distribution and/or have been recorded elsewhere from the Namibian and/or South African west coast (e.g. Savage *et al.* 2001, Steffani 2007, 2009, 2010b, Steffani & Pulfrich 2004, 2007, Zettler *et al.* 2009). The most abundant species was the polychaete *Paraprionospio pinnata* (44% of overall abundance), which is a low-oxygen indicator species prevalent in OMZs worldwide. Generally, the benthic community composition in terms of species diversity and phyla dominance is in agreement with studies from other OMZs around the world (e.g. Gutierrez *et al.* 2000, Levin *et al.* 2000, Gallardo *et al.* 2004, Gooday *et al.* 2009, Levin *et al.* 2009).

In contrast to the core of OMZs where macrofauna density is often reduced, macrofauna has been found to increase at the edges of OMZs dominating the benthic fauna (e.g. Mullins *et al.* 1985, Gooday *et al.* 2009, Levin *et al.* 2009). Levin *et al.* (2009), for example, reported dramatic changes in macrofaunal dominance from the core of the OMZ at the Pakistan margin to the lower boundary and documented the existence of dissolved oxygen thresholds for macrofauna between 0.1 and 0.2 ml/ℓ. Below such thresholds, most taxa are excluded through physiological intolerance to hypoxia, while above them selected taxa are able to take advantage of an abundant food supply. The availability of both oxygen and organic carbon seem to determine the richness of macrofaunal species in OMZs until the oxygen content rises to about 0.45 ml/ℓ; above that level oxygen is much less important

© NMP 2014

(Levin & Gage 1998). It has been further hypothesized that under conditions of permanent hypoxia, small-bodied animals, with greater surface area for O_2 adsorption, should be more prevalent than large-bodied taxa (Levin 2003). However, body sizes were found not to be smaller within the lower OMZs of the Oman (Levin *et al.* 2000) and Pakistan margins (Levin *et al.* 2009), and it was suggested that the abundant food supply in the lower or edge OMZs promotes larger macrofaunal body size. Zettler and co-workers (2009), who studied the macrofauna community in the OMZ off northern Namibia (offshore the Kunene River mouth, which is at the northern fringe of the OMZ), reported a far lower species diversity in the hypoxic zone than compared to oxygenated nearshore areas, but the high dominance of molluscs (not typically found in core OMZs) led them to suggest that the community is probably rather representative of the fringes of the upwelling cells of the northern Benguela than of the centre where severe anoxia and high hydrogen sulphide concentrations occur. Molluscs also contributed a relatively significant proportion to the fauna in the SP-1 target area and as the Sandpiper licence area is situated at the southern fringe of the OMZ, a similar scenario is likely to apply, suggesting that the macrofauna is playing a significant role in the benthos of the target areas. Similarly, in an early study by Sanders (1968) of the benthos in the Namibian OMZ, a reduction in macrofauna species diversity has been observed in the core, whereas higher abundances and biomasses have been recorded from the edge of the OMZ.

4.3.2.2 Objectives and Key Questions

As part of their Environmental Management Programme for the Sandpiper licence area, NMP has committed to undertaking a benthic macrofauna verification survey to collect information on general macrofauna distribution patterns in the three target areas. This will also aid in verifying some of the assumptions on which the assessment of impacts was based. This initial survey will be followed by a macrofauna monitoring programme, whose principal objective is to study the rate of recovery of disturbed macrofaunal communities once the dredging activity has ceased in a particular dredge block. Recovery has been shown to be both spatially and temporally variable, and to confidently measure the ecological recovery rate of mined areas, it is therefore necessary to develop a benthic monitoring plan that is not only appropriate in the medium-term (~5 years), but has the flexibility and potential to be extended into the long-term.

The key objectives for the *verification survey* are:

- Establish a data set on general macrofauna distribution patterns in all three target areas;
- Relate the distribution patterns to environmental factors such as water depth, sediment texture, near-bottom oxygen concentrations, organic carbon content, and H_2S concentrations; and
- Investigate the relative importance of the smaller macrofauna size fractions.

The key questions for the *monitoring programme* are the following:

- What is the rate of recovery of the physical environment e.g. in-filling of mined-out areas with unconsolidated sediments?
- What is the process of the recovery of the benthic macrofauna?
- How long after the disturbance does it take for the benthic community to recover to at least an ecologically functional community?
- How does the physical environment (e.g. sediment particle size, organic matter, dissolved oxygen) influence the recovery rate?

© NMP 2014

4.3.2.3 Survey Method and Design

4.3.2.3.1 General Sampling Design

Sampling for macrofauna will involve the use of a Day grab or box corer. Both sampling tools are capable of retrieving a sediment sample with an undisturbed surface. The Day grab has the advantage that it can be handled from a smaller surveying vessel. Once retrieved, macrofauna samples will be taken from the larger grab with subcorers with an inside diameter of 9.6 cm x 30 cm length (72.4 cm^2). It is proposed to take one to two subcorers per grab. The sample volume collected with this method is in agreement with other studies conducted in OMZs (e.g. Gallardo *et al.* 2004, Gooday *et al.* 2009, Levin *et al.* 2000, but see Zettler *et al.* 2009). From the same grab, sediment particle size and total organic carbon (TOC) will be determined. In addition, near-bottom dissolved oxygen concentrations will be measured with a CTD and H_2S concentrations in the pore water analysed for a selected number of grabs, and in addition in a number of gravity cores down to depth. These measurements are described in the proposal for the sediment properties verification survey (Lwandle 2012). The measurement of the H_2S concentrations will shed light on the possibility of the presence of substantial amounts of thio-bacteria in the sediments (**NatMIRC bullet point 5**).

The original macrofauna baseline survey in SP-1 used a 1-mm sieve to separate the macrofauna from the sediment as this is the traditional standard mesh size used in macrofauna surveys (Rumohr 2009). Studies on macrofaunal abundance in OMZs, however, often use smaller sieve sizes in anticipation that many macrofauna species will be generally smaller (e.g. Gallardo *et al.* 2004, Gooday *et al.* 2009, Levin *et al.* 2009). Sieve sizes used in OMZ studies vary between 0.3 mm (e.g. Gallardo *et al.* 2004, Gooday *et al.* 2009, Levin *et al.* 2000, 2009), 0.5 mm (e.g. Sahling *et al.* 2002, Gutiérrez *et al.* 2000, Palma *et al.* 2005), and 1 mm (e.g. Rosenberg *et al.* 1983, Zettler *et al.* 2009, see also Levin & Gage 1997 for references on studies using sieve sizes ranging from 0.3 to 1.0 mm). For example, the only recently published study on the Namibian OMZ macrofauna (northern Namibia), has used a 0.1m^2 van Veen grab and a sieve size of 1 mm (Zettler *et al.* 2009), similar to the Sandpiper benthic baseline study. To determine the relative importance of the various size fractions, it is proposed to sieve the samples on-board through a 0.3-mm sieve. In the laboratory sorting procedure, the 0.3 - 0.5 mm, 0.5 - <1 mm, and the >1 mm size fractions will be separated for a number of samples with a nested sieve design and analysed separately to indicate the right mesh size for the long-term monitoring study and also permit comparison to the baseline study. (**NatMIRC bullet point 6**). Sieving of the samples will be conducted with an automated Wilson autosiever that gently keeps the material in the sieve in motion by flotation with water from below instead of spraying with water from above. This will reduce damage to fragile organisms. As found during the benthic baseline survey and substantiated by the extensive geological mapping by NMP, it can be expected that the surficial sediment layers (top >30 cm) will contain significant amounts of large broken shell pieces. This not only will drastically increase the amount of material retained on the 0.3 mm screen and thus the sieving time, but may also damage the organisms. It is thus proposed to use a 3 mm or 5 mm screen to separate this shelly layer from the actual macrofauna sample. Careful visual inspection of the material retained on the larger screen will ensure that any larger organisms retained are transferred to the macrofauna sample. The sieved sample will be stored in 10% buffered formalin.

In the laboratory, macrofauna samples will be re-sieved through a 0.3-mm sieve and sorted under a stereo binocular microscope at 10-25 x magnification. If needed, the sample may be stained with Rose Bengal to aid in the sorting. Specimens will be identified to the lowest taxon possible and counted. Wet biomass will be estimated by blot-drying the specimens on absorbent tissue for a

© NMP 2014

standard period of time and weights recorded per species per sample using an analytical balance. Taxa retained on the 0.3 mm screen that traditionally are considered to be meiofauna (e.g. nematodes, copepods, ostracods and foraminifera) will not be included in counts, biomass measurements or subsequent analyses. This is in line with other studies on OMZ macrofauna (e.g. Levin *et al.* 2000, Gallardo *et al.* 2004). At first, a minimum of ten samples will be sorted with a nested sieve design separating the three size fractions. After analysis of the absence/presence and relative importance of macrofauna in the various fractions, a final sieve size will be determined.

4.3.2.3.2 Sampling Layout

For the verification survey, an increased spatial coverage has been opted for at the expense of replication per site. This will provide a better resolution of macrofaunal distribution patterns across the three target areas. Small scale patchiness, however, cannot be investigated with this design but increased replication per site in the monitoring survey will provide data on small-scale variability (see Monitoring Programme below). Sampling stations will be spread across the target areas in a grid pattern with increased spatial coverage in the mine blocks proposed for dredging within SP-1 and SP-2. Proposed numbers of sample stations are 16 in SP-1 (plus 4 monitoring sites, see below), 18 in SP-2, and 12 in the smaller SP-3; this amounts to a total of 46 samples (plus the four impact and four reference sites for the monitoring survey, see below). Figures 4 (a - c) illustrate the proposed layouts of the sampling stations in the three target areas SP-1, SP-2, and SP-3.

4.3.2.3.3 Monitoring Programme

Continuing from the initial assessment survey, the severity of the removal and destruction of benthic communities by the dredging process and the subsequent recovery (functional recovery) process need to be ascertained. A post-dredging benthic monitoring programme thus needs to be established.

Worldwide, the study of benthic assemblages has been used to investigate the impacts on the seafloor of human activities. There is continuous debate whether such monitoring programmes should focus on macrofauna or meiofauna, or on both (e.g. Somerfield *et al.* 1995, Coull & Chandler 1998, Kennedy & Jacoby 1999, Schratzberger *et al.* 2001). Typically macrofauna is the preferred option as sample collection and species identification is comparatively easier (Kennedy & Jacoby 1999). Macrobenthos is commonly used as biological indicator because as a group they are relatively sedentary and reflect the quality of their immediate environment, many benthic species have relatively long life spans and their responses integrate water and sediment quality changes over time, and they include diverse species with a variety of life history characteristics and tolerances to stress and can usually be classified into different functional groups. Examples of the use of macrofaunal monitoring surveys include studies on the effects of oil pollution (e.g. Dauvin *et al.* 2003), organic enrichment (Pearson & Rosenberg 1978, Macleod *et al.* 2004), offshore drilling operations (Daan *et al.* 1995, 1996), submarine tailings disposal (Ellis 1982, Burd 2002), and particularly of marine aggregate dredging operations (e.g. Newell *et al.* 1998, Herrmann *et al.* 1999, Newell *et al.* 2004).

In low-oxygen environments such as OMZs, body size seems to be very important as small organisms are best able to cover their metabolic demands in the OMZ, and besides adaptation to low oxygen often have a capability to conduct anaerobic metabolism. Meiofauna may thus increase in dominance in relation to macro- and megafauna (Levin 2003). However, the Sandpiper licence area and specifically the target areas are at the edge of the OMZ, and several studies have shown that

© NMP 2014

macrofauna has been found to increase at the edges of OMZ dominating the benthic fauna (see above). The difficulty in conducting meiofauna monitoring surveys in comparison to macrofauna studies thus favours the use of macrofauna for long-term studies, and the extensive use of macrofauna surveys for a wide variety of anthropogenic disturbances suggests that data on macrofauna composition and abundance should be able to shed light on it. Macrofauna is also routinely and often solely collected in studies on OMZ benthos (e.g. Levin & Gage 1998, Levin *et al.* 2000, 2009, Ueda *et al.* 2000, Gallardo *et al.* 2004, Arntz *et al.* 2006, Gooday *et al.* 2009, Zettler *et al.* 2009).

In identifying and assessing the impacts of phosphate dredging on the macrobenthic communities, it is important to recognize that the marine environment can be very variable both in space and time. An impact should not therefore be characterized as being the difference in some measure at a particular site before and after a disturbance, but should be distinguished as being the relative difference between changes at a disturbed/impact site compared with changes that have occurred in a similar undisturbed reference site (Underwood 1992, 1993, 1994). In other words there must be some change from before to after a disturbance and such change must be significantly different from what occurred in undisturbed reference areas. Community parameters, however, vary both spatially as well as with time, fluctuating in response to natural variations in the environment (these may be monthly, seasonal or annual variations). Without adequate indices of natural variability, it will be inherently difficult to place dredging-related impacts in context. It is therefore important to have a number of impact sites in association with a number of reference sites that are in a similar environment (e.g. depth and sediment texture) but will remain undisturbed over the period of the monitoring programme. Here it is important to note that it would be prudent to select sites that will also not be affected by other anthropogenic activities such as trawling. If possible, the sites should either be located in areas not utilised by the trawling industry or trawling should be excluded from the immediate area for the duration of the monitoring programme. This is important as effects of trawling may have traditionally affected parts of the mining licence area beyond the 200-m isobath but since trawling will not occur in the target areas once phosphate dredging operations commence (due to safety issues), this impact should also be avoided for the reference sites. The envisaged position of the reference sites are, however, such that conflict is expected to be low as trawling usually occurs in deeper waters.

The proposed position of the sampling stations is illustrated in Figure 4 (a - c). For operations in SP-1, four impact stations and four associated reference sites are proposed. At each site, five replicate samples will be taken. Included in the sampling procedure should be at least the sampling for sediment properties (i.e. grain size analysis) as well as near-bottom dissolved oxygen concentrations and organic matter content. Sites have been selected according to the currently proposed mine schedule to fall into the mine blocks that will be mined in Year 1 and Year 2 of the schedule. This ensures that any information on recovery processes can be collected as early as possible to inform the Environmental Management Programme. Prior to operations being initiated in SP-2, a second monitoring programme needs to be established and similarly for activities in SP-3.

Sampling in SP-1 should be undertaken both before the start of operations, as well as at regular intervals after completion of dredging to determine the (functional) recovery rates of the benthic communities. One of the basic assumptions of developing a benthic monitoring programme is that recovery of disturbed macrofaunal communities does in fact occur. The process and rate of recovery is, however, strongly dependent on the rate of the in-filling of sediment in the mined-out areas, and the type of sediment. A wide range of recorded recovery rates highlight the inherent difficulties in the application of general impact/recovery predictions to sites with varying environmental

characteristics (Robinson *et al.* 2005). From existing information on the natural rehabilitation of mined-out areas in the deep-water diamond mining licence area in southern Namibia, it is known that despite the reduced wave and current action at the depths at which mining is currently being conducted (100-150 m), significant smoothing and in-filling of mined areas is visible in sidescan sonar surveys 1 - 2 years after mining (Penney & Pulfrich 2004). However, such information cannot be simply extrapolated to the central Namibian shelf, where the sedimentation and near-bottom current regime is likely to be very different. It is recommended that high resolution geophysical surveys (e.g. side scan sonar) are conducted immediately after dredging, and 2-3 years post-dredging (and potentially at later years depending on the results) to determine the depth of the dredged trenches and the sediment infilling-rates. Depending on the geophysical survey results, it is assumed that the first post-dredging survey can be conducted 2-3 years after cessation of dredging (three years for Target Block 1 and two years for Target Block 2 of the SP-1 resource). The subsequent sampling interval can best be determined after the first post-dredging sampling campaign, but an appropriate interval may be every 2-3 years. Periodically reviewing the monitoring plan as new data are collected and analysed will ensure that the monitoring plan and associated sampling schedule remains a dynamic process.

Traditionally, the ecological recovery of the disturbed seafloor has been defined as the establishment of a successional community of species, which progresses towards a community that is similar in species composition, population density and biomass to that previously present. Measures used to assess recovery typically include biodiversity analysis such as the numbers of species and/or individuals in an assemblage. However, this approach presents a number of challenges, especially when the physical characteristics of the sediment have been altered to such an extent that it can no longer accommodate its original assemblage. Recovery in the sense of the above definition may thus not be achieved (only when the sediment properties revert to their original state). For this reason, it may be more sensible to consider the functional capacity (or health) of the ecosystem rather than simply the range and proportion of species present. Some ecosystem functions can be undertaken by a variety of different organisms, leading to the notion of possible functional redundancy, whereby the loss of a particular species may not affect the basic functioning of an ecosystem as long as the function performed by that species is taken up by another species from the same functional group. To address this issue, many studies have recently focussed on functional diversity to assess faunal recovery following anthropogenic perturbations by incorporating biological differences among species showing that function- or trait-based diversity metrics may represent appropriate additional methods for assessing changes in ecosystem function (e.g. Borja *et al.* 2003, 2010, Bremner *et al.* 2006, Josefson *et al.* 2009, Cooper *et al.* 2008, Hussin *et al.* 2012). In terms of dredging impact on functional diversity, communities of organisms inhabiting an area of dredged seabed may possibly differ in composition or diversity from the pre-dredged state, but may develop similar functional capacity through the recovery process (functional recovery). Therefore, system recovery may not require similar biomass, biodiversity or community composition. It is thus proposed to utilise a variety of analyses including biodiversity measures, multivariate approaches as well as functional traits analyses to describe the macrofaunal colonization process after the dredging impact.

© NMP 2014

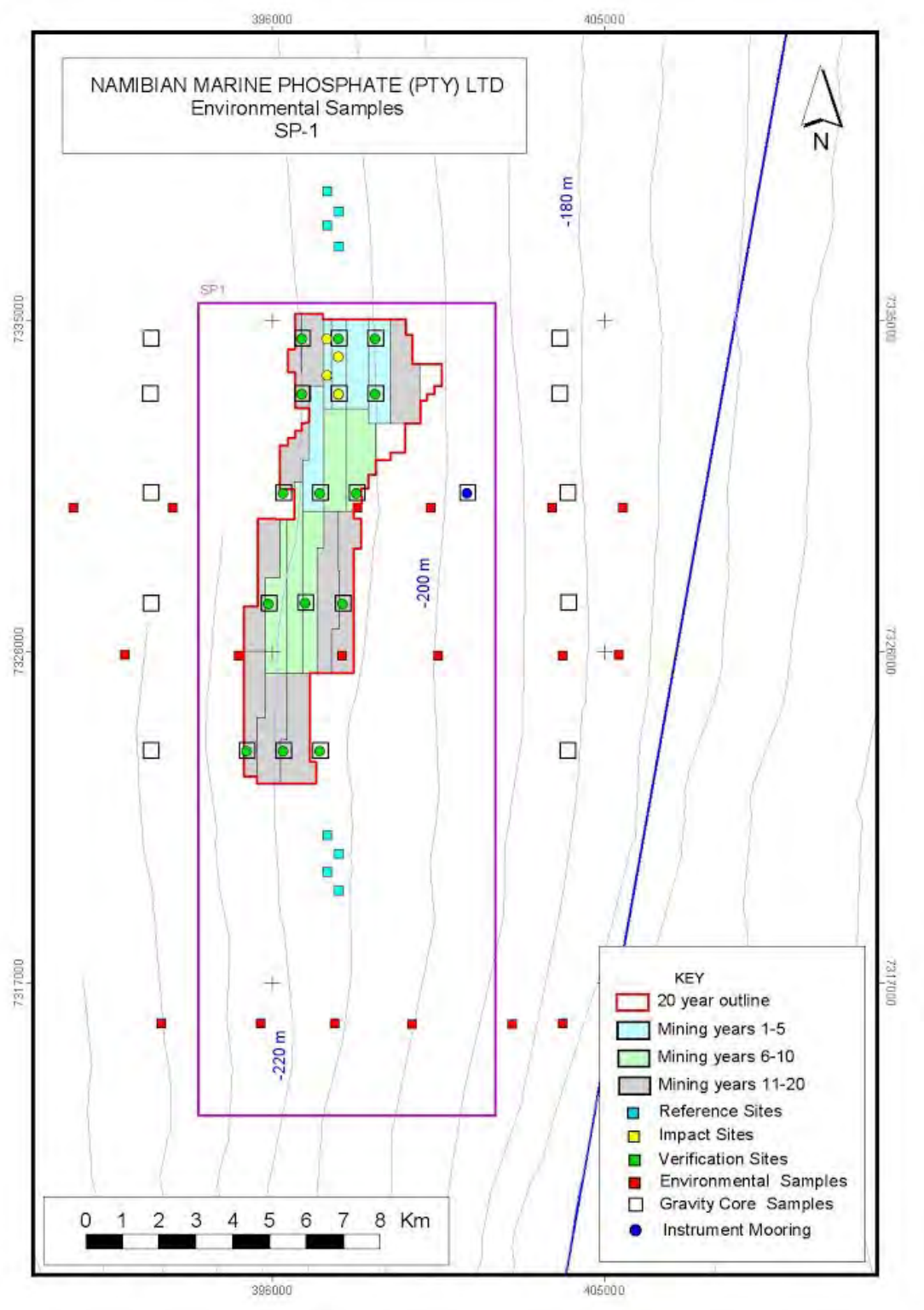


Figure 4 (a): Layout of macrofauna sampling stations for the verification and monitoring survey in SP-1.

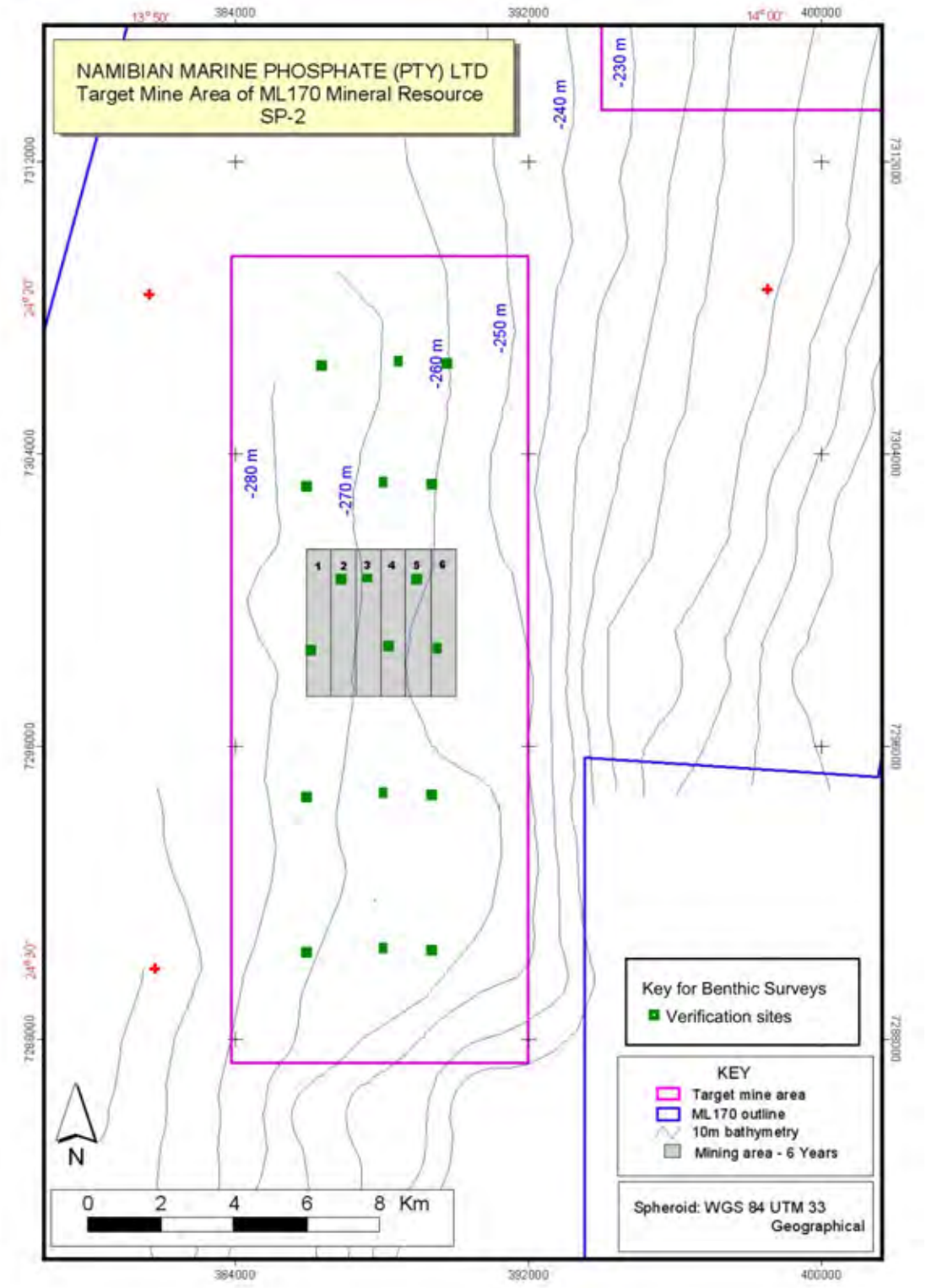


Figure 4 (b): Layout of macrofauna sampling stations for the verification survey in SP-2.

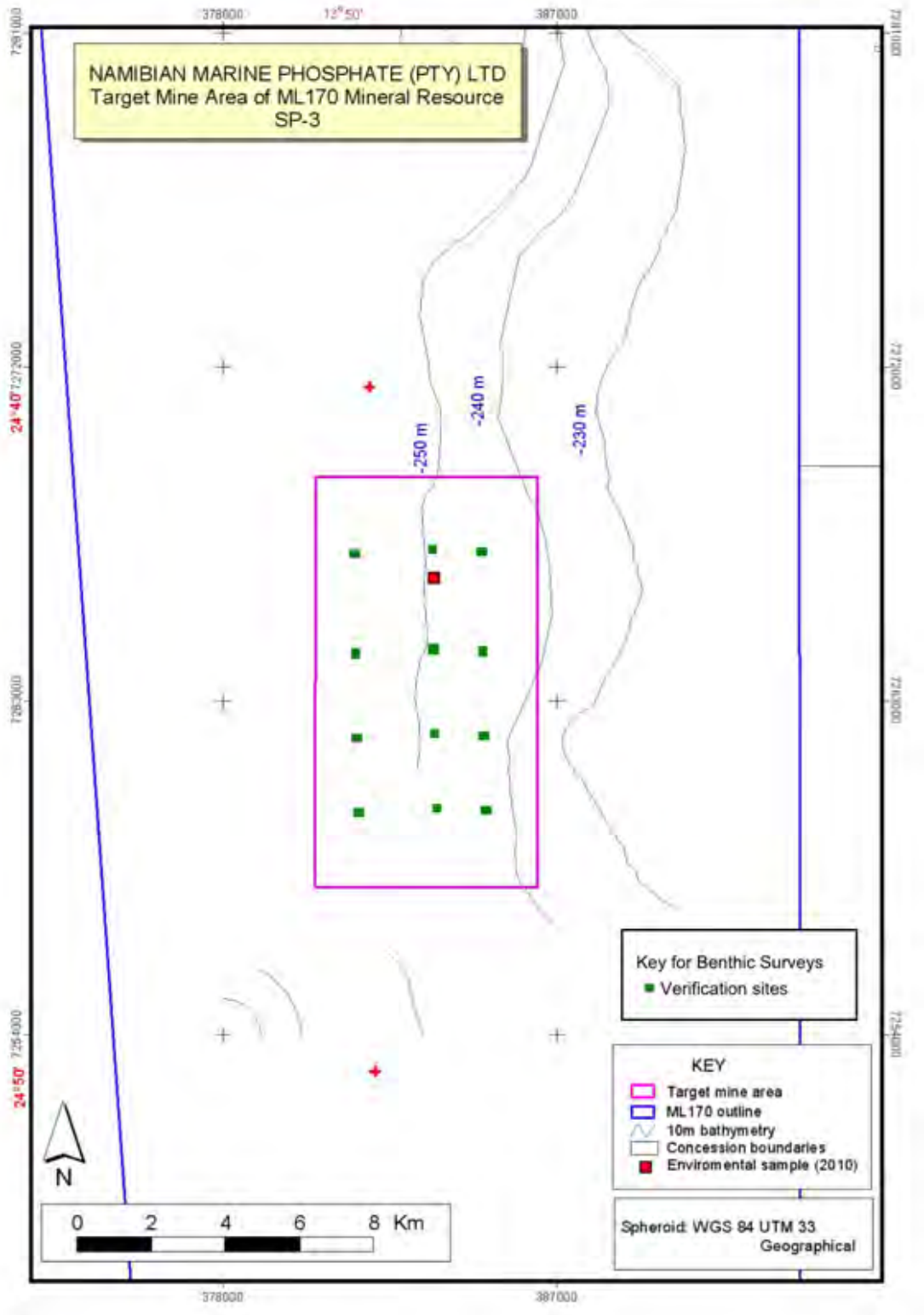


Figure 4 (c): Layout of macrofauna sampling stations for the verification survey in SP-3.

NMP Consolidated Verification Study - Fish, Mammals and Seabirds

Prepared by Mr. D. Japp
Capricorn Fisheries Monitoring cc

4.3.3 INTRODUCTION

The Environmental Impact Assessment (EIA) for the proposed phosphate mining in ML-170 specialist report Appendix 1a on fish resources, fisheries, marine mammals and birds identified five primary impacts *viz.*

1) the likely impact of dredging on commercial fisheries;
2) the likely impact of dredging on the main commercial fish species;
3) the likely impact of dredging on the recruitment of commercially important species;
4) the likely impact of dredging on fish biodiversity and
5) the likely impact of dredging on seabirds and marine mammals.

These impacts and the associated estimates of environmental risk were in part based on marine survey data provided by NatMIRC as well as historical information on fisheries and the Benguela Ecosystem as a whole. The risk assessment has therefore had to use information from surveys etc. in the proximity of the MLA and made assumptions on impacts such as fish recruitment and biodiversity, by extrapolating data from the nearest sampling points from which relevant data were available.

These data have therefore provided a baseline which informed the risk assessment, based on the best available information. The EIA also included a proposal for the verification of the EIA assessment.

Responses to the EIA from NatMIRC were outlined in a letter dated 16 June 2012 and discussed with NatMIRC in a meeting (Facilitated by the Governor of Erongo Province) on 10 September 2012 in Swakopmund. NatMIRC concerns and issues included 13 bullet points. Of these, four (bullets 10, 11, 12 & 13,) related to the component of the EIA relating to Fish resources, mammals and seabirds.

Summarised these concerns were :

1. Turbidity affecting marine predators that use visual cues to forage prey;
2. Spawning activities of fish in the dredging area was relatively unknown;
3. The importance of the proposed dredging area as a nursery ground for juvenile hake;
4. Impacts of the proposed dredging on the ecosystem impacts was uncertain – in particular trophic (feeding) interactions.

© NMP 2014

4.3.3.1 Actions to Address the Identified Issues

In the discussions between NMP and NatMIRC to address the concerns in 1-4 above the following was proposed:

a) A risk assessment been undertaken – this would form a basis on which to inform on the potential risk to the main commercial species if the proposed phosphate mining were to proceed. In particular the risk associated with SP1 and scaled up to include the associated risk if dredging were to expand to SP2, SP3 and or the simultaneous expansion of dredging in other mining lease areas across the Namibian shelf.
b) The outputs of the proposed risk assessment model can then be compared to the risk levels identified in the NPM EIA;
c) Undertake a structured survey of the proposed dredging area – in particular focus on the area proposed to be dredging in the first phase (SP1). This survey will aim to verify the current assumed baseline for biodiversity, fish abundance (density), recruitment (size distribution) and other biological aspects (diet of main commercial species for trophic studies, spawning state of main commercial species etc).
d) These data would then be used to :

    i) verify the assumed baseline historical data used in the EIA;
    ii) provide additional inputs and supporting information for the risk assessment model;
    iii) provide inputs into the current trophic modelling initiatives for the Benguela and the risks to the ecosystem associated with the likely mining impacts.

The proposal to address the issues is therefore a step-wise approach that first assesses the likely risk based on a modelling approach, then verification of the baseline EIA assumptions using in-situ survey data and also further inputs into the risk model derived from the survey as well as providing baseline data for inputs in trophic models currently applied to the broader Benguela ecosystem.

4.3.3.1.1 Terms of reference for proposed activities

1) Risk Assessment

It is proposed that appropriate modelling skills be sourced to undertake a mathematical risk assessment. To do this the following is needed (although the modeller may have alternative or additional requirements). Note also that typically these risk assessments are well-established procedures in fisheries stock assessments and include forward projections for set periods e.g. 20 years.

Key Inputs to the risk assessment:

1) Use the current models used to assess the key fish stocks in Namibia – hake, monk, horse mackerel and small pelagic;
2) These models are based on many sets of criteria, reference sets / data, indices etc. Outputs for the annual setting of TACs assess risk to determine the effects of different levels of TACs, variability in indices and numerous other parameters that have elements of uncertainty associated with them (General Linear Modeling is a common statistical methodology used);

© NMP 2014

3) The proposal therefore aims to incorporate the additional risk to the main commercial resources that may or may not be impacted by the introduction of phosphate mining. Key elements could include (the modellers can inform on this) the following :

a. Biomass estimates (fish density) and the exclusion of dredging areas from the overall abundance of key commercial stocks. This can include for example only SP1 and also a scaling effect around the dredged area(s) and also any potential expansion of dredging from other concession holders (it may also require alternative stratification methods);
b. The potential impact / loss of recruitment to the known key fisheries stocks, in particular hake, monk, sardine and horse mackerel (scaling effects also applied).
c. Possibly the potential loss of spawn for key species if it can be shown conclusively that spawning occurs in the mined area(s);
d. Potential displacement of stock – i.e. fish moving out of the mined areas due to disturbance.
e. Input additional information that may inform the model after the monitoring and verification surveys.

The outputs from the model could then inform on any changes or additional risk to the stocks associated with mining and consolidated with the cumulative impacts that may be associated with other impacts (fishing, dredging /mining etc).

2) In-Situ Survey(s)

The proposal is to conduct a survey within and surrounding the proposed dredging site. It is critical that this survey is compatible and data are consistent with the current survey methods used for the fish stock assessments. This will most likely require that the proposed survey be integrated with the current fishery surveys – this will ensure compatibility of data, reduce overall costs and ensure adequate expertise is available on the survey.

Typically the survey design will incorporate :

a) Fisheries swept area surveys (demersal);
b) Fisheries Acoustic survey (integrated with swept area surveys); and
c) Marine mammal, seabird and other marine fauna observations.

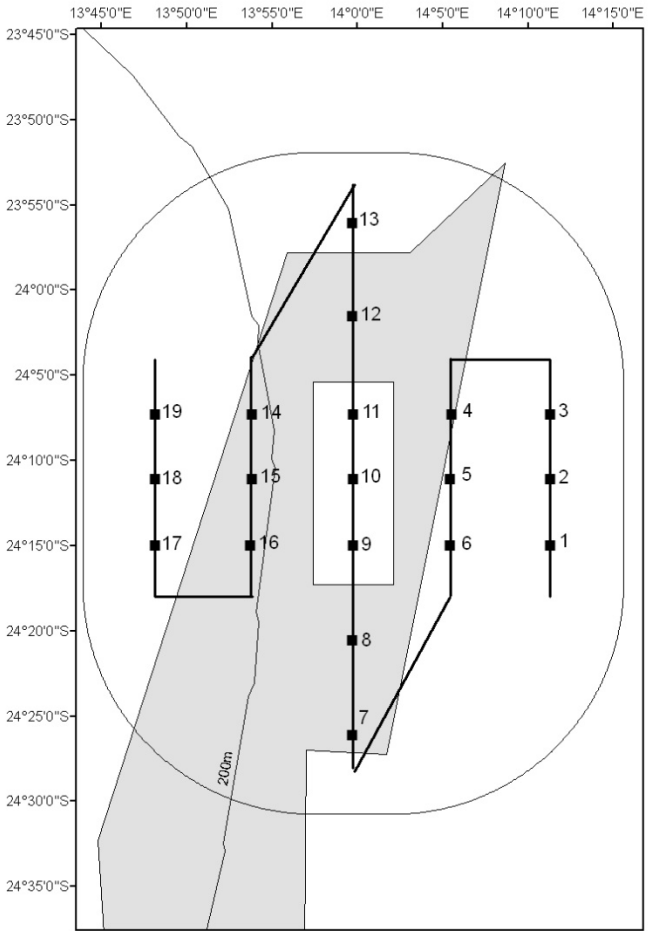


Figure 5: Location of survey stations in SP-1

4.3.3.2 Survey Design

A simple transect design using swept areas, and if considered necessary, simultaneously the collection of acoustic data, is proposed. Schematically the survey design with sampling stations is shown in Figure 5. *Note* :

This is not intended to be prescriptive and will need refinement and discussion with marine scientists at NatMIRC.

4.3.3.2.1 Key elements of the survey

a) Trawls are undertaken north to south following the bathymetry;
b) Typically trawls will be for 20-30 minutes each (max. 1.5 nm);
c) Stations to be positioned within the area to be dredged (SP-1 initially) and thereafter at suitable intervals in a perimeter around the dredge area;
d) Standardisation of trawl gear (similar to that used in biomass surveys);
e) It is essential that stations cover the dredge area prior to any dredging that may take place as well as stations within the MLA and then some distance (to be agreed) outside the MLA and within the 25 km zone used in the fisheries EIA report (Appendix 1a). A total of no more than 20 stations are proposed taking approximately 3-6 days of survey time.
f) Acoustics can also be run along transects and between lines (primarily to determine small pelagic targets) – this is not a high priority but the need can be determined in discussion with the Namibian marine scientists.

4.3.3.3 Expected Outputs

1. A comparative relative abundance estimate of the main commercial species in the dredged area and adjacent grounds (biomass). This can potentially show any changes in relative abundance due to dredging (such as species displacement to areas adjacent to the dredged area);
2. Verification of relative species abundance in the area with the on-going and historical abundance estimates of the main commercial species;
3. Species counts and classification of all flora and fauna (including fish and mega fauna) captured in the trawls. This can be compared with stations from adjacent historical surveys;
4. Provision for a marine mammal and seabird specialists or suitable marine observers to record mammals, seabirds, turtles and other interactions while in the survey area;
5. Length frequency measurements of the main species and sex ratios;
6. Basic biological data collection on main commercial species including gonad staging for comparative spawning and recruitment indices;
7. Use of digital photography to record species;
8. Deployment of CTDs (if an appropriate vessel is used) to determine essential water conditions (conductivity, temperature, depth).

4.3.3.4 Time Frames

A survey prior to the commencement of dredging should be undertaken. Preferably this should be coordinated with other swept area surveys in the area (most likely monk or hake surveys) using the same vessel. The survey can be repeated annually (for the first 5 years as reviewed) at the same time for the duration of the dredging activity. Transects can subsequently be included in the other proposed dredging areas (SP-2 and SP-3), but due to the initiation of the project in SP-1, it is recommended that priority should be given to a focused survey around this target area.

4.3.3.5 Conclusions

Correctly designed and undertaken with professional staff and a suitable sampling platform, the survey can provide a baseline from which the changes in fish availability, abundance, recruitment,

© NMP 2014

biodiversity (as best can be determined from swept area trawls), marine mammals, seabirds and other flora and fauna can be estimated.

This baseline is a “snapshot” that can be compared with historical data in the proximity of the MLA. Changes of the many parameters measured can be tracked over the lifetime of the exploitation and can m be used to determine the effects (environmental impacts) of the proposed project over time. The data would be subjected to scientific and statistical scrutiny for accurate interpretation.

© NMP 2014

Amended Scope of Fish, Mammals and Seabirds Verification Survey, following discussions with MFMR – July 2013.

Prepared by Mr. D. Japp
Capricorn Fisheries Monitoring cc



© NMP 2014

CAPRICORN FISHERIES MONITORING
Reg. No. CK 99 / 24441 / 23
Unit 15 Foregate Square, Table Bay Boulevard, Cape Town, South Africa, 8002
P.O. Box 50035, Waterfront, Cape Town 8001
Tel/Fax : (021) 425 2161 Fax: 425 1994 Cell: 082 – 788 6737

25 February 2014

Namibia Marine Phosphate (Pty) Ltd
127 Theo-Ben Gurirab Str,
WALVIS BAY, Namibia

Attention : Mr M Woodbourn

Re: Verification of Fisheries Data used in the NMP Impact Assessment

Dear Mr M Woodbourn

We refer to the verification survey of the proposed phosphate mining area. In particular we submit herewith our suggested actions to address the fisheries issues raised by NatMIRC and the peer reviewers of the EIA.

The information used by the fisheries impact assessment team was primarily data provided from numerous surveys undertaken by NatMIRC (MFMR). The concerns raised by MFMR and the reviewing parties primarily relate to these data mostly not specifically coinciding with the proposed mining area.

We wish to stress however, that the survey data provided by NatMIRC (MFMR) is based on globally accepted practice when surveying fish stocks. The method employed either uses randomised trawls or fixed transects. The data provided by NatMIRC (MFMR) were a mixture of both.

A key point is that these surveys undertaken by NatMIRC (MFMR) are standardised and apply internationally -recognised sampling practice. Because of the extent of the ocean and the nature of the grounds on which commercial fish stocks are found, surveys sample a very small part of these areas and rely on extrapolations to estimate biomass and other parameters used in fisheries.

Namibian Marine Phosphate (NMP) in their quest to find suitable vessels such that the verification process would be as close as possible to the methodology used by the Namibian and other international research scientists (e.g. Nansen programme) requested that the vessels used by the ministry (MFMR) be utilised for the purposes of verifying the information used in the fisheries component of the EIA. Regrettably it has proven impossible for numerous reasons to get access to these vessels, in particular the *FV Welwitchia* which has historically been used to assess the monk stocks. A further complication was that for the biomass estimates to be compatible using an alternate vessel e.g. an industry trawler, it would require a costly and time-consuming calibration exercise at sea, involving the unavailable *FV Welwitchia.*

Given these difficulties, and the willingness of NMP to explore all options the following approach to the verification process has been adopted.

1. Employ an independent fisheries quantitative scientist (Dr James Gaylard) to assess the likely biomass of the main commercial fisheries stocks that may be impacted by dredging. This involved using the NatMIRC historical biomass estimates and extrapolating these estimates to the actual area to be mined i.e. SP-1, and licence area of the NMP Sandpiper deposit.

2. Employing a professional consultant (in this case a Namibian fisheries scientists Dr Hillka Ndjaula) to assess the likely recruitment impact on the main commercial fish species (using data acquired from the NatMIRC scientists)

The results from both these studies are pending and will be submitted in due course for review.

© NMP 2014

The key results from these studies show that the area to be mined is proportionately extremely small (compared to the total area of the main commercial fish species) and that no significantly (in the context of the EIA) useful information would be obtained by undertaking a biomass-directed survey that would have been standardised to the historical biomass surveys conducted in Namibia. This conclusion applied equally to the biomass estimates of spawner biomass and recruitment. The study did show that there is a significant difference between monk and hake, where monk is in greater numbers and biomass than hake in the MLA. Nevertheless the estimates of biomass of these two key groundfish species in the twenty year mine target area of SP-1 is miniscule.

The work undertaken by Dr. H. Ndajula is still in process but suggests that the proposed mined area has no unique spawning processes, or at least no spawning indicators that suggest it is different from any other areas in Namibian waters.

Given all of the above we have concluded that undertaking of a calibrated, standardised survey of the MLA focused on the SP-1 area will produce no significantly useful additional quantitative information on the biomass of monk and hake. Consequently we advise NMP to adopt a different strategy, one that we envisage would be supported by NatMIRC / MFMR.

The recommendation: NMP are to charter a dedicated monk (commercial) vessel and undertake a structured sampling survey using standard monk trawl gear. Although this will not provide directly comparable biomass estimates it will allow for the following to be done by a group of professional scientist in a rigorous manner:

1. Quantify all fish species caught in and around SP-1 and the immediate area of the MLA. This would include weighing and measuring, of key species;
2. Quantifying all species captured, estimating their relative proportions in the catch and undertaking biological analysis of key species (similar to that done by NatMIRC on their surveys);
3. Recording all species captured – this will provide a baseline comparison of biodiversity with the historical surveys;
4. Recording at the same time the nature of the substrate and bottom profile;
5. Measuring common environmental parameters – salinity, oxygen, temperature, water depth, water clarity (CTD) etc
6. Recording the occurrence of surface species such as large pelagics, marine mammals and birds.

The survey is designed to quantify the biodiversity of the area and compare this with the known information of the region, i.e. a biodiversity verification assessment.

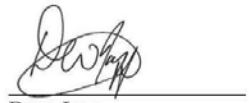
The survey will also obtain full commercial data on target catch (monk), hake and the other bycatch species. This will allow for a crude biomass estimate on spawner biomass and recruitment that can then form a baseline for future surveys in the area.

From this point, it is necessary that:

- A suitable commercial vessel is obtained from which to conduct the biodiversity assessment;
- That NatMIRC / MFMR acknowledged the scientific reasoning and approach as adopted; and
- That NatMIRC / MFMR provide the necessary approvals, if they have not already done so.

We trust that this meets with your approval, and we look forward to working on this project with you.

Yours sincerely



Dave Japp
CapFish cc

Capricorn Fisheries Monitoring (CapFish)
Members: D. Japp - C. Heinecken – J. Wissema
Providing : Marine Monitoring Services - Marine Observers – Fisheries & Aquaculture

SANDPIPER PROJECT

Verification Programme Report:
Mining Licence Area No. 170

SECTION D : APPENDICES

APPENDIX 5

Curricula Vitae and Terms of Reference

5.1: Curricula Vitae
5.2: Terms of Reference

APPENDIX 5

CURRICULA VITAE & TERMS OF REFERENCE

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed "Attention: Administration Manager," at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

contents

5.1: CURRICULA VITAE 1

5.1.1 Independent Programme Reviewer and Process Quality Controller 1
5.1.1.1 Mr P Morant : Abbreviated Curriculum Vitae 1
5.1.2 Specialist consultants 2
5.1.2.1 Prof. J Compton: Abbreviated Curriculum Vitae 2
5.1.2.2 Dr R Carter: Abbreviated Curriculum Vitae 3
5.1.2.3 Mr D Japp: Abbreviated Curriculum Vitae 5
5.1.2.4 Dr N Steffani: Abbreviated Curriculum Vitae 6
5.1.2.5 Prof M Gibbons: Abbreviated Curriculum Vitae 7
5.1.3 Project Coordinator 9
5.1.3.1 Mr J Midgley: Abbreviated Curriculum Vitae 9

5.2: TERMS OF REFERENCE 10

5.2.1 Independent Programme Reviewer and Process Quality Controller 10
5.2.2 Specialist consultants 11
5.2.2.1 Prof. J Compton: Terms of Reference 11
5.2.2.2 Dr R Carter: Terms of Reference 12
5.2.2.3 Mr D Japp: Terms of Reference 20
5.2.2.4 Dr N Steffani: Terms of Reference 28
5.2.3 Project Coordinator 38
5.2.3.1 Mr J Midgley: Terms of Reference 38

© NMP 2014

5.1: CURRICULA VITAE

5.1.1 Independent Programme Reviewer and Process Quality Controller

5.1.1.1 Mr P Morant : Abbreviated Curriculum Vitae

Name:	Patrick Digby Morant
Date of birth:	24 February 1946
Place of birth:	Dar-es-Salaam, Tanzania
Current Employment:	Independent Environmental Consultant, CSIR Associate
Experience:	36 years in coastal and marine environmental management. 25 years in environmental impact assessment
Qualifications:	M.Sc. Environmental Science (University of Cape Town) B.Sc. (Hons) 1st class: Microbiology (University of Cape Town)
Professional	Registered Professional Natural Scientist
Registration:	No 401514/83

Patrick Morant is a practicing professional environmental scientist and manager with a primary focus on the marine and coastal environment. Since graduating with an M.Sc. in Environmental Science he has headed the CSIR's Estuarine and Coastal Research Unit and managed a number of multidisciplinary research and consulting groups in the CSIR. He has led and/or participated in over forty environmental impact assessments of marine diamond mining in Namibia and offshore petroleum exploration and production along the west coast of Africa from Cameroon to South Africa. Currently he is associated with the CSIR's Environmental Management Services (EMS) group and variously leads and contributes to EIA and SEA projects besides reviewing reports and mentoring interns.

Patrick Morant also was part of the team that established the Benguela Current Large Marine Ecosystem (BCLME) Programme and contributed two thematic reports to the foundation documentation. He played an active role in the programme throughout its existence and led two studies: Oil Spill Contingency Planning in the BCMLE Region; and Cumulative Impacts of Oil Exploration and Production on the Northern Angolan Continental Shelf. He has also authored or co-authored two book chapters and a number of publications in the peer-reviewed literature.

I certify that to the best of my knowledge and belief, this CV correctly describes myself, my qualifications, and my experience. I understand, that any willful misstatement described herein may lead to my disqualification or dismissal, if engaged.

© NMP 2014

5.1.2 Specialist consultants

5.1.2.1 Prof. J Compton: Abbreviated Curriculum Vitae

Education:

Harvard University	Earth Science	Ph.D.	1986
University of California, San Diego	Chemistry/Earth Science	B.A.	1981

Professional Background:
2004-present Associate Professor, Department of Geological Sciences, University of Cape Town

Supervised: Honours students (28), Masters students (20), Doctoral Students (4) Post Doctorates (4)

Areas of Specialisation:
Low-temperature and sedimentary geochemistry of marine sediments.
Geochemical cycles and Earth history.

Professional Societies – Offices held:
American Geophysical Union
Southern African Society for Quaternary Research (SASQUA) President 2003-2005
SCOR (Scientific Committee on Oceanic Research) Executive Committee 2008-2012
South African National Committee member 2005-2012; President 2009-2012
Geological Society of South Africa (Council Vice Chair of the Western Cape Branch 2005-2011)

Publications (sample) - Articles in Refereed Journals: 2012 – present.

Wigley, R. and **Compton**, J.S., 2012. Microstratigraphy of a Miocene layered phosphatic pebble from the western margin of South Africa. *Sedimentology* 60, 666-678. doi: 10.1111/j.1365-3091.2012.01355.x

Viglietti, P.A., Smith, R.M.H., **Compton**, J.S., 2013. Origin and palaeoenvironmental significance of Lystrosaurus bonebeds in the earliest Triassic Karoo Basin, South Africa, *Palaeogeography, Palaeoclimatology, Palaeoecology*, doi: 10.1016/j.palaeo.2013.08.015.

Brumfitt, I.M., Chinsamy, A., and **Compton**, J.S., 2013. Depositional environment and bone diagenesis of the Mio/Pliocene Langebaanweg bonebed, South Africa. *South African Journal of Geology*, 116, 241-258 doi:10.2113/gssajg.116.2.241.

Toms, J.A., **Compton**, J.S., Smale, M., van der Heyden, S., 2014. Variation in palaeo-shorelines explains contemporary population genetic patterns of rocky shore species. Biological Letters 10: 20140330. http://dx.doi.org/10.1098/rsbl.2014.0330

Cawthra, H.C., Bateman, M.D., Carr, A.S., **Compton**, J.S., Holmes, P.J., 2014. Understanding Late Quaternary change at the land-ocean interface: A synthesis of the evolution of the wilderness coastline, South Africa. *Quaternary Science Reviews*

5.1.2.2 Dr R Carter: Abbreviated Curriculum Vitae

1. **Proposed Position**: Principal Scientist

2. **Name of Firm**: Lwandle

3. **Name of Staff**: Robin Carter

4. **Date of Birth**: 07/05/1946
   Nationality: South African

5. **Education**: 1978 MSc – Biological Oceanography
   1983 PhD – Marine Ecology

6. **Membership in Professional Associations**: Registered as Professional Natural Scientist in marine science with the South African Council for Natural Scientific Professions (registration # 400245/060) and a professional member of the South African Institute of Ecologists and Environmental Scientists.

7. **Further Training Courses**:

8. **Countries of Work Experience** : South Africa, Mozambique, Angola, Namibia

9. **Languages**:

	speaking	reading	writing
English	good	good	good
Afrikaans	fair	fair	fair

10. **Employment Record**

    Period: 9 years
    Employer: Lwandle
    Position held: Principal Scientist

11. **Detailed Tasks Assigned**: 12. **Work undertaken that best illustrates capability to handle tasks assigned:**

Name of Assignment or Project: Marine light monitoring
Year: 2014
Location: Mozambique
Client: ERM – Environmental Resource Management
Main project features: Monitoring of light radiation in the marine and terrestrial environment. Deployment and recovery of equipment and data curation.
Positions held: Principal Scientist
Activities performed: Management of project

Name of Assignment or Project: NMP Environmental Survey - Verification survey for water column and sediment properties
Year: 2013
Location: Namibia
Client: Namibian Marine Phosphate
Main project features: Verification (metocean, water column and benthic) survey for water column and sediment properties in an offshore marine phosphate mining lease area in Namibia for Namibian Marine Phosphate, Namibia.

© NMP 2014

Positions held: Principal Scientist
Activities performed: To oversee sampling regime and manage field team.

Name of Assignment or Project: Anadarko LNG Project
Year: 2014
Location: Palma Bay, Mozambique
Client: Anadarko Petroleum Corporation
Main project features: Marine Ecology surveys
Positions held: Principal Scientist
Activities performed: Post ESHIA marine environmental and monitoring systems design for an LNG plant.

Name of Assignment or Project: Marine ecology assessments for proposed extensions to the Port of Ngqura
Year: 2013
Location: Coega Industrial Development Zone, Algoa Bay, Eastern Cape, South Africa
Client: CSIR
Main project features: Expansion of existing harbour and associated facilities into Algoa Bay by dredging and construction and operations.
Positions held: Principal Scientist
Activities performed: Marine ecology specialist study as part of an EIA for the establishment of a manganese bulk handling facility.
Name of Assignment or Project: Bio-monitoring program Transnet
Year: 2013
Location: Port of Cape Town
Client: Transnet
Main project features: Field work associated with bio monitoring program on the effects of dredging and dredge spoil behavior.
Positions held: Principal Scientist

Name of Assignment or Project: Block 1506 West Hub
Year: 2012
Location: Angola
Client: ARC
Main project features: Block 1506 West Hub offshore Angola marine environmental survey for ARC on behalf of Eni.
Positions held: Principal Scientist

13. **Certification**:
I certify that to the best of my knowledge and belief, this CV correctly describes myself, my qualifications, and my experience. I understand, that any willful misstatement described herein may lead to my disqualification or dismissal, if engaged.

5.1.2.3 Mr D Japp: Abbreviated Curriculum Vitae

David William Japp	South African Citizen
DOB :	30 June 1956
Current Employment :	International consulting Fisheries and Marine Scientist
Professional Registration :	**SA COUNCIL FOR NATURAL SCIENTIFIC PROFESSIONS or SACNASP**
Highest Qualification :	Master of Science in Ichthyology and Fisheries Science (Rhodes university)

David William Japp is a practising professional marine and fisheries scientist. His career includes 10 years as a navigator in the Merchant Navy, 8 years of study (University of Cape Town and Rhodes University), 10 years as a principal researcher (Sea Fisheries Research Institute and Marine and Coastal Management) and 18 years as a consultant in the marine environmental field. He is a founder and full partner in the Marine and Fisheries consulting group *CapFish (SA) (Pty Ltd*. In addition to the management functions in CapFish he consults broadly in the marine and fisheries field. His specialisation includes direct fisheries assessments and in impacts of offshore oil and gas activities. He has done 25 scientific publications and more than 100 technical reports.

Since 2004 David Japp has contracted to the World Bank and the Food and Agricultural Organisation of the United Nations (FAO) undertaking project development in East Africa where he specialises in fisheries and coastal zone management. Since 2004 he has managed fisheries projects in South Africa, Mozambique, Kenya, Uganda, Angola and Tanzania. He was responsible for the management and implementation of the fisheries components in the Marine and Coastal Management Project (MACEMP) from 2006 - 2012, the South West Indian Ocean Fisheries Project (SWIOFP) from 2008 to 2013 and currently the development of the Tanzanian fisheries programme under the SWIOFISH project. These projects have ranged in value from $15 – $65 million.

Mr Japp has worked on policy and governance aspects of fisheries in the region (South Africa, Kenya, Tanzania), Fisheries economics (Namibia and South Africa) and many fisheries-related programmes involving fisheries management and biology. Mr Japp has also undertaken numerous MSC assessments, including South African hake, Tristan da Cunha lobster and Russian Sea of Okhotsk Pollock. Other MSC-related activities include pre-assessments of SA Tuna pole, SA longline hake, Kenya Lobster, Tanzania Octopus, Namibia hake, Uruguay hake and Mozambique shallow and deep-water shrimp. In Mozambique he is currently working with WWF in a Fisheries Improvement Project for shallow and deep-water shrimp.

In addition to fisheries, Mr Japp works broadly as an environmental practitioner involved extensively in Environmental Impact Assessments. His specialisation is on ecosystems and also the offshore oil and gas sector where he manages a specialist team of consultants providing assessments, spatial mapping (GIS), Marine Mammal (MMO), Passive Acoustic (PAM) and Fisheries Liason (FLO) services to the hydrocarbon industry.

© NMP 2014

5.1.2.4 Dr N Steffani: Abbreviated Curriculum Vitae

Company Profile

Steffani Marine Environmental Consultant was established in 2002 by Dr. Nina Steffani. The office is based in Cape Town, South Africa and includes laboratory facilities for the taxonomic identification of benthic macrofauna invertebrates. Dr. Steffani is registered with the South African Council for Natural Scientific Professions (SACNASP) as *Professional Natural Scientist*.

Summary Profile of C. Nina Steffani

Nina Steffani has extensive experience in marine biological research resulting in the completion of two postgraduate degrees and scientific publications in international and national high-class rated journals. Her main area of scientific research is in the field of rocky shore ecology and invasive biology. At the University of Cape Town, she was employed as scientific diver, research assistant, postdoctoral research fellow and research associate.

Since 2002, Nina has worked as a Senior Marine Environmental Consultant at Steffani Marine Environmental Consultant and is primarily involved in the preparation of Marine Baseline Studies, Marine Specialist Reports, Environmental Impact Assessments and Environmental Management Plans, focussing both on rocky and soft-bottom substrates. She is highly experienced in the taxonomic identification of benthic macrofauna species, and has many years of experience in leading and conducting rocky shore and sandy beach field surveys. Furthermore, she is a registered scientific diver.

She has a proven track-record of successful project completion with work conducted for e.g. De Beers Marine, De Beers Marine Namibia, Namdeb, CSIR, Pisces Environmental Services, Lwandle Technologies, Anchor Environmental Consultants, EnviroAfrica, EcoSense, BCLME, DAFF (M&CM), SAMICOR, Transhex, De Beers Namaqualand, Portnet, Transnet, and IMT.

Academic Qualification

1996 – 2001	Ph.D. Zoology, Department of Zoology, University of Cape Town, South Africa
1987 – 1994	Diplom (equivalent to M.Sc.) Biology, Studies in Biology, University of Hamburg, Germany

5.1.2.5 Prof M Gibbons: Abbreviated Curriculum Vitae

Address: Department of Biodiversity and Conservation Biology, University of the Western Cape, Private Bag X17, Bellville 7535, South Africa. Tel: +27 21 959 2475, Fax: +27 21 959 2312, Email: mgibbons@uwc.ac.za

Educational History

• 1984 - 1988	University of Cape Town	PhD Zoology
• 1980 - 1983	University of Liverpool, UK	B.Sc. (Honours) Marine Biology.

Employment History:
Biodiversity and Conservation Biology Department, UWC 01/01/2006 – present, Full Professor

Research Interests:
Marine ecology, specifically pelagic ecology and biological oceanography: I have a special interest in zooplankton and in the processes responsible for structuring assemblages at all temporal and spatial scales. I have also run a research programme (with colleagues at UCT and the NHM, London) on marine invertebrate biodiversity, which essentially follows an interest in training students in the taxonomy and systematics of marine invertebrates. Recent interests are focused on understanding the changes to pelagic ecosystems of Namibia following the collapse of pelagic fish populations there at the end of the 1960s.

Postgraduate and Research Students:

- Ph.D. – Six current students, five past students
- M.Sc. – Three current students, 15 past students
- B.Sc. (Hons) – Three current students, 28 past students

Research Outputs:

- Publications in Peer Reviewed Journals – 94
- Books and/or Chapters in Books – 6
- Technical Reports – 15
- Popular Scientific Articles – 24
- Presentations at Conferences and Workshops – >150

Recent Publications – 2014 / 2013:

Toefy R and Gibbons MJ. (2014) Regional generalisations about the relationships between the environment and foraminifera. *Marine Pollution Bulletin* http://dx.doi.org/10.1016/j.marpolbul.2013.12.034

Rohner CA, Couturier LIE, Richardson AJ, Pierce SJ, Prebble C, Gibbons MJ and Nichols PD (2014). Diet of whale sharks *Rhincodon typus* inferred from stomach content and signature fatty acid analyses. *Marine Ecology Progress Series* **493:** 219–235.

Gibbons MJ and Richardson AJ (2013) Beyond the jellyfish joyride and global oscillations: advancing jellyfish research. *Journal of Plankton Research* **35:** 929-938

Harkins GW, D'Amato ME and Gibbons MJ (2013) Self-maintaining or continuously refreshed? The genetic structure of *Euphausia lucens* populations in the Benguela upwelling ecosystem. *Journal of Plankton Research* **35:** 982-992

Moloney CL, Fennessy S, Gibbons MJ, Roychoudhury A, Shillington FA, von der Heyden BP and Watermeyer K. (2013). What is the evidence for offshore marine ecosystem change in South Africa? *African Journal of Marine Science* **35:** 427-448

Roux J-P, van der Lingen CD, Gibbons MJ, Moroff NE, Shannon LJ, Smith ADM and Cury PM (2013) Jellyfication of marine ecosystems as a likely consequence of overfishing small pelagic fish: Lessons from the Benguela. *Bulletin of Marine Science* **89:** 249-284

Utne-Palm AC, Locatello L, Mayer I, Gibbons MJ and Rasotto MB (2013) An insight into the reproductive biology of the bearded goby, *Sufflogobius bibarbatus* (von Bonde, 1923). *Journal of Fish Biology* **82:** 725-731

Zootaxa, **2504:** 20-30.

Other:

- Assistant editor: *African Journal of Marine Science.*
- Associate Editor: *Journal of Plankton Research* (2008-2011).
- Editorial Board Member: *Journal of Plankton Research* (2012-present).
- Member: Small Invertebrates and Seaweeds Scientific Working Group (DAFF: 2012-present)
- Member: Scientific Advisory Board of De Beers Marine Namibia (Pty) Ltd (2012-present)
- NRF Rating: B2
- H Index: 25 (http://scholar.google.co.za/citations?user=8akWJoUAAAAJ&hl=en)
- Awarded JDF Gilchrist Medal, 2014.

5.1.3 Project Coordinator

5.1.3.1 Mr J Midgley: Abbreviated Curriculum Vitae

Jeremy Luke Midgley:	South African Citizen
DOB:	31 March 1963
Current Employment:	J Midgley & Associates (14 years) Environment – Health – Safety Consulting
Professional Registration:	SA COUNCIL FOR NATURAL SCIENTIFIC PROFESSIONS. No. 400205/09
Qualifications:	M/Sc.: Environmental and Geographical Sciences (University of Natal) B.Sc. (Hons.): Geology (University of Cape Town)
Masters Thesis:	Towards a Financial Evaluation of a Semi-disturbed Indigenous Habitat through its Precipitation-runoff Attenuation Capabilities.
Honours Thesis:	A bathymetric investigation of the south east Cape Basin titled: Submarine topography of the Cape Passage.

Jeremy Luke Midgley is a practising professional environmental and Health and Safety consultant. His career includes two years as a mine geologist at Barbrook Mine Barberton (Rand mines), one year working in Angola (Roan Selection Trust) as a diamond exploration geologist based in Cafunfu. This was followed by five years with the marine diamond mining company Namibian Minerals Corporation (NAMCO) with group responsibilities for Environment, Health and Safety. During this period the company was accredited to the international environmental standard ISO 14001. The liquidation of NAMCO provided the opportunity to start his own consulting company, J Midgley and Associates, for which he is the principal consultant.

This company has successfully served a variety of clients (marine and terrestrial) with a wide range of environmental, health and safety services for the last 14 years. These services focus primarily on risk assessments and mitigation, considering environment, safety and quality aspects of these operations. Impact assessments, management plans, compliance monitoring protocols and compliance reporting systems have been prepared for marine and terrestrial diamond mining and exploration companies in both Namibia and South Africa. Environmental management plans have been developed for several brick mining and manufacturing operations. A number of safety systems have been developed and implemented for marine salvage companies, and specialist (HV) and (LV) electrical companies. More recently environmental consulting and project management services have been provided to a number of marine phosphate projects in Namibia. A number of companies have been progressed to certification standards of the International Maritime Organisation (IMO) and NOSA. J Midgley and Associates often works in collaboration with other consultancies, both large and small.

In his personal capacity Jeremy is a qualified stress management practitioner.

© NMP 2014

5.2: TERMS OF REFERENCE

5.2.1 Independent Programme Reviewer and Process Quality Controller

The CSIR (Mr P Morant) was appointed to oversee environmental quality control / process control of the NMP EIA (2012). Following the decision to undertake the verification requirements as detailed in the EMP (2012), NMP requires the continuity services of the CSIR (Mr P Morant), providing similar services for the verification programme.

Independent Review of the Verification Programme Report

Namibian Marine Phosphate (Pty) Ltd (NMP) requires the continuity of document review services and environmental compliance guidance of the CSIR, as provided by Mr P. Morant during the EIA phase of NMP's environmental assessment of the impact of the dredging of marine sands rich in phosphate from ML 170. This continuity of services extends to the verification programme, when a number of studies will be undertaken to gather data specifically from the mining licence area. This information will subsequently serve to verify the original impact assessment (EIA of 2012).

Work – Proposal and Quotation request.

The principal services to be provided by the reviewer (Mr P Morant) of CSIR are:

1. The reviewer will serve as the overall quality controller for the Verification Survey and Report including:
   - Review of the individual specialists' verification reports
   - The re-assessment of the potential environmental impacts as determined from the verification assessments;
   - The environmental management plan (EMP);

2. The reviewer will provide advice on an ad hoc basis throughout the Verification Programme.

Specialist Studies

Specialist whom you will need to contact that form part of the broader investigations of this verification programme include:

- Dr Robin Carter: (+ 27 (0) 829223504 – robin@lwandle.co.za),
  Water Column and Sediments and Related Studies

- Dave Japp (+ 27 (0) 827886737 – + 27 (0) 21 4256226 – dave@capfish.co.za),
  Fish, Mammals and Seabirds and Related Studies.

- Dr Nina Stefani: (+ 27 (0) 21 – 7059915 – 0722172060 – ninasteffani@telkomsa.net),
  Macrofauna Assessment.

- Tim McClurg: (+ 27 (0) 31 7621 1356 – mcclurgs@telkomsa.net),
  Epifauna

- Dr Simon Forster (simon.forster@physalia.demon.co.uk),
  Meiofauna

- Dr Bronwen Kirby (+27 (0) 21 959 3033 bkirby@uwc.ac.za),
  Thiobacteria

- Roy van Ballegooyen (+ 27 (0) 21 8882400 - RvBalleg@cisr.co.za),
  Plume Modelling

- Gordon Rigg (+27 (0) 832570731 - Gordon.rigg@marinedataconsultants.co.za),
  Geophysical Data Assessment.

Project Coordination

NMP has appointed Jeremy Midgley & Associates to coordinate the verification programme, the CSIR (in the person of Mr. P. Morant) will be required to work closely with Mr. Midgley.

5.2.2 Specialist consultants

5.2.2.1 Prof. J Compton: Terms of Reference

Terms of Reference for
1) A review of offshore phosphorite deposits on the Namibian margin; and,
2) The establishment of a preliminary model for the origin, age and deposition of phosphorite in ML 170

i) Scope of work:
- Strontium isotope analysis of the lithological units from a series of cores from the ML 170;
- Confirmation of the stratigraphy;
- Core logs / stratigraphy verification;
- Full literature review of west coast phosphorites; and,
- Provision of a compendium of all references.

ii) Expected outputs
- Preliminary model for the age and origin for the deposition of phosphorites;
- Description of the geological setting of the origin and depositional history;
- Review / confirmation of the stratigraphy; and,
- Integrated report.

iii) Analytical methods considered
The application of strontium isotope analysis to a series of cores from ML 170 will establish the age of phosphorite formation as well as the final depositional age of the deposits. Strontium isotope analysis is a highly informative and an extremely powerful technique for determining the complex geological history of these deposits.

Process approximately 24 Sr samples from the major lithological units of the cores. Select from key stratigraphic samples different grain types (pelletal phosphorite grains, skeletal phosphorite grains, calcareous foraminifera and mollusc shell if present) and compare with the Sr-derived ages. From these different sediment components we can determine when the phosphorite formed, when it was reworked and finally when it was deposited.

From these results a geological / depositional model for the deposit integrating the strontium ages with the overall stratigraphy is to be written up.

iv) Primary Resources

The following cores can be provided for the assessment; they have been collected from ML 170. These are from shallow to deep as follows: 1364, 1397, 1384, 1441, 1442, 1478, 1479.

v) Note

The development of a depositional model for the deposits offshore and the use of Sr isotope ages could be fundamental to verifying / substantiating the chronology as currently determined for the phosphorite deposits offshore South Africa.

5.2.2.2 Dr R Carter: Terms of Reference

Verification Assessment
Sediment Properties and Water Column Features
Verification of Impacts in the proposed Mining Area ML 170

i) Need for Verification Assessment

The conclusions and predictions of the environmental effects of dredging marine pelletal phosphate ore reserves on the Namibian continental shelf are primarily based on the sediment properties in the dredging areas. We consider that the information on this is robust as it is drawn from the seminal work conducted by Bremner (1978), direct surveys of sediment properties across one of the dredging areas by Rogers (2008) and because it is consistent with adduced distributions of turbulent energy across the shelf which control sediment texture distributions. All of this indicates that the sediments in the dredging areas are predominantly muddy sand. Hydrogen sulphide, methane and other chemical flux rate measurements conducted by, *inter alia*, Namibian and South African marine scientists indicate that these are low as sedimenting pelagically produced particulate organic matter (POM) does not accumulate on these sediments. Further, the phosphate ore body is considered to be derived from estuarine deposition in the Pliocene (2.6—1.0 MA, Compton 2012) so any organic material incorporated in the ore body would be extremely refractory. This implies that the only sources of sulphur in the ore body itself would be pyrites which have low dissolution rates.

On the basis of the above the water quality and associated environmental risks associated with the dredging process, were considered to be predominantly physical as opposed to biogeochemical. Consequently the conclusions on sediment textures in the mine licence area are of pivotal importance in the environmental assessment.

It is clear from comments received from interested parties in Namibia especially that this is a contentious issue as, although no data or analyses (peer reviewed or not) are presented in support of alternative views, there is a persistent concern that sulphidic sediments will be exposed during dredging with important consequences for water quality.

In our view the only practical response to this is to conduct a verification survey in the identified dredging areas on sediment properties, water quality and local oceanographic processes prior to the commencement of any dredging operations.

ii) Proposed Verification Survey

Scope

The verification survey will focus on:

- **Sediment properties** including:
    - Surficial particle size and sediment texture distributions (box core). This is to confirm conclusions reached in the EIA studies that sediments in the proposed dredging areas are mainly fine and medium sands with minimal mud. Although this has been done via analyses of sediment core samples from the dredging areas post the EIA, which have shown 80-90% sand, the companion measurements on sediment properties that will be made (below) can only be properly understood in terms of the host sediment environment (**NatMIRC bullet points 1, 2 & 8**);
    - Subsurface sediment particle size and texture distributions to ~2.5 m depth in the sediment (gravity core) (indirectly **NatMIRC bullet points 1,2 & 8**);
    - Surficial and deep sediment organic content, POC and PON concentrations (indirectly **NatMIRC bullet point 1&2**);
    - Surficial and deep sediment trace metal concentrations (NatMIRC bullet point 4)
    - Surficial and deep sediment trace metal elutriation measurements to show the proportion of trace metals held in the particulate phase in the sediment that may be released into the dissolve phase and thereby become bioavailable (**NatMIRC bullet point 4**);
    - Sediment pore water inorganic nutrient (N, P & Si) concentrations to demonstrate risks of departures from Redfield ratios when translocated to the upper water column during dredging (**NatMIRC bullet point 9**);
    - Sediment pore water hydrogen sulphide concentrations to show potential fluxes to the water column when disturbed by dredging (**NatMIRC bullet point 1 & 2**);
    - If the CSIR methane detection system is operational methane concentrations in sediment pore water will also be measured.

NatMIRC (**bullet point 5**) express a need for the collection of baseline information on Thio-bacteria. There are no regional distribution data that we would be able to match whatever was found. The presence and role of these organisms depends on H_2S flux which requires organic matter supply and its incorporation in the sediments. We will be able to see this from sediment properties and the turbulence estimates from the moored Aquadopp current meter. Therefore from the acquired sediment property data we will be able to make probability statements on the presence and roles of this class of bacteria.

© NMP 2014

- **Water column properties** including:
    - Vertical profiles of the distributions of temperature, conductivity, dissolved oxygen (DO), chlorophyll fluorescence (Chl) and turbidity measured by a multi-probe internal logging CTD extending from the sea surface to within 5 m of the sea bed (partially addresses **NatMIRC bullet point 2**);
    - Near sea bed temperature, conductivity, DO and turbidity time series measurements to elucidate background concentrations and possible variations linkable to internal tide generated turbulence (**NatMIRC bullet point 2**);
    - Near sea bed high frequency current measurements (Aquadopp – see Figure 1) to determine turbulence and sediment resuspension events linkable to internal tide generated turbulence. This will be complementary to the DO and turbidity time series (**NatMIRC bullet point 2** and confirmatory data for the internal tide generated turbulence control of POM capture in Namibian continental shelf sediments hypothesis), and
    - Currents and indirect measurements (beam attenuation) of suspended sediments (equivalent to turbidity) through the upper water column (<100 m depth) measured by upward looking ADCP (Figure 1) (partially addresses **NatMIRC bullet points 7 & 8**).

In their commentary NatMIRC expresses a need for 'site specific' simulation modelling of dredge plume behaviour 'using current, heavy metal and trace metal data[1] from the site collected during different seasons' (**NatMIRC bullet point 8**). This requirement appears to be based on some misconceptions of the effectiveness of simulation modelling in providing unique, 'site specific' predictions on dredge plume and constituents of dredge plume behaviour.

Dredge turbidity plume simulations in commonly applied modelling platforms, (e.g. Delft 3D, DHI's Mike 21) primarily utilise currents, water column density structure and sediment particle sedimentation (sinking) velocity. The latter is an important determinant of plume distributions and is well established theoretically (Stoke's Law) and through direct measurement in, e.g., settling tubes. This to the point that standardised coefficients are employed with the main caveat being whether the particles will behave individually or cohesively. The latter is more characteristic of clay sized sediments and has the net result of accelerating sedimentation for these smaller and lighter particles. Figure 2 summarises settling velocity for a range of fine grained sediments. This figure ignores cohesive behaviour and therefore represents minimal velocities. Currents obviously advect the sinking sediment particles down the current path but also play a role in plume dispersion as dispersion is proportional to current velocity. The higher the velocity the higher the model coefficient for plume dispersion will be. This is also a predetermined relationship and is independent of the site being modelled.

Consequently two of the important determinants of turbidity plume behaviour are treated generically in modelled simulations. It is this and the broad similarity of measured plume behaviour between sites with wide ranges of sediment types and hydrodynamics that allow the extrapolation of modelled and real plume metrics and behaviour to the NMP case. The reliability of the extrapolation is enhanced by the very good investigation conducted by CSIR into dredge plumes from the bulk dredging of sediments for diamond recovery in southern Namibia where the upper water column at least is similar to that of the NMP licence area.

[1] In common usage these are the same group of elements comprising the transition metals, metallic elements such as arsenic and cadmium and lanthanides.

Therefore unless NatMIRC has information that shows that sediment properties in the dredge area are such that vastly different dynamic behaviour will arise or that the upper water column deviates from that described by Boyd and summarised by Shannon I see no value, but quite some cost, in conducting simulation modelling. Note that this also applies to heavy metals as these would be modelled as a conservative tracer, i.e. dilution alone will predict their concentrations, making their behaviour similar to that predicted for the sediment plume.

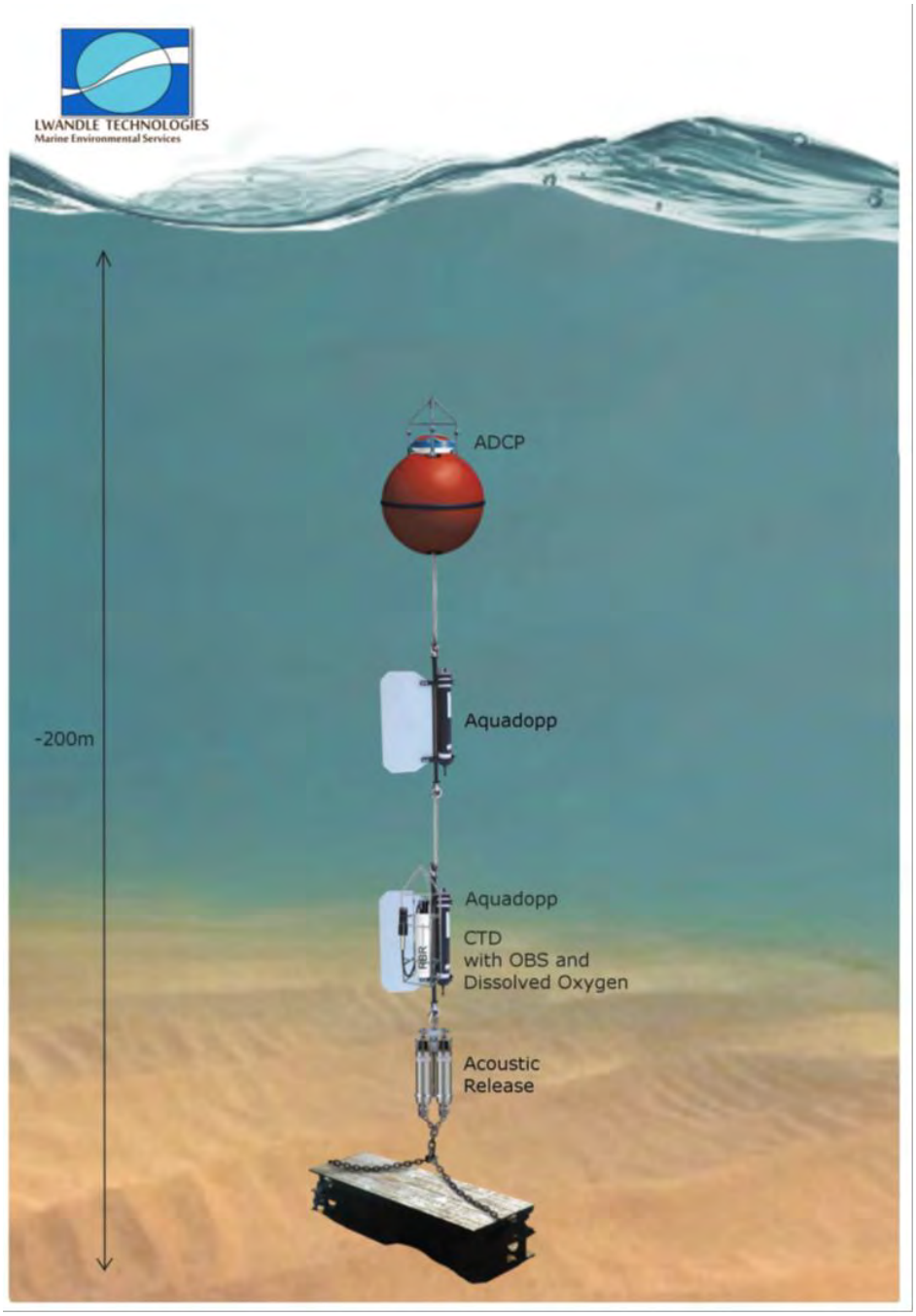


Figure 1: Schematic representation of ADCP, Aquadopp and CTD+DO+turbidity mooring to be deployed as part of the NMP verification survey.

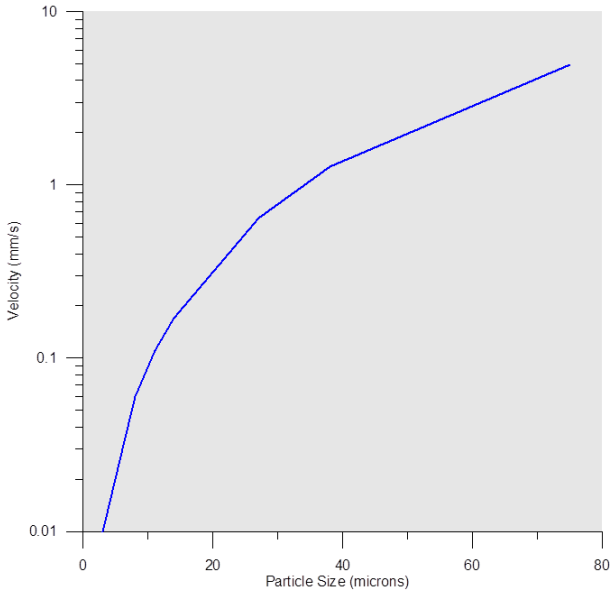


Figure 2: Sedimentation velocity for a range of fine grained sediment particle sizes as predicted by Stoke's Law.

Survey area

The survey area is defined as dredge area SP-1. A grid of sampling sites will be placed across SP-1 such that the broad distributions of sediment properties can be determined. Figure 3 shows the provisional sampling station layout (Black open squares). These are planned to coincide with the benthos sampling sites where possible. The provisional location of the moored instrumentation is shown.

© NMP 2014

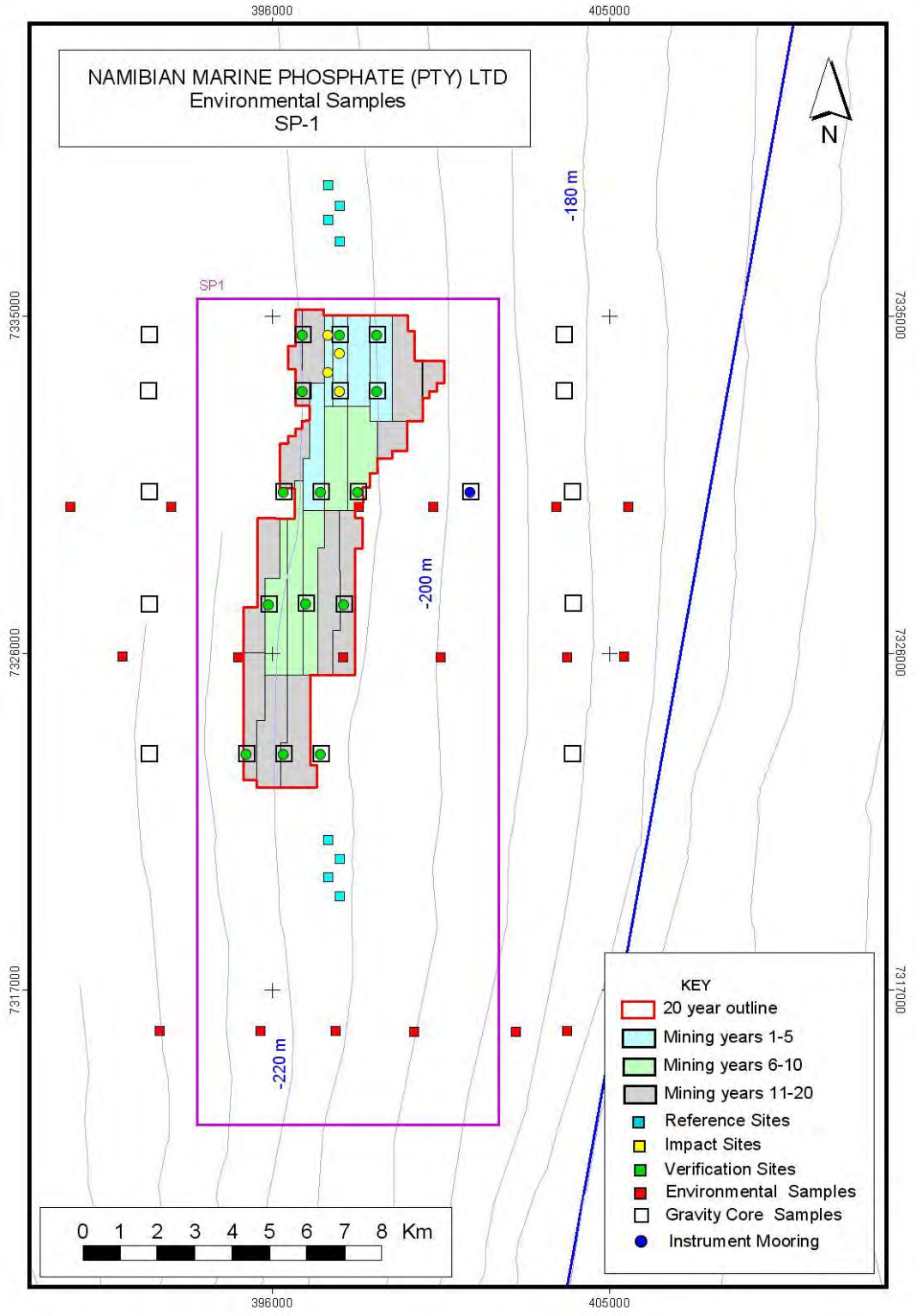


Figure 3: Provisional verification sampling sites in Dredge Area SP-1. Note that the verification survey sites are represented by black open squares. Green squares represent sites identified for benthos sampling (Steffani); additional sampling sites for the benthos monitoring programme are shown in yellow (impact) and blue (reference). The blue square shows the provisional moored instrumentation site.

© NMP 2014

The provisional sampling grids will generate 26 box core samples in SP-1 in a configuration of 5 transects of 5 stations each plus the additional sample at the moored instrumentation site. Samples on the transects will be aligned with the stations identified by Dr Nina Steffani. In a separate survey gravity core samples will be taken from these sites. In addition to the above, sediment samples will be obtained from the benthos verification sites in SP-2 and SP-3 (Steffani) and analysed for particle size, organic C and N content.

CTD profiling (6 Hz) and water sampling will be conducted at one site on each of the transects. One of these will be at the mooring location. Water sample depths will be 0m, 10m, 20m, 50m, 100m, 150m & 200m.

iii) Survey temporal coverage

Moored instrumentation

The planned duration for the moored instrumentation deployment (ADCP, Aquadopp, CTD+DO+Turbidity) is 90 days[2] within which will be a service interval at ~45 days. The 90 day period is predicated on the frequency of lunar barotropic internal tides and associated sediment resuspension events (Monteiro et al 2005). The intention of the mooring is to capture a number of these events (~6) and link concurrent variability in near sea bed oxygen and turbidity levels. The reason for the mid-deployment service interval is that the mooring recovery record for the Namibian continental shelf is not good (similar to South Africa and Mozambique) and the relatively short service interval will ensure that at least 50% of the planned measurements will be obtained. I.e. if the mooring is lost post service the initial measurement period data would have been downloaded at the end of the 1st measurement period, if the mooring is not recovered at the service visit a duplicate set will be deployed giving coverage for the 2nd measurement period.

Water column profiling and sediment sampling

The water, sediment and benthos verification survey will be a once-off event with a duration of 8-10 days at sea. The survey will be conducted in conjunction with the service visit for the moored instrumentation. Seabed coring will be conducted during a separate survey of the dredging areas (date and duration to be determined).

iv) Reporting and deliverables

The following reports will be issued:

- An installation report immediately prior to survey commencement with equipment specifications and calibration and method statements for each of the procedures to be employed
- A mooring deployment report
- A preliminary field survey report listing measurements and sampling with commentary on the water quality, sediment properties and benthos survey
- A mooring recovery and redeployment report

[2] NatMIRC suggest a 12 month deployment period for the ADCP to show seasonal variation. The area is highly variable on a range of space and time scales and to properly constrain seasonal variability would require at least a multi-year deployment programme. This is beyond the scope of the verification measurements.

- A final mooring recovery report, and
- A draft final verification report to be delivered in paper and electronic copies to the Namibian Marine Phosphate (Pty) Ltd within three weeks of the completion of sample processing (physical, chemical and biological). This report will be a fully referenced, scientific document.

5.2.2.3 Mr D Japp: Terms of Reference

Verification Assessment
Fish, Mammals and Seabirds:
Verification of Impacts in the proposed Mining Area ML 170

i) Need for Verification Assessment

The Environmental Impact Assessment (EIA 2012) for the proposed phosphate mining in ML-170 specialist report Appendix 1a on fish resources, fisheries, marine mammals and birds identified five primary impacts *viz.*

1) the likely impact of dredging on commercial fisheries;
2) the likely impact of dredging on the main commercial fish species;
3) the likely impact of dredging on the recruitment of commercially important species;
4) the likely impact of dredging on fish biodiversity and
5) the likely impact of dredging on seabirds and marine mammals.

These impacts and the associated estimates of environmental risk were in part based on marine survey data provided by NatMIRC as well as historical information on fisheries and the Benguela Ecosystem as a whole. The risk assessment has therefore had to use information from surveys etc. in the proximity of the MLA and made assumptions on impacts such as fish recruitment and biodiversity, by extrapolating data from the nearest sampling points from which relevant data were available.

These data have therefore provided a baseline which informed the risk assessment, based on the best available information. The EIA also included a proposal for the verification of the EIA assessment.

Responses to the EIA from NatMIRC were outlined in a letter dated 16 June 2012 and discussed with NatMIRC in a meeting (Facilitated by the Governor of Erongo Province) on 10 September 2012 in Swakopmund. NatMIRC concerns and issues included 13 bullet points. Of these, four (bullets 10, 11, 12 & 13,) related to the component of the EIA relating to Fish resources, mammals and seabirds.

Summarised these concerns were :

1. Turbidity affecting marine predators that use visual cues to forage prey;
2. Spawning activities of fish in the dredging area was relatively unknown;
3. The importance of the proposed dredging area as a nursery ground for juvenile hake;
4. Impacts of the proposed dredging on the ecosystem impacts was uncertain – in particular trophic (feeding) interactions.

ii) Proposed Actions to Address the Identified Issues

In the discussions between NMP and NatMIRC to address the concerns in 1-4 above the following was proposed:

a) A risk assessment be undertaken – this would form a basis on which to inform on the potential risk to the main commercial species if the proposed phosphate mining were to proceed. In particular the risk associated with SP1 and scaled up to include the associated risk if dredging were to expand to SP2, SP3 and or the simultaneous expansion of dredging in other mining lease areas across the Namibian shelf.
b) The outputs of the proposed risk assessment model can then be compared to the risk levels identified in the NPM EIA;
c) Undertake a structured survey of the proposed dredging area – in particular focus on the area proposed to be dredging in the first phase (SP1). This survey will aim to verify the current assumed baseline for biodiversity, fish abundance (density), recruitment (size distribution) and other biological aspects (diet of main commercial species for trophic studies, spawning state of main commercial species etc).
d) These data would then be used to:

    i) verify the assumed baseline historical data used in the EIA;
    ii) provide additional inputs and supporting information for the risk assessment model;
    iii) provide inputs into the current trophic modeling initiatives for the Benguela and the risks to the ecosystem associated with the likely mining impacts.

The proposal to address the issues is therefore a step-wise approach that first assesses the likely risk based on a modeling approach, then verification of the baseline EIA assumptions using in-situ survey data and also further inputs into the risk model derived from the survey as well as providing baseline data for inputs in trophic models currently applied to the broader Benguela ecosystem.

iii) Terms of reference for proposed activities

1) Risk Assessment

It is proposed that appropriate modeling skills be sourced to undertake a mathematical risk assessment. To do this the following is needed (although the modeler may have alternative or additional requirements). Note also that typically these risk assessments are well-established procedures in fisheries stock assessments and include forward projections for set periods e.g. 20 years.

Key Inputs to the risk assessment:

i) Use the current models used to assess the key fish stocks in Namibia – hake, monk, horse mackerel and small pelagic;
ii) These models are based on many sets of criteria, reference sets / data, indices etc. Outputs for the annual setting of TACs assess risk to determine the effects of different levels of TACs, variability in indices and numerous other parameters that have elements of uncertainty associated with them (General Linear Modeling is a common statistical methodology used);
iii) The proposal therefore aims to incorporate the additional risk to the main commercial resources that may or may not be impacted by the introduction of phosphate mining. Key elements could include (the modelers can inform on this) the following:

    a. Biomass estimates (fish density) and the exclusion of dredging areas from the overall abundance of key commercial stocks. This can include for example only SP1 and also a

© NMP 2014

scaling effect around the dredged area(s) and also any potential expansion of dredging from other concession holders (it may also require alternative stratification methods);

b. The potential impact / loss of recruitment to the known key fisheries stocks, in particular hake, monk, sardine and horse mackerel (scaling effects also applied).
c. Possibly the potential loss of spawn for key species if it can be shown conclusively that spawning occurs in the mined area(s);
d. Potential displacement of stock – i.e. fish moving out of the mined areas due to disturbance.
e. Input additional information that may inform the model after the monitoring and verification surveys.

The outputs from the model could then inform on any changes or additional risk to the stocks associated with mining and consolidated with the cumulative impacts that may be associated with other impacts (fishing, dredging /mining etc).

2) In-Situ Survey(s)

The proposal is to conduct a survey within and surrounding the proposed dredging site. It is critical that this survey is compatible and data are consistent with the current survey methods used for the fish stock assessments. This will most likely require that the proposed survey be integrated with the current fishery surveys – this will ensure compatibility of data, reduce overall costs and ensure adequate expertise is available on the survey.

Typically the survey design will incorporate:

a) Fisheries swept area surveys (demersal);
b) Fisheries Acoustic survey (integrated with swept area surveys); and
c) Marine mammal, seabird and other marine fauna observations.

iv) Survey Design

A simple transect design using swept areas, and if considered necessary, simultaneously the collection of acoustic data, is proposed. Schematically the survey design with sampling stations is shown in Figure 1. *Note* : This is not intended to be prescriptive and will need refinement and discussion with marine scientists at NatMIRC.

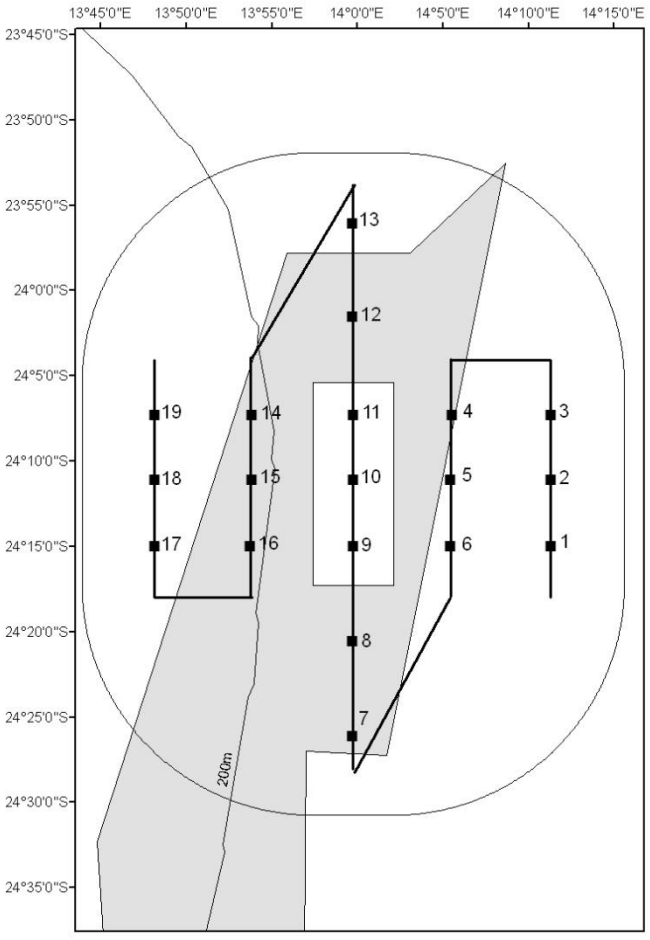


Figure 1 Location of survey stations in SP –1

Key elements of the survey are :

a) Trawls are undertaken north to south following the bathymetry;
b) Typically trawls will be for 20-30 minutes each (max. 1.5 nm);
c) Stations to be positioned within the area to be dredged (SP-1 initially) and thereafter at suitable intervals in a perimeter around the dredge area;
d) Standardisation of trawl gear (similar to that used in biomass surveys);
e) It is essential that stations cover the dredge area prior to any dredging that may take place as well as stations within the MLA and then some distance (to be agreed) outside the MLA and within the 25 km zone used in the fisheries EIA report (Appendix 1a). A total of no more than 20 stations are proposed taking approximately 3-6 days of survey time.
f) Acoustics can also be run along transects and between lines (primarily to determine small pelagic targets) – this is not a high priority but the need can be determined in discussion with the Namibian marine scientists.

v) Expected Outputs

I. A comparative relative abundance estimate of the main commercial species in the dredged area and adjacent grounds (biomass). This can potentially show any changes in relative abundance due to dredging (such as species displacement to areas adjacent to the dredged area);
II. Verification of relative species abundance in the area with the on-going and historical abundance estimates of the main commercial species;
III. Species counts and classification of all flora and fauna (including fish and mega fauna) captured in the trawls. This can be compared with stations from adjacent historical surveys;
IV. Provision for a marine mammal and seabird specialists or suitable marine observers to record mammals, seabirds, turtles and other interactions while in the survey area;
V. Length frequency measurements of the main species and sex ratios;
VI. Basic biological data collection on main commercial species including gonad staging for comparative spawning and recruitment indices;
VII. Use of digital photography to record species;
VIII. Deployment of CTDs (if an appropriate vessel is used) to determine essential water conditions (conductivity, temperature, depth).

vi) Time Frames

A survey prior to the commencement of dredging should be undertaken. Preferably this should be coordinated with other swept area surveys in the area (most likely monk or hake surveys) using the same vessel. The survey can be repeated annually (for the first 5 years as reviewed) at the same time for the duration of the dredging activity. Transects can subsequently be included in the other proposed dredging areas (SP-2 and SP-3), but due to the initiation of the project in SP-1, it is recommended that priority should be given to a focused survey around this target area.

vii) Conclusions

Correctly designed and undertaken with professional staff and a suitable sampling platform, the survey can provide a baseline from which the changes in fish availability, abundance, recruitment, biodiversity (as best can be determined from swept area trawls), marine mammals, seabirds and other flora and fauna can be estimated.

© NMP 2014

This baseline is a “snapshot” that can be compared with historical data in the proximity of the MLA. Changes of the many parameters measured can be tracked over the lifetime of the exploitation and can be used to determine the effects (environmental impacts) of the proposed project over time. The data would be subjected to scientific and statistical scrutiny for accurate interpretation.

© NMP 2014

viii) Adjustment

Verification Assessment

Adjustment Programme

for

Fish, Mammals and Seabirds

Verification of Impacts in the proposed Mining Area ML 170

CAPRICORN FISHERIES MONITORING
Reg. No. CK 99 / 24441 / 23
Unit 15 Foregate Square, Table Bay Boulevard, Cape Town, South Africa, 8002
P.O. Box 50035, Waterfront, Cape Town 8001
Tel/Fax : (021) 425 2161 Fax: 425 1994 Cell: 082 – 788 6737

25 February 2014

Namibia Marine Phosphate (Pty) Ltd
127 Theo-Ben Gurirab Str,
WALVIS BAY, Namibia

Attention : Mr M Woodbourn

Re: Verification of Fisheries Data used in the NMP Impact Assessment

Dear Mr M Woodbourn

We refer to the verification survey of the proposed phosphate mining area. In particular we submit herewith our suggested actions to address the fisheries issues raised by NatMIRC and the peer reviewers of the EIA.

The information used by the fisheries impact assessment team was primarily data provided from numerous surveys undertaken by NatMIRC (MFMR). The concerns raised by MFMR and the reviewing parties primarily relate to these data mostly not specifically coinciding with the proposed mining area.

We wish to stress however, that the survey data provided by NatMIRC (MFMR) is based on globally accepted practice when surveying fish stocks. The method employed either uses randomised trawls or fixed transects. The data provided by NatMIRC (MFMR) were a mixture of both.

A key point is that these surveys undertaken by NatMIRC (MFMR) are standardised and apply internationally -recognised sampling practice. Because of the extent of the ocean and the nature of the grounds on which commercial fish stocks are found, surveys sample a very small part of these areas and rely on extrapolations to estimate biomass and other parameters used in fisheries.

Namibian Marine Phosphate (NMP) in their quest to find suitable vessels such that the verification process would be as close as possible to the methodology used by the Namibian and other international research scientists (e.g. Nansen programme) requested that the vessels used by the ministry (MFMR) be utilised for the purposes of verifying the information used in the fisheries component of the EIA. Regrettably it has proven impossible for numerous reasons to get access to these vessels, in particular the *FV Welwitchia* which has historically been used to assess the monk stocks. A further complication was that for the biomass estimates to be compatible using an alternate vessel e.g. an industry trawler, it would require a costly and time-consuming calibration exercise at sea, involving the unavailable *FV Welwitchia*.

Given these difficulties, and the willingness of NMP to explore all options the following approach to the verification process has been adopted.

1. Employ an independent fisheries quantitative scientist (Dr James Gaylard) to assess the likely biomass of the main commercial fisheries stocks that may be impacted by dredging. This involved using the NatMIRC historical biomass estimates and extrapolating these estimates to the actual area to be mined i.e. SP-1, and licence area of the NMP Sandpiper deposit.

2. Employing a professional consultant (in this case a Namibian fisheries scientists Dr Hillka Ndjaula) to assess the likely recruitment impact on the main commercial fish species (using data acquired from the NatMIRC scientists)

The results from both these studies are pending and will be submitted in due course for review.

© NMP 2014

The key results from these studies show that the area to be mined is proportionately extremely small (compared to the total area of the main commercial fish species) and that no significantly (in the context of the EIA) useful information would be obtained by undertaking a biomass-directed survey that would have been standardised to the historical biomass surveys conducted in Namibia. This conclusion applied equally to the biomass estimates of spawner biomass and recruitment. The study did show that there is a significant difference between monk and hake, where monk is in greater numbers and biomass than hake in the MLA. Nevertheless the estimates of biomass of these two key groundfish species in the twenty year mine target area of SP-1 is miniscule.

The work undertaken by Dr. H. Ndajula is still in process but suggests that the proposed mined area has no unique spawning processes, or at least no spawning indicators that suggest it is different from any other areas in Namibian waters.

Given all of the above we have concluded that undertaking of a calibrated, standardised survey of the MLA focused on the SP-1 area will produce no significantly useful additional quantitative information on the biomass of monk and hake. Consequently we advise NMP to adopt a different strategy, one that we envisage would be supported by NatMIRC / MFMR.

The recommendation: NMP are to charter a dedicated monk (commercial) vessel and undertake a structured sampling survey using standard monk trawl gear. Although this will not provide directly comparable biomass estimates it will allow for the following to be done by a group of professional scientist in a rigorous manner:

1. Quantify all fish species caught in and around SP-1 and the immediate area of the MLA. This would include weighing and measuring, of key species;
2. Quantifying all species captured, estimating their relative proportions in the catch and undertaking biological analysis of key species (similar to that done by NatMIRC on their surveys);
3. Recording all species captured – this will provide a baseline comparison of biodiversity with the historical surveys;
4. Recording at the same time the nature of the substrate and bottom profile;
5. Measuring common environmental parameters – salinity, oxygen, temperature, water depth, water clarity (CTD) etc
6. Recording the occurrence of surface species such as large pelagics, marine mammals and birds.

The survey is designed to quantify the biodiversity of the area and compare this with the known information of the region, i.e. a biodiversity verification assessment.

The survey will also obtain full commercial data on target catch (monk), hake and the other bycatch species. This will allow for a crude biomass estimate on spawner biomass and recruitment that can then form a baseline for future surveys in the area.

From this point, it is necessary that:

- A suitable commercial vessel is obtained from which to conduct the biodiversity assessment;
- That NatMIRC / MFMR acknowledged the scientific reasoning and approach as adopted; and
- That NatMIRC / MFMR provide the necessary approvals, if they have not already done so.

We trust that this meets with your approval, and we look forward to working on this project with you.

Yours sincerely



Dave Japp
CapFish cc

Capricorn Fisheries Monitoring (CapFish)
Members: D. Japp - C. Heinecken – J. Wissema
Providing : Marine Monitoring Services - Marine Observers – Fisheries & Aquaculture

5.2.2.4 Dr N Steffani: Terms of Reference

Verification Assessment
Benthos

i) Need for Verification Assessment

Namibian Marine Phosphate (Pty) Ltd (NMP) has been awarded a 20-year mining licence (ML170), which is located on the Namibian continental shelf offshore Conception Bay in water depths ranging from 180 to 300 m covering a total area of 2233 km^2. Within the mineralized resource zones of the licence area, also named Sandpiper licence area, three target areas have been identified, i.e. Sandpiper-1 (SP-1), 2 (SP-2), and 3 (SP-3). SP-1 is in the north of ML170 in water depth from 190-235 m, SP-2 is in the centre in depth 245-285 m and SP-3 is in the south at 235-270 m depth.

With the exception of a benthic macrofauna and sediment property survey derived from 20 stations in SP-1, information on the physical and biological environment specific to the ML170 is very sparse. Most of the impact assessments discussed in the Benthic Specialist Study are thus based on assumptions that are arrived from publicly available data from areas outside the Sandpiper licence area. The assumptions drawn from these data are deemed robust, but nonetheless it is recommended that an initial 'verification' survey to confirm these. An important aspect of this verification survey is the sampling of the macrofauna communities in all three dredging target areas. Continuing from this initial verification survey, the severity of the removal and destruction of benthic communities by the dredging process and the subsequent recovery (functional recovery) process need to be ascertained. A post-dredging benthic monitoring programme thus needs to be established.

ii) Benthic Habitat

Dredging for offshore marine phosphate deposits is destructive by nature and thus inevitably affects the benthic communities of the receiving environment. The sea bed disturbed by the dredging activity is home to many communities, living on (epifauna) or in (infauna) the superficial sediments of the sea floor, with the greatest abundance to a depth of ~20 cm. The fauna is typically divided by size into megafauna (>10 cm), macrofauna (large enough to be retained on a 1-mm sieve, while some researchers also use a 500-micron sieve), meiofauna (0.1-1 mm) and microfauna (<0.1 mm). The macrofauna usually constitute the dominant biomass or organisms within marine sediments and typical taxa include polychaete annelids, smaller crustaceans (e.g. amphipods, isopods, shrimps, crabs), and molluscs (gastropods and bivalves) besides many other phyla. Megafauna include large crustaceans, molluscs, and echinoderms, and are often associated with the surface of the sea floor. The meiofauna is dominated by the large and diverse groups of nematodes and harpacticoid copepods, while microfauna include bacteria and protists. Macrofauna and other benthic fauna are a major food source for fish and other benthic predators, and play important roles in ecosystem processes such as nutrient cycling, pollutant metabolism, and dispersion and burial of organic matter.

The northern and central Benguela regions are characterised by the occurrence of natural shelf hypoxia, which is referred to as Oxygen Minimum Zone (OMZ) (Monteiro *et al.* 2011). OMZs have dissolved oxygen concentrations of ≤0.5ml/ℓ and typically impinge upon the continental margins of upwelling regions. Off Namibia, this layer extends between at least 18°S and 28°S and up to 60 km from the shore. The hypoxic conditions depict seasonal variation, locally shifting to anoxic conditions in late

© NMP 2014

summer-autumn (Monteiro *et al.* 2008). A further significant feature of the central Namibian middle shelf is an extensive mud belt comprising organically rich diatomaceous oozes originating from planktonic detritus from the high productivity in the upwelled waters. The diatomaceous mud belt with a thickness of up to 14 m extends over 700 km in an N-S direction and 100 km in an E-W direction. Depending on the local bathymetry and dynamic current intensity, the landward flank of the mud belt is found at 15-104 m water depth, and the seaward flank from 45-151 m (Bremner 1983). The mud belt is characterised by often anoxic bottom water conditions and high H_2S fluxes, occasionally resulting in H_2S eruptions with devastating effects on the local fauna. These natural events can spread over 20 000 km^2 (Weeks *et al.* 2004).

The Sandpiper Mining Licence Area lies offshore from the mud belt at the fringe of the central Namibian OMZ and is thus affected by variable dissolved oxygen conditions with bottom-water oxygen concentrations probably below 0.5 ml/ℓ, but it is likely to be less affected by high H_2S concentrations in the surficial sediments or near-bottom waters, or severe anoxic conditions. Despite oxygen depletion, benthic assemblages can thrive in OMZs as many organisms have developed highly efficient ways to extract oxygen from oxygen-depleted water (e.g. small bodies, enhanced respiratory surface area, blood pigments, and specialised enzymes) (Levin 2003). Within OMZs, foraminiferans, meiofauna, and macrofauna typically exhibit high dominance and relatively low species richness (Levin 2003). In contrast to meiofauna, macrofauna and megafauna often have depressed densities and low diversity in the cores of OMZs, where the oxygen concentration is lowest, but they can form dense aggregations at the OMZ edges (Levin 2003, Levin *et al.* 2009).

Very little is known about the Namibian OMZ benthic infauna (see Arntz *et al.* 2006, Zettler *et al.* 2009). In May 2010, a macrofauna baseline survey was conducted by NMP in SP-1 as this is the initial priority area for proposed dredging operations (Steffani 2010a). Overall species richness of the benthic macrofauna assemblages was relatively low and strongly dominated by polychaetes (64% of species), followed by crustaceans, and molluscs. Most species found in the study area have a larger geographical distribution and/or have been recorded elsewhere from the Namibian and/or South African west coast (e.g. Savage *et al.* 2001, Steffani 2007, 2009, 2010b, Steffani & Pulfrich 2004, 2007, Zettler *et al.* 2009). The most abundant species was the polychaete *Paraprionospio pinnata* (44% of overall abundance), which is a low-oxygen indicator species prevalent in OMZs worldwide. Generally, the benthic community composition in terms of species diversity and phyla dominance is in agreement with studies from other OMZs around the world (e.g. Gutierrez *et al.* 2000, Levin *et al.* 2000, Gallardo *et al.* 2004, Gooday *et al.* 2009, Levin *et al.* 2009).

In contrast to the core of OMZs where macrofauna density is often reduced, macrofauna has been found to increase at the edges of OMZs dominating the benthic fauna (e.g. Mullins *et al.* 1985, Gooday *et al.* 2009, Levin *et al.* 2009). Levin *et al.* (2009), for example, reported dramatic changes in macrofaunal dominance from the core of the OMZ at the Pakistan margin to the lower boundary and documented the existence of dissolved oxygen thresholds for macrofauna between 0.1 and 0.2 ml/ℓ. Below such thresholds, most taxa are excluded through physiological intolerance to hypoxia, while above them selected taxa are able to take advantage of an abundant food supply. The availability of both oxygen and organic carbon seem to determine the richness of macrofaunal species in OMZs until the oxygen content rises to about 0.45 ml/ℓ; above that level oxygen is much less important (Levin & Gage 1998). It has been further hypothesized that under conditions of permanent hypoxia, small-bodied animals, with greater surface area for O_2 adsorption, should be more prevalent than large-bodied taxa (Levin 2003). However, body sizes were found not to be smaller within the lower OMZs of the Oman (Levin *et al.* 2000) and Pakistan margins (Levin *et al.* 2009), and it was suggested that the

abundant food supply in the lower or edge OMZs promotes larger macrofaunal body size. Zettler and co-workers (2009), who studied the macrofauna community in the OMZ off northern Namibia (offshore the Kunene River mouth, which is at the northern fringe of the OMZ), reported a far lower species diversity in the hypoxic zone than compared to oxygenated nearshore areas, but the high dominance of molluscs (not typically found in core OMZs) led them to suggest that the community is probably rather representative of the fringes of the upwelling cells of the northern Benguela than of the centre where severe anoxia and high hydrogen sulphide concentrations occur. Molluscs also contributed a relatively significant proportion to the fauna in the SP-1 target area and as the Sandpiper licence area is situated at the southern fringe of the OMZ, a similar scenario is likely to apply, suggesting that the macrofauna is playing a significant role in the benthos of the target areas. Similarly, in an early study by Sanders (1968) of the benthos in the Namibian OMZ, a reduction in macrofauna species diversity has been observed in the core, whereas higher abundances and biomasses have been recorded from the edge of the OMZ.

iii) Objectives and Key Questions

As part of their Environmental Management Programme for the Sandpiper licence area, NMP has committed to undertaking a benthic macrofauna verification survey to collect information on general macrofauna distribution patterns in the three target areas. This will also aid in verifying some of the assumptions on which the assessment of impacts was based. This initial survey will be followed by a macrofauna monitoring programme, whose principal objective is to study the rate of recovery of disturbed macrofaunal communities once the dredging activity has ceased in a particular dredge block. Recovery has been shown to be both spatially and temporally variable, and to confidently measure the ecological recovery rate of mined areas, it is therefore necessary to develop a benthic monitoring plan that is not only appropriate in the medium-term (~5 years), but has the flexibility and potential to be extended into the long-term.

The key objectives for the *verification survey* are:

- Establish a data set on general macrofauna distribution patterns in all three target areas;
- Relate the distribution patterns to environmental factors such as water depth, sediment texture, near-bottom oxygen concentrations, organic carbon content, and H_2S concentrations; and
- Investigate the relative importance of the smaller macrofauna size fractions.

The key questions for the *monitoring programme* are the following:

- What is the rate of recovery of the physical environment e.g. in-filling of mined-out areas with unconsolidated sediments?
- What is the process of the recovery of the benthic macrofauna?
- How long after the disturbance does it take for the benthic community to recover to at least an ecologically functional community?
- How does the physical environment (e.g. sediment particle size, organic matter, dissolved oxygen) influence the recovery rate?

iv) Survey Method and Design

General Sampling Design

Sampling for macrofauna will involve the use of a Day grab or box corer. Both sampling tools are capable of retrieving a sediment sample with an undisturbed surface. The Day grab has the advantage that it can be handled from a smaller surveying vessel. Once retrieved, macrofauna samples will be

taken from the larger grab with subcorers with an inside diameter of 9.6 cm x 30 cm length (72.4 cm^2). It is proposed to take one to two subcorers per grab. The sample volume collected with this method is in agreement with other studies conducted in OMZs (e.g. Gallardo *et al.* 2004, Gooday *et al.* 2009, Levin *et al.* 2000, but see Zettler *et al.* 2009). From the same grab, sediment particle size and total organic carbon (TOC) will be determined. In addition, near-bottom dissolved oxygen concentrations will be measured with a CTD and H_2S concentrations in the pore water analysed for a selected number of grabs, and in addition in a number of gravity cores down to depth. These measurements are described in the proposal for the sediment properties verification survey (Lwandle 2012). The measurement of the H_2S concentrations will shed light on the possibility of the presence of substantial amounts of thio-bacteria in the sediments (**NatMIRC bullet point 5**).

The original macrofauna baseline survey in SP-1 used a 1-mm sieve to separate the macrofauna from the sediment as this is the traditional standard mesh size used in macrofauna surveys (Rumohr 2009). Studies on macrofaunal abundance in OMZs, however, often use smaller sieve sizes in anticipation that many macrofauna species will be generally smaller (e.g. Gallardo *et al.* 2004, Gooday *et al.* 2009, Levin *et al.* 2009). Sieve sizes used in OMZ studies vary between 0.3 mm (e.g. Gallardo *et al.* 2004, Gooday *et al.* 2009, Levin *et al.* 2000, 2009), 0.5 mm (e.g. Sahling *et al.* 2002, Gutiérrez *et al.* 2000, Palma *et al.* 2005), and 1 mm (e.g. Rosenberg *et al.* 1983, Zettler *et al.* 2009, see also Levin & Gage 1997 for references on studies using sieve sizes ranging from 0.3 to 1.0 mm). For example, the only recently published study on the Namibian OMZ macrofauna (northern Namibia), has used a 0.1m^2 van Veen grab and a sieve size of 1 mm (Zettler *et al.* 2009), similar to the Sandpiper benthic baseline study. To determine the relative importance of the various size fractions, it is proposed to sieve the samples on-board through a 0.3-mm sieve. In the laboratory sorting procedure, the 0.3 - 0.5 mm, 0.5 - <1 mm, and the >1 mm size fractions will be separated for a number of samples with a nested sieve design and analysed separately to indicate the right mesh size for the long-term monitoring study and also permit comparison to the baseline study. (**NatMIRC bullet points 6**). Sieving of the samples will be conducted with an automated Wilson autosiever that gently keeps the material in the sieve in motion by flotation with water from below instead of spraying with water from above. This will reduce damage to fragile organisms. As found during the benthic baseline survey and substantiated by the extensive geological mapping by NMP, it can be expected that the surficial sediment layers (top >30 cm) will contain significant amounts of large broken shell pieces. This not only will drastically increase the amount of material retained on the 0.3 mm screen and thus the sieving time, but may also damage the organisms. It is thus proposed to use a 3 mm or 5 mm screen to separate this shelly layer from the actual macrofauna sample. Careful visual inspection of the material retained on the larger screen will ensure that any larger organisms retained are transferred to the macrofauna sample. The sieved sample will be stored in 10% buffered formalin.

In the laboratory, macrofauna samples will be re-sieved through a 0.3-mm sieve and sorted under a stereo binocular microscope at 10-25 x magnification. If needed, the sample may be stained with Rose Bengal to aid in the sorting. Specimens will be identified to the lowest taxon possible and counted. Wet biomass will be estimated by blot-drying the specimens on absorbent tissue for a standard period of time and weights recorded per species per sample using an analytical balance. Taxa retained on the 0.3 mm screen that traditionally are considered to be meiofauna (e.g. nematodes, copepods, ostracods and foraminifera) will not be included in counts, biomass measurements or subsequent analyses. This is in line with other studies on OMZ macrofauna (e.g. Levin *et al.* 2000, Gallardo *et al.* 2004). At first, a minimum of ten samples will be sorted with a nested sieve design separating the three size fractions. After analysis of the absence/presence and relative importance of macrofauna in the various fractions, a final sieve size will be determined.

© NMP 2014

v) Sampling Layout

For the verification survey, an increased spatial coverage has been opted for at the expense of replication per site. This will provide a better resolution of macrofaunal distribution patterns across the three target areas. Small scale patchiness, however, cannot be investigated with this design but increased replication per site in the monitoring survey will provide data on small-scale variability (see Monitoring Programme below). Sampling stations will be spread across the target areas in a grid pattern with increased spatial coverage in the mine blocks proposed for dredging within SP-1 and SP-2. Proposed numbers of sample stations are 16 in SP-1 (plus 4 monitoring sites, see below), 18 in SP-2, and 12 in the smaller SP-3; this amounts to a total of 46 samples (plus the four impact and four reference sites for the monitoring survey, see below). Figures 1 (a - c) illustrate the proposed layouts of the sampling stations in the three target areas SP-1, SP-2, and SP-3.

vi) Monitoring Programme

Continuing from the initial assessment survey, the severity of the removal and destruction of benthic communities by the dredging process and the subsequent recovery (functional recovery) process need to be ascertained. A post-dredging benthic monitoring programme thus needs to be established.

Worldwide, the study of benthic assemblages has been used to investigate the impacts on the seafloor of human activities. There is continuous debate whether such monitoring programmes should focus on macrofauna or meiofauna, or on both (e.g. Somerfield *et al.* 1995, Coull & Chandler 1998, Kennedy & Jacoby 1999, Schratzberger *et al.* 2001). Typically macrofauna is the preferred option as sample collection and species identification is comparatively easier (Kennedy & Jacoby 1999). Macrobenthos is commonly used as biological indicator because as a group they are relatively sedentary and reflect the quality of their immediate environment, many benthic species have relatively long life spans and their responses integrate water and sediment quality changes over time, and they include diverse species with a variety of life history characteristics and tolerances to stress and can usually be classified into different functional groups. Examples of the use of macrofaunal monitoring surveys include studies on the effects of oil pollution (e.g. Dauvin *et al.* 2003), organic enrichment (Pearson & Rosenberg 1978, Macleod *et al.* 2004), offshore drilling operations (Daan *et al.* 1995, 1996), submarine tailings disposal (Ellis 1982, Burd 2002), and particularly of marine aggregate dredging operations (e.g. Newell *et al.* 1998, Herrmann *et al.* 1999, Newell *et al.* 2004).

In low-oxygen environments such as OMZs, body size seems to be very important as small organisms are best able to cover their metabolic demands in the OMZ, and besides adaptation to low oxygen often have a capability to conduct anaerobic metabolism. Meiofauna may thus increase in dominance in relation to macro- and megafauna (Levin 2003). However, the Sandpiper licence area and specifically the target areas are at the edge of the OMZ, and several studies have shown that macrofauna has been found to increase at the edges of OMZ dominating the benthic fauna (see above). The difficulty in conducting meiofauna monitoring surveys in comparison to macrofauna studies thus favours the use of macrofauna for long-term studies, and the extensive use of macrofauna surveys for a wide variety of anthropogenic disturbances suggests that data on macrofauna composition and abundance should be able to shed light on it. Macrofauna is also routinely and often solely collected in studies on OMZ benthos (e.g. Levin & Gage 1998, Levin *et al.* 2000, 2009, Ueda *et al.* 2000, Gallardo *et al.* 2004, Arntz *et al.* 2006, Gooday *et al.* 2009, Zettler *et al.* 2009).

© NMP 2014

In identifying and assessing the impacts of phosphate dredging on the macrobenthic communities, it is important to recognize that the marine environment can be very variable both in space and time. An impact should not therefore be characterized as being the difference in some measure at a particular site before and after a disturbance, but should be distinguished as being the relative difference between changes at a disturbed/impact site compared with changes that have occurred in a similar undisturbed reference site (Underwood 1992, 1993, 1994). In other words there must be some change from before to after a disturbance and such change must be significantly different from what occurred in undisturbed reference areas. Community parameters, however, vary both spatially as well as with time, fluctuating in response to natural variations in the environment (these may be monthly, seasonal or annual variations). Without adequate indices of natural variability, it will be inherently difficult to place dredging-related impacts in context. It is therefore important to have a number of impact sites in association with a number of reference sites that are in a similar environment (e.g. depth and sediment texture) but will remain undisturbed over the period of the monitoring programme. Here it is important to note that it would be prudent to select sites that will also not be affected by other anthropogenic activities such as trawling. If possible, the sites should either be located in areas not utilised by the trawling industry or trawling should be excluded from the immediate area for the duration of the monitoring programme. This is important as effects of trawling may have traditionally affected parts of the mining licence area beyond the 200-m isobath but since trawling will not occur in the target areas once phosphate dredging operations commence (due to safety issues), this impact should also be avoided for the reference sites. The envisaged position of the reference sites are, however, such that conflict is expected to be low as trawling usually occurs in deeper waters.

The proposed position of the sampling stations is illustrated in Figure 1(a - c). For operations in SP-1, four impact stations and four associated reference sites are proposed. At each site, five replicate samples will be taken. Included in the sampling procedure should be at least the sampling for sediment properties (i.e. grain size analysis) as well as near-bottom dissolved oxygen concentrations and organic matter content. Sites have been selected according to the currently proposed mine schedule to fall into the mine blocks that will be mined in Year 1 and Year 2 of the schedule. This ensures that any information on recovery processes can be collected as early as possible to inform the Environmental Management Programme. Prior to operations being initiated in SP-2, a second monitoring programme needs to be established and similarly for activities in SP-3.

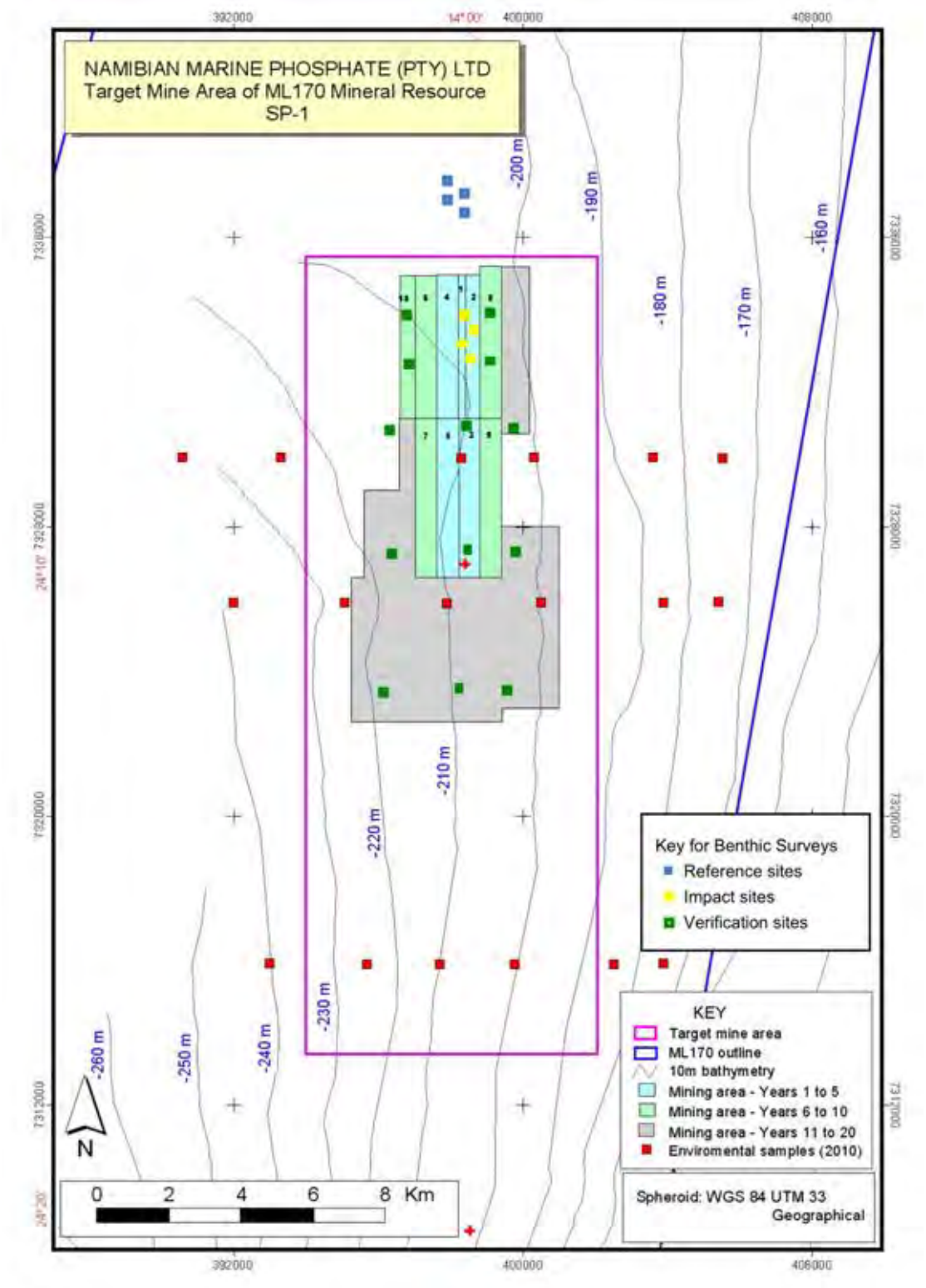


Figure 1 (a): Layout of macrofauna sampling stations for the verification and monitoring survey in SP-1.

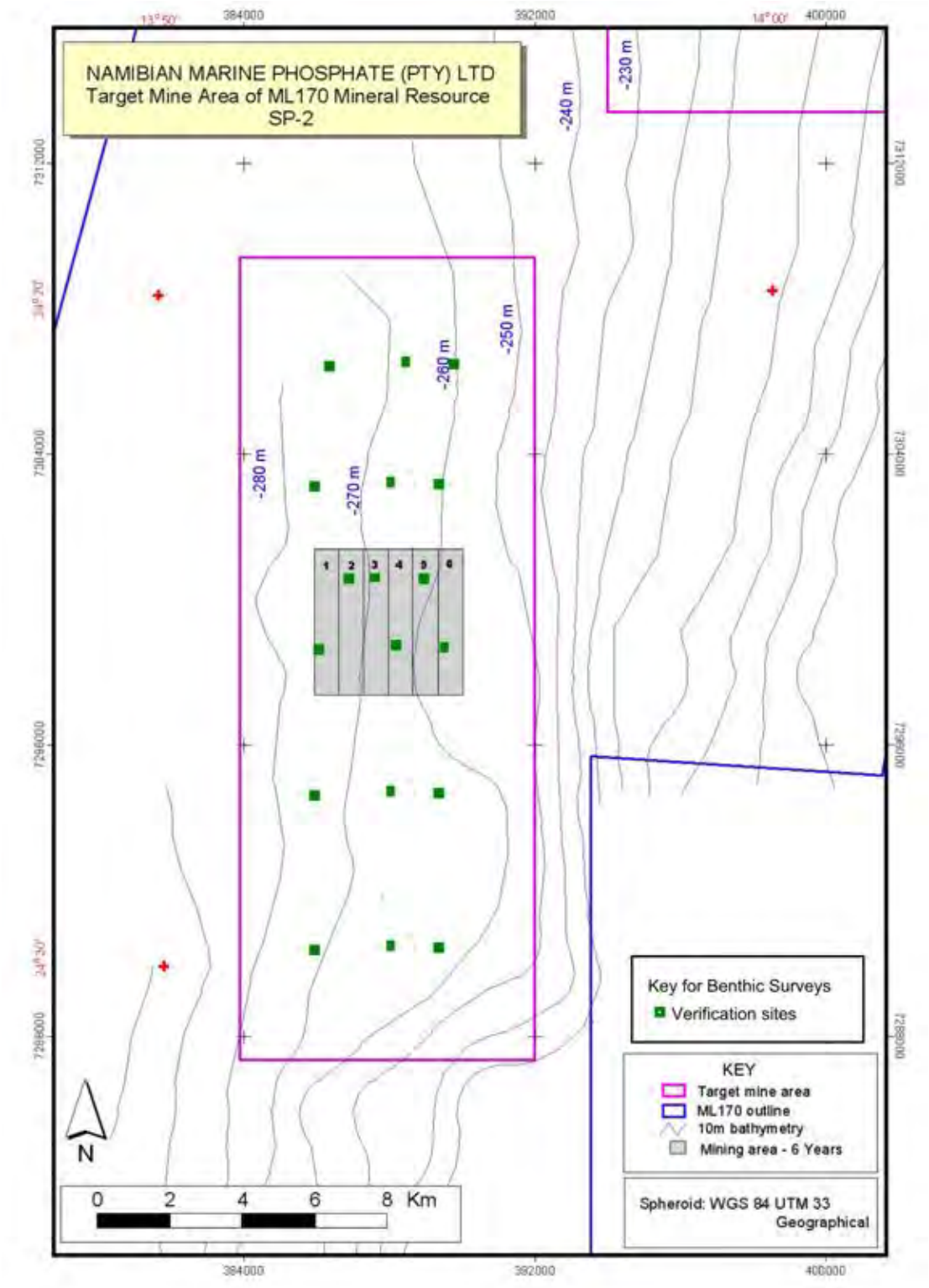


Figure 1 (b): Layout of macrofauna sampling stations for the verification survey in SP-2.

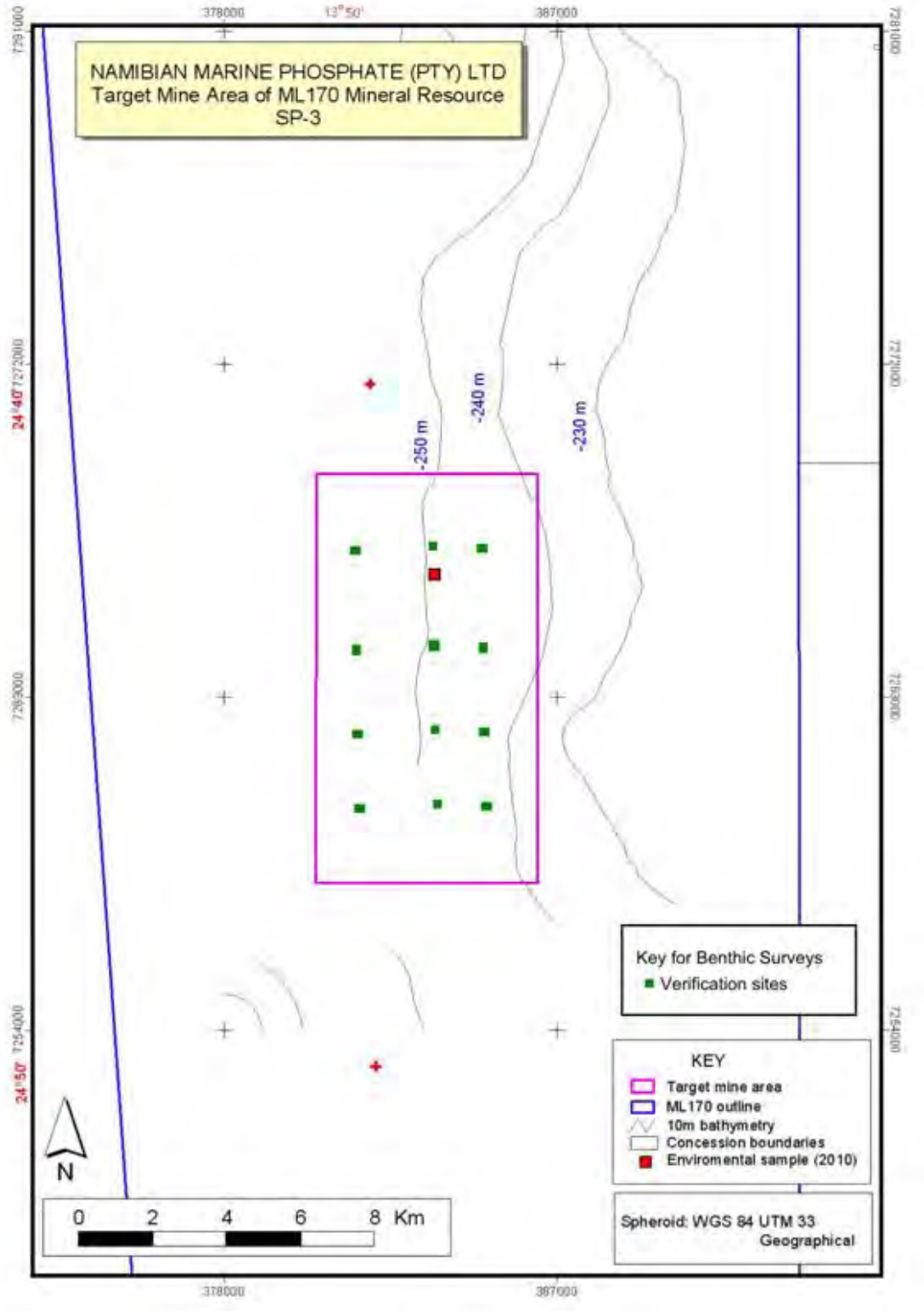


Figure 1 (c): Layout of macrofauna sampling stations for the verification survey in SP-3.

Sampling in SP-1 should be undertaken both before the start of operations, as well as at regular intervals after completion of dredging to determine the (functional) recovery rates of the benthic communities. One of the basic assumptions of developing a benthic monitoring programme is that recovery of disturbed macrofaunal communities does in fact occur. The process and rate of recovery is, however, strongly dependent on the rate of the in-filling of sediment in the mined-out areas, and the type of sediment. A wide range of recorded recovery rates highlight the inherent difficulties in the application of general impact/recovery predictions to sites with varying environmental characteristics (Robinson *et al.* 2005). From existing information on the natural rehabilitation of mined-out areas in the deep-water diamond mining licence area in southern Namibia, it is known that despite the reduced wave and current action at the depths at which mining is currently being conducted (100-150 m), significant smoothing and in-filling of mined areas is visible in sidescan sonar surveys 1 - 2 years after mining (Penney & Pulfrich 2004). However, such information cannot be simply extrapolated to the central Namibian shelf, where the sedimentation and near-bottom current regime is likely to be very different. It is recommended that high resolution geophysical surveys (e.g. side scan sonar) are conducted immediately after dredging, and 2-3 years post-dredging (and potentially at later years depending on the results) to determine the depth of the dredged trenches and the sediment infilling-rates. Depending on the geophysical survey results, it is assumed that the first post-dredging survey can be conducted 2-3 years after cessation of dredging (three years for Target Block 1 and two years for Target Block 2 of the SP-1 resource). The subsequent sampling interval can best be determined after the first post-dredging sampling campaign, but an appropriate interval may be every 2-3 years. Periodically reviewing the monitoring plan as new data are collected and analysed will ensure that the monitoring plan and associated sampling schedule remains a dynamic process.

Traditionally, the ecological recovery of the disturbed seafloor has been defined as the establishment of a successional community of species, which progresses towards a community that is similar in species composition, population density and biomass to that previously present. Measures used to assess recovery typically include biodiversity analysis such as the numbers of species and/or individuals in an assemblage. However, this approach presents a number of challenges, especially when the physical characteristics of the sediment have been altered to such an extent that it can no longer accommodate its original assemblage. Recovery in the sense of the above definition may thus not be achieved (only when the sediment properties revert to their original state). For this reason, it may be more sensible to consider the functional capacity (or health) of the ecosystem rather than simply the range and proportion of species present. Some ecosystem functions can be undertaken by a variety of different organisms, leading to the notion of possible functional redundancy, whereby the loss of a particular species may not affect the basic functioning of an ecosystem as long as the function performed by that species is taken up by another species from the same functional group. To address this issue, many studies have recently focussed on functional diversity to assess faunal recovery following anthropogenic perturbations by incorporating biological differences among species showing that function- or trait-based diversity metrics may represent appropriate additional methods for assessing changes in ecosystem function (e.g. Borja *et al.* 2003, 2010, Bremner *et al.* 2006, Josefson *et al.* 2009, Cooper *et al.* 2008, Hussin *et al.* 2012). In terms of dredging impact on functional diversity, communities of organisms inhabiting an area of dredged seabed may possibly differ in composition or diversity from the pre-dredged state, but may develop similar functional capacity through the recovery process (functional recovery). Therefore, system recovery may not require similar biomass, biodiversity or community composition. It is thus proposed to utilise a variety of analyses including biodiversity measures, multivariate approaches as well as functional traits analyses to describe the macrofaunal colonisation process after the dredging impact.

© NMP 2014

5.2.3 Project Coordinator

5.2.3.1 Mr J Midgley: Terms of Reference

Terms of Reference: Verification Survey
Project Management, Environmental Supervision and Consultation
Verification of Impacts in the proposed Mining Area ML 170

Scope of services required:

- Liaising with the Client's representative:
  - Provide regular progress reports;
  - Provide immediate deviation reports;
  - Confirm progressive budget utilisation;
  - Confirm timelines; and,
  - Participate / lead / present / report on any meetings that the client deems approximate, to any audience as required.
- Identifying and confirming specialist consultants and independent reviewers suitable to undertake the required tasks competently:
  - Ensuring that they are provided with review reports, and all documents of relevance so that they can provide an assessment in context;
  - Ensuring timeous delivery of their work;
  - Coordinate and facilitate a peer review (of the specialists' assessments) workshop when the individual reports are completed (final draft); and,
  - Ensure that the appointed independent reviewers provide reports covering the scope of their assessments.
- Project management including:
  - Management of all appointed specialist consultants;
  - Management of respective scope of works;
  - Meeting of the agreed timelines of delivery;
  - Obtaining budgets for work to be undertaken;
  - Managing the respective budgets;
  - Optimising the work done by each of the specialist consultants and coordinating work modules between them; and,
  - Managing, producing, compiling an integrated verification study report.
- Environmental services
  - Providing an overall assessment of the impacts of the project based on the findings of the individual specialist studies and any peer / independent reviews undertaken; and,
  - Assessing habitat conditions from input data.
- Logistics, for the various marine surveys:
  - Obtain quotes and options for vessels, insurance and related transfer of equipment, samples and personnel across all disciplines; and,
  - Manage all budgets related to such.
- Travel and participate;
  - In marine cruises, acting as the client's representative.
- Payment approvals
  - Approve all consulting parties' invoices, verifying that work done, matches the scope of work agreed to be undertaken.
- Final report:
  - This must consist of:

        - A verification programme report, with appendices;
        - A executive summary (standalone);
        - Independent reviewers report; and,
- These reports must be provided in a high quality finish.
- Adjustments: advise client and provide reasons for any adjustments in respect of:
    - Time lines; and,
    - Budgets.

© NMP 2014

SANDPIPER PROJECT

Verification Programme Report:
Mining Licence Area No. 170

SECTION D : APPENDICES

APPENDIX 6

Dredging Project Description

CONDITIONS OF USE OF THIS REPORT

COPYRIGHT © NAMIBIAN MARINE PHOSPHATE (PTY) LTD 2014

ALL RIGHTS RESERVED

© NMP 2014. All rights to the intellectual property and/or contents of this document remain vested in Namibian Marine Phosphate (Pty) Ltd. (NMP). This document is issued for the sole purpose for which it is supplied. All rights reserved. No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of Namibian Marine Phosphate (Pty) Ltd, except in the case of brief quotations embodied in critical reviews and certain other non-commercial uses permitted by copyright law. For permission requests, write to Namibian Marine Phosphate (Pty) Ltd, addressed “Attention: Administration Manager,” at the address below.

Email: info@namphos.com
127 Theo-Ben Gurirab Street
Walvis Bay
Namibia

contents

1 INTRODUCTION **1**

2 THE LOCATION OF DREDGING **1**

3 THE DREDGING SYSTEM **4**

4 THE DREDGING CYCLE **7**

5 EXCLUSION ZONE AROUND SP-1 **9**

6 THE SCALE OF THE DREDGING AREA **9**

figures

Figure 1: General Location of the project of Mining Licence 170. 2
Figure 2: SP-1, the primary target dredge area. 3
Figure 3: A schematic of a TSHD. 4

tables

Table 1: Parameters describing the target recovery area of the Sandpiper-1 (SP-1) deposit. 4
Table 2: Duration (estimated) of the dredge cycle. 8

© NMP 2014

1 INTRODUCTION

The information in this chapter focuses exclusively on the activities to be undertaken in marine mining licence ML 170 located some 120 km to the southwest of Walvis Bay (Figure 1).

The key operational aspects for the marine component of the project for SP-1 comprise:

- Recovery of phosphate sediment from water depths of 200 m to 225 m;
- An annual recovery volume of 5.5 million tonnes of phosphate rich sea bed material to a thickness of up to 3 m, extracted from an area of up to 3 km^2, 60 km^2 for the 20 year period of the mine licence issue;
- The phosphate sands will be recovered by a trailing suction hopper dredger (TSHD);
- A large hopper (space where the slurry is stored onboard) provides for economy of scale;
- TSHD technology is proven and is supported by well known established environmental protocols; and,
- Conducting the marine operation in a safe and responsible manner with respect to the conditions at sea, and other marine.

2 THE LOCATION OF DREDGING

The Sandpiper marine phosphate project is located on the Namibian continental shelf approximately 120 km south southwest (SSW) of Walvis Bay. The eastern boundary of the Mining Licence Area is approximately 60 km off the coast (directly west of Conception Bay). The water depths in the licence area range from 180 to 300 m, (Figure 1). The Mining Licence Area is 25.2 km wide (greatest width) and 115 km long (longest length) and covers an area of 2233 km^2.

NMP has verified to internationally approved standards the existence of a potentially world-class phosphate deposit of 1,832 Mt (at 15% P_2O_5) in the Mining Licence Area[1]. The Mining Licence Area covers 2233 km^2.

The phosphate-enriched sediments and defined mineral resources are located throughout the entire Mining Licence Area. Within the ML three target dredging areas have been identified, with the assessment of the target dredge site Sandpiper-1 (SP-1) being the focus of the Verification Programme (Figure 2). The other sites (SP-2 and SP-3) may be considered at a later stage and will be subject to their own specific environmental evaluations.

[1] 1,832 million tons (at 15% P_2O_5) [comprising: Measured 4,09 Mt, Indicated 220,35 Mt at 20.13% P_2O_5 and Inferred 1,607.8 Mt at 18.9% P_2O_5]

© NMP 2014

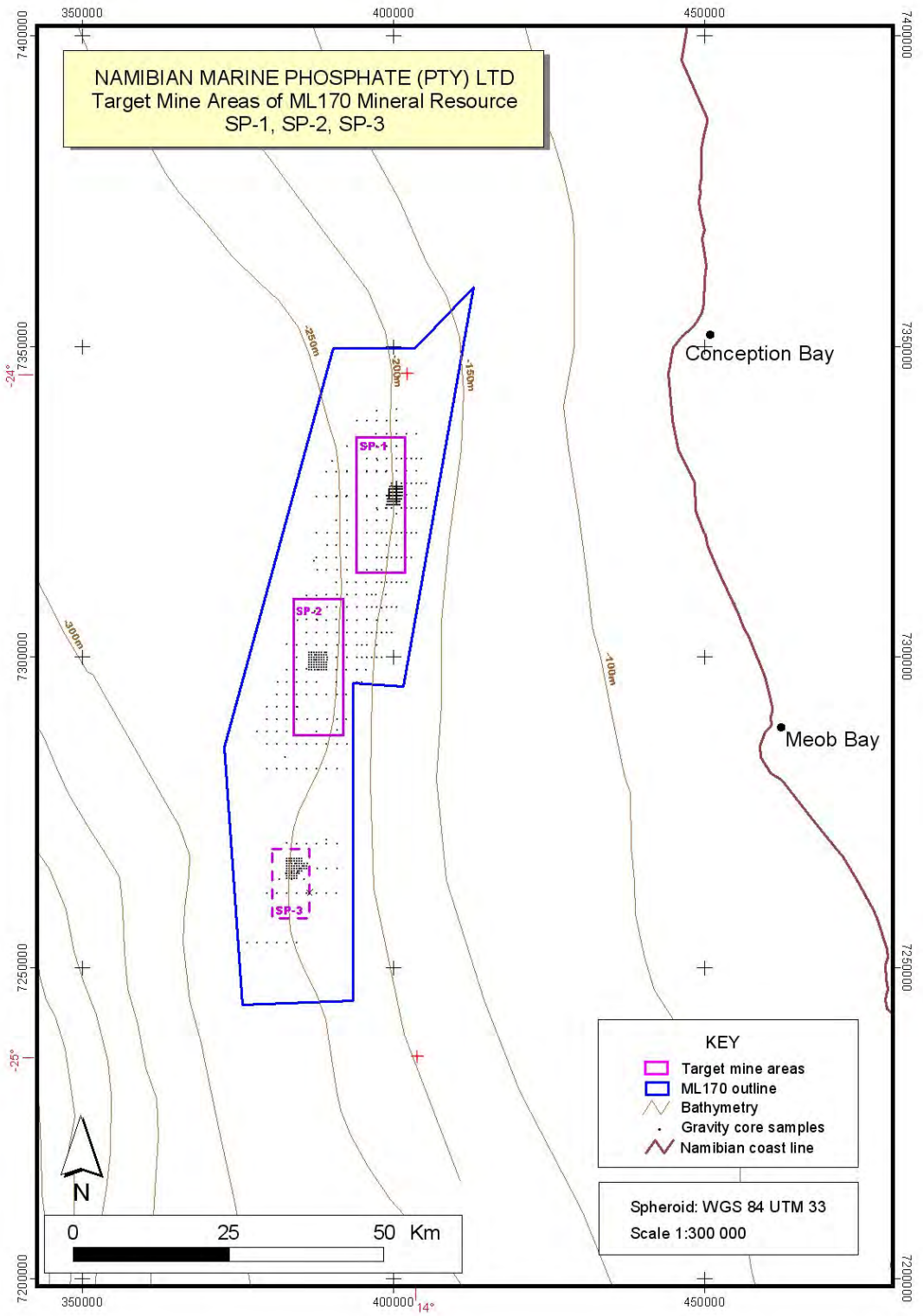


Figure 1: General Location of the project of Mining Licence 170.

© NMP 2014

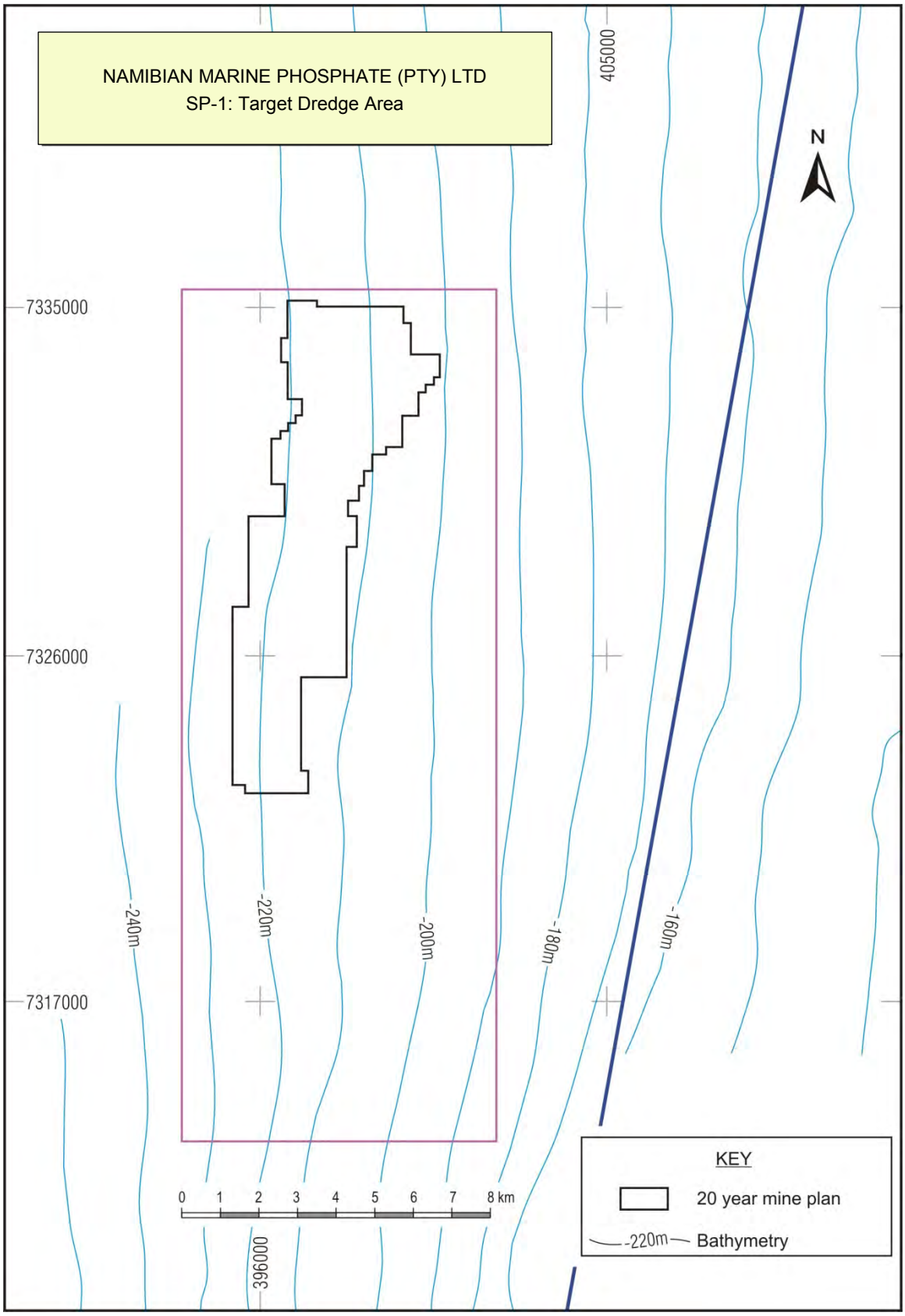


Figure 2: SP-1, the primary target dredge area.

Details of the target dredge site within SP-1 are presented in Table 1.

Table 1: Parameters describing the target recovery area of the Sandpiper-1 (SP-1) deposit.

Detail	Sandpiper -1 (SP-1)
Approx width - km	8
Approx length - km	22
Area (km^2)	176
Thickness Avg - m	1.69
Thickness Max - m^2	2.5
Thickness Min (m)	0.50
Area mineable - km^2	160
Avg area mined/pa - km^2	2.44
Water depth range - m	190 - 235
Life of deposit - yrs	51

3 THE DREDGING SYSTEM

Trailing suction hopper dredging technology has been determined to be the optimal method by which the deposit can be exploited (Figure 3).

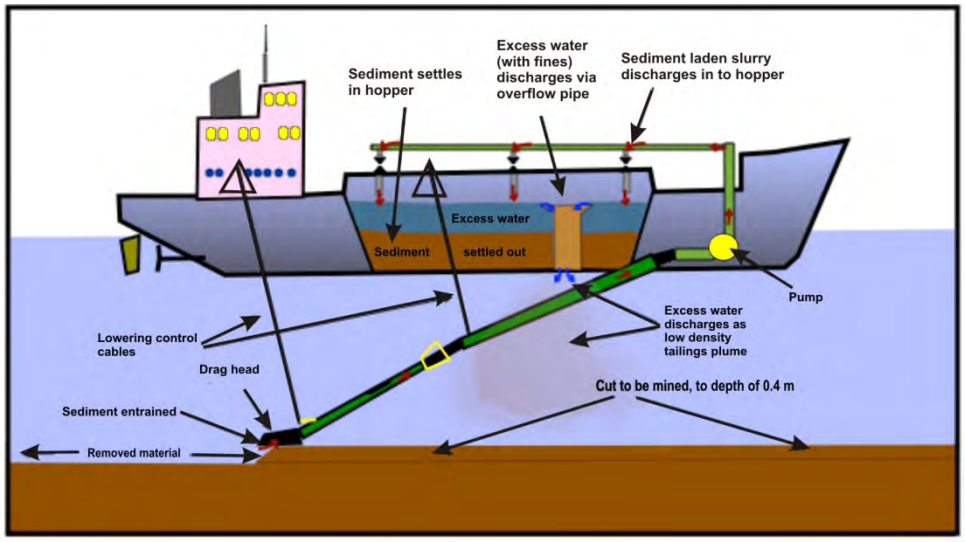


Figure 3: A schematic of a TSHD.

A trailing suction hopper dredging (TSHD) is a large self-propelled vessel with:

- Retractable dredge arms (usually two, but in this instance only one), which 'trail' on the sea floor behind the vessel;
- Large pumps which generate a suction force, via which the dredge head entrains the sediments with seawater;
- A suction 'dredge' head, designed to extract (typically 'cut and jet') the target sediments;
- An integrated large cargo hold, ("hopper)" in to which the dredged sediments are held temporarily, and
- Secondary pumps are used to transfer (pump) the sediment from the vessel to the shore.

The Belgian company, Jan De Nul, has currently been identified as a preferred supplier of services. It is a major international dredging company with the optimal experience, capacity and resources to recover the marine phosphate-rich sediments.

Dredging of these marine sediments will be conducted from a large TSDH dredger, such as, but not limited to, the MV *Cristobal Colon*. Such a vessel (in this case the *Cristobal Colon)* has the following characteristics:

- Built in 2009;
- Accommodation for 46 persons;
- 223 m length;
- 41 m beam;
- Draught loaded 15.15 m;
- A dredging depth of 155 m;
- Dredge head of 3 m width;
- 46,000 m^3 hopper capacity;
- A dredging speed of 1 to 2 knots;
- A maximum sailing speed of 18 knots;
- The vessel has total bunker capacity of 6,740 m^3;
- Under normal operational conditions the vessel can remain at sea for approximately three weeks without requirement for additional bunkers or victualling.
- Hopper capacity:
  - Effective 37,750 m^3 hopper capacity, (equates to 64,175 tonnes of phosphate enriched sediments[3]). The actual capacity of the hopper is 46,000 m^3 but 8,250 m^3 of sediments are retained to optimize vessel stability;
- Lean water overboard:
  - Excess water containing fine overflow material is discharged from the hopper between 10 and 15 m below the sea surface, depending on total vessel load. [NOTE: the discharge takes place through the bottom of the ship, i.e. there are no overside discharges on to the sea surface.
  - Between 10 and 15% of the dredged fine material (this being a portion of the < 100 micron size fraction) will be discharged overboard with the 'lean water.'

[3] The specific gravity of phosphate enriched marine sediments of this deposit is 1.7.

© NMP 2014

Recovery of marine phosphates from the water depths of the mining licence area, with water depths of greater than 190 m, has required that aspects of the recovery system be modified. These key modifications are, the length of the trailing arm and the size of the dredge head:

- Dredging depth:
  - The dredging depth has been extended to 225 m. These depth extensions are to allow recovery of sediments from the deposit, i.e. the resource area of SP-1 target dredge area water depths of 200 – 225 m;
- Dredge head:
  - The dredge head will be designed to optimise material recovery and to minimize the total weight of the extended dredge arm (The dredge head is currently configured to a 3 m width); and
  - The individual dredge lane depths are in the order of 0.5 to 0.75 m.

Dredging control

Dredging control for the vessel is maintained by means of the following systems and equipment:

- A positioning system;
- A dredging computer;
- A suction tube position monitoring system (STPM), and
- A dynamic tracking computer.

Positioning system

Dredging control is based upon a vessel positioning system. The Z or vertical co-ordinate of the ship is obtained from swell and tidal data from a prediction model based on historical data. The positioning computer determines the actual ship and draghead position as co-ordinates and presents the results, relative to the area to be dredged, on navigational displays. These position results are derived by calculation from the X, Y, Z inputs from the STPM system as described below and the ship's bearing provided by the gyrocompass. The positioning computer also determines the actual vertical offset of the draghead as compared to the target dredge depth. Information outputs from the computer include:

- Plots of dredged tracks;
- Position of the vessel and draghead visualized on screen on a background of bathymetric data, obstacles and buoys. The display is in plan view with a differential colour chart showing the amount still to be dredged, together with a longitudinal and cross profile of the trench marking seabed level and target level, and
- Changes in X and Y co-ordinates as input to the dynamic tracking system.

Dredging control computer

The dredging control computer enables all the dredging processes such as the dredging level of the draghead, pump settings and 'lean water' to be controlled. The interface between the positioning computer and the dredging control computer enables control of the dredging process to pre-defined levels of input to the system from pre-dredge survey information and pipe profile design requirements.

Suction tube position monitoring system (STPM)

The STPM is a system comprising a system of pressure and angle transducers, which allows the determination of the draghead position relative to the ship. This makes relative X, Y and Z co-ordinates of the draghead available to the positioning system and dredging computers.

© NMP 2014

Dynamic tracking
This system can control the vessel's track automatically and, therefore, the draghead's horizontal position by compensating for wind and current effects on the ship. It achieves such control by automatically adjusting rudder direction, propellers and bow thrusters.

Progress monitoring
During the process of line cut dredging, the progress is monitored on board by means of the dredging control systems and the multibeam or survey results. The dredging control system allows for the actual draghead depth and the target depth at the draghead position to be compared online and the difference displayed.

Survey
The survey procedures ensure that the survey methods used comply with the specifications and that surveys are carried out in an accurate and efficient manner. The procedures cover all survey works.

Equipment
The dredger is equipped with a multibeam echo sounder. This allows online surveys without the need of a separate survey vessel within the mining area. Alternatively, should the circumstances make surveying from the dredger less favourable, a separate survey vessel can be mobilised.

4 THE DREDGING CYCLE

The dredging cycle is divided into four consecutive activities, these are:

1. *Dredging:* Recovery of the phosphate-rich sediments;
2. *Sailing loaded*: With a fully loaded hopper, sailing to the location of discharge;
3. *Discharging:* Transferring the load to a containment location (buffer pond) ashore, and[4]
4. *Sailing back empty*: Returning to the Mine Licence Area, to initiate further dredging cycles.

The estimated duration of the various components of the dredge cycle based on current technical information, are presented in Table 2.

[4] Land based environmental implications related to the transfer of sediments to shore are discussed in the Terrestrial EIA-EMPR.

© NMP 2014

Table 2: Duration (estimated) of the dredge cycle.

Activity	Estimated Duration
Lowering: The vessel is on station, and dredge arm is lowered and the dredge head engages the sea floor.	0.25 hrs
Dredging: The dredge head is engaged in the sediments. Through a series of transects in the target mine area the dredge head will be engaged with the seabed in order that hopper is filled to capacity, 46,000 m^3. (Sailing speed of 1 to 2 knots)[5]	16.0
Hoisting*:* The hopper is full, and the dredge arm is returned inboard.	0.25
Sailing*:* The vessel sails to the point of discharge. This duration will vary depending on sea conditions and, in particular, on the distance to be travelled. Maximum sailing speed is 18 knots.	6.0
Connecting*:* Berthing and connecting to the shore discharge point	0.5
Transfer slurry ashore: Pumping the sediment ashore.	6.2
Disconnecting: Disconnection from the shore discharge point and undocking	0.5
Sailing: The vessel sails back to the mining licence area.	6.0
Estimated duration of the average dredge cycle	35.7 hrs

Phosphate sediment recovery will take place within the SP-1 target dredge site. The sediments here are located between 200 and 225 m water depth.

The vessel will recover sediments from individual continuous lanes within the target dredge area within the SP-1. The length of each lane (cut) is 4 km. This lane length may vary as determined from geotechnical information obtained during the dredging process and/or as revised from on-going resource development exploration. Dredging will predominantly take place in a north – south (or south – north) direction i.e. aligned with the predominant swell and wind direction.

The target dredge area has a mine plan, wherein individual blocks are identified to provide a resource for each year of dredging. Initially during Year 1, 400 m x 4 km, and in Year 2, which represents full production the active mine block is 600 m x 4 km. In the initial 4 km cut, the dredger will sail at approximately 1 knot, which results in the seabed engaged dredge head, which is 3 m wide, cutting to a depth of 0.75 m. In order to fill one hopper (vessel) load, 4 parallel adjacent, or near adjacent cuts within the target dredged area are required. The vessel will cover approximately 16 km during this period. Subsequent cuts within the same lane will be made, so that the full vertical extent (< 3 m) of the deposit is extracted. By varying the speed of the vessel, the depth of cut can be increased (shallower cut) or decreased (deeper cut), to a maximum of 0.75 m).

[5] Cut depth is variable as relates to, sea surface swell and hydraulic compensation to the drag head, speed of the vessel and the specific characteristics of the sediments dredged.

© NMP 2014

The vessel will continue to dredge vertically within the particular lane to a point just above the footwall clay. Depending on the particular location within the deposits, these footwall clays may be located at depths from 1 m to 3 m below the original seabed level. The intention is not to cut (dredge) into the footwall clay, but to rather leave a residual thickness of marine sediments over the footwall. This residual thickness will vary, but is envisaged to be between 10 and 15 % of the original volume of target sediment layer(s). This residual sediment remaining above the footwall clay will be present as an uneven 'hummocked' surface. The depth of dredging is managed through vessel-based positional software, integrated with the hydraulic winch compensation systems that control the position of the dredge arm and consequently the location of the drag head.

5 EXCLUSION ZONE AROUND SP-1

In order to ensure the safety of operations, an operational safety exclusion 'no go' zone will be declared over the active target mining area[6]. In the case of SP-1 this is envisaged as a 23 x 9 km rectangular area, totalling 207 km^2. Note: the target area of SP-1 is a 22 x 8 km block, the safety exclusion zone is larger to accommodate for vessel turning requirements. This is a restricted activity area from which the sediments are recovered[7]. The restricted area applies only to bottom trawl demersal fishing activities, and not to pelagic fishing or general vessel traffic. Fish stock assessment and research surveys are not intended to be restricted by the enforcement of this exclusion zone, standard rights of passage under international maritime convention will apply under these conditions[8].

These exclusion zones will be established with the authorities and advised to all shipping through Notices to Mariners.

6 THE SCALE OF THE DREDGING AREA

The scale of the dredge area is primarily controlled by the annual export/sales requirement of 3 million tonnes of 'rock phosphate'. In order to generate the required export volume, 5.5 million tonnes of marine sediments need to be recovered on an annual basis. This is based on the average tonne of marine sediment containing 60% ore grade phosphate.

The actual area that needs to be dredged annually to meet the export target of 3 million tonnes of rock phosphate depends on the thickness of the deposit[9]. The thickness of the deposit in SP-1 varies from 0.5 m, to 1.69 m, which at full production results in area of 2.44 km^2 being dredged annually. The thickness of the deposit is determined from exploration work conducted in ML 170.

[6] The areas of exclusion will be reviewed with fisheries so as to minimise the potential loss of access to fishing grounds.
[7] The total Mining Licence Area is 2233 km^2, the area of exclusion of target mining area SP-1 is 207 km^2, and hence, restricted access covers approximately 9 % of the Mining Licence Area.
[8] Notification is required of the intention to conduct such surveys 14 days before the planned survey.
[9] Production deposit thicknesses will differ to some degree from that determined from exploration activities.

© NMP 2014