BENEFIT

Benguela Environment Fisheries Interaction and Training Programme (BENEFIT) Research Projects

GLOBEC Report No.25

GLOBEC

GLOBAL OCEAN ECOSYSTEM DYNAMICS

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Benguela Environment Fisheries Interaction and Training Programme (BENEFIT) Research Projects

I. Hampton, N. Sweijd and M. Barange (Eds.)

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TABLE OF CONTENTS

BENEFIT 1998-2007: AN INTRODUCTION

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The Benguela Environment Fisheries Interaction and Training (BENEFIT) Programme ended in December 2007 after the establishment of the Benguela Current Commission. This brought to fruition a decade of collaboration among the three national marine research institutes of Marine and Coastal Management (M&CM) in South Africa, the National Marine Research and Information Center (NatMIRC) in Namibia and the Instituto Nacional de Investigação de Pequeira (INIP) in Angola. This collaboration, together with the involvement of a wide range of research and educational institutions and agencies, was funded primarily by donor aid - the Norwegian Agency for Development Cooperation (NORAD), the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), and the French Priority Solidarity Fund (FSP) being the main contributors - along with contributions in cash and in kind from the three governments. Much of the work was done in partnership with international research institutes, of which the Institute of Marine Research (IMR) in Bergen, Norway (who, *inter alia*, supported a very significant deployment of the research vessel, *Dr Fridtjof Nansen*), the Baltic Research Institute in Germany (IOW), and the Institute for Research Development (IRD) in France, deserve special mention. A comprehensive record of the history and development of BENEFIT and its sister programme, the GEF- funded Benguela Current Large Marine Ecosystem (BCLME) Programme, is due for publication this year in the book, Benguela: Current of Plenty: A history of international cooperation in marine science and ecosystem management (BCC, in press).

BENEFIT was an affiliated programme of GLOBEC, and the flagship of GLOBEC's work in southern Africa (GLOBEC, 1999; Ashby, 2004). The links between BENEFIT and GLOBEC emanated from their common connection to the South African Benguela Ecology Programme (BEP), a key multi-institutional research partnership linking Universities, fisheries laboratories and resource managers in South Africa, which inspired both GLOBEC and BENEFIT. The BEP included a sub-programme called SARP (Sardine and Anchovy Recruitment Project) that mirrored plans for a worldwide study of the ecosystems supporting large populations of small pelagic fish, later to become a regional programme of GLOBEC under the name of SPACC (Small Pelagic fish And Climate Change Programme; GLOBEC, 1997). The role of Benguela scientists in the development of both SPACC and GLOBEC was significant, and so when BENEFIT was conceived GLOBEC was a logical umbrella to provide international exposure, credibility and intellectual support to this new and exciting regional initiative. From its first international engagement, at the 5th Scientific Advisory Council of the International Geosphere Biosphere Programme (IGBP) in Kenya, September 1998, BENEFIT was introduced as a GLOBEC-SPACC activity in Africa and an emerging activity in the broader global change African networks.

The links between GLOBEC and BENEFIT were not only institutional but extremely practical. Both programmes organised common field cruises (e.g. GTZ/BENEFIT/SPACC Meteor cruise, October 2000, to better understand the impact of meso-scale physical structures and processes on zooplankton production with reference to fish recruitment), workshops (e.g. "Long-term dynamics of the Benguela and Humboldt Current upwelling systems: a comparison from an ecosystem perspective", Swakopmund, November 2002) and reports such as this one. Both programmes engaged at the highest level, exemplified by the meeting of the GLOBEC Scientific Steering Committee and the BENEFIT science community at the 2004 BENEFIT Forum and the fact that the Director of the GLOBEC International Office chaired the BENEFIT International Scientific Advisory Panel from 2005.

A very significant part of BENEFIT was the suite of marine research projects funded and carried out between 1998 and 2007 under its auspices. These were all intended to contribute to BENEFIT's over-arching goal of enhancing scientific capacity in the region for the optimal and sustainable

utilisation of the Benguela ecosystem's living marine resources through 1) increasing understanding of the dynamics of key resources and of environmental influences on them, and 2) increasing human and material capacity for marine research and resource management. Three broad foci (Resource Dynamics, Environment and the Linkages between them) were formulated in the BENEFIT Science Plan, published in 1997, in which specific research and capacity-building activities for addressing the problems were proposed. Within these broad guidelines, researchers from the region proposed research projects which were considered, evaluated and, if appropriate, approved, by the programme structures. These included BENEFIT Resources and Environmental Working Groups, who worked research proposals into an annual research agenda. The Programme's Management and Policy Committees (later replaced by a Management Action Committee and Ministerial Board), adjudicated the allocation of funds for this work and monitored progress. Scientific progress was also annually assessed and scientific guidance given, by an International Advisory Panel (ISAP) consisting of experts covering the various disciplines, and representing the major international partners in the Programme (ie. Norway, Germany, France, GLOBEC, etc.).

The BENEFIT community was kept abreast of research progress at annual meetings, where project leaders presented their results to a broad audience, including the ISAP, and participants met to re-focus their research or formulate proposals for new projects. Principal Investigators were required to produce interim or final progress reports on their projects in a prescribed format for evaluation by the various BENEFIT Committees and the ISAP. The final evaluation of the projects was done by the ISAP at the closing BENEFIT Meeting in Swakopmund, Namibia, November 2007. Their report is included in this volume for completeness. To assist the ISAP in this evaluation, Ian Hampton (who served as the BENEFIT Technical Officer at various stages of the Programme), was commissioned by the BENEFIT Secretariat to produce a document summarising the objectives, conduct and achievements of each project, based on the final project reports. It was subsequently agreed by the ISAP that this document be worked up to publication standard and published in the GLOBEC Report series as a comprehensive, integrated record of the scientific achievements and legacy of BENEFIT. This Report is the result.

The summaries give in each case a brief account of the project's objectives, the rationale for it, the research approach and the most significant findings and other achievements. Outputs in terms of data and other deliverables are documented where appropriate, and publications and theses emanating from each project listed on a project-by-project basis, and in a single bibliography of BENEFIT and BENEFIT-affiliated publications following the individual summaries. The Report also contains the final assessment report of the ISAP and a list of BENEFIT research cruises, key scientific meetings and selected training activities to illustrate the extent of the Programme's activities.

In all cases, the projects were joint enterprises, involving scientists from at least two of the regional partner countries as well as, in many cases, one or more of the international partner countries or organisations. This was a guiding principle for BENEFIT research projects, which served to strengthen and broaden the scientific base of the research, foster inter-regional and international cooperation, and strengthen scientific capacity in the region by offering opportunities for young and/or less experienced scientists to further their education in marine research through participation in the projects. Many students took advantage of this opportunity, and the financial support which went with it, to attain post-graduate degrees at regional and overseas universities, as will be seen from the listed thesis titles. In this sense, the projects became a training ground, supplementing the non project-based training activities of BENEFIT (not reported on here). The skills acquired through participation in the projects, whether they contained a specific training component or not, are in themselves a valuable output of the research programme.

The summaries do not presume to evaluate the individual projects, as this was done elsewhere. Rather, they are an attempt to give an overview of BENEFIT's research activities in an easily-accessible form, and to highlight the achievements, great or small, with a few examples of concrete outputs where appropriate.

It should be noted that although the BENEFIT Programme came to an end in late 2007, some of the projects described here are still continuing in some sense or other, and are yet to produce their final results. Others have merged into national projects, or are likely to continue as regional projects under the Benguela Current Commission, whose founding in 2007 is one of the legacies of BENEFIT. Equally, many other completed and current marine research activities in the Benguela Current region, although not linked to BENEFIT in any formal sense, probably owe their existence to some extent to BENEFIT, which in itself is an achievement of the programme.

The names listed with each project are generally the Principal Investigators, who were contacted where possible to approve the text, which in most cases differed substantially from the reports on which they were based because of the need for condensation and for a consistent format and level of detail. For some of the projects (particularly those completed in the first phases of the programme), not all of the listed Principal Investigators could be contacted, and not all of those contacted responded to requests for input. In these cases the texts had to be finalised by Ian Hampton from whatever information was available.

Although projects from the Resources and Environment working groups were treated separately in the Programme for administrative reasons, they have been integrated in this Report by listing them alphabetically by Principal Investigator to break down what many felt was a somewhat artificial distinction.

While every reasonable attempt has been made to check on the accuracy of the summaries and to present a balanced, objective view of the achievements, there will inevitably still be some errors in content, interpretation or emphasis. It is hoped that these will prove to be minor, and that this document will give an accurate overall sense of BENEFIT's scientific achievements in the 10 years of its existence.

We are highly indebted to Ian Hampton for his work on this volume and the many other documents that he has authored and edited for the BENEFIT Programme. His dedication and attention to detail have played a significant part in the successes the Programme has achieved. We also gratefully acknowledge the financial assistance of GLOBEC, and the technical assistance of Dawn Ashby, in publishing this Report.

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Ashby D.M. (Ed.). 2004. Update of the Report on the GLOBEC National, Multinational and Regional Programme Activities, 2004. GLOBEC Special Contribution No. 7: 195pp.

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Monitoring of variability in the inshore environment in the Benguela system

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Project description

The primary purpose of this project was to put instrumentation in place at key localities along the coast and in the nearshore marine environment (shallower than 30 m) to build up or continue time series of data for monitoring the inshore environment. A major subsidiary goal was the standardisation of instrumentation, calibration and data collection methods within the region.

The project was motivated by the need to detect long term changes in, for example, the coastal wind regime at key upwelling sites and, in the long term, to provide environmental data for ultimately relating the dynamics of inshore resources to changes in their immediate environment. From 2004, region-wide monitoring of anthropogenic contaminants of the coastal environment such as heavy metals was added as a project objective.

In December 2005 the project was integrated with the BENEFIT Offshore Monitoring, Phytoplankton Monitoring and Estuaries projects into a single project aimed at ultimately providing standardised inputs to a system-wide State of Environment Report to satisfy the needs of the Benguela Current Commission. Environmental parameters and inshore monitoring sites (*inter alia*) were listed and prioritised and the key problems identified. It is anticipated that in the short to medium term, regional monitoring activities in the region will be planned on this basis.

Achievements

Coastal anemometer network

Taking the lead from M&CM in South Africa, who collect wind data from Mike Cotton (MC) Systems automated weather stations with dial-up modems at eight sites around the South African coastline, a coastal network of MC Systems automatic weather stations was set up in Namibia through BENEFIT on GTZ funds. The first step was taken in 1998, when a station was set up at Diaz Point in Lüderitz with the assistance of M&CM. This was necessary to maintain the long time series of wind speed and direction measurements made by lighthouse-keepers (dating back to 1960) that would otherwise have ceased with the closing of the manned lighthouse there. Figure 1 shows wind anomalies at Diaz Point for the entire period. A database of weather measurements at Swakopmund was started in the late 1990s through the installation of an MC automatic weather station at NatMIRC, also funded by GTZ. In 2000 two additional units were installed by the Ministry of Fisheries and Marine Resources at Ichaboe and Mercury Islands respectively. In 2002 a 20-year time series of wind data was discovered at Möwe Bay, and in 2004 the project funded an installation and service visit to all Namibian automatic weather stations by MC Systems.

A Vaisala automatic weather station was first installed in the Namibe laboratory in southern Angola in December 2003 through the project, but due to ongoing problems related to the air temperature and humidity, this system was replaced by an MC Systems automatic weather station in December 2006 on project funds. Identical stations were set up at the same time by the project at the INIP laboratories in Luanda and Lobito. All three stations are now returning data. An example of the output is given in Figure 2 which shows that the average wind speed at each station during the first 9 months of 2007 was less than 4 ms^{-1}, prevailing from the WSW.

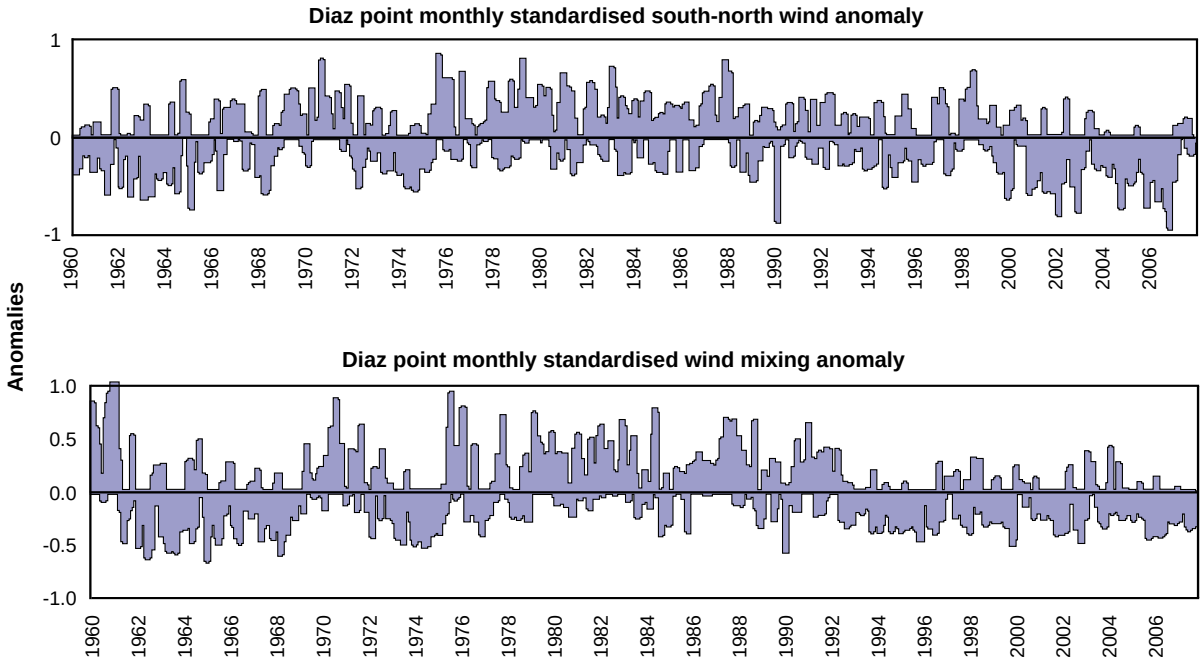

Figure 1. Standardised anomalies in the wind pattern at Diaz Point, Lüderitz between 1960 and 2007.

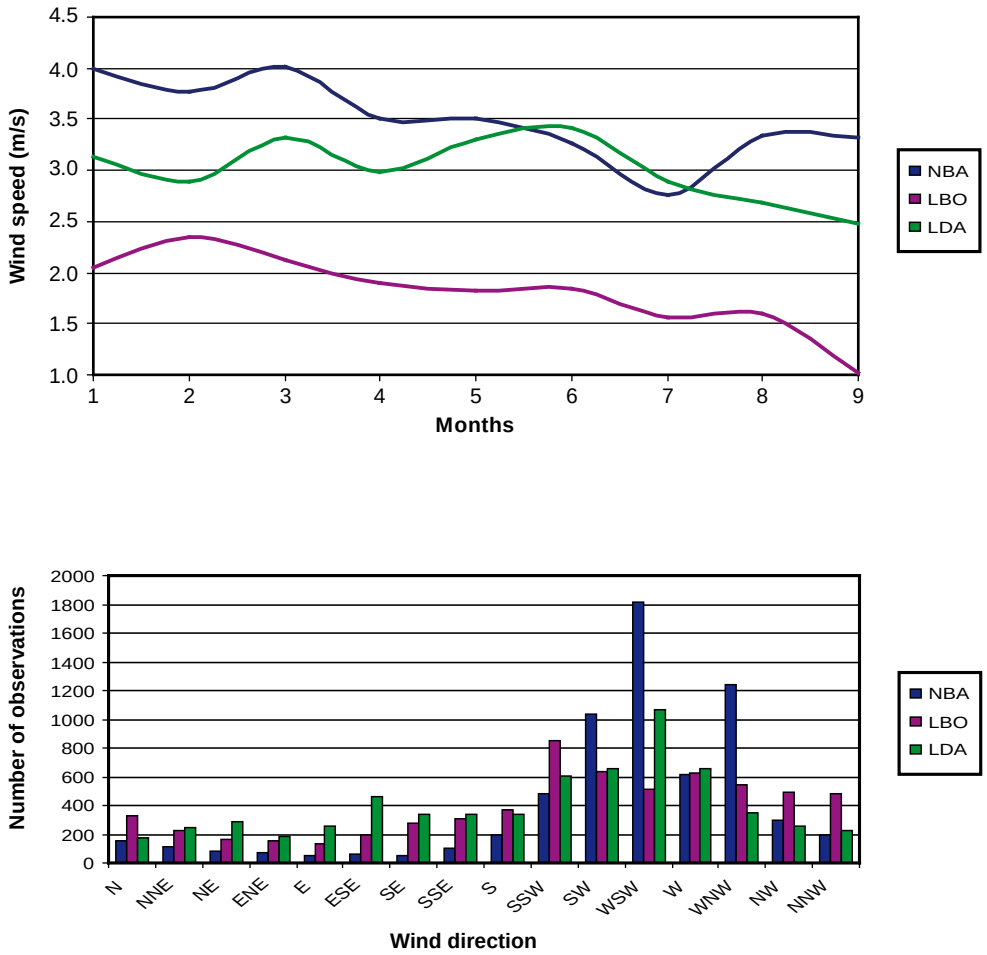

Figure 2. Mean wind speed (upper panel) and direction (lower panel) at Namibe (NBA), Lobito (LBO) and Luanda (LDA) between January and September 2007, from MC Systems automatic weather stations.

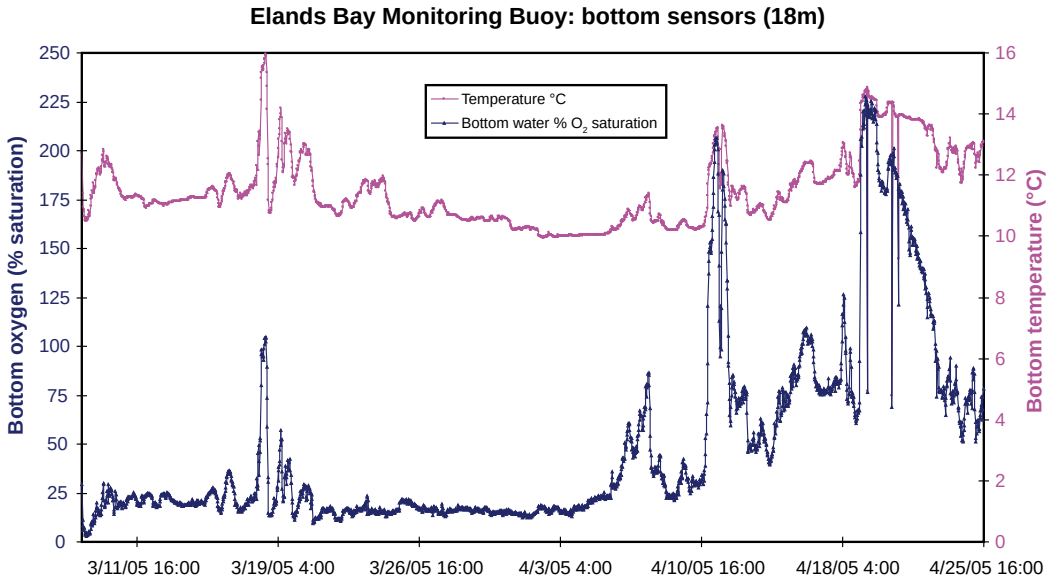

Figure 3. Temperature and oxygen saturation on the bottom in Elands Bay between 11 March and 25 April 2005 from inshore oceanographic mooring.

Nearshore dissolved oxygen/temperature/hydrogen sulphide

In South Africa, monitoring buoys were deployed in the summer of 2003 off Elands Bay and Lamberts Bay through the project. The data are available in real time and are displayed on a website using the most recent transmitted data. The records (e.g. Fig. 3) clearly reveal sustained episodes of hypoxia on the bottom in summer, and that these were interrupted by intermittent higher oxygen concentrations, closely associated with an increase in bottom temperature due (in summer to downwelling). The hypoxic conditions can lead to, *inter alia*, walk-outs and subsequent mass mortality in rock lobsters with serious socio-economic consequences. The monitoring system is a forerunner to an early warning system for detecting the development of such potentially harmful conditions in this region.

In Namibia, GTZ purchased an SBE 16 moored dissolved oxygen and temperature logger which has been deployed sporadically at a number of sites in the Lüderitz region from 2000 to present, with support from the project. Time series of sea surface temperature and oxygen measurements from this mooring are shown in Figure 4. Additional activities were the setup of a network of sea surface temperature time series measurements at Lüderitz harbour to add to a time series dating back to 1973, and at Ichaboe and Mercury Islands and Möwe Bay. The project also funded attempts to find a suitable digital alternative to the mercury thermometers currently in use, and an attempt to put in a moored temperature logger at Diaz Point. Another activity was the supply of hydrogen sulphide sampling equipment to Mercury and Ichaboe Islands where opportunistic sampling takes place during hydrogen sulphide eruptions.

Monitoring of anthropogenic contaminants: "Mussel Watch"

Routine sampling and analysis of trace contaminants (lead, cadmium, copper, zinc, iron and manganese) in mussel populations has been conducted by M&CM for about the last 15 years as an indicator of short- and long-term changes in contaminant levels in the sea. The programme in its current form is to be incorporated into a wider inshore monitoring programme along the South African coast. Mussel Watch (Namibia) was established in mid-2005 as an extension of this programme, with training assistance from M&CM, funded by the project. At present, sampling is done once every six months in the Swakopmund/Walvis Bay area, and the sorted and shelled mussels couriered to M&CM for analysis. One staff member from Lüderitz has received training in sampling, but the equipment needed to process the samples is not in place. Mussel watch has not yet been extended to Angolan waters due to the anticipated problems of sample transport, and the fact that the South African sample analysis center is already over-extended.

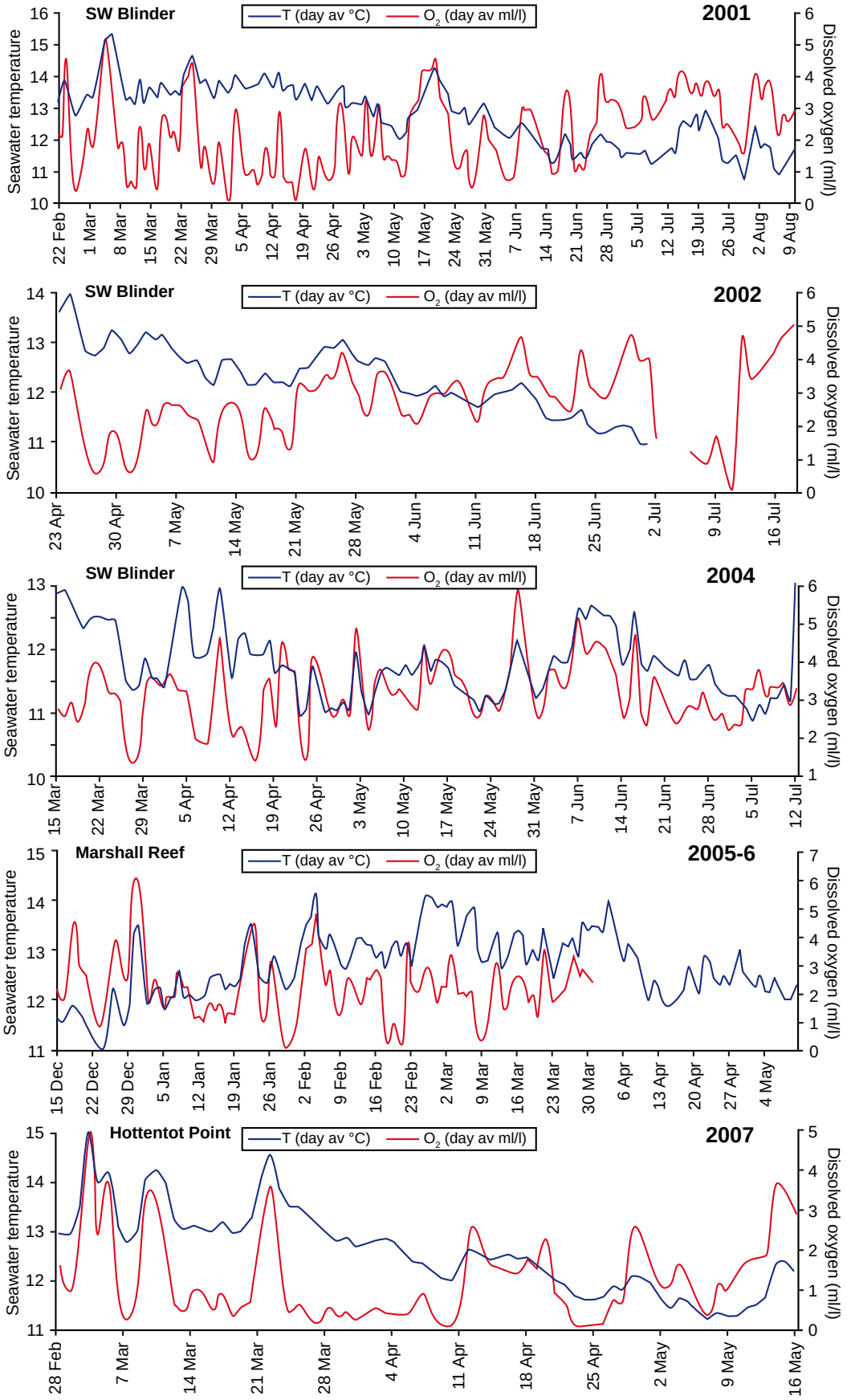

Figure 4. Near-shore sea surface temperature and dissolved oxygen measurements from inshore oceanographic mooring at various sites in the Lüderitz region between 2001 and 2007. The oxygen measurements should be regarded as relative at this stage due to uncertainties in the calibration.

Data analysis

The 45-year time series of wind data from Diaz Point lighthouse has been analysed to elucidate seasonal and interannual variability in wind-driven upwelling at Lüderitz. The work was submitted as a Masters thesis to UCT by Kathleen Noli-Peard, with assistance from BENEFIT, and has recently been accepted. The hydrogen sulphide data have been analysed through the associated BENEFIT (SEDLAB) project on hydrogen sulphide generation and dynamics (Currie *et al*., this report).

Other data collected from the project are yet to be analysed in full to meet the project's long-term goal of relating the dynamics of inshore resources to changes in the coastal environment.

Outputs

Data

The data from this project are stored on the Institutional databases at INIP, NatMIRC, the Marine Research Laboratory, Lüderitz, and M&CM.

Theses

Peard, K.R. 2007. Seasonal and biannual variability of wind-driven upwelling at Lüderitz, Namibia. MSc thesis, University of Cape Town, South Africa. 108pp.

Application of remote sensing in the Benguela ecosystem

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Project description

The overall objectives of this project were to a) investigate algorithms for generating ocean colour products applicable to the Benguela, and b) to use the outputs in association with satellite-derived SST imagery to study upwelling processes and plankton dynamics in different parts of the system at various spatial and temporal scales. The project is important for improving the quality of satellite-derived ocean colour products, and for improving understanding of the way in which the ecosystem responds to upwelling events, increasing the value of satellite imagery in environmental early warning systems.

The major portion of the research was undertaken by a contracted investigator (Scarla Weeks) whose tasks included: (1) optimising the processing of high resolution SeaWiFS data for the Benguela system, (2) observing hydrogen sulphide eruptions off Namibia through satellite imagery, (3) monitoring the evolution of a coccolithophorid bloom in the southern Benguela, and (4) developing chlorophyll and temperature indices for the system, with a focus on the southern Benguela. In addition, Chris Bartholomae investigated temperature and ocean colour variability off Namibia using high resolution satellite data in support of resource management, and in related studies supported by the IRD/IDYLE Programme, Claude Roy used low resolution (4 km) temperature data to investigate the implications of upwelling variability for anchovy recruitment in the southern Benguela. Also as an IRD/IDYLE project, Herve Demarcq developed an integrated chlorophyll index from low resolution SeaWiFS data to examine the temporal and spatial variability of phytoplankton production in the Benguela, and developed temperature and chlorophyll climatologies for the ecosystem.

Achievements

The main achievement of this project has been the generation of a large amount of high-quality satellite imagery, from which much has been learned about near-surface physical and biological processes in the Benguela system. Some particular examples are highlighted here.

Optimisation of processing parameters

Following a detailed investigation into the SeaWiFS bio-optical algorithms, some of the processing parameters were modified to optimise them for use in Benguela regional waters. It was found that constituents other than chlorophyll were at times contributing significantly to the in-water light field, and that because of major events such as hydrogen sulphide eruptions in the northern Benguela, no one set of processing parameters was adequate for processing all of the data over a long time series. A quantitative analysis of high resolution NOAA AVHRR and SeaWiFS ocean colour data for the southern Benguela ecosystem was undertaken, and initial operational indices derived for its use in ecosystem studies.

Hydrogen sulphide eruptions

High resolution ocean colour satellite images of sulphide-laden surface water (lower panel, Fig. 1) have shown that hydrogen sulphide eruptions off central Namibia are much more frequent and extensive than previously believed, and consequently probably have far more serious consequences for the ecosystem than was previously thought.

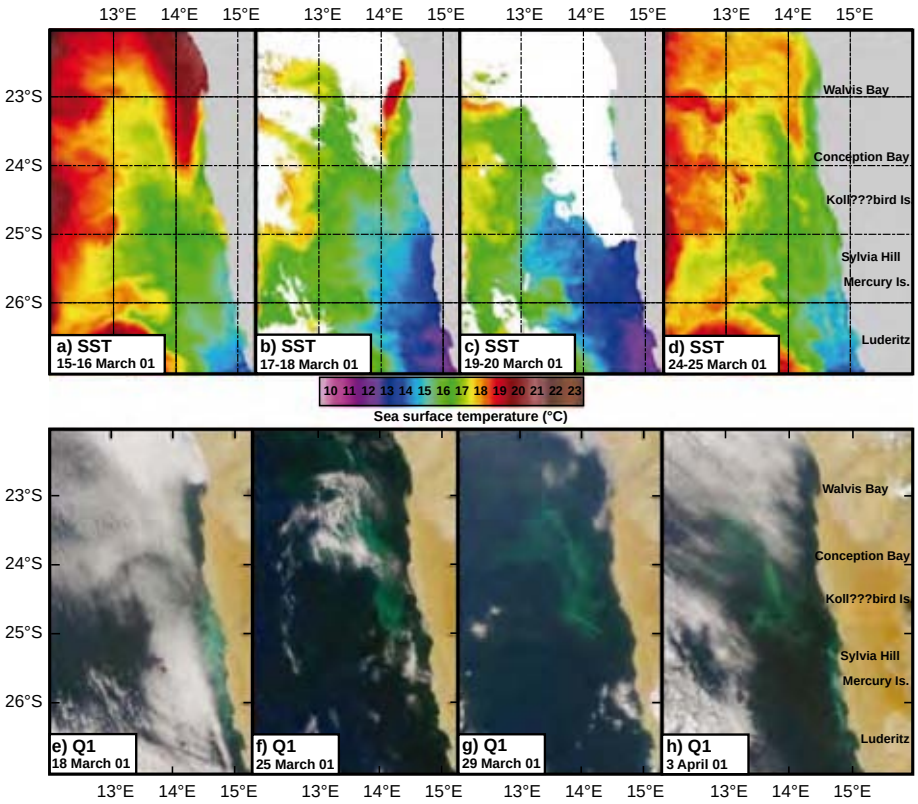

Figure 1. NOAA AVHRR false-colour SST and SeaWiFS quasi-true colour images (upper and lower panels respectively) for the region 12°-16°E; 22°-27°S during the period March-April 2001. Areas of milky turquoise colouration in the lower panel indicate high concentrations of suspended sulphur granules in surface waters (note that the individual images in the lower panel do not necessarily correspond to those in the upper panel).

Temperature and chlorophyll indices

Plots of satellite-derived indices of SST and near-surface chlorophyll in the southern Benguela over a number of years (Fig. 2) both clearly show the Cape Columbine and Cape Peninsula upwelling cells, the seasonality and synchronous nature of the upwelling at these two localities and the rapidly pulsating nature of the upwelling in the southern Benguela (the latter is in contrast to the northern Benguela where the indices have shown that the upwelling is more widespread and more perennial).

From this study, integrated SST, upwelling and chlorophyll indices were derived for the Cape Peninsula, St Helena Bay and Namaqua shelf areas, enabling temporal and spatial patterns in upwelling intensity at these locations to be more comprehensively quantified and compared than has previously been possible.

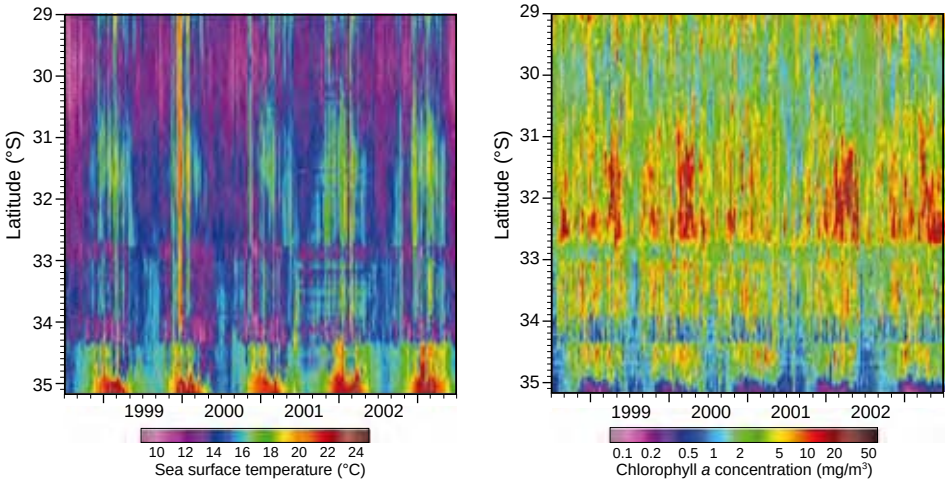

Figure 2. Hovmueller shelf width-averaged plots for the southern Benguela inner shelf (0-100 m) from 29.00°S to 35.18°S: (left) SST for July 1998 - June 2003 and (right) chlorophyll *a* concentration for July 1998 - June 2003.

Angola/Benguela frontal processes

The interannual variability of the seasonal warming in the northern Benguela caused by the intrusion of tropical water from the north is clearly shown in the decades-long SST time series in Figure 3. The images show that the extent of the warming is determined to some extent by the intensity of the upwelling off Namibia in summer, which means that satellite derived SST measurements along the Namibian coast can be used to track this seasonality. Latitudes of specific isotherms can easily be derived from such time series as environmental indicators, for use in further analysis.

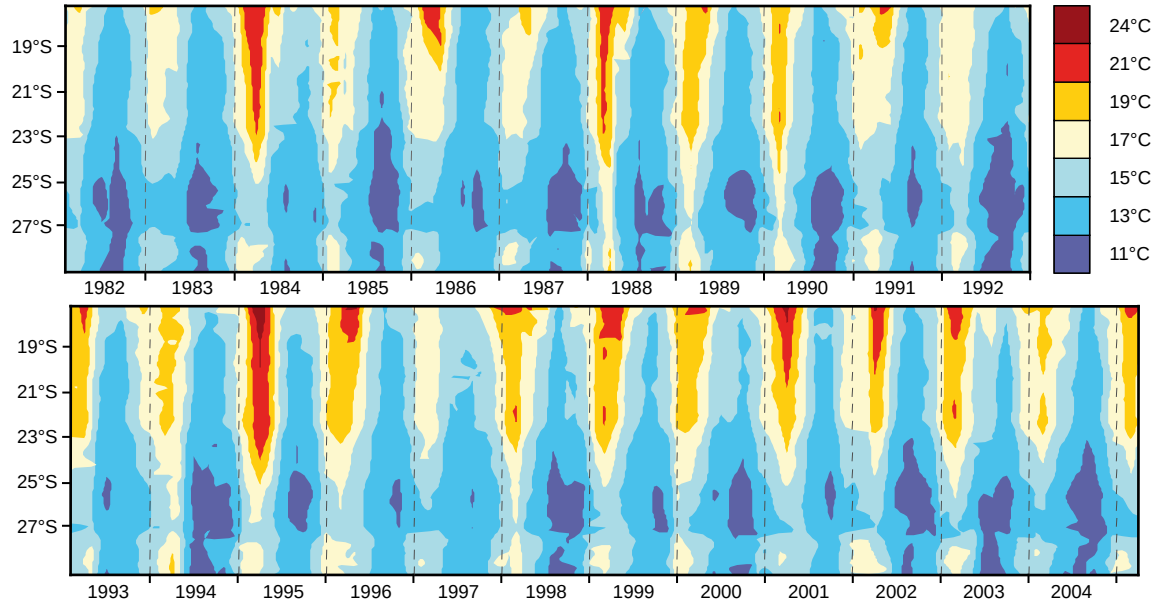

Figure 3. Satellite-derived sea surface temperatures along the Namibian coast; January 1982 - March 2005.

Variability of upwelling and ecological implications

A monthly time series of the mean SST over the continental shelf between Cape Point and the Cunene River from January 1986 to January 2000 has been calculated by averaging the SST between the coastline and the 500 m isobath (Fig. 4). This index highlights the main environmental events that have occurred over the last 15 years. On close examination it shows that during the major climatic events there is a tendency for the northern and southern Benguela to be out of phase. The cause for such a dipole structure remains unknown.

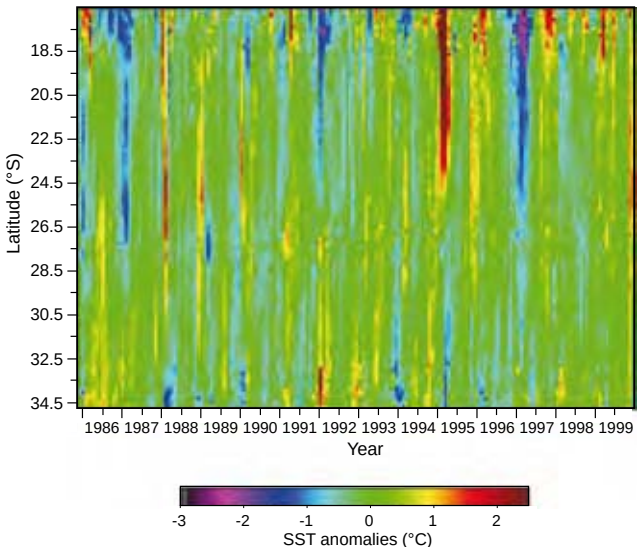

Figure 4. Hovmueller plot of monthly SST anomalies over the continental shelf from January 1986 to January 2000.

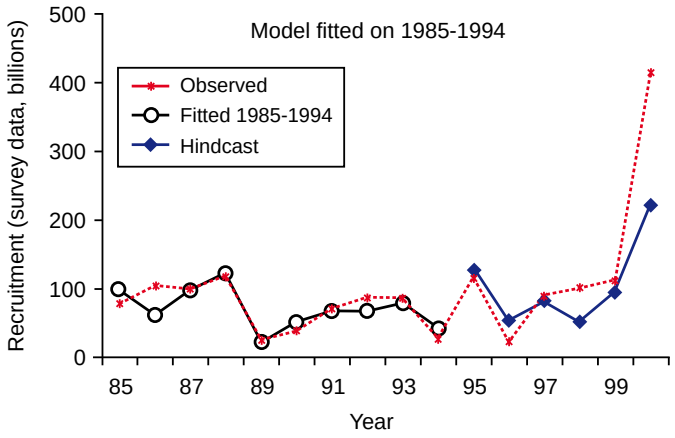

Figure 5. Observed and modelled anchovy recruitment time-series in the southern Benguela.

An empirical relationship between acoustic estimates of anchovy recruitment and two satellite-derived temperature-anomaly indices (surrogates for transport off the Cape Peninsula during December and upwelling intensity off the West Coast in January) has been developed as a predictor of anchovy recruitment strength, and tested on a subset of the data. The fit (Fig. 5) is encouraging, but needs to be tested over a longer time series.

Integrated chlorophyll index

SeaWiFS data were used to compute monthly mean chlorophyll distributions between 12 and 34°S to a defined offshore concentration limit (Fig. 6, left panel) on a temporal and spatial scale relevant to the dynamics of recruits of commercially exploited fish populations in the region. Seasonal and interannual patterns of chlorophyll concentration within the Benguela system between 1997 and 2002 derived from these averages are shown (Fig. 6, right panel).

Outputs

Data

A large volume of high-quality satellite data from this project has been archived on hard drives at UCT, backed up on hard drives at M&CM and NatMIRC.

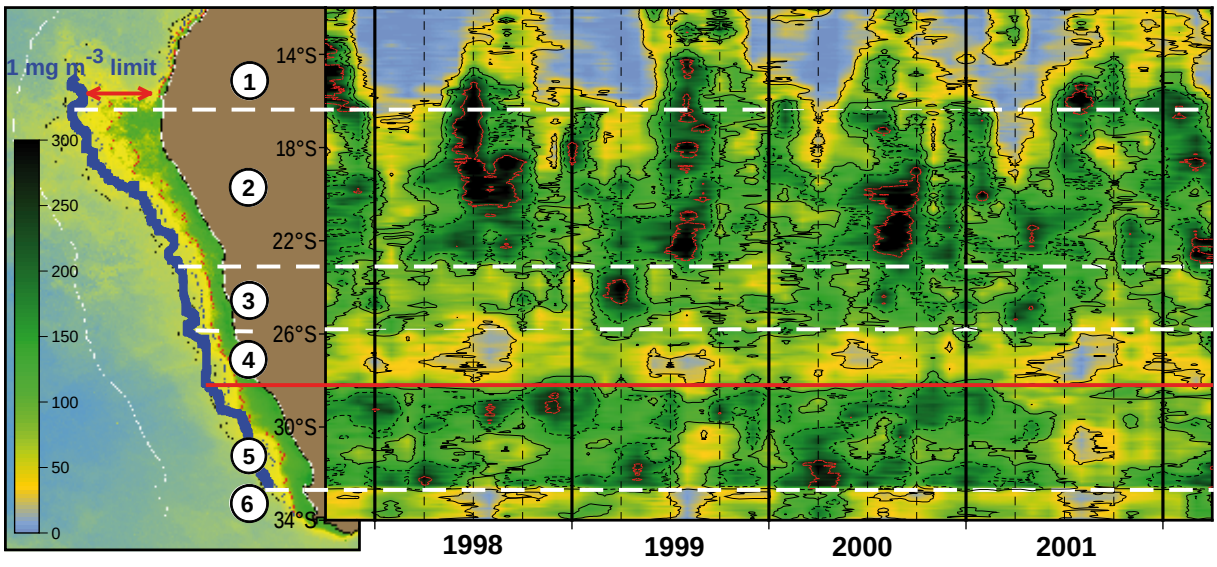

Figure 6. Monthly averages of chlorophyll *a* estimated from SeaWiFS data from October 1997 to March 2002.

Publications

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Theses

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Ground-truthing of remotely-sensed ocean colour

Ray Barlow[1], Deon Louw[2] and Jim Aiken[3]

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[2]National Marine Information and Research Centre, Swakopmund, Namibia

[3]Plymouth Marine Laboratory, United Kingdom

Project description

The main thrust of this project was to ground-truth and improve estimates of near-surface pigment levels from SeaWiFS ocean colour data. An associated objective was to improve understanding of relationships between ocean colour measurements derived from SeaWiFS and primary production.

Samples collected from a wide range of sites between 1998 and 2002 from local and foreign vessels (including two BENEFIT cruises) were used for ground truthing ocean colour imagery and for absorption and pigment analysis. The samples were analysed and interpreted through a collaborative effort between Ray Barlow and Scarla Weeks (OceanSpace UCT), partly through a BENEFIT project on applications of remote sensing. In addition, Ray Barlow participated in three NASA-coordinated SeaWiFS HPLC Analysis Round-Robin (SeaHARRE) pigment intercomparison experiments with support from this project. These experiments, the second of which used samples collected from the southern Benguela during a NASA/ESA – sponsored cruise on *RV Africana* (BENCAL), were aimed at comparing and improving procedures used in different laboratories to estimate pigment concentration *in situ*. The project has been complemented by studies at M&CM in which the relationship between ocean colour and pigment composition has been investigated through studies on light absorption and photosynthesis by pigments in the phytoplankton, and by laboratory experiments on photoadaptation in selected phytoplankton species. The latter were carried out by a PhD student (Marianne Balarin) who was funded through this project.

Achievements

Ground truthing of SeaWiFS data

Initial comparisons, based on data from three areas, showed poor correlation between HPLC measurements of chlorophyll *a* concentration and SeaWiFS estimates derived using standard NASA bio-optical algorithms and processing parameters (Fig. 1), from which it was concluded that the default algorithms and parameters were not ideal for the high productivity waters of the Benguela. It was also found that the frequent upgrading of the processing parameters by NASA was resulting in an inconsistent time series for the Benguela.

Through close collaboration with members of the SeaWiFS project team, including a number of visits to NASA by Scarla Weeks, partly funded by BENEFIT, various problems were addressed and optimal processing parameters for Benguela regional waters developed and applied. The performance of the algorithm using both the most recent NASA default parameters and the Benguela processing parameters was tested on 24 HPLC measurements of integrated chlorophyll from the northern and

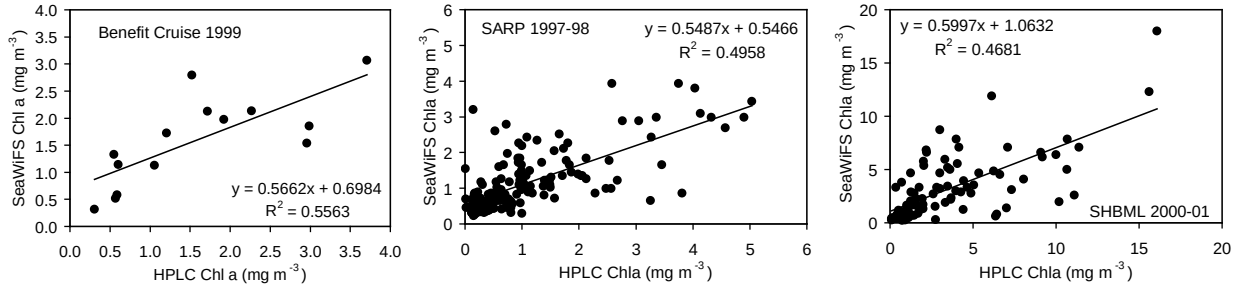

Figure 1. Comparison between selected SeaWiFS and HPLC chlorophyll *a* data sets.

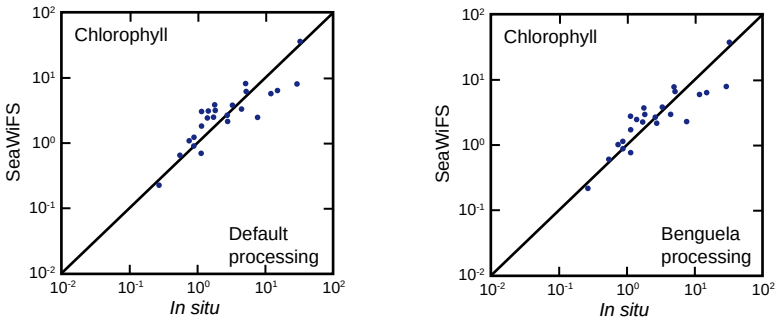

Figure 2. Correlation between SeaWiFS chlorophyll and *in situ* integrated chlorophyll using NASA default (left) and Benguela-optimised (right) processing parameters.

southern Benguela system between 1998 and 2002. The results (Fig. 2) show a marked improvement over Figure 1 for both sets of parameters. Although the performance of the Benguela parameters in this case was only marginally better, it is expected that the difference would have been greater had more of the samples come from highly-productive inshore waters. Clearly, more work along these lines is necessary to continue improving the validation and calibration of regional ocean colour products.

Phytoplankton variability

Monthly measurements of chlorophyll *a* were made by NatMIRC on the Walvis Bay monitoring line over a 4-year period to monitor phytoplankton variability in the northern Benguela, as a contribution to this project. These have shown *inter alia* that concentrations in 2004 were generally higher and more widely distributed than in the three previous years. In the southern Benguela, data from a monthly time series of phytoplankton pigments on the St Helena Bay monitoring line over an annual cycle (June 2000 – July 2001) were used to derive diagnostic pigment indices for assessing the composition of phytoplankton communities. Temporal and spatial changes in three of these indices (characterising diatoms, dinoflagellates and small flagellates respectively) are shown in Figure 3, indicating the seasonal variability in phytoplankton community structure in this region.

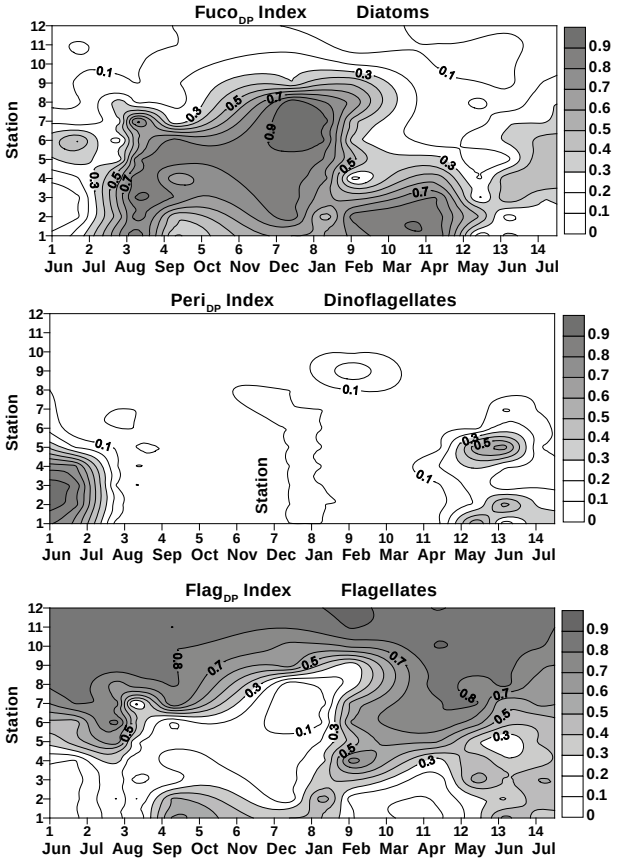

Figure 3. Seasonal patterns in (top) the Fuco$_{DP}$ (diatom) index, (centre) the Peri$_{DP}$ (dinoflagellate) index, and (bottom) the Flag$_{DP}$ (small flagellate) index, on the St Helena Bay monitoring line between June 2000 and July 2001.

Bio-optical studies

On a number of cruises, light absorption spectra were obtained for various phytoplankton pigments, and photosynthesis rates measured using a Fast Repetition Rate Fluorometer. These studies yielded a wealth of information on the absorption properties of phytoplankton pigments, which has improved understanding of the way in which ocean colour changes with changes in pigment concentration brought about by changes in the structure of the phytoplankton community.

The photoadaptation experiments have shown *inter alia* that dinoflagellates photosynthesise and grow best under low irradiance levels, as opposed to diatoms which can tolerate relatively high light levels. This partially explains why diatoms are often associated with blooms during upwelling. Another general finding is that while photoprotective pigments increase with increasing light intensity, photosynthetic pigment content in both unicellular and multicellular phytoplankton increases many times as light intensity decreases during growth.

Outputs

Publications

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Fishwick J., J. Aiken, R. Barlow, H. Sessions, S. Bernard and J. Ras. 2006. Functional relationships and bio-optical properties derived from phytoplankton pigments, optical and photosynthetic parameters; a case study of the Benguela ecosystem. Journal of the Marine Biological Association of the United Kingdom 86: 1267-1280.

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Hooker S.B., H. Claustre, J. Ras, L. Van Heukelem, J-F. Berthon, C. Targa, R.G. Barlow and H. Sessions. 2000. The first SeaWiFS HPLC analysis round-robin experiment (SeaHARRE-1). NASA SeaWiFS Postlaunch Technical Report Series, 14: 42pp.

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Balarin M.G. 2007. Comparative laboratory study of photoacclimation in selected dinoflagellate and diatom species of the Benguela ecosystem. PhD thesis, University of Cape Town, South Africa. 185pp.

Phytoplankton photosynthesis in the southern Benguela

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[2]National Marine Information and Research Centre, Swakopmund, Namibia

[3]Plymouth Marine Laboratory, United Kingdom

Project description

This project, which was carried out at a late stage in the BENEFIT Programme (i.e. between 2005 and 2007) was aimed at investigating the seasonal variability in photosynthetic parameters, phytoplankton light absorption and pigment concentrations in the Southern Benguela, and the relationships between these and primary production. It was motivated by the need to improve understanding of the functioning and variability of phytoplankton within the food web, and of how these might be affected by climate change.

Water samples for pigment analysis and ^{14}C photosynthesis-irradiance (P-E), Fluoresence, Induction and Relaxation (FIRe) and phytoplankton absorption experiments were collected from a range of depths at 20 stations on the shelf during acoustic surveys of the South African West Coast in October 2006 and May 2007 from RV *Africana*. In the P-E experiments, samples from each depth were incubated at 15 different irradiances to estimate photosynthesis rates from radiocarbon activity. After normalisation to chlorophyll *a* concentrations to give chlorophyll-specific production rates, these were used to estimate the parameters in the continuous exponential photosynthesis model of Platt *et al*. (1980). FIRe rates were determined by fluorometer, pigment concentrations by liquid chromatography, and phytoplankton light absorption cross-sections by spectrophotometer.

Dr Margareth Kyewalyanga of the Institute of Marine Sciences, University of Dar-es-Salaam, participated in some of the field work for collaboration and the training of a PhD student (Tarron Lamont) in ^{14}C photosynthesis experiments.

Achievements

In total, 93 P-E experiments were conducted, from which photosynthesis-irradiance plots such as that in Figure 1 were constructed.

The diagnostic indices from the pigment analysis indicated that diatoms dominated the communities at most stations during October 2006 (Fig. 2a), whereas in May they were less dominant, with roughly equal mixtures of diatoms and small flagellates being found at four of the stations (Fig. 2b). Dinoflagellates and prokaryotes were comparatively rare at all of the stations in both years.

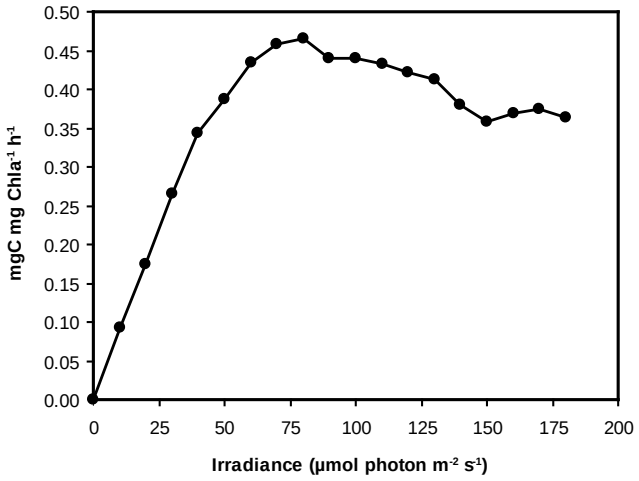

Figure 1. Photosynthesis- irradiance plot for a 3 m sample at 33.24°S.

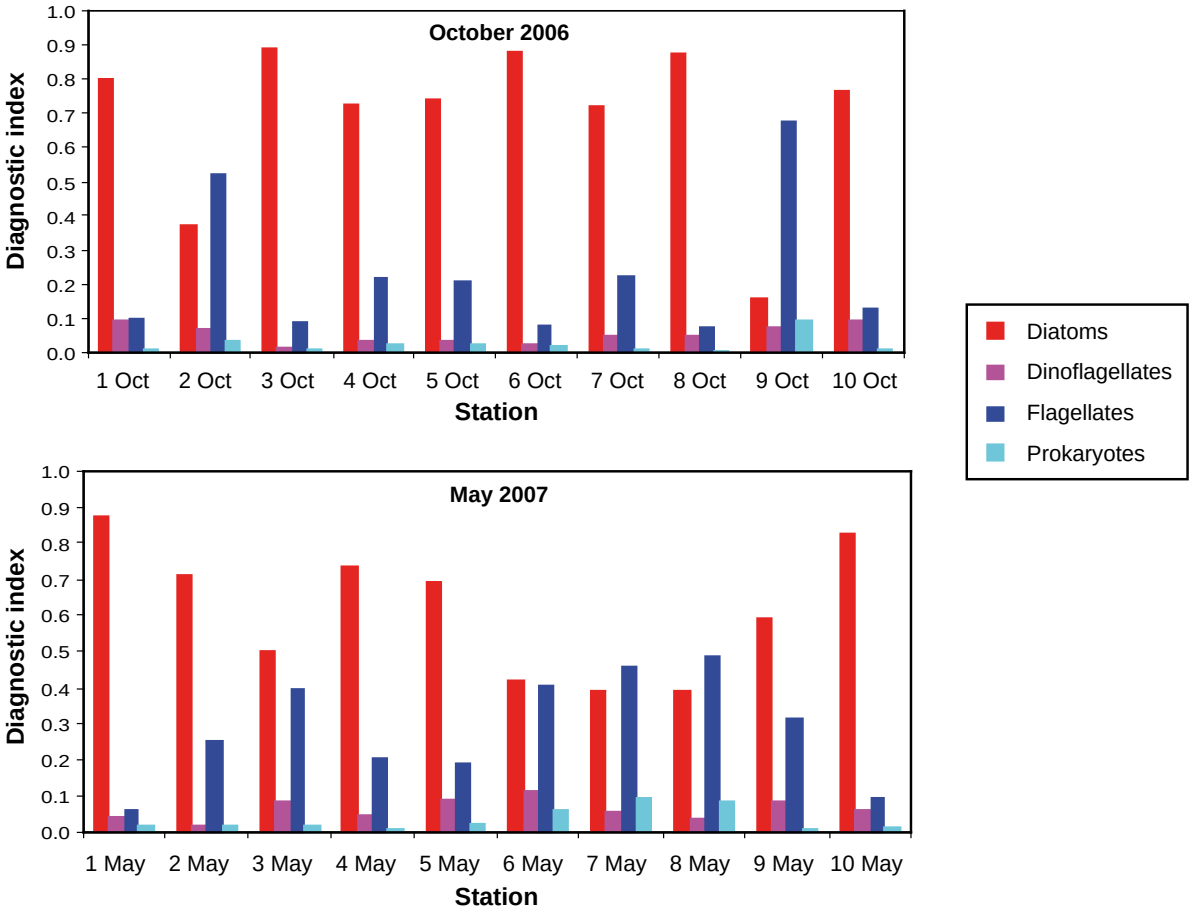

Figure 2. Integrated diagnostic indices in the euphotic zone for stations in a) October 2006 and b) May 2007.

The daily integrated water column primary production (estimated using the model of Platt *et al*.,1980), and the overall primary production were both generally higher in October 2006 than in the following May. There was considerable variation in primary production between stations and years, which it was suggested may have been due to variations in the light reactions of phytoplankton photosynthesis (monitored by the FIRe experiments) and differences in phytoplankton biomass, rather than to variations in the light absorption cross-section, which varied little between the stations or years. High production seemed to occur where the phytoplankton biomass was high and the population was healthy and actively photosynthesising (indicated by an elevated quantum yield through photosynthesis, and a high so-called "connectivity factor", which measures the efficiency of energy transfer between photosynthetic units). Conversely, low production was associated with either low phytoplankton biomass (e.g. in newly upwelled water) or with lower rates of photosynthesis, where phytoplankton growth was probably in a declining phase. It was concluded that the photochemical quantum yield and the connectivity factor appear to be the main photo-physiological parameters influencing primary production in the southern Benguela. It was recommended that the study be continued under the Benguela Current Commission and extended into the northern Benguela to further improve understanding of the functioning and variability of phytoplankton within the food web of the Benguela system, and the possible effects on phytoplankton production of climate change.

Outputs

The main output from this project is the improved understanding of the photochemical reactions which govern photosynthesis by phytoplankton in the southern Benguela, and the P-E curves, which will enable phytoplankton production to be predicted from irradiance measurements.

Offshore oceanographic monitoring and fisheries in the Benguela current

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[2]Marine and Coastal Management, Cape Town, South Africa

[3]Instituto Nacional de Investigação Pesqueira, Luanda, Angola

Project description

The immediate goal of this project was to maintain, and in some cases initiate, a set of regular ship-based oceanographic transects to monitor environmental conditions in the most important spawning, transport and nursery areas for selected target species in the northern and southern Benguela. The aim was to sample these areas sufficiently regularly, and in sufficient detail, to be able to produce state of the environment reports at monthly intervals and to link this information to the results of other monitoring efforts (e.g. from satellite monitoring, process studies and moored instruments) and mesoscale fisheries surveys. A second objective was to contribute to long-term data sets on dissolved oxygen and zooplankton, and information on seasonal changes. The project as a whole was aimed at contributing to the long-term goal of predicting recruitment through a better understanding of the effect of measurable environmental variables on recruitment.

Achievements

In 2000, NatMIRC's regular oceanographic monitoring programme was incorporated into this project in the interests of regional standardisation. A line off Walvis Bay (chosen as the primary line) has been surveyed at approximately monthly intervals, and a second line (just north of Palgrave Point, at 20°S) somewhat less frequently every year from 2002. The lines are run to 70 nmiles offshore. Temperature, salinity, dissolved oxygen, nutrients, chlorophyll *a* and copepod biomass have been sampled at each of the nine stations on the lines. In total, 66 monitoring surveys have been conducted since 2000. The results, which are usually produced within a month of the cruise, have been published in regular state of the environment reports, meeting one of the major objectives of this project. The project has been particularly successful, generating a data set which is an invaluable resource for investigating seasonal and annual changes in the environment over a long period. Examples of some of the many time series which have been constructed from the data are shown in Figures 1 to 3.

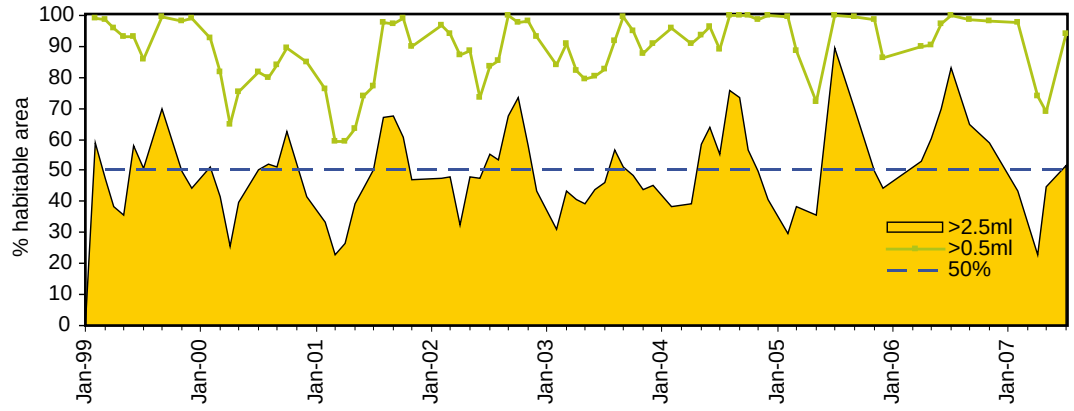

Figure 1. Percentage habitable area of water with dissolved oxygen content ≥ 2.5 ml l^{-1} (yellow) and ≥0.5 ml l^{-1} (green) off Walvis Bay. 2.5 ml l^{-1} is considered to be the lowest threshold for survival of pelagic eggs and larvae.

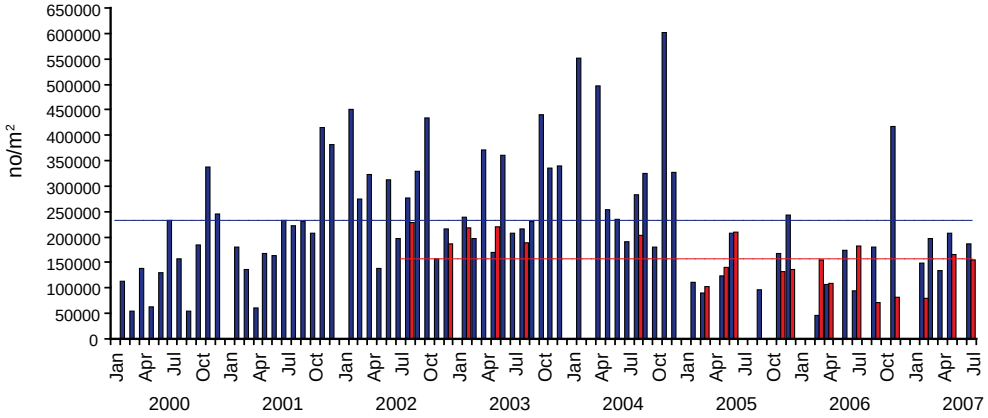

Figure 2. Copepod abundance (number m^{-2} surface water) along Walvis Bay (blue bars) and Palgrave Point (red bars) lines. The horizontal lines show the average abundance for the two transects.

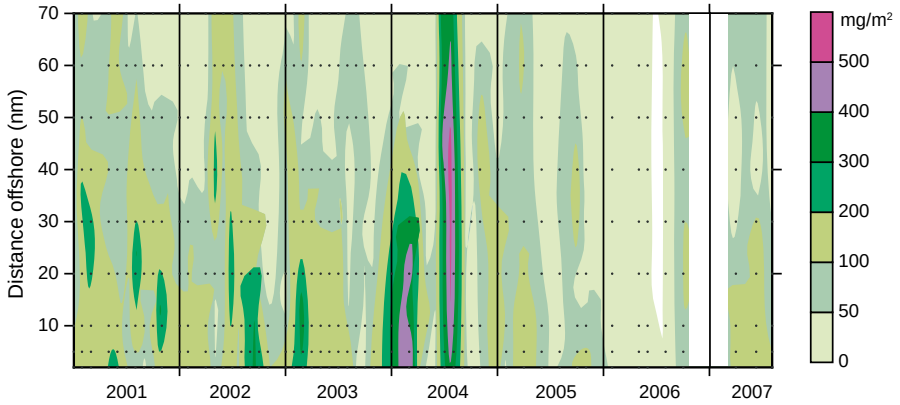

Figure 3. Integrated chlorophyll *a* concentration (mg m^{-3}) on the Walvis Bay line.

In South Africa, partly through this project, a monitoring line off St Helena Bay has been sampled from M&CM vessels to a distance of around 90 nmiles offshore at monthly intervals between April 2000 and the present. CTDO profiles were taken and nutrients, phytoplankton (as chlorophyll *a*), microzooplankton and zooplankton sampled at 12 stations spaced between 2 and 10 nmiles apart. ADCP and acoustic back-scatter measurements were made continuously between stations on vessels equipped for this. An inshore (20 m) station in St Helena Bay and a deeper (105 m) one off Cape Columbine were also sampled regularly for the same parameters. A large volume of high-quality data has been collected through these activities, and some comprehensive time series generated, from which much has been learned about the seasonality of thermal structure, chlorophyll *a*, dissolved oxygen concentration and zooplankton distribution and community structure in and offshore of St Helena Bay. For example, it has been found that near-surface chlorophyll *a* concentrations in the St Helena Bay region are remarkably high throughout the year, with peaks due to dinoflagellate blooms in late summer and autumn (Fig. 4), and that while there is strong seasonality in temperature gradients outside the bay, there is little seasonal variation in temperature within the bay itself. Oxygen is supersaturated in the bay in the upper mixed layer due to primary production, but depleted in the bottom mixed layer by the decomposition of organic material. Low oxygen water near the bottom is a persistent feature offshore to a distance of about 80 km from the coast except when winter storms or downwelling in summer oxygenate the water column to the bottom (Fig. 5). Note that since 2005 this feature has extended considerably further offshore. An index of low oxygen water over the shelf off St Helena Bay for the past seven years, derived from the monitoring has been proposed as an indicator of the state of the shelf environment – see Figure 6. Zooplankton abundance in summer during the monitoring period was much greater than in winter (e.g. Fig. 7), and significantly higher than when previously monitored (in the late 1970s), in line with the general trend of increasing zooplankton abundance which has been observed in the southern Benguela (see Verheye and Kreiner, this report).

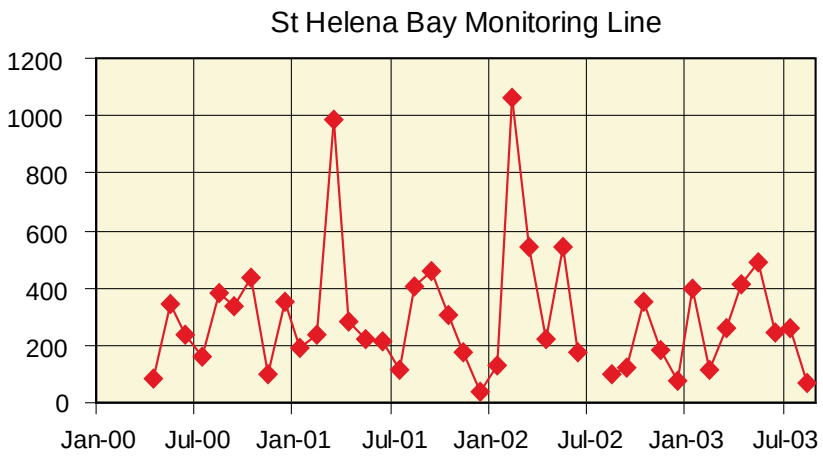

Figure 4. An index of chlorophyll based on the mean chlorophyll within the upper 30 m of the water column, integrated from the coast to 50 nmiles offshore along the St Helena Bay Monitoring Line for monthly surveys from April 2000 to August 2003.

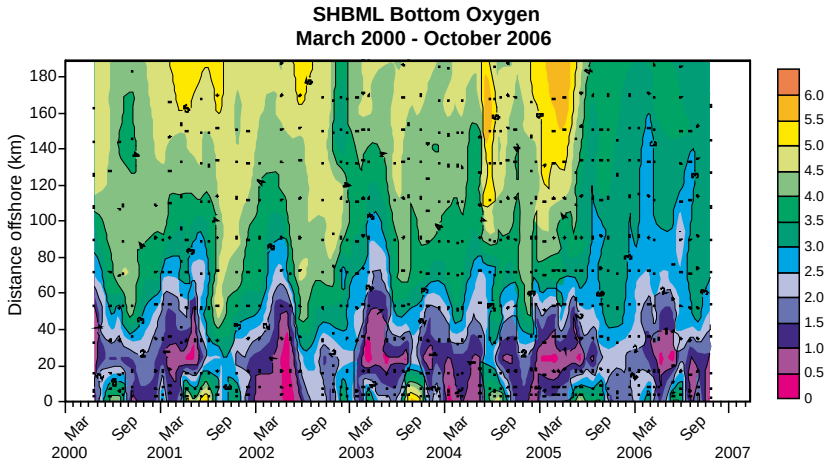

Figure 5. Concentration of dissolved oxygen at the bottom on the St Helena Bay Monitoring Line, March 2000 – October 2006. Note the increase in the offshore extent of low oxygen water since 2005.

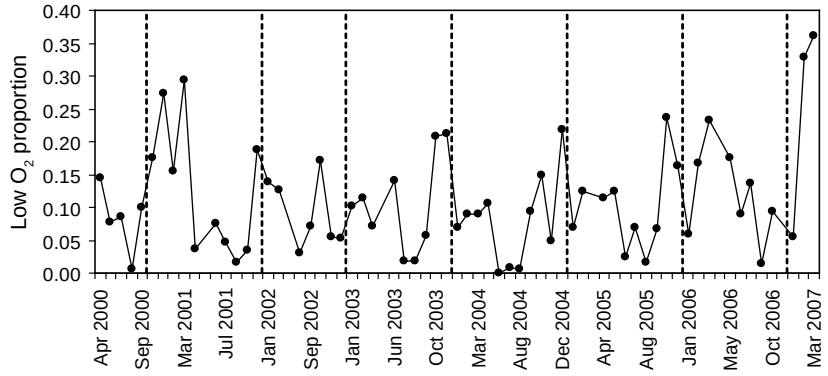

Figure 6. Proportion of shelf water off St Helena Bay where oxygen levels were lower than 2 ml l^{-1} between April 2000 and March 2007.

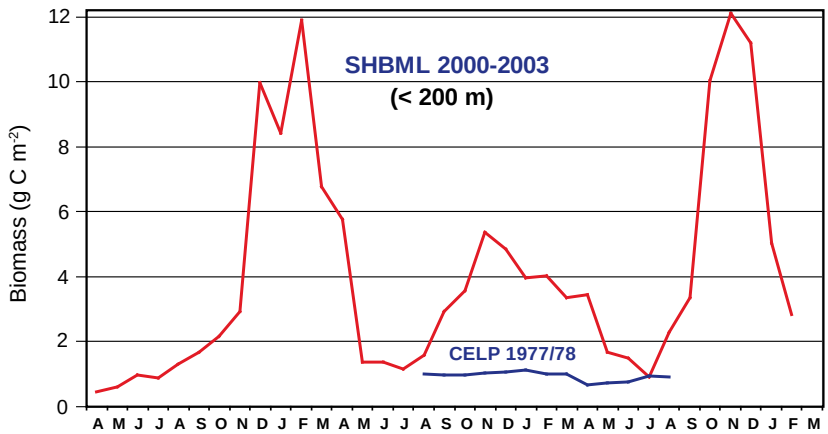

Figure 7. Seasonal cycle of < 1600 µm zooplankton density (expressed as g C m^{-2}) at the seven inner stations of the St Helena Bay Monitoring Line between 2000 and 2003, compared to dry weights from the Cape Egg and Larval Programme (CELP) in 1977/78.

Off Angola, although some monitoring has been done on a line off Namibe (some of it for training purposes), the project has not yet progressed to the state where data are collected on a regular basis. Note however that a considerable amount of physical, chemical and zooplankton data has been collected at monitoring stations off Namibe, Lobito, Luanda and south of the Congo River during routine resource surveys by *Dr Fridtjof Nansen*.

Outputs

Data

All Namibian monitoring data are archived within the Ministry of Fisheries and Marine Resources national database, OCEANBASE. Copies of the physical/chemical data are also archived at the South African Data Centre for Oceanography (SADCO), Stellenbosch. The South African physical-chemical data are stored on the M&CM internal database and periodically transferred to SADCO. Data from the Namibe monitoring line are archived by INIP, and from the Angolan stations monitored during *Dr Fridtjof Nansen* surveys, by IMR, Bergen.

Publications

Data from the shipboard monitoring have been used in the following publications.

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Horse mackerel diel behaviour in the Benguela current system in relation to environmental parameters

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[3]Institute of Marine Research, Bergen, Norway

Project description

The main objective of this study was to describe and improve understanding of diel vertical migration (DVM) patterns in Cape horse mackerel *Trachurus trachurus capensis* in the northern Benguela through a combination of acoustic, environmental and feeding ecology studies. The project arose from the need to improve understanding of the effects of horse mackerel behaviour on estimates of biomass from acoustic surveys, which are used routinely in the northern Benguela to assess the state of the resource. The biomass estimates are the primary input to management of horse mackerel in both Namibia and Angola.

DVM patterns were studied through a number of 24-hour diel cycle observations in the autumns of 2001 and 2002 from *RV Dr Fridtjof Nansen*. The 2001 study was carried out over one day on the outer shelf off the Cunene River, and the 2002 study at one station off Angola and three cross-shelf stations off the Cunene River. The fish were detected acoustically at three frequencies and sampled by a small pelagic trawl fitted with three codends to enable discrete sampling of selected layers. A Hydrobios plankton multinet equipped with five nets was used to identify available food items. Horse mackerel stomach contents were analysed for prey weight and digestive state.

Achievements

In 2001, a clear DVM in adult Cape horse mackerel was observed (Fig. 1). In the 2002 study, a pronounced DVM was observed in adult Cape horse mackerel offshore of the Cunene River, but it was less pronounced in juveniles closer inshore (Fig. 2). In the offshore waters the fish were distributed between 150 and 200 m during the day, just above oxygen-deficient waters and layers of euphausids on which they appeared to feed selectively. At night the fish rose to a depth of around 50 m. The euphausids also rose to the surface at night, but were distributed over a wider depth

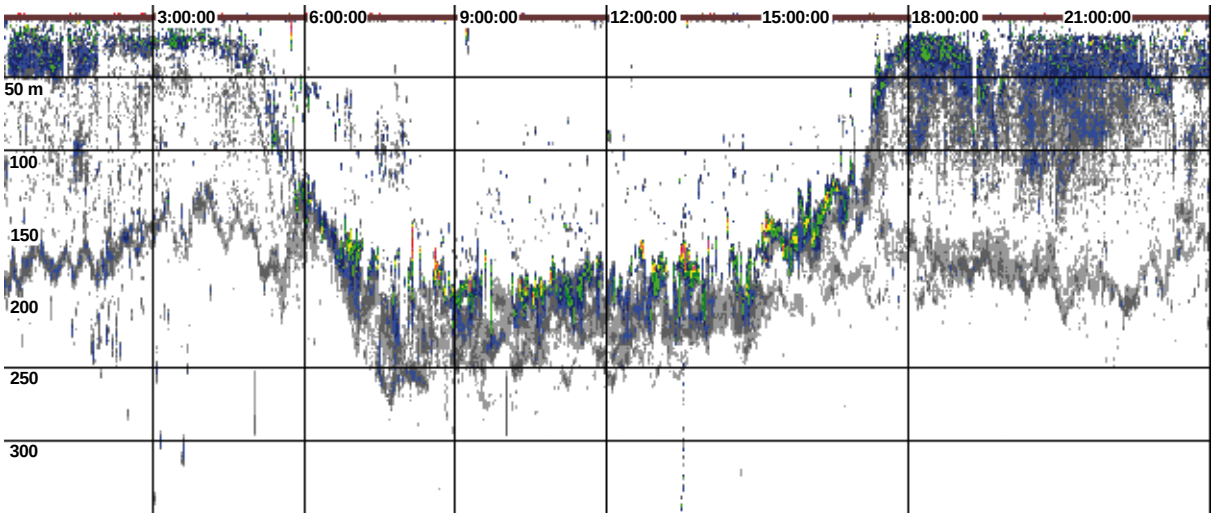

Figure 1. 38 kHz echogram showing diel vertical migration of adult Cape horse mackerel over deep water (approximately 1000 m) off the Cunene River in August 2001.

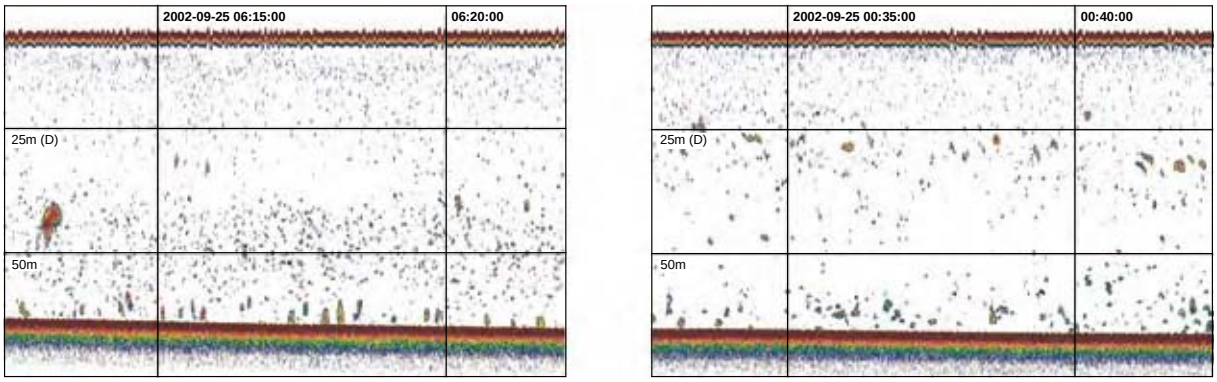

Figure 2. 38 kHz echograms showing diel change in behaviour of juvenile Cape horse mackerel in shallow water (approximately 100 m) off the Cunene River in September 2002. Day (left) and night (right).

range. Horse mackerel ascent started at around 15h00, and descent at around 05h00. Feeding peaked during the afternoon, just before the start of the vertical migration (Fig. 4). No DVM of either Cape or Cunene horse mackerel *Trachurus trecae* (which occurred in approximately equal amounts) was observed at the Angolan station, in shallow water.

In summary, in both 2001 and 2002 adult Cape horse mackerel showed clear DVM patterns, but the patterns were different in Namibian and Angolan waters. Furthermore, the pattern, position in the water column and aggregating behaviour of juveniles in shallower water were different from that of the adults. The confinement of Cape horse mackerel to the midwater in the northern Benguela as opposed to the southern Benguela, where they habitually descend to the bottom during the day, seems to be primarily due to the low-oxygen bottom layer in the northern Benguela.

The feeding periodicity of Cape horse mackerel appears to be the same in the northern Benguela as in the southern Benguela, with feeding occurring mostly in the afternoon before the onset of migration towards the surface. As in the south, the DVM is not synchronised with the feeding periodicity, and cannot be directly attributed to it.

Figure 3 shows that the stomach contents in both years were completely dominated by euphausiids and mostly unidentifiable crustaceans, with euphausids dominating in 2001 and crustacean remains in 2002. It is notable that despite their abundance in the region, copepods were insignificant in the diet in both years, unlike in the southern Benguela, where they are an important component in the diet of *T. t. capensis*.

Figure 3. Composition by weight of Cape horse mackerel stomach contents from 2001 and 2002 studies.

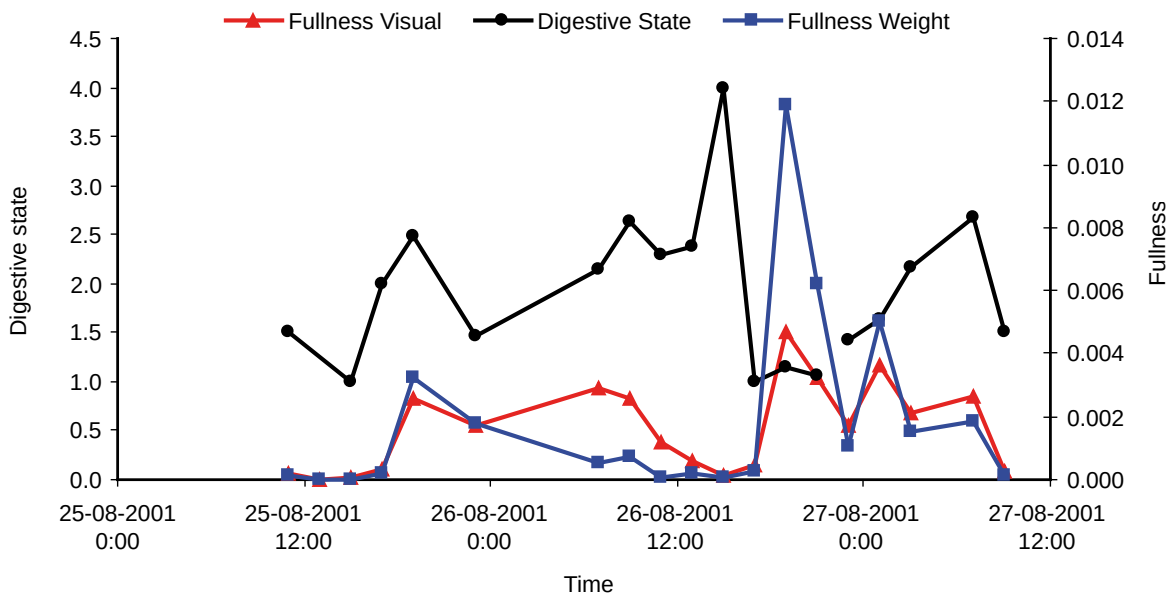

Figure 4. Fullness of Cape horse mackerel stomachs and digestive state over a 48 hour cycle in August 2001.

Output

Data

The acoustic and environmental data from this project are stored on CDs. The trawl and biological data are archived in the *Dr Fridtjof Nansen* (NANSIS) database.

Publications

Axelsen B-E., J-O. Krakstad and G. Bauleth-D'Almeida. 2004. Aggregation dynamics and behaviour of the Cape horse mackerel (*Trachurus trachurus capensis*) in the northern Benguela – implications for acoustic abundance estimation. In: U.R. Sumaila, D. Boyer, M.D. Skogen and S.I. Steinsham (Eds). Namibia's fisheries: ecological, economic and social aspects. Delft: Eburon. p.135-164.

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Relationship between right whale populations off Namibia, Angola and South Africa

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Project description

The aim of this project was to estimate the number of southern right whales *Eubalaena australis* occurring off the coast of Namibia and southern Angola in winter/spring, and the fraction of these which have previously been sighted off South Africa, thereby providing information on relationships between southern right whales in the northern and southern Benguela. It was also hoped that the study would be able to detect trends in abundance of these animals in the northern Benguela over time.

Whales were counted through low-altitude sighting surveys from a light aircraft flown by one of the Principal Investigators (Rod Braby). The surveys, which were conducted in spring 2003, 2004 and 2005, covered an area within 1 km of the coast between southern Angola and the Orange River, with most of the effort being concentrated in the south of Namibia. Animals were counted and some photographed for identification by reference to the South African right whale catalogue.

Achievements

In Figure 1 the numbers of sightings of adults with calves and unaccompanied adults in the three surveys are shown in relation to previous aerial sightings.

From Figure 1 and the paucity of incidental sightings before the early 1990s (Roux *et al*., 2001), it was tentatively concluded that there has been an increase in numbers since the last aerial survey in the 1970s, but that there is no obvious sign of an increase in the number of cows with calves. It would appear as if the southern right whale population visiting the Northern Cape and Namibia in spring is still small, and that there is little sign of the nursery ground off Namibia which evidently existed in the late eighteenth century.

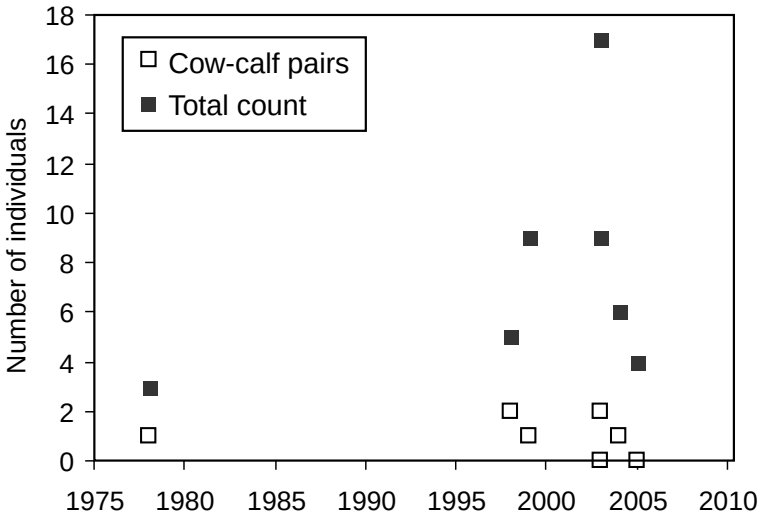

Figure 1. Numbers of all right whales and cow-calf pairs seen in aerial surveys of the coastline between the Northern Cape/ Orange River, South Africa, and Cunene River/Baia dos Tigres, Angola, 1978-2005.

A match was made between a calf photographed at De Hoop on the south coast of South Africa in 1999 and an adult photographed south of the Orange River (at 29°27.7'S) in 2003, increasing the likelihood that there is some mixing between South African and Namibian populations. However, because only three cows with calves were photographed, the BENEFIT surveys produced insufficient information for estimating the mixing rate between northern and southern Benguela populations. More surveys are needed to rectify this situation.

Apart from the scientific information, an achievement of the project has been the solving of the logistical and other problems involved in surveying a remote coastline at low altitude from the air with inadequate meteorological information. This, and the training given in aerial reconnaissance, will prove valuable in future work of this nature off the coast of Namibia.

Output

A photographic catalogue of identifiable individuals breeding and visiting the northern Benguela has been initiated.

Collection and management of Acoustic Doppler Current Profiler (ADCP) information

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[2]School of Marine Sciences, University of Maine, USA

Project description

The aim of this project, which was one of the earliest BENEFIT projects, was to a) improve the quality of ADCP data from the vessels operating in the region which are equipped with this instrument, b) standardise the data collection and analysis methods, and c) promote the routine collection of ADCP data on oceanographic cruises and fisheries surveys to improve understanding of water movement over the shelf and enable fish distribution and movements to be related to prevailing current patterns. It was also intended that the data be incorporated into a regional ADCP database for use by participants in the BENEFIT programme.

The project started by checking the performance and data quality of all ADCP units in use on vessels in the region (*RV Africana*, *RV Algoa* and *RV Dr Fridtjof Nansen*). This was followed by operator training, *inter alia*, through the development and upgrading of user-friendly operational instructions, and the initiation of a system for storing and archiving data. At a later stage, a start was made in developing a comprehensive set of software for processing the data on all the ships to replace the manufacturer's software, which was considered to be inadequate for the high-quality processing necessary.

This project made a strong start, culminating in the collection and analysis of ship-mounted ADCP data on a number of research cruises in the Benguela region, including the multi-national BENEFIT training cruise on *Africana* in July 1999 (Hocutt and Verheye, 2001). Unfortunately, due largely to manpower problems, and the fact that South Africa was the only country in the region collecting ADCP data on a regular basis, the project came to a halt as a regional project before achieving its main aims. It did however produce results which have been used in a number of publications and presentations, and gave impetus to other ADCP work in the region, as detailed below.

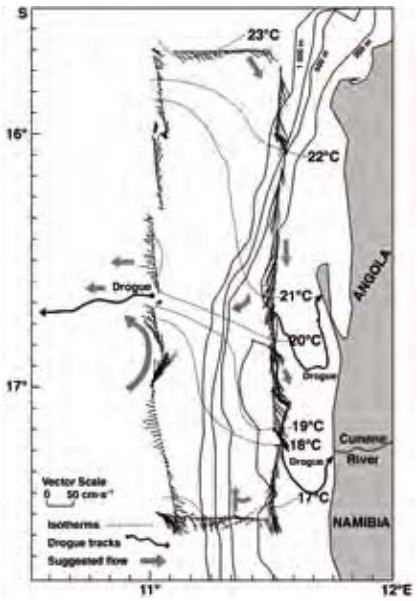

Figure 1. Near-surface currents in the Angola/ Benguela frontal zone during July 1999 inferred from ship-borne ADCP measurements (vectors) and three drogue tracks (from Figure 3, Boyd *et al*., 2001). The broad arrows show the authors' interpretation of the surface flow.

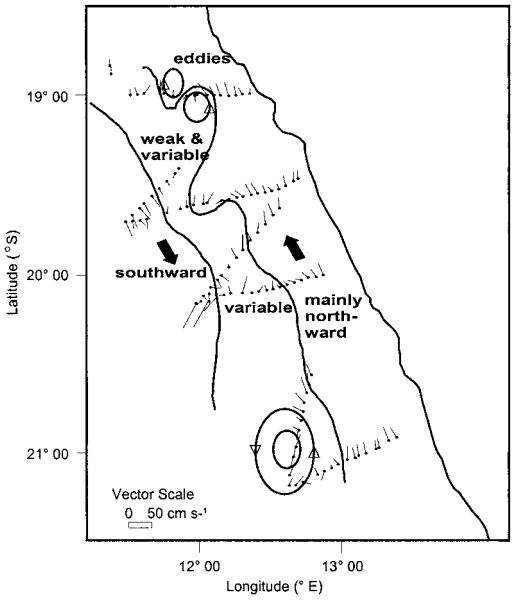

Figure 2. Water flow at a depth of 35 m over the Namibian shelf in July 1999, inferred by the authors from ship-borne ADCP measurements (vectors). From Figure 5, Mouton *et al*., 2001 (figure courtesy of South African Journal of Science).

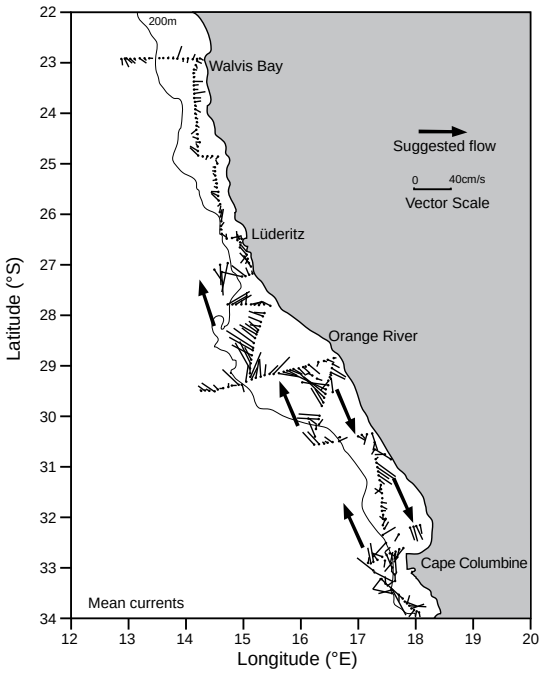

Figure 3. Water flow at a depth of 34 m over the shelf of the central and southern Benguela in July 1999, inferred by the authors from ship-borne ADCP measurements (vectors). From Figure 1, Iita *et al*., 2001 (figure courtesy of South African Journal of Science).

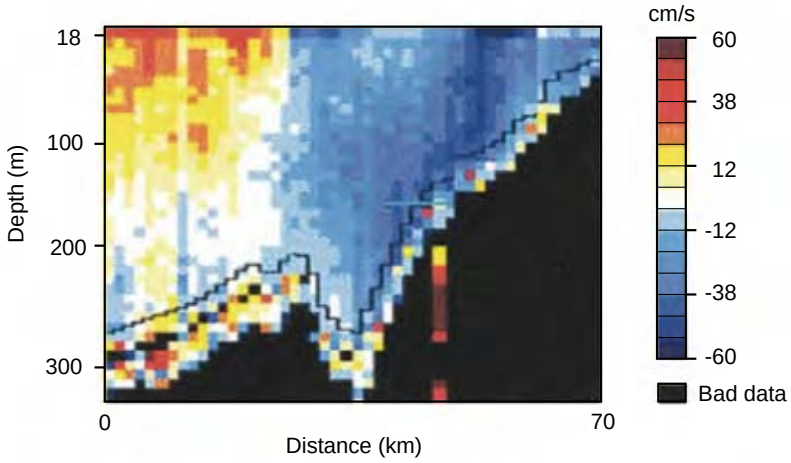

Figure 4. Vertical section of current flow off Cape Columbine in July 1999, from ship-borne ADCP measurements. Northward flow is shown in red and southward flow in blue. From Figure 2, Iita *et al*., 2001 (figure courtesy of South African Journal of Science).

Achievements

Through this project, a considerable amount of training in the use of ADCPs was given within the region, and a substantial volume of ADCP data collected on cruises in the northern and southern Benguela in the earlier stages of the project. ADCP data collected on the BENEFIT Training Cruise on *RV Africana* in 1999 and analysed through this project produced much information (some of it new) on water movement over the shelf in a number of regions between Cape Columbine and the Angola/Benguela front (e.g. Figs. 1 to 4, taken from Mouton *et al*., 2001; Iita *et al*., 2001; Boyd *et al*., 2001. See also Figure 5, Largier *et al*., this report, for a synthesis of the information gained on near-surface currents in the Benguela through this and other BENEFIT training cruises in 1999). In another study, Sundby *et al*. (2001) used ADCP data collected from *Dr Fridtjof Nansen* to describe spawning patterns of Cape hake in the northern Benguela in relation to water movement there. The water circulation at 35-50 m depth inferred from this study is shown in Figure 5.

A Namibian researcher, Aina Iita, was awarded a Masters degree by the University of Cape Town for work funded by this project, which also funded trips by her to Germany and Norway for training and discussions on the processing, validation and storage of ADCP data, particularly through the CODAS system. Her thesis dealt with how CODAS could improve the accuracy and consistency of ADCP data.

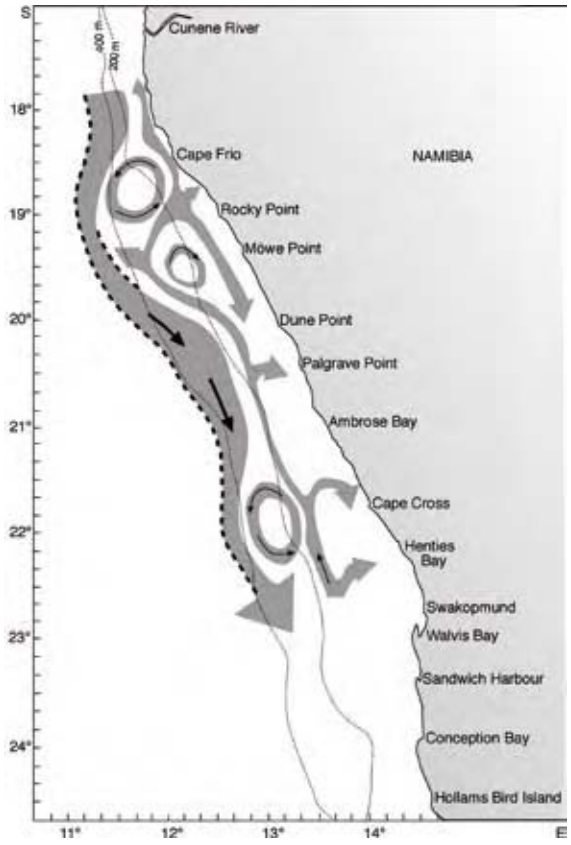

Figure 5. Water circulation between 35 and 50 m off Namibia inferred from hydrographic and ship-borne ADCP measurements in September/October 1998. From Sundby *et al*., 2001 (figure courtesy of South African Journal of Marine Science).

Despite its premature termination, this project made considerable progress in identifying the problems associated with such an ambitious undertaking, and was instrumental in a number of operators being trained in the collection and analysis of ADCP data, and in raising awareness of the need for specialised, high quality processing software for the intended purpose. Furthermore, through the initial training and use of ADCPs in studying the early life history of fish, the project gave impetus to the use of ADCPs in South Africa's Sardine and Anchovy Recruitment (SARP) Project, in which ADCP measurements are central, and in ongoing work on the relation between fish distribution and water movement in the Agulhas Current region.

Outputs

Publications

Boyd A.J., V.L.L. Filipe and C.H. Bartholomae. 2001. Near-surface currents and hydrology off southern Angola in July 1999. South African Journal of Science 97: 219-222.

Hocutt C.H. and H.M. Verheye. 2001. BENEFIT marine science in the Benguela Current region during 1999: Introduction. South African Journal of Science 97: 195-198.

Iita A., A.J. Boyd and C.H. Bartholomae. 2001. A snapshot of the circulation and hydrology of the southern and central shelf regions of the Benguela Current in winter 1999. South African Journal of Science 97: 213-217.

Sundby S., A.J. Boyd, L. Hutchings, M.J. O'Toole, K. Thorisson and A. Thorsen. 2001. Interaction between Cape hake spawning and the circulation in the northern Benguela upwelling ecosystem. South African Journal of Marine Science 23: 317-336.

Mouton D.P., A.J. Boyd and C.H. Bartholomae. 2001. Near-surface currents and hydrology off northern Namibia in July 1999. South African Journal of Science 97: 209-212.

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Iita A.T. 2002. Characteristics of near-surface circulation patterns in the Benguela as derived from ADCP (Acoustic Doppler Current Profiler). MSc thesis, University of Cape Town, South Africa. 89pp.

Co-operative governance of the Orange and Cunene river mouth estuaries

Alan Boyd[1], Hannes Holzhausen[2] and Domingos da Silva Neto[3]

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[2]National Marine Information and Research Centre, Swakopmund, Namibia

[3]Instituto Nacional de Investigação Pesqueira, Luanda, Angola

Project description

This was a multi-disciplinary project aimed initially at assessing knowledge of the ecology of the Orange and Cunene River estuaries and human impacts on them in order to identify what needs to be done to manage these estuaries effectively. The work was conducted by a multi-national, multi-institute team consisting of scientists from M&CM, NatMIRC, INIP, the Council for Scientific and Industrial Research (CSIR), South Africa, the Department of Tourism, Environment and Conservation of the Northern Cape Provincial Government, the Nelson Mandela Metropolitan University (NMMU), South Africa, and the Ministries of Environment and Tourism and Agriculture, Water and Rural Development, Namibia. A number of other government agencies (such as the National Biodiversity Institute in South Africa), consultancies and NGOs were also involved.

After an initial comprehensive scoping workshop in October 2003, the project was pursued through a series of field trips (eight in all from February 2004 to August 2006) of typically five to 10 days duration, in which various aspects of the ecosystem (e.g. hydrology, vegetation, plankton, fish, bird and invertebrate populations) were studied. Most of these studies were done during low-flow conditions, but late in the project (February 2006) the opportunity arose for hydrological measurements in the Orange River estuary during high-flow, pre-flood conditions.

The results of the various studies have largely been reported independently. The progress of the project as a whole has been reported from time to time at various regional meetings, including the Southern African Marine Science Symposium (SAMSS) in 2005 and meetings of the Orange River Mouth Interim Management Committee (ORMIMC), as well as at an Estuarine and Coastal Sciences Association (ECSA) workshop in Lisbon in September 2004.

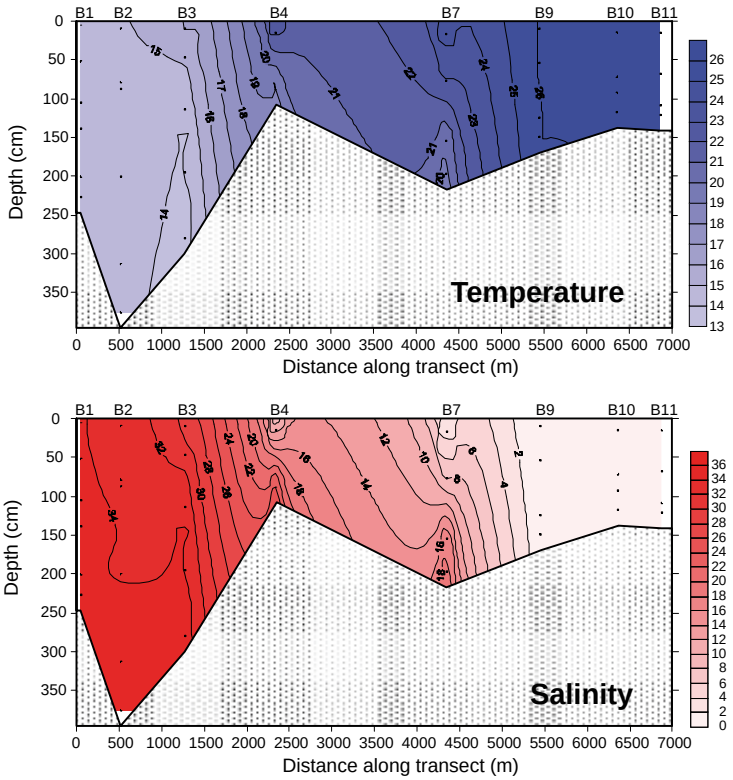

Figure 1. Temperature and salinity sections for the central channel of the Orange River estuary at high spring tide in February 2005.

Achievements

The major achievement of this project has been to put the importance of the estuaries of the arid west coast of Southern Africa on the map in the minds of researchers, managers and politicians, and to lay the groundwork for co-operative international governance of the Orange and Cunene River estuaries, both of which lie along international boundaries.

Specific achievements of the BENEFIT-funded aspects of the Programme include:

- Mapping of the thermohaline conditions of the Orange River (Fig. 1) and Cunene River (Fig. 2) estuaries during typical low-flow conditions, and the Orange River estuary during a high-flow period. It has been found that when the flow is low, there is extensive salinity penetration into the Orange River estuary, in contrast to the Cunene estuary, which is basically fresh. From a commissioned study by the CSIR on factors impacting on the Orange River estuary and its catchment area, it was concluded that the salinity in this estuary can function in different modes, depending on the amount of fresh water which is allowed to reach it. This study also examined the impact of historical developments in the flood plain, the role of factors such as mouth management and back-flooding of the estuary, and underscored the need for sufficient fresh water to be allowed to reach the estuary.
- Confirmation that there has been a decline in the availability and size of large pelagic species (notably the dusky kob *Argyrosomus coronus*) in the vicinity of the Cunene estuary since 2001 (Fig. 3). The work has also shown the absence of various angling species which have previously been recorded there such as elf *Pomatomus saltatrix*, West Coast steenbras *Lithognathus aureti*, blue stingray *Dasyatus pastinaca*, common eagle ray *Myliobatis aquila* and smooth houndshark *Mustelus mustelus*.

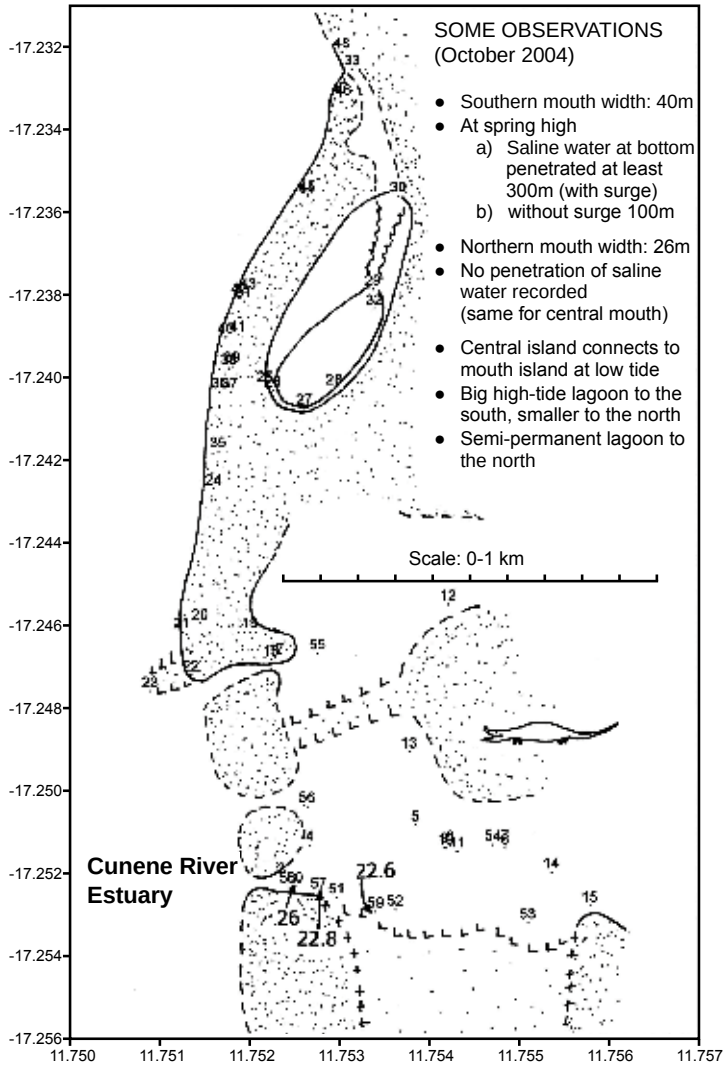

Figure 2. Map of the Cunene River mouth in October 2004, showing salinity characteristics. The small numerals show where GPS readings were taken and the larger numerals salinity readings.

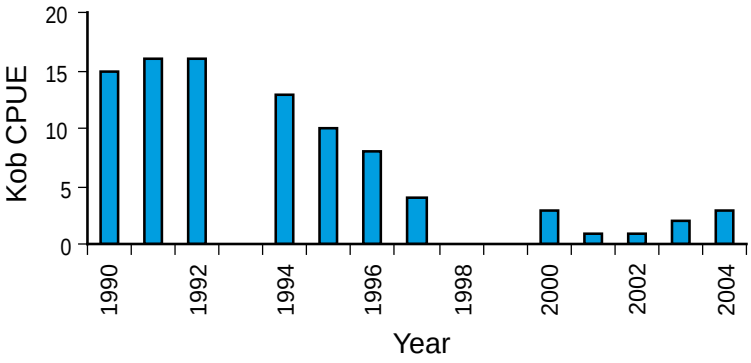

Figure 3. Decline in catches of dusky kob in the vicinity of the Cunene estuary since the early 1990s.

- Sampling of fish in the Orange estuary to a distance of 35 km upstream in four trips, and the Cunene estuary to 5 km upstream on one trip, with the purpose of establishing the importance of these estuaries as nursery areas for estuarine fish. In all, 33 species from 17 families were captured from the Orange River. The numbers, biomass and diversity were orders of magnitude greater than in all the previous studies there combined. More than half of the species were marine or estuary-dependent, suggesting that the Orange River estuary is an extremely important nursery area, and not just a freshwater conduit as was previously thought. It was observed that the Orange and Cunene estuaries share a number of important species such as leervis *Lichia amia* and West Coast steenbras, which suggests that these two systems may be important in linking fish populations of Angola, Namibia and South Africa, and for maintaining the range of some species at over 1000 km.
- Hydrological measurements and sampling of phytoplankton in the Cunene River estuary and adjacent coastline during a low-flow period in October 2004, for comparison with a study by the CSIR a decade previously. A key finding was the fresh nature of the water at the mouth and along the beach on the Angolan side, compared to the saline water in the surf-zone on the Namibian side, right up to the mouth (Fig. 4). This is consistent with the finding of a northwards current in the surf zone on the Angolan side of the mouth, extending many km up the coast (Fig. 5). The phytoplankton sampled in the mouth and in the northward-flowing estuarine plume consisted mainly of diatoms.

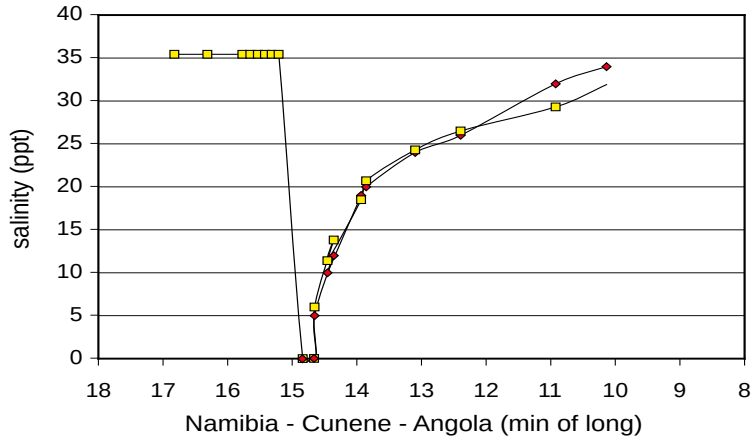

Figure 4. Longshore distribution of salinity in the surfzone on either side of the Cunene River mouth in October 2004, measured from bottle samples (□) and by refractometer (◊).

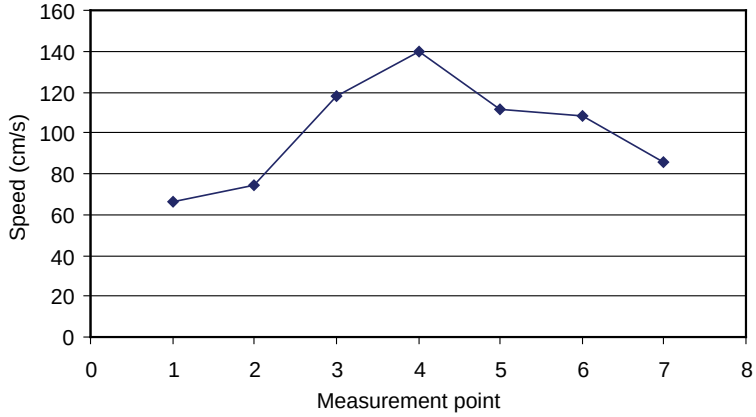

Figure 5. Longshore northward current velocities north of the Cunene River mouth in October 2004. The distance between the first and last measurement point is approximately 1 km.

- Compilation of a booklet on the birds of the Orange River estuary and the surrounding area. This was jointly funded by BENEFIT under the current project, and the "Working for Wetlands" Programme of the National Biodiversity Institute. The booklet has been published by the University of Cape Town's Avian Demography Unit as Guide 5 in its "Bright Continent" series.
- Sampling of invertebrate fauna (macrozoobenthos, hyperbenthos and macrozooplankton) in the Orange River estuary in August 2004 and February 2005, the Cunene estuary in October 2004 and, for comparison, the Kwanza and Catumbela estuaries in Angola in September 2005. The research in Angola was undertaken by a PhD student (Shaun Deyzel) from NMMU. The study showed that all four estuaries were river dominated, even in the low-flow periods during which they were sampled, and that marine influence is probably highly variable, resulting in few invertebrate species and relatively low biomass in the estuaries. The Orange River estuary has probably moved towards more stable estuarine conditions as a result of river regulation, leading to the establishment of more permanent euryhaline populations not present during earlier studies. The relatively calm backwaters in the two Angolan estuaries are probably important in that they appear to be the only habitats that currently allow the establishment of estuarine populations in the lower reaches of these systems. It has been suggested that in the larger river-dominated estuarine systems between Cape Point and Luanda, the marine nearshore region functions as an important estuarine zone, which may be negatively impacted by water abstraction from the rivers in ways which are not yet understood.
- A baseline survey of vegetation and physio-chemical characteristics of the Orange River mouth to establish transects for long-term monitoring and examine the rehabilitation potential of the mouth, done for the Working for Wetlands Programme. This was followed up by further funded field studies to determine groundwater salinity and the depth of the water table below the desertified marshes, and to study the potential of the marshes to recover naturally should the soil and groundwater conditions become favourable. The work was carried out by NMMU as part of the BENEFIT-funded project, and was timed to coincide with other BENEFIT field trips there. The follow-up work allowed the project to continue up to, and include, the flooding of the saltmarsh in 2006.

In all of the above studies, with the exception of the ornithological project and the first Orange River vegetation study, the field work was funded and supported in other ways by BENEFIT.

Output

The main tangible output of the project is the report of the scoping workshop in 2003 and a series of reports on the individual field trips and the results obtained.

A less tangible, but no less valuable, achievement of this project has been its success in building up a multi-national, multi-disciplinary constituency of researchers and stake-holders in the Orange and Cunene estuarine ecosystems, on which to found future attempts to understand, protect, and where necessary, restore and improve the biodiversity and ecological functioning of these unique ecosystems.

Publications

Shaw G.A., Adams, J.B. and T.G. Bornman. 2008. Sediment characteristics and vegetation dynamics as indicators for the potential rehabilitation of an estuary salt marsh on the arid west coast of South Africa. Journal of Arid Environments 72(6): 1094-1106.

Theses

Shaw G. 2007. The rehabilitation of the Orange River Mouth salt marsh: seed, wind and sediment characteristics. MSc thesis, Nelson Mandela Metropolitan University, Port Elizabeth, South Africa. 164pp.

Investigation of errors in surveys of fish resources in the Benguela current

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Project description

The purpose of this project was to address the major sources of uncertainty in acoustic and trawl surveys of fish in the northern and southern Benguela, with a view to a) assessing the major sources of uncertainty and their effect on biomass estimates, and b) conducting experiments to better quantify the uncertainties, and reduce them where possible.

The project was executed mainly through the following regional workshops, all of which had input from local and, in most cases, overseas specialists.

1. A workshop in Cape Town in December 1999 to assess the use of distance-sampling techniques for improving sonar and sighting estimates of the biomass of near-surface schools.
2. A workshop in Swakopmund in September 2000 to investigate the various designs used in acoustic and trawl surveys in the region, and in particular the possible use of adaptive sampling techniques to reduce sampling variance in acoustic surveys of pelagic species with highly patchy distributions, such as sardine.
3. A synthesis workshop in Cape Town in December 2000 to quantify and prioritise as far as possible the major sources of error in acoustic and trawl surveys in Angola, Namibia and South Africa, and model their effect on biomass estimates.
4. A second synthesis workshop, held in Cape Town in November 2003, to assess progress made in reducing the uncertainties identified above and update the inputs to the error model where necessary.

Following a recommendation by the synthesis workshop in 2000, a regional study into the effects on the sardine estimates of sound absorption in dense, vertically extensive schools was initiated and carried out through this project, in which Namibian and South African researchers collaborated. The approach was to develop corrections for absorption on the basis of regressions between the density of the schools and the reduction in the intensity of the echo from the sea bed beneath them.

Other experimental work conducted under this project was done on a dedicated cruise on *Dr Fridtjof Nansen* in April 2003, during which target strength measurements were made and sonar data capture software tested. In addition, a simulation study into various adaptive designs for acoustic surveys of sardine in Namibia was initiated.

Achievements

Distance sampling workshop (December 1999)

This workshop, which was attended by a specialist in distance-sampling (Dr David Borchers, Research Unit for Wildlife Population Assessment, University of St Andrews, Scotland) and by sonar specialists Drs Olé Misund (IMR, Norway) and Pierre Fréon (IRD, France), succeeded in bringing together, for the first time, specialists in the range of technical and analytical techniques needed to apply distance-based methods to surveys of pelagic fish schools. The problems of interpreting sonar and sightings data were reviewed, and the basic principles of both line-transect and point transect-based sampling methods presented. It was concluded from an application of

the technique to a set of sonar data from sardine schools in Namibia that distance sampling and associated analytical methods, possibly with forward-looking rather than sideways-looking sonar (a new approach) could in principle be useful in surveys of near-surface fish schools in the Benguela Current, but that problems arising from the non-random vertical distribution of schools would have to be solved. Various experimental approaches to solving these problems were suggested. It was also concluded that line transect distance-sampling methods could be useful for estimating abundance from visual observations of sardinella schools in Angola, in support of sonar and/or echo sounder surveys there.

Survey design workshop (September 2000)

At this workshop, which was attended by, among others, two statisticians from the Department of Statistical Sciences, University of Cape Town and representatives of the Namibian pelagic fishing industry, the designs used in acoustic surveys of pelagic fish and trawl surveys of hake in the region were reviewed. Most discussion centred on ways of reducing the sampling variance in acoustic surveys of sardine off Namibia, in which sampling variance is particularly high because of the extreme patchiness and relative scarcity of the fish. Suggestions were put forward for optimising the use of scouting fishing vessels during the surveys, and for the development of formal rules for re-sampling areas of high density through the application of adaptive sampling theory. A project to develop and test these ideas through simulations based on data from the Namibian sardine surveys was proposed, and subsequently funded by BENEFIT through the Survey Errors project. Unfortunately, despite a promising start, this project had to be terminated because of manpower problems.

Survey errors workshop (December 2000)

This workshop was aimed at quantifying as far as possible the major sources of uncertainty in acoustic surveys of sardine, anchovy, horse mackerel and sardinella in the region, and in trawl surveys of hake in Namibia and South Africa and demersal assemblages (including shrimp) in Angola. It was attended by survey practitioners from the region, and a trawl gear specialist (Dr Aril Engås) from IMR, Bergen. For each species and survey type, the participants attempted through discussion to agree on the likely magnitude and distribution of each of the sources of uncertainty identified as important. These error distributions were input to a Monte Carlo simulation model which generated an overall error distribution from which various error statistics were computed. In some cases the simulations were re-run with certain errors removed to examine the contribution of these sources of uncertainty to the overall uncertainty.

For the acoustic surveys, the major conclusions were that a) uncertainty in target strength (particularly of horse mackerel) is of over-riding concern for estimation of absolute biomass throughout the region, that b) surface schooling and target identification are particularly problematic for surveys of pelagic fish in Angola, and c) that sound absorption in dense, vertically extensive schools is a potentially serious source of negative bias in surveys of sardine in South Africa and (particularly) Namibia. It was noted that most sources of uncertainty result in negative bias, and that in most cases, the inclusion of sources of error other than sampling error into the error model approximately doubled the CV estimated from the sampling error alone.

The major conclusion regarding the trawl surveys was that in both the Namibian and the South African hake surveys, the chief sources of uncertainty are the reaction of the fish to the gear (particularly herding responses) and uncertainty regarding the proportion of the population too far off the bottom to be sampled in bottom trawls, arising from variability in the vertical distribution. Interestingly, the model outputs tentatively suggested that in both the Namibian and the South African surveys, the catchability coefficient (q) is probably close to 1, which is highly relevant to stock assessment models based on the survey estimates.

The workshop made a number of recommendations on retrospective studies and field work which could be done to improve information on survey errors, including the study on sound absorption in sardine schools, which was subsequently taken up within this overall project.

Survey methods workshop (November 2003)

At this workshop, the error distributions decided upon at the previous workshop were re-visited, updated and re-prioritised on the basis of new information, where available. The workshop confirmed that target strength remains the major source of absolute error in acoustic surveys, and that herding, escapement and (in the case of the South African surveys) the large proportion of untrawlable ground on the south coast, are the largest source of uncertainty in trawl surveys of hake.

Study of sound absorption in sardine schools

This effect has been quantified empirically by regressing the reduction in the strength of the bottom echo beneath schools against school area density (*cf*. Fig. 1), for 94 sardine schools from South African national surveys, 73 schools from the Namibian national surveys and 74 schools from a BENEFIT study in South African waters in April 2002 from *Dr Fridtjof Nansen*, which was specifically directed at this problem. The measured attenuation was compared with that predicted from measurements of volume back-scattering strength through the school, using first-order scattering theory.

From the above, a common empirical relationship between correction factor and school area backscattering cross-section has been developed for schools in Namibia and South Africa (Coetzee *et al*., 2008). The correction is now being applied in routine surveys of sardine in South Africa, as well as retrospectively to surveys between 1998 and 2003 (Coetzee *et al*., 2008), but has yet to be applied in Namibia.

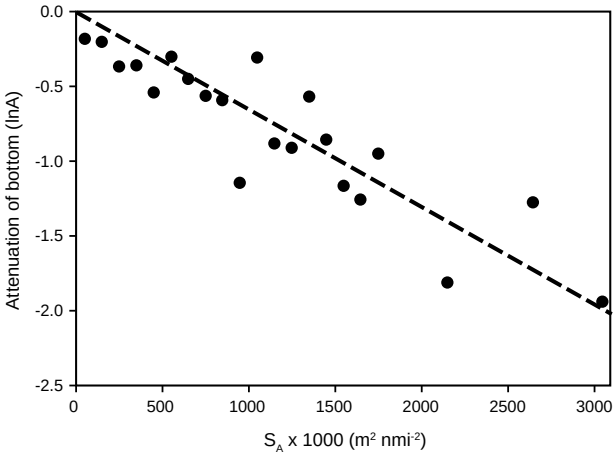

Figure 1. Relationship between bottom attenuation below sardine schools in Namibia and South Africa and the measured school back-scattering cross-section (from Coetzee *et al*., 2008).

Acoustic methodology studies, April 2003

On this cruise, sardine schools were too scarce for the intended sonar studies, and the density of sardine aggregations detected at night too dense for planned *in situ* experiments on sardine target strength. However, excellent data on the target strength of juvenile horse mackerel near the surface were obtained using split-beam *in situ* techniques (Fig. 2).

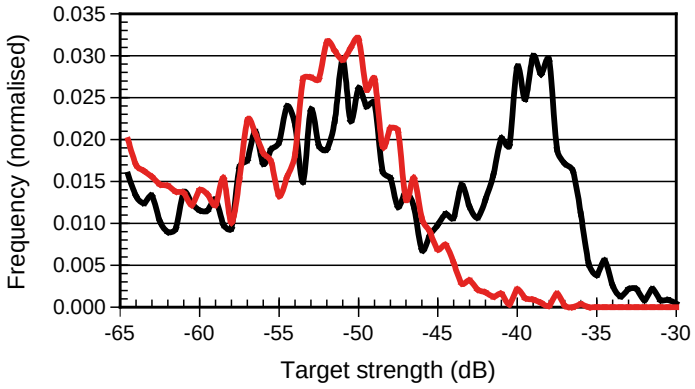

Figure 2. *In situ* target strength distributions for juvenile horse mackerel (black curve) overlaid on the target strength distribution of weak scatterers (in red) recorded in the same area earlier in the day.

Note that although relatively few survey methodological studies were carried out under this project, some of the problems identified at the workshops were investigated either through other BENEFIT projects (i.e. those on target identification and gear performance) or through national projects on, for example, the target strength of horse mackerel in Namibia, and the assessment of biomass in near-surface schools of sardinella in Angolan waters. The value of the project was more in the synthesis and regional prioritisation of problems, which is proving to be valuable in the planning of regional research into survey questions.

Output

The main output from this project was the set of workshop reports dealing with the methodological questions, and the nature, magnitude and importance of the major sources of error in surveys of fish resources in the Benguela.

Publications

Coetzee J.C, D. Merkle, C.L. de Moor (formerly Cunningham), N.M. Twatwa, M. Barange and D.S. Butterworth. 2008. Refining estimates of South African pelagic fish biomass from hydro-acoustic surveys: quantifying the effects of target strength, signal attenuation and receiver saturation. African Journal of Marine Science 30(2): 219-231.

Identification of acoustic targets

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Project description

The objective of this project was to investigate the use of multi-frequency acoustic techniques and multiple-codend nets to improve target identification in acoustic surveys of pelagic and mesopelagic fish in the Benguela Current. The project is of importance because of the difficulty often experienced during acoustic surveys in distinguishing between echo returns from co-occurring aggregations of pelagic and mesopelagic fish of different species, macrozooplankton and micronekton. In particular, it was hoped that acoustic identification of targets would supplement, and even largely replace, the time-consuming, cumbersome and potentially biased net-sampling methods currently in use.

The project had two foci: a) the search for species-specific differences in the backscatter simultaneously received from identified targets at four frequencies (*i.e*. 18, 38, 120 and 200 kHz), and b) testing the utility of a multi-codend net for sampling different scattering layers in the water column selectively.

The project started in 1999 with a multi-frequency study off *Dr Fridtjof Nansen*, which was carried out in Namibia and South Africa. A second multi-frequency study was carried out from *Nansen* on the western Agulhas Bank in the following year. The approach in both studies was to compare the frequency distributions of the mean volume back-scattering strengths at each frequency for each species identified. A Discriminant Function Analysis (DFA), based *inter alia* on the ratio of the backscattering intensity at the different frequencies, was used to search for sets of variables able to discriminate between species and/or target types.

In the net-sampling component of the project, a Bergen MultiSampler, consisting of three nets which could be opened remotely attached to the codend of a conventional midwater or bottom trawl, was used to investigate species composition of schools and layers during three BENEFIT research cruises on *Dr Fridtjof Nansen*. Samples from the different schools and layers caught in the three codends were examined for differences in species composition and length distribution. Any such differences were related to the acoustic appearance of the target from which the sample was taken. The work was conducted by Charlene Rogers for a BTech degree at the Cape Peninsula University of Technology, Cape Town.

Achievements

Largely through this project, fully functional, calibrated multi-frequency systems were set up on *RV Africana* and *RV Algoa*, and transducers on *Dr Fridtjof Nansen* re-positioned, enabling all of these vessels to conduct quantitative multi-frequency work routinely.

The DFA showed that the multi-frequency techniques tested were capable of powerful discrimination between many of the homogeneous scattering layers which occur frequently in the Benguela, but that they were not able to discriminate between the main pelagic species (anchovy and sardine) which are currently assessed by acoustic surveys in the region (see Fig. 1 and Tables 1 and 2).

Table 1. Success in acoustic discrimination between five species/species groups encountered during the surveys.

Species discriminated between		Success	Discrimination success based on frequency combinations		
			18/38khz	18/120kHz	38/120kHz
Sardine	Mesopelagics	✓		✓	✓
Sardine	Euphausiids	✓	✓		✓
Sardine	Copepods	✓		✓	✓
Sardine	Anchovy	×			
Anchovy	Mesopelagics	✓		✓	✓
Anchovy	Copepods	✓		✓	✓
Anchovy	Euphausiids	✓	✓	✓	
Mesopelagics	Copepods	×			
Mesopelagics	Euphausiids	✓	✓	✓	
Euphausiids	Copepods	✓	✓	✓	✓

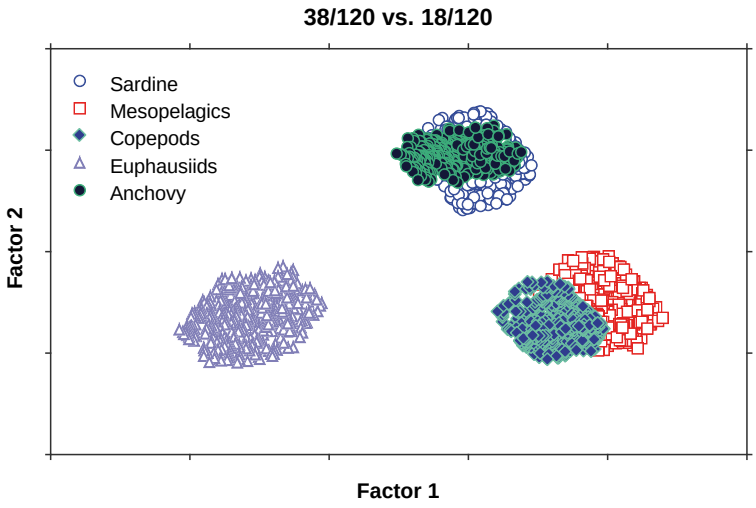

Figure 1. Factor scores by species. The factors are the ratio between the back-scattering intensity at 38 and 120 kHz, and at 18 and 38 kHz respectively.

Table 2. Identification matrix indicating classification success (or otherwise) for the five species/ species groups in the survey, based on the factor scores in Figure 1.

Correct classification (%)		Sardine P = 0.20	Anchovy P = 0.20	Mesopelagics P = 0.20	Euphausiids P = 0.20	Copepods P = 0.20
Sardine	59.50	238	162	0	0	0
Anchovy	63.25	147	253	0	0	0
Mesopelagics	81.00	0	0	324	0	76
Euphausiids	100.00	0	0	0	400	0
Copepods	87.00	0	0	52	0	348
Total	**78.15**	**385**	**415**	**376**	**400**	**424**

The MultiSampler results indicated that schools and layers which in conventional sampling with a single-coded midwater trawl would be sampled together, are often very different in species composition and in most cases in length distribution too. This has significant implications for the acoustic surveys in areas where the targets are not homogeneous in terms of species and/or size of the animals.

It was concluded that the project had thrown light on the identity of many of the acoustic targets commonly encountered in the region, and that some combination of the acoustic and net-sampling techniques (including the use of neural networks, cluster analysis and further development of the DFA techniques tested here) would ultimately prove to be the most reliable for identification of the targets of most concern to biomass surveys.

Outputs

- Fully functional, calibrated multi-frequency systems on *Africana*, *Algoa* and *Dr Fridtjof Nansen.*
- BTech degree at Cape Peninsula University of Technology (Charlene Rogers).

Abundance and distribution of mesopelagic fish in the Benguela ecosystem

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[2]University of Bergen, Bergen, Norway

[3]Institute of Marine Research, Bergen, Norway

Project description

This project was centred on an acoustic survey of the distribution and abundance of mesopelagic fish (in particular, the lantern fish *Lampanyctodes hectoris* and the light fish *Maurolicus muelleri*) between Cape Town and Walvis Bay from *Dr Fridtjof Nansen* in August/September 2006. The project was initiated at a late stage in the Programme using bridging Norwegian funds. It was motivated by perceptions from two acoustic surveys in the southern Benguela in the 1980s that the biomass of mesopelagic fish in the Benguela ecosystem is high, and from mass-balance models that they are important in the food web. It was one of the few BENEFIT projects aimed specifically at an ecologically important, but essentially non-commercial resource.

The survey, which covered the shelf to a depth of 500 m between 23 August and 12 September, was carried out at a primary frequency of 38 kHz. Data were also collected simultaneously at other frequencies to assist in target identification, and to improve single-fish detection in *in situ* experiments on the target strength of *M. muelleri*, *L. hectoris* and another common myctophid, *Symbolophorous boops*. Acoustic targets were identified by aimed fishing with midwater and bottom trawls. Eggs and larvae were sampled at regular stations throughout the survey with a Hydrobios Multinet, and eggs while underway using a Continuous Underway Fish Egg Sampler (CUFES).

Preliminary results have now been reported on, *inter alia*, the distribution and abundance of *L. hectoris*, *M. muelleri*, *S. boops* and the clupeoid *Etrumeus whiteheadi* (round herring), and on the distribution of *L. hectoris* and *M. muelleri* eggs and larvae. These are summarised below.

Achievements

Figure 1 shows the horizontal distribution of *L. hectoris* and *M. muelleri* deduced from the acoustic data, and Figure 2 that of *S. boops* and *E. whiteheadi*. Figure 1 shows that *L. hectoris* and *M. muelleri* were both widely distributed across the shelf throughout the region, with *L. hectoris* being more concentrated in the north and *M. muelleri* more in the south. The distributions in Figure 2 are more patchy, *S. boops* being highly concentrated in a small area on the edge of the shelf between Easter Point and Walvis Bay, and *E. whiteheadi* in a small area close inshore off Lüderitz.

The Hydrobios net samples showed that lightfish eggs were ubiquitous across the mid and outer shelf throughout the region, whereas myctophid (*L. hectoris* and *S. boops*) eggs were more patchily distributed (Fig. 3). Lightfish larvae were more patchily distributed than the eggs, but the distribution of the myctophid larvae was somewhat broader than that of their eggs.

Preliminary *in situ* 38 kHz target strength/length relationships were obtained for *L. hectoris*, *M. muelleri* and *S. boops*. In these experiments, multiple targets were screened out by comparing the ranges of candidate single targets detected simultaneously by a split-beam 38 kHz transducer and an adjacent single-beam 200 kHz transducer operating on a shorter pulse. The *L. hectoris* and *M. muelleri* relationships, which are considered to be more reliable than that for *S. boops*, are shown in Figure 4.

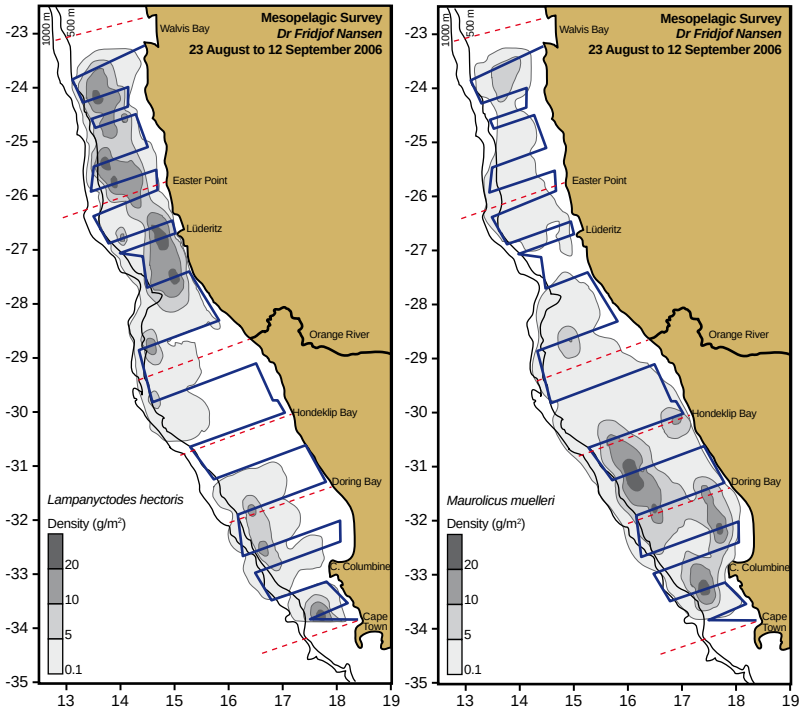

Figure 1. Horizontal distribution of lanternfish (left) and light fish (right) deduced from acoustic estimates of density along the transects shown.

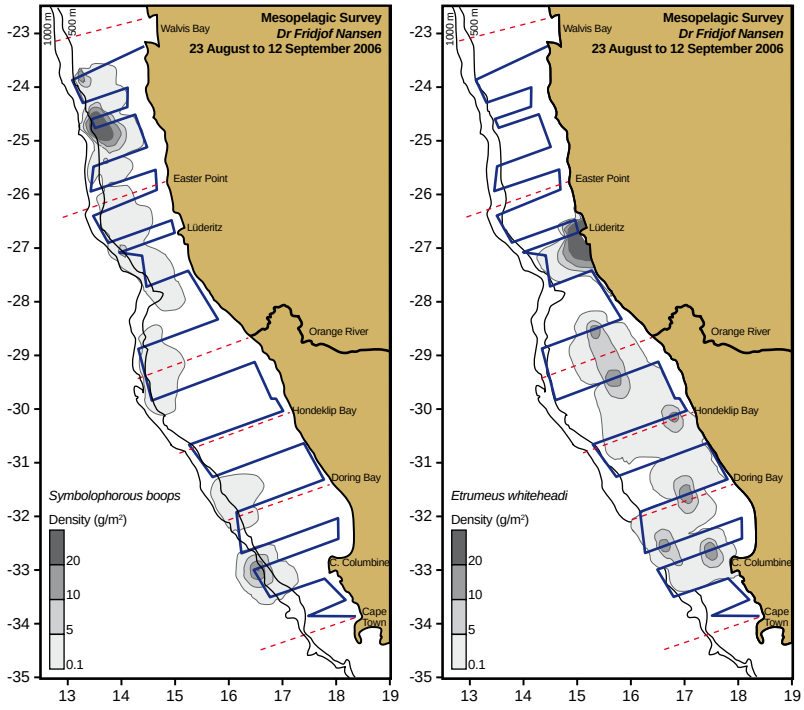

Figure 2. Horizontal distribution of *S. boops* (left) and round herring (right) deduced from acoustic estimates of density along the transects shown.

The relationships are the first *in situ* target strength expressions to be obtained for these three species. In addition to their use in this survey, they should prove to be valuable in future surveys of mesopelagic fish in the Benguela (the *L. hectoris* and *M. muelleri* expressions are already being used in routine acoustic surveys in South African waters), especially if the expressions can be extended through further experimentation to cover a wider range of *M. muelleri* and *S. boops* lengths. These two relationships need to be confirmed by experiments on more homogeneous *M. muelleri* and *S. boops* aggregations than those encountered in this survey, which usually contained a mixture of species. Information on the depth-dependence of *L. hectoris* target strength may come from an experiment during the survey in which target strength measurements were made on a descending layer (Fig. 5) using a lowered 38/120 kHz split-beam transducer package kept a short distance from the layer.

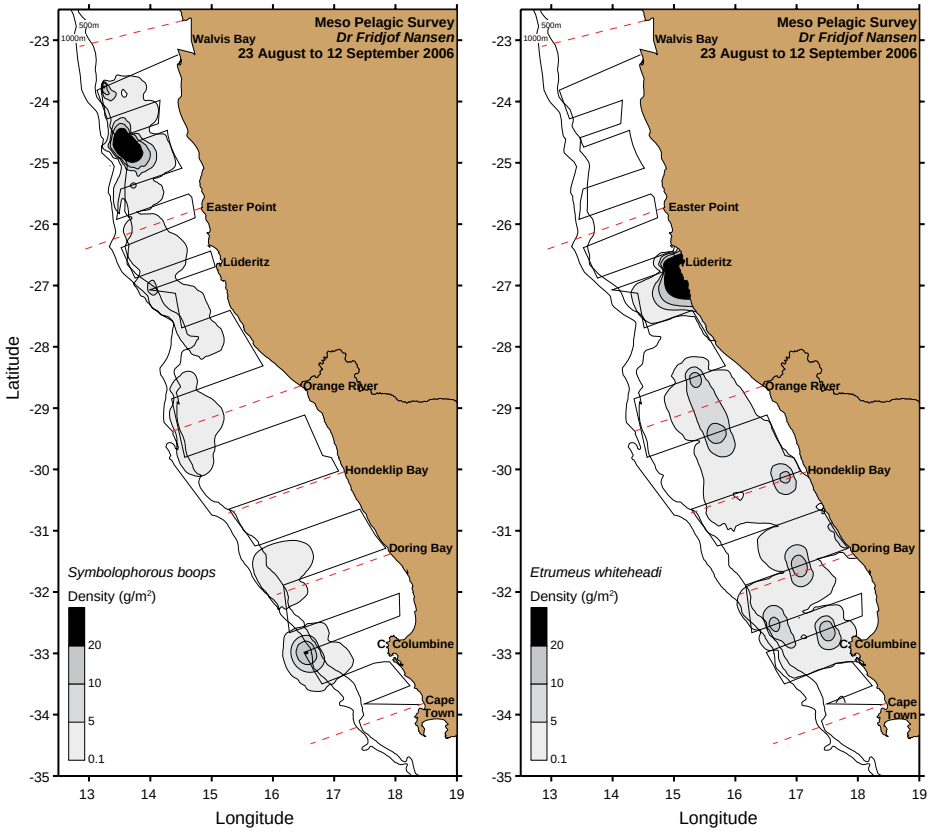

Figure 3. Distribution of (left) lightfish and (right) myctophid (*L. hectoris* and *S. boops*) eggs, from Hydrobios net samples.

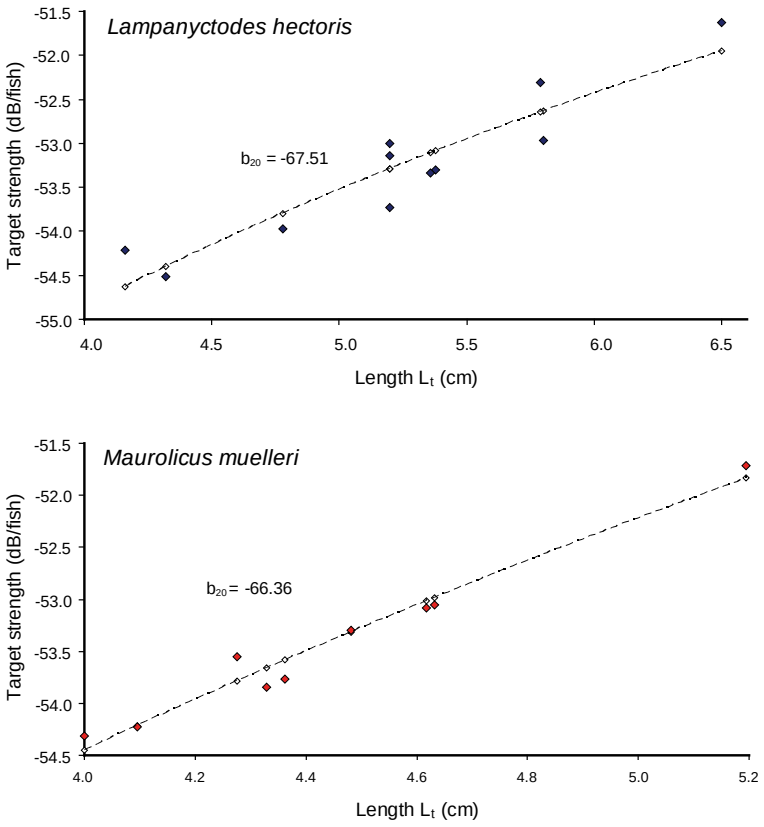

Figure 4. Preliminary 38 kHz target strength/length relationships for *L. hectoris* (top) and *M. muelleri* (bottom) from *in situ* measurements.

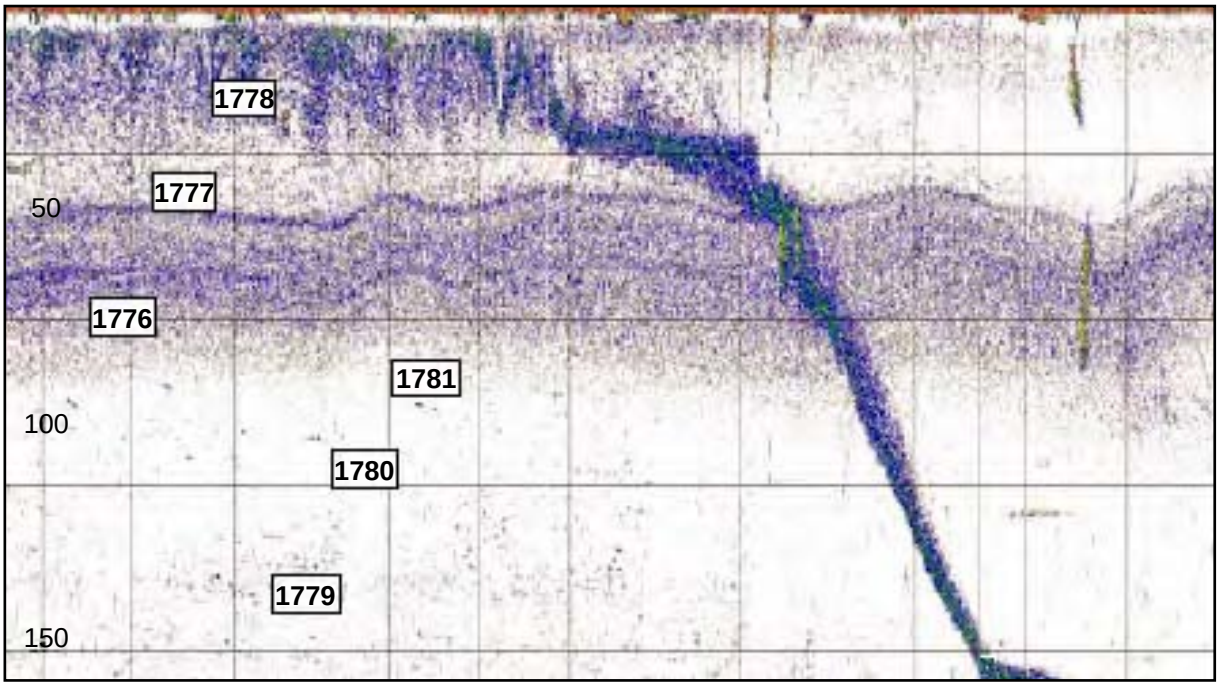

Figure 5. Dawn descent of an *L. hectoris* layer on 3 September 2006, approximately 30 miles south of Lüderitz.

In Table 1, preliminary acoustic estimates of *L. hectoris*, *M. muelleri* and *S. boops* biomass, obtained using the preliminary target strength relationships from this study, are given for the whole survey, and for the area between Cape Town and the Orange River.

Table 1. Preliminary acoustic estimates of *L. hectoris*, *M. muelleri* and *S. boops* biomass between Cape Point and Walvis Bay in August/September 2006. The CVs reflect the sampling error.

	L. hectoris		***M. muelleri***		***S. boops***	
Area	Biomass (tonnes x 10^3)	CV (%)	Biomass (tonnes x 10^3)	CV (%)	Biomass (tonnes x 10^3)	CV (%)
Cape Town to Orange River	564	16	103	31	254	44
Total area	709	15	745	22	284	41

These are the first direct estimates of the biomass of mesopelagic fish in the Benguela ecosystem as a whole, and are consistent with earlier perceptions of high abundance. The *S. boops* estimate is the first of its kind, but should probably not be used at this stage because of the greater sampling error and the fact that the target strength relationship is considered to be very much less certain than those for the other two species.

The data from the survey are being analysed in greater detail to refine the biomass estimates, and investigate environmental influences on the distribution and behaviour of mesopelagic fish and their ichthyoplankton in the Benguela ecosystem.

Outputs

The main outputs from the project at this stage are the data set from the survey, archived in the Nansen database (NANSIS), and the target strength-length relationships, which are already in general use in South African acoustic surveys.

Dynamics of hydrogen sulphide and methane in Namibian inner shelf sediments

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Project description

This project monitored the sedimentary processes on the inner Namibian shelf which result in the generation and dispersal of hydrogen sulphide, to improve understanding of the temporal variability in the generation of sulphide and methane in the diatomaceous mud belt on the inner shelf sediments, and of their fluxes into the overlying water. Further objectives were to investigate sources of the hydrogen sulphide, and to determine the extent to which resident sulphide-oxidizing bacteria are able to reduce hydrogen sulphide in the sediment. The project at large is of importance to ecosystem studies because of the highly toxic nature of the water during the hydrogen sulphide eruptions which occur sporadically, but dramatically on the inner shelf of central Namibia.

The project was carried out through the monitoring at 2-monthly intervals of four Sediment Laboratory (SEDLAB) sites in the Walvis Bay/Swakopmund region between May 2001 and May 2004, at which the water column was sampled for oxygen, methane, sulphide and nutrients, and sediment sampled with a multicorer. Methane, hydrogen sulphide and sulphate reduction rates in the sediments were measured, as well as the concentration of large sulphur bacteria in the sediment.

Achievements

The SEDLAB monitoring was kept up successfully throughout the 3-year period, and produced much new information on the sedimentary processes which result in the generation and dispersal of hydrogen sulphide and methane on the inner shelf off central Namibia. Marked fluctuations in the content of methane and hydrogen sulphide in the sediment, and in the flux of methane and hydrogen sulphide out of the sediments into the water column were observed throughout the study period (Fig. 1). These fluctuations were episodic and seemingly unrelated to the seasonally varying flux of organic matter and/or oceanographic conditions. Free methane gas was found consistently within

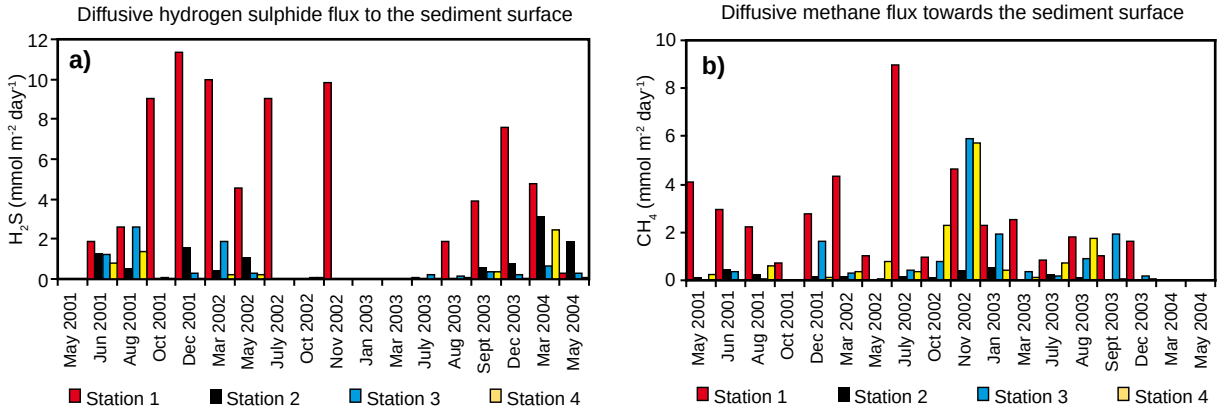

Figure 1. Diffusive flux of hydrogen sulphide (left) and methane (right) to the sediment surface over the entire SEDLAB monitoring period.

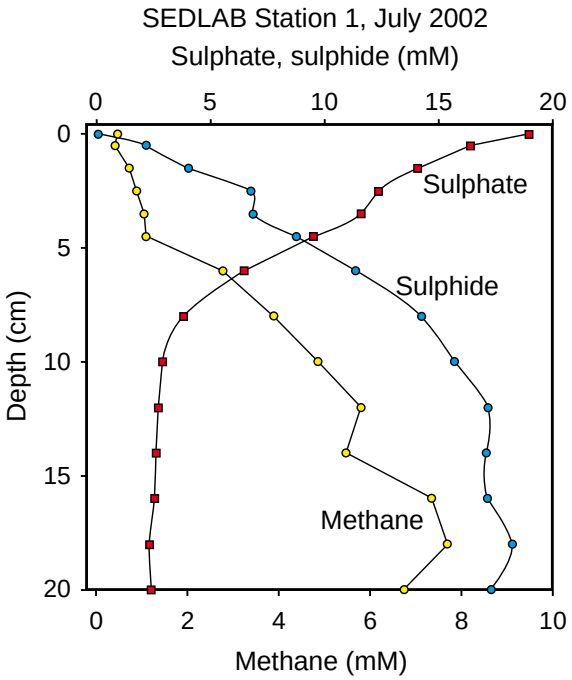

Figure 2. Representative depth profile of dissolved sulphate, sulphide and methane concentration from SEDLAB Station 1, July 2002.

centimetres of the sediment surface at the SEDLAB station closest to Walvis Bay (Fig. 2), which is the area most prone to eruptive events. The temporal variations in sediment methane concentration were correlated at all SEDLAB stations, although the farthest stations were more than 100 km apart, suggesting a possible large-scale physical mechanism driving episodic methane discharge. Oxidation of hydrogen sulphide by large sulphur bacteria (particularly *Thiomargarita namibienses* and *Beggiatoa* spp., which form dense mats over extensive areas of mud on the inner shelf) was found to be of major importance in the removal of hydrogen sulphide from the system when oxygen concentrations on the bottom are low for a prolonged period. The relative abundance and distribution of these bacteria on the inner shelf varied considerably during the study period (Fig. 3).

This project was complemented by independent studies between 2001 and 2004 on the nature and extent of the mud belt on the inner shelf through acoustic and visual observations from *RV Dr Fridtjof Nansen*, *RV Welwitschia*, *RV Meteor* and *RV Alexander von Humboldt*, and experiments on the tolerance of a number of resident species (juvenile horse mackerel and gobies) to elevated levels of hydrogen sulphide. Furthermore, satellite remote sensing has revealed that naturally occurring hydrogen sulphide eruptions and the resulting hypoxia are much more extensive and longer-lasting events than previously suspected, probably with important consequences for the marine ecosystem and coastal fisheries. These studies, although not part of the project, have enabled the findings to be placed in a wider context, adding significantly to the project's value as an ecological study.

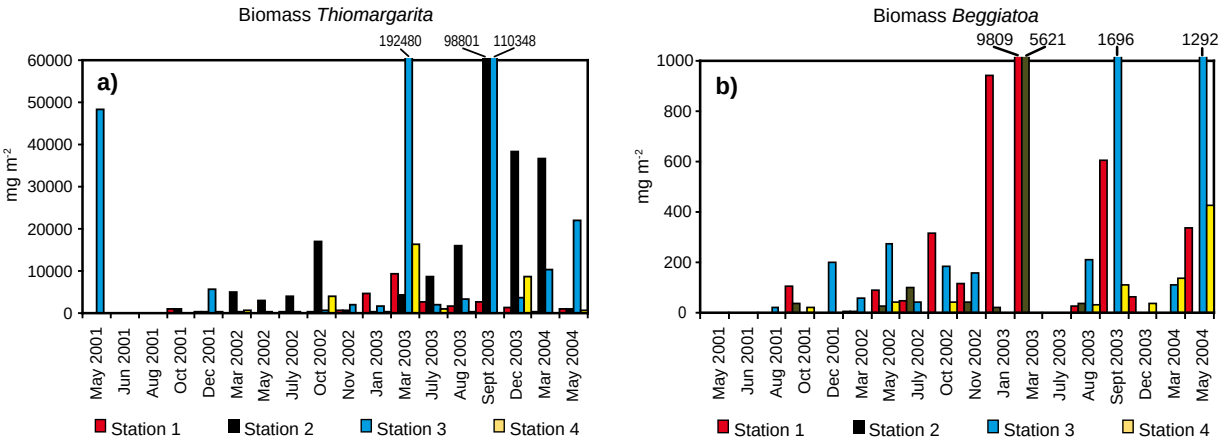

Figure 3. Biomass of *Thiomargarita* and *Beggiatoa* spp. at SEDLAB stations between May 2001 and May 2004.

Output

Publications

Brüchert V., B. Currie, K.R. Peard, U. Lass, R. Endler, E. Julies, T. Leipe and S. Zitzmann. 2006. Biogeochemical and physical control of shelf anoxia and water column hydrogen sulphide in the Benguela coastal upwelling system off Namibia. In: L.N. Neretin (Ed.). Past and present water column anoxia. Springer, Netherlands. p.161-193.

Age determination of fish in the Benguela region

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Project description

The aim of this project was to assess, improve where necessary, and standardise the techniques used in the Benguela region to age various commercially exploited fish species. Inherent in the project was building capacity within the region for routine determination of the age of exploited species. The project is of direct relevance and major importance to management, in that accurate ageing is a pre-requisite for the age-structured assessment models needed to make management recommendations for these species, and limited ageing capacity in the region has been a major obstacle to stock assessments for the past few decades.

The project was carried out almost entirely through a series of regional workshops, at which training in otolith preparation, reading and interpretation was given by specialists in the field. The skill of the participants, and the reliability of the method(s) *per se*, were assessed by comparing replicate age readings between and among readers. On the basis of the stability in these readings, judgements were made on whether the extant ageing methods and skills were reliable enough for the method to be used to generate age information for use in stock assessments in the region, and if not, to make recommendations for improvements.

The project also supported an MSc study into the growth and mortality of sardine pre-recruits in the southern Benguela.

Achievements

Horse mackerel otolith-reading workshops

After an initial attempt to validate presumed annual rings in horse mackerel through a laboratory study, three regional workshops were held in Swakopmund between 2000 and 2003 to train participants in the preparation and reading of *Trachurus capensis* and *T. trecae* otoliths. The first two were led by the late Dr Michael Kerstan, and the third by Dr Deon Durholtz. At the first workshop it was concluded that reading of whole otoliths was too unreliable, and that other methods of otolith preparation (particularly burning and slicing) should be explored. This method was tried at the second workshop, at which otoliths were interpreted via group examination of individual otoliths displayed using an image enhancement system. It was found that specimens could be read reasonably well, and that individual participants produced acceptably precise age determinations. However, the variability within the group was too great for the generation of consistent, comparable age keys. At the third workshop, at which a similar approach was used, the results were again generally too unstable and imprecise for the method to be acceptable for stock assessment. The problem with this, and the previous workshop, was the inexperience of most of the participants, due largely to high staff turn-over rates within their respective institutes. It was recommended that to overcome this problem, efforts be made to build up a stable core of experienced readers in the region through improved staff retention measures, in-house experiential training and the development of an otolith exchange programme.

The data from the third workshop have been used in a case study on the effects of ageing errors on stock assessments and management advice for horse mackerel in Namibia (Wilhelm *et al*., 2008). In-house ageing of horse mackerel has continued in Namibia, using age data from the 2003 workshop and results from the case study.

Hake and dentex otolith-reading workshops

A regional workshop to assess the current methods of ageing hake (*Merluccius capensis* and *M. paradoxus*) and dentex (*Dentex angolensis* and *D. macrophthalmus*), explore ageing alternatives and provide training in otolith interpretation to researchers new to the field was held at the University of Cape Town in June 2004. Dr Ana Gordoa and Dave Japp gave expert advice on hake ageing to the Namibian and South African participants, while Dr Steve Brouwer advised the Angolan participants on the ageing of dentex.

Hake

It was found that for hake, whole otoliths gave better results than sliced otoliths. The readings were however imprecise, and there were large differences in otolith interpretation within the group, particularly regarding the identification of the first annulus and the identification of false rings. It was recommended that further attention be given to clarifying identification criteria, and that effort be devoted to validating the techniques. Namibian readers continued reading previously collected otolith samples for stock assessment purposes after the workshop, and met again with South African readers at a further regional ageing workshop in Swakopmund in September 2005, where four new readers (three Namibian and one South African) were trained, and the four readers trained at the previous workshop were tested to see whether their performance had improved. It was found that the performance of the previously-trained readers had improved (Table 1), and that the participants generally performed better than in 2004, presumably because of the better-defined identification criteria and greater all round experience gained over time. Another achievement was the generation of material for a reference collection of *M. capensis* and *M. paradoxus* otoliths from specimens for which there was a high degree of reader agreement.

Table 1. Comparison between the measurement variations in three readings of the same otolith by readers who participated in both the 2004 and 2005 workshops. The variation is expressed as the CV in the individual readings (in %).

Reader	2004	2005
Nam 1	54.6	24.9
Nam 2	50.2	37.4
SA 1	30.6	19.7
SA 2	50.9	19.9

After the first workshop, the Namibian readers generated six age-length keys for hake, which were used in an indirect validation study presented at the Southern African Marine Science Symposium in Durban in July 2005.

In May 2006, a further BENEFIT/BCLME mini-workshop was held at M&CM in Cape Town to assess the possible use of hake otoliths taken from seal scats for validating age determinations. This approach builds on data collected by Dr J.P. Roux from seal colonies along the Namibian coast. Otoliths extracted from seal scats are used to compute length distributions of the hake (mainly *M. capensis*) taken by the seals. Monthly sampling at the various colonies provides the opportunity to identify discrete hake cohorts and monitor the growth of hake otoliths, and particularly to validate the deposition of periodic features. The value of the approach lies in the possibility of validating at least the annuli for the first two years, when *M. capensis* are available to the seals.

The pilot study, carried out on 300 otoliths from seal scats from an identified strong 1998 (winter-spawned) *M. capensis* cohort indicated that the first visible hyaline band is usually false, and that only the second at about 8 mm otolith diameter should be identified as the first true annulus, which seems to form in winter. Confirmation of this important result by analysing otoliths from other strong cohorts is needed. Following the cohorts from strong year-classes identified in the seal scats though the survey samples appears promising as an indirect age-validation technique. The technique is being investigated by Margit Wilhelm at NatMIRC as part of a Doctoral dissertation.

Dentex

At the 2004 workshop, Angolan researchers were trained in the burn-embed-and-slice technique of otolith preparation, and in the interpretation of annuli of sparid species from the sliced dentex otoliths. The readability of the specimens generated by this technique was acceptable. Preparation techniques were refined at the workshop and 300 otoliths prepared for reading. At a follow-up workshop in Lobito in October 2005, which ran concurrently with a maturity-staging workshop, Angolan readers re-interpreted these otoliths. Growth and maturity parameters were calculated from the generated age data.

The hake and dentex workshops showed satisfactory results in terms of training readers, standardising interpretation criteria and improving precision and performance of readers in the region. They were also instrumental in generating material for a reference collection of hake otoliths, and in fostering regional collaboration in ageing, which will be maintained in future via an exchange programme and the establishment of a reference otolith collection.

Sardine and sardinella otolith-reading workshops

The first workshop on these species, which was jointly funded by BENEFIT and the BCLME Programme, was held in Swakopmund in December 2006, with the purpose of providing training in the preparation and interpretation of otoliths from sardine and *Sardinella aurita*, and assessing the performance of researchers in generating age estimates. The workshop was led by Dr Deon Durholtz, using the same approach as in the horse mackerel workshops. As in these workshops, the readings were very variable, again largely because of the inexperience of the trainees. After the refining of interpretation criteria through group discussions, the readings generally became more replicable. With more experiential training, further improvements can be expected. The sardine and sardinella otolith specimens generated during the preparation component were found to be difficult, if not impossible to read whole, probably due to the use of inappropriate resin to embed them. It was recommended that the technique be tested using the proper materials, and that if the results were still unsatisfactory, the use of the burn-and-slice technique be explored.

A second sardine and sardinella otolith reading workshop was held in November 2007, employing the same approach as the previous workshop. Proper application of the preparation method using appropriate materials generated clearly readable specimens for all three clupeid species (*Sardinops sagax*, *Sardinella aurita* and *S. maderensis*). Consequently, it was concluded that the burn-and-slice approach was not necessary for routine age determination of these species. The performance of the readers (in terms of the stability/precision with which they interpreted otolith features) improved markedly from the first workshop, but was still not sufficient for routine age determination. It was recommended that measurements of otolith features be used to resolve this problem.

Outputs

General

The main outputs from this project were:

- a set of preliminary age data for the species studied (to be used with caution because of their imprecision and the uncertainties associated with them),
- the increased number and capacity of researchers in the region trained to prepare and analyse fish otoliths, and
- the initiation of reference otolith collections to facilitate training and prevent “drift” in otolith interpretation by individual researchers.

Publications

Wilhelm M.R., M.D. Durholtz and C.H. Kirchner. 2008. The effects of ageing biases on stock assessments and management advice: a case study on Namibian horse mackerel. African Journal of Marine Science 30(2): 255-261.

Theses

Weni E. 2006. Growth and mortality rates of sardine (*Sardinops sagax*) pre-recruits in the Southern Benguela region during early 2001. MSc thesis, University of Cape Town, South Africa. 67pp.

Abundance and distribution of *Aequorea forskalea* and *Chrysaora hysoscella* in the northern Benguela

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Project description

The central aim of this project was to improve information on the distribution, abundance and behaviour of the hydromedusae *Aequorea forskalea* and *Chrysaora hysoscella* in the northern Benguela through acoustic surveys and other observations. The study was motivated by the fact that these large medusae are extremely abundant and widespread in the northern Benguela (probably more so now than in previous years), and are potentially major predators in the ecosystem. They are also a source of error in acoustic surveys of pelagic and mesopelagic fish in Namibian waters, in that they often co-occur with fish aggregations, contributing to the back-scatter and making target identification by trawl more difficult.

The project started with opportunistic observations of *A. forskalea* and *C. hysoscella* at the surface and underwater (from an ROV) in the late 1990s. Since then it has been focused on developing acoustic techniques of assessing their abundance, with most of the effort going into estimating target strength. This was approached by 1) regressing acoustic backscatter from medusae against estimates of volume density from midwater trawl catches in the same vicinity (the so-called "comparison" method), 2) measurements on tethered animals of different sizes to establish target strength/size relationships, and 3) *in situ* target strength experiments in which echoes from single free-swimming medusae were averaged. Ancilliary studies included an investigation into parasite infestation and its effects on target strength, and studies on the variability in the target strength of tethered animals. In 2003 an acoustic survey of medusae over a large part of the Namibian shelf was conducted from *Dr Fridtjof Nansen*, giving the first direct estimates of abundance.

Note that this project received considerable and essential assistance from Dr Andrew Brierley and Dr Chris Lynam (University of St Andrews, UK), whose participation was funded through a Royal Society (London) – National Science Foundation Science Engineering and Technology Development grant in Zoology, awarded to the University of the Western Cape.

Achievements

The early observations confirmed the likely importance of *A. forskalea* and *C. hysoscella* in the ecosystem and gave some indication of their vertical and horizontal distribution. It was found *inter alia* that both species were very patchily distributed with high abundances in places, that *C. hysoscella* tended to be closer inshore than *A. forskalea*, and that the depth of *A. forskalea* spp. tended to increase with increasing sea surface temperature. In a 24-hour feeding study on large *C. hysoscella* in Walvis Bay in September 2003 (the first of its kind), Flynn and Gibbons (2007) found that their diet was diverse, ranging from dinoflagelates to carideans, and that it included abundant benthic species, especially at night. The latter is a finding of ecological significance in view of the predominance of medusae off Namibia, and the increased flow of surface production to the benthos since the collapse of the pelagic fisheries there.

The target strength studies on tethered medusae have produced the first target strength/size relationships for these species, and the *in situ* measurements the first reported target strength estimates for free swimming medusae anywhere. The relationships from these studies, and from the earlier comparison method, are shown in Figure 1.

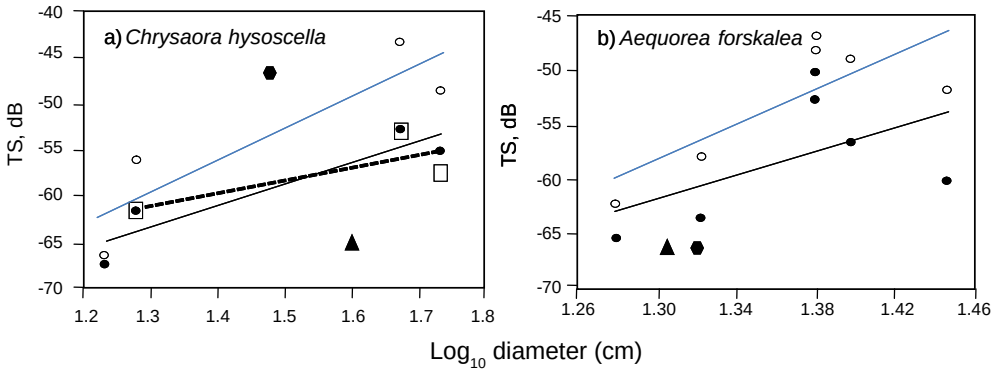

Figure 1. 38 kHz target strength/size relationships for *Chrysaora hysoscella* and *Aequorea forskalea* from measurements on tethered animals. The solid triangles show the modes from the *in situ* measurements on free-swimming medusae, and the solid hexagons estimates from the comparison method.

A further achievement has been the extraction of crude spectral signatures from both *A. forskalea* and *C. hysoscella* from simultaneous *in situ* target strength measurements at four frequencies between 18 and 200 kHz. These show a clear pattern of decreasing target strength with increasing frequency for both species (Fig. 2); information which will be extremely useful for target identification by multi-frequency techniques.

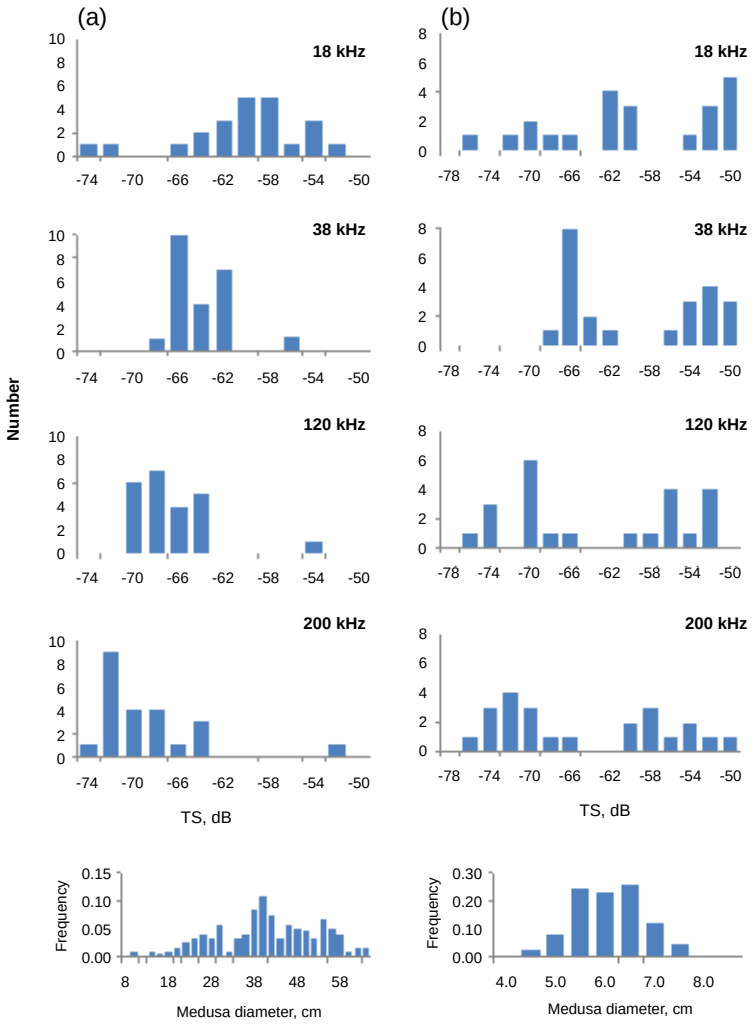

Figure 2. Distribution of *Chrysaora hysoscella* (left) and *Aequorea forskalea* (right) target strength at 18, 38, 120 and 200 kHz (top to bottom), from simultaneous detections of single targets at these frequencies, and corresponding size distributions in the experiments (bottom panel). The stronger echoes in the *Aequorea forskalea* distributions (*i.e.* above about -60 dB) are believed to be from small pelagic fish.

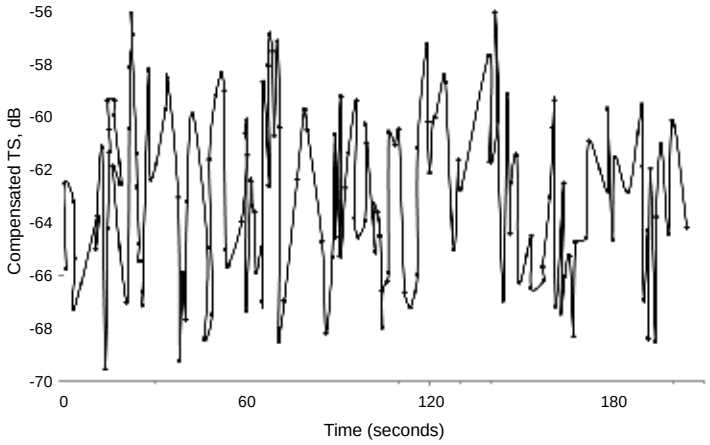

Figure 3. Example of cyclic variation in target strength of an individual tethered *Chrysaora hysoscella*, believed to be due to periodic contractions and dilations of the umbrella.

The measurements on tethered animals revealed cyclic variations in target strength (e.g. Fig. 3) which were related to regular contractions and dilations of the umbrella. The high degree of variability has implications for the precision of acoustic surveys. Another achievement of methodological interest was the quantification through a simple geometrical back-scattering model of the contribution to the target strength of parasitic hyperid amphipods, with which these medusae (particularly *C. hysoscella*) can be heavily infested. (The effect was shown to be small except in cases of extreme infestation.)

The key conclusion from the survey in 2003, which produced much information on the size structure of the jellyfish populations off Namibia and how this varies with latitude, distance offshore and depth, was that the biomass of large medusae in the system is probably of the order of 10 million tonnes, far exceeding that of pelagic finfish in the system. This is a finding of major ecological significance.

In summary, this project has made significant advances in developing acoustic techniques for studying the distribution and behaviour of large medusae in the northern Benguela, and for estimating their abundance, and has demonstrated conclusively the importance of these species in the ecosystem. Most of the findings have been reported in peer-reviewed journals, which increases the value of this project from an international perspective.

Outputs

Publications

Brierley A.S., B-E. Axelsen, D.C. Boyer, C.P. Lynam, C.A. Didcock, H.J. Boyer, C.A.J. Sparks, J.E. Purcell and M.J. Gibbons. 2004. Single-target echo detections of jellyfish. ICES Journal of Marine Science 61: 383-393.

Brierley A.S., B-E. Axelsen, E. Buecher, C.A.J. Sparks, H.J. Boyer and M.J. Gibbons. 2001. Acoustic observations of jellyfish in the Namibian Benguela. Marine Ecology Progress Series 210: 55-66.

Brierley A.S., D.C. Boyer, B-E. Axelsen, C.P. Lynam, C.A.J. Sparks, H.J. Boyer and M.J. Gibbons. 2005. Towards the acoustic estimation of jellyfish abundance. Marine Ecology Progress Series 295: 105-111.

Buecher E., C. Sparks, A.S. Brierley, H.J. Boyer and M.J. Gibbons. 2001. Biometry and size distribution of *Chrysaora hysoscella* (Cnidaria, Scyphozoa) and *Aequorea aequrea* (Cnidaria, Hydrozoa) off Namibia, with some notes on their parasite *Hyperia medusarum*. Journal of Plankton Research 23: 1073-1080.

Flynn B.A. and M.J. Gibbons. 2007. A note on the diet and feeding of *Chrysaora hysoscella* in Walvis Bay Lagoon, Namibia, during September 2003. African Journal of Marine Science 29: 303-307.

Lynam C.P., M.J. Gibbons, B-E. Axelsen, C.A.J. Sparks, J.C. Coetzee, B.G. Heywood and A.S. Brierley. 2006. Jellyfish overtake fish in a heavily fished ecosystem. Current Biology 16: 492-493.

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Sparks C.A.J., E. Buecher, A.S. Brierley, H.J. Boyer, B-E. Axelsen and M.J. Gibbons. 2001. Observations on the distribution and relative abundance of the scyphomedusan *Chrysaora hysoscella* (Linné, 1766) and the hydrozoan *Aequorea aequorea* (Forskål, 1775) in the northern Benguela ecosystem. Hydrobiologia 451: 275-286.

Theses

Axelsen B-E. 2007.Acoustic identification and abundance estimation of horse mackerel, jellyfish and mesozooplankton in the Benguela Ecosystem. PhD thesis, University of Bergen, Norway. 40pp. + 8 papers.

Flynn B.A. 2006. Diet and feeding of *Chrysaora hysoscella* in Walvis Bay Lagoon. BSc Hons thesis, University of the Western Cape, South Africa. 33pp.

Lynam C.P. 2005. Ecological and acoustic investigations of jellyfish. PhD thesis, University of St Andrews, United Kingdom. 264pp.

Sparks C.A.J. 2002. Observations on the distribution of Medusae in the northern Benguela ecosystem. MSc thesis, University of the Western Cape, South Africa. xiii + 85pp + 2 papers.

Biology and ecology of pelagic gobies

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Project description

The broad aim of this project was to improve understanding of the biology and feeding ecology of the pelagic goby *Sufflogobius bibarbatus* in the central Benguela and of its current role in the ecosystem. The importance of the project stems from the fact that gobies are believed to be major consumers of primary and secondary production in the central Benguela, and that they have become the main constituent of the diets of top predators such as seals and penguins since the collapse of the sardine in the 1970s. Furthermore, there is potential for a commercial fishery on gobies, which are currently almost totally unexploited. Better knowledge of the basic biology, life history and feeding ecology of the species, about which very little is known at present, is necessary both for quantifying its importance and functioning in the food web, and for assessing the likely effects of exploitation.

The project started as a feeding study in which stomach contents of gobies taken incidentally in research bottom trawls (and one midwater trawl) in the region by NatMIRC and the *Nansen* Programme were analysed by a Masters student at the University of the Western Cape. In addition, information on abundance and distribution was collected from *Dr Fridtjof Nansen's* bottom trawl database. In 2003, the project was allied with a bilateral South African/Norwegian project on the ecology of gobies in the Benguela system, which was given dedicated time on *Dr Fridtjof Nansen* in early 2003 to investigate goby behaviour (specifically vertical migration patterns) and assess the possibility of estimating goby biomass acoustically. The bilateral project has also examined physiological responses of *S. bibarbatus* to low oxygen and elevated hydrogen sulphide levels through experiments in aquaria, and investigated the genetic structure of the population.

In another development, the BCLME Programme took over the abundance estimation and distribution components of the original project in 2003 as part of BCLME Project LMR/CF/03/08 on mesopelagic fishes, in recognition of the importance of obtaining estimates of goby biomass for understanding energy and material flows within the Benguela ecosystem. BENEFIT continued to support the study by funding the time on *Dr Fridtjof Nansen* needed for the field work.

The project as a whole has largely been executed as a series of small, discrete studies to make it suitable for student training. The work has been done mainly by South African Masters students studying in South Africa and in Norway, and Norwegian and other students studying at the MPhil and PhD level in Norway.

Achievements

Food and feeding

The main findings from an analysis of the stomach contents of 3270 gobies taken in 10 bottom trawls unevenly distributed over the habitat were that almost all of the stomachs contained sand or mud, indicating feeding on the bottom, and that polychaetes and euphausiids were the most frequent prey items (Fig. 1). The composition of the diet did not appear to depend on the size of the fish or the depth of water in which they were caught, although the relative proportion of the different prey

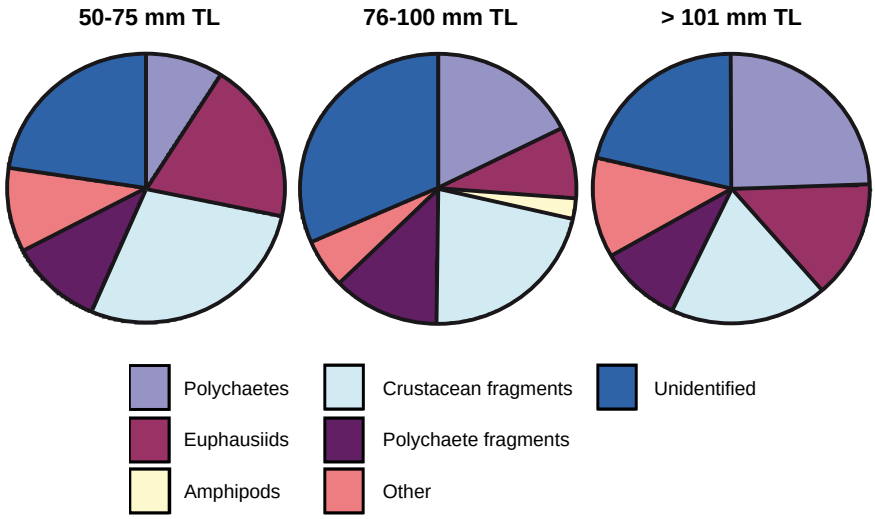

Figure 1. Diet composition by size class of *Sufflogobius bibarbatus* caught in demersal trawls. N= 795, 771 and 392 from left to right.

types did change with fish size and depth, with euphausiids and other crustaceans being more important in smaller fish on the inner shelf and polychaetes in larger animals taken further offshore (> 200 m). Preliminary analysis of gut fullness and weight suggested that feeding is greater in the morning than later in the day. In the 300 samples from the single midwater trawl copepods were the most common prey item. Phytoplankton was also common in these stomachs, but no attempt was made to quantify or identify the material.

A further 1650 gobies were collected systematically over the complete diel cycle during two 24 h anchor stations conducted during a dedicated cruise in early 2006. Unfortunately, because of problems with jellyfish in the water column, samples could only be collected from demersal trawls. Preliminary results support earlier observations on the dominance of benthic prey in the diet, supplemented by larger zooplankton (hyperiid amphipods and euphausiids) on the return of migratory individuals to the seabed.

Although the results of the diet analysis are incomplete, they indicate that gobies of all sizes derive a substantial proportion of their diet from the benthos. Given evidence that pelagic gobies in the northern Benguela have recently expanded their range to the north (Dr J-P. Roux, Ministry of Fisheries and Marine Resources, Namibia, pers. comm.) it seems likely that there has been a major change in the trophic pathways there compared to the situation at the end of the 1960s when the system was dominated by sardine.

Distribution and abundance

Incidental information on the distribution and abundance of the demersal component of the population has been extracted from the *Nansen* trawl database and mapped (Fig. 2), but has yet to be analysed further. The maps suggest that there are both seasonal and interannual changes in distribution, in agreement with seasonal changes in the amount of gobies in the diet of seals in different parts of the region.

Associated studies

Through the bilateral project between South Africa and Norway on goby ecology and the BCLME project on mesopelagic fish, the early results from the BENEFIT project have been expanded considerably, and understanding of goby biology, behaviour and distribution significantly increased. There have been important findings on the physiological responses which enable gobies to tolerate low levels of oxygen and high levels of hydrogen sulphide, the genetic structure of the population, and aspects of vertical migration relevant to acoustic assessment. Estimates of minimum biomass

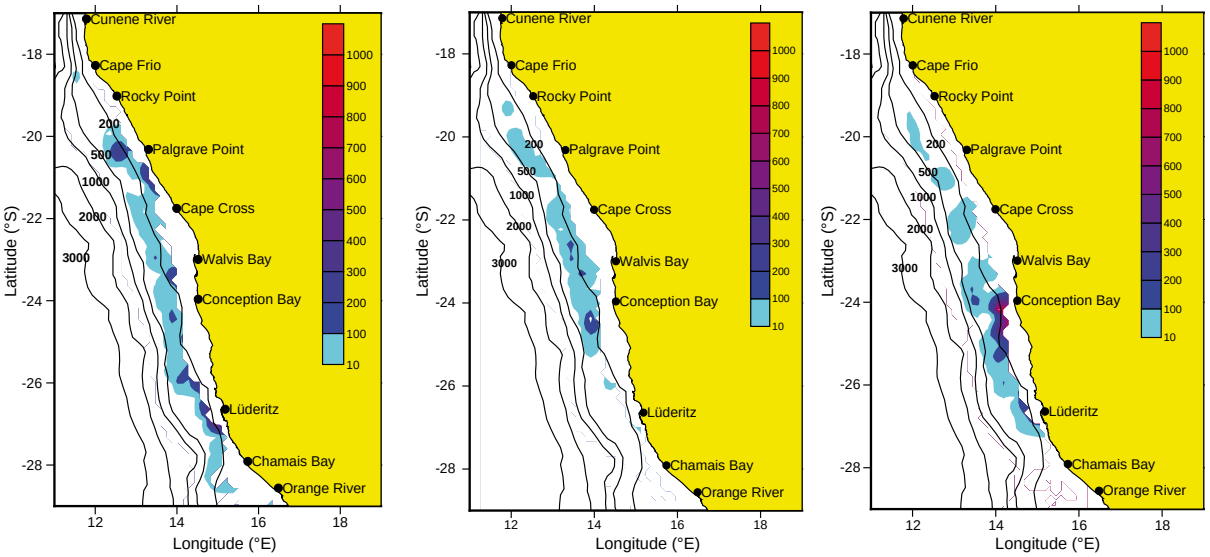

Figure 2. Distribution and abundance (kg hr^{-1}) of *Sufflogobius bibarbatus* caught in demersal trawls across the Namibian shelf, in summer 1997, 1998 and 1999 (left to right) during surveys by *Dr Fridtjof Nansen*.

based on catches in demersal trawl surveys in the region over a 15-year period are consistent with a high biomass, although direct estimation of total population size remains elusive because of the difficulty of assessing by trawl the (probably major) part of the population which is off the bottom. Further studies into the possibility of assessing this component acoustically are currently underway.

Acoustic studies of vertical migration coupled with demersal and pelagic trawling with a multinet sampler and environmental sampling demonstrated that gobies and their major predator, juvenile hake, descend to hypoxic bottom layers at sunrise and ascend at sunset to shallower, more oxygen-rich water. Video observations revealed that gobies stayed relatively inactive in the bottom layer during the day, which is similar to what was observed in the aquaria experiments. Although it is known from acoustic and trawl observations that juvenile hake also stay close to the bottom during the day, none were observed in the video recordings of the bottom sediment, suggesting that they avoided the anoxic bottom water inhabited by the gobies. Large numbers of gobies (both adult and juveniles) were caught by pelagic trawl in the upper layers during dark hours. From these observations it has been hypothesised that gobies ascend to oxygen-rich water to restore their oxygen debt, doing so after dark to minimise the risk of predation.

The behavioural studies, done in a purpose-built closed aquarium system on *Dr Fridtjof Nansen*, showed that gobies have a remarkable tolerance to hypoxia and hydrogen sulphide, being able to respond rapidly to stimulation even after 4.5 hours in levels of < 0.01 ml dissolved oxygen l^{-1}, and recovering completely after six hours exposure to sulphide concentrations of 14 to 90 µ mol l^{-1}. It has been hypothesised that the great success of *S. bibarbatus* and hake, which also has a high tolerance to hypoxia, is largely due to their remarkable physiological ability to exploit this harsh, almost uninhabitable environment as a refuge from predators. Follow-up acoustic and physiology experiments, including a comparative study on hake, are planned to investigate this hypothesis further. A number of overseas specialists are expected to collaborate in the study because of the uniqueness and interest of the findings to date.

The genetic study, based on fragment analysis of mitochondrial DNA, suggested that the *S. bibarbatus* population in the northern Benguela is not a single panmictic population, but is comprised of a mosaic of population units (particularly south of Walvis Bay) which may be linked to complex circulation patterns associated with strong local upwelling features (De Silva *et al.*, submitted).

Outputs

Publications

De Silva P.M.C.S, G. Naevdal, T. Johansen and A.G.V. Salvanes. submitted. Evidence of genetic heterogeneity in the goby, *Sufflogobius bibarbatus*, in the Benguela ecosystem, based on fragment analysis of mtDNA. Marine Biology Research.

Theses

Cedras R. in prep. Diet and feeding of the pelagic goby, *Sufflogobius bibarbatus*, off Namibia. MSc thesis, University of the Western Cape, South Africa.

De Silva M.P. 2005. Population genetic structure of the pelagic goby, *Sufflogobius bibarbatus*, in the Northern Benguela ecosystem, based on PCR-RFLP analysis of the mitochondrial control region and the ND3/4 region. MPhil thesis, University of Bergen, Norway. 48pp.

Nduane N. 2005. Population genetic studies of *Sufflogobius bibarbatus* in the Benguela ecosystem. MPhil thesis, University of Bergen, Norway. 65pp.

Rengqe L.C. 2005. Diel vertical migration of the pelagic goby *Sufflogobius bibarbatus* in the northern Benguela ecosystem. MPhil thesis, University of Bergen, Norway. 64pp.

Catching efficiency of a demersal sampling trawl

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Project description

The broad aim of this project was to gain information on the reaction of hake (both *Merluccius capensis* and *M. paradoxus*) to the bottom trawls used in swept-area surveys in the region, and to improve understanding of the influence of environmental factors on availability and catchability. The project was motivated by the need to improve both absolute and relative estimates of hake abundance from trawl surveys, which provide essential input data for stock assessment models used in managing the hake stocks in Namibia and South Africa. The project has been built around six gear-performance experiments on *RV Dr Fridtjof Nansen* between 2000 and 2005 (mainly in Namibian waters), aimed at estimating herding effects and escapement under the fishing line, and elucidating diurnal migration patterns.

In the herding experiments, which were done in 2000 and 2001, herding was estimated by comparing catch rates for sweeps of different length. The escapement experiments, in which the species- and length- dependency of escapement under the fishing line of the trawl were investigated, were carried out in Namibian waters in 2002 and 2003. A collecting bag was attached under the trawl to catch fish escaping below the fishing line, and a video camera mounted on the top panel of the trawl to observe behaviour in front of the trawl. The vertical migration study, which was done in 2004 and 2005, examined whether *M. paradoxus* off Namibia perform extensive diurnal vertical migrations in deep waters; a question highly relevant to timing of the trawling in demersal swept-area surveys. Intensive bottom and pelagic trawling was carried out at the same location at depths of between 540 and 560 m during 2004, and at around 450 m in 2005.

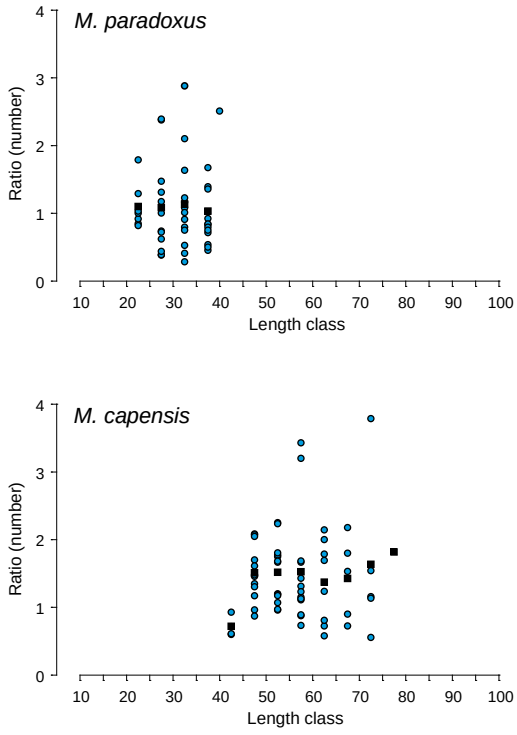

Figure 1. Ratio of numbers of hake caught with 100 m sweeps to numbers caught with 40 m sweeps in herding experiments from *Dr Fridtjof Nansen* off Namibia in 2000 and 2001.

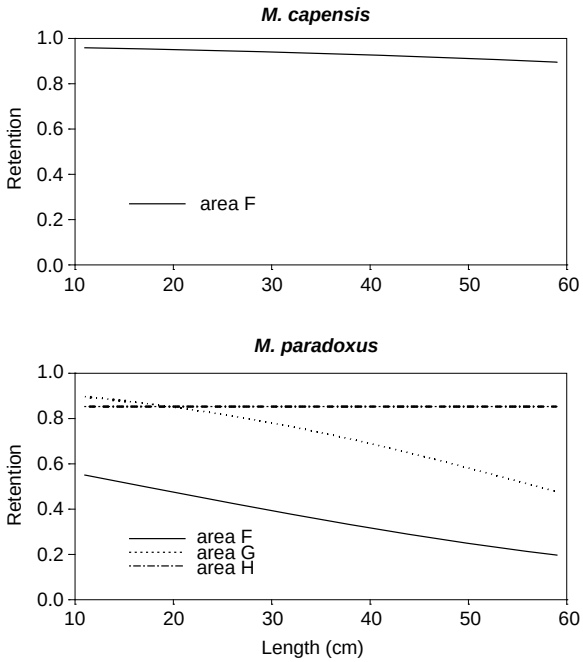

Figure 2. Mean retention of *M. capensis* and *M. paradoxus* as a function of length by area from *Dr Fridtjof Nansen* experiments in 2003. Area F = 300 m, Area G = 450 m and Area H = 570 m (from Fig. 10, Jørgensen *et al*., 2007. Figure courtesy of African Journal of Marine Science).

Achievements

In the herding experiments it was found that in Namibian waters, large *M. capensis* were herded into the net, but that there was no evidence of herding for somewhat smaller *M. paradoxus* (Fig. 1). There was no clear evidence of herding for any size of *M. paradoxus* in South African waters, and insufficient data to establish whether *M. capensis* was herded or not.

The escapement experiments in 2002 and 2003 found that escapement below the fishing line varied by species, length, depth and year (Jørgensen *et al*., 2007). In *M. capensis* it was generally below 5% in both years, but in *M. paradoxus* it averaged 10-20% in 2002, and ranged between 10% and over 50% in 2003, depending on depth (Fig. 2). Escapement was modelled as a function of length and depth, giving the retention curves for *M. capensis* and *M. paradoxus* shown in Figures 3 and 4 respectively. The difference between the years appeared to be related to differences in oxygen concentration close to the bottom, which was about 50% higher in 2003 than in 2002. Escapement of *M. capensis* decreased slightly with increasing length whereas in *M. paradoxus* there was a marked increase in escapement with increasing length in shallow waters, but no length dependency in deep waters (Fig. 2). It is believed that these observations may be explained in part by differences in behaviour and visual acuity between the species. The finding that escapement is both size and species dependent, and that it can vary from year to year, challenges the assumption made in the current stock assessment model that catchability in the Namibian hake demersal trawl surveys is constant, which could have important consequences for stock assessment, and thereby management, of the two species.

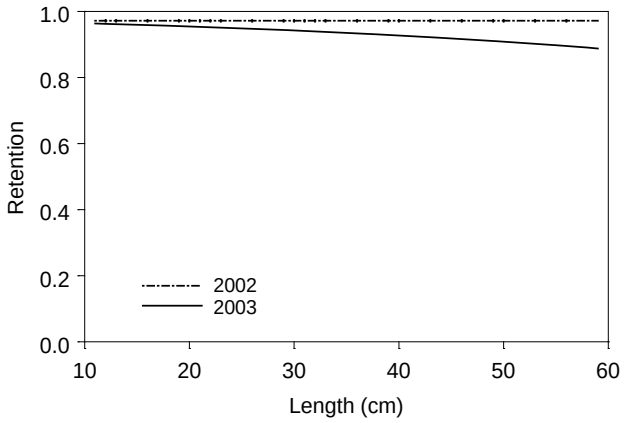

Figure 3. Predicted retention of *M. capensis* as a function of length from modelling of data from *Dr Fridtjof Nansen* experiments in 2002 and 2003 (from Fig. 11, Jørgensen *et al*., 2007. Figure courtesy of African Journal of Marine Science).

The vertical migration study in 2004 and 2005 was effectively restricted to *M. paradoxus* since too few *M. capensis* were captured for analysis. Acoustic recordings were made continuously during the experimental period, and key environmental variables sampled in detail. The 2004 results indicated a weak tendency towards lowest catch rates around noon, contrary to some previous studies in which catches of hake peaked during the day. In contrast, the 2005 results showed a diurnal pattern with a peak in the afternoon, conforming to the earlier studies. No marked diel difference in mean length was observed in either the bottom or the pelagic trawls. Since only small hake were caught, it was not possible to make any inference about possible length dependence in diel migration.

In summary, the project has provided useful information on the behaviour of hake (particularly *M. paradoxus* in Namibia) during both bottom and pelagic trawling, and some information on the influence of the environment on such behaviour. However, since catchability is likely to vary considerably in time and space, and appears from this study to be both species- and size-specific, it is clear that estimating catchabilty coefficients of hake by direct experiment is a multi-facetted, challenging problem. Many more, and more extensive, experiments are needed to arrive at any firm conclusions.

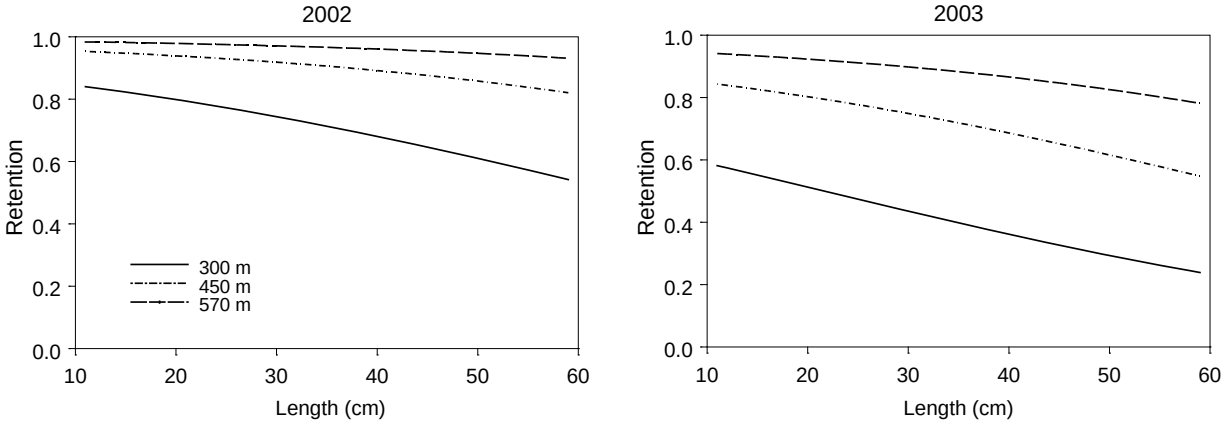

Figure 4. Predicted retention of *M. paradoxus* as a function of length from modelling of data from *Dr Fridjof Nansen* experiments in 2002 and 2003 (from Fig. 12, Jørgensen *et al*., 2007. Figure courtesy of African Journal of Marine Science).

Outputs

Publications

Jørgensen T., A. Engås, E. Johnsen, T. Iilende, P. Kainge and P. Schneider. 2007. Escapement of Cape hakes under the fishing line of the Namibian demersal sampling trawl. African Journal of Marine Science 29(2): 209-221.

Reproductive biology of big-eye dentex (*Dentex macrophthalmus*) in the Benguela current

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Current affiliation: Ministry of Fisheries, Wellington, New Zealand

Project description

The broad objective of this project was to investigate the reproductive biology of *Dentex macrophthalmus* to provide reference points for assessment of the stock size through per-recruit modelling, which is believed to be the most appropriate stock assessment method for this species, as in many other sparids. The project was motivated by the high abundance and great economic importance of *D. macrophthalmus* in Angola, and the fact that comparatively little is known about its basic biology and life history strategies.

The project has to date focussed on elucidating spawning periodicity by following changes in gonad and liver mass in specimens sampled during surveys by *Dr Fridtjof Nansen* in March/April 2004 and 2005 and the fishing vessel *Visconde de Eza* in November/December 2003, and from artisanal fishing boats in Lobito every month between February 2005 and February 2006. The data have also been used to follow seasonal changes in length distribution, develop length/weight and other morphological relationships, and to derive maturity ogives for males and females.

To support growth studies, training was given in the preparation and reading of *D. macrophthalmus* otoliths at three regional workshops between 2004 and 2005, led by specialists in sparid ageing from M&CM and Rhodes University, Grahamstown. The first was combined with a hake-ageing workshop under the BENEFIT Ageing Workshops project, and the second (in Lobito) with a maturity-staging workshop. The third workshop, held in Luanda, was aimed at providing further training in estimating age and growth rates of *D. macrophthalmus*, and at analysing reproductive data.

Achievements

The project has made a start towards improving the management of the resource by increasing knowledge of the fish's reproductive biology and life history, about which very little was known previously. The gonadostomatic indices from the year-round sampling at Lobito have given some indication of the seasonality of spawning in this area (Fig. 1), but the hepatostomatic indices revealed little. Maturity ogives constructed from the complete data set (Fig. 2) have provided estimates of

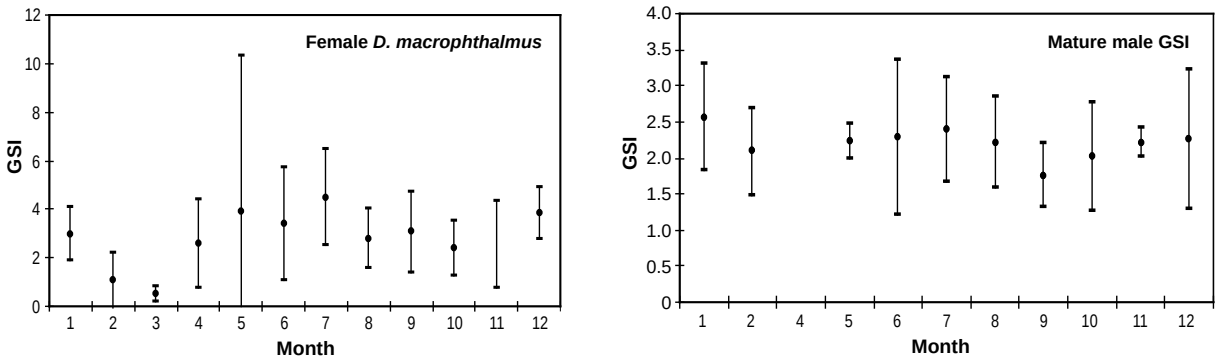

Figure 1. Monthly gonadostomatic indices of female (left) and male (right) *D. macrophthalmus* sampled at Lobito from February 2005 to February 2006.

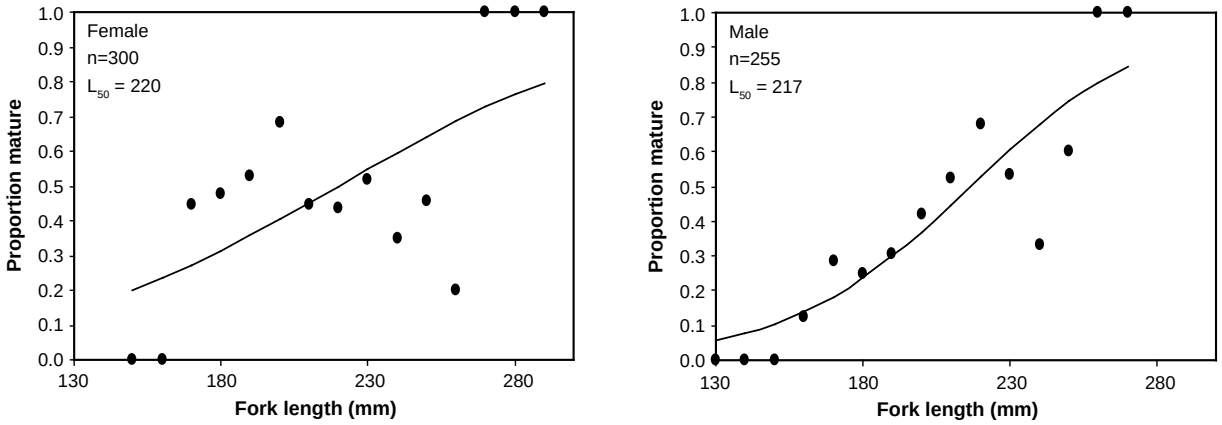

Figure 2. Maturity ogives of female (left) and male (right) *D. macrophthalmus*.

the length-at-50% maturity for females and males (220 mm and 217 mm total length respectively). However, these data need to be re-analysed since some fish may have been incorrectly staged. The histological samples that were processed will have to be re-analysed to confirm size-at-maturity.

The project has generated a growth curve (Fig. 3) and provided estimates of k, t_o and L_∞ (k = 0.3, t_o = -2.33 and L_∞ = 237) all of which appear to be realistic values for this species. At this stage the growth increments in the otolith have not been validated as annuli. In addition, length/weight regressions have been developed for males, females and both sexes combined (e.g. Fig. 4).

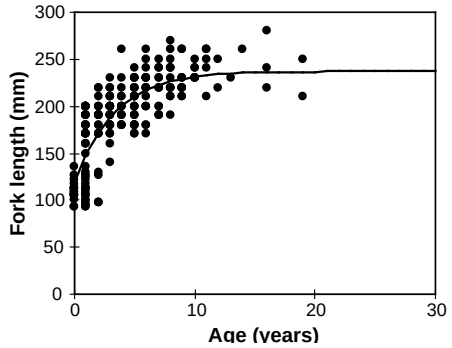

Figure 3. Combined male and female von Bertalanffy plot for *D. macrophthalmus* sampled in Angolan waters.

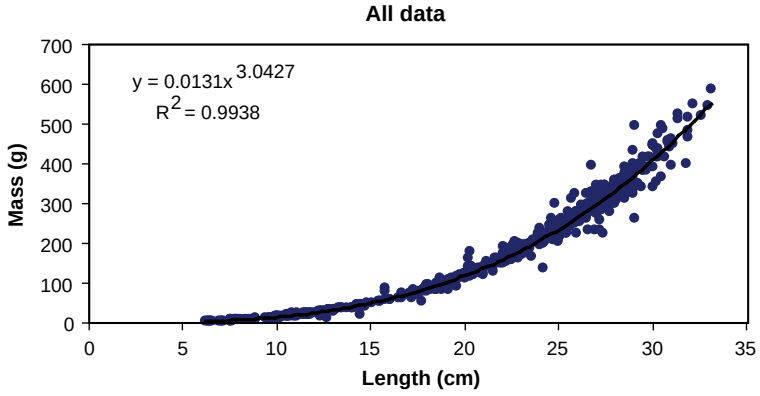

Figure 4. Combined male and female length/weight regression for *D. macrophthalmus* sampled in Angolan waters.

At the workshops, progress was made in refining methods of preparing *D. macrophthalmus* otoliths, and in training Angolan and Namibian researchers to read them. At the first workshop, the readability of otoliths prepared by the burn-and-slice technique was found to be acceptable. Some 300 *D. macrophthalmus* otoliths prepared by this technique were used to train readers at this and subsequent workshops. Although the variability in the readings was high (particularly for less experienced readers), some initial growth and maturity parameters were extracted from the age material. Further information on the workshops is given in the report on the BENEFIT Ageing Workshops project.

A useful start has been made through this project in generating the information on *D. macrophthalmus* reproductive biology and life history that is needed for stock assessment, but much more will have to be done (for example on defining spawning areas and spawning frequency) to meet the broad objectives of the project.

Output

The main outputs from this project are the length/weight, growth and maturity curves shown in Figures 2 to 4, and the experience gained through the project in reading and interpreting *D. macrophthalmus* otoliths and staging gonads for maturity studies.

Regional stock assessment workshops

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Project description

The purpose of this project was to examine critically the current procedures used in the assessment and management of key stocks in the region through international peer review, and make recommendations for improvement. This was done through a series of annual workshops, led by an international review panel. A second function of the workshops was to provide training for participants from the region with less experience in stock assessment by a) exposing them to a high level of debate on stock assessment issues and b) holding special training sessions during the workshops on selected topics, led by the international experts.

All of the workshops were structured along the lines of an international fisheries commission scientific meeting, and all were led by a panel of international experts under the chairmanship of a panel member (Dr Tony Smith, CSIRO, Hobart, Australia). It was required in all cases that the workshop produce and formally adopt a report by the end of the meeting containing a summary of the discussions and all approved recommendations. This was necessary since prompt action was needed to implement many of the recommendations.

In all, five annual week-long workshops were held fully or partly under this project, all within the Department of Mathematics and Applied Mathematics, University of Cape Town. The dates, topics and the main funding sources were as follows:

Workshop	Dates	Topics	Funding
1	20-24 November 2000	Hake (Namibia) West coast rock lobster (South Africa)	BENEFIT
2	18-24 November 2001	Sardine (Namibia and South Africa) Progress on recommendations of Workshop 1	BENEFIT
3	10-15 December 2002	Abalone (South Africa) Seals (Namibia) Progress on recommendations on rock lobster from Workshop 1	BENEFIT South African National Research Foundation (NRF)
4	12-17 January 2004	Hake (Namibia and South Africa) Progress on recommendations on seals from Workshop 3	BENEFIT BCLME NRF
5	6-11 December 2004	Cape and Cunene horse mackerel Progress on recommendations on hake from Workshop 3	BENEFIT BCLME NRF

The international experts who participated in these workshops are listed below.

- Kerim Aydin, USA (Workshop 3)
- Kevern Cochrane, FAO, Rome (Workshop 3 – joint Chairman)
- Robin Cook, UK (Workshop 4)
- Michael Fogarty, USA (Workshop 1)
- Norman Hall, Australia (Workshop 1)
- Jim Ianelli, USA (Workshop 4)

- Ana Parma, Argentina (Workshops 1, 2 and 3)
- John Pope, UK (Workshop 4)
- Joseph Powers, USA (Workshop 4)
- André Punt, Australia/USA (All workshops – Rapporteur at all workshops)
- Beatriz Roel, UK (Workshop 2)
- John Shepherd, UK (Workshop 1)
- Tony Smith, Australia (All workshops – Chairman at all workshops)
- Paul Starr, Canada/New Zealand (Workshop 5)
- Gunnar Stefansson, Iceland (Workshop 3)
- Tore Strømme, Norway (Workshop 4)

Achievements

These workshops were highly successful in bringing together the stock assessment work on key species in the Benguela which has been done within the region, and subjecting it to thorough scrutiny by international experts. Many of the recommendations made for improving the methods have been implemented in full or in part, improving the quality of the stock assessment work in the region and the ensuing management advice. The workshops have also performed a valuable educational function for local scientists, and have effectively brought together managers from the region into a common forum, giving them a foretaste of the kind of debate and joint decision-making which will be necessary for joint management of regional stocks through the Benguela Current Commission.

Outputs

The output of this project consists of the five workshop reports, which detail all discussions, decisions and recommendations made in the formal sessions, as well as summaries of the training sessions, and all submitted working papers. The documents are on record within the archives of the Marine Resource Assessment and Management Group (MARAM), Department of Mathematics and Applied Mathematics, University of Cape Town.

Study of water movement in the southeast Atlantic through drifter tracking

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Project description

This is one of the earliest and longest-running BENEFIT projects, which was aimed at following the movement of near-surface water in the southeast Atlantic by satellite-tracking the movement of drifters released into the Benguela Current system at various points along the shelf between central Angola and the Agulhas Bank. The rationale for it was that the information would be of use in hydrodynamic models, and for relating dispersal of plankton and ichthyoplankton in the northern and southern Benguela to movements of the near-surface water.

Between July 1999 and May 2004, 38 drifters (29 of them purchased by BENEFIT and the rest by NOAA) were deployed off the coasts of Angola and Namibia and the west coast of South Africa. Most of these were 6 m-long WOCE-SVP "holey sock" drifters drogued between 12 and 18 m. They were tracked by the Argos satellite tracking system, the costs of which were covered by the South African National Argos Programme and the Global Drifter Program (GDP), based in Miami, USA.

The data were downloaded weekly, and after editing and kriging to give smoothed 6-hourly values, have been archived in the GDP database, from which they can be retrieved via the web. Tracks from drifters released during the BENEFIT training cruise were analysed in Cape Town and California for publication in the South African Journal of Science. These and others have been further analysed by John Largier's research group (first at Scripps Institution of Oceanography and later at the Bodega Marine Laboratory, University of California), and at a workshop in Cape Town in December 2005.

Achievements

Data have been returned from all but one of the drifters released (see Figure 1, which gives a sense of the volume of data collected, and of how drifters released close to the coast eventually move out into the South Atlantic). Many of them moved offshore and returned data for a year or more (one returned data for 3 years). They generally spent up to a few months in the Benguela current system before moving offshore.

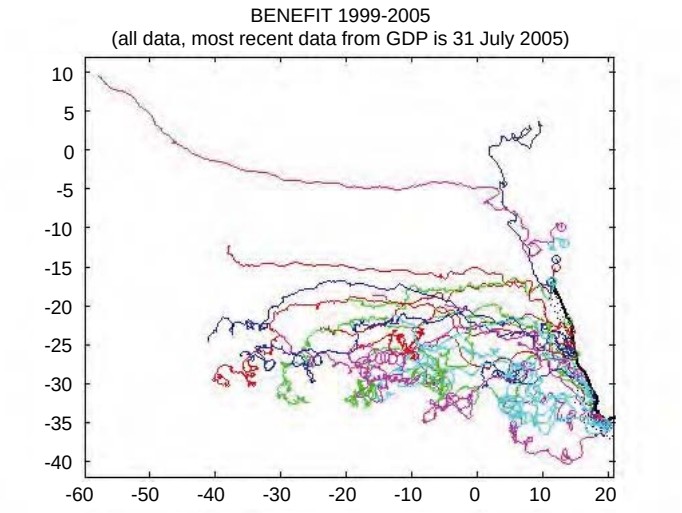

Figure 1. Track lines of all drifters deployed in the project up until 31 July 2005.

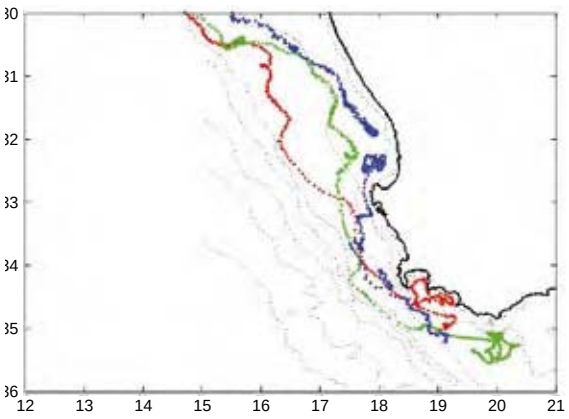

Figure 2. Initial trajectories for three drifters deployed over the Western Agulhas Bank in May 2004.

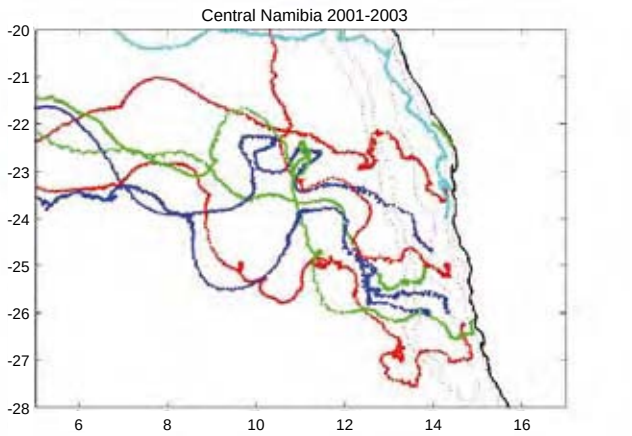

Figure 3. Initial trajectories of drifters deployed over the shelf between Lüderitz and Swakopmund during 2001, 2002 and 2003.

The initial trajectories of drifters deployed over the Agulhas Bank (Fig. 2) and between Lüderitz and Swakopmund (Fig. 3) are of particular interest from the point of view of the transport of fish spawning products. Figure 2 clearly shows the retention of surface water on the Western Agulhas Bank and in St Helena Bay, and the movement of surface water around Cape Point to the shelf off Namaqualand. In Figure 3 the direct offshore movement of surface water in all cases is clearly evident, except for the one released inshore at 24°S (about 50 nmiles south of Walvis Bay). The track of this one is of particular interest, showing surface water moving a long distance northwards along the shelf before moving offshore at about 20°S (near Palgrave Point).

From the study in 1999, Largier and Boyd (2001) produced the conceptual model of surface transport between Cape Columbine and the Cunene River shown in Figure 4. They concluded that the strong offshore transport in the Lüderitz region limits the exchange of near-surface plankton (and, by implication, ichthyoplankton) between the southern and northern Benguela, effectively separating

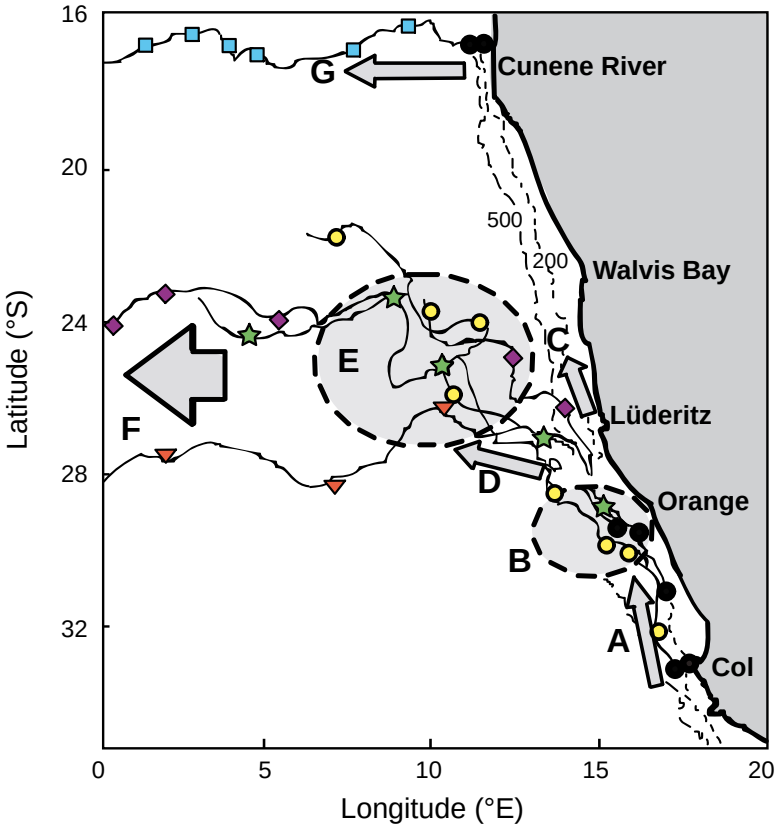

Figure 4. Proposed characterisation of surface transport based on drifter study in 1999. A) Alongshore advection, B) Diffusive exchange due to inertial motions, C) Alongshore advection, D) Offshore advection, E) Diffusive exchange due to meso-scale eddies, F) Westward advection across South Atlantic, G) Offshore advection. From Figure 6, Largier and Boyd, 2001 (courtesy of South African Journal of Science).

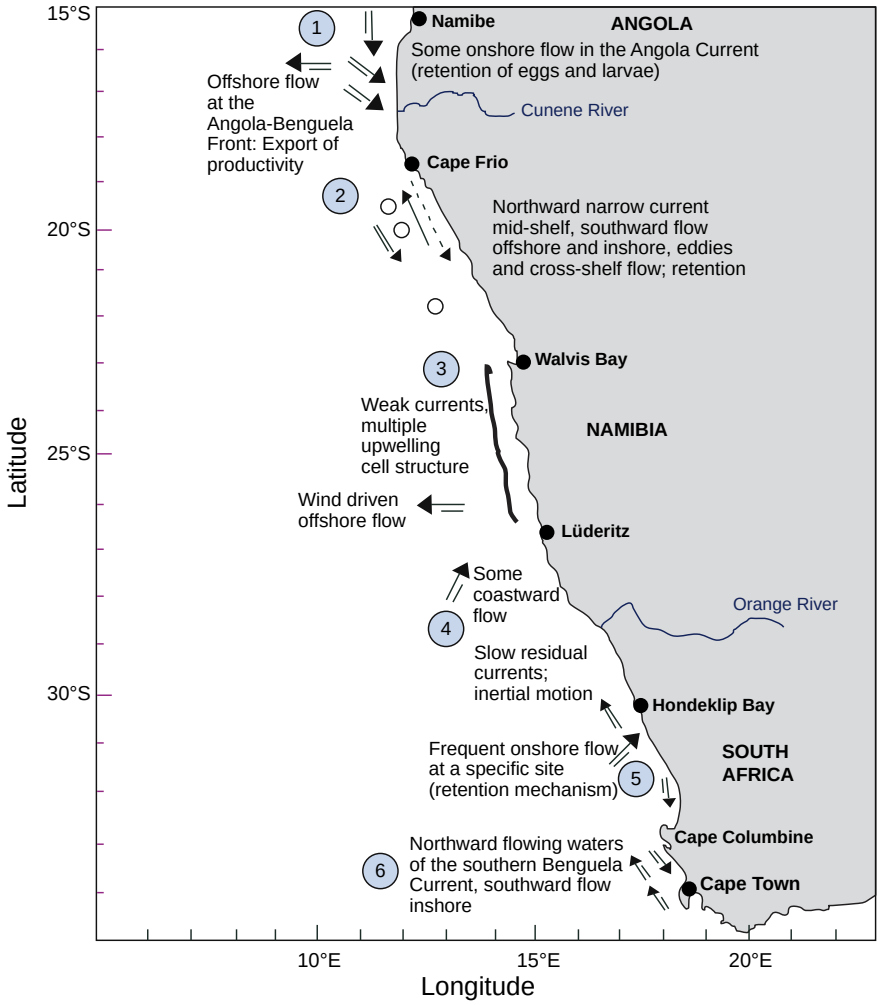

Figure 5. Schematic representation of key features of the near-surface currents in the Benguela from data collected during seven BENEFIT training cruises in 1999. From Figure 1, Bailey *et al*., 2001, (courtesy of South African Journal of Science).

the two systems biologically. Interestingly, the drifters released over the mid-shelf showed some onshore movement at all latitudes and poleward movement inshore in the south, demonstrating how larvae and pre-recruits of pelagic fish could be retained within the coastal upwelling zone. Onshore transport was most marked over the outer shelf and midshelf region on either side of the Orange River cone which appeared to be recurrent and topographically controlled. This could provide a permanent mechanism for the retention in the southern Benguela of planktonic organisms drifting northwards over the middle and outer shelf. Of particular interest was the result that three drifters released within 10 km of the coast off the Cunene and Orange River mouths and north of Cape Town beached within days of their deployment. This indicated the existence of mechanisms in the nearshore region for the transport of plankton and ichthyoplankton (including the pelagic stages of benthic organisms) into the coast, which would be beneficial for recruitment.

A schematic representation of the key near-surface currents in the Benguela, derived from a synthesis of information from all BENEFIT training cruises in 1999 (seven in all), and including the results of this and the BENEFIT ADCP project, is shown as Figure 5 (from Bailey *et al*., 2001).

Although collection of data has now come to an end, the project still has much to offer since considerably more can be done with the data that have been collected. This includes the calculation of drifter velocities for areas of biological interest, and the study of small-scale variability in position and velocity to obtain estimates of horizontal dispersal due to eddy diffusion (e.g. Largier and Boyd, 2001). To extract the most from the data they should be compared and

integrated with other data and information on currents, and related to distributions of plankton. For this, drifter plots for specific times and locations will have to be overlaid with satellite data on sea-surface temperature, chlorophyll and sea surface height. Surface circulation inferred from dynamic height measurements and satellite data on winds can also be compared directly with the drifter tracks and speeds.

Outputs

Data

The positions of all 37 successfully-tracked drifters have been stored on the GDP database, from which they may be accessed through the internet.

Publications

Bailey, G.W., A.J. Boyd, C.R. Duncombe Rae, B. Mitchell-Innes and A. van der Plas. 2001. Synthesis of marine science research in the Benguela Current system during cruises linked to the BENEFIT training programme in 1999. South African Journal of Science 97: 271-274.

Hocutt, C.H. and H.M. Verheye. 2001. BENEFIT marine science in the Benguela Current region during 1999: Introduction. South African Journal of Science 97: 195-198.

Largier, J. and A.J. Boyd. 2001. Drifter observations of surface water transport in the Benguela Current during winter 1999. South African Journal of Science 97: 223-229.

Movement and foraging behaviour of Cape fur seals in southern Africa in relation to fishing operations

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[2]IRD, France

[3]Marine Research Laboratory, Lüderitz, Namibia

[4]Marine and Coastal Management, Cape Town, South Africa

Project description

The main objectives of this project were to investigate movements of Cape fur seals *Arctocephalus pusillus pusillus*, factors affecting their foraging behaviour, and the potential for interactions between foraging seals and the commercial fisheries of the region. The latter is an important, high-profile issue because of possible competition between seals and fisheries for resources, the disruptive effect of seals on some fishing operations (e.g. purse seining), and the mortality inflicted upon seals by fishermen and fishing operations.

Movements were tracked through Argos satellite-linked tags fitted to seals at three breeding colonies in Namibia (Atlas Bay, Cape Cross and Cape Frio) and three in South Africa (Kleinzee, Geyser Rock and Seal Island, Mossel Bay), over a period of three years. In all, 54 animals were successfully tagged.

The data were analysed at four workshops, in Bergen, Swakopmund, Cape Town and Oslo, at which a strong emphasis was placed on training Namibian and South African scientists in the use of Geographical Information Systems (GIS) and the analysis and interpretation of tracking data.

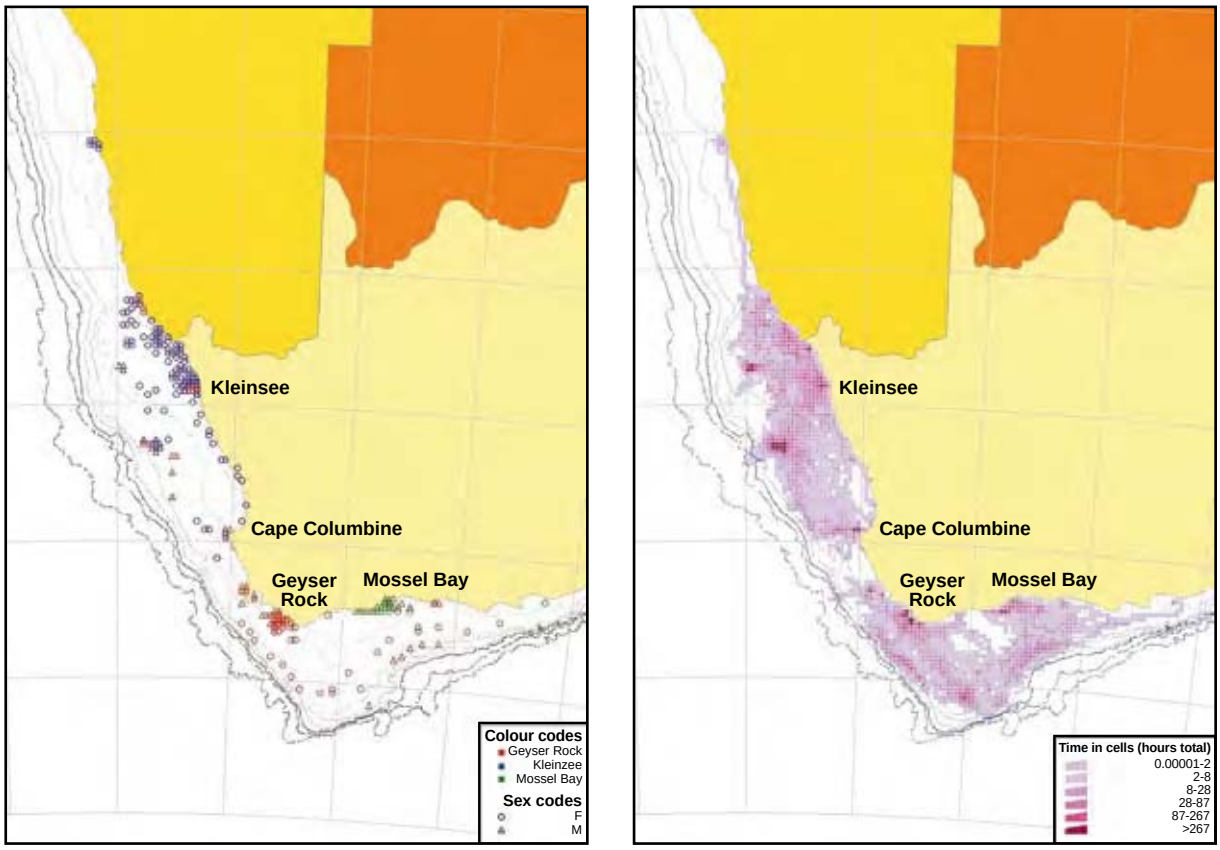

Figure 1. (Left) total time spent by Cape fur seals tagged in South Africa within 100 km² cells off the South African coast between 2003 and 2004, and (right) locations of most intensive foraging.

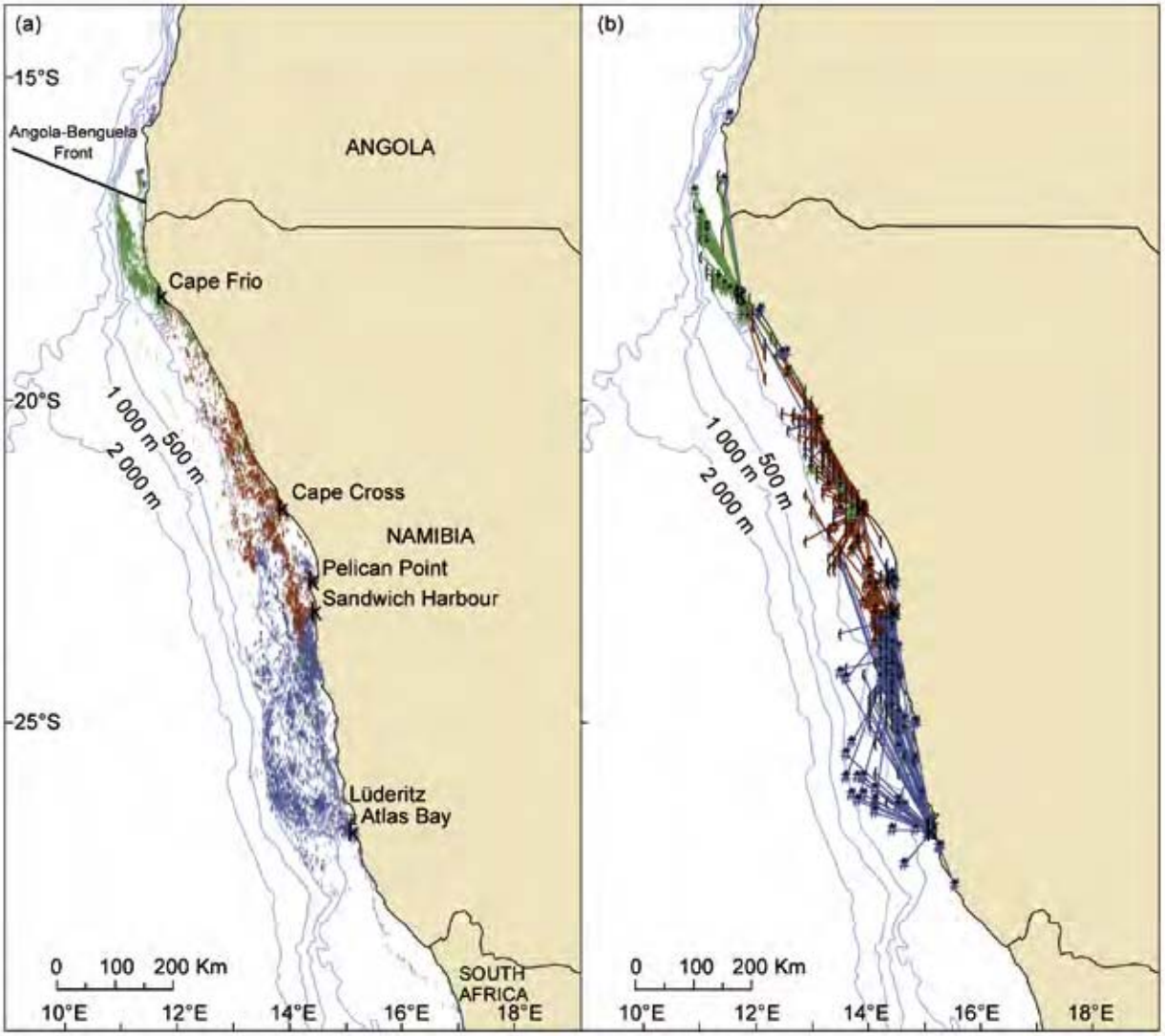

Figure 2. Positions (left) and foraging trips (right) of seals tagged at Atlas Bay (blue), Cape Cross (red) and Cape Frio (green) in 2003 and 2004.

Achievements

The main achievement of the project has been the successful tracking of seal movements from all the colonies sampled, for periods of up to eight months. This has enabled at-sea movements of seals before, during and after the breeding season to be described in detail for the first time, and their feeding ranges during these different periods to be determined. In the case of Atlas Bay and Kleinsee, tagging in different years allowed some investigation into inter-annual differences in foraging behaviour.

South Africa

The tracks of 95 foraging trips by seals tagged in South Africa (cf. Fig. 1) were captured in a GIS, and related to satellite-derived SST and chlorophyll distributions and gradients, bathymetry and distance from colony through Generalised Linear and Additive models. It was found that coarse-scale oceanographic features had only a weak affect on seal foraging behaviour, but that foraging strategies were consistent with the expected distribution of their food on this scale. Between Kleinzee and Cape Columbine, seals foraged mainly in coastal areas and on two highly productive shallow banks close to the shelf break which are heavily fished by hake trawlers. Little activity was observed in the St Helena Bay region, except during the months when the abundance of pelagic fish recruits there is high. None of the animals tagged at Kleinsee traversed the area between Cape Columbine and Cape Town, suggesting that there may be little or no overlap between seals from

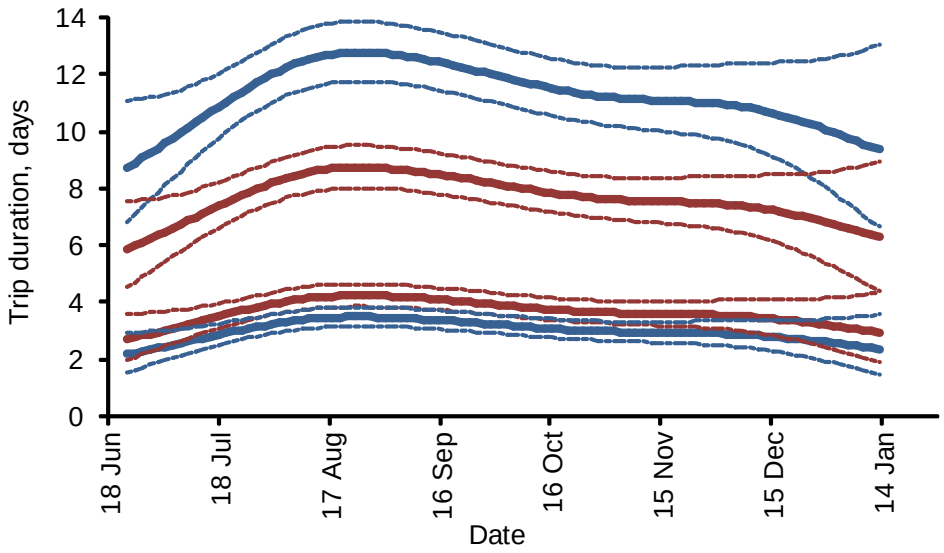

Figure 3. Predicted effects (from GAMM model) of season, sex and body size on duration of foraging trips (± 1 standard error) by Cape fur seals tagged in Namibia. Upper curves for largest adult male (blue) and female (red), and lower curves for smallest male and female.

Kleinzee and the two study colonies in the south. On the Agulhas Bank, seals from Geyser Rock and Mossel Bay foraged predominantly along the shelf break, where hake trawling activity is high, and in inshore regions to the west and east of the two colonies, respectively. The shelf break and midshelf region is also a spawning ground for pelagic fish, which comprise a large proportion of the diet of Cape fur seals. In all areas there were clear differences between the feeding strategies of males and females, most probably due to differences in foraging behaviour and/or diet preferences. The overall conclusions were that although Cape fur seals have the ability to access large areas, they do demonstrate strong preferences for certain areas where feeding conditions are good, and that in South African waters environmental conditions play only a minor role in their distribution.

Namibia

Figure 2 shows the distribution of the 29 seals tagged in Namibia and of their foraging trips. It was found that these seals generally remained within the northern Benguela system bordered by the Angolan front and the Lüderitz upwelling cell, although the tracks of two animals showed that these borders can be crossed. In the south the seals made long (5 to 7 days) trips to distant, dispersed and variable foraging areas at the shelf break. Foraging time was short compared to travel time, indicating poor feeding habitats. In the central region, shorter trips were made to dispersed foraging areas within the 200 m isobath, while in the north the trips were longer (6 to 8 days) to persistent aggregated foraging grounds at the shelf break or on the shelf. As in the south, trips were long and foraging times short compared to travel times, but fidelity to the foraging area suggests better feeding conditions than further south. Fidelity to colonies was also higher in the north compared to the southern and central regions. Foraging behaviour was found to differ between the sexes, as in the southern Benguela, and between size classes (e.g. Fig. 3). The overall picture to emerge is that within the northern Benguela, Cape fur seals move frequently between colonies and foraging areas, resulting in seal-prey interactions at regional, inter-colony scales rather than at local, intra-colony scales, particularly in the southern and central areas.

Outputs

Data

A database consisting of the seal tracks and data on anchovy, sardine, hake and horse mackerel catches in Namibia and South Africa has been compiled, through which the seals/fisheries data are available to all countries involved in the project.

Impact of seasonal variations in the poleward undercurrent and cross-shelf circulation on environmental conditions in the Benguela upwelling system

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Project description

The main goal of this project was to investigate and quantify, for the first time, the transport of South Atlantic Central Water (SACW) into the northern Benguela by the poleward undercurrent, and its effect on environmental conditions in the ecosystem, particularly the development of harmful hydrogen sulphide outbreaks over the shelf. The rationale for the project was that oxygen conditions over the entire shelf have an important impact on marine living resources of the northern Benguela and on the developmental stages of its commercial fish stocks.

Following on a successful BENEFIT pilot study in 2002/2003, in which an ADCP was moored 20 miles off Walvis Bay for a number of months, an array consisting of an upward-looking 300 kHz ADCP and a string of temperature, salinity and oxygen sensors (Fig. 1), was moored in 130 m of water off Walvis Bay, close to one of the standard NatMIRC monitoring stations, which are sampled monthly. The array was deployed in January 2004 and gathered current, temperature, salinity, oxygen and zooplankton backscattering data (from the ADCP) hourly until September 2005. CTDO data from the monitoring line provided information on environmental conditions across the shelf and for calibrating the mooring's instruments.

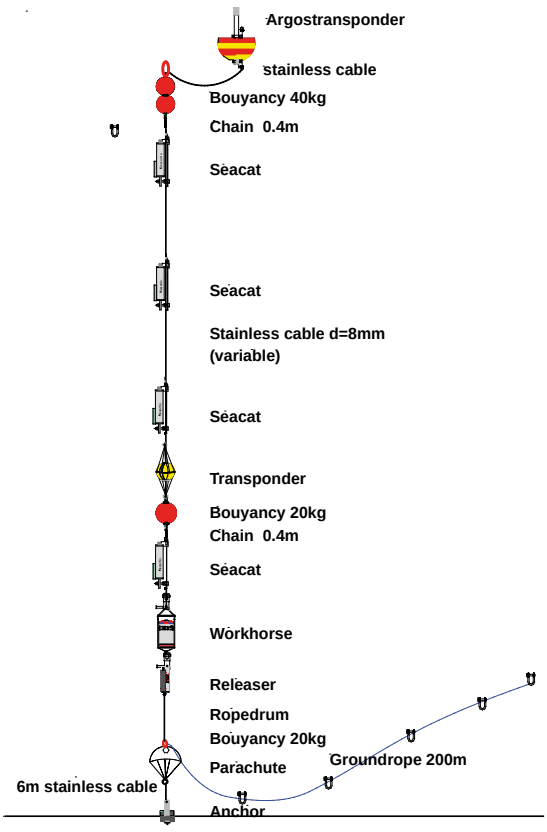

Figure 1. Mooring configuration.

Achievements

A clear seasonal signal in both along-shelf and cross-shelf currents was found (Fig. 2). The poleward current was most pronounced from mid January to mid-March, followed by northward flow in the winter months. Cross-shelf flow was generally weaker than along-shelf flow, with offshore flow being strongest at the surface in the winter months. The proportion of SACW to Eastern South Atlantic Central Water (ESACW) was highest in the summer and lowest in winter but varied considerably with depth (Fig. 3). These patterns clearly show that in summer the poleward undercurrent transports oxygen-depleted but nutrient-rich SACW into the northern Benguela, and that in the upwelling (predominantly winter) season, oxygen-rich ESACW spreads northwards.

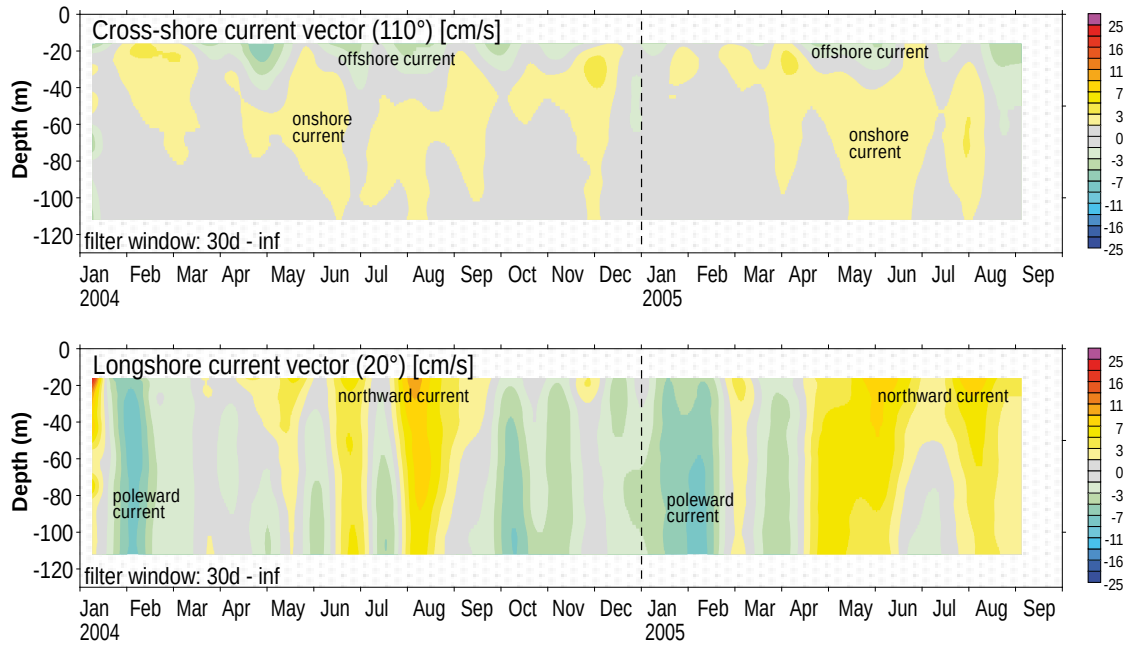

Figure 2. Time series of current fields.

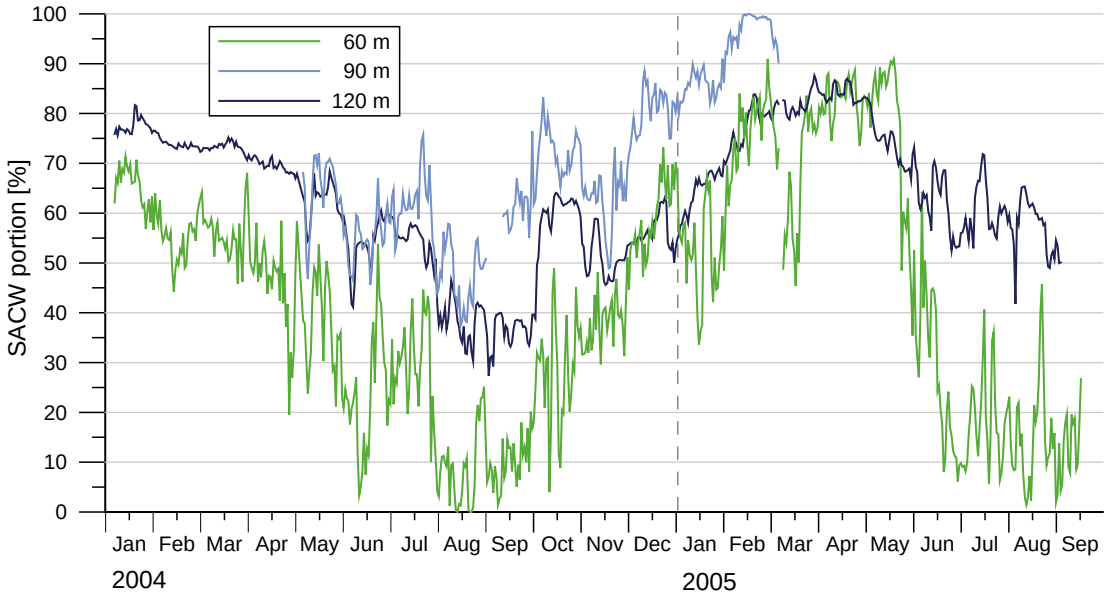

Figure 3. Proportion of SACW water at three depths.

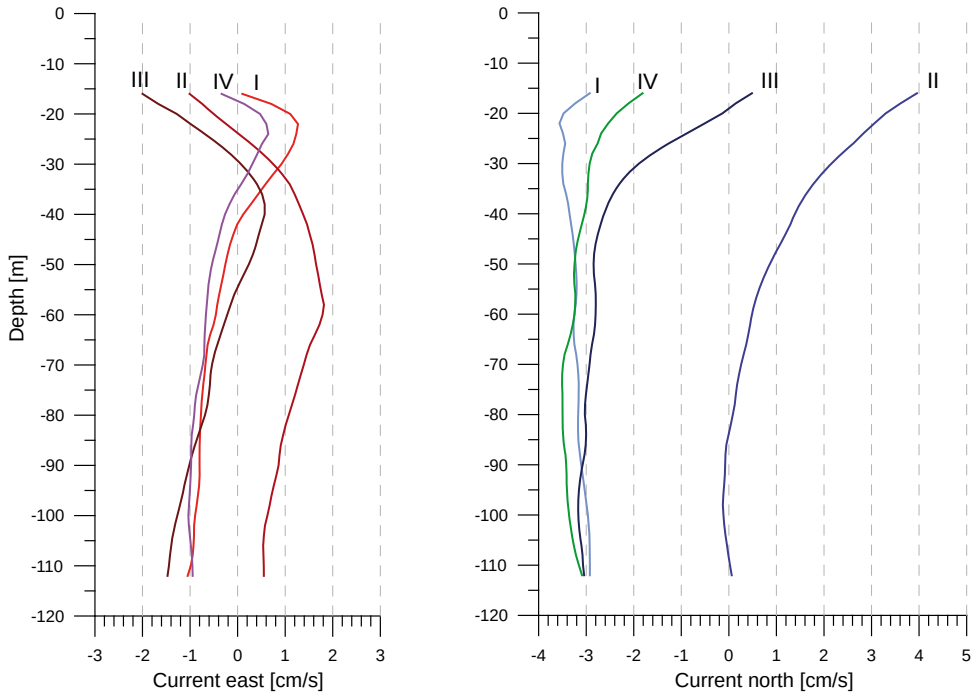

Figure 4. Means of cross- and along-shelf currents in four periods. I = January - March 2004, II = May - September 2004, III = October - December 2004, IV = January - March 2005.

The water mass composition of the upper central layer to a large extent controls the oxygen balance on the shelf. It was calculated that the oxygen deficit in the northern Benguela amounts to about 60 to 80 µmol l^{-1} at the shelf edge, increasing to up to 150 µmol l^{-1} on the shelf, due to local oxygen consumption. In summer, anoxic bottom waters were correlated with SACW fractions of over 55%. Hydrogen sulphide events (detected by satellite) were also associated with high SACW fractions.

Figure 4, which shows the temporal average of cross- and along-shelf current velocity in four periods as a function of depth, illustrates the seasonal variation in cross- and alongshelf flow throughout the water column. From these data, seasonal differences in the depth and velocity of the alongshore (SACW *vs*. ESACW) transport has been described, as well as seasonal differences in Ekman offshore transport in the surface layer, and in the advection of water onshore through the compensatory flow beneath it.

The acoustic backscatter measurements from the ADCP have shown high spatial and temporal variability in zooplankton abundance and depth distribution, with strong diurnal migration patterns in some periods, and an almost total absence of diurnal migration in others (Fig. 5). On longer time scales, a correlation has been found between the lack of zooplankton close to the bottom and the strength of the poleward undercurrent. Integrated zooplankton biomass in the water column was found to be highest during the upwelling season.

Outputs

Publications

Lass H.U. and V. Mohrholz. 2008. On the interaction between the subtropical gyre and the subtropical cell on the shelf of the SE Atlantic. Journal of Marine Systems, doi:10.1016/j.jmarsys.2007.09.008.

Mohrholz V., C.H. Bartholomae, A.K. van der Plas and H.U. Lass. 2007. The seasonal variability of the northern Benguela undercurrent and its relation to the oxygen budget on the shelf. Continental Shelf Research 28(3): 424-441.

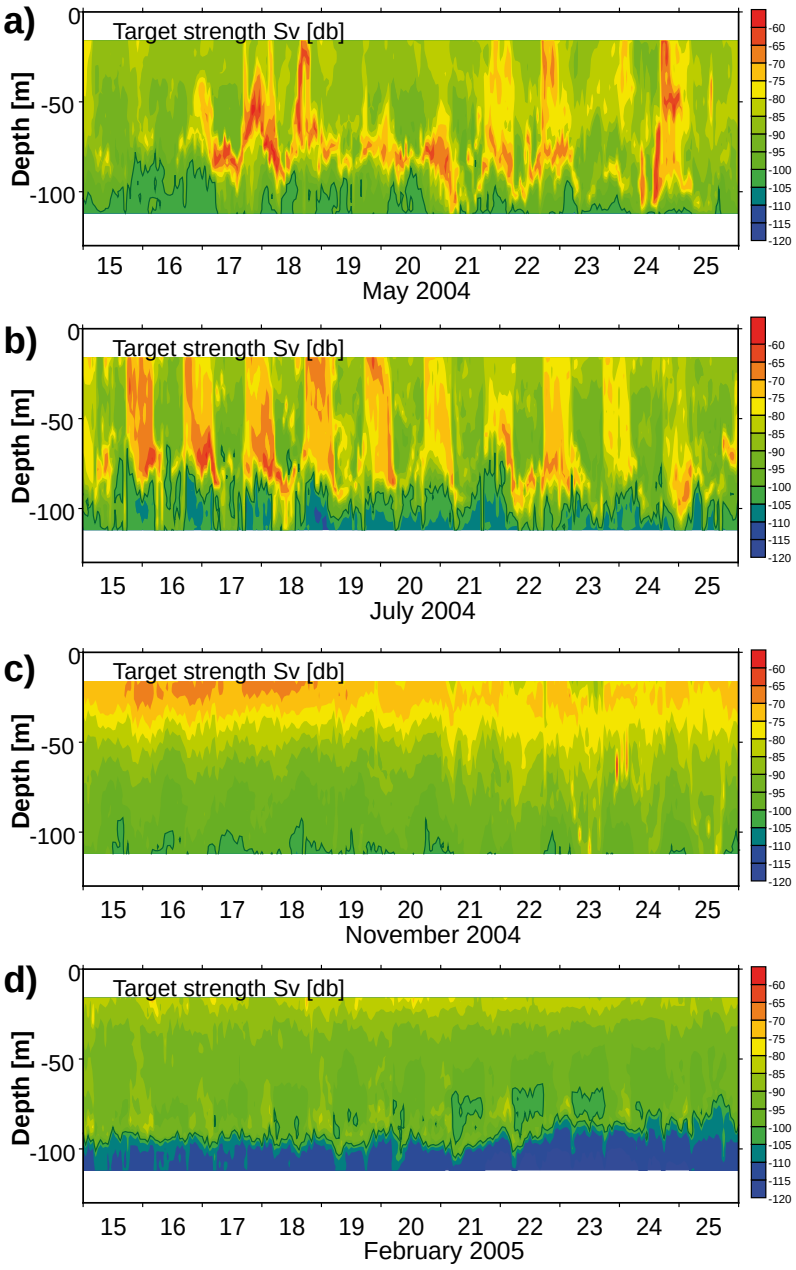

Figure 5. Vertical distribution of backscatter (a measure of zooplankton abundance) in different periods.

Dynamics of hypoxia in the central Benguela system

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[2]National Marine Information and Research Centre, Swakopmund, Namibia

[3]Marine and Coastal Management, Cape Town, South Africa.
Current affiliation: Lincoln University, Lincoln, New Zealand

Project description

This project was the first step in an investigation whose long-term overall goal is to provide a high resolution model of the coupled physical and biogeochemical processes that determine hypoxia on the inner shelf of Namibia, to improve understanding of hypoxia in the Benguela system, and the ability to predict the effect of climate change on upwelling and biogeochemical fluxes and ultimately, fish production. The underlying hypothesis is that fish production potential along the Namibian coastline is limited not by food availability, but by persistent low oxygen conditions on the Namibian shelf, caused by a unique interaction between physical and biogeochemical processes.

The project focused on building a time series of high-resolution data on the dynamics of hypoxia at a site on the inner shelf to improve conceptual understanding of the underlying processes as a basis for future modelling studies. Oxygen, methane, temperature and salinity were monitored hourly over an annual cycle (October 2002 – November 2003) by means of a biogeophysical mooring 20 nmiles offshore off Walvis Bay. Quasi-monthly sediment cores were collected at this site to provide an integrated measure of new production and fluxes of various nutrients through the sediments. The time series was supplemented by measurements from a high resolution package deployed by the Institut für Ostseeforschung, Warnemünde (IOW) for the period December 2002 to March 2003. The data have been fully analysed, and the interpretations published in the primary literature.

Achievements

The monitoring was successfully carried out over the full annual cycle, generating the first high-resolution oxygen/methane/temperature/salinity time series in the Benguela upwelling system (Fig. 1). The data show how anoxia, as measured by changes in dissolved methane, is initially triggered by the intrusion of hypoxic equatorial waters, after which fluxes of reduced metabolites in the sediment can hold the benthic layer in its anoxic condition for extended periods. The system is brought back gradually into hypoxia by the increasing impact of fresher, colder Cape Basin central water. The remote trigger was found to be crucial, in that local forcing alone is insufficient to develop anoxic conditions. The robustness of this model to annual and seasonal variability was tested and confirmed using a 10 year quasi-monthly set of data from the whole water column. Subsequent work has shown how remote hypoxia boundary conditions and regional wind stress modulate the hypoxia on the Namibian shelf. The key new insight was that variability is not driven by changes in upwelling and productivity rates but by changes in the ventilation fluxes.

The new understanding gained through this study, which has confirmed the hypothesised importance of interactions between remote physical forcing and local biogeochemical activity, will be valuable in the modelling and forecasting of changes in low oxygen water on the shelf as part of an environmental early warning system. It has also proved to be valuable in shaping work plans for BCLME-funded research projects on low oxygen water, which have advanced the overall research effort on this important topic.

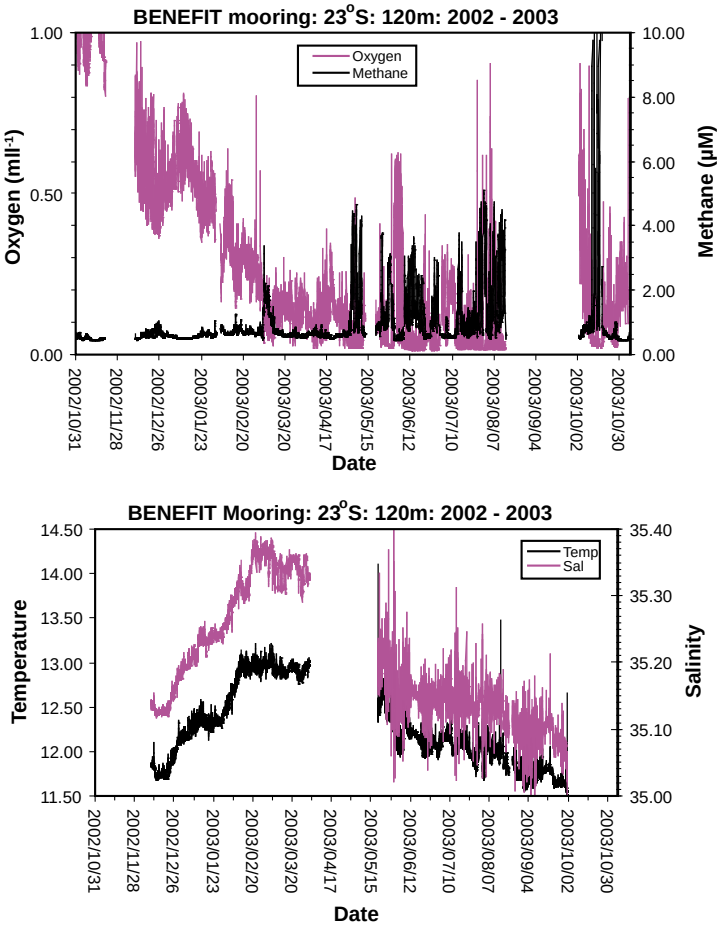

Figure 1. Time series of (top) dissolved oxygen and methane and (bottom) temperature and salinity in the benthic boundary layer from the BENEFIT biogeochemical mooring. The seasonal cycle in temperature and salinity is clearly seen, as is the transition from hypoxia to anoxia in late summer and the subsequent increase in dissolved methane.

Outputs

Publications

Monteiro P.M.S., G. Nelson, A. van der Plas, E. Mabille, G.W. Bailey and E. Klingelhoeffer. 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.

Monteiro P.M.S. and A.K. van der Plas. 2006. Forecasting Low Oxygen Water (LOW) variability in the Benguela System. In: L.V. Shannon, G. Hempel, P. Malanotte-Rizzoli, C.L. Moloney and J.D. Woods (Eds). Benguela: Predicting a large marine ecosystem. Elsevier Large Marine Ecosystems 14: 71-90.

Monteiro P.M.S., A.K. van der Plas, G.W. Bailey, P. Manalotte-Rizzoli, C. Duncombe Rae, D. Byrnes, G. Pitcher, P. Florenchie, P. Penven, J. Fitzpatrick and U. Lass. 2006. Low Oxygen Water (LOW) forcing scales amenable to forecasting in the Benguela ecosystem. In: L.V. Shannon, G. Hempel, P. Malanotte-Rizzoli, C.L. Moloney and J.D. Woods (Eds). Benguela: Predicting a Large Marine Ecosystem. Elsevier Large Marine Ecosystems 14: 295-308.

Monteiro P.M.S, A.K. van der Plas, J-L. Melice and P. Florenchie. 2008. Interannual hypoxia variability in a coastal upwelling system: Ocean-shelf exchange, climate and ecosystem-state implications. Deep Sea Research I 55(4): 435-450.

Monteiro P.M.S., A. van der Plas, V. Mohrholz, E. Mabille, A. Pascall and W. Joubert. 2006. The variability of natural hypoxia and methane production in a coastal upwelling system: oceanic physics or shelf biology? Geophysical Research Letters 33: L16614.

van der Plas A.K., P.M.S. Monteiro and A. Pascall. 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.

Theses

Joubert W. 2006. Seasonal variability in sediment oxygen demand on the organic-rich Namibian inner shelf mud belt. MSc thesis, University of Cape Town. 97pp.

Migratory behaviour, ageing and assessment of shortfin mako (*Isurus oxyrinchus*) and blue (*Prionace glauca*) sharks

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[2]Iziko Museum, Cape Town, South Africa

Project description

This was originally intended as a 4-year study into the migration, age and growth of the shortfin mako shark *Isurus oxyrinchus* and the blue shark *Prionace glauca* as the basis for a regional co-management plan for harvesting these sharks, but was cut short after two years by the ending of the BENEFIT funding. Nonetheless, progress towards this goal was made, both through the work achieved under this project, and through collaboration with a BCLME project on the bycatch of threatened seabirds, sharks and turtles in the ecosystem.

The effort over the two years during which this project ran was concentrated on determining migration patterns through tagging, developing expertise in the ageing of sharks (largely through a week-long visit to NatMIRC by an expert, Sabine Wintner, from the Natal Sharks Board in March 2005), and age and growth studies, which included attempts to validate band periodicity in the vertebrae by oxytetracycline (OTC) marking of the tagged animals. A further activity was the training of a large number of Namibian observers in the identification and biological sampling of large pelagic sharks.

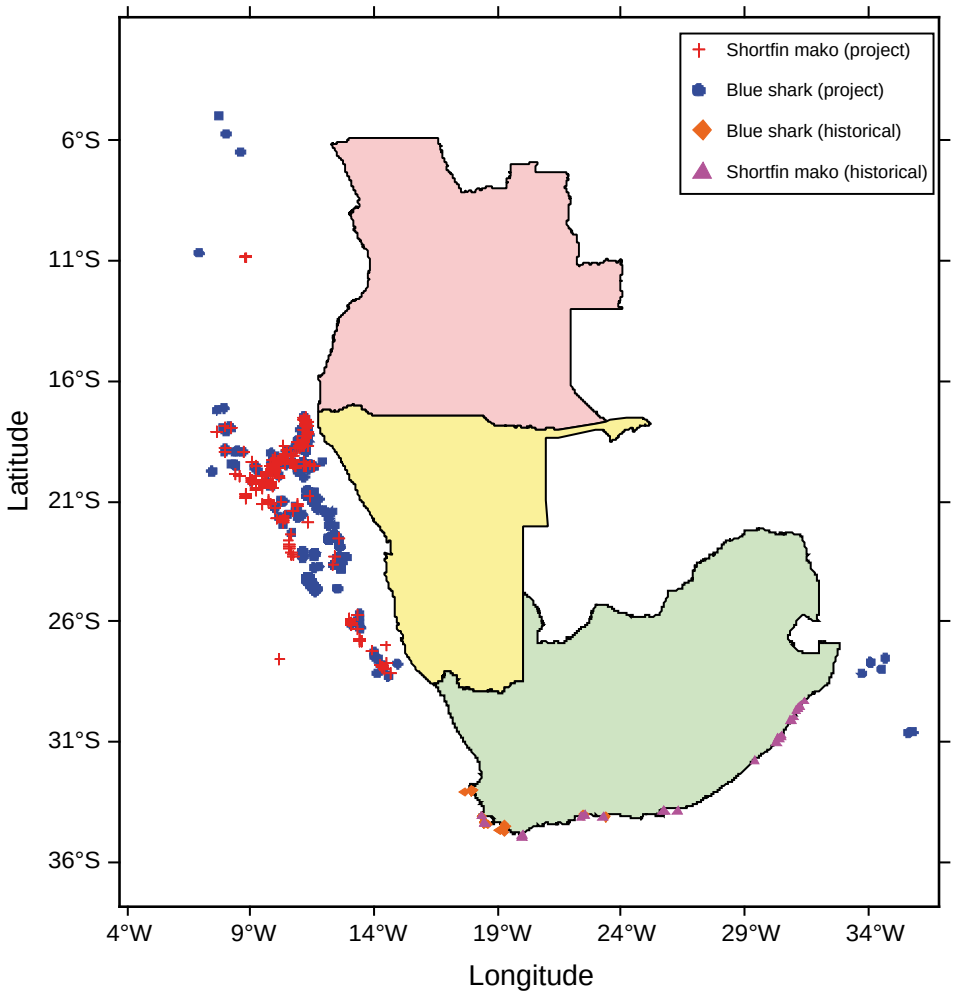

Figure 1. Positions of tagged-and-released blue sharks (blue dots) and shortfin mako sharks (red crosses) in this project, and of previous taggings on the South African coast.

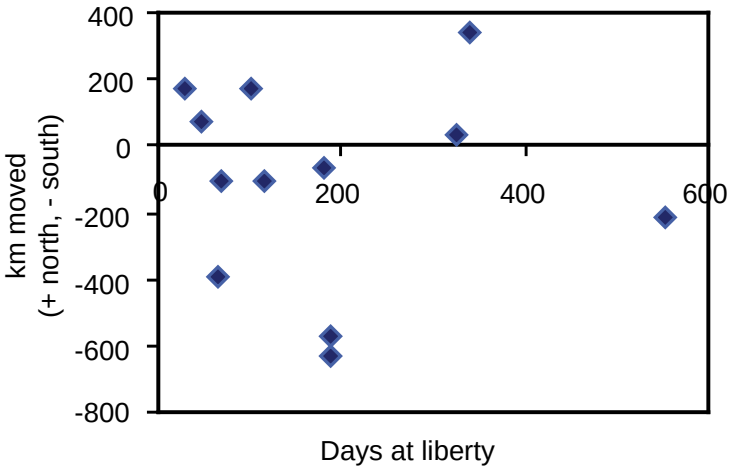

Figure 2. Days at liberty of tagged blue sharks and distances moved before capture.

Achievements

Tagging studies

415 blue and 399 shortfin mako sharks were tagged and released in eight survey trips during the course of this project. Most of the tagged animals were injected with OTC before release. The release positions are shown in Figure 1. By the end of 2005, 12 of the blue sharks had been recaptured, mostly within 200 km of their release positions, although a number had travelled considerably greater distances, both to the north and south (Fig. 2). From this it has been tentatively suggested that there may be a common population extending from South Africa to the Gulf of Guinea. No recaptures of tagged shortfin mako sharks have been reported.

Archival pop-up satellite tags were attached to three blue sharks on 25 October 2005 to collect more information on their behaviour. One of these detached prematurely after 19 days and was retrieved 14 days later. Figures 3 and 4 show the temperature and depth history respectively of the tag before and after attachment to the shark, revealing that this animal made frequent excursions from near the surface to as deep as 150 m, occupying a temperature range of about 8°C. No data have been received from the other two tags, which were due to have detached on 30 April 2006 and 31 July 2006, respectively.

Age and growth

Vertebrae samples were taken from 108 blue sharks and 88 shortfin mako sharks for age determination. By the end of 2005 vertebrae from only three of the OTC-marked animals had been collected, none of which had been at large for long enough to verify annual ring formation.

Training

Through this project, Sabine Wintner trained NatMIRC scientists on the sectioning and reading of shark vertebrae, and Heidi Skrypzeck visited M&CM to train co-investigators in shark tagging. In addition, 115 Namibian fisheries observers were trained in the identification of large pelagic sharks and in the taking of biological samples from these animals.

Outputs

The main outputs from this project have been the information on the movement of blue sharks, the report on the training visit by Sabine Wintner, and a manual and video for the training of observers. The large number of Namibian observers trained in the identification and sampling of sharks is also a valuable product of the project.

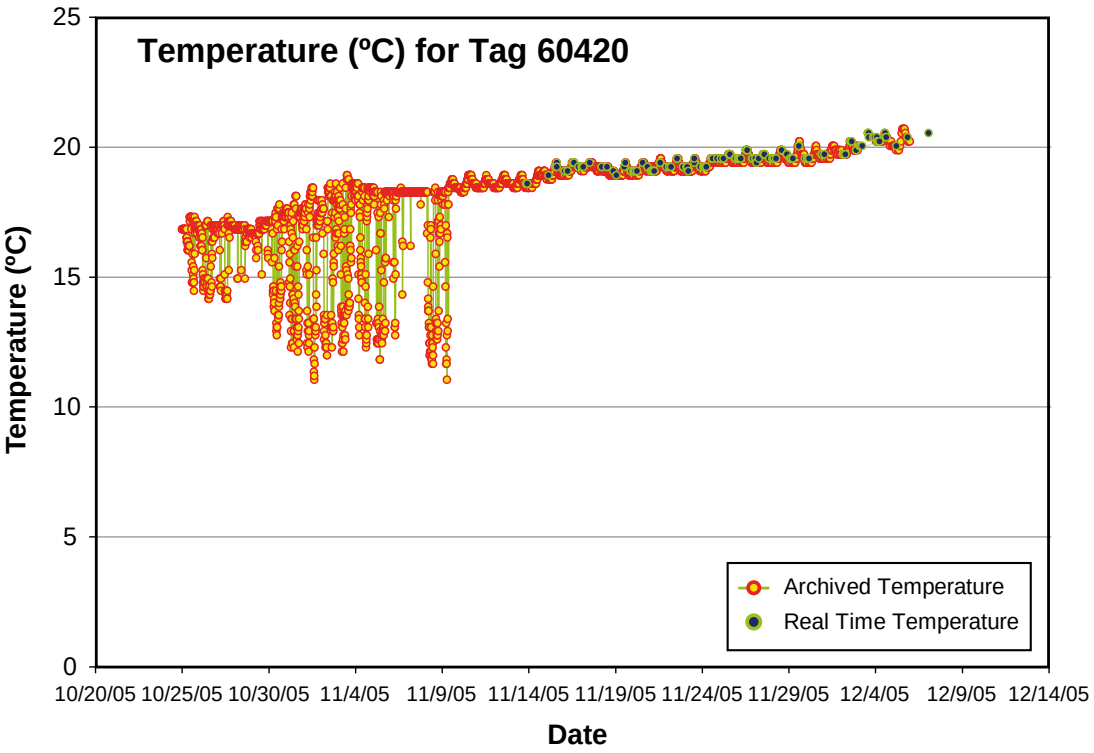

Figure 3. Temperature recorded by archival pop-up satellite tag attached to a male blue shark on 25 October 2005. The tag detached from the shark on 13 November, and thereafter recorded surface temperature. Temperature changes while attached are due to changes in depth (*cf*. Fig. 4).

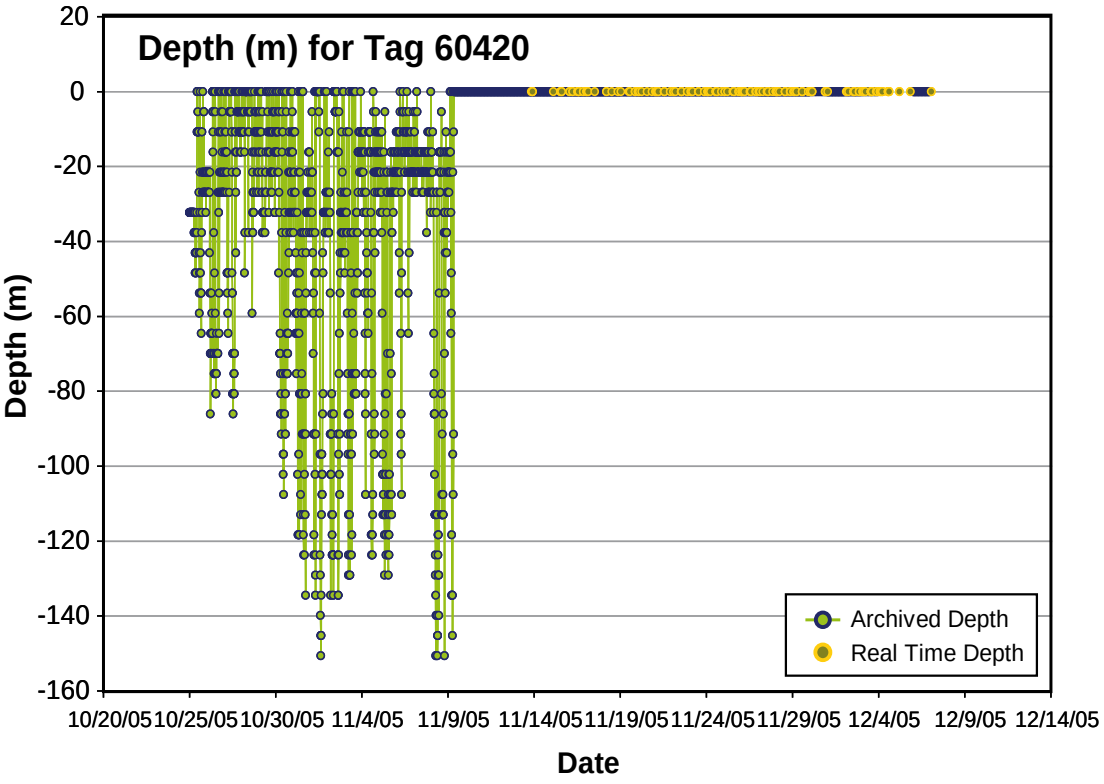

Figure 4. Depth recorded by archival pop-up satellite tag attached to a male blue shark on 25 October 2005. The tag detached from the animal on 13 November.

Early life stages of pelagic fish in the northern Benguela

Erling Kåre Stenevik[1] and Anja Kreiner[2]

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[2]*National Marine Information and Research Centre, Swakopmund, Namibia*

Project description

This project was aimed at contributing to the broad goal of elucidating recruitment patterns of pelagic fish in the northern Benguela.

In the first stage of the project, which started in 2001, valuable information was obtained on the spawning sites of sardine and anchovy, the spawning depth of sardine, vertical distributions of sardine and anchovy eggs and larvae, and mechanisms controlling the inshore retention of larvae.

The effort in the second phase of the project was aimed at extending the results of the first phase, and testing the utility of a Continuous Underway Fish Egg Sampler (CUFES) for monitoring the distribution of spawning fish with pelagic eggs (e.g. sardine and anchovy) off Namibia. The work was based on four ichthyoplankton surveys from *Dr Fridtjof Nansen* between 2002 and 2005 in which eggs, larvae and zooplankton were sampled with a 5-net towed multi-sampler, and the buoyancy of sardine, anchovy and horse mackerel eggs and newly hatched larvae was measured. The CUFES system was tested on the second of these cruises, in February 2003.

Achievements

The first phase of the project gave valuable information on, *inter alia*, the vertical and horizontal distribution of ichthyoplankton in (mainly) Namibian waters in relation to the environment, particularly temperature and oxygen concentration (e.g. Stenevik *et al*., 2001, 2003; Stenevik, 2003). It also provided important information on the vertical distribution and buoyancy of sardine and anchovy ichthyoplankton, which has increased understanding of the effect of these factors on the dispersal of their eggs and larvae, and has been useful for designing CUFES surveys and interpreting the results obtained from them.

The second phase of the project has further characterised the spawning habitats of sardine and anchovy in the northern Benguela (e.g. Stenevik and Kreiner, 2005) and increased understanding of, *inter alia*, diel vertical migration of anchovy larvae (Stenevik *et al*., 2007), the age and growth of sardine and anchovy larvae in relation to their vertical and horizontal distribution (Stenevik *et al*., 2003), and the relation between the abundance and distribution of larvae and oxygen concentration (Kreiner *et al*., 2008). A paper synthesising the new findings on the early life stages of sardine, anchovy and horse mackerel in the northern Benguela, based on the results of this project, is in preparation (Kreiner *et al*., presented at the Eastern Boundary Upwelling Systems symposium in June 2008, and submitted for publication in the proceedings).

The CUFES trials in February 2003, which were conducted using a borrowed system, were successful in showing that sardine, anchovy and horse mackerel eggs can be collected continuously while underway (Fig. 1), and that continuous sampling is useful for estimating the spatial distribution of sardine eggs and their abundance (see Fig. 2, showing the correlation between model estimates of egg density based on CUFES counts and those obtained from the multi-net sampler). It was consequently recommended that a CUFES system be built and used for routine monitoring of pelagic fish spawning in Namibian waters. A system was subsequently purchased through a BCLME project and installed on *RV Welwitchia*, from which it is now being used regularly. It is expected that this initiative will lead to long term benefits in the form of greater understanding of sardine spawning habitats, and possibly independent estimates of spawning biomass from estimates of the daily egg production.

The research initiated and stimulated by this project is being continued under other, non-BENEFIT projects.

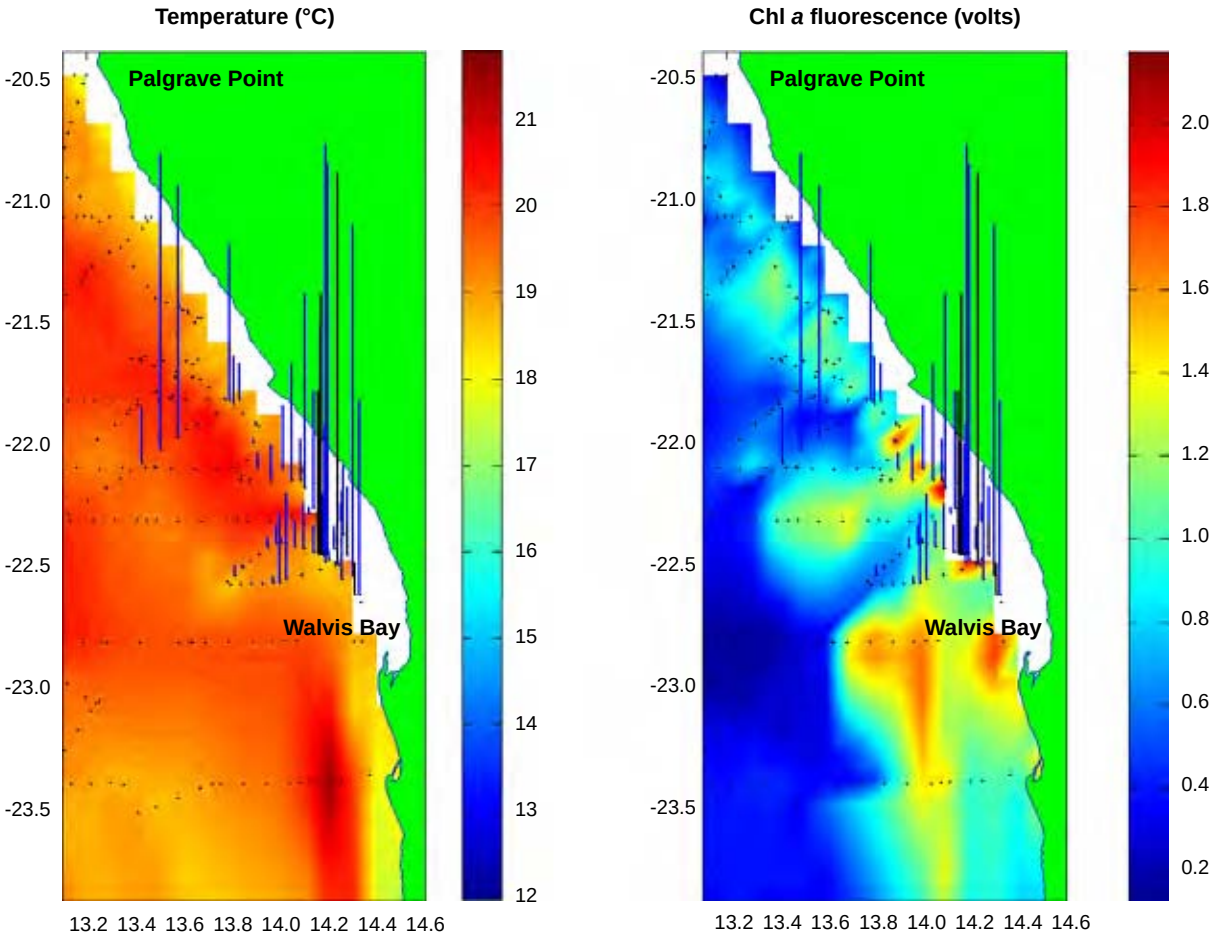

Figure 1. Number of sardine eggs (blue bars) and horse mackerel eggs (black bars) collected per CUFES sample during February 2003, plotted over temperature (left) and chlorophyll *a* (right).

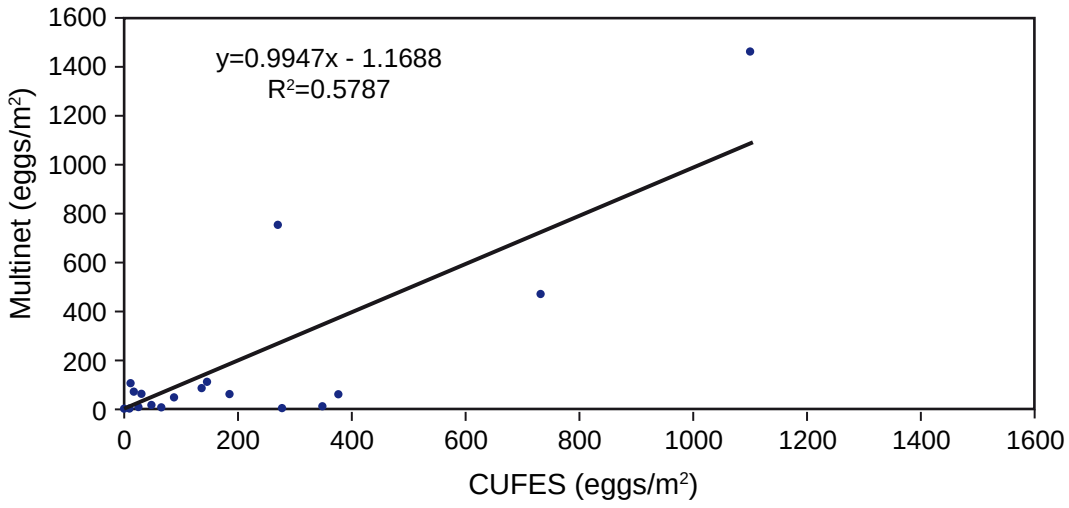

Figure 2. Correlation between sardine egg density modelled from CUFES counts and that estimated from discrete multi-net samples above the thermocline. The eddy diffusivity coefficient used in the CUFES model was based on the average wind speed over the previous 8 hours.

Outputs

Publications

Kreiner A., E.K. Stenevik and W. Ekau. 2008. Sardine (*Sardinops sagax*) and anchovy (*Engraulis encrasicolus*) larvae avoid regions with low dissolved oxygen concentration in the northern Benguela Current System. Journal of Fish Biology 73: 1-8.

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Stenevik E.K. 2003. Recruitment mechanisms of sardine (*Sardinops sagax*) and anchovy (*Engraulis capensis*) in the Northern Benguela: retention in an advective environment. Dr Scient. thesis, University of Bergen, Norway.

Coordinated demersal surveys in Namibia and South Africa

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Project description

The overall objective of this project, as originally framed, was to harmonise national trawl surveys in the region to facilitate regional analysis and so improve abundance estimates and understanding of the life history of demersal species, particularly the hakes. The project was motivated by the extreme importance of swept-area estimates of demersal fish (particularly hake) abundance for resource management in the region, and by the need to make better use of data collected on trawl surveys than had hitherto been possible by the overburdened national institutes in the region.

In 2005 the project was re-focussed on the relation between the South African and Namibian stocks of *Merluccius paradoxus*. This was done through delineation of spawning times and areas and larval dispersion patterns, and the collection of material for a study on genetic relationships between eggs, larvae, juveniles and adults collected at different sites within the survey area. The project was complemented by Namibian and South African national projects, and by three transboundary demersal trawl surveys in 2003, 2004 and 2005 with similar objectives funded by the BCLME Programme, which also partially funded analysis of the genetic material.

Between 2000 and 2007, 15 bottom trawl surveys were carried out off Namibia and the South African west coast for these projects, all of them from *RV Dr Fridtjof Nansen*. Harmonisation with national trawl surveys was achieved by linking up with them in time as much as possible, and by intensive intercalibrations, in which the performance of the trawl gear on *Nansen* was compared with that of the commercial vessels used for routine trawl surveys in Namibia and *RV Africana* in South Africa. Theoretical and empirical studies were also carried out to compare the systematic, transect-based survey design used in Namibian national surveys with the random stratified design used in the South African surveys.

From 2003 onwards, the effort was directed at mapping the distribution of hake (particularly *M. paradoxus*) by size class between Cape Agulhas and the Cunene River, using the same survey design and the same trawl and sampling procedures that have been used for hake surveys in Namibia since 1990. The *Nansen* surveys, which were mainly carried out along the South African west coast, took place in the same period (January-February) as the Namibian national surveys, thus providing a synoptic cover of hake distribution over most of the species' distributional range. This work was specifically aimed at elucidating the relationship between South African and Namibian stocks of *M. capensis* and *M. paradoxus* (in particular).

In 2005 the focus shifted to the study of *M. paradoxus* egg and larval distribution through the collection of hake ichthyoplankton during trawl surveys of the South African west coast in April/ May 2007 and September 2007. Material for the genetic study was collected on both cruises for analysis under the BCLME project.

In all of the surveys, temperature, salinity and dissolved oxygen were sampled routinely, and on some of them, currents were profiled continuously by ADCP. These data have been used not only in this project, but in other BENEFIT and BCLME oceanographic studies.

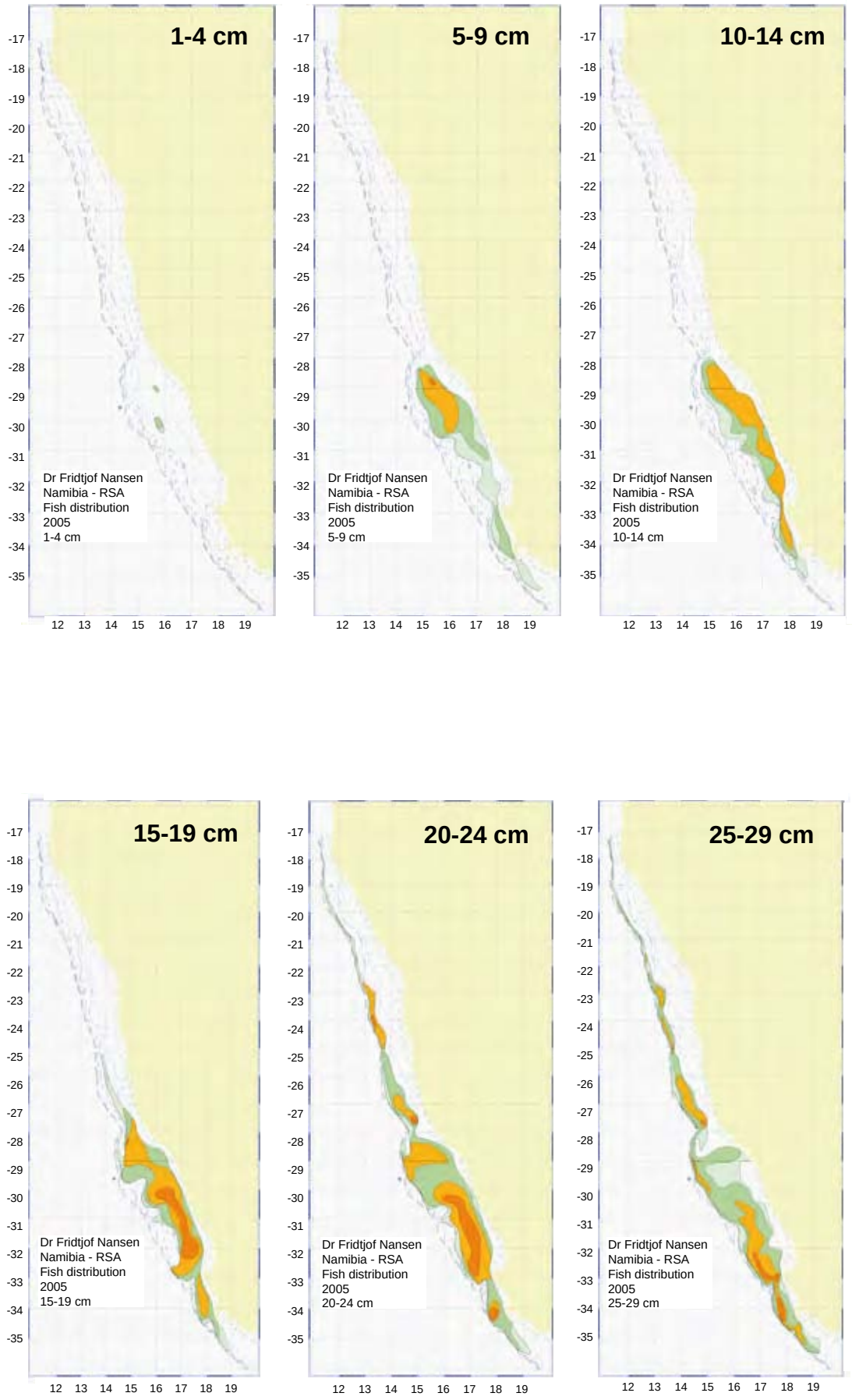

Figure 1a. Distribution of *M. paradoxus* by size class, January – March 2005.

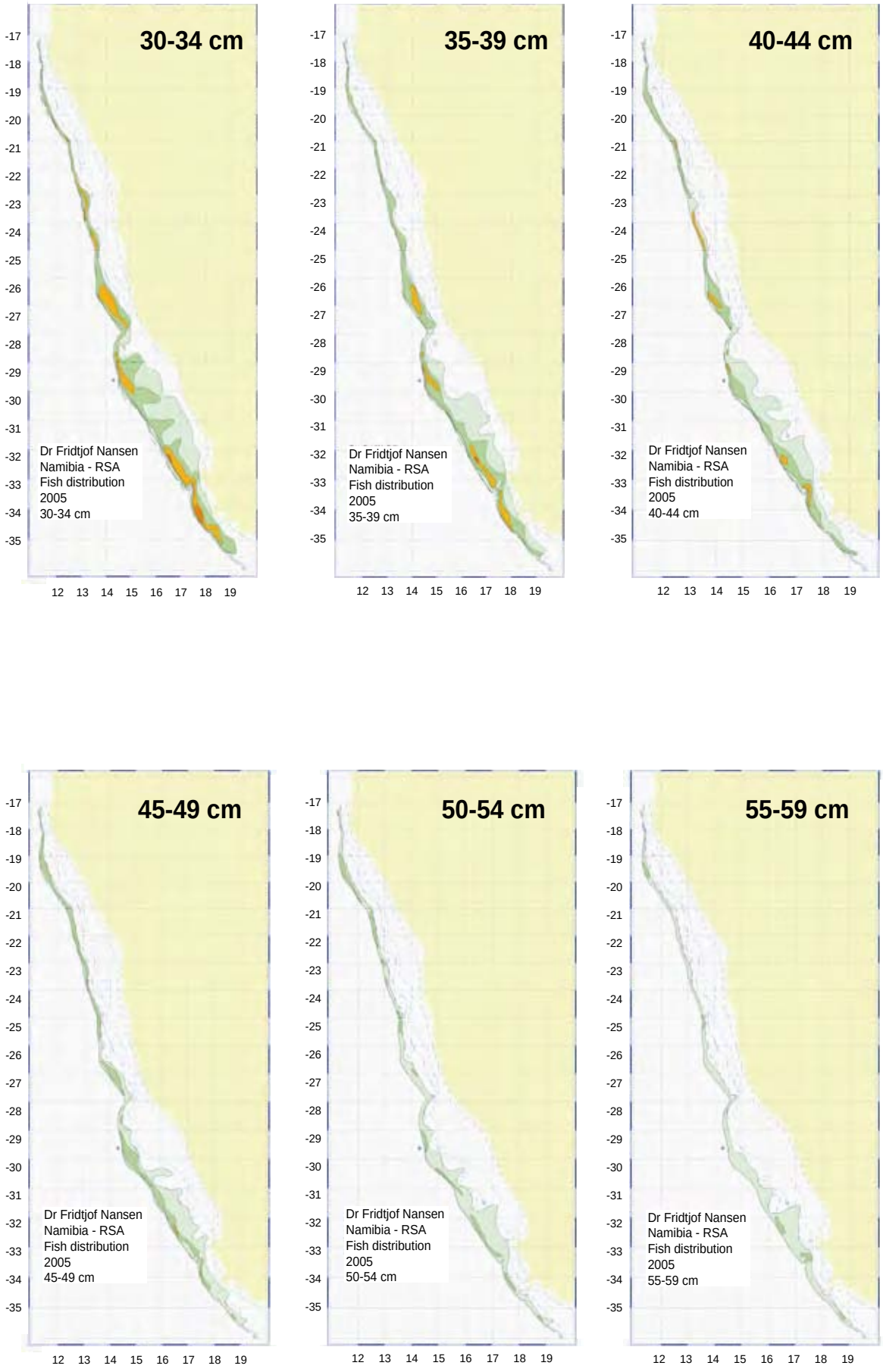

Figure 1b. Distribution of *M. paradoxus* by size class, January – March 2005 continued.

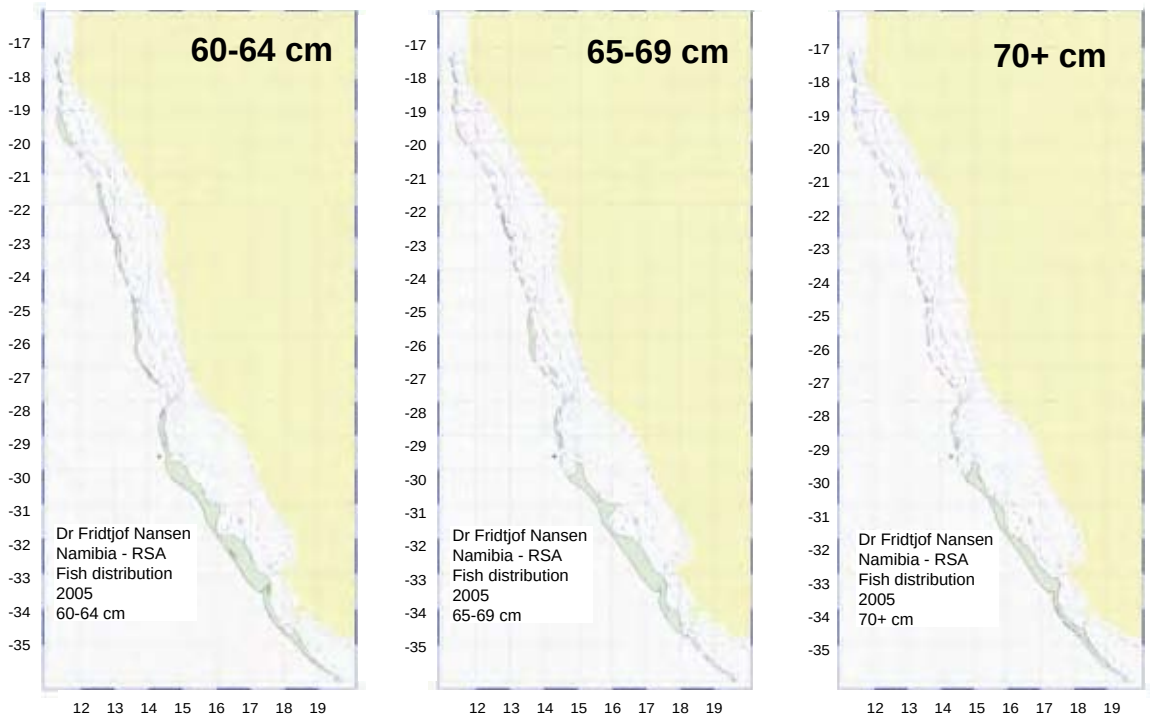

Figure 1b. Distribution of *M. paradoxus* by size class, January – March 2005 continued.

Achievements

Intercalibrations

The intercalibrations with the commercial trawlers in Namibia, which carried similar gear to that used on *Nansen*, showed little difference in catch rate or in the size distribution of hake caught by the different vessels, irrespective of depth or level of catches. In contrast, there were significant differences in both catch rate and the size distribution in the intercalibrations between *Nansen* and *Africana*, which differ in both trawl gear and fishing procedures. Since the differences depended on depth, a depth-dependent conversion factor was developed for use in comparing estimates from the two vessels. An important conclusion from the work is that the gear factor is considerably more important than the vessel factor. Note that through these intercalibrations, *Nansen* has effectively become a reference vessel for demersal trawl surveys in the region.

Comparison of survey designs

An experiment to compare the stratified random and transect-based designs was carried out off St Helena Bay in 2002 in an earlier stage of the project. 50 stations were sampled twice following first a stratified random design, then a systematic transect-based design. The study showed no significant difference in the species composition or in the mean catch rate and length distribution of hake caught in the two surveys. The data were analysed by the Department of Statistical Sciences, University of Cape Town, using a classical non-spatial statistical approach. The conclusions were supported by Discriminant Function and Correspondence analyses, which were unable to separate the species composition, abundances of hake or length distributions by design type.

The empirical results were supported by simulation studies on a computer-generated stock with density structure overlaid by random noise. It was found that systematic sampling gave more precise estimates of abundance than random sampling, and that the gain in precision was related to the patchiness of the distribution. These findings are in line with what would be expected from standard sampling theory but which can seldom be demonstrated in practice.

Spatial distribution of M. paradoxus by size class

The surveys between 2003 and 2007 have provided a wealth of information on the horizontal distribution of *M. paradoxus* by size class between Cape Agulhas and the Cunene River. An example from the survey in February 2005 is shown in Figure 1. General features to emerge from the three cruises were that:

- Fish less than 4 cm in length were found exclusively south of the Orange River, mostly concentrated into a narrow latitudinal range of less than 2 degrees around 200 m bottom depth off Namaqualand. As size increased, the latitudinal range broadened (more towards the south than northwards), the median depth shifted to below 200 m, and the depth range widened.
- Fish between 25 and 30 cm in length were found at high densities off Lüderitz (possibly indicating a nursery ground) and between Doring Bay and Cape Town (32-34°S). Densities of fish in this size range were low off the north of Namibia and between Lüderitz and the Orange River.
- The larger size classes (35 to 60 cm) were generally distributed further north off Namibia, but were less dense in the far north. Fish in these size classes were roughly equally distributed between Namibia and South Africa.

The proportion of the total *M. paradoxus* biomass which was found in Namibian waters was greatest for fish between 35 and 55 cm in length, and declined for larger fish (e.g. Fig. 2, constructed from the 2005 surveys). The largest sizes were almost exclusively found in South African waters. The extent to which this reflects true migratory patterns or alternatively, results from the targeting of different sized fish in the two countries, is uncertain at present.

The above patterns, which are consistent with findings from Namibian trawl surveys in the 1990s from *Dr Fridtjof Nansen*, strongly indicate that *M. paradoxus* do not spawn in Namibian waters, which is a major finding of the study.

Ichthyoplankton surveys

Very few *M. paradoxus* eggs and larvae were found in the ichthyoplankton sampling in April/ May 2007, but in the September survey, comparatively large numbers were found offshore off the Cape Peninsula. The data have been processed and have been used, *inter alia*, to elucidate ichthyoplankton drift patterns (Stenevik *et al*., in press).

Studies on ageing, birth dates and spawning grounds

A considerable number of otoliths were collected from juvenile and very young *M. paradoxus* to estimate birth date distributions and growth rates of the young fish, and thereby examine whether modes in the micro age structure are due to narrow environmental windows for successful spawning. The data analysis is still to be completed, for which additional funding will be needed.

Environmental information

Through the environmental measurements that have been made on all of the cruises, a large amount of environmental information covering the west coast of Southern Africa has been generated. The data are being held in a database at IMR for integration with the information on fish distribution and behaviour, and for use in oceanographic studies in general.

Use of genetics to elucidate life history

Studies on tissues from *M. capensis* and *M. paradoxus* collected in 2004 have found DNA markers to differentiate between the two species (von der Heyden *et al*., 2007a). The technique has subsequently been used to distinguish between *M. capensis* and *M. paradoxus* ichthyoplankton collected in a survey in 2005 (von der Heyden *et al*., 2007b), providing for the first time separate distribution maps for the eggs and larvae of the two species (Stenevik *et al*., in press). From this it has been concluded that differences in the cross-shelf distribution of *M. capensis* and *M. paradoxus* ichthyoplankton probably lead to differences in their drift routes, and thereby to different nursery areas for the two species (Stenevik *et al*., 2008).

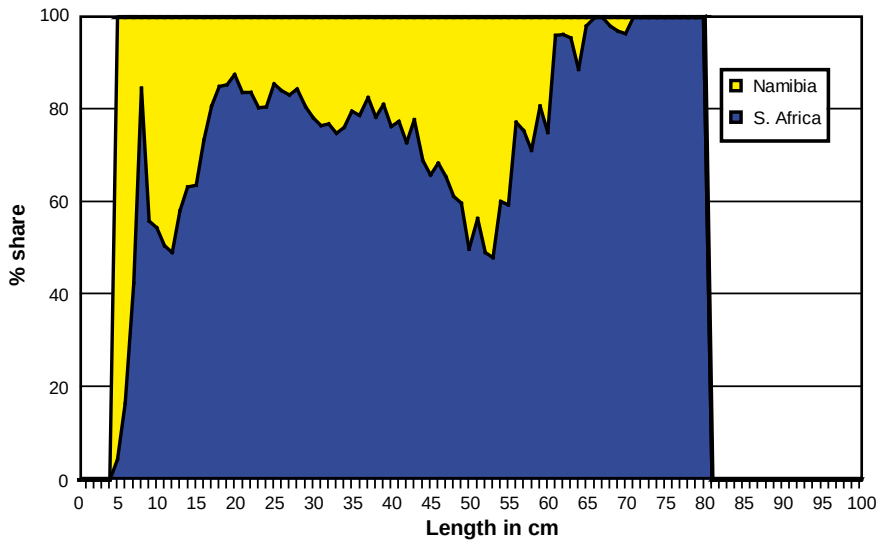

Figure 2. Division of *M. paradoxus* biomass between Namibia and South Africa by size class, from *Dr Fridtjof Nansen* trawl surveys in 2005.

Outputs

The main outputs from this project are the large archive of biological and physical/chemical data held at IMR, and comprehensive reports on all of the *Dr Fridtjof Nansen* surveys conducted under this project, many of which contain extensive preliminary results.

Publications

The following publications have emanated from the BCLME genetic study, based partly on material collected during the latter stages of the project.

Stenevik E.K., H.M. Verheye, M.R. Lipinski, M. Ostrowski and T. Stromme. 2008. Drift routes of Cape hake eggs and larvae in the southern Benguela Current system. Journal of Plankton Research, 30(10): 1147-1156.

von der Heyden S., M.R. Lipinski and C.A. Matthee. 2007a. Mitochondrial DNA analyses of the Cape hakes reveal an expanding, panmictic population for *Merluccius capensis* and population structuring for mature fish in *Merluccius paradoxus*. Molecular Phylogenetics and Evolution 42: 517-527.

von der Heyden S., M.R. Lipinski and C.A. Matthee. 2007b. Species-specific genetic markers for identification of early life-history stages of Cape hakes, *Merluccius capensis* and *Merluccius paradoxus* in the southern Benguela Current. Journal of Fish Biology 70 (Suppl. B): 262-268.

Characterisation and comparison of sardine and anchovy spawning habitats in the northern and southern Benguela

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[2]National Marine Information and Research Centre, Swakopmund, Namibia

Project description

The objective of this project was to characterise and compare the spawning habitats of sardine and anchovy in the northern Benguela in terms of environmental parameters, and to compare the findings with what is known about the spawning habitats of these species in the southern Benguela. The project is directly relevant and important to ecosystem studies in the northern and southern Benguela because of the importance of small pelagic fish in both of these ecosystems.

The study was carried out as a Masters project at NatMIRC by Beau Tjizoo. It was based on a retrospective analysis of data on the distribution and abundance of sardine and anchovy eggs collected from the South West Africa Pelagic Egg and Larvae (SWAPELS) surveys between Hollam's Bird Island and Cape Frio from 1972 to 1985, and from *Dr Fridtjof Nansen* surveys between 1999 and 2004, conducted as part of the BENEFIT Programme. Single factor quotient analysis was used to test whether sardine and anchovy in the northern Benguela during the study periods spawned preferentially within certain SST, surface salinity, oxygen and bottom depth ranges, and whether there were any differences in this respect between the two species and between the periods. In addition, the thermohaline characteristics of the species' spawning areas were compared using temperature-salinity plots. The results of these analyses were compared with those from similar studies on sardine and anchovy spawning habitats in the southern Benguela.

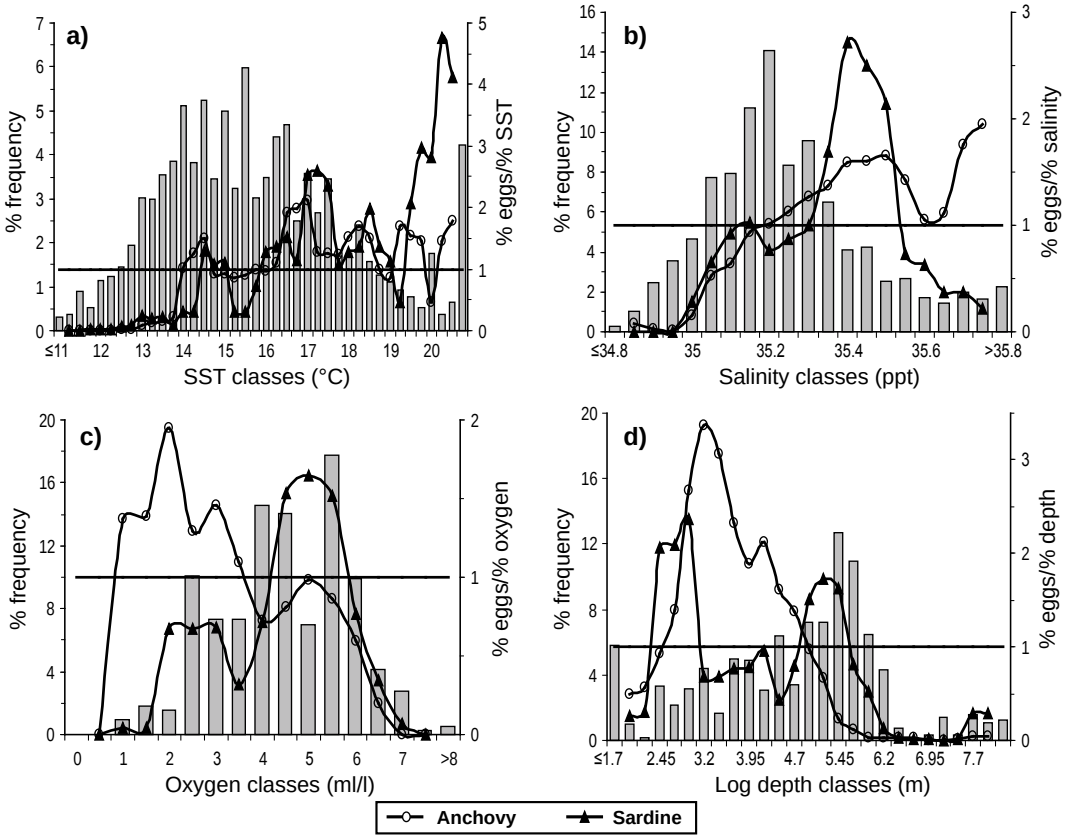

Figure 1. Quotient curves for egg abundance and the four chosen environmental variables for sardine and anchovy in the northern Benguela from SWAPELS data. The histograms show the distribution of the environmental parameters, and the horizontal lines the threshold for selection (from Tjizoo, 2008).

Achievements

From the selectivity quotient curves (e.g. Fig. 1), it was concluded that:

1. In both periods, sardine and anchovy spawned preferentially in areas of similar surface temperature (>14°C), although in the later period, sardine appeared to select somewhat cooler water for spawning than anchovy. Anchovy appeared to select a broader salinity range for spawning than sardine during the SWAPELS period (Fig. 1b), but an opposite trend was noted in the *Nansen* data.
2. No interannual trend could be detected in the temperature and salinity ranges apparently selected for spawning by anchovy or sardine during the SWAPELS period (e.g. Fig. 2a for SST). However, in most of the spawning seasons, both species appeared to prefer increasingly warmer water as the season progressed (e.g. Fig. 2b).
3. Aggregated TS plots indicate that anchovy eggs were found in all three of the water types reported in the region, but that sardine eggs were restricted to oceanic mixed water and Benguela Current water (Fig. 3). A similar pattern was observed in data from the recent period. The overlap in the temperature and salinity of the waters in which sardine and anchovy eggs were found was greater than in the southern Benguela, where anchovy eggs tend to be found preferentially in warm, saline water and sardine in cooler water of lower salinity.
4. There were clear differences in the oxygen selectivity curves for the two species in both periods, but the differences were not the same in each case. Anchovy spawned in water of lower oxygen concentration than sardine during the earlier period, but in the later period they spawned only in well-oxygenated water.
5. Sardine tended to spawn in deeper water than anchovy during the SWAPELS period (Fig. 1d), but in the later period, this tendency was not as marked. Both species were mainly found north of Walvis Bay in both periods (e.g. Fig. 4).

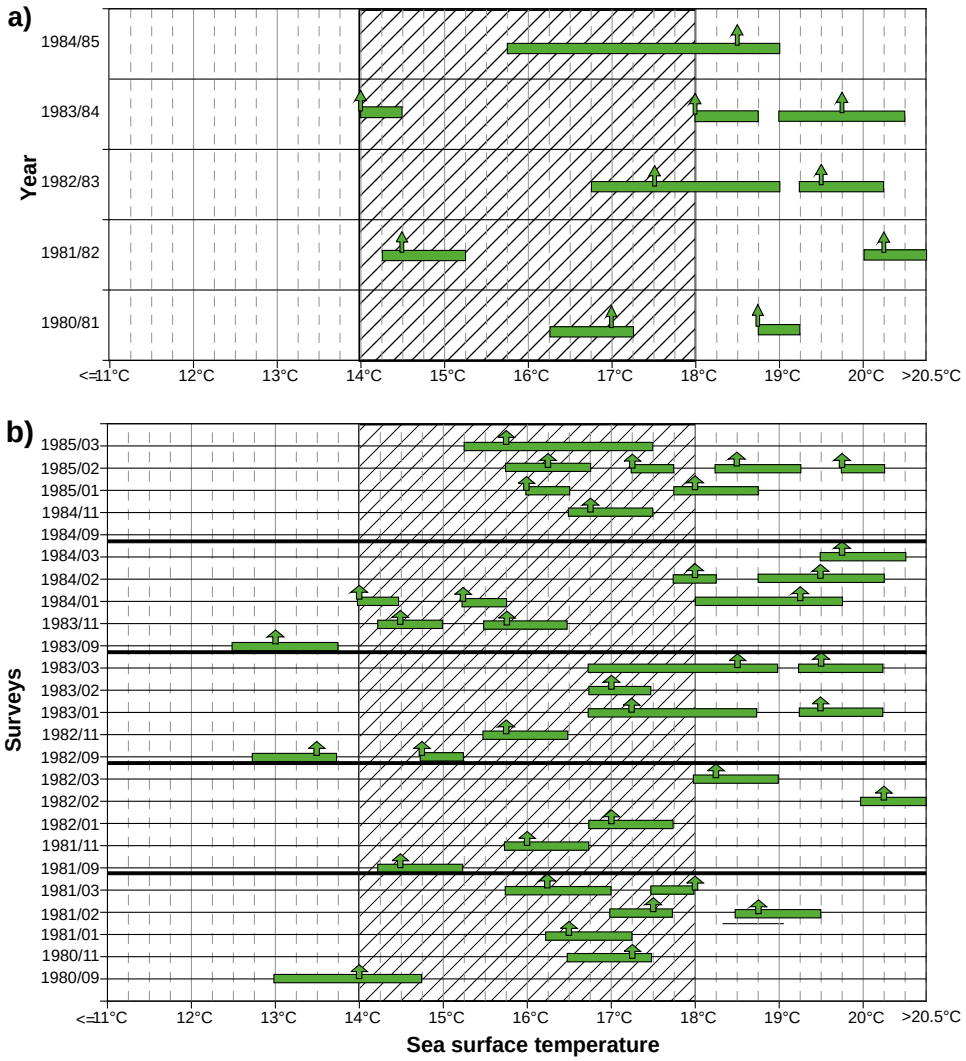

Figure 2. Apparent SST preferences of spawning sardine during (a) different years of the SWAPELS surveys and (b) over individual months during those years. Horizontal green bars show the SST ranges where the selectivity quotient was > 1, and arrows the peak of the selected range. Thick horizontal lines separate the different spawning seasons. The shaded area marks the SST range over which sardine and anchovy spawn in the four eastern boundary current systems (from Parrish *et al*., 1983; Tjizoo, 2008).

The overall picture to emerge is that although there were some differences in habitat selection between the earlier and later periods (possibly due to ecosystem changes between the two periods), the environmental parameters tested in this study do not play a strong role in determining when and where sardine and anchovy in the northern Benguela spawn. It is suspected that, as in the California Current and the southern Benguela, other environmental factors such as plankton, currents, winds and upwelling intensity may be more important in this respect.

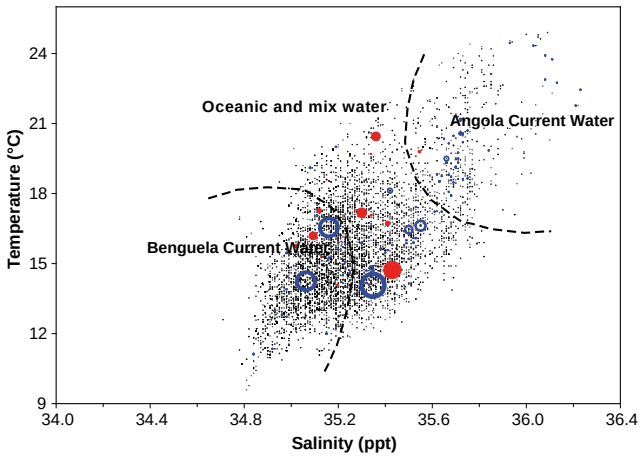

Figure 3. Plots of surface temperature and salinity from SWAPELS data collected during the spawning season between 1980 and 1985, overlaid by plots of sardine (red) and anchovy (blue) abundance. The diameter of the coloured symbols is proportional to egg abundance. The different water types are separated by the dashed lines (From Tjizoo, 2008).

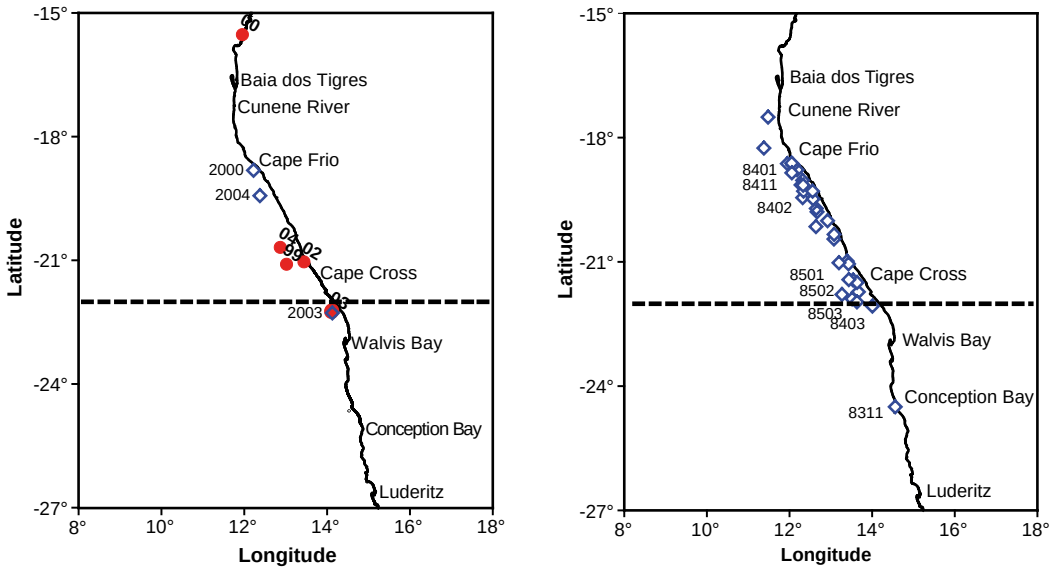

Figure 4. Locations of centroids representing the centre of gravity of sardine (red) and anchovy (blue) eggs derived from all of the SWAPELS surveys. Selected cruises are labelled (the first two digits representing the year and the last two the month) to demonstrate the shift in spawning habitat between 1983 and 1985. The two spawning grounds of sardine and anchovy in the northern Benguela defined by Le Clus (1990) are separated at 22°S latitude, shown as a dashed line (from Tjizoo, 2008).

Outputs

Data

All data used in this project have been consolidated into an access database at NatMIRC.

Theses

Tjizoo, B.M. 2008. Characterization and comparison of anchovy and sardine spawning habitat in the northern Benguela. MSc thesis, University of Cape Town, South Africa. 107pp.

Identification of acoustic targets off Angola

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[2]National Marine Information and Research Centre, Swakopmund, Namibia

[3]Institute of Marine Research, Bergen, Norway

[4]Campus de Gambelas, University of Algarve, Faro, Portugal

Project description

The objective of this project was to develop acoustic/spatio-temporal descriptors for the remote classification of acoustic targets during surveys of horse mackerel and sardinella off the coast of Angola, and particularly for distinguishing between echoes from Cunene horse mackerel, Cape horse mackerel, sardinella and other species and species groups. The project was motivated by the fact that echoes from other species can be confused or interfere with echoes from the target species, and that conventional identification by trawl is both cumbersome and potentially biased because of species and size selectivity.

The approach was to search for characteristic, species–specific patterns in the backscatter from species or species groups of known identity, in its most developed form through the application of a step-wise General Discriminant Analysis (GDA) in which suites of acoustic, morphological and spatial/temporal variables with power to discriminate between the various targets were sought.

Achievements

Using data from single-frequency (38 kHz) acoustic surveys in Angolan waters from *Dr Fridtjof Nansen* between 1997 and 2000, a knowledge base of reference observations on 18 different target types was compiled by a regional team of experienced operators and used in the GDA to identify traits characteristic of common species or species groups. From this, a classification scheme involving three acoustic and two spatial descriptors was set up and tested on subsets of the data. The classification success for the various target types is summarised in Table 1, from which it can be seen that the overall success rate for all types, based only on the most likely classification (Algorithm 1) was 46%, but that the success rate increased to 62% and 71% respectively if based on the second and third most likely classifications as well (Algorithms 2 and 3). For Cape horse mackerel and sardinella spp., success rates of 80% and 75% respectively were achieved when the classification was based on all three algorithms. These success rates, although low compared to those in similar studies on assemblages of only a few species, are encouraging considering the complexity of the assemblage in this study.

The multi-species classification matrix, based only on the most probable classifications, is shown in Table 2. Note that in many cases where a species or group was incorrectly classified (e.g. Cunene horse mackerel or mixtures of Cunene horse mackerel and other species), it was assigned to a mixed group which contained that species or one of the species in that group.

The results from this study demonstrate that a relatively straightforward analysis of conventional acoustic survey data collected at a single frequency combined with ancillary spatio-temporal information can provide useful indications on the identity of single- and multi-species pelagic fish aggregations in Angolan waters, including two of the main targets of acoustic surveys there (Cape horse mackerel and *Sardinella* spp.). While the algorithm does not assist in the identification of the other main target of acoustic surveys in Angolan waters (Cunene horse mackerel) and some other species and groups, it may still provide operators with valuable cues as to when trawling is most required, and be useful in that respect. The study as a whole points the way to the eventual automation or semi-automation of target identification in these and other similar acoustic surveys in the region.

Table 1. Overall correct classification rates (in %) predicted by the algorithm when considering the most likely (Rank 1), two most likely (Ranks 1 and 2) and three most likely (Ranks 1, 2 and 3) classifications. Pelagic Group 1 consists of clupeiforms, and Pelagic Group 2 hairtail, false scad and African moon fish. (From Table 8, Vaz Velho *et al*., 2006).

Acoustic groups	Rank of correct classification		
	1	1 + 2	1+2+3
Pelagic 1/ Sardinella	89	89	89
Cape horse mackerel	80	80	80
Sardinella	75	78	86
Lantern fish/ Cunene horse mackerel	70	80	80
Pelagic 2/ Demersal	67	67	67
Demersal	67	70	76
Demersal/ Cunene horse mackerel	61	83	87
Bigeye grunt/ Pelagic 2	33	67	67
Cunene horse mackerel	31	38	38
Bigeye grunt	25	25	75
Lantern fish	22	72	72
Bigeye grunt/ Cunene horse mackerel	20	40	40
Pelagic 2	13	13	75
Pelagic 1/ Pelagic 2	0	50	50
Sardinella/ Pelagic 2	0	48	71
Sardinella/ Cunene horse mackerel	0	0	0
Round herring	0	0	0
Global	**46**	**62**	**71**

Table 2. Classification rates (in %) for all species and species groups, considering only the most probable classification in each case. Correct classifications are shown in bold. (From Table 9, Vaz Velho *et al*., 2006).

Acoustic Group		Predicted group membership																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Cunene horse mackerel	1	**31**	13	13	6				6							13	6	6	6
Cunene horse mackerel/bigeye grunt	2		**20**			20				20							20		20
Cunene horse mackerel/demersal	3	4		**61**				17		4					9				4
Cunene horse mackerel/lanternfish	4				**70**								10				20		
Cunene horse mackerel/sardinella	5	50	50																
Cape horse mackerel	6						**80**												20
Bigeye grunt	7			25				**25**									50		
Bigeye grunt/pelagic 2	8								**33**								30	30	
Sardinella	9		14	3				3		**75**		3			3				
Sardinella/pelagic 1	10		11								**89**								
Sardinella/pelagic 2	11	10	14					5	5	24			19				24		
Lanternfish	12	11			44				6				**22**	11			6		
Lanternfish/pelagic 2	13			22						11			11				33	22	
Demersal	14	6		6	6		3	3							**67**	3			6
Demersal/pelagic 2	15							33								**67**			
Pelagic 2	16								25			25		25			**13**	13	
Pelagic 1/pelagic 2	17								25					25			50		
Round herring	18						50	50											

Outputs

The main outputs of the project are the classification algorithm itself and the experience gained in using it.

Publications

Vaz Velho F., B-E. Axelsen, P. Barros and G. Bauleth-D'Almeida. 2006. Identification of acoustic targets off Angola using General Discriminant Analysis. African Journal of Marine Science 28(3-4): 525-533.

Retrospective analysis of zooplankton community structure in the Benguela current large marine ecosystem

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[2]*National Marine Information and Research Centre, Swakopmund, Namibia*

Project description

The overall objective of the project was to quantify changes in zooplankton abundance and community structure in the northern Benguela over the past 50 years, for comparison and integration with information on long-term changes in zooplankton abundance and community structure in the southern Benguela. The project was motivated by the need for baseline information on natural and anthropogenically forced changes in the Benguela ecosystem as a whole, which is a pre-requisite for ecosystem management.

The project started as a BENEFIT project, with a retrospective analysis of a small subset of the SWAPELS (South West Africa Pelagic Egg and Larvae Survey) zooplankton sample archive from the 1970s and 1980s by two post-graduate students (T. Mainoane and S. Tsotsobe). In 2004 the project was taken over by the BCLME Programme and expanded to include the full SWAPELS collection and more recent data collected on the NatMIRC monitoring line off Walvis Bay. BENEFIT continued to support the project, specifically through partial funding of a regional training workshop on zooplankton taxonomy and identification, and of a PhD student involved in the study.

The bulk of the work comprised the curation and cataloguing of some 15000 zooplankton samples from the SWAPELS surveys, and the retrospective analysis of a representative subset of about 800 samples from this collection to quantify the abundance and describe the community structure of zooplankton in the northern Benguela during this period. Zooplankton samples routinely collected on the NatMIRC monitoring line since 2000 were analysed in the same way to provide an inter-decadal comparison for the Walvis Bay region, on which the SWAPELS analysis was initially focused.

A full-time sample curator and part-time sample analyst were engaged through the project, with initial financial assistance from the ENVIFISH and VIBES/IDYLE Programmes, in recognition of the collection's scientific value. The data management was contracted to the International Ocean Institute, University of the Western Cape, who were responsible for constructing a Benguela Plankton Portal to meet the BCLME's requirements for a comprehensive inventory of plankton metadata in the ecosystem. In addition, studentships were awarded to a PhD student (Fabienne Cazassus), and to a BSc Hons/ MSc student (Ignatius Kauvee) to work within the project. The training workshop was co-funded by BENEFIT and the Alfred P. Sloan Foundation through the Census of Marine Life (Zooplankton) Programme.

Achievements

The achievements of the project have been reported in detail to the BCLME in the final report of BCLME Project EV/PROVARE/02/05, prepared by Hans Verheye and submitted in June 2007, from which the summary below has been compiled.

A major achievement has been the capture of zooplankton data from the enormous number (approximately 20000) of samples collected during the SWAPELS surveys, from which hitherto only the ichthyoplankton had been extracted and analysed. This has allowed inter-decadal changes in zooplankton abundance, distribution and community structure in the northern Benguela to be described for the first time, and to be compared with corresponding long-term changes in the zooplankton of the southern Benguela, thus providing an integrated overview of changes in zooplankton in the entire Benguela ecosystem over half a century. Some of the major features are summarised below.

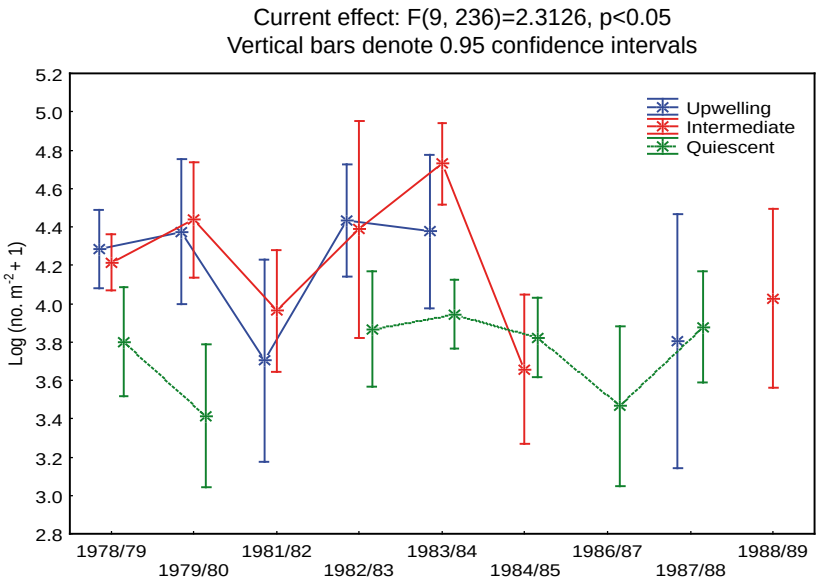

Figure 1. Year and season effect on copepod abundance during the SWAPELS period from a GLM. The year runs from 1 July of one year to 30 June the next.

During the SWAPELS period copepod abundance was consistently higher during the upwelling (August-October) and intermediate (November-January) seasons than during the quiescent (February-April) season, with maxima and minima in 1983/84 and 1984/1985 respectively (Fig. 1). This signal was so strong that it often masked inter-annual patterns. During the Benguela *Niño* in 1984, copepod abundance during the upwelling and intermediate seasons dropped dramatically, and only recovered slowly, with a much reduced seasonality in subsequent years. In contrast, copepod abundance was fairly consistent during the quiescent season over the entire time period. There were considerable inter-seasonal and inter-annual changes in the copepod communities during the SWAPELS period, with distinctly different community structures before, during, and after the Benguela *Niño* in 1984 (Fig. 3).

Copepod abundance was highly variable in the NatMIRC samples, again with clear seasonal cycles (Fig. 2), but changes in the community structure during the sampling period (2000-2006) were not significant. It was found that a reduction in primary productivity in the summer of 2005/2006 due to reduced upwelling was reflected in a significant reduction in copepod abundance off Walvis Bay, and that the copepod species composition in this period was significantly different to that in all other years.

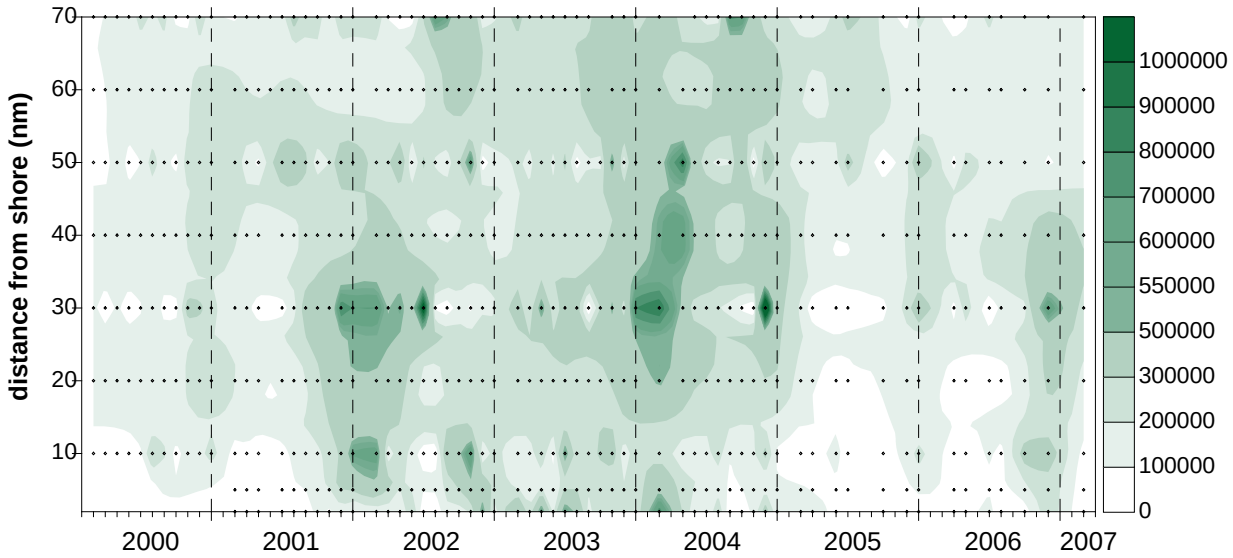

Figure 2. Copepod abundance (no m^{-2}) between February 2000 and February 2007 along the Walvis Bay transect. The dots represent the station positions.

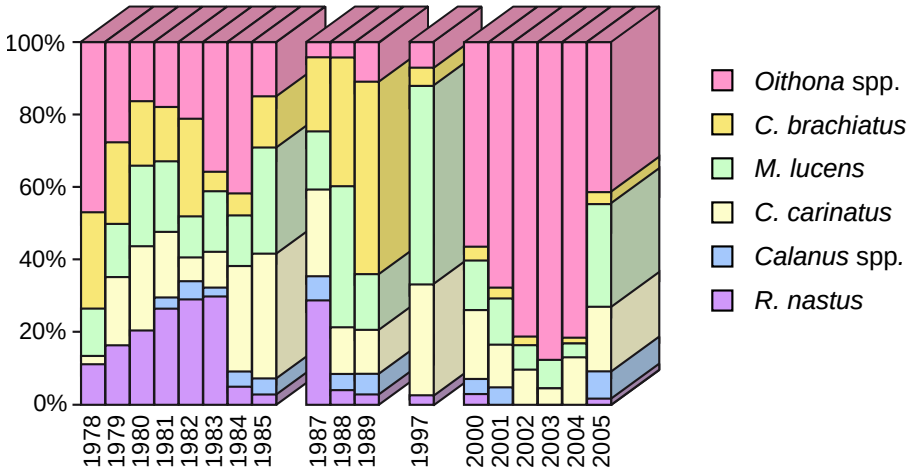

Figure 3. Long-term, decade-scale changes in copepod community structure (expressed as percentage composition of the six most dominant species – adults and copepodites C5 combined, shown on the right) on the Walvis Bay transect since the 1970s.

Overall, despite some gaps in the data set, it has been concluded that mesozooplankton biomass and total copepod abundance in the northern Benguela has been increasing over the past five decades. In addition, there is evidence to suggest considerable inter-decadal variability associated with large-scale changes in coastal upwelling. The "turning point" in upwelling and zooplankton appears to coincide with the Benguela *Niño* in 1984. There is evidence to suggest than another reversal occurred in the early 2000s.

Comparison with the southern Benguela (Fig. 4) shows that although there have been marked long-term changes in the abundance, distribution and structure of the copepod community there as well, the changes in the two sub-systems do not seem to have been in synchrony.

Another achievement of the project has been the construction of the plankton database, which currently contains 91964 records from 4465 samples at 648 stations, spanning the wider Benguela from its northern boundary to Durban in the Indian Ocean. Data are held from 1958 to 2001, with greater emphasis on the older data. The Benguela Plankton Portal, which consists of the metadata and metadata directory, the database itself and a comprehensive bibliography containing 233 publications at present, will continue to be an invaluable tool for further retrospective analysis of plankton data in support of research and management in the Benguela region, if properly maintained and supported by users.

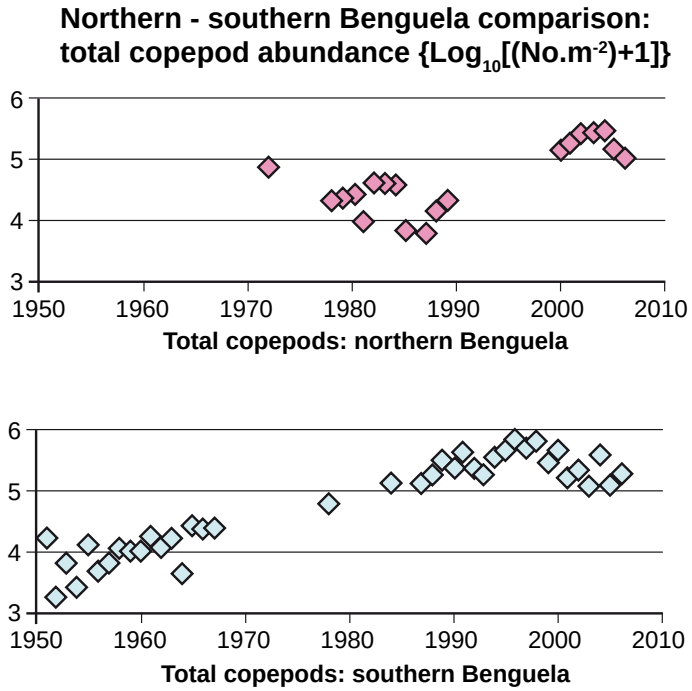

Figure 4. Comparison of time-series of total copepod abundance in the northern and southern Benguela since the 1950s. Data points are annual mean abundances.

Outputs

Data

A major output of the project is the Plankton Database and Benguela (Zoo)plankton Portal described above.

Publications

Hansen F.C., R.R. Cloete and H.M. Verheye. 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.

Hutchings L., H.M. Verheye, J.A. Huggett, H. Demarcq, R. Cloete, R.G. Barlow, D. Louw and A. da Silva. 2006. Variability of plankton with reference to fish variability in the Benguela Current Large Marine Ecosystem - an overview. In: L.V. Shannon, G. Hempel, P. Malanotte-Rizzoli, C.L. Moloney and J.D. Woods (Eds.). Benguela: Predicting a large marine ecosystem. Elsevier Large Marine Ecosystems 14: 91-124.

Verheye H.M. 2000. Decadal-scale trends across several marine trophic levels in the southern Benguela upwelling system off South Africa. Ambio 29(1): 30-34.

Theses

Kauvee I.K.V. assisted by M.J. Gibbons and H.M. Verheye. 2005. Observations on the composition of the copepod community either side of the Lüderitz upwelling cell. I.K.V. Kauvee BSc Hons thesis, University of the Western Cape, South Africa. 41pp.

Tsotsobe S.V. 2005. Temporal and spatial variability in copepod abundance, distribution and community structure off Walvis Bay in the northern Benguela current, 1979-1981. MSc thesis, University of the Western Cape, South Africa. 111pp.

BENEFIT INTERNATIONAL SCIENTIFIC ADVISORY PANEL FINAL PROGRAMME EVALUATION

On the occasion of the final BENEFIT/BCLME Symposium, held in Swakopmund, 19-21 November 2007, the BENEFIT International Scientific Advisory Panel (ISAP) conducted a final evaluation of the programme. The evaluation had a particular focus on BENEFIT scientific achievements and their impacts, but included some generic views on BENEFIT's contribution to the development of marine science in the region through training and capacity building efforts, the lessons that have been learned both scientifically and programmatically, and the legacy of BENEFIT in the region. The evaluation was primarily based on the experiences of the ISAP over the 10 years of BENEFIT science, and in particular the 2004 and 2006 ISAP project evaluation exercises, the 2007 final summary of project reports, and the presentations and discussions held during the final BENEFIT/BCLME Symposium. It must be noted that while this report is focused on BENEFIT alone, some of the achievements and lessons learned cannot be separated from those of its sister programme, the Benguela Current Large Marine Ecosystem (BCLME). This report is addressed to the Management Action Committee and Ministerial Board of BENEFIT, and to donor agencies in Germany, Norway and France, for their own use.

General remarks

1. BENEFIT's biggest success has been the breakdown of national barriers between national institutions and scientists in Angola, Namibia and South Africa. This has resulted in the development of a Benguela scientist trademark that was non-existent at the start of the programme and that has been successfully taken up by a new generation of scientists in the region. The shared research cruises, workshops and annual meetings required significant personal and institutional commitments. The individual and collective motivation to ensure the success of the Benguela vision has been remarkable and crucial for the success of BENEFIT.
2. BENEFIT arrived at exactly the right time for the region. The political and social developments at national level, from the end of apartheid in South Africa, the independence of Namibia and the renewed hopes for an end to the Angolan civil war, provided unique opportunities to catalyse national and personal hopes and aspirations, and these were taken up with enthusiasm.
3. BENEFIT has been a very successful mechanism for developing collaborative agencies in the region to focus their mandate and further their objectives at a regional level. The interaction between regional scientists and those of donor and research institutions in Norway, Germany and France opened training and scientific opportunities to the region, and provided a framework that allowed the region to take its rightful place in the international arena. Scientific collaborations with the international community, in particular, exceeded the programme's expectations and added much international exposure to regional partners.
4. The scientific expertise in the three countries was extremely uneven at the start of the programme, with large gaps between Angolan and the highly skilled South African scientists, in particular. Ten years later, scientific expertise has improved in all three countries, and the gap between the three has narrowed. It is noted that Namibia, where the BENEFIT Secretariat was located, has improved the most, partially because there was a quasi-perfect match between what the country needed and what BENEFIT offered. Although very significant progress has been achieved in Angola the country was not ready to join its partners on an equal footing. It is noted that science sustainability, particularly in Angola, has not yet been achieved. Angola, and to a lesser extent also Namibia, continues to require outside support to ensure its long term sustainability, for example through regional institutions like the Benguela Current Commission and its donors. South Africa, being already at a high level, has not developed much further in terms of marine research capability. However, some of the newly-created expertise has been funnelled towards private consultancies, to the detriment of the established research institutions, but to the benefit of the country as a whole.
5. BENEFIT was created by the fisheries research institutes of the three countries. It offered much needed oxygen for science to institutions whose mandate is not focused on the science *per se*. However, while the relationship with South African Universities was fruitful, BENEFIT had only

a small interaction with the University of Namibia and failed to engage properly with Angolan universities. The requirement of the donor agencies to focus the research on direct management needs may have played a role in this situation.

6. The ISAP recognises that without BENEFIT the regional scientific landscape would have been unrecognisable: it is likely that bilateral donor-country collaborations would have remained but not in a coordinated manner, loosing the regional coherence provided by BENEFIT; research activity overall would have been much less and it is likely that Angola would have been left behind scientifically; research on the interface between environment and resources would have weakened; international participation would have been on a considerably smaller scale and much more difficult to achieve (e.g. BENEFIT provided assistance to facilitate the issue of permits for foreign vessel entry into national EEZs). Without BENEFIT it is unlikely that the Benguela Current Commission would have been created.

BENEFIT Scientific Objectives

The overall goal of the programme was to develop the enhanced science capability required for the optimal and sustainable utilisation of living resources of the Benguela ecosystem by,

- Improving knowledge and understanding of the dynamics of important commercial stocks, their environment, and linkages between environmental processes and stock dynamics.
- Building appropriate human and material capacity for marine science and technology in the countries bordering the Benguela ecosystem.

This goal was to have been achieved through three objectives:

i. To increase knowledge of the dynamics of key Benguela resources through improved monitoring of the abundance and distribution of these resources and through research on stock dynamics

ii. To develop an integrated monitoring capability for quantifying environmental variability in the Benguela region on appropriate time and space scales

iii. To identify linkages between the dynamics of the key Benguela resources and the physical forces that influence population variability, in order to forecast how climate variability and change will alter the distribution, productivity, food web and stocks of the Benguela ecosystem.

7. The ISAP concludes that the programme maintained adequate focus on these objectives through its life. Overall very good progress has been achieved, particularly with regard to scientific objectives i and ii, but with some notable exceptions.
8. It is noted that the interactions between environment and resources (the letter I in BENEFIT, objective iii), although included in many of the projects, was not as explicitly addressed as the programme required. However, this was a very ambitious objective at the time of implementation. In hindsight the creation of an “Interactions” working group would have helped address this lack of explicit research focus.
9. Among the scientific gaps not filled by BENEFIT the ISAP particularly identifies the lack of adequate hydrodynamic modelling capabilities in Namibia and Angola (in South Africa this was developed in parallel to BENEFIT by other French-led initiatives) and the insufficient research emphasis on the links between atmospheric and ocean climate throughout the region, particularly as we enter the era of climate change.

BENEFIT Scientific Achievements - Environment Working Group

10. Consideration of environmental data in a broader ecosystem context has become prominent in the scientific work of regional scientists and students. Climate forcing has been identified as a major driver for ecosystem variability, and the relationship between environmental processes, fish recruitment and fish biomass has been increasingly recognised.
11. Considerable methodological progress has been made through projects, monitoring activities and intensive training; including *inter alia* the routine use of CTD, mooring equipment, weather stations, satellite images and highly sophisticated laboratory equipment.

12. The implementation of new inshore monitoring lines and support to existing standard monitoring transects off all three countries is one of the success stories of BENEFIT, although there are logistical and financial problems in continuing this work across the region. Inshore monitoring has provided ample opportunity for training on the job and should provide further benefits through the Benguela Current Commission.

13. The monthly State of the Environment reports produced by NatMIRC is considered one of the most remarkable achievements of the Environment Working Group of BENEFIT.

With regards to specific research highlights the ISAP selected the following:

14. Over the years a considerable new conceptual understanding of long-term physical forcing in the Benguela has been achieved, including the Benguela-*El Niño* connections, variability in the tropical Atlantic and its impact on the Benguela system, and the seasonality of alongshore and cross-shelf currents in the northern Benguela.

15. Similar conceptual understanding has been developed with respect to the external and internal causes and dynamics of low-oxygen events off Namibia. This understanding will be of use in the development of early warning systems.

16. Of particular significance is the excellent field and satellite monitoring work on hydrogen sulphide and methane emissions by sediments, identifying their mechanisms, lack of seasonality and its pulsating nature. It is recommended that the full extent of the information collected is exposed internationally through additional peer-reviewed publications.

17. BENEFIT made a substantial contribution to the identification of long-term (decadal) and medium term (interannual) fluctuations in zooplankton biomass in the region, reporting consistent but asynchronous biomass increases in the northern (since the late 1970s) and southern Benguela (since 1950), as well as dramatic changes in composition since 2001.

18. Excellent progress has been achieved over the years regarding the use of satellite information to quantify primary production across the Benguela and its seasonality, with state of the art work on ground-truthing ocean colour, pigment-separated production estimates, and separation of the region into production provinces (Angola-Benguela-Frontal Zone, Northern Namibia, Lüderitz upwelling cell/Orange River cone, Namaqua Shelf and Agulhas Bank)

19. Finally, considerable work has been devoted to understanding the dynamics of the Angola-Benguela front.

BENEFIT Scientific Achievements - Resources Working Group

20. One of the major methodological achievements has been the standardisation of fish ageing techniques throughout the region, due to the regular and intensive training workshops conducted. However, there are still concerns over the accuracy of age/length keys for most commercial species in the region.

21. Equally, BENEFIT funded a series of workshops on survey error and stock assessment, with international participation, raising regional and in some cases setting international standards.

22. The coordination of demersal stock assessment cruises across the region, particularly by the research vessel *Dr Fridtjof Nansen*, has been instrumental in developing the concept of transboundary resources, providing scientific support for the creation of a Benguela Current Commission.

With regards to specific research highlights the ISAP selected the following:

23. Thanks to BENEFIT scientists in the region developed considerable new understanding of the early life history, recruitment, growth, migration patterns and, as a result, life history strategies of Cape hakes. Some interesting links with environmental variability have emerged.

24. World leading methodology has been developed in the region for the acoustic identification and biomass estimation of jellyfish in the northern Benguela, as well as ecological understanding of the role of these organisms.

25. An intensive seal tagging programme has provided new and crucial information to ascertain the interactive dynamics of seal colonies in the Benguela. A similar programme on sharks terminated before it could demonstrate the value of tagging programmes.

26. It is noted that hydro-acoustic techniques have been used in the region to push forward a number of target identification and biomass estimation projects, from horse mackerel to mesopelagic fish, using multi-frequency techniques.

Capacity building

The capacity building component of BENEFIT was to have been addressed through three collective objectives:

i. to build human capacity in the region, particularly in areas of greatest need and greatest historical disadvantage,

ii. to develop, enhance and maintain the national and regional infrastructure and cooperation needed to support fisheries-related marine science and technology in the region,

iii. to make countries in the region, and the region as a whole, more self-sufficient in marine science and technology, so that the living resources of the Benguela ecosystem can be managed nationally on a sustainable basis for the benefit of local inhabitants.

27. The ISAP acknowledges the intensive capacity building efforts carried out during BENEFIT, both at sea and in laboratories, in the region and overseas, aimed at students, scientists and technicians. Job training and academic training was particularly good, although specialised dedicated training (e.g. in scientific writing, biostatistics, distance-learning) was not maximised. As a result of the training the ISAP has noted excellent progress in the ability of regional scientists to deliver oral communications and produce posters. However, due to the lack of self-confidence and experience in scientific writing, not enough publications have been published in international peer-review journals, although the best BENEFIT science is of international standard.

28. It must be acknowledged that BENEFIT also increased the responsibilities of scientists and technicians in the region, and many battled to fulfil their line functions while conducting BENEFIT research. Some of the developed capacity has been transferred from research to management, which might be a positive outcome in terms of overall national development. However, this also reflects the lack of career development opportunities for young scientists and technicians. This is an aspect that needs to be tackled by the BCC and the three national fisheries authorities. Likewise, expectations for the BCC must recognise the feeling of personal overload that many regional scientists have felt through the last decade.

29. Not all the capacity developed during BENEFIT has stayed in the region. The export of scientific capacity outside the region, however, clearly demonstrates the quality of the training conducted by BENEFIT and the regional partners. The ISAP concludes that brain drain would have been even more serious without BENEFIT.

30. Unfortunately BENEFIT has contributed little to the development of proper scientific project management procedures, from formal and standard proposal development, timely and adequate reporting, detailed accountability of the use of funds[1] and of research activities conducted, etc. This is a problem that needs to be addressed (as a training need) and that originates from the excessive reliance on direct government, non-competitive funding modes.

31. While regional infrastructure has improved over the last decade, BENEFIT did not have sufficient ambition in this regard. The marine research infrastructure in the region is still a national responsibility, leaving few long lasting regional infrastructures or networks. A notable exception is the support to the Namibe laboratory in Angola and the Angolan research vessel *Tombwa*, but these facilities are not much utilised and their viability is in question.

[1]Funds were adequately used and accounted for at programme level, but detailed fund management information at individual project level was not available for scrutiny.

Organisation and infrastructure issues

32. The duration of BENEFIT (10 years) is considered to have been adequate to ensure that the expectations of a programme of this size were realised, providing some continuity and stability. The obtaining of legal status of the programme, a bone of contention at the onset, has proven not to be a necessity and in fact might have been detrimental to the programme, had it occurred.
33. The overall performance of the BENEFIT Office has been excellent, driven by the commitment, professionalism and dedication of its Directors, Programme manager, and other support staff. It is acknowledged that the Office spent a considerable amount of time dealing with uniquely complex political and structural issues. However, mechanisms should have been in place from the beginning to ensure more effective data and information management procedures. It is concluded that the donors did not provide sufficient guidelines to help structure the programme in this regard.
34. To address this shortfall, the ISAP recommends that all BENEFIT project reports, meeting minutes, presentations, etc. be stored digitally and placed where they can be accessed electronically for years to come. This function must be completed urgently.
35. In hindsight the creation of part-time, paid responsible officers for each working group could have assisted in sharing the burden of project and information management responsibility. Without this leadership, and without proper mechanisms in place, the working groups have not been strong enough to drive and manage the projects.
36. The other side of this coin, however, is that BENEFIT had the flexibility to respond to the needs of the community in a dynamic and fast response mode that more rigid structures would not have allowed. This flexibility was greatly appreciated by scientists in the region, and used regularly to unblock situations.
37. It is concluded that BENEFIT, particularly in its final 5 years, had too many small projects (in addition to the BCLME projects later implemented in parallel), and that the scientists in the region struggled to cope with this reality. As a result the programme was not sufficiently integrated, with too much focus on small issues and not enough connectivity to the major objectives of the programme. The science has often been too fragmented, and many of the projects lacked in-depth analysis of the results, particularly in terms of statistical analysis, modelling and discussion. It is recommended that programmes like BENEFIT should focus on fewer, more integrated projects.
38. The dual funding of BENEFIT did not pose significant scientific or logistical problems, but this was largely because the work programme was clearly separated between “Resources” and “Environment”, with different donors addressing each aspect. This model did not facilitate interactions between both sectors of the programme, one of the cornerstones of BENEFIT’s scientific vision. The nature of science on the interfaces suggests that the interactions between the Environment and Resources activities would have been better addressed if the programme had been structured according to challenges or research questions rather than disciplines.
39. The departure of the last Director of BENEFIT before the completion of the work programme has created difficulties. It is recommended that future programmes ensure that their coordination office remains fully in place for some time after the programmes are completed.

BENEFIT Legacy

40. Scientifically BENEFIT has provided valuable multidisciplinary and transboundary research outputs to underpin the implementation of the Ecosystem Approach to Fisheries throughout the region, including the development of indicators, decision tools, risk assessments, etc. BENEFIT clearly paved the way to some Benguela Current Large Marine Ecosystem (BCLME) projects, and thanks to the assistance of the FAO and the commitment of the three regional countries, the Benguela has become a world leader in EAF implementation.
41. From a training perspective there is little doubt that scientific capacity has increased considerably as a result of BENEFIT, but also that some of this capacity has moved away from research (e.g. into management), into the private sector (e.g. consultancies) and in some cases away from the region. The reasons behind these developments are complex and specific to each regional country. Strengthening the private sector (particularly in South Africa) has been an important way of keeping scientific expertise in the Benguela.

42. Methodologically, the application of transboundary research surveys and the standardisation of a diverse range of techniques and methodologies are likely to shape regional research cooperation and transboundary management implementation for many years to come.
43. Institutionally the most significant legacy of BENEFIT is the creation of the Benguela Current Commission. A lesson for the future is that such a complex management structure was not forced from the start but rather developed naturally as the scientific issues matured. Focusing regional collaboration on the science (largely not as contentious as management issues) allowed sufficient time for management developments to occur.
44. BENEFIT and BCLME have initiated monitoring and linking of both *in situ* and satellite observations of the coastal waters around southern Africa, which form the basis for GOOS-Africa. This needs to be further developed and consolidated under the BCC. This is seen as a model for developing GOOS in the developing world.
45. Finally, the International Scientific Advisory Panel would like to congratulate all the region's scientific and institutional participants, donor agencies and international scientists, for completing a remarkable programme of collaborative science. We believe that BENEFIT will shape the mindset of the region for many years and will provide a successful template for implementation in other regions. The ISAP is proud to have contributed to this achievement.

Signed, December 2007:

Dr Manuel Barange (Chair, Plymouth Marine Laboratory, UK)
Dr Gabriella Bianchi (Institute of Marine Research/FAO, Norway/Italy)
Prof. Bodo von Bodungen (Baltic Sea Research Institute, Germany)
Prof. John Field (UCT, South Africa)
Dr Pierre Fréon (IRD, France)
Prof. Gotthilf Hempel (University of Kiel, Germany)
Dr Ole Arve Misund (Institute of Marine Research, Norway)
Dr Claude Roy (IRD, France).

APPENDIX A.
BENEFIT CRUISES, KEY SCIENTIFIC MEETINGS AND SELECTED TRAINING ACTIVITIES

Neville Sweijd

The following is a record of the cruises, key workshops and other scientific meetings sponsored, facilitated or hosted by BENEFIT and its partners over the life of the programme, and a selected list of BENEFIT training activities between 2003 and 2007, when the training programme had its own budget.

Cruises

Table A1 lists the cruises of *RV Dr Fridtjof Nansen* from 1995 onwards which were associated with BENEFIT, or which were conducted through bilateral arrangements between Angola and Norway. The total number of ship days amount to 2319. Prior to that, the vessel carried out several national and regional cruises in the region (totalling 1104 days), with the first South African cruises taking place in 1994. Also included in the Table are the less regular cruises of other vessels sponsored by other partners in which BENEFIT participated, amounting to 502 days in total.

Table A1. Cruises in the Southeast Atlantic between 1995 and 2007 conducted in association with BENEFIT, or through bilateral arrangements between Angola and Norway

Year / Country	Cruise Description	Survey period		Days
		From	To	
RV Dr Fridtjof Nansen				
1995				
Namibia	Methodology	16/01/1995	19/02/1995	34
Angola	Pelagic and demersal fish	26/02/1995	02/04/1995	35
Namibia	Hake and other demersal fish	20/04/1995	28/05/1995	38
Namibia	Horse mackerel	31/05/1995	22/06/1995	22
Angola	Deep-water shrimp etc.	27/07/1995	13/08/1995	17
Angola	Pelagic fish	22/08/1995	22/09/1995	31
Congo/Gabon	Pelagic and demersal fish	15/08/1995	23/08/1995	8
Namibia	Hake recruitment	27/09/1995	06/10/1995	9
South Africa	Sardine behaviour	09/10/1995	18/10/1995	9
Total				**203**
1996				
Namibia	Hake and other demersal fish	12/01/1996	18/02/1996	37
Angola	Pelagic fish	28/02/1996	01/04/1996	33
Namibia	Hake ecology and survey methodology	10/04/1996	01/05/1996	21
Namibia	0-group hake	03/05/1996	13/05/1996	10
Namibia	Horse mackerel	04/06/1996	23/06/1996	19
Regional (BENEFIT)	Sardine behaviour	25/06/1996	28/06/1996	3
Regional (BENEFIT)	Sardine behaviour	28/06/1996	13/07/1996	15
Angola	Demersal fish and Angola dome	16/07/1996	08/08/1996	23
Angola	Pelagic fish	19/08/1996	05/09/1996	17
Namibia	Hake and other demersal fish	09/09/1996	14/10/1996	35
Total				**213**

Year / Country	Cruise Description	Survey period		Days
		From	To	
RV Dr Fridtjof Nansen				
1997				
Namibia	Hake and other demersal fish	10/01/1997	20/02/1997	41
Angola	Pelagic fish	26/02/1997	18/03/1997	20
BENEFIT	Angola/Benguela front	04/04/1997	22/04/1997	18
BENEFIT	Sonar studies	29/04/1997	12/05/1997	13
Angola	Demersal resources	15/05/1997	02/06/1997	18
Namibia	Horse mackerel	11/06/1997	29/06/1997	18
Namibia	Valdivia Bank	02/07/1997	13/07/1997	11
Namibia	Orange roughy	16/07/1997	01/08/1997	16
Angola	Dentex	06/08/1997	03/09/1997	28
BENEFIT	Horse mackerel	13/09/1997	26/09/1997	13
BENEFIT	Hake ichthyoplankton	27/09/1997	20/10/1997	23
Total				**219**
1998				
Namibia	Hake and other demersal fish	12/01/1998	21/02/1998	40
Angola	Pelagic fish	02/03/1998	28/03/1998	26
Namibia	Young hake	30/03/1998	04/04/1998	5
BENEFIT	Sonar studies	17/04/1998	05/05/1998	18
Angola	Demersal resources	07/05/1998	22/05/1998	15
Namibia	Horse mackerel	25/05/1998	14/06/1998	20
BENEFIT	Fish behaviour	16/06/1998	28/06/1998	12
Namibia	Orange roughy	01/07/1998	24/07/1998	23
Angola	Pelagic fish	27/07/1998	23/08/1998	27
BENEFIT	Hake early life stages	23/09/1998	05/10/1998	12
BENEFIT	Horse mackerel	07/10/1998	18/10/1998	11
Total				**209**
1999				
Namibia	Hake and other dermersal fish	11/01/1999	20/02/1999	40
Namibia	0-group hake	22/02/1999	28/02/1999	6
Angola	Demersal resources	01/03/1999	29/03/1999	28
Namibia	Horse mackerel target strength	20/05/1999	27/05/1999	7
BENEFIT	Trawl experiments	27/05/1999	13/06/1999	17
Namibia	Sardine	14/06/1999	04/07/1999	20
Namibia	Orange roughy	05/07/1999	31/07/1999	26
Angola	Pelagic fish	05/08/1999	26/08/1999	21
BENEFIT	Jellyfish	30/08/1999	05/09/1999	6
BENEFIT	Multifrequency acoustics	06/09/1999	17/09/1999	11
BENEFIT	Hake recruitment	28/09/1999	18/10/1999	20
Total				**202**
2000				
South Africa	Hake stocks	20/01/2000	15/02/2000	26
BENEFIT	Horse mackerel recruitment	16/02/2000	08/03/2000	21
Angola	Demersal resources	09/03/2000	14/04/2000	36
BENEFIT	Trawl experiments	27/04/2000	17/05/2000	20
South Africa	Hake stocks	18/05/2000	11/06/2000	24
BENEFIT	Multifrequency acoustics etc.	12/06/2000	30/06/2000	18
Namibia	Grid selection experiments	17/07/2000	26/07/2000	9
Angola	Pelagic fish	28/07/2000	20/08/2000	23
Total				**177**

Year / Country	Cruise Description	Survey period		Days
		From	To	
RV Dr Fridtjof Nansen				
2001				
South Africa	Hake stocks	31/01/2001	24/02/2001	24
Angola	Demersal resources	25/02/2001	25/03/2001	28
BENEFIT	Horse mackerel recruitment	28/03/2001	11/04/2001	14
BENEFIT	Acoustic survey errors	18/04/2001	02/05/2001	14
Angola	Pelagic resources	19/07/2001	18/08/2001	30
BENEFIT	Horse mackerel diel migration	20/08/2001	31/08/2001	11
BENEFIT	Jellyfish	01/09/2001	07/09/2001	6
BENEFIT	Multifrequency acoustics	08/09/2001	15/09/2001	7
BENEFIT	Efficiency of bottom trawls	16/09/2001	30/09/2001	14
South Africa	Bottom trawl studies	04/10/2001	13/10/2001	9
Total				**157**
2002				
BENEFIT	Demersal survey, South Africa	17/01/2002	12/02/2002	26
Namibia	Bottom trawl intercalibration	17/02/2002	25/02/2002	8
Angola	Demersal resources	27/02/2002	27/03/2002	28
BENEFIT	Recruitment studies	02/04/2002	15/04/2002	13
BENEFIT	Acoustic errors	18/04/2002	01/05/2002	13
Angola	Pelagic resources	17/08/2002	17/09/2002	31
BENEFIT	Horse mackerel vertical distribution	19/09/2002	27/09/2002	8
BENEFIT	Efficiency of bottom trawls	08/10/2002	15/10/2002	7
Total				**134**
2003				
BENEFIT	Demersal survey, South Africa	10/01/2003	10/02/2003	31
South Africa	Intercalibration of bottom trawls	01/02/2003	10/02/2003	9
BENEFIT	Recruitment studies on anchovy	14/02/2003	27/02/2003	13
Angola	Demersal resources	28/02/2003	01/04/2003	32
BENEFIT	Errors in pelagic fish surveys	21/04/2003	01/05/2003	10
BENEFIT	Hake vertical migration	20/04/2003	01/05/2003	11
Angola	Pelagic resources	20/07/2003	19/08/2003	30
BENEFIT	Jellyfish studies	20/08/2003	02/09/2003	13
BENEFIT	Intercalibration with *RV Africana*	29/09/2003	05/10/2003	6
BENEFIT	Efficiency of bottom trawls	06/10/2003	18/10/2003	12
Total				**167**
2004				
BENEFIT	Gobies	12/01/2004	18/01/2004	6
BENEFIT	Recruitment studies	19/01/2004	01/02/2004	13
BENEFIT	Intercalibration and Orange River	05/02/2004	10/03/2004	34
Angola	Demersal resources	12/03/2004	13/04/2004	32
BCLME	Orange River	19/04/2004	02/05/2004	13
Angola	Pelagic resources	28/07/2004	27/08/2004	30
BCLME	Orange River	28/08/2004	09/09/2004	12
South Africa	Intercalibration with *RV Africana*	10/09/2004	20/09/2004	10
BENEFIT	Efficiency of bottom trawls	22/09/2004	12/10/2004	20
Total				**170**
2005				
BENEFIT	Recruitment studies	13/01/2005	27/01/2005	14
BCLME/BENEFIT	Trans-boundary demersal survey	04/02/2005	10/03/2005	34
BENEFIT	Gobies	12/03/2005	23/03/2005	11
Angola	Demersal resources	25/03/2005	25/04/2005	31
BENEFIT	Pelagic resources	17/07/2005	25/08/2005	39
BENEFIT	Efficiency of bottom trawl	27/08/2005	16/09/2005	20
BENEFIT	*Merluccius paradoxus*	26/09/2005	17/10/2005	21
Total				**170**

Year / Country	Cruise Description	Survey period		Days
		From	To	
RV Dr Fridtjof Nansen				
2006				
BENEFIT	Gobies	10/01/2006	21/01/2006	11
BENEFIT	Hake, South African West Coast	27/01/2006	26/02/2006	30
Angola (BENEFIT)	Demersal resources	28/02/2006	31/03/2006	31
Angola-Gabon	Oil pollution/fish resources	01/04/2006	19/04/2006	18
Angola (BENEFIT)	Pelagic resources	21/07/2006	21/08/2006	31
BENEFIT	Mesopelagic fish, Namibia/SA	22/08/2006	12/09/2006	21
Northern Angola	Environmental studies	07/10/2006	21/10/2006	14
Total				**156**
2007				
BENEFIT	Hake, South African West Coast	10/01/2007	05/02/2007	26
BENEFIT	Hypoxic environment studies	07/02/2007	23/02/2007	16
Angola (BENEFIT)	Demersal resources	24/02/2007	26/03/2007	30
BENEFIT	Hake multidisciplinary study	30/03/2007	19/04/2007	20
Angola-Namibia N (BENEFIT)	Pelagic resources	07/07/2007	16/08/2007	40
South Africa (BENEFIT)	Hake multidisciplinary study	14/09/2007	21/09/2007	7
South Africa	Test multi- beam sonar	21/09/2007	24/09/2007	3
Total				**142**
Total (*Dr Fridtjof Nansen*)				**2319**
RV Africana				
BENEFIT Training	Training	07/05/1999	02/06/1999	26
BENEFIT Training	Training	10/07/1999	14/07/1999	4
BENEFIT Cruise	Training (oceanography, plankton, fish, Northern Benguela)	15/02/2002	19/03/2002	32
RV Alexander von Humboldt				
Multi-institutional Cruise	Three BENEFIT / Angola Legs	05/01/2004	31/05/2004	147
RV Algoa				
BENEFIT Training	Supplement *RV Africana* Cruise	21/07/1999	03/08/1999	13
RV Petr Kottsov				
BENEFIT Cruise	Plankton, Northern Benguela	April 1997		
RV Melville				
ASTTEX	Physical oceanography, S. Atlantic (M&CM, U. Maine)	02/01/2003	16/01/2003	14
Multi-institutional Cruise	Paleo-oceanography	23/03/2003	02/05/2003	40
RV Meteor				
Namibia	Benthos, oceanography, biochemistry, Angola and Namibia	07/06/2000	11/03/2000	120
Regional Benguela	Biogeochemistry,geophysics, geology, micropalaentology, oceanography, hydrography, microbiology	20/01/2003	13/04/2003	83
RV Poseidon				
Angolan shelf	Oceanography and plankton (IOW, ZMT*,INIP, NatMIRC,M&CM)	30/04/1999	10/05/1999	10
RV Welwitchia				
BENEFIT Training	Supplement *RV Africana* Cruise	21/07/1999	03/08/1999	13
Total (other vessels)				**502**
Total (all vessels)				**2821**

*ZMT = Centre for Tropical Marine Ecology, Bremen, Germany

Key scientific meetings

Table A2. Key workshops and other scientific meetings sponsored, facilitated or hosted by BENEFIT and its partners over the life of the programme.

Event	Location	Date
Workshop/seminar on Fisheries Resource Dynamics in the Benguela Current Ecosystem	Swakopmund, Namibia	30 May–2 June 1995
BENEFIT Resources Programme Planning Workshops	Swakopmund, Namibia	22–26 March 1999
BENEFIT Survey Errors Workshop	Cape Town, South Africa	4–7 December 2000
BENEFIT Annual Forums	Swakopmund, Nambia	April 2000–2004, 2006
BENEFIT Linkage Workshop	Cape Town, South Africa	22–23 March 2001
Southern African Marine Science Symposium 2002	Swakopmund, Namibia	1–5 July 2002
GTZ/BENEFIT-GLOBEC Workshops on Long-term Dynamics of the Benguela and Humboldt Current Upwelling Ecosystems	Various locations in Namibia	4–15 November 2002
BENEFIT Survey Methods Workshop	Cape Town, South Africa	14–16 November 2003
BENEFIT Stock Assessment Workshops	Cape Town, South Africa	5 workshops between November 2001 and December 2004
INIP Science Plan Workshop	Cacuacau, Angola	1–2 December 2003
BENEFIT Estuaries Workshop	Swakopmund, Namibia	21–23 November 2003
BCLME Biodiversity Workshop	Swakopmund, Namibia	26–27 April 2004
Lüderitz Upwelling Cell/Orange River Cone (LUCORC) Workshop	Cape Town, South Africa	28–29 July 2004
Southern Africa Marine Science Symposium 2005	Durban, South Africa	3–7 July 2005
Angola/Benguela Front Workshop	Swakopmund, Nambia	3 – 4 April 2006
BCLME Hake Research Workshop	Cape Town, South Africa	9–11 May 2006
BCLME/BENEFIT Northern Benguela Pelagic and Midwater Resources Workshop	Windhoek, Namibia	26–28 September 2007
BENEFIT Fish Ageing Workshops	Various locations in Angola, Namibia and South Africa	7 workshops between 2000 and 2007
BENEFIT/BCLME Final Meetings	Swakopmund, Namibia	November 2007

Selected training activities

Table A3. Selected BENEFIT courses and other training activities between 2003 and 2007.

Event	Location	Date
2003		
Fluorometer Calibration Workshop	Cape Town, South Africa	20–21 August
2004		
BENEFIT Training Cruise	*RV Africana*	5–14 July
NANSEN/BENEFIT Stock Assessment Course	Swakopmund, Namibia	23 September–1 October
Acoustic Workshop	Swakopmund, Namibia	20–25 September
2005		
Lectures at University of Namibia by Rhodes University	Windhoek, Namibia	29 March–8 April
2006		
Ship-board Training	Various South African vessels	43 days between 21 June and 10 October
Stock Assessment Course	Swakopmund, Namibia	26–30 June
Children and the Sea (lectures)	Swakopmund, Namibia	26 June
Aquarium Tours	Cape Town and Durban, South Africa	4–7 September
Library Training	Cape Town, South Africa	1–4 November
Instrumentation Training	Swakopmund, Namibia	21 November–2 December
Training in observation and sampling of seabirds	Cape Town, South Africa	1–14 December
Ballast Water Course	Luanda, Angola	4–7 December
2007		
Training in Sampling and Identification of Zooplankton	Swakopmund, Namibia	8–18 January
Taxonomy Training	Swakopmund, Namibia	22–26 January
Training in Harmful Algal Blooms	Swakopmund, Namibia	22 January–2 February
GIS Training	Swakopmund, Namibia	29 January–2 February
Ship-board Training	Various South African vessels	29 August–16 September 30 September–10 October
Life and Communications Skills Workshops	Cape Town, South Africa, Swakopmund, Namibia and Luanda, Angola	February–March
Environment Impact Assessment Course	Swakopmund, Namibia	23–27 April
Modelling Course	Swakopmund, Namibia	14–25 May
English Course (1)	Swakopmund, Namibia	4–22 June
ECHOVIEW Course	Swakopmund, Namibia	2–6 July
Survey Design Course	Swakopmund, Namibia	25–29 July
MATLAB Course	Swakopmund, Namibia	3–13 July
English Course (2)	Luanda, Angola	August
ARCGIS Training	Swakopmund, Namibia	26–30 November

APPENDIX B.
SELECTED PUBLICATIONS FROM BENEFIT ACTIVITIES

N. Sweijd and I. Hampton

The following are publications (including theses) which emanated directly from the BENEFIT projects in the text, and from some of the other activities conducted regionally by collaborating or partner institutions and programmes (excluding BCLME projects). Note that theses which were supported by BENEFIT in other ways (e.g. through scholarships or bursaries independent of the research projects) are not included.

Aiken J., J. Fishwick, S. Lavender, R. Barlow, G. Moore, H. Sessions, S. Bernard, J. Ras and N. Hardman-Mountford. Validation of MERIS reflectance and chlorophyll during the BENCAL cruise October 2002: preliminary validation of new demonstration products for phytoplankton functional types and photosynthetic parameters. International Journal of Remote Sensing 28: 497–516.

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Axelsen B-E., G. Bauleth-D'Almeida and A. Kanandjembo. 2003. *In situ* measurements of the acoustic target strength of Cape horse mackerel *Trachurus trachurus capensis* off Namibia. African Journal of Marine Science 25: 239–251.

Axelsen B-E. 2007. Acoustic identification and abundance estimation of horse mackerel, jellyfish and mesozooplankton in the Benguela ecosystem. PhD thesis, University of Bergen, Norway. 40pp. + 8 papers.

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