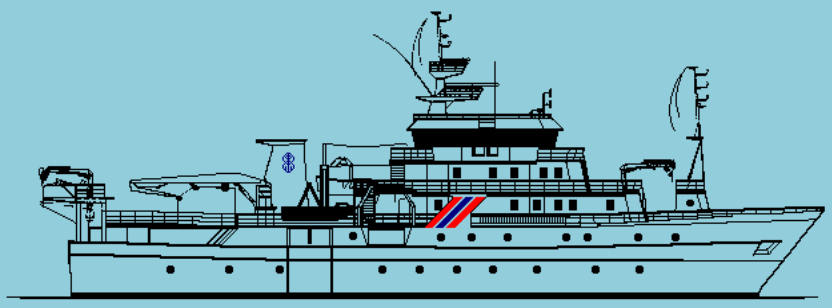

2007 BENEFIT SURVEY NO. 2

THE INFLUENCE OF DISSOLVED OXYGEN CONCENTRATIONS ON THE DISTRIBUTION AND TROPHODYNAMICS OF PELAGIC FISH LARVAE AND KEY ZOOPLANKTON SPECIES IN THE BENGUELA CURRENT REGION

Cruise report No 2/2007

7 February – 23 February 2007

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Bergen September 2007

THE EAF-NANSEN PROJECT

FAO started the implementation of the project "Strengthening the Knowledge Base for and Implementing an Ecosystem Approach to Marine Fisheries in Developing Countries (EAF-Nansen GCP/INT/003/NOR)" in December 2006 with funding from the Norwegian Agency for Development Cooperation (Norad). The EAF-Nansen project is a follow-up to earlier projects/programmes in a partnership involving FAO, Norad and the Institute of Marine Research (IMR), Bergen, Norway on assessment and management of marine fishery resources in developing countries. The project works in partnership with governments and also GEF-supported Large Marine Ecosystem (LME) projects and other projects that have the potential to contribute to some components of the EAF-Nansen project.

The EAF-Nansen project offers an opportunity to coastal countries in sub-Saharan Africa, working in partnership with the project, to receive technical support from FAO for the development of national and regional frameworks for the implementation of Ecosystem Approach to Fisheries management and to acquire additional knowledge on their marine ecosystems for their use in planning and monitoring. The project contributes to building the capacity of national fisheries management administrations in ecological risk assessment methods to identify critical management issues and in the preparation, operationalization and tracking the progress of implementation of fisheries management plans consistent with the ecosystem approach to fisheries.

LE PROJET EAF-NANSEN

La FAO a initié la mise en oeuvre du projet "Renforcement de la base des connaissances pour mettre en œuvre une approche écosystémique des pêcheries marines dans les pays en développement (EAF-Nansen GCP/INT/003/NOR)" en décembre 2006. Le projet est financé par de l'Agence norvégienne de coopération pour le développement (Norad). Le projet EAF-Nansen fait suite aux précédents projets/ programmes dans le cadre du partenariat entre la FAO, Norad et l'Institut de recherche marine (IMR) de Bergen en Norvège, sur l'évaluation et l'aménagement des ressources halieutiques dans les pays en développement. Le projet est mis en oeuvre en partenariat avec les gouvernements et en collaboration avec les projets grands écosystèmes marins (GEM) soutenus par le Fonds pour l'Environnement Mondial (FEM) et d'autres projets régionaux qui ont le potentiel de contribuer à certains éléments du projet EAF-Nansen.

Le projet EAF-Nansen offre l'opportunité aux pays côtiers de l'Afrique subsaharienne partenaires de recevoir un appui technique de la FAO pour le développement de cadres nationaux et régionaux visant une approche écosystémique de l'aménagement des pêches et la possibilité d'acquérir des connaissances complémentaires sur leurs écosystèmes marins. Ces éléments seront utilisés pour la planification et le suivi des pêcheries et de leurs écosystèmes. Le projet contribue à renforcer les capacités des administrations nationales responsables de l'aménagement des pêches en introduisant des méthodes d'évaluation des risques écologiques pour identifier les questions d'aménagement d'importance majeure ainsi que la préparation, la mise en œuvre et le suivi des progrès de la mise en œuvre de plans d'aménagement des ressources marines conformes à l'approche écosystémique des pêches.

CRUISE REPORTS "DR. FRIDTJOF NANSEN"

BENEFIT SURVEYS

The influence of dissolved oxygen concentrations on the distribution and trophodynamics of pelagic fish larvae and key zooplankton species in the Benguela Current region

7 February - 23 February 2007

by

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INTRODUCTION

1.1. BACKGROUND

The Benguela is unique among Eastern Boundary Current Systems in that it is bounded by warm-water frontal systems along both its northern and southern borders. The northern boundary is the Angola-Benguela Front, a permanent feature at the surface, identifiable to a depth of at least 200 m. It is maintained throughout the year within a narrow band of latitudes, typically between 14 and 17°S, within which it moves depending on the strength of the Benguela and Angola currents and associated factors such as wind forcing. The southern boundary of the Benguela upwelling system is considered to be the Agulhas Current retroflection area, between 36 and 37°S. This warm-water boundary also moves during the year, and tropical Agulhas Current water leaks into the South Atlantic, mostly in the form of rings, shed from this current, and filaments. Like its counterpart in the north, these Agulhas intrusions appear to affect the living resources of the southern Benguela system.

Another special characteristic of the Benguela Current system is the extended area of oxygen-depleted water masses. A seasonality of the hypoxia is observed with increasing latitude. South of 32°S during summer, there is usually a significant reduction in the dissolved oxygen of the upper mixed layer and oxygen depletion of the bottom layers below the thermocline. North of approximately 32°S the seasonality of dissolved oxygen in the water column decreases along with the decline in seasonality of upwelling-inducing equatorward winds. Nevertheless, a seasonal oxygen fluctuation can be detected as far north as Lüderitz (27°S). To the North, there is an almost permanent hypoxic layer overlying the bottom. In some areas, oxygen concentrations < 1 ml l^{-1} are found in 50 to 100 m water depths and thus may be a limiting factor for many pelagic species, particularly their early developmental stages, even more important than currents, temperature gradients or food limitation caused by weak upwelling. On the continental shelf, oxygen levels may reach critical minimum concentrations, which enable hydrogen sulphide to appear in the near-bottom water layer. Work on effects of oxygen depletions on pelagic species, their recruitment or migration and distribution pattern, are scarce. First initiatives in this region were started in 2000 by Namibian and Norwegian researchers, followed by German and South African researchers during the FRS '*Africana'* training cruise in 2002 and the RV '*A.V. Humboldt'* expedition in 2004. In the final report of the BENEFIT project on early life stages (N 2001/005) it is recommended to carry on with the investigations of the influence of low oxygen waters on early life stages of pelagic fish.

This project aims to contribute to elucidate the mechanisms and parameters that control the life cycles and vertical or horizontal migration strategies of key pelagic organisms in the Benguela Current region as an example for large upwelling areas.

1.2. OBJECTIVES OF THE SURVEY

The aim of the survey was to map the hydrographical and biological diversity and animal behaviour in the Angola-Benguela frontal zone in order to answer the following key question:

How do zooplankton organisms, especifically early life stages of pelagic fish, cope with low DOC?
Is the large-scale distribution of oxygen inhibiting the retention mechanisms and life cycles of planktonic organisms?

Methods followed:
The above objectives were addressed during this expedition by different sampling strategies and methods described in the following chapters. A fundamental activity was a general mapping of temperature, oxygen, primary productivity, and plankton distribution This was followed and accompanied by in-depth studies on physiological and ecological adaptations at localised "hot-spots". Physiological experiments were performed onboard, while studies on growth, genetics and isotope measurements on the sampled material will follow in the home laboratories.

1.3. PARTICIPATION

The participants consisted of scientific staff from:

MCM, South Africa:
Hans Verheye, Marco Worship and Susan Jones

NatMIRC, Namibia:
Anja Kreiner, Twalinohamba Akawa and Allie Gumbo

INIP, Angola:
Antonio da Silva, Bernardo Fernandez and Alice Martins

ZMT, Germany:
Werner Ekau, Matthias Birkicht, Stefanie Bröhl and Andreas Kunzmann

AWI - Germany:
Friedrich Buchholz

MarZoo, Germany:
Holger Auel

and IMR, Norway:
Jens Otto Krakstad (Cruise Leader), Tor Egil Johannson and Tore Mørk

1.4. NARRATIVE

The ship left Walvis Bay on Wednesday 7th February at 19:50 UTC (Local time = UTC+1). The vessel immediately started the first transect off Walvis Bay. The sampling grid roughly followed the station plan worked during the FRS "*Africana*" cruises in 1999 and 2002 and the 2nd and 3rd legs of the FS "*A. v. Humboldt*" cruise in 2004. Four cross-shelf transects were conducted at 23ºS, 20°30'S, 19°S and 15°S, and two transects were conducted across the Angola–Benguela Frontal Zone along the coast in a north–south direction at 10°30'E and 11°30'E, from 18°S to 14°S (Figure 1). The final positions of transects were determined based on satellite images of the sea surface temperature received at regular intervals during the survey. Plankton and hydrographical stations were predetermined on transect lines and *ad hoc* on selected stations.

Three 24-h intensive sampling stations were conducted: (1) North of the front at 14°50'S, 11°30'E, (2) at 17°00'S, 11°15'E in the frontal zone, and (3) at 18°26'S, 11°15'E, south of the front.

The ship arrived back in Walvis Bay at 10:00 UTC on the 23rd February.

1.5. SURVEY EFFORT

Figure 1 shows the cruise tracks with plankton and hydrographical stations. A total distance of 2060 NM was covered in the area and 71 plankton sampling stations with 70 CTD casts and 272 casts with different plankton sampling equipment were successfully conducted during the survey. All sampling stations are listed in Annex I.

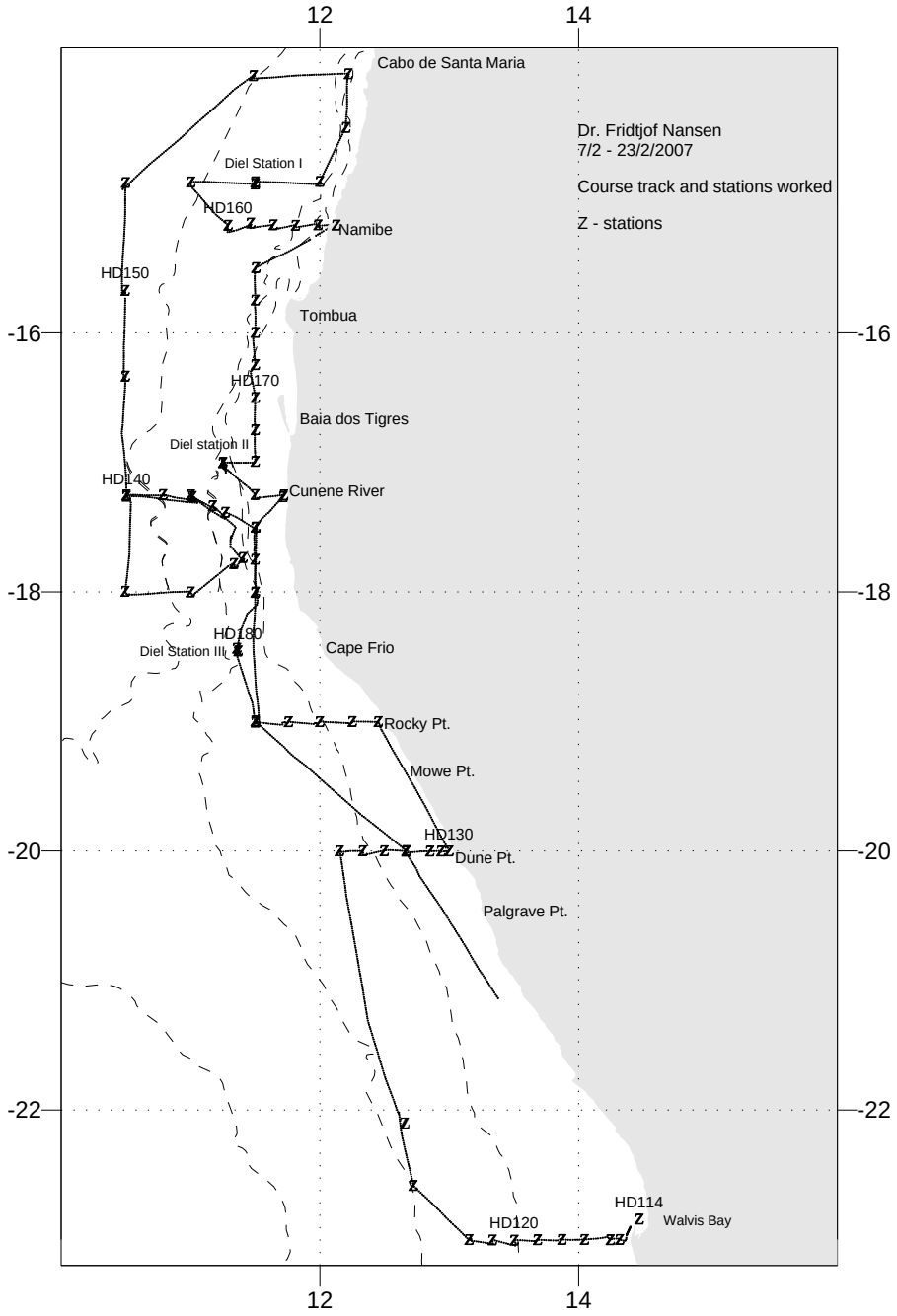


Figure 1. Course track with plankton and hydrographical stations in the survey area. The 200 m, 1000 m and 3000 m depth contours are indicated

METHODS & RESULTS

2.1. HYDROGRAPHIC INVESTIGATIONS

J-O. Krakstad, W. Ekau, M. Birkicht, T. Akawa

Introduction

The Namibian and Angolan shelf between 15°S and 25°S is characterized by nearly continuous upwelling, high primary production, extreme water column oxygen depletion, and bottom waters that become episodically sulphidic (Bailey et al., 2001; Boyd, 1983). These 'sulphide events' are believed to adversely affect the regional living resources (fish and crustaceans) owing to the toxicity of sulphide. The mechanisms and biogeochemical implications of these sulphidic events are largely unknown.

It is clear that hypoxic conditions in the OMZ (Oxygen Minimum Zone) play an important role in the regulation of biogeochemical fluxes in the water column. This suggests that hydrographic conditions, nutrient transport and transformation may be important for the oxygen budget of the water column and the primary and secondary production of that ecosystem.

Upwelling along the coast is induced by trade winds: the offshore Ekman transport of surface waters is balanced by upwelling of relatively oxygen-rich intermediate waters of East South Atlantic Central Water (ESACW) origin. The ESACW is presumably transported by the Ekman compensation current below the thermocline from offshore onto the shelf. Weakened trade winds reduce advection of oxygenated ESACW to the shelf environment; high oxygen demand by decay of sinking organic matter together with H_2S flux from the sediment into the bottom layer overwhelms the oxygen content of the water column and leads to a strong oxygen depletion till H_2S accumulating in the water column after days.

Knowledge on the oceanographic, biological and biogeochemical processes is mandatory to understand the functioning of the upwelling system, which in turn is necessary for the calculation of the Nitrogen deficit and primary production.

Material and methods

The ship-based measurements comprised various sections across the shelf, where oxygen (Winkler), nutrients, H_2S and phytoplankton (Chl_a) were measured. Water samples for nutrient and oxygen (Winkler) measurements were taken at 4-11 discrete depths according to vertical water column structure and the presence of different water masses: within the euphotic zone of the ESACW (East South Atlantic Water (surface-400 m) at 0 m; 10 m ; 20

m; 30m, the Oxycline (100 m), the oxygen minimum (~400 m), the SACW (South Atlantic Central Water) at 500 m, the AAIW (Antarctic Intermediate Water) between 600 m to 1000 m, and the NADW (North Atlantic Deep Water) below 1200 m. Samples for H_2S analysis were only taken from the bottom at shallow stations in the area around Walvis Bay.

An in-line Turner Design SCUFA Fluorometer was continuously measuring Chlorophyll levels [RFU] at -5m below the sea surface while underway during the entire cruise. The instrument was configured with a bright blue photodiode, a 420 nm Excitation filter and a 680 nm Emission filter. It was calibrated against the secondary orange standard dye. The maximum output was equivalent to 5Volt = 100%. It had a linear temperature compensation of 2.14%/°C.

An in-line Seabird SBE 21 Thermosalinograph continuously logged temperature (ITS-90 [deg C]) and salinity (TSS-78 [PSU]) at a depth of 5m en route during the entire cruise. Data were simultaneously stored in memory and transmitted to a computer serial port, allowing independent data logging and real-time data acquisition. The SBE 21 was mounted close to the ship's seawater intake. The SBE 21 was connected to an AC-powered interface box positioned near the computer. Real-time logging was carried out using the PC-based Seabird Seasave software.

A Seabird 911+ CTDO probe was used to obtain vertical profiles of depth, temperature, salinity and oxygen. Real-time logging was carried out using the PC-based Seabird Seasave software. CTD casts were conducted on predetermined environmental sampling transects to a maximum of 1500 m depth and to a few meters above the bottom at shallower stations,. The CTD was attached to a 12-bottle water sampler rosette (Hydrobios). First, samples for dissolved oxygen were taken with a silicon tube into 60.00 mL Winkler-bottles. Single samples from randomly selected depths (usually between 2 and 11) were analysed for dissolved oxygen on board with an 725 Dosimat (Metrohm), which is controlled by a colour agent (starch solution), on a specially designed titration board for ships cruises according to the WOCE protocol. Regression analysis of the oxygen measurements according to the Winkler method and the CTD-data resulted in a good fit:

Ox = 1.057 (+/- 0.022) * OxCTD + 0.021 (+/- 0.021)

Whenever time permitted, spectrophotometrical nutrient analyses (NH_4^+ , NO_2^-, NO_3^-, o-PO_4^{3-} , $Si(OH)_4$) were carried out immediately after collection in 100mL PE-bottles according to a modified manual procedure of Grasshoff (1999) for small sample amounts. Samples for H_2S analysis were collected in Winkler-bottles and fixed with $Zn(CH3COO)_2$. A single-beam filter photometer SQ300 from Merck with 1 cm and 5 cm cuvettes was used for photometrical

analysis. Phosphate and silicate were measured at 820 nm, ammonia at 620 nm and nitrate/nitrite at 540 nm. The remainder of the samples was stored immediately at -18°C.

A Turner Design 10-AU005 Field Fluorometer configured with a 10-050R excitation filter, a 034-0395R emission filter (680 nm interference filter), a 10-032 1ND reference filter, and a 10-089 Blue Mercury Vapor Lamp and was used to determine Chl *a* in the euphotic zone (0 m, 10 m, 20 m, 30 m). The configuration is specially designed for the determination of Chl-*a* (*in vivo*) in the presence of high blank, humic substances, or Chl-*b* (*in vivo*).

Meteorological data logged from the onboard Aanderaa meteorological station included wind direction and speed, air temperature, incident solar intensity and sea surface temperature (SST). All data were averaged by unit distance sailed (1 NM).

Results

Figures 2, 3 and 4 show underway sea surface temperature, salinity and chlorophyll data respectively, and clearly identify the position of the frontal zone with the cooler, less saline surface water masses of the Benguela system in contrast to the Angola Current water masses. The actual front was identified around 16°S (Fig. 2). Minimum salinity concentrations were observed off the Kunene River mouth and were due to river afflux (Fig. 3). The chlorophyll recordings indicate that areas of maximum primary production corresponded with the area of riverine input from the Kunene River and the upwelling region off Cape Frio (Fig. 4). Changes in the water masses are reflected in cross-shelf transects of oxygen, temperature and salinity profiles in the upper 200 m (Figures 5, 6, 7 and 8) at 23ºS (Walvis Bay monitoring line), 20°30'S (near Palgrave Point monitoring line), 19°S (Rocky Point) and 15°S (Namibe monitoring line). Of particular importance are the hypoxic water masses observed at around 150 m depth, particularly in Figures 6 and 7.

Figure 9 shows an alongshelf profile at 11°30'E (T3) across the frontal zone. The figure illustrates changes in water masses, oxygen, temperature and salinity with depth from the tropical Angola Current system, across the front, and to the Benguela Current system. The tropical water masses can be identified in the upper 30 m to 16°S, characterised by temperatures >25°C, salinity >25.8 PSU and oxygen >4.0 ml/l. Both temperature and salinity decreased southwards with surface temperatures <18°C and salinity <35.6 PSU at 19°S. The oxygen concentration decreased rapidly below 30 m depth, reaching 1 ml/l around 100 m depth and a minimum of 0.4 ml/l around 400 m depth (not seen on figure).

Figure 2. Sea surface temperature at 5 m depth recorded underway during the cruise

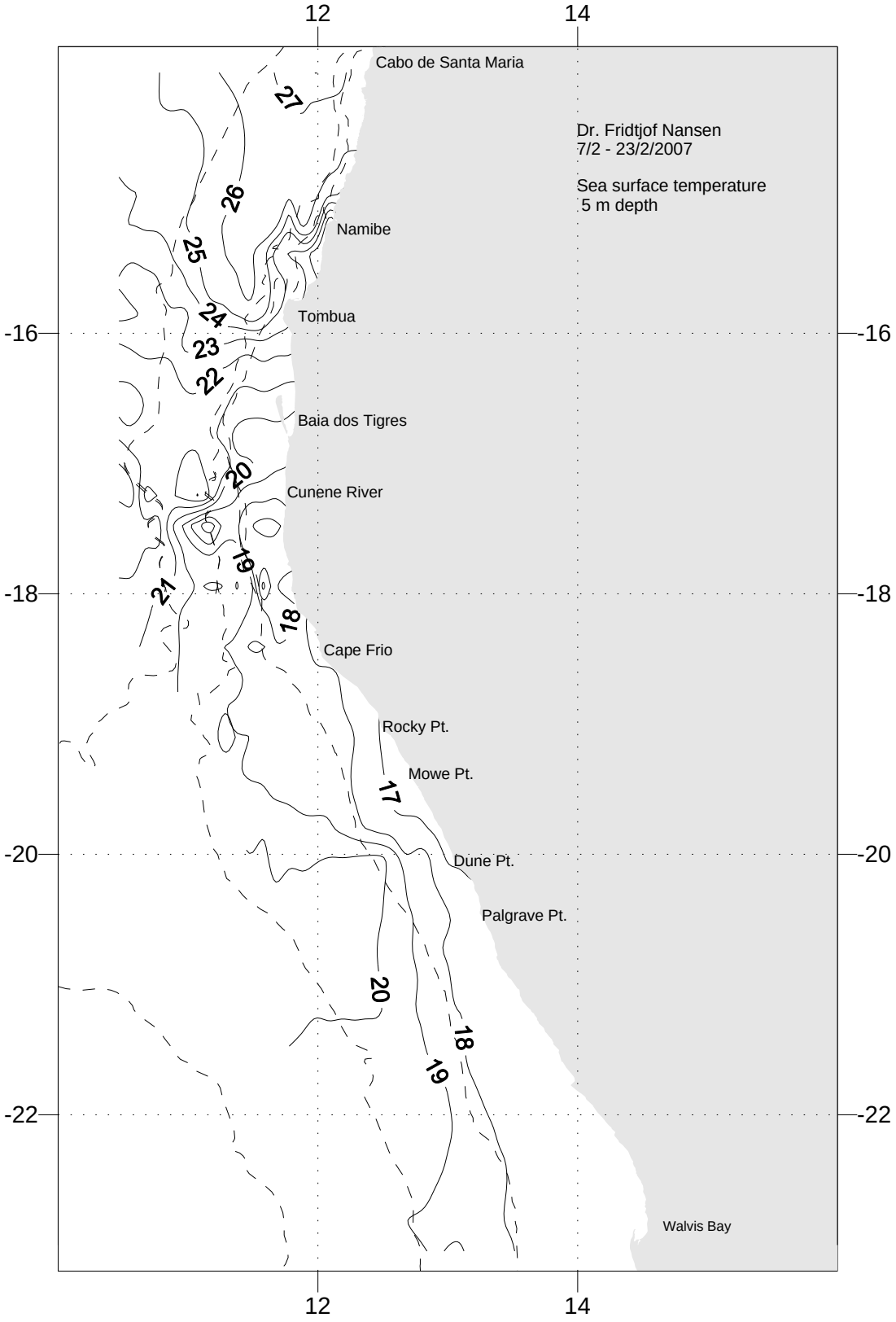


Figure 3. Sea surface salinity at 5 m depth recorded underway during the cruise

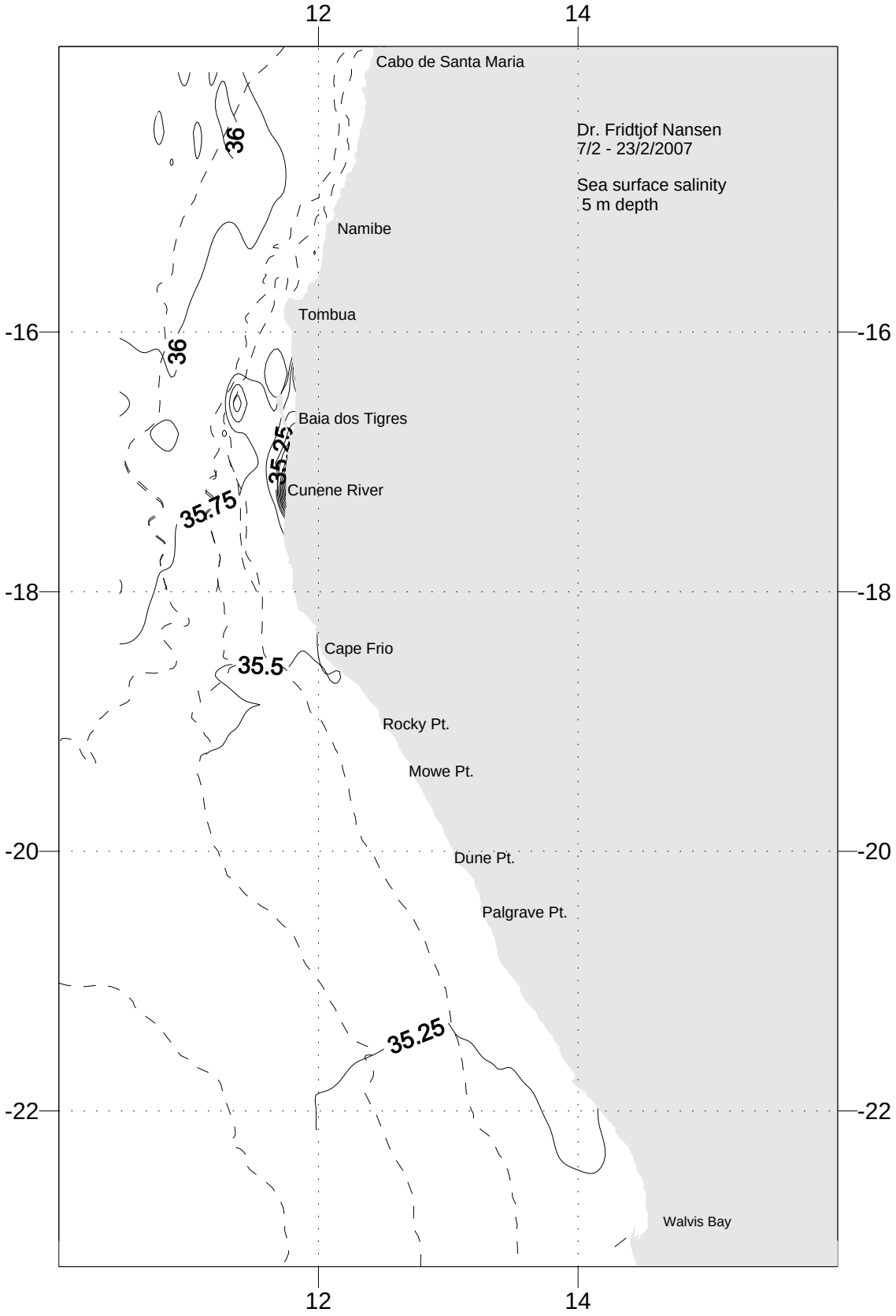
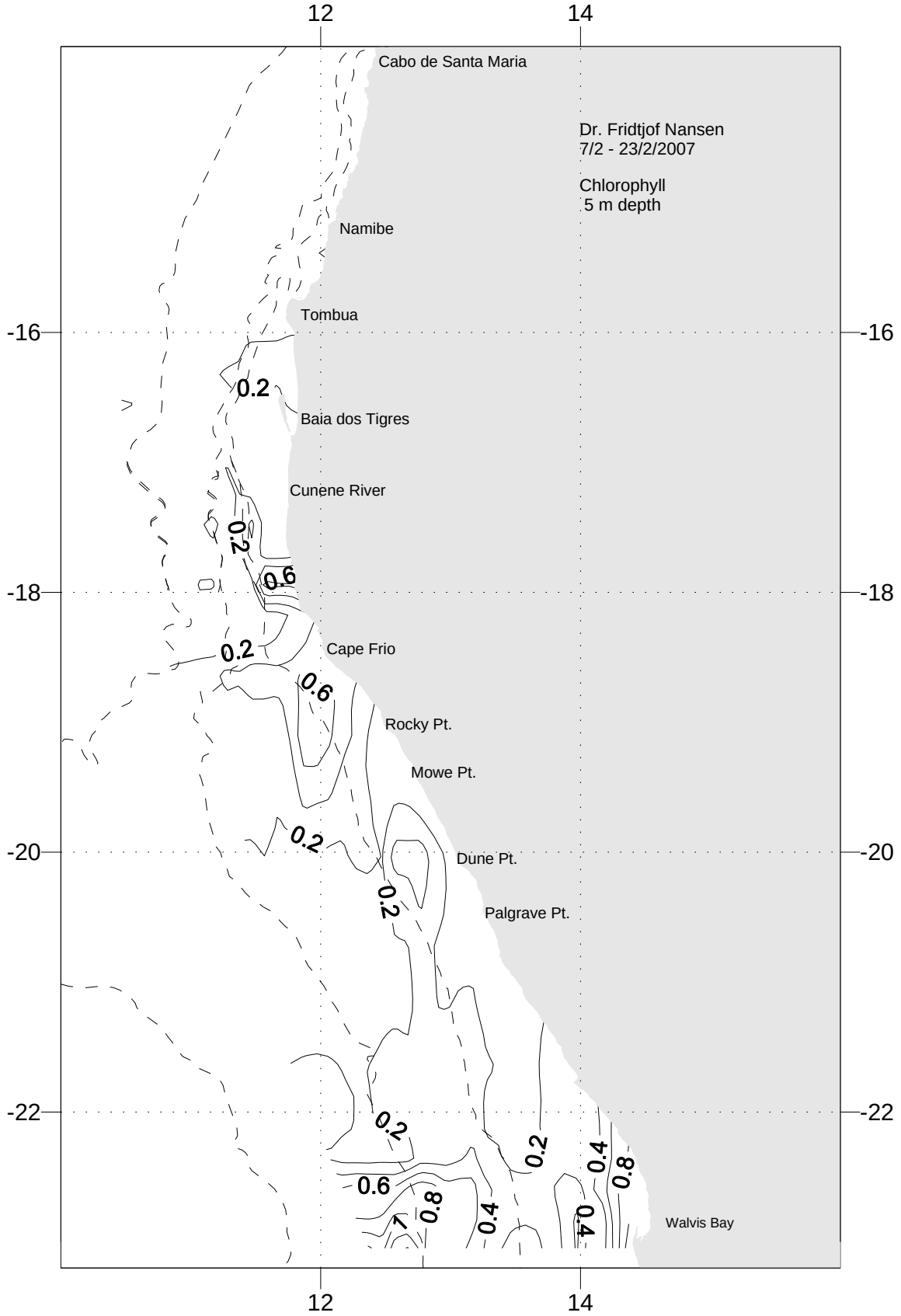


Figure 4. Sea surface chlorophyll at 5 m depth recorded underway during the cruise



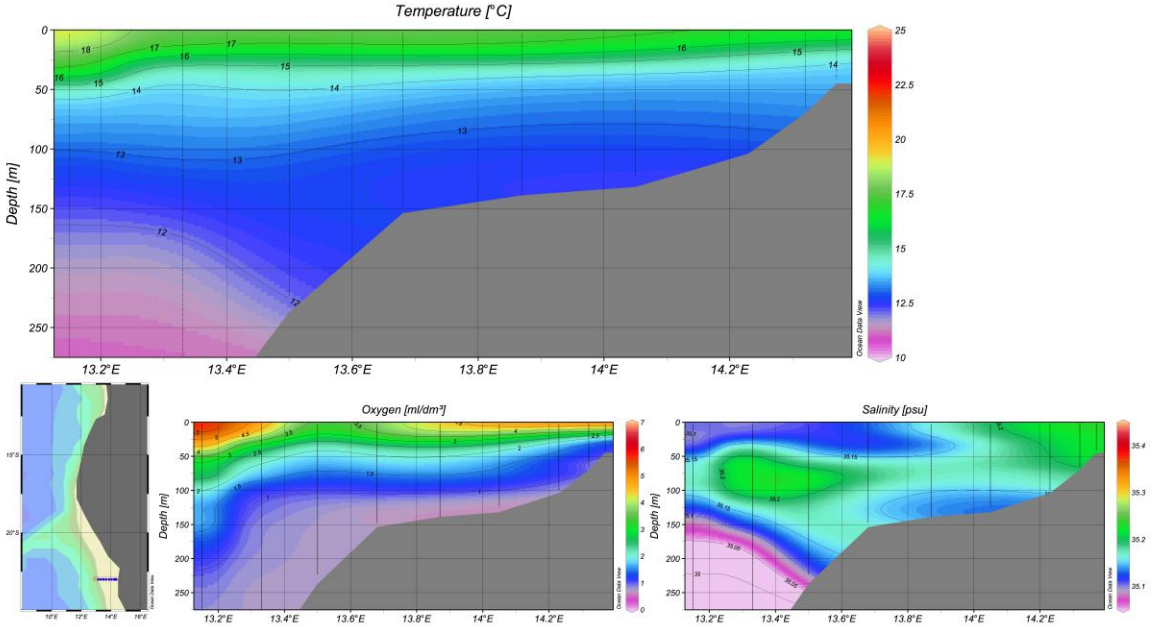


Figure 5. Cross-shelf transect at 23ºS (T8, off Walvis Bay) showing the temperature, oxygen and salinity profiles between 0 and 260 m depth

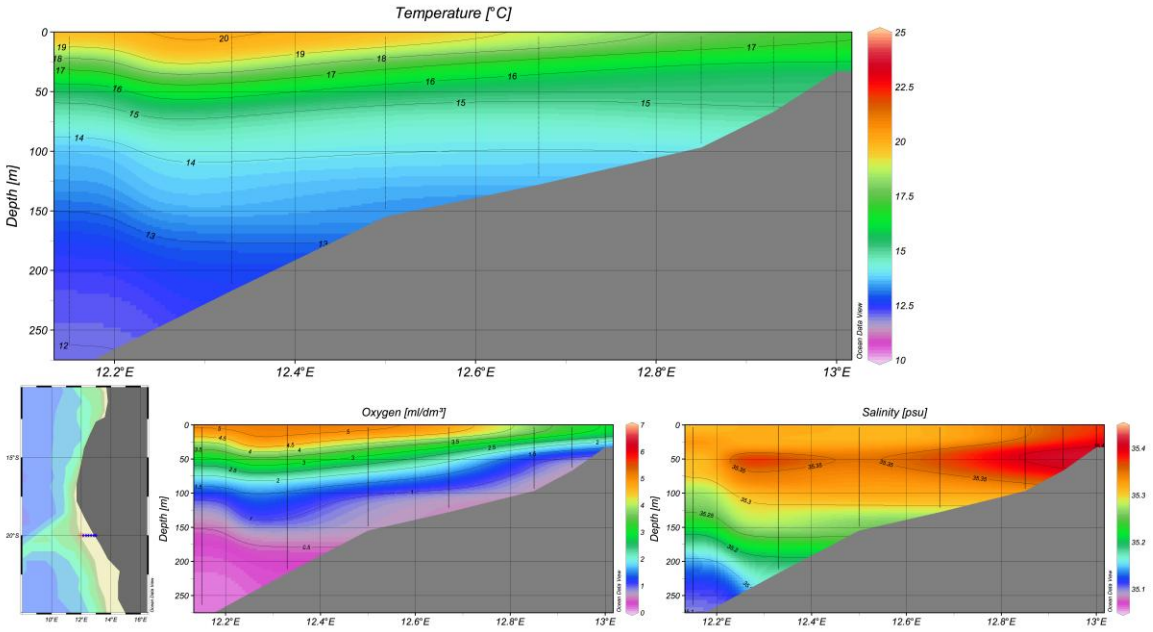


Figure 6. Cross-shelf transect at 20°30'S (T7a, off Palgrave Point) showing the temperature, oxygen and salinity profiles between 0 and 260 m depth

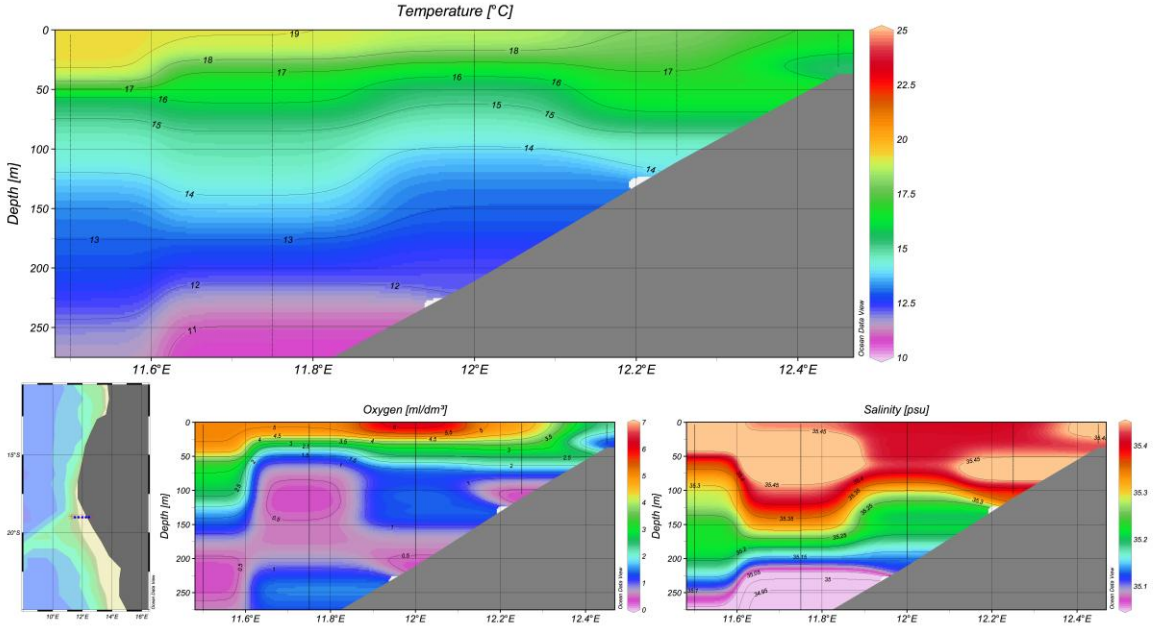


Figure 7. Cross-shelf transect at 19°S (T5, off Rocky Point) showing the temperature, oxygen and salinity profiles between 0 and 260 m depth

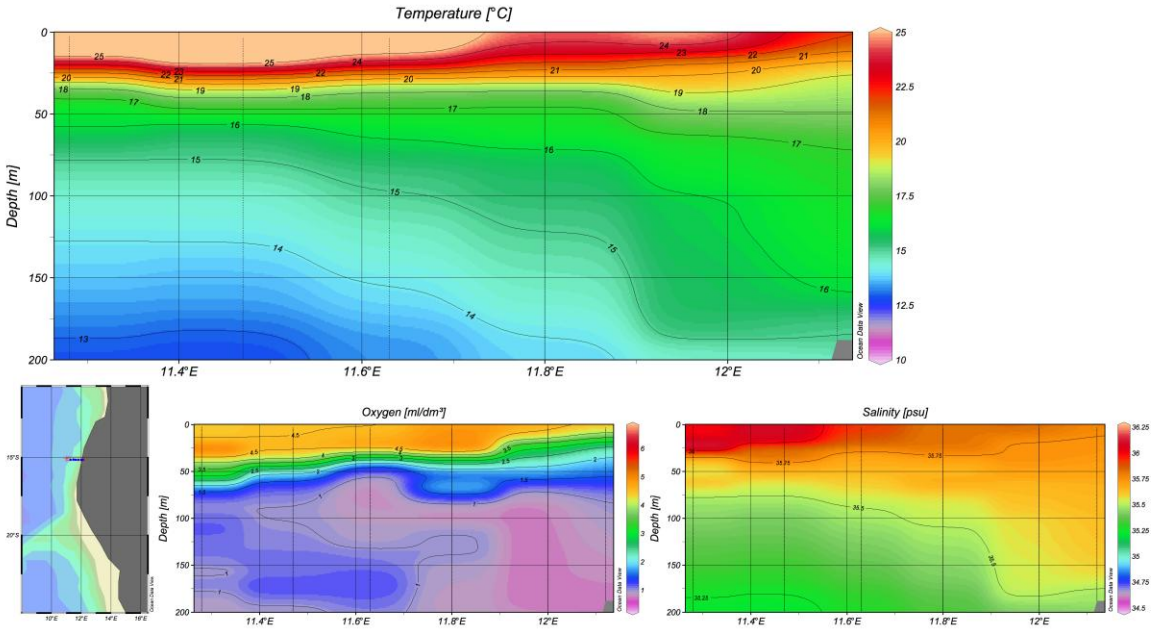


Figure 8. Cross-shelf transect at 15°S (off Namibe) showing the temperature, oxygen and salinity profiles from 0 – 200 m depth

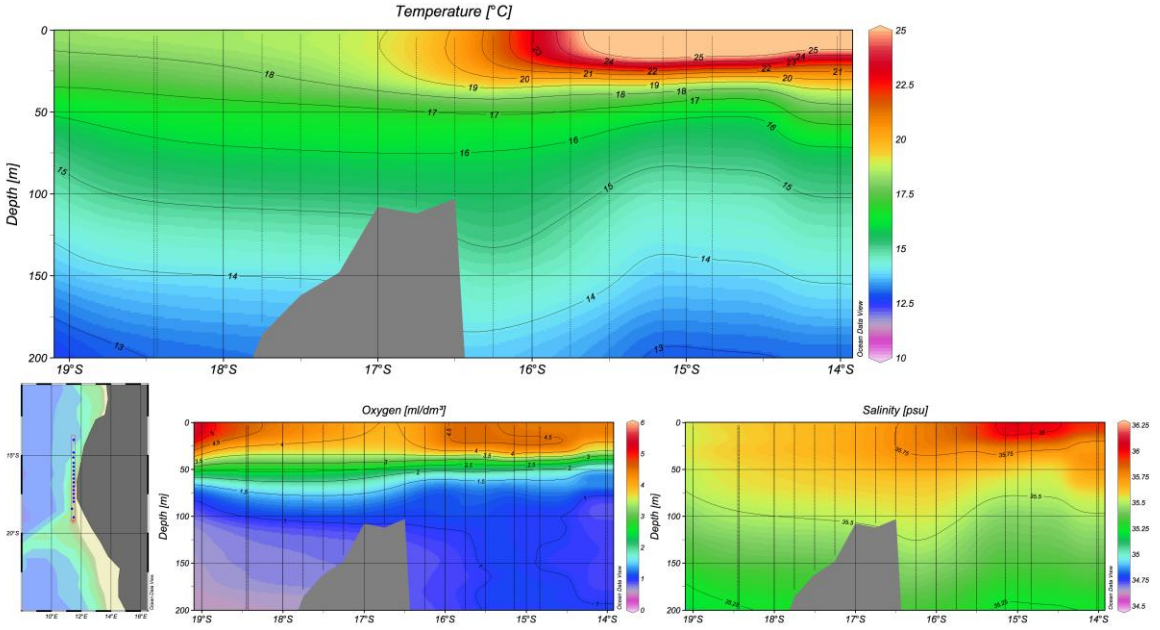


Figure 9. Along shelf profile at 11°30'S (T3) showing, temperature, oxygen and salinity profiles between 0 – 200 m depth

2.2. **ZOOPLANKTON STUDIES**

H. Verheye, H. Auel, A. da Silva, A. Kreiner

Vertical Multinet samples were collected at all stations, 59 hauls in total; in some instances, including three 24-hour stations, a double vertical net haul was performed, the first from 600m to the surface, and the second from 200m to the surface, yielding 9 depth strata (600-500m, 500-400m, 400-300m, 300-200m, 200-140m, 140-100m, 100-60m, 60-30m and 30-0m) to allow fine-scale vertical distribution studies. These, as well as selected samples from oblique Multinet hauls in the upper 200m (66 in total) will be used to analyse vertical and horizontal distribution patterns of zooplankton key species (from routine stations) and their diel vertical migration behaviour (from three 24-h stations).

At 23°S and 20°S (two Namibian monitoring lines), and at 15°S (the Angolan monitoring line off Namibe) zooplankton samples were taken using the WP-2 net. These samples will be analysed in the respective countries as part of their routine monitoring. On the 15°S line several nets were used for zooplankton sampling in order to compare data collected with different gears during the SWAPELS programme (1970s and 1980s) under a BCLME project (Ph. D. student Fabienne Cazassus). Details of gear and sampling depth used during this cruise are given in Table 1.

Table 1. Details of different gear used to sample zooplankton for comparative studies

Net	Sampling depth	Mesh size	Haul type
WP-2	Max. 200 m	200 μm	vertical
N 70 V	Max. 200 m	200 μm	vertical
Bongo	Max. 50 m	300 μm	oblique
Multinet	Max. 200 m	180 μm	vertical

Secondary production

H. Verheye, A. Kreiner

Marine secondary production is defined as the conversion by heterotrophs of assimilated energy derived from primary producers into body tissue, or the amount of tissue (= biomass) accumulated by zooplankton (and zoobenthos) per unit time and per unit area, regardless of its fate. It includes production lost to predators and other loss sources as well as reproductive products (viz. eggs). Copepods are very suitable for estimating zooplankton production because of their abundance and life history features. Calculation of copepod production requires data on both their biomass (obtained from net tows, e.g. using the MultiNet) and their growth rate. The latter comprises somatic growth (weight gain) of larval and juvenile stages plus reproductive growth (fecundity or egg production) of adult females (the contribution by adult males is negligible).

Secondary production work in the northern Benguela Current and Angola-Benguela Front region has been conducted during BENEFIT cruises in 1997, 1999, 2002, and 2004, and focussed on the measurement of both the reproductive growth of adult females of several dominant calanoid copepods and, to a lesser extent, on the somatic growth of juvenile (copepodite) stages [incl. the diapausal 5^{th} copepodite stage C5] of a single species, *Calanoides carinatus*. This copepod is known to enter into a state of developmental arrest (dormancy, diapause) at its pre-adult stage C5: when environmental conditions are unfavourable for its reproduction and scope for population growth, the animals delay their final moult to adulthood and assume a temporary state of dormancy ; they descend to great depths in offshore waters where they adopt very reduced metabolic rates, surviving on energy reserves stored in the form of lipids (see papers by Auel *et al*. 2005 and Verheye *et al*. 2005 in *African Journal of Marine Science*, Vol. 27).

During this cruise, no routine estimates of *C. carinatus* C5 growth rate were obtained, because of the limited deep sampling capabilities present onboard the *Dr Fridtjof Nansen* (see winch cable length being limited to reach a max. sampling depth of only 600m, beyond which

most of the diapausal population usually resides). In a few instances (some stations in the southern part of the cruise grid as well as on the Namibe Monitoring Line - NML), adult females of *C. carinatus* were found sufficiently abundant in the surface layer to warrant egg production rate (EPR) measurements (see below). However, daily EPRs proved to be zero to very low in most cases (with the exception of the inshore NML station).

The focus during this cruise was therefore on the measurement of reproductive growth by females of other calanoid copepods. Daily egg production rate (EPR) was measured from bottle incubations. Adult female copepods were carefully sorted from Driftnet collections (until 11 Feb. when the net was lost, possibly to a propeller shark…) and vertical and oblique Multinet collections and placed either singly or in pairs or triplets (depending on species and body size) into 1-litre incubation bottles, maintained at ambient see surface temperatures in an on-deck flow-through incubator. After 24 hours, the incubations were terminated, the condition of the females was assessed and the number of eggs spawned was counted under a microscope. The number of eggs per female during a 24-h period is a measure of their fecundity or daily egg production rate.

In total, 118 EPR experiments were conducted during the cruise, and daily EPRs were obtained for between 12 and 15 species (some of which still remain to be identified in the laboratory). Although more rigorous analysis of the data is required, good active reproduction was observed at only a limited number of stations, viz. (in chronological order) T1-2, Add 5, T2-2, T1-3, T1-4, T2-5, NML 2, NML 1, T3-6, and T3-3 slope. In contrast, at all the other stations examined, daily EPR was zero or near-zero, despite there being good evidence that the females had been actively grazing prior to their capture (given the large number of faecal pellets produced during most incubation experiments).

Ecophysiological studies, respiration and diversity

H. Auel

Another major objective of the cruise was to conduct ecophysiological and biochemical studies on zooplankton organisms in the Benguela upwelling region and in the Angola/Benguela Current frontal zone. Respiration measurements were conducted with different species of copepods and pelagic amphipods to establish their metabolic activities and nutritional requirements.

The Benguela coastal upwelling area off Namibia is the northernmost limit of the hyperiid amphipod *Themisto gaudichaudi* whose centre of distribution is located in the Southern Ocean around Antarctica. Along the transect at 23°S (Walvis Bay Monitoring Line) the

species represented a dominant zooplankton component in terms of biomass. In contrast, further north *T. gaudichaudi* occurred only sporadically and in reduced abundance or was completely absent. Individuals collected along the Walvis Bay Monitoring Line were incubated at an *in situ* temperature of 14 to 15°C and at slightly elevated temperatures of 18 to 19°C in order to test whether physiological factors, such as increasing metabolic needs due to elevated water temperatures, might determine the northern limit of the distribution range. Moreover, based on respiration rates determined on board, the energy demands and ingestion rates of the amphipods can be calculated and the predation impact of this predatory species on the mesozooplankton community estimated. In addition, frozen samples of *T. gaudichaudi* were collected for biochemical analyses of lipid content and fatty acid/alcohol composition in order to assess its diet composition by means of trophic biomarkers. These data will contribute to a latitudinal comparison of *Themisto* species stretching from the Arctic to the Antarctic region.

Additional respiration measurements concentrated on the tropical epipelagic copepod species *Euchaeta marina*, which occurred abundantly in the northern part of the study area north of the Angola-Benguela Front. These experiments delivered valuable supplementary data for ongoing studies on the respiration rates and metabolic activities of cold-water species of the same family Euchaetidae from polar and deep-sea habitats.

In co-operation with Friedrich Buchholz (AWI-BAH), respiration measurements were carried out with individuals of the krill species *Euphausia hanseni*. Although krill are generally known as metabolically very active crustaceans performing extended diurnal vertical migrations, during this cruise dense aggregations of krill were also detected in the intermediate oxygen minimum layer. The experiments will reveal the oxygen requirements of *E. hanseni* and help to understand how this species can survive at very low ambient oxygen concentrations of <1 ml O_2 l^{-1}.

In total, more than 150 deep-frozen samples of different zooplankton organisms, in particular copepods, have been collected for further biochemical and molecular genetic analyses at the laboratory. Additional material was preserved in alcohol for genetic studies. This material will contribute to several ongoing research projects, such as “COPS – Biodiversity and Ecology of Deep-sea Copepods in Polar Seas” funded by the German National Science Foundation, and “CmarZ – Census of Marine Zooplankton”, a sub-project of the global marine biodiversity initiative “CoML – Census of Marine Life”.

2.3. Distributional and physiological studies on Euphausiids

F. Buchholz

The work on krill complements the study of the ecological role of ichtyo- and zooplankton under food web aspects as well as in eco-physiology. In fact, extended cooperative and comparative work on both copepods and euphausiids are an integrative part of the project. Equally, data on primary production are essential to assess krill physiology. The described krill approach relates to four linked topics: functional biodiversity, life cycle strategies, growth/productivity and physiological/biochemical adaptation:

Functional biodiversity

Eight major species were found in the Multinet catches, which will be related to neritic and oceanic water masses. A previous cruise in the same region indicated thermal boundaries, which may also be related to the varying oxygen content. Such zoogeographical considerations are particularly useful under adaptive and food web aspects. It was found that the largest euphausiid, *Euphausia hanseni* dominated the species assemblage and showed considerably higher population densities than in February 2004 (Figure 10).

Life cycle strategies

Generally, in krill the egg maturation/spawning cycle is closely related to the moult cycle. Both cycles may be synchronized by external factors, and as new results show, by nutritional pulses, like plankton blooms. The current results on *Euphausia hanseni* point to a sharp synchronisation of both cycles and a strong dependence on actual upwelling events. Such close coordination of growth and reproductive processes may be considered a specific adaptation to the seasonal upwelling regime. How this in turn relates to the specific trophic environment of the area is again valuable to study under food web aspects. How krill copes with the necessity of having to cross the oxygen-depleted water strata to gain access to the productive is being integrated.

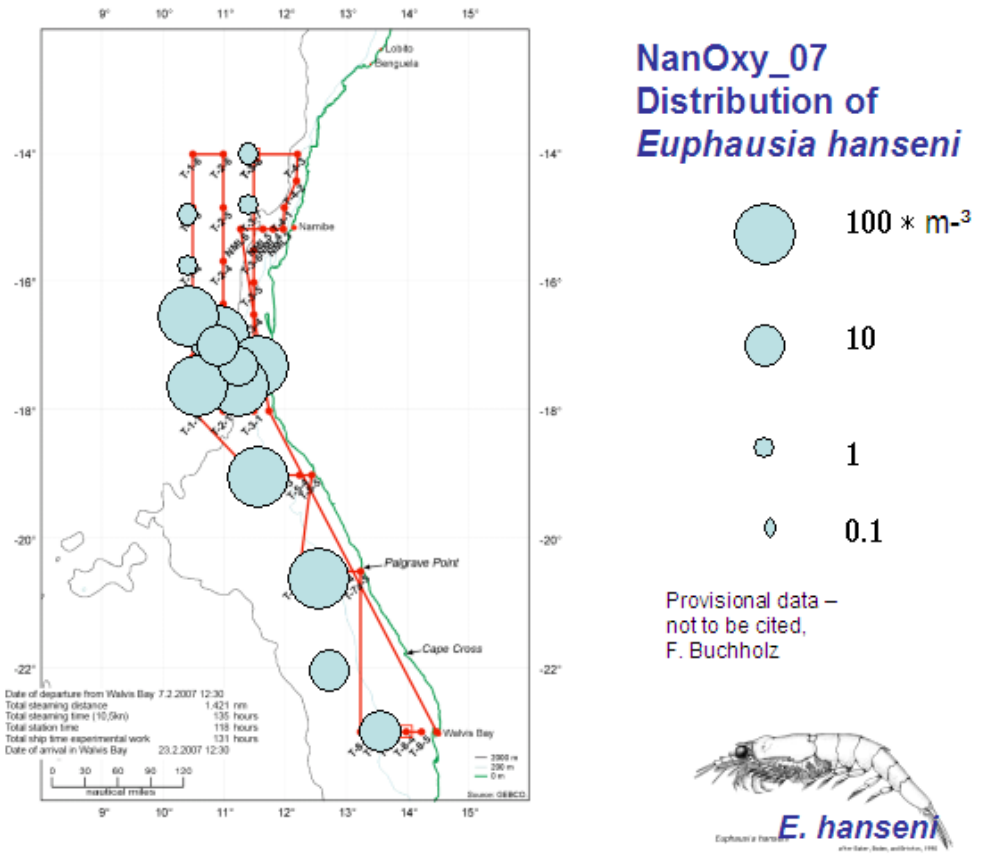
Growth and productivity

Growth in krill is moult-dependent. Intermoult period was measured in aquaria, on board, in order to assess productivity. When determining egg maturity, the rate of production of eggs can be assessed. This in turn leads to an assessment of female productivity, from which population productivity can be derived.

Physiological/biochemical adaptation

The results obtained during this cruise confirm previous detailed data on the typical diurnal vertical migration (DVM) pattern with a focus on *E. hanseni*. The summer DVM range was determined at >300m reaching to the surface. As such, krill has to cross the oxygen-depleted layer of ca. 500m and a temperature differential of up to 10°C twice per day. How this is related to respiration capacity and thermal tolerance was addressed during the cruise. The first respiration rates (in cooperation with A. Kunzmann and H. Auel) were measured at defined oxygen concentrations and will be complemented by the determination of key aerobic and anaerobic metabolic enzymes, and their adaptive capacity, according to Buchholz (2003). A comparison with temperate and polar krill species will be useful, because these species are considered extremely oxygen dependent. furthering addition, a food web relationship may be added by determining the specific induction of various digestive enzymes.

Figure 10. Densities of the krill *Euphausia hanseni* estimated from catches with the Tucker krill trawl



Buchholz, F. (2003). Experiments on the physiology of Southern and Northern krill, *Euphausia superba* and *Meganyctiphanes norvegica*, with emphasis on moult and growth - a review, Marine and freshwater behaviour and physiology, 36, 229-247.

2.4. Studies on Ichthyoplankton

S. Bröhl, W. Ekau, A. Kreiner, S. Jones

Numerous experimental results have demonstrated that fish larvae respond negatively to low dissolved oxygen concentration (DOC) in terms of their behaviour and/or survival. Considering this, the correlation between larval density and DOC found in recent studies in the Benguela region (Ekau and Verheye, 2005) support the hypothesis, that DOC is a relevant factor impacting ultimately on the recruitment of fish in the area. In all three pelagic species (*Sardinops sagax, Engraulis encrasicolus, Trachurus capensis*) that the authors investigated, the correlation of their density with DOC was higher than for that with depth. A threshold value of 2.5 ml O_2 l^{-1} was found to be significant to explain an impact of DOC on larval abundance and distribution.

Specific objectives during the cruise for fish larvae were to determine growth and mortality studies by analysing otolith microstructures and micro-elements for growth variation and environmental impact. Growth increment patterns were to be related to zooplankton biomass and production and will give insight into dependence of recruitment success and secondary production. The oxygen minimum layer was to be related to distribution or the spawning behaviour of adult pelagic fish. Critical/minimum oxygen levels were to be determined at which normal development of larvae occurs.

Work at sea

Samples were collected on 5 transects by means of a Multinet (MN_{obl}). The Multinet was equipped with 5 nets of 500 µm mesh size and a mouth area of 0.25 m^2. It was towed obliquely in 5 different depth strata. A total of 66 hauls were taken. The net was equipped with electronic flow meters to measure the nets' trajectory through the water, with temperature and salinity probes to measure *in situ* environmental conditions. Samples were preserved in buffered formalin (4% in seawater) for community studies, in alcohol (ethanol) for genetic studies, and frozen for age determination. All samples were analysed roughly for their content of fish larvae. These preliminary results were standardised to individuals / m^2 in terms of the volume of water filtered by each net and the depth of the stratum.

Total abundances of both fish larvae and fish eggs were very low with 1043 and 27 counted individuals respectively (preliminary result). More than 500 of these were belonging to mesopelagic groups such as Myctophidae, Bathylagidae etc. Carangids were the most abundant non-mesopelagic family with c. 200 individuals, followed by gobiids with 88 individuals.

The outer transect T1 and the southern transects T5, T7a and T8 were almost void of fish larvae except for a few stations. High abundances were found only at the stations along the near-coast transect T3.

Clupeid larvae were extremely scarce and exclusively found between 16 and 18°S at the shelf stations, showing a focal area, north of the Kunene upwelling event.

The vertical distribution of sardine larvae was restricted to the upper 40 m. This correlated with a drop of oxygen concentration within this layer from 4 ml/l to <2 ml/l. Other taxa, such as the Soleidae and mesopelagic species seemed to be more tolerant against low oxygen.

a) b)

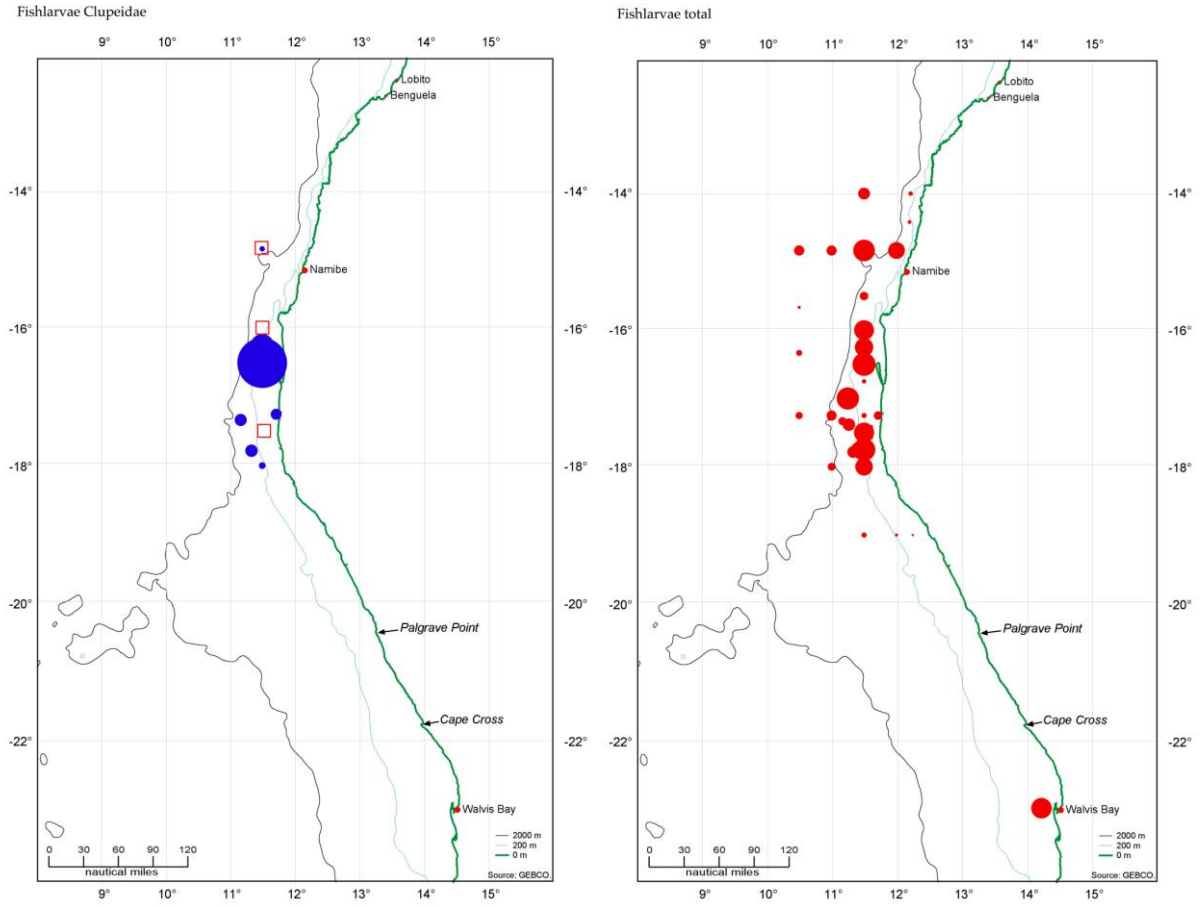


Figure 11. Distribution of stations with (a) Clupeid and (b) all fish larvae indicating relative abundance

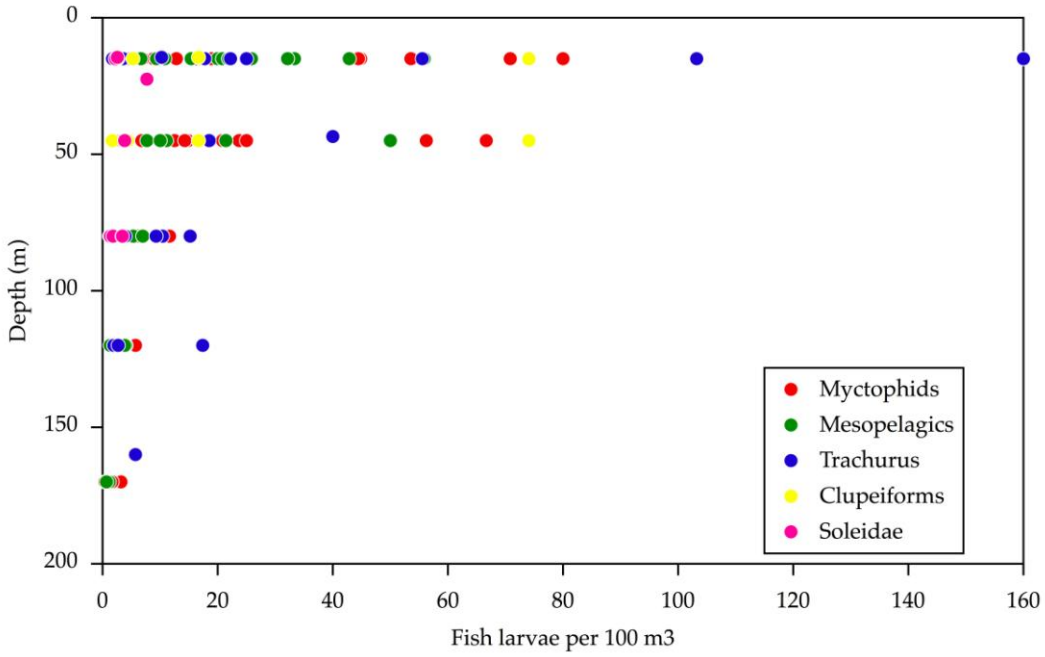


Figure 12. Distribution and density of fish larvae with depth, all stations and species

2.5. Respiration Physiology of Fish Larvae and Krill

A. Kunzmann

Studies on metabolism provide insight into energy requirements of animals. The common method to estimate metabolism is to measure or calculate a Standard or Routine Oxygen Consumption (SOC or ROC). Areas with variable oxygen concentrations, such as the Benguela Current system, are a challenge for fish and crustacean zooplankton. Numerous experimental studies have demonstrated that pelagic fish larvae respond negatively to low oxygen concentrations in terms of their behaviour and/or survival. On the other hand, it has been demonstrated that both krill and benthic fish occur in low-oxygen areas of 1 ml/l and less. Little is known about the oxygen tolerance of fish larvae of different species and at which levels oxygen becomes critical for their survival.

During this cruise 54 oxygen consumption experiments with fish larvae, krill and some simple first-trials on a few other zooplankters (e.g. jellyfish, copepods, amphipods) have been performed (Table 2). The following equipment was used:

- Intermittent flow respirometer, with circular, flat-bottom acrylic respiration chambers of different volumes (according to size of animal). Oxygen content and temperature were automatically monitored using a computer-controlled oxygen probe (WTW). When O_2 saturation dropped below a certain value, the water was exchanged with oxygenated seawater from a separate tank. For more detail see Kunzmann et al. (2007); Zimmermann & Kunzmann (2001).
- Closed bottle respirometer, with glass chambers of different volumes (according to size of animal). Oxygen content and temperature were automatically determined using a PreSens Optode system (Microx and Fibox).

All systems were filled with sterile-filtered (Sartobran 0.2 µm), natural seawater. Most measurements were performed at ambient temperatures of 17-18 °C (in the northern part of the expedition area, temperatures up to 21 °C were used). Individual experiments lasted between a few hours and two days and were repeated with gradually lowered O_2 concentrations, in some cases down to 0% oxygen.

A major problem was the successful catch of life animals in good condition. Most fish larvae were dead, both in catches of the Multinet and the Tucker trawl. Of the few survivors most clupeid larvae died within two hours of the catch. Only flatfish and *Leptocephalus* larvae survived in larger numbers. The most successful stations were shallow coastal stations (T3-2 and Add 11) on February 20th.

Because identification of life fish larvae is difficult, only broader taxonomic groups are presently considered in this report (see Table 2). Larvae of flat fish (Soleidae), Leptocephalus (Anguilliformes), sardines (Clupeidae) and krill (*Euphausia hanseni*) were measured and subsequently frozen at -80 °C for subsequent detailed taxonomic identification.

Preliminary results indicate that krill tolerates low oxygen levels down to 30% saturation. Some individuals even survived after several hours of exposure to as low as 10%, while 5% oxygen seems to be the ultimate limit. This is in contrast to *Leptocephalus* larvae, which easily tolerate oxygen saturation levels of 5%. Two individuals were kept for more than three hours at zero oxygen without any harm. Also the flatfish larvae tolerated a low oxygen saturation. At levels of 10% they responded with increased ventilation rates, which at 5% turned to fast pumping. All individuals recovered within minutes after oxygen levels were raised again to 50% and more. A long-term experiment using krill groups of 15-20 individuals with gradually and controlled oxygen levels of 90-80, 80-70, 70-60, 60-50,50-40 and 40-30%, which was running until the last day of the cruise, will give more details on the critical level of oxygen.

References:

Kunzmann, A.; Schmidt, M.K.; Yuwono, E. (2007) Routine respiration and activity of the Indonesian mangrove crab Scylla serrata (Forskål, 1775), Decapoda, Brachyura, Crustaceana 80(1):77-95.

Zimmermann, C.; Kunzmann, A. (2001) Baseline respiration and spontaneous activity of sluggish marine tropical fishes of the family Scorpaenidae. Mar. Ecol. Prog. Ser. 219: 229 – 239.

Table 2. List of experiments performed

Code	Group	Species	No. of anim.	Station	Date Start	Exp Dur	Equipment	Tem (°C)
E1	Amphipod	Themisto	2		09.02.2007	11:27	Microx	16
E2	Krill	E.uphausia hanseni	5		10.02.2007	02:17	Microx	16
E3	Decapod	? Sergestive	3		10.02.2007	03:59	Microx	16
E4	Krill	Euphausia hanseni	2		10.02.2007	02:14	Fibox	16
E5	Cnidaria	small	3		10.02.2007	02:17	Microx	16
E6	Krill	Euphausia hanseni	3		11.02.2007	02:29	Fibox	16
E7	Fish	Flatfish	3	136,T3-1,N3,4,5	11.02.2007	02:19	Fibox	16
E7-2	Fish	Flatfish	2	136,T3-1,N4,5	11.02.2007	01:14	Microx	16
E8	Fish	Flatfish	1	136,T3-1,N5	11.02.2007	11:58	FT, FR1.3, 80/90/1	17
E8-2	Fish	Flatfish	1	136,T3-1,N5	11.02.2007	01:34	Fibox	17.8
E8-2b	Fish	Flatfish	1	136,T3-1,N5	11.02.2007	09:11	Fibox	17.8
E9-2	Fish	Flatfish	1	136,T3-1,N5	11.02.2007	30:15	FT, FR1.3, 80/90/1	17
E9-3	Fish	Flatfish	1	136,T3-1,N5	12.02.2007	05:57	FT, FR1.3, 60/70/1	17
E9-4	Fish	Flatfish	1	136,T3-1,N5	12.02.2007	12:02	FT, FR1.3, 50/60/1	17
E9-5	Fish	Flatfish	1	136,T3-1,N5	13.02.2007	24:03	FT, FR1.3, 30/40/1	17
E9-6	Fish	Flatfish	1	136,T3-1,N5	14.02.2007	06:10	FT, FR1.3, 10/20/1	17
E10	Fish	Flatfish	1	136,T3-1,N5	12.02.2007	33:34	Microx	17
E10-2	Fish	Flatfish	1	136,T3-1,N5	13.02.2007	19:08	Microx	17
E11	Fish	Sardine	1	142, N5	13.02.2007	01:45	Fibox	16.9
E12	Fish	eel-like larvae	1	add4, N3	13.02.2007	30:00	Fibox	17
E13-3	Krill	Euphausia hanseni	1	Tucker/149, T1-3	14.02.2007	02:38	Fibox	17.4
E13-4	Krill	Euphausia hanseni	1	Tucker/149, T1-3	14.02.2007	03:42	Fibox	17
E13-5	Krill	Euphausia hanseni	1	Tucker/149, T1-3	14.02.2007	06:54	Microx	17
E13-6	Krill	Euphausia hanseni	1	Tucker/149, T1-3	14.02.2007	12:38	Fibox	17
E14	Fish	eel-like larvae	1	add4, N3	14.02.2007	57:16	FT, FR1.3,100/10/20	17
E15	Fish	Leptocephalus	1	Tucker/151, T1-5	15.02.2007	26:57	Fibox	17
E16	Copepod	blue cops	8	Tucker/151, T1-5	15.02.2007	09:20	Microx	17
E17	Fish	Leptocephalus	1	151, T1-6	16.02.2007	22:41	Microx	17
E18	Krill	Euphausia hanseni	2	156, T3-7	16.02.2007	04:14	Fibox	17
E19	Fish	unknown	2	T3-7-4,N5	16.02.2007	03:08	Fibox	17
E20	Fish	Flatfish	2	136,T3-1,N5	16.02.2007	10:44	Fibox	17
E21	Fish	Flatfish	1	136,T3-1,N5	17.02.2007	26:19	Microx	18.5
E22	Fish	Flatfish	1	136,T3-1,N5	17.02.2007	30:50	Fibox	18.5
E23	Krill	Euphausia hanseni	10	Tucker/T3-7	17.02.2007	14:00	FT, FR3, 50/70/1	18.5
E24	Krill	Euphausia hanseni	16	166, NML1	18.02.2007	01:49	FT, FR3, 30/40/1	18.5
E24-2	Krill	Euphausia hanseni	16	166, NML1	18.02.2007	04:53	FT, FR2, 50/60/1	18.5
E25	Krill	Euphausia hanseni	18	166, NML1	18.02.2007	14:00	FT, FR2, 55/60/1	18.5
E26	Fish	eel-like larvae	1	add4, N3	19.02.2007	04:20	Fibox	18.5
E27	Fish	Leptocephalus	1	156-b, N4	19.02.2007	32:34	Microx	18.5
E28	Krill	Euphausia hanseni	18	Tucker, T3-3	19.02.2007	06:20	FT, FR2, 50/55/1	18.5
E28-2	Krill	Euphausia hanseni	18	Tucker, T3-3	19.02.2007	12:14	FT, FR2, 45/50/1	18.5
E29	Fish	Flatfish	5	Add10, Tucker	20.02.2007	18:33	FT, FR0.6	18.5
E30	Fish	Flatfish	1	Add10, Tucker	20.02.2007	18:48	Fibox	18.5
E31	Fish	Flatfish	3	T3-2, N2	20.02.2007	12:53	Microx	18.5
E32	Fish	Mesopelagic	1	Add13, N5	21.02.2007	24:48	Fibox	18.5
E33	Fish	Flatfish	1	T3-2, N2	21.02.2007	31:17	Microx	18.5
E33-b	Fish	Flatfish	1	T3-2, N2	22.02.2007		Microx	18.5
E34	Krill	Euphausia hanseni	10	Tucker	21.02.2007	10:59	FT, FR2, 20/30/1	18.5
E34-2	Krill	Euphausia hanseni	7	Tucker	21.02.2007	09:26	FT, FR1.5, 25/30/1	18.5
E34-3	Krill	Euphausia hanseni	8	Tucker	22.02.2007	01:48	FT, FR1, 15/20/1	18.5
E34-4	Krill	Euphausia hanseni	8	Tucker	22.02.2007	06:38	FT, FR1, 80/90/1	18.5
E34-5	Krill	Euphausia hanseni	5	Tucker	22.02.2007		FT, FR1, 80/90/1	18.5
E35	Fish	Flatfish	4	Add10, Tucker	22.02.2007		Fibox	18.5
E35-b	Fish	Flatfish	4	Add10, Tucker	22.02.2007		Fibox	18.5

2.6. MULTIFREQUENCY ACOUSTIC SAMPLING AND ANALYSIS

J-O. Krakstad and F. Buchholz

Equipment

A Simrad ER 60 echosounder connected to four transducers with operating frequencies of 18 kHz, 38 kHz, 120 kHz (split beam) and 200 kHz (single beam) were used continuously during the survey. All acoustic transducers were calibrated successfully in Elefant Bay in Angola on 8/8-2006 and no major deviation from prior calibrations was observed. The calibration report with the technical specifications and operational settings used can be found in Annex II. To minimise differences in sampling resolution, the pulse length and band width setting of the transducers were set to short/wide (18 kHz; 0.7ms), medium/wide (38 kHz; 1.0 ms) and long/narrow respectively (120 kHz and 200 kHz; 1.0 ms). Data were logged continuously on transects to Simrad ER 60 .raw files. Ping rates were set to a maximum of 1.2 per second, and all transducers had synchronised trigging.

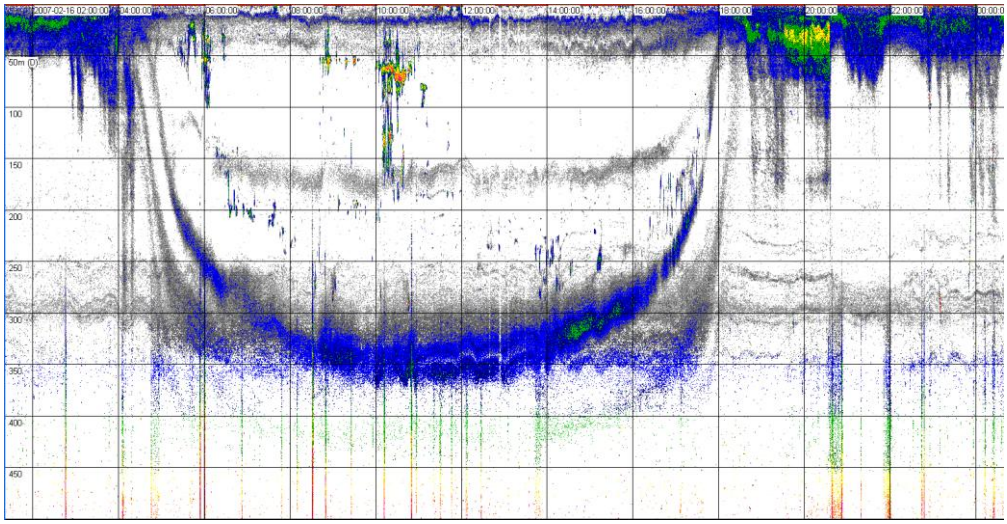
Results

The four echosounders were running continuously during the survey and were used to identify scattering layers of krill, copepods and other zooplankton. The three diel cycles in Figure 13 give a good overview of the observations made during the survey and represent at least two contrasting systems. The oxygen, temperature and salinity profiles in Figure 14 correspond with the diel cycles in Figure 13. The observed scattering layer corresponds to layers of changing water characteristics. At all three diel stations the dominant part of the zooplankton backscatter was observed descending into the hypoxic water masses during the day, probably using these layers as a refuge from less tolerant predators.

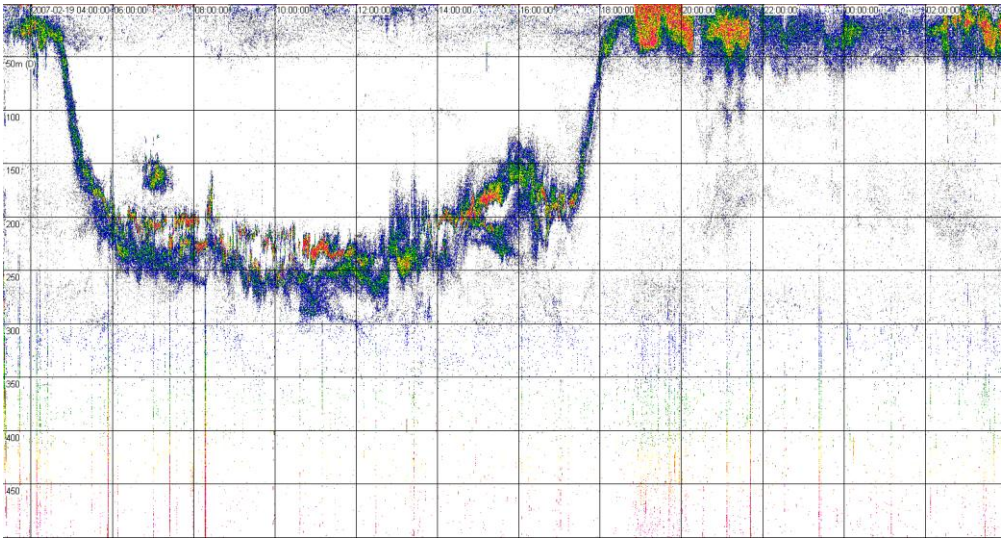
The first diel station off Angola (Figure 13a) was conducted north of the front at 14°50’S, 11°30’E. The station was characterised by mainly low-energy backscattering. Several pulses with different zooplankton (not yet identified) can be observed migrating downward in the morning, stabilising at different depths (120 m, 300 m and 400 m, respectively,) before migrating up again in the evening. It is worth noting that animals with the most extensive migration range started descending first in the morning and have the fastest descent rate, and *vice versa* in the evening. In addition to the migrating layers, three layers did not seem to perform diel migration, one seemed stable in the upper 50 m during the entire 24 hour period while the two others were found at 300 m and around 500 m depth (not visible on the echogram).

The second diel station (Figure 13b) was conducted at 17°00'S, 11°15'E in the frontal zone while the third diel station (Figure 13c) was conducted 18°26'S, 11°15'E, south of the front. These two stations showed similar results with one main scattering layer migrating down to ~250 m depth during the day and a less defined layer staying in the upper 50 m during the entire 24 h period. A stable scattering layer at 500 m (not visible in the echogram) was present in both localities, while diel station III also had a stable scattering layer at 350 m depth (visible on the 38 kHz only). Both stations gave considerably stronger backscattering than was observed during the first diel station and the scattering layer observed during the second diel station was stronger than during the third. The main scattering layer on both echograms are likely to be krill *Euphausia hanseni*, and it is apparent that this species spent the daylight hours within the hypoxic watermasses.

a) Diel station I at 14°50’S, 11°30’E



b) Diel station II at 17°00’S, 11°15’E



c) Diel station III at 18°26’S, 11°15’E

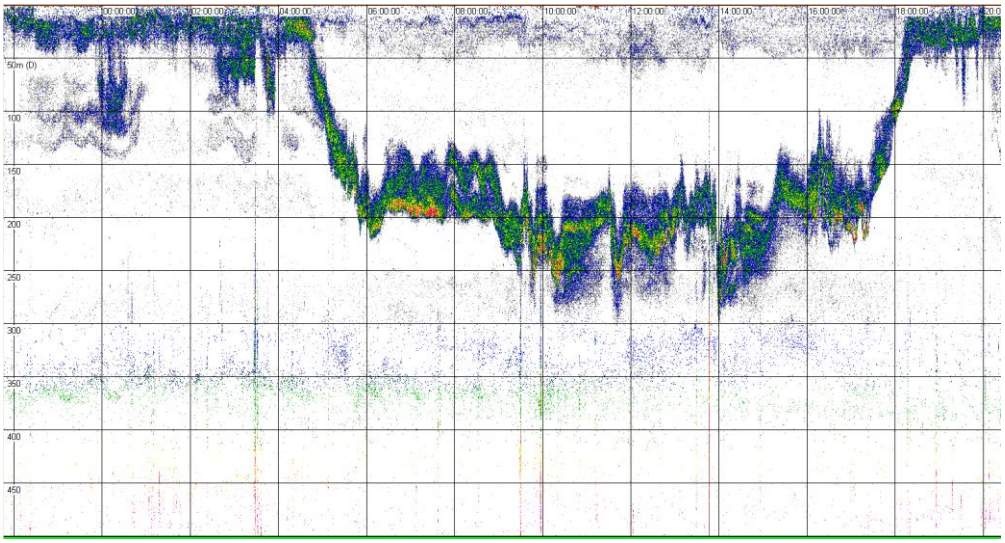
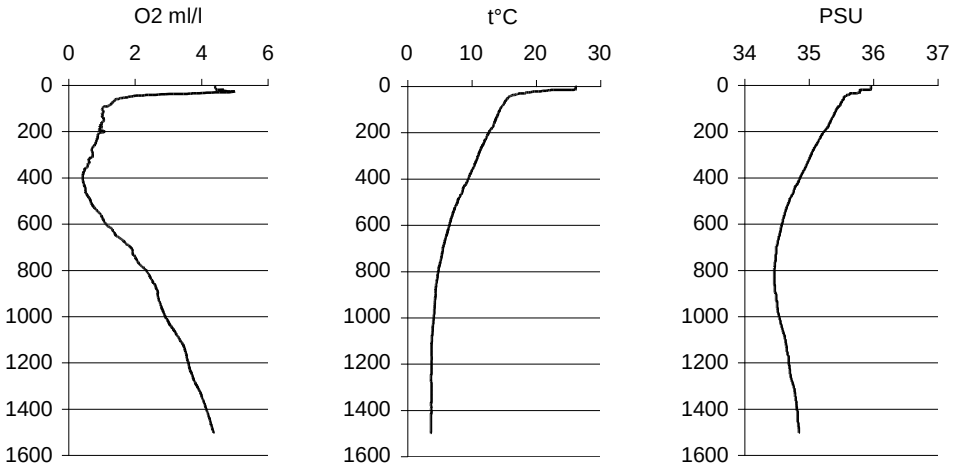
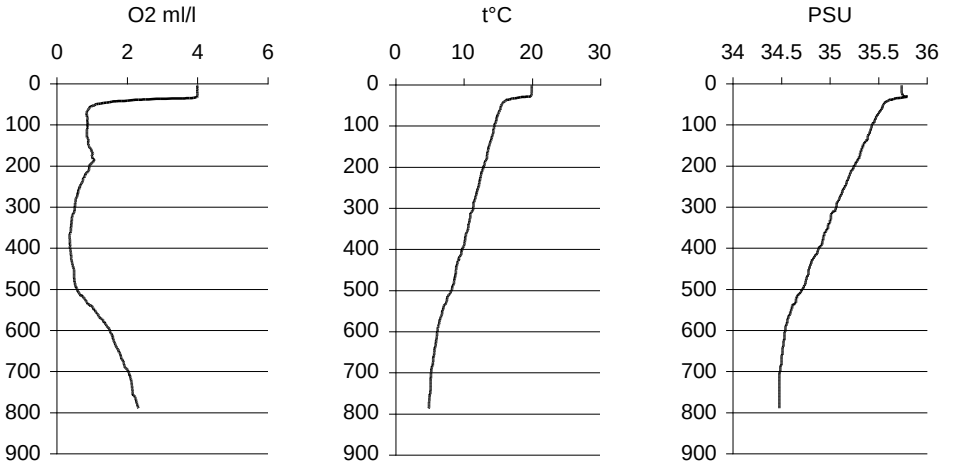


Figure 13. Composite pictures of acoustic backscattering recorded with the 120 kHz echosounder. S_V colour minimum =-75db. a) Diel station I at 14°50’S, 11°30’E, b) Diel station II at 17°00’S, 11°15’E and c) Diel station III at 18°26’S, 11°15’E. The illustrations show the diel vertical migration of zooplankton, migration speed and timing, and the depth where the layers stabilise during day and night.

a) Diel station I at 14°50'S, 11°30'E



b) Diel station II at 17°00'S, 11°15'E



c) Diel station III at 18°26'S, 11°15'E

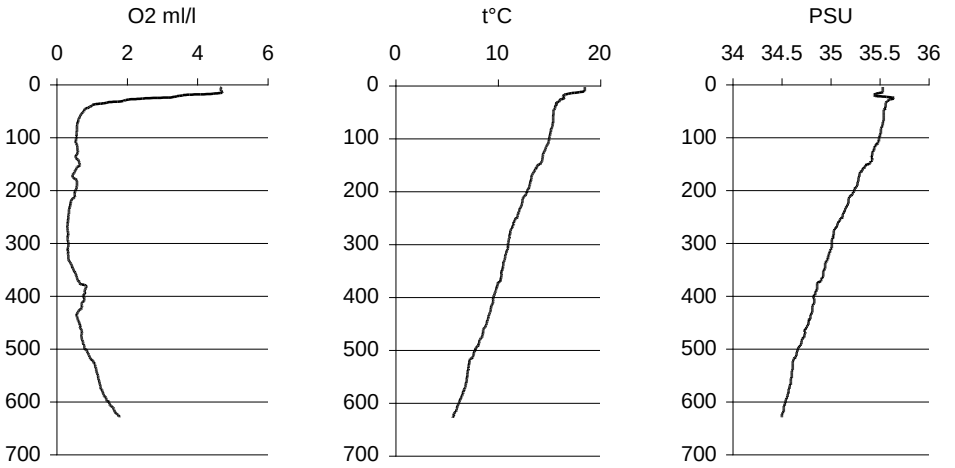


Figure 14. Oxygen, temperature and salinity profiles at the three diel stations, a) at 14°50'S, 11°30'E, b) at 17°00'S, 11°15'E and c) at 18°26'S, 11°15'E. Note different y- scale

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We like to thank the Captain and crew of the RV '*Dr. Fridtjof Nansen'* for their cooperation and the pleasant working environment on board. A special thanks goes to Christo Whittle (University of Cape Town) for supplying us with regular updates of SST images.

ANNEX I LIST OF STATIONS AND EQUIPMENT USED

CTD station	NatMIRC/ZMT	Lat	Long	Depth	GMT	Date GMT!	Comments
114	23002	23°00.35'S	14°21.52'E	47	21:56	7-Feb-07	CTD (no bottom sample), WP2, Phyto
115	23005	22°59.81'S	14°18.88'E	73	23:48	7-Feb-07	CTD (no bottom sample), WP2, Phyto, OMulti
116	23010	22°59.66'S	14°14.05'E	104	1:36	8-Feb-07	CTD (no bottom sample), WP2, Phyto, OMulti
117	23020	22°59.85'S	14°02.61'E	132	3:49	8-Feb-07	CTD (no bottom&surface sample), WP2, Phyto, Omulti
118	23030	22°59.96'S	13°52.04'E	146	6:09	8-Feb-07	CTD, WP2, Phyto, OMulti
119	23040	23°00.17'S	13°40.69	154	8:35	8-Feb-07	CTD, WP2, Phyto,OMulti
120	23050	23°00.33'S	13°30.15'E	237	11:06	8-Feb-07	CTD, WP2, Phyto, OMulti
121	23060	23°00.27'S	13°19.95'E	356	14:11	8-Feb-07	CTD, WP2, Phyto,OMulti
122	23070	22°59.93'S	13°09.20'E	322	16:56	8-Feb-07	CTD, WP2, Phyto,OMulti
123	-	22°34.9'S	12°43.2	910	22:25	8-Feb-07	CTD (no bottle samples taken) , Tucker
124	20050	20°00.02'S	12°08.97'E	285	15:30	9-Feb-07	CTD (no surface sample), Omulti
125	20040	19°59.98'S	12°19.92'E	217	18:00	9-Feb-07	CTD, WP2, Phyto, Tucker
126	20030	19°59.74'S	12°29.3'E	155	21:09	9-Feb-07	CTD, WP2, Phyto
127	20020	20°00.19'S	12°39.86'E	127	23:06	10-Feb-07	CTD, WP2, Phyto, OMulti, Corer
128	20010	20°00.01'S	12°50.66'E	97	1:56	10-Feb-07	CTD, WP2, Phyto, Driftnet
129	20005	20°00.05'S	12°56.10'E	67	3:05	10-Feb-07	CTD, WP2, Phyto, OMulti, Driftnet
130	20002	19°59.90'S	12°59.90'E	33	4:13	10-Feb-07	CTD, WP2, Phyto, Driftnet
131	T5-5	19'00.09'S	12°27.00'E	37	10:56	10-Feb-07	CTD, VMulti, OMulti, Phyto, Driftnet
132	T5-4	19°00.07'S	12°14.92'E	111	12:44	10-Feb-07	CTD, VMulti, OMulti,
133	T5-3	19°00.67'S	11°59.37'E	211	15:06	10-Feb-07	CTD, VMulti, OMulti, Phyto,
134	T5-2	19°00.23'S	11°45.25'E	302	18:24	10-Feb-07	CTD, VMulti, OMulti, Phyto, Tucker (lost cup)
135	T5-1	19°00.42'S	11°30.124'E	300	22:19	10-Feb-07	CTD, VMulti, OMulti, Phyto (Vmulti: no samples; 1 cup broken)
136	T3-1	18°00.17'S	11°29,97'E	242	6:06	11-Feb-07	CTD, VMulti, OMulti, Driftnet (lost net)
137	T3-2	17°30.10'S	11°30,35'E	170	11:00	11-Feb-07	CTD, VMulti, OMulti, Phyto
138	Add 1	17°23.16'S	11°15,96'E	521	14:19	11-Feb-07	CTD, VMulti, OMulti, Tucker
139	T2-2	17°15.78'S	11°00,67'E	1914	18:28	11-Feb-07	CTD, VMulti, Omulti (twisted, no samples taken), Tucker, Phyto
140	T1-2	17°15.76'S	10°30.27'E	3270	0:13	12-Feb-07	CTD (1500m), deep VMulti (twisted, no samples taken), shallow Vmulti, Omulti, Phyto

141	T1-1	17°59.88'S	10°29.70'E	3586	8:27	12-Feb-07	CTD, VMulti, Omulti, Phyto
142	T2-1	18°00.91'S	10°59.95'E	2550	13:20	12-Feb-07	CTD, VMulti, Omulti, Phyto
143	Add 2	17°47.10'S	11°22.21'E	565	17:45	12-Feb-07	CTD, VMulti, Omulti, Tucker
144	Add 3	17°44.00'S	11°24.15E	256	20:52	12-Feb-07	CTD, Tucker, Ringnet, Benefit-MN successful test
no CTD	Add 4	17°34.14'S	11°18.85E	576	23:00	12-Feb-07	VMulti
145	Add 5	17°20.18'S	11°10.26'E	897	3:05	13-Feb-07	CTD, Vmulti, Omulti, Phyto
146	T2-2a	17°15.12'S	11°00.00'E	2125	6:01	13-Feb-07	CTD, Phyto, Omulti, deep Vmulti (600m),
147	Add 6	17°15'00S	10°47.00'E	2968	11:30	13-Feb-07	CTD, Phyto, Vmulti, Omulti
148	T1-2a	17°15.05'S	10°30.12'E	2756	15:00	13-Feb-07	CTD, VMulti, Omulti, Tucker
149	T1-3	16°20.29'S	10°29.57'E	3582	22:45	13-Feb-07	CTD (1500m) surface not released, Tucker, VMulti, Omulti, Phyto
150	T1-4	15°40.00'S	10°30.00'E	3466	05:50	14-Feb-07	CTD, Phyto, deep Vmulti (600m), Omulti, Tucker, Phyto for food
151	T1-5	14°15.31'S	10°29.93'E	3505	15:45	14-Feb-07	CTD (1500m), Phyto, Vmulti, Omulti, Tucker
152	T3-8	14°1.021'S	11°29.26'E	3063	03:30	15-Feb-07	Tucker, CTD, Phyto, Omulti, VMulti,
153	T4-3	14°00.09'E	12°13.16'E	486	10:04	15-Feb-07	CTD, Vmulti, Omulti, Phyto
154	T4-2	14°24.96'S	12°12.01'E	413	14:50	15-Feb-07	CTD, Vmulti, Omulti, Phyto
155	T4-1	14°49.93'S	11°59.90'E	1608	19:11	15-Feb-07	CTD, Vmulti, Omulti, Phyto
156	T3-7	14°50'S	11°30'E	2577	00:00	16-Feb-07	CTD (1500m), Phyto, Tucker
no CTD	T3-7-1	14°51'S	11°29'E	2630	02:00	16-Feb-07	Omulti, deep Vmulti (600 m)
no CTD	T3-7-2	14°50'S	11°30'E	2577	06:00	16-Feb-07	Omulti, deep Vmulti (600 m)
157	T3-7-3	14°52'S	11°30'E	2506	10:00	16-Feb-07	Omulti, deep Vmulti (600 m), CTD,Tucker
no CTD	T3-7-4	14°50'S	11°30'E	2577	14:00	16-Feb-07	Omulti, deep Vmulti (600 m)
158	T3-7-5	14°50'S	11°30'E	2577	18:00	16-Feb-07	Omulti, deep Vmulti (600 m), CTD
no CTD	T3-7-6	14°50'S	11°30'E	2577	22:00	16-Feb-07	Omulti, deep Vmulti (600 m)
159	T2-5	14°51'S	11°00'E	3224	03:26	17-Feb-07	CTD, Omulti, Vmulti
160	NML-6	15°10.7'S	11°17'E	2582	07:40	17-Feb-07	CTD, vWP-2-200m, vN70V-200m, oBongo-50m, Phyto, Vmulti
161	NML-5	15°09.23'S	11°27.90'E	2241	11:57	17-Feb-07	CTD, vWP-2-200m, vN70V-200m, oBongo-50m, Phyto, Vmulti
162	NML-4	15°10'S	11°38.28'E	1852	15:09	17-Feb-07	CTD, vWP-2-200m, vN70V-200m, oBongo-50m, Phyto, Vmulti
163	NML-3	15°10.2'S	11°48.7'E	1160	18:38	17-Feb-07	CTD, vWP-2-200m, vN70V-200m, oBongo-50m, Phyto, Vmulti
164	NML-2	15°10'S	11°59'E	415	22:02	17-Feb-07	Tucker, CTD, vWP-2-200m, vN70V-200m, oBongo-50m, Phyto, Vmulti
165	NML-1	15°10'S	12°07.5'E	189	01:35	18-Feb-07	CTD, vWP-2-200m, vN70V-200m, oBongo-50m, Phyto, Vmulti

166	T3-6	15°30'S	11°30'E	1739	07:50	18-Feb-07	CTD, Phyto, Omulti, Vmulti
167	Add 7	15°45'S	11°30'E	1468	10:55	18-Feb-07	CTD
168	T3-5	16°00'S	11°30'E	1230	12:56	18-Feb-07	CTD, Phyto, Omulti, Vmulti
169	Add-08	16°15'S	11°30'E	552	16:05	18-Feb-07	CTD, Tucker, Phyto, Omulti, Vmulti
170	T3-4	16°30'S	11°30'E	104	20:04	18-Feb-07	CTD, Phyto, Omulti, Vmulti
171	Add-09	16°45'S	11°30'E	112	22:50	18-Feb-07	CTD, Phyto, Omulti, Vmulti
172	T3-3	17°00'S	11°30'E	108	01:26	19-Feb-07	CTD, Phyto, Vmulti, Omulti
173	T3-3-Slope	17°00'S	11°15'E	807	03:45	19-Feb-07	CTD (800 m), Tucker, Phyto
no CTD	T3-3-Slope-1	17°00'S	11°15'E	788	06:00	19-Feb-07	Omulti, deep Vmulti (600 m)
no CTD	T3-3-Slope-2	17°00'S	11°15'E	742	10:00	19-Feb-07	Omulti, deep Vmulti (600 m), Tucker
0	T3-3-Slope-3	17°00'S	11°15'E	650	14:00	19-Feb-07	Omulti, deep Vmulti (600 m), Tucker at 19:15
174	T3-3-Slope-4	17°00'S	11°15'E	683	18:00	19-Feb-07	Omulti, deep Vmulti (600 m), CTD (800 m)
no CTD	T3-3-Slope-5	17°00'S	11°15'E	799	22:00	19-Feb-07	Omulti, deep Vmulti (600 m), Tucker
no CTD	T3-3-Slope-6	16°59'S	11°15'E	865	02:00	20-Feb-07	Omulti, deep Vmulti (600 m)
175	Add 10	17°15'S	11°30'E	148	06:15	20-Feb-07	CTD for Jens!, Vmulti, Omulti, Phyto, Tucker
176	Add 11	17°15'S	11°43'E	35	09:10	20-Feb-07	Omulti, CTD for Jens!, Phyto
no CTD	Add 12	17°27'S	11°33'E	140	11:10	20-Feb-07	Tucker
177	T3-2	17°30'S	11°30'E	163	11:58	20-Feb-07	CTD, Phyto, Omulti, Vmulti
178	Add 13	17°45'S	11°30'E	188	14:35	20-Feb-07	Omulti, Vmulti, Phyto
179	T3-1	18°00'S	11°30'E	240	17:13	20-Feb-07	CTD, Omulti, Vmulti, Phyto, Tucker
180	Add-14-1	18°26'S	11°22'E	676	22:00	20-Feb-07	Omulti, deep Vmulti (600 m), Phyto, CTD (700 m)
no CTD	Add-14-2	18°26'S	11°22'E	677	02:00	21-Feb-07	Omulti, deep Vmulti (600 m)
no CTD	Add-14-3	18°26'S	11°22'E	675	06:00	21-Feb-07	Omulti, deep Vmulti (600 m)
no CTD	Add-14-4	18°26'S	11°22'E	670	10:00	21-Feb-07	Omulti, deep Vmulti (600 m), Tucker
no CTD	Add-14-5	18°26'S	11°22'E	670	14:00	21-Feb-07	Omulti, deep Vmulti (600 m)
181	Add-14-6	18°26'S	11°22'E	670	18:00	21-Feb-07	Omulti, deep Vmulti (600 m), CTD, Tucker
182	T5-1	19°00.42'S	11°30.124'E	300	00:00	22-Feb-07	CTD
183	T7a-4/20020	18°00	12°39'E	127	10:00	22-Feb-07	CTD, corer

ANNEX II CALIBRATION WITH REFERENCE SPHERE

Vessel: "Dr. Fridtjof Nansen"		Date:	
Echo sounder:		Locality:	
Transducer:	Sphere:	Bottom depth: m	
Sound vel: m/s (measured in situ)	r_{sphere}: m	$T_{sph-dep.}$: °C, $S_{sph-dep.}$: ‰	TS_{sphere}: dB (correct for sound vel.

TX/RX no:	Frequency: kHz	Date previous calibration:

Settings in sound velocity menu during calibration:

Mean sound velocity between 0 m and sphere depth: m/s (settings to be optimised according the present

Setting parameters in transmitter/receiver menu:	Previous values:	Values appeared at this calibration	Values set after calibration
Transducer depth (m) during (has to be 0,0 m during calibration)			
Absorption coefficient (dB/km)			
Pulse duration (ms)			
Band width (kHz)			
TX effect ref. transducer terminals (W)			
Equivalent beam angle (10 log ψ) (dB)			
S_V transducer sensitivity (dB)			
TS transducer sensitivity (dB)			
Angle sensitivity along ship			
Angle sensitivity athwart ship			
3 dB beam width along ship (deg)			
3 dB beam width athwart ship (deg)			
Along ship deviation from centre (deg)			
Athwart ship deviation from centre (deg)			

Measured values before any adjustments: (measured with sphere in acoustic axis)

Read TS_{sphere}: dB	Read S_A: m^2/nmi^2

Theoretical S_A in existing sphere depth (m^2/nmi^2)	

$$S_A = \frac{\sigma}{r^2 \psi} 1852^2 \qquad \sigma = 4\pi 10^{0.1TS}$$

Read S_A after control/adjustment of S_V transducer sensitivity (m^2/nmi^2)	

Remarks: *lowering keel: out* *in*

File name:

Weather conditions: ☒very good ☐good ☐bad (tick) Wind speed: m/s

In cases where a variance of the transducer sensitivity is > 0,3 dB there has to be searched for possible causes. If no faults can be proven, a new calibration has to be made after relatively short time.

Vessel: "Dr. Fridtjof Nansen"		Date:	
Echo sounder:		Locality:	
Transducer:	Sphere:	Bottom depth: m	
Sound vel: m/s (measured in situ)	r_{sphere}: m	$T_{sph\text{-}dep.}$: °C, $S_{sph\text{-}dep.}$: ‰	TS_{sphere}: dB (correct for sound vel.

TX/RX no:	Frequency: kHz	Date previous calibration:

Settings in sound velocity menu during calibration:

Mean sound velocity between 0 m and sphere depth: m/s (settings to be optimised according the present

Setting parameters in transmitter/receiver menu:	Previous values:	Values appeared at this calibration	Values set after calibration
Transducer depth (m) during (has to be 0,0 m during calibration)			
Absorption coefficient (dB/km)			
Pulse duration (ms)			
Band width (kHz)			
TX effect ref. transducer terminals (W)			
Equivalent beam angle (10 log ψ) (dB)			
S_V transducer sensitivity (dB)			
TS transducer sensitivity (dB)			
Angle sensitivity along ship			
Angle sensitivity athwart ship			
3 dB beam width along ship (deg)			
3 dB beam width athwart ship (deg)			
Along ship deviation from centre (deg)			
Athwart ship deviation from centre (deg)			

Measured values before any adjustments: (measured with sphere in acoustic axis)

Read TS_{sphere}: dB	Read S_A: m^2/nmi^2

Theoretical S_A in existing sphere depth (m^2/nmi^2)	

$$S_A = \frac{\sigma}{r^2 \psi} 1852^2 \qquad \sigma = 4\pi 10^{0.1TS}$$

Read S_A after control/adjustment of S_V transducer sensitivity (m^2/nmi^2)	

Remarks: *lowering keel:* *out* *in*

File name:

Weather conditions: ☒very good ☐good ☐bad (tick) Wind speed: m/s

In cases where a variance of the transducer sensitivity is > 0,3 dB there has to be searched for possible causes. If no faults can be proven, a new calibration has to be made after relatively short time.

Vessel: "Dr. Fridtjof Nansen"		Date:	
Echo sounder:		Locality:	
Transducer:	Sphere:	Bottom depth: m	
Sound vel: m/s (measured in situ)	r_{sphere}: m	$T_{sph\text{-}dep.}$: °C, $S_{sph\text{-}dep.}$: ‰	TS_{sphere}: dB (correct for sound vel.

TX/RX no:	Frequency: kHz	Date previous calibration:

Settings in sound velocity menu during calibration:

Mean sound velocity between 0 m and sphere depth: m/s (settings to be optimised according the present

Setting parameters in transmitter/receiver menu:	Previous values:	Values appeared at this calibration	Values set after calibration
Transducer depth (m) during (has to be 0,0 m during calibration)			
Absorption coefficient (dB/km)			
Pulse duration (ms)			
Band width (kHz)			
TX effect ref. transducer terminals (W)			
Equivalent beam angle (10 log ψ) (dB)			
S_V transducer sensitivity (dB)			
TS transducer sensitivity (dB)			
Angle sensitivity along ship			
Angle sensitivity athwart ship			
3 dB beam width along ship (deg)			
3 dB beam width athwart ship (deg)			
Along ship deviation from centre (deg)			
Athwart ship deviation from centre (deg)			

Measured values before any adjustments: (measured with sphere in acoustic axis)

Read TS_{sphere}: dB	Read S_A: m^2/nmi^2

Theoretical S_A in existing sphere depth (m^2/nmi^2)	

$$S_A = \frac{\sigma}{r^2 \psi} 1852^2 \qquad \sigma = 4\pi 10^{0.1TS}$$

Read S_A after control/adjustment of S_V transducer sensitivity (m^2/nmi^2)	

Remarks: *lowering keel:* *out* *in*

File name:

Weather conditions: ☒very good ☐good ☐bad (tick) Wind speed: m/s

In cases where a variance of the transducer sensitivity is > 0,3 dB there has to be searched for possible causes. If no faults can be proven, a new calibration has to be made after relatively short time.

Vessel: "Dr. Fridtjof Nansen"		Date:	
Echo sounder:		Locality:	
Transducer:	Sphere:	Bottom depth: m	
Sound vel: m/s (measured in situ)	r_{sphere}: m	$T_{sph\text{-}dep.}$: °C, $S_{sph\text{-}dep.}$: ‰	TS_{sphere}: dB (correct for sound vel.

TX/RX no:	Frequency: kHz	Date previous calibration:

Settings in sound velocity menu during calibration:

Mean sound velocity between 0 m and sphere depth: m/s (settings to be optimised according the present

Setting parameters in transmitter/receiver menu:	Previous values:	Values appeared at this calibration	Values set after calibration
Transducer depth (m) during (has to be 0,0 m during calibration)			
Absorption coefficient (dB/km)			
Pulse duration (ms)			
Band width (kHz)			
TX effect ref. transducer terminals (W)			
Equivalent beam angle (10 log ψ) (dB)			
S_V transducer sensitivity (dB)			
TS transducer sensitivity (dB)			
Angle sensitivity along ship			
Angle sensitivity athwart ship			
3 dB beam width along ship (deg)			
3 dB beam width athwart ship (deg)			
Along ship deviation from centre (deg)			
Athwart ship deviation from centre (deg)			

Measured values before any adjustments: (measured with sphere in acoustic axis)

Read TS_{sphere}: dB	Read S_A: m^2/nmi^2

Theoretical S_A in existing sphere depth (m^2/nmi^2)	

$$S_A = \frac{\sigma}{r^2 \psi} 1852^2 \qquad \sigma = 4\pi 10^{0.1TS}$$

Read S_A after control/adjustment of S_V transducer sensitivity (m^2/nmi^2)	

Remarks: *lowering keel: out* *in*

Weather conditions: ☒very good ☐good ☐bad (tick) Wind speed: m/s

In cases where a variance of the transducer sensitivity is > 0,3 dB there has to be searched for possible causes. If no faults can be proven, a new calibration has to be made after relatively short time.

Calibration carried out by: