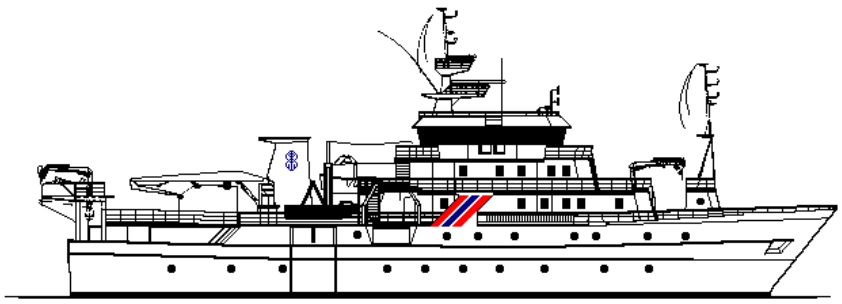

BENEFIT SURVEYS

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CRUISE REPORTS "DR. FRIDTJOF NANSEN"

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Diel vertical migration in horse mackerel

19 - 28 September 2002

by

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TABLE OF CONTENTS

CHAPTER 1. INTRODUCTION

1.1. BACKGROUND

This cruise is the second of two cruises to investigate the diel vertical migration of horse mackerel in the in the Northern Benguela ecosystem. The first cruise focused on diel vertical migration in T. *tracurus capensis* and tried to explain observed behavioural differences between the Northern and the Southern Benguela ecosystem (see Cruise Report, Ben 3 – 2001). This cruise will look at ecological differences between the two closely related species *T. tracurus capensis and T. trecae.*

Horse mackerel *Trachurus trachurus capensis* undertake extensive diel vertical migrations in South African and Namibian waters. This behaviour is also observed in the closely related *T. trecae* species that inhabit Angolan waters. The two species coexist in a narrow area along the Angola – Benguela front in the border area between Angola and Namibia. Both species are known to commonly form dense shoals in midwater and close to the bottom during the day and migrate to midwater in the evening and disperse. This phenomenon may be linked to different food (e.g. dense midwater zooplankton scattering layers) and hydrographic conditions. The diel migratory pattern is relatively distinct but it is not satisfactory understood in any of the two species. It is for example known that it for unknown reasons in periods can cease completely.

The aim of this study is to investigate the pattern of diel migration of the horse mackerel species in an area were they coexist. Various abiotic and biotic factors will be examined, together with their feeding periodicity in an attempt to explain their behaviour and investigate potential differences in ecological strategy between the two species. An attempt to collect multi frequency data on the target strength of the

two species will also be made.

1.2. DIEL MIGRATIONS IN RELATION TO ABUNDANCE ESTIMATION

Hydroacoustic surveying is a foremost means of estimating the abundance of pelagic fish, and is applied for a number of species world-wide. The main advantages of the method are the ability of sampling large volumes of water with relatively low effort and the high sample resolution in both the horizontal and the vertical planes. Acoustic surveying has the last decade been utilised in the direct assessment of the commercially important pelagic fish species of Namibia and Angola, specifically horse mackerel (*Trachurus trachurus capensis*, *T. trecae*), sardinella (*Sardinella madarensis*, *S. aurita*), anchovy (*Engraulis capensis*) and sardine (*Sardinops sagax*). The method relies, however, on the fundamental assumptions that 1) unbiased returns from all targets are recorded, 2) that the recorded acoustic intensity can be correctly allocated among the taxons present, and 3) that the acoustic intensities of each taxon can be correctly converted to actual animal densities. Assumption 1 may, however, be violated under the following conditions:

- If targets inhabit volumes not covered by the acoustic beam, i.e. if they occupy the acoustic blind zones, at the time of sampling. Specifically, if these are in the near-bottom dead zone, in which targets are masked by the first bottom returns, and the upper blind zone, or between the surface and the upper integration limit of the transducer (transducer near field + the narrowest part of the beam). This is a problem in species that are distributed close to the bottom (e.g. horse mackerel) or the surface (sardinella) during surveying.
- If the recorded back-scattering area s_A (m^2/nm^2) of scatters is affected by the presence of the vessel,

i.e. avoidance behaviour. Vessel avoidance may cause fish to move out of the acoustic beam, in which case they are not recorded, or to change their angular orientation within the beam (i.e. to dive), and hence their scattering properties. Bias in acoustic abundance estimates due to vessel avoidance is reported for a range of pelagic fish species.

- Attenuation of the acoustic signal due to absorption in dense scattering layers may cause a range- and density dependent non-linear reduction in recorded density.

Assumption 2 entails that the different taxons of the ensonified population can be recognised. Combining visual scrutiny of the scattering patterns and independent trawl samples from the ensonified population usually identifies the targets, but problems are frequently encountered due to:

- spatial and/or temporal changes in scattering properties of taxons due to changes in behaviour (e.g. schooling/shoaling, dispersing, vertical migration)
- overlapping distributions, masking acoustic characteristics of different targets (e.g. horse mackerel mixed with aggregations of prey items like euphausiids and/or copepods).

Representative biological samples are prerequisite also for obtaining mean size and mean weight estimates needed to convert acoustic density to total number of individuals and to total biomass, respectively. For splitting the biomass on size groups, size distribution and size-weight keys are required as well. Commonly used in acoustic surveying for this purpose are sampling trawls that are specially designed to catch representatively. There are, however, certain limitations related to trawl performance, mainly:

- Availability – the extent to which the targets were present in the sampled volume (trawl sample volume is always very small compared to the acoustic sample volume)
- Catchability – the extent to which the targets encountered in the trawl path are caught (usually both

size- and species dependent)

- Compatibility – the extent to which the acoustically and biologically sampled volumes can be compared to (knowledge of trawl position, depth and geometry, and contamination of biological sample from other depths).

Consequently, reliable estimates depend on the researchers' ability to identify target species from non-target species, and ultimately therefore on their vertical movements in the water column. During routine resource surveys non-target groups of plankton (e.g. euphausiids, copepods), ichtyoplankton (egg and larvae of any species) and nekton (mesopleagic fish such as lanternfish) often represent considerable challenges when allocating backscatter energy to target taxons. Knowledge of the vertical movements of targets is then of obvious importance both for the acoustical and the biological sampling.

The calculation of absolute fish densities requires that the dorsal aspect acoustic target strength (TS) at the given frequency can be predicted (see e.g. BENEFIT Cruise Report 2/2001 for formulas). Angular orientation of targets introduces variation in the backscatter at the level of several orders of magnitude. Systematic changes in angular orientation, e.g. between day and night, warm and cold seasons and between shelf and slope habitats, may consequently introduce bias to acoustic abundance estimates. Another important reason for studying the behaviour, and in particular systematic vertical movements, of target species is therefore to build up the knowledge of how angular orientations and degrees of polarisation can be expected to vary at different times of day and night, and in different environmental regimes. This information can then, in turn, be used for evaluation and ideally for *ad-hoc* correction of echo-integration values.

1.3. OBJECTIVES OF THE SURVEY

The overall survey objective was to study the vertical migration of horse mackerel and other scattering organisms *in situ* at a deep slope-environment in the Namibian Benguela, where horse mackerel would be distributed in mid-water during daytime. Specific objectives were:

- To conduct calibrated acoustic measurements of Cape horse mackerel (*Trachurus trachurus caensis* and *T. trecae*) at 18, 38, 120 and 200 kHz during two consecutive 24 hrs stations.

- To identify the different main groups of planktonic scatterers in the ecosystem, mainly euphausiids and copepods using multinet plankton samplers.

- To identify the different main groups of nektonic scatterers in the ecosystem, which was mainly horse mackerel, but also some round herring and predatory fish, using pelagic trawl fitted with codend multisampler.

- To study the diurnal variations in recorded acoustic volume density s_V (dB ref. 1m @ 1 ɣPa) and area density s_A (m^2/nm^2) of the horse mackerel and related species.

- To collect stomach samples from the horse mackerel to map the stomach contents and, if feasible, to establish feeding periodicities.

- To conduct *in situ* experiments to determine oxygen tolerance level in horse mackerel and other species and to relate this information to the observed migratory behaviour of horse mackerel and related species.

- To log meteorological (air and sea surface temperature, wind strength and direction), hydrographical (temperature, salinity, oxygen) and current (ADCP profiling) conditions.

1.4. PARTICIPATION

The scientific staff consisted of:

From IIM: Filomena VAZ-VELHO and Fransisco DE ALMEIDA.

From NatMIRC: Graca D'ALMEIDA, Jens-Otto KRAKSTAD, Helvi MUPUPA, Hilma ASINO and Justina SHITINDI.

From IMR: Bjørn Erik AXELSEN (Cruise leader), Roar SKEIDE, Leif NØTTESTAD, Magne OLSEN, Tore MØRK and Ingve FJELDSTAD.

1.5. NARRATIVE

The RV "Dr. Fridtjof Nansen" departed from Walvis Bay 19 September 08:00 (local time) and headed northwards towards Cunene River to search for mixed aggregations of the two horse mackerel species. A search grid from 100 - 500 m bottom depth was used to cover the shelf from Kunene river to 16°15' S in Angola. Mixed aggregation of *T. t. capensis*, *T. trecae* and *Dentex macrophthalmus* was found in the bottom layer together with scattering layer in midwater consisting mostly of calanoids at 16º25' S 11º30' E around 150 m depth on the shelf. This aggregation was monitored acoustically continuously for

duration of 35 hrs. 11 cycles of bottom trawl, multi-sampler, plankton multinet, CTD and ADCP were conducted during the experiment. The vessel moved south to conduct a second period of experiments after completion of the first diel sycle. Aggregations of *T. t. capensis* mixed with scattering layers in midwater consisting mainly of calanoids was found at 17° 24' S. A transect was set up in the east - west direction from 800 -25 m bottom depth and surveyed three times over an period of 48 h. A station with suitable aggregations of *T. t. capensis* was selected midway on this transect at 17° 24' S 11° 28' E and xx cycles of bottom trawl, multi-sampler, plankton multinet, CTD and ADCP was conducted at this spot in between periods of drifting to collect multi frequency target strength data on *T. t. capensis*. After having washed the trawls, the ship headed back for Walvis Bay, and docked in the morning 28 September 2002.

CHAPTER 2. METHODS

2.1. SURVEY AREA

The continental shelf in northern Namibia from about 18°00' S and north to 16°15'S in Southern Angola was surveyed in order to find suitable mixed aggregations of horse mackerel (*T. t. capensis* and *T. trecea*) for a diel cycle experiments. The shelf was the main searching area, as the target for the experiments was aggregations of horse mackerel that occupied midwater during daytime, for mapping their diurnal vertical migration, preferably where food availability (i.e. euphausiids and copepods) would be good. The area between the 100 and 500 m isobaths was surveyed to 16°24 S in Angola, following a triangular transect grid. A suitable location for experiment one, with a scattering layer consisting mostly of calanoid copepods, was found at the Angolan shelf at about 16°24' S 11°30' E (Figure 1). The bottom depth in the area was about 100 m. The second experiment was conducted along an east – west transect at 17°24' S. Four transects, two at night and two during day time, were conducted at this site with trawl positions at the offshore (Figure 1, 2a) and inshore (Figure 1, 2c) end of the transect as well as a 48 h diel station at 17°24' S 11°29' S (Figure 1, 2c).

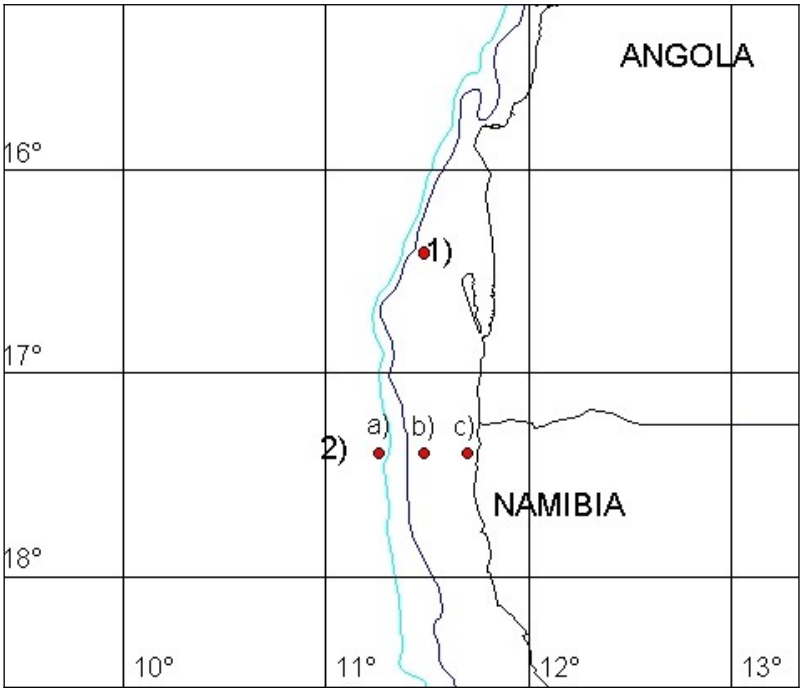

Figure 1. *Survey area. 1) Diel station experiment 1 in Angola. 2) Diel experiment 2 in Namibia, a) offshore trawl station at 800 m bottom depth, b) 48 h diel station at 170 m, c) inshore trawl station (See figure xx for shelf profile for area 2)*

2.2. HYDROGRAPHY AND WEATHER DATA

Meteorological information such as air and surface temperature, wind speed and direction and solar intensity was logged continuously from the ANDREAA weather station. CTD casts from the Seabird 911+ CTD were conducted to obtain profiles of temperature, salinity and oxygen. Samples for calibration of the oxygen and salinity sensors were also collected. The oxygen and salinity samples were analysed on board the vessel and calibration coefficients applied accordingly. Current measurements were carried out at selected stations using a 150 kHz RDI ADCP (Acoustic Doppler Current Profiler).

2.3. MULTIFREQUENCY ACOUSTIC SAMPLING

Two EK 500 echosounders equipped with four acoustic transducers mounted on the submersible keel

(Fig. 2) operating at nominal frequencies of 18, 38, 120 kHz (split-beam, EK1) and 200 kHz (single-beam, EK 2) were operated throughout the survey. Integration limits were set to 5 m below the transducer and 0.5 m off the bottom. The keel was in the lowered position during the entire survey.

The 18 kHz, 38 kHz, 120kHz and the 200kHz transducers were all calibrated in Baia dos Elefantes in Angola 7/9 –2002 during the Angolan pelagic biomass survey. The technical specifications and the calibration reports from the calibration are given in Annex IV. No major corrections had to be applied after calibration, except from the 120 kHz transducer were the SV transducer gain had changed from 26, 01db to 26,53 after this calibration. A second calibration was therefore conducted on this transducer at Langstrand outside Walvis Bay 27/9-2002 after the survey. This calibration confirmed the new values (See Annex XX for calibration report).

To minimise differences in sampling resolution, the pulse length and band width setting of the 18 kHz was set to short/wide, the 120 and 200 kHz transducer was set to long/narrow, while the 38 kHz transducer was set to medium/wide. The transducer depth was 5.5 m during operation. Logging of acoustic raw data was done using the Windows based SonarData_Echolog® Version 2.0 only. Analysis and post processing of logged data was done using Sonardata_Echoview® Version 2.25 software.

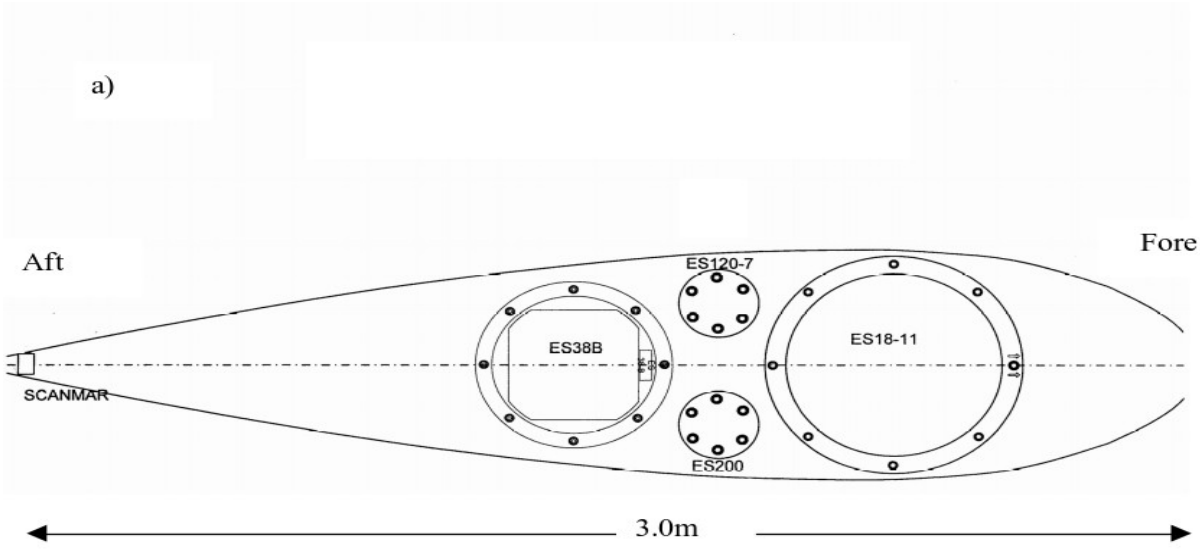

Figure 2. *Transducer arrangement of the drop keel of R/V "Dr. Fridtjof Nansen" showing schematic illustration of the new orientation of the transducers on the keel (scale 1:10)*

TRAWL SAMPLING

Sampling trawls used included the large pelagic trawl (30 m vertical opening) with the multisampler attached and a bottom trawl (5 m vertical opening). The multisampler was equipped with three codends without inner lining, which were remotely opened and closed to obtain discrete, uncontaminated samples from layers at different depths or schools. Thyborøn' Kombi 6.7 m^2 1,670 kg trawl doors were used in all hauls.

FIGURE 3. *The MultiSampler trawl during operation*

Random sub-samples of fish representative of the total catch were taken from the trawl catches when the total catch was not sampled. The sizes of the samples were determined from the degree of mixing of the catch. In cases where the catch was small, the total catch was always sampled. The number and total weight for each species were recorded in each sample and raised to the total catch. A random sub-sample of about 100 specimens of horse mackerel (*T. t. capensis* and *T. trecae*) and, when present round herring (*Etrumeus whiteheadii*) were measured to the nearest 1 mm below total length in order to obtain the size composition of the catch. These sub-sample were also analysed for biological parameters including individual total wet weight (± 0.1 g), sex, gonad maturity stage and stomach fullness (1-5; 1=empty, 5=completely filled) were recorded. Horse mackerel stomachs were preserved in 4 % buffered formaline for further analyses onshore.

A total of 65 trawls were completed during the survey with the multisampler trawls and the bottom trawl. All catches were sorted for species composition and entered into the NAN-SIS trawl database. A summary of all catches is shown in ANNEX II

2.4. PLANKTON MULTI NET

The Hydrobios plankton multinet were deployed during every trawl sycle to collect discrete samples of zooplankton at different depths. Five samples can be collected from each deployment. The plankton samples made it possible to identify acoustic scattering layers from zooplankton at all depths during the survey and to identify available food items for the horse mackerel in the survey area.

FIGURE 4. *The Hydrobios multinet plankton sampler in the surface*

2.5. DIEL EXPERIMENT ONE

(To be updated)

Three consecutive 24 hrs diel cycle experiments were completed for identification of different scattering layers, and examination of structural patterns and trophic relations. Acoustic data at all four frequencies

were logged continuously throughout the experiments. Biological samples were collected during continuos cycles, each consisting of depth-discrete plankton- and nekton tows, using respectively pelagic trawl and plankton nets and hydrographic profiling (CTD casts). ADCP recordings were conducted continuously throughout the experiments.

All sampling activities during the experiments were restricted to a 5 nm long study track. The sampling cycles commenced with a pelagic trawl haul using the codend multisampler, obtaining three depth-specific samples per deployment. The sampling depth was selected in order to target vertically separated scattering layers, whenever present.

Next was deployment of the zooplankton multinet sampler (Hydrobios Multinet). The sampler was equipped with 5*405 ɣm nets, each fitted with flowmeters. The sampler was hauled obliquely at a speed of 0.5 $m.s^{-1}$ while the ship towed at 2 knots (1 $m.s^{-1}$) towing speed, giving an approximate speed of 1.5 $m.s^{-1}$ through the water. Depth specific current speed and direction, including vertical and error components were measured continuously throughout the experiments using a RD Instrument Acoustic Doppler Current Profiler (ADCP).

The species and size compositions of the scattering layers were determined using the trawl- and plankton samples (lengthing of copepods will be done ashore). The hydrographical sampling (CTD) provided profiles of water temperature, salinity and dissolved oxygen. Changes in hydrographical conditions over time were plotted in Surfer. Water samples were collected for calibration of the oxygen probe. A total of 11 cycles were completed, constituting a total of 37 trawl samples using the codend multisampler and 22 trawls with the small pelagic trawl, 11 multinet plankton samples and 8 CTD casts.

2.6. DIEL EXPERIMENT TWO

2.6.1. Cross shelf distribution

2.6.2. 48 h diel station

2.6.3. Predator-prey behavioural studies

2.7. MULTI FREQUENCY ACOUSTIC ANALYSIS

CHAPTER 3. RESULTS

3.1. OCEANOGRAPHIS CONDITIONS

Eight CTD stations were carried out during the diel experiments. The station depth was generally 950 m but the CTD was lowered to 500 m since the focus of the experiments was in the upper 300 m. At station 694 (24 August 17:22) the whole water column was sampled. Water bottles were fired at the bottom and surface of the profile for calibration of the oxygen sensor and additional samples were taken at selected depths. Samples from all depths were preserved for oxygen. Oxygen samples were analysed on board using the standard Winkler method. Time serie figures for the recorded levels were prepared using Surfer and are shown in Fig. 3. Complete overviews of all profiles are given in ANNEX III.

Figure 3. Timeseries composites of recorded salinity, oxygen and temperature during the diel cycle experiments.

3.1.1. Temperature

The hydrographic time series composites of the temperature recordings (Fig 3) show that the water column was relatively stable throughout the sampling period. An uplift of isotherms from 26 August is evident, due to upwelling from a depth of approximately 200 m under stronger southerly wind conditions. The individual station profiles (Appendix III) show the absence of a well-defined thermocline throughout

the sampling period. The upper 50 m of the water column was very well mixed (∂T 0.5°C between 50 m and surface) but even at 150 m ∂T was generally just above 1°C. Below this depth the temperature decreased gradually to about 7°C at 500 m.

3.1.2. Salininity

Salinity profiles showed similar non-stratified trends to temperature with salinities of about 35.4‰ in surface waters, 35.3 ‰ at 150 m depth slowly decreasing to 34.6 ‰ at 500 m.

3.1.3. Oxygen

The dissolved oxygen profiles showed more dramatic changes with depth than did temperature and salinity. The individual station profiles (Appendix III) show in general a decrease from 5ml/l in surface waters to about 3 ml at 150 m. Between 150 and 200 m there was a strong oxycline with a 2 ml/l drop in the concentration of dissolved oxygen (DO) to around 1 ml/l at 200 m. An oxygen minimum of 0.3 - 0.5ml/l DO was evident at around 300 m from 24 to 25 August. This tongue of low oxygen water could be advected by the polar undercurrent from the north (Angolan dome). Beneath this layer, oxygen levels increased with depth to 4 ml/l at 900 m (Station 694). The depth of the oxycline moved higher in the water column from 26 to 27 August with active upwelling (of water above the oxycline) as seen from the temperature profiles. At the final station on 27 August the base of the oxycline was at 140 m (1.2 ml/l DO) compared with 2.8 ml/l DO at this depth in the beginning of the series.

3.1.4. ADCP data

The ADCP data will be analysed in Bergen at a later stage.

3.2. DIEL CYCLE EXPERIMENT ONE

Table xx. *Species compositions from all hauls during diel sycle 1*

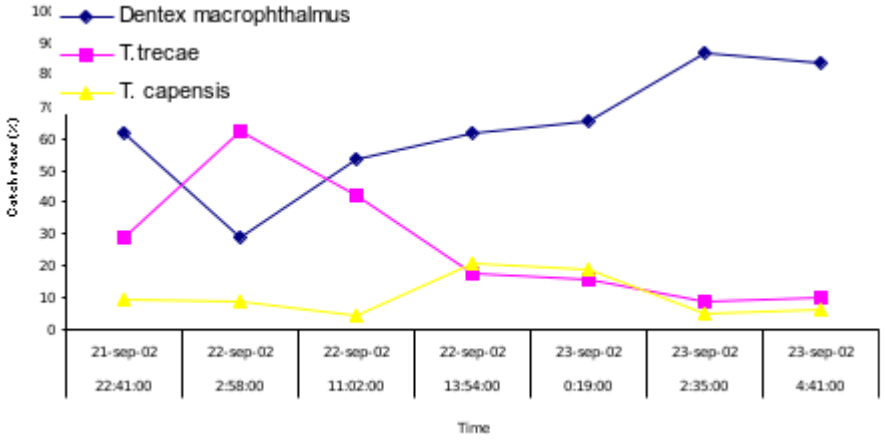

Figure xx. *Catch rates of horse mackerel (T. trecae, T. t. capensis) and Dentex macrophthalmus during diel sycle 1*

Figure 4. Composites of the acoustic recordings during the three 24 hour periods of the diel experiment.

3.2.1. Size distribution of the sampled horse mackerel

The horse samples mackerel was juveniles, ranging from 14 to 23 cm total length. Two cohorts were present, one with a modal peak around 16 cm and one peaking around 18 cm total length. Multisampler trawls indicates that the cohorts of horse mackerel were separated and have different trends in the migration patterns. (Figure 6). The graph shows the percentage length frequency of horse mackerel trawled on with the multinet. The cohorts are separated at night a) 24/08/2001 at 2:51 am. Some separation is evident in the morning b) 26/08/2001 at 8:04 am, more mixed in the afternoon before they ascend to the surface c) 24/08/2001 at 3:53pm. and d) clearly separated again when the vertical migration to the surface starts 26/08/2001 at 06.47 pm. All times are GMT.

Figure 6. Graph showing percentage length frequency of horse mackerel trawled on with the multinet at a) 24/08/2001 at 2:51 am, b) 24/08/2001 at3:53pm, c) 26/08/2001 at 8:04am and d) 26/08/2001 at 06.47pm. The different lines corresponds to the depths were the multinet trawl were opened.

Figure Total catch / hour of all species during the diel sycle

Figure Catch rates of horse mackerel during the diel cycle. Note different scale on y-axes

3.3. DIEL SYCLE 2

3.3.1. Cross shelf distribution

Figure 5. *Typical echogram showing the day a) and night b) situation during the experiments. The different identified layers are shown in the echograms*

3.3.2. 48 h diel station

3.3.3. Predator prey relationships

3.4. FEEDING

A total of XX stomach samples were sampled from *T. t. capensis* and *T trecae*. All data on feeding will be analysed on shore.

Fig Stomack fullness of horse mackerel during diel cycle 1 and 2. Data show mean and 95 % confidence interval a) for all

trawls.

3.5. MULTINET PLANKTON SAMPLER

A total of 23 multinet stations were conducted. On each of these station 5 samples were collected on different depths. Details of the hauls can be found in Annex XX. All plankton samples will be analysed on shore.

3.6. MULTIFREQUENCY ACOUSTIC ANALYSIS

The s_V ratios for the different a scattering layer of Horse mackerel euphausiids and shrimps were analysed. The result is preliminary and the calibration constants from after the survey has not been applied. The ADCP was running throughout the survey and has among others created noise for the acoustic collection, especially at 120 and 200 kHz. To compare backscattering values at different frequencies resolvable pulse volumes must also be comparable. The resolving distance ($c\tau/2$), and hence resolvable volume, depends on the pulse length, which therefore ideally should be identical on all frequencies. However, the EK 500 only facilitates relative standard settings (Short/ Medium/ Wide) which differ between frequencies. Vertical bins must therefore averaged to obtain comparable resolvable pulse volumes between frequencies. This will be done after the data has been cleaned. The results here are therefore meant only as an example. It is also important that the data sampled contains backscattering from one species only.

The s_V ratios obtained are shown in figure xx. The results show a clear overlap between the different targets at all three frequencies and it is evident at they can not be separated with multifrequency at this stage. However this pattern may change when calibrated and noise filtered outputs are applied.

Figure xx s_V ratios for horse mackerel (red line), euphausiids (yellow line) and shrimp (blue line) at 18 /120 (a), 18/38 (b)and 38/120 (c) kHz