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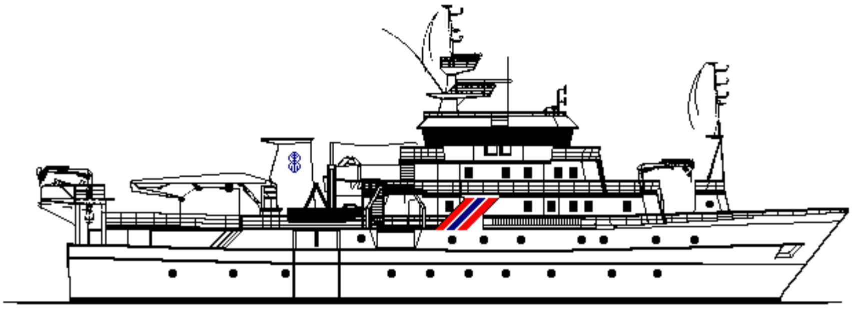
CRUISE REPORTS "DR. FRIDTJOF NANSEN"



BENEFIT SURVEYS

Cruise Report No 10/99

Part1: Jellyfish acoustic properties, distribution and abundance

31 August - 6 September 1999

Part2: Application of multiple frequency acoustics for improvement of *in situ* target identification

6 - 17 September 1999

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Bergen
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BENEFIT SURVEYS

Cruise Report No 10/99

Part 1: Jellyfish acoustic properties, distribution and abundance

31 August - 6 September 1999

by

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Institute of Marine Research
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CHAPTER 1 INTRODUCTION

1.1 BACKGROUND

The jellyfish species *Chrysaora hysoscella* (class Scyphozoa, colloquially known as “reds”) and *Aequorea aequorea* (class Hydrozoa, “mags”) occur in great abundance in Namibian waters. There is some evidence to suggest that prior to the 1970s this was not the case (eg Hart and Currie 1960, Stander and de Decker 1969), and it is possible therefore that these jellyfish have become established as a major component of the Bengualan ecosystem over only a relatively short period of time (Fearon et al. 1992). Rapid increases in jellyfish abundance (blooms) have been reported in recent years from numerous marine ecosystems worldwide (e.g. Mills 1995). Although the diets of *C. hysoscella* and A. *aequorea* are not well described, related species are known to prey upon fish eggs and larvae (e.g. Purcell 1989). The increase of jellyfish abundance off Namibia appears to have coincided with a period of decline of commercial fish catches there (pilchard and anchovy - Shannon et al. 1992), and it has been suggested that these phenomena are in fact directly linked. In the Black Sea introduction of the jellyfish *Mnemiopsis leidyi* has been implicated in the crash of fish stocks there (Travis 1993). In addition to their potential predatory impact on fish, jellyfish also hamper fishing activities off Namibia by clogging and subsequently bursting trawl nets. Jellyfish also cause problems to the diamond extraction industry by blocking suction devices used to dredge marine alluvial sediments.

Despite potential ecological and economic importance of jellyfish in Namibian waters, little of their biology or population dynamics is known (Gibbons et al. 1992). Some information on the distribution and abundance of reds and mags is available from Bongo net surveys (Pagès 1991, Fearon et al. 1992), but these nets are small (50 cm mouth opening) and are unlikely to provide unbiased data, partiularly for adult C. *hysoscella* that may attain umbrella diameters exceeding 50 cm. Acoustic survey techniques are used commonly for studies of distribution and abundance of fish and zooplankton, and may be useful for studies on jellyfish (Mutlu 1996, Monger et al. 1998) as well. Knowledge of mesoscale distribution and abundance variation, which acoustic surveys may be able to provide, would be of great value to a number of parties operating in Namibian waters.

Acoustic abundance estimation requires knowledge of the acoustical backscattering properties of the ensonified targets in order to identify observed scatters as a given species. Due to the limited information that can be obtained from the target in conventional single frequency echosounders, some *a priori* knowledge of the acoustical appearence of the target species at the given frequency is prerequisite, even though frequent trawl samples confirming the allocation of acoustical density to given species are necessary in any case.

Unless all ensonified targets can be resolved as single echo targets by the echosounder, which is hardly ever the case, knowledge of the dorsal aspect target strength (TS) is required in order to convert the acoustical densities of the targets into an absolute measure of biomass. Target strength is thus an essential parameter in acoustic abundance estimation. Very little work has been conducted on jellyfish regarding either acoustical target identification or measurements of dorsal aspect target strength.

For fish, assuming that the target strength increases proportionally to body length, the target strength at a given frequency can be expressed as a a function of mean total length. For jellyfish, a similar procedure can be followed, relating target strength to the diameter of the umbrella or to wet weight (Mutlu 1996, Monger et al. 1998). This has been carried out in experimental settings at 120 and 200 kHz for the common jellyfish *Aurelia aurita* (Mutlu 1996) and at 200, 420 and 1000 kHz for the gelatinuos zooplankters *Aequora victoria* and *Pleurobrachia bachei* (Monger et al. 1998). To the best of our knowledge, however, no measurements have been reported at 38 kHz, a frequency commonly used in fish abundance estimation surveys, nor have any *in situ* measurements, at any given frequency, been published.

The high abundances of A. *aequora* and C. *hysoscella* along the Namibian coast provide excellent opportunities for studying these animals, as well as a strong motivation for elaborating their acoustic characteristics.

1.2 OBJECTIVES OF THE SURVEY

The overall goal of the cruise was to determine whether acoustic survey techniques are applicable for mapping distribution and abundance of jellyfish in Namibian waters. In order to achieve this, the following objectives were identified:

To carry out repeated acoustic measurements of aggregations of jellyfish at 18, 38 and 120 kHz to elaborate potential acoustical characteristics of A. *aequora* and C. *hysoscella* for target identification purposes (cf. Brierley et al. 1998). Identification of the recorded species was to be conducted using standard pelagic sampling trawl. In order to achieve a high degree of compatability between the acoustic observations and the fish samples, frequent hauls of short duration each were to be executed.

To measure the acoustic target strength of A. *aequora* and C. *hysoscella* at 18, 38 and 120 kHz *in situ* using hull mounted split-beam transducer in combination with SIMRAD EK 500 echosounder.

To conduct an on/off shelf mesoscale survey of jellyfish distribution, using information from 1 and 2 to guide acoustic identification of common jellyfish species

1.3 PARTICIPATION

The scientific staff consisted of:

From Namibia:
Helen BOYER, Michael EVENSON, Antoinette HEITA and Gerhard OECHSLIN

From South Africa:
Emmanuelle BUECHER and Conrad SPARKS

From United Kingdom:
Andrew BRIERLEY

From Norway:
Bjørn Erik AXELSEN (Cruise leader), Tore MØRK and Roar SKEIDE.

1.4 NARRATIVE

Previous observations suggested that mags and reds are co-occurring north of 22°00’S, and after departure from Walvis Bay 31 August at 10h00, course was set north-west. Reds are generally considered to be an inshore species, and mags are associated with warmer waters. Warmer waters are to be expected to the north, and also further offshore because upwelling diminishes with distance offshore. The shelf also narrows to the north of Walvis Bay, and thus less time would be needed to traverse the shelf. Once out at the 100 m depth contour the ship turned north until 18h30, by which time it was dark and the *Multisampler* was assembled (although with only 2 nets). The first samples were taken at 22°02’S 13°27’E. All net hauls taken at this location contained a mixture of reds and mags (Site 1).

In an attempt to sample single species aggregations the ship next proceeded northwards to shallower waters (50 m) at 21°30’S. The first haul was conducted at the surface. There were, however, too much fish and too little jelliyfish in the catch for this location to be suitable for our purposes, and we therefore returned to 21°28’S 13°38’E, where we had passed a marked scattering layers at 80 m depth. The first catch comprised entirely of reds, and a 24 hour day-night station (onshore) was conducted in this area (Site 2).

An offshore area dominated by mags was sought next. The first attempt was made at 350 m depth, at 21°26'S 12°41'E, but resulted in no catch from the surface, nor from a layer at 70 m depth, and only myctophiid fish were caught from a layer at 300 m depth. The ship then headed north-east, but no apparent change in species composition or distribution could be observed acoustically. No mags were cought in the samples along this course. The ship therefore returned to the latitude of Site 1 (22°02'S 13°27'E), where there was a mixture of reds and mags in the sample in the morning the 4 September, but further wete, to about 225 m bottom depth. The first catch, at 22°00'S 13°08'E, was a substantial one consisting of mags only. A 24 hour day-night station (offshore) was conducted in this area (Site 3).

The final activity was an onshore-offshore transect along 22°00'S in order to elucidate the daytime spatial distribution of jellyfish across the shelf. The "Dr. Fridtjof Nansen" docked in Walvis Bay 6 September at 07h00.

CHAPTER 2 METHODS

2.1 HYDROGRAPHY AND WEATHER DATA

CTD- casts were carried out once on each study site. For the 24-hour diel cycle stations, ADCP (Acoustic Doppler Current Profiler) measurements were carried out as well. ADCP readings reveal depth stratified information about current speed and direction, also vertically. All relevant meteorological information such as air and surface temperature, wind speed and direction and solar intensity was logged continously from the ANDREAA weather station.

2.2 TRAWL SAMPLING

Especially designed sampling trawls with 2000 kg Thyborøen trawl doors were used in all hauls. The trawl doors were chackelled for pelagic trawling, also during demersal trawling. Detailed illustrations of all pelagic and demersal sampling trawls, including the *Multisampler* system, are illustrated in **Annex I**. For each trawl station, catch size and species composition was determined and punched onto NANSIS-database following standard procedure. For the jellyfish, umbrella diameter, gonad diameter, oral arm length and total wet weight were measured and punched onto EXCEL spreadsheets. For C. *hysoscella*, the occurrence of parasites were denoted as well. Some stations had to be disregarded due to tearing of the trawl extension, and in one case the codend.

2.2.1 Multisampler

The Multisampler (see Skeide et al. 1997) was assembled and tested on the deck, and rigged on the mid-sized pelagic trawl (15 m vertical opening) during transit northwards from Walvis Bay. For the first deploymnet only 2 codends were attached, and the third was sewn onto the crossbars later the following day.

The *Multisampler* performed well during the cruise, with the exception of some early deployment problems caused by a faulty seawater sensor. This sensor normally disconnects the batteries when the net is out of water, preventing the batteries from discharging on deck between trawling events. To overcome this fault a blind-plug was used to keep the batteries connected, but this initially proved unreliable as it temporarily disconnected during deployment preventing the net from closing. It was then attempted to carefully sand down the connector pins on the sensor, which eliminated the problem. There were, however, also some problems with the motor in the release unit, caused by water leaking into the interior of the motor. This could not be repaired with the tools available on the ship, but the problem was overcome as long as the oil was replaced between each deployment.

A split in each of the codend-panels, sewn lightly together with thin thread, allowed for "controlled" bursts in case of the catch becoming too big. Similarily, a split was cut in the top panel of the extension in front of the *Multisampler* to reduce damage during tearing. Despite precautions taken, the mid-sized multisampler trawl (15 m vertical opening) was torn from time to time due to high concentrations of jellyfish. Tearing occurred when executed close to the surface. The larger sampling trawl (30 m opening) without *Multisampler* was rougher in use, and was only torn at one occasion, and then only in the codend.

2.2.2 Trawl sample volume

In order to calculate the overall sample volume of a trawl, certain assumptions must to be made. Jellyfish will not actively avoid the net, and will therefore primarily be caught were the meshes are large enough to stop them, e.g. no herding effect. From the extension and backwards, the meshes are 40 cm (stretched) for all sampling trawls, and in front of this they are 1620 mm and larger (**Annex I**). Assuming for now that the sampling trawl only catches jellyfish effectively from the 40 cm panels and backwards, the volume sampled by the trawl V can be considered as cylinder, where the diameter is half the opening of the trawl in this section O (m) and the height is towed distance td (m), hence (1):

$$V = \pi(O/2)^2 \text{ td} \qquad (\text{m}^3) \qquad (1)$$

To estimate the opening of the trawl in the sampling section, a Scanmar height sensor was mounted on the top panel during two experimental hauls. An 8" float was attached to the bottom panel to ensure that the sensor detected the correct distance. The opening was measured to 12 m (11.7 and 11.8 m, int two separate trials) (**figure 1**). Using the known vertical opening of the trawl (from headline to footrope, 30 m), the sample depth interval (19 to 31 m from the surface) was calculated as well. If n is number of individuals in the sample and V is the volume sampled by the trawl (m^3), the volume density, or number of individuals per unit sampled volume, ρ_V (n/m^{-3}) corresponds to (2):

$$\rho_V = n/V \qquad (\text{n}\cdot\text{m}^{-3}) \qquad (2)$$

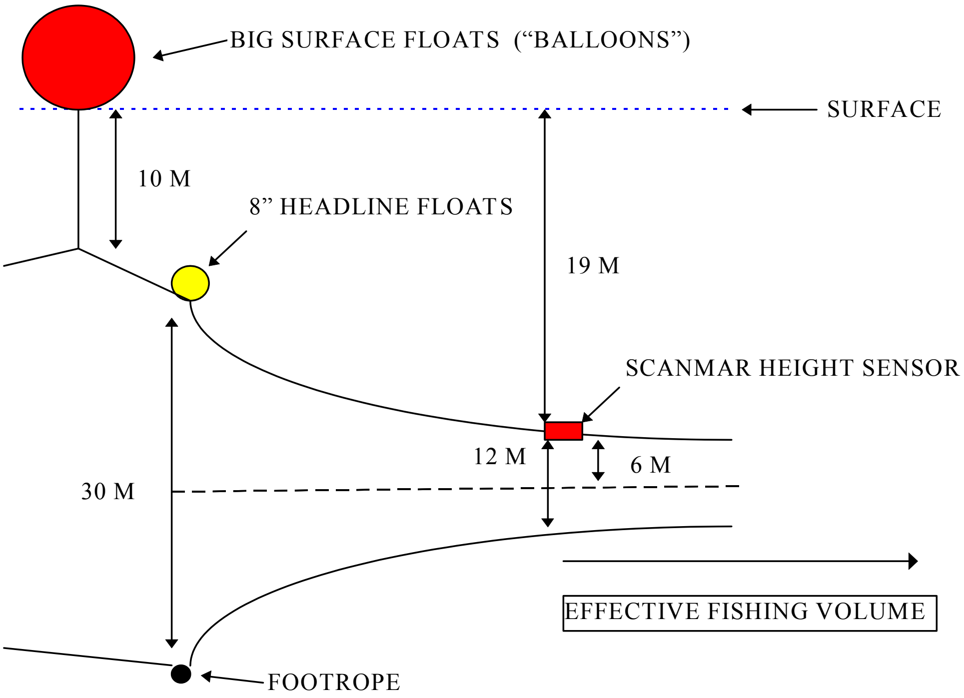


Figure 1 Illustration of the sampling trawl rigged with "balloons".

2.3 ACOUSTIC OBSERVATIONS

A Simrad EK500 echosounder was operated continuously at frequencies 18, 38 and 120 kHz throughout the cruise. Calibrations of all three frequncies were carried out on the second part of the cruise, and the recorded data will have to be corrected accordingly. However, the draft in all three transducers were fairly low (see this report, part 2), and the new settings will not incur major changes in the data. Raw data from all frequencies were logged in parallel to the Bergen Echo Integrator (BEI) and to SonarData Echolog_EK. EK500 transciever menu settings are given in **Annex II**. A Hewlett Packard Deskjet printer was set to print all frequencies simulataneously, with colour S_V minimum set to -90 dB. Another printer recorded an expansion of the 38 kHz echogram in periods of particular interest (the 24 hour stations). Recordings from the different 24 hour stations were scrutinised, using both software systems and the trawl data.

2.4 TARGET STRENGTH MEASUREMENTS

Unless all ensonified targets can be resolved as single echo targets by the echosounder, which is hardly ever the case, knowledge of the dorsal aspect target strength (TS) is required in order to convert the acoustical densities of the targets into numbers of individuals and hence into an absolute measure of biomass. Two approaches were attempted in order to elucidate jellyfish target strength, specifically direct measurements from the hull mounted transducers (*in situ* method) and backcalculation from integrator values to sigma considering sample volume and density (comparison method).

2.4.1 *In situ method*

Making use of the single target detection algorithm in the EK500, TS recordings of single targets were offloaded from the serial port to an IBM compatible computer. The single target detection algorithm has its clearly identified limitations (Soule et al. 1995), but tracking single targets (Ona and Hansen 1991) using the split beam technology, multiple targets interpreted as single echo targets by the EK 500 can be expelled from the recorded material. By tracking individual targets one will also reduce the likeliness off some individuals contributing more to the estimated mean than others, obtain a measure of within and between ping variation, and reveal rough information about the tilt angle of the fish between consecutive pings.

For fish, assuming that the target strength increases proportionally to body length, the target strength at a given frequency can be expressed as a a function of mean total length (L) in the logarithmic domain using equation (3):

$$TS = x \log L + y \quad (\mathrm{dB}) \tag{3}$$

where x and y are linear regression coefficients. If the average acoustic backsacattering crossection, σ (m), of the ensonified population is known, recorded area backscattering coefficient, S_A (m^2/nm^2) can be converted to number of fish per unit squared nautical mile, ρ_A using (4):

$$\rho_A = S_A/\sigma \tag{4}$$

Split beam echosounders, like the Simrad EK500 38 kHz system used in this investigation, combine the signals from four quadrants of the transducer (with individual signal detection and time varied gain amplification) in pairwise fashion by simple summing, forming four half beams. Selecting the larger of the arithmetical means of target strengths computed for each pair of adjacent samples, the target strength detection algorithms then compute the target strength in the range -50 dB to -20 dB with 0.375 dB resolutiuon in several steps (described in Foote et al., 1986). In order to calculate mean average backscattering crossection, the observations must be converted from the logarithmic domain (dB) to the intensity domain. This can be achieved assuming (5) (Love 1971):

$$TS = 10 \log(\sigma/4\pi) \qquad (\mathrm{dB}) \tag{5}$$

At 38 kHz, σ has been shown to be proportional to the squared total length of the fish for many comercially important species. For faciliation of direct comparison between different regressions series, equation (1) can thus be modified to a one-coefficient form, keeping x=20 (Love 1977), giving equation (6):

$$TS = 20 \log L + b_{20} \quad (dB) \tag{6}$$

Mean TS can then be calculated from mean σ using (3), and by inserting mean total length from the fish sample, b_{20} can be calculated by rearranging (4) with respect to b_{20}. The relation between umbrella diameter and target strength for jellyfish may, however, not follow a 20 logL dependence usually observed in fish (Mutlu 1996). Ideally therefore, discrete measurements of different sized populations should be carried out in order to estabish a valid regression between umbrella diameter and target strength.

Jellyfish, being zooplankters, can be assumed to have a "behaviour" independent of the presence of the ship. Obtaining reliable TS-measurements may therefore be done using hull-mounted transducers at short range. However, encountering loosely aggregated targets in distinct mono-species layers in adequate density is needed to ensure reliable conditions for *in situ* measurements of target strength. Representative samples of the jellyfish are also prerequisite.

2.4.2 *Comparison method*

The comparison method (Misund and Beltestad 1996, Misund et al. 1997) is based on backcalulating average acoustic bacscattering crossection σ (m^2) from recorded area backscattering coefficient S_A and area density using (4) rearranged as (7):

$$\sigma = S_A/\rho_A \tag{7}$$

This type of calculations have previously been carried out on schools of herring, mackerel and horse mackerel by repeated integration of the schools, mapping of their overall geometry using multibeam sonar, and capture of the entire school using purse seiner (Misund and Beltestad 1996, Misund et al. 1997).

Similarily for mono-species layers of jellyfish, one could consider the volume sampled by the trawl, and the total number of individuals in the sample. Average umbrella diameter could then be related to target strength using (5).

To convert sample volume density ρ_V (n/m^3) (see chapter 2.2.2) to area density ρ_A (n/nm^2), the total number of individuals must be related to the surveyed area in nm^2. The trawl sample volume can be considered a cylinder, according to (1). Assuming that the recorded acoustic density in the depth range of the trawl sample is representative for the density in the volume sampled by the trawl, the area density can be considered as (8):

$$\rho_A = n/1852^2 \cdot td \cdot (\pi(O/2)^2)^{-2} \quad (n/nm^2) \qquad (8)$$

where n is number of fish and td is towed distance (m).

2.5 VISUAL OBSERVATIONS

The distribution patterns of reds and mags are at present not fully understood. Determining their spatial distribution is difficult due to the lack of catch records. Surface observations, although crude, does provide some information on their occurrence.

Visual observations were carried out from the bow of the “Dr. Fridtjof Nansen” by two observers. Most of the observations were made while the ship was steaming at a speed of 9 knots. Observations were also made during trawling. All observations were made at ten minute intervals every hour. An attempt was made to observe jellyfish during the night on 1 September. This was unsuccessful as the area observed differed form that during the day and it was considered too dangerous (due to rough weather and poor visibility), and all subsequent observations were therefore made in daytime.

CHAPTER 3 RESULTS

3.1 WEATHER CONDITIONS

Weather conditions were good and stable with moderate wind, ranging from 0 to 25 m/s (**figure 2**). It was generally cloudy, but no rain throughout the cruise. The Solar intensity levels measured on top of the wheelhouse are given in **figure 3**. The temperature at the sea surface (**figure 4**) and in the air ranged from 12.4 to 16.0°C and from 9.8 to 14.6°C, respectively.

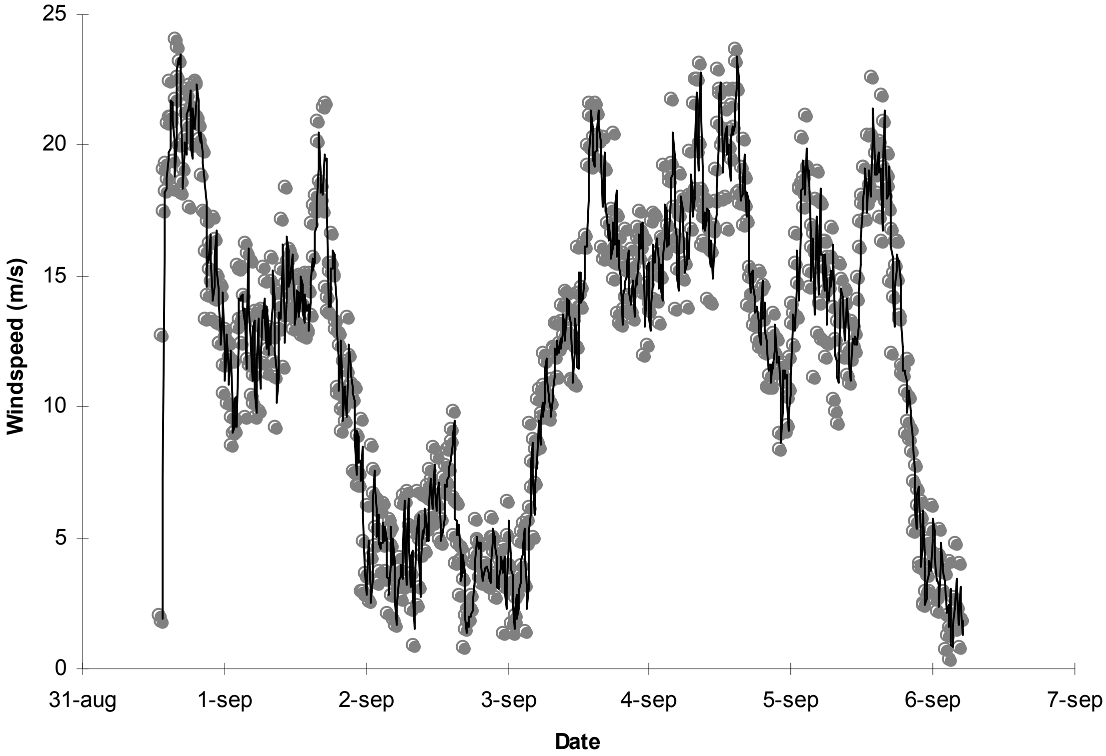


Figure 2 Wind speed recorded every 10 min with the Andreaa weather station throughout the cruise (−: moving average).

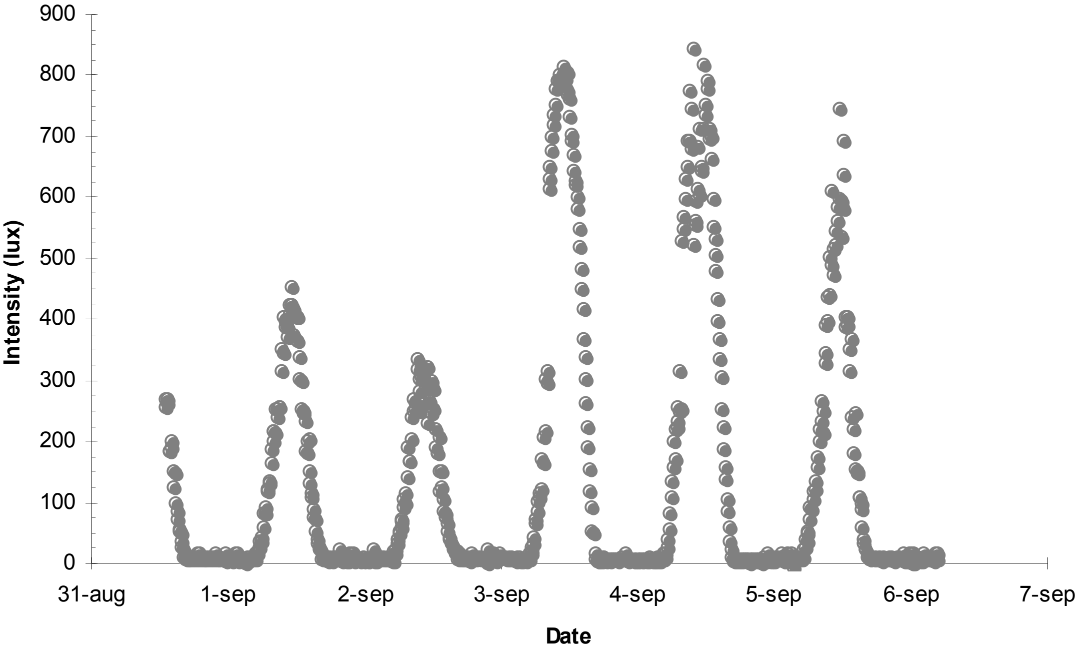


Figure 3 Surface solar intensity (lux) recorded every 10 min with the Andreaa weather station throughout the cruise.

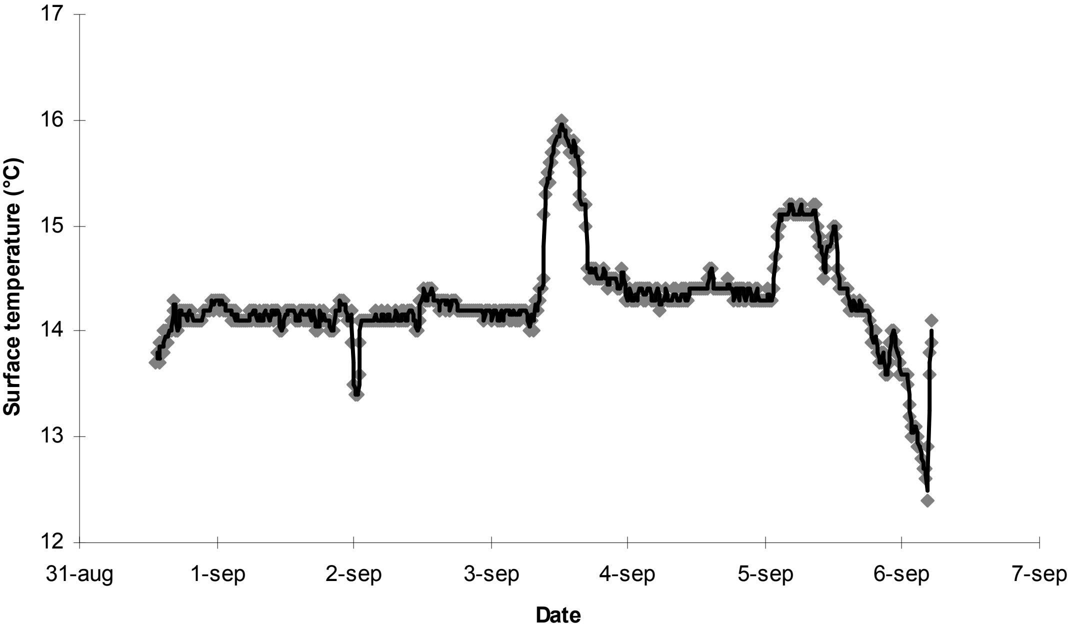
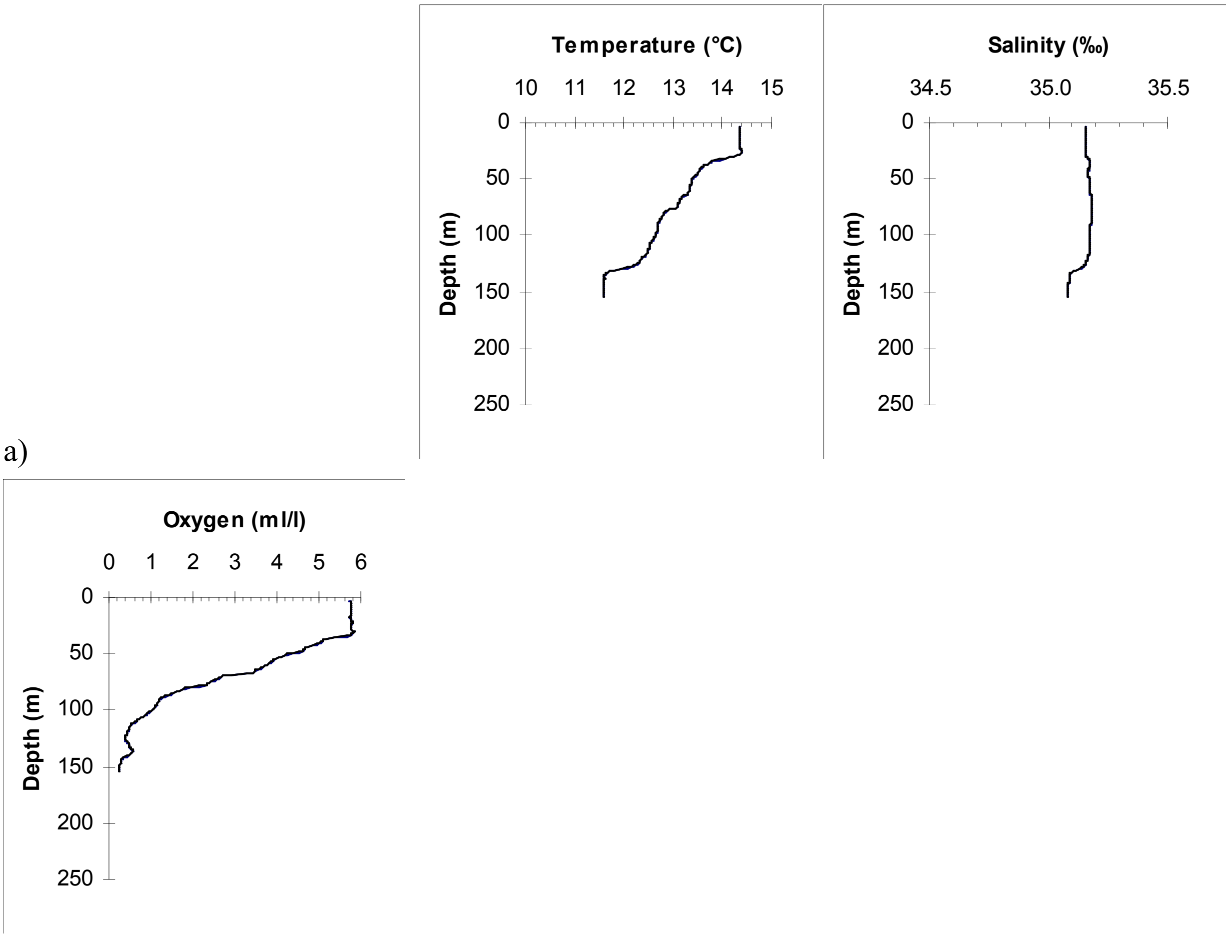


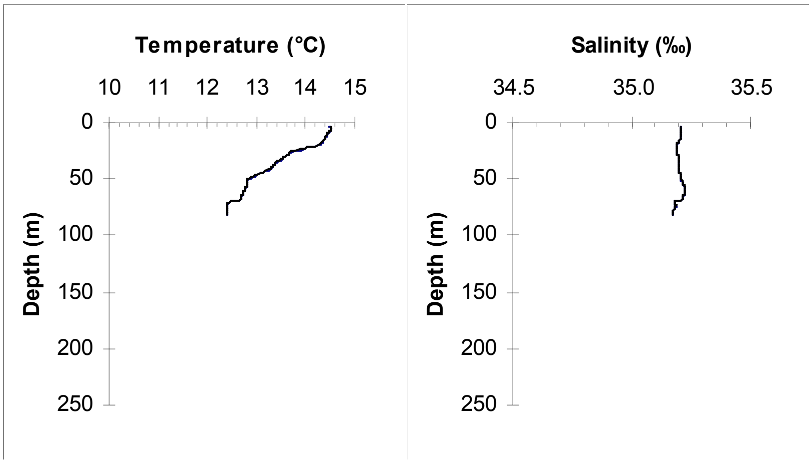
Figure 4 Surface temperature (°C) recorded every 10 min with the Andreaa weather station throughout the cruise (−: moving average).

3.2 HYDROGRAPHY

Hydrographical profiles for the three main study sites are given in **Figure 5**.



a)



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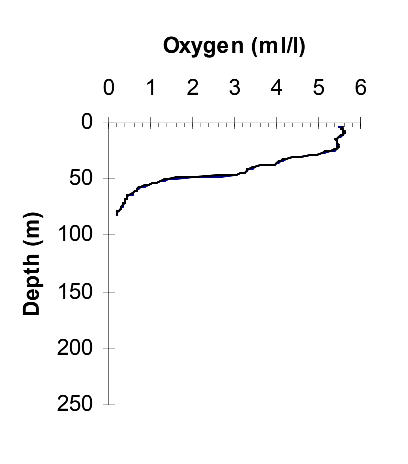

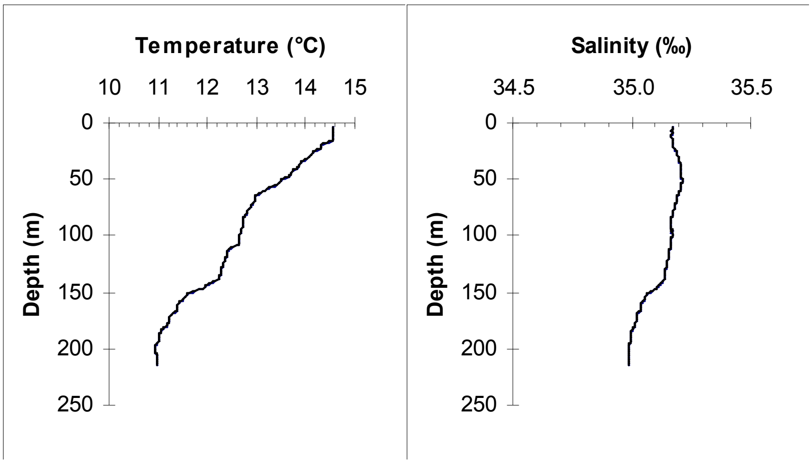

c)

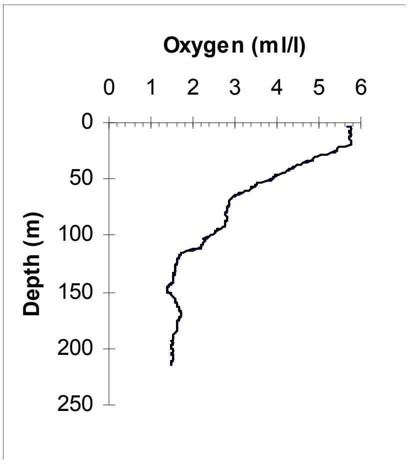

Figure 5 CTD profiles at a): study site 1; b): study site 2; and c): study site 3.

3.3 BIOLOGICAL DATA

A total of 2488 Mags and of 869 Reds from the trawl samples were analysed. The relationship between total weight and umbrella diameter were determined for both reds and mags. **Figure 6** showes the relationship between umbrella diameter and total weight, gonad diameter and oral arm length, respectively, for Reds on station 359. (For both species, the weight increased exponentially with the size of the umbrella. From the additional measurements, we noticed that for *Chrysaora*, the relationship between the size of the gonads and the size of the umbrella was linear. On the desk, the oral arms were generally broken. We suppose that this fragile part of the medusae broke during the trawl, especially when clogging occurred. Consequently, the relationship between the oral arms and the diameter was not so good. The table summarises the mean sizes and weights of the Mags and the Reds.

3.4 VERTICAL DISTRIBUTION

During the cruise a total of 66 trawls were performed, 39 with the big pelagic trawl and 9 with the medium sized trawl with the *Multisampler* (with 3 nets each time, corresponding to a total of 27 trawls). The majority of catches were dominated by jellyfish. Apart from the empty trawls, only one catch (station 395) did not contain jellyfish. On most occasions the greatest concentrations of jellyfish were found at the surface (10-25 m from the surface). The maximum number of Mags collected was 1 314 kg/min at 10 m (station 388). The maximum number of Reds was 689.96 kg/min at 15 m (station 359). Visual observations suggested that at night there was a general migration (particularly by reds) to the very near surface zone. However, jellyfish were not always confined to the surface: on one occasion the multisampler revealed large numbers of mags at 150 m (151.74 kg/min, station 395) but failed to catch many individuals on the same deployment at 100 (130.78 kg/min, station 396) and 50 m depths (0.95 kg/min, station 397). Later catches with the same net at the same site suggested that mags too exhibit some vertical migration.

3.5 ABUNDANCE

A summary of date/time, depth and jellyfish catch rates for all stations is given in **table 1**. A complete record of trawl data and catch rates for all species is given in **Annex III**. The trawl samples showed that jellyfish were patchily distributed and in some areas extremely abundant (**figure 7**). Dense aggregations of jellyfish in the opening of the trawl may however have reduced the water flow through the trawl opening (“clogging”, “bucket effect”), which to some degree may have have biased the catch rates. Despite potential sample-bias, the trawl samples

Figure 6 Relationships between umbrella diameter (cm) and A): total wet weight (kg), B): gonad diameter (cm), and C): Oral arm length (cm) for C. *hysoascella* at ststion 359.

Table 1 Catch data for jellyfish for all trawl stations. Grey indicates night-time samples.

Station	Date	Time Start	Time Stop	Depth (m)	Bottom (m)	Total (kg/min)	Reds (kg/min)	Mags (kg/min)
356	31-aug	18:08:07	18:33:28	112	158	3.0	2.2	0.8
357	31-aug	20:28:55	20:45:24	10	161	5.7	4.8	0.9
358	1-sep	05:35:00	05:48:00	10	164	171.8	144.7	26.5
359	1-sep	11:54:48	11:59:52	15	160	766.0	679.0	86.9
360	1-sep	13:00:12	13:08:22	20	160	59.0	53.8	5.2
361	1-sep	13:14:37	13:19:33	90	159	1.4	1.0	0.4
362	1-sep	13:30:05	13:35:37	126	158	2.2	2.0	0.2
363	1-sep	19:14:01	19:21:47	10	161	499.4	417.1	81.9
364	2-sep	00:04:31	00:09:33	10	50	9.9	6.3	0.0
365	2-sep	01:32:06	01:37:08	10	84	26.5	26.5	0.0
366	2-sep	02:41:04	02:46:01	10	85	41.8	41.8	0.0
367	2-sep	03:56:50	04:00:31	10	85	5.2	5.2	0.0
368	2-sep	05:22:11	05:27:48	10	88	19.1	19.1	0.0
369	2-sep	06:24:42	06:30:06	40	89	372.4	353.3	19.1
370	2-sep	09:40:20	09:47:58	50	94	215.3	215.3	0.0
371	2-sep	12:34:00	12:39:01	10	85	94.3	94.1	0.1
372	2-sep	13:45:46	13:49:57	58	84	0.0	0.0	0.0
373	2-sep	13:54:47	13:59:54	38	85	0.0	0.0	0.0
374	2-sep	14:06:52	14:12:11	17	85	1.8	1.8	0.0
375	2-sep	15:45:37	15:51:06	10	84	59.3	59.0	0.3
376	2-sep	17:18:40	17:20:18	10	85	399.7	399.1	0.5
377	2-sep	18:49:23	18:56:18	10	88	100.5	100.2	0.2
378	2-sep	20:10:39	20:15:53	60	88	1.0	1.0	0.0
379	2-sep	20:22:37	20:27:53	30	88	14.1	14.1	0.0
380	2-sep	20:33:01	20:38:05	16	88	6.5	6.5	0.0
381	2-sep	22:50:00	22:55:00	10	87	333.4	333.1	0.0
382	3-sep	00:28:05	00:33:00	10	84	89.1	88.0	0.2
383	3-sep	10:52:47	10:57:13	10	358	0.0	0.0	0.0
384	3-sep	11:45:58	11:50:45	65	382	0.0	0.0	0.0
385	3-sep	12:41:02	12:56:09	270	395	17.4	0.6	0.0
386	3-sep	15:55:57	16:00:50	10	298	0.5	0.5	0.1
387	3-sep	17:30:02	17:36:03	10	195	79.4	72.4	3.1
388	4-sep	00:06:16	00:10:51	10	225	1314.1	8.9	1305.2

389	4-sep	01:42:56	01:47:47	10	278	8.0	1.2	6.7
390	4-sep	03:10:28	03:15:06	10	256	18.6	8.0	4.3
391	4-sep	04:40:11	04:45:00	10	224	97.0	11.9	85.1
392	4-sep	06:02:39	06:08:08	10	224	61.2	12.8	48.4
393	4-sep	07:31:37	07:36:40	10	221	26.6	4.2	22.4
394	4-sep	09:03:27	09:09:49	10	226	35.9	1.2	34.0
395	4-sep	10:42:43	10:47:54	150	224	162.3	10.5	151.7
396	4-sep	10:56:02	11:02:17	100	224	130.8	0.0	130.8
397	4-sep	11:10:01	11:15:23	50	226	0.9	0.0	0.9
398	4-sep	12:32:00	12:37:00	10	227	190.8	15.6	175.2
399	4-sep	13:46:00	13:51:00	150	227	3.4	2.1	1.3
400	4-sep	13:59:00	14:04:00	100	225	67.9	0.0	67.9
401	4-sep	14:12:00	14:17:00	50	224	3.4	0.0	3.4
402	4-sep	15:21:06	15:26:01	10	226	1125.9	39.9	1086.0
403	4-sep	16:45:33	16:51:11	150	226	41.9	6.3	35.5
404	4-sep	16:58:13	17:02:55	100	227	66.5	3.3	63.2
405	4-sep	17:13:19	17:18:34	50	226	13.9	0.6	13.3
406	4-sep	18:37:46	18:41:48	10	228	1120.0	49.7	1070.2
407	4-sep	20:16:56	20:23:55	180	232	6.6	4.5	1.2
408	4-sep	20:35:08	20:39:34	100	235	35.8	1.2	34.7
409	4-sep	20:49:27	20:54:50	50	233	4.7	0.8	3.9
410	4-sep	22:05:57	22:13:13	10	227	1089.2	61.7	1027.5
411	4-sep	23:37:30	23:42:36	150	225	50.8	2.4	47.8
412	4-sep	23:50:35	23:55:36	100	226	61.8	0.4	61.4
413	5-sep	00:04:49	00:09:49	50	227	169.4	1.8	167.0
414	5-sep	03:38:14	03:43:23	380	418	0.0	0.0	0.0
415	5-sep	03:51:22	03:57:27	300	422	0.0	0.0	0.0
416	5-sep	04:07:32	04:14:04	200	429	0.0	0.0	0.0
417	5-sep	07:35:33	07:42:06	10	400	0.0	0.0	0.0
418	5-sep	11:48:57	11:54:22	10	292	5.9	2.9	3.0
419	5-sep	13:14:51	13:19:42	10	227	546.0	7.5	538.4
420	5-sep	15:10:51	15:16:01	10	173	747.7	467.3	280.4
421	5-sep	16:42:40	16:47:36	10	144	430.4	257.4	173.0

figure 7

are assumed to be a valid index of jellyfish abundance. The trawl sampling also revealed that even though the distribution of both common jellyfish species was extremely patchy, reds nevertheless were dominant inshore, whereas mags were more common in the deeper waters off shore.

It was not possible to identify the jellyfish acoustically during surveying at any of the applied frequencies. Echoes omitted from jellyfish within the observed dense plankton layers may have been covered by plankton echoes, but even where the trawl samples indicated extremely high densities above the scattering plankton layer, the recorded S_A values were low. Reds and mags being extremely weak sound scatterers was also supported by measurements indicating that both species had densities indistinguishable from water (~1.0) (see also Mutlu 1996).

Post-processing of calibrated acoustic data in conjunction with systematic scrutinisation information on trawl depth and wire length enabled, however, more representative Sa values to be extracted from the recorded data for each net haul. Considering only those hauls where the catch comprised > 95% by wet mass of C. *hysoscella*, a statistically significant ($p < 0.01$) linear relationship between volume corrected catch (numbers) and Sa at 38 kHz was derived (**figure 8**).

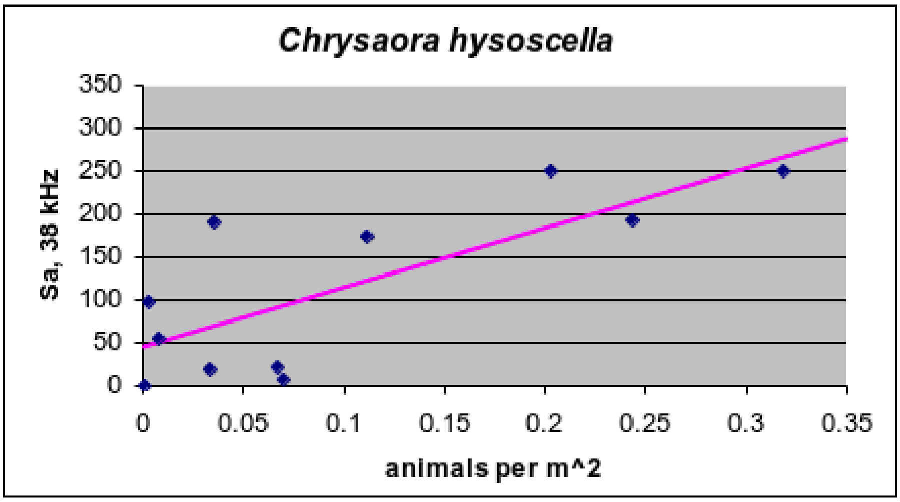

Figure 8 Relationship between Sa and numerical abundance of C. *hysoscella* at 38 kHz.

No significant relationship between S_A and sample density was detected at 18 or 120 kHz. It is probable that backscatter detected at 120 kHz was caused predominantly by small zooplankton that were not retained by the relatively large meshes of the pelagic trawls we used.

3.6 TARGET STRENGTH

Target strength measurements were carried out *in situ* on mono-species aggregations of reds on all frequencies. The ship was drifting freely during the course of the experiments and the ping rate was maximised in order to obtain as many repeated measurments of single targets as possible. Both day and night-time observations were made. TS considerations were also to be carried out from integration of jellyfish layers and consideration of trawl sample voulme using the comparison method.

3.6.1 *In situ measurements*

Weak single target echoes that may have been omitted from jellyfish were observed. Interestingly, the observed patterns of the targets were quite different between frequencies. At 18 kHz, very few targets were detected, whereas a more reasonable target density was observed at 38 kHz. Of the latter, parts of the recorded material appeared applicable for computation of mean recorded acoustic backscattering crossection. At 120 kHz, the target density was too high for reliable identification of single targets. A between-beam traingulation analysis, increasing the stringency of the single target detections (Demer et al. 1999), will be carried out at a later stage.

3.6.2 *Comparison method*

This approach is based on mean recorded area backscattering coefficient S_A as described in chapter 2.2.2. Combining area density calculated from volume density with recorded acoustic density for the same water volume in a preliminary analysis, mean acoustic backscattering coefficient was calculated to range between -57 and –31 dB at 38 kHz for C. *hysoscella*.

3.7 VISUAL SURFACE OBSERVATIONS

A total of 28 observations series were carried out from 31 August to 4 September. Alltogether 3158 reds and 332 mags were observed. Although the highest abundance group for mags was situated offshore and for reds inshore, no distinct pattern in their overall distribution pattern can be discerned. No mags were observed in the northern regions of the surveyed area.

CHAPTER 4 DISCUSSION

4.1 TRAWL SAMPLING

All pelagic sampling trawls on R/V "Dr. Fridtjof Nansen" are identical from the extension and backwards, with fine meshes (40 cm, **Annex I**). The two pelagic trawls applied were the biggest one (30 m vertical opening) and the intermediate one (15 m opening, *Multisampler*). Only the biggest trawl could be used at the surface due to problems with tearing of the smaller one. The problems of tearing may be related to the fact that the largest trawl inevitably will select out jellyfish more selectively due to the larger meshes from the extension and forewards. The tearing may however also have been caused by the fact that the rigedly mounted metal frame behind the extension reduced the flexibility of the trawl. Furthermore, the extension in the smaller trawl consists of square meshes, in order to keep the side-, top- and bottom panels straight to avoid bulbs around the metal framework of the multisampler, and these have considerably lower tearing strength than diamond meshes have. If, however, as previously assumed effective catching of jellyfish primarily takes place were the meshes are small enough to retain the jellyfish (e.g. no herding or "inflow" effect), the effective sampling volume will be the same for the two trawls. There will nevertheless be bias both from haul to haul with the same trawl and between the two pelagic trawls. A poistive bias may caused by jellyfish being lead in to the trawl by the current created by the trawl, and a negative bias is the "bucket-effect", or reduced inflow of water into the trawl, which also sometimes cause tearing of the nets.

4.2 ACOUSTIC SAMPLING

Jellyfish appeared as weak acoustic scatters. In some instances, jellyfish echoes may have been disguised by the massive backscattering plankton layers, but even in cases where extreme densities were recognised from the trawl samples at the surface (above the plankton layer), only wek integrator values were recorded. It therefore seems unlikely that they can be surveyed acoustically at the frequencies and with the technical configuration applied in the current investigation, at least with the high concentrations of plankton prevailing in the Benguela.

However, careful post-processing of acoustic and net haul data however revealed a linear and statistically significant relationship between catch size and integrated echo energy for reds, and multi-beam filtering techniques may be of help to extract jellyfish echoes from plankton. Further processing may hopefully reveal a similar relationship for mags, although our impression at this stage is that mags are much less detectable acoustic targets than reds. Reds and mags being extremely weak sound scatterers was supported by measurements indicating that both species had densities indistinguishable from water (~1.0) (see also Mutlu 1996).

4.3 BIOLOGY

Reds and mags appeared to have different cross shelf distribution patterns. Catches containing reds only were made exclusively inshore (<100 m bottom depth), while mixed catches were made on the mid-shelf (100-250 m), and clean catches of mags were only made offshore (>250 m). Both species of jellyfish feed primarily on crustacean zooplankton and fish larvae, and one of the reasons for the spatial seperation of the two species could thus be competition for food.

4.4 CONCLUDING REMARKS

- Mags and reds are weak acoustic targets, and can presently not be integrated in acoustic surveying using the technical configuration applied in this investigation. Thus, even great aggregations of jellyfish are unlikely to bias acoustic fish abundance estimates, given conditions similar to the ones in the present survey. Nevertheless, a significant linear relationship between sample density and recorded S_A strongly suggests that reds are acoustically detectable.

- Mags and reds were patchily distributed and may occur in very high densities.

- The distribution of both jellyfish species appeared to be confined to the upper 150 m of the water column, and reds were typically found shallower than mags within this range. Both species seemed to undertake some diel vertical migration: the proportion of mags in the upper 50 m multisampler net (from sample depths 150, 100 and 50 m) increased with the onset of darkness, whereas reds were caught in larger numbers in surface trawls at night than in the day. Higher densities of reds at the surface at night was supported by visual observations of the jellyfish.

- Reds and mags appeared to have different cross shelf distribution patterns. Catches containing reds only were made exclusively inshore (<100 m bottom depth), while mixed catches were made on the mid-shelf (100-250 m), and clean catches of mags were only made offshore (>250 m).

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ANNEX I ILLUSTRATIONS OF SAMPLING TRAWLS

ANNEX II SIMRAD EK 500 TRANCEIVER MENU SETTINGS

Tranceiver 1 (38 kHz, keel mounted)

/TRANSCEIVER MENU/Transceiver-1 Menu/Mode=Active
/TRANSCEIVER MENU/Transceiver-1 Menu/Transducer Type=ES38B
/TRANSCEIVER MENU/Transceiver-1 Menu/Transd. Sequence=Off
/TRANSCEIVER MENU/Transceiver-1 Menu/Transducer Depth=8.00 m
/TRANSCEIVER MENU/Transceiver-1 Menu/Absorption Coef.=10 dBkm
/TRANSCEIVER MENU/Transceiver-1 Menu/Pulse Length=Medium
/TRANSCEIVER MENU/Transceiver-1 Menu/Bandwidth=Wide
/TRANSCEIVER MENU/Transceiver-1 Menu/Max. Power=2000 W
/TRANSCEIVER MENU/Transceiver-1 Menu/2-Way Beam Angle=-21.0 dB
/TRANSCEIVER MENU/Transceiver-1 Menu/Sv Transd. Gain=27.45 dB
/TRANSCEIVER MENU/Transceiver-1 Menu/TS Transd. Gain=27.65 dB
/TRANSCEIVER MENU/Transceiver-1 Menu/Angle Sens.Along=21.9
/TRANSCEIVER MENU/Transceiver-1 Menu/Angle Sens.Athw.=21.9
/TRANSCEIVER MENU/Transceiver-1 Menu/3 dB Beamw.Along=6.8 dg
/TRANSCEIVER MENU/Transceiver-1 Menu/3 dB Beamw.Athw.=6.7 dg
/TRANSCEIVER MENU/Transceiver-1 Menu/Alongship Offset=-0.03 dg
/TRANSCEIVER MENU/Transceiver-1 Menu/Athw.ship Offset=0.06 dg

Tranceiver 2 (120 kHz, keel mounted)

/TRANSCEIVER MENU/Transceiver-2 Menu/Mode=Active
/TRANSCEIVER MENU/Transceiver-2 Menu/Transducer Type=ES120-7
/TRANSCEIVER MENU/Transceiver-2 Menu/Transd. Sequence=Off
/TRANSCEIVER MENU/Transceiver-2 Menu/Transducer Depth=8.00 m
/TRANSCEIVER MENU/Transceiver-2 Menu/Absorption Coef.=38 dBkm
/TRANSCEIVER MENU/Transceiver-2 Menu/Pulse Length=Long
/TRANSCEIVER MENU/Transceiver-2 Menu/Bandwidth=Narrow
/TRANSCEIVER MENU/Transceiver-2 Menu/Max. Power=1000 W
/TRANSCEIVER MENU/Transceiver-2 Menu/2-Way Beam Angle=-20.6 dB
/TRANSCEIVER MENU/Transceiver-2 Menu/Sv Transd. Gain=25.62 dB
/TRANSCEIVER MENU/Transceiver-2 Menu/TS Transd. Gain=25.62 dB
/TRANSCEIVER MENU/Transceiver-2 Menu/Angle Sens.Along=21.0
/TRANSCEIVER MENU/Transceiver-2 Menu/Angle Sens.Athw.=21.0
/TRANSCEIVER MENU/Transceiver-2 Menu/3 dB Beamw.Along=7.6 dg
/TRANSCEIVER MENU/Transceiver-2 Menu/3 dB Beamw.Athw.=7.6 dg

/TRANSCEIVER MENU/Transceiver-2 Menu/Alongship Offset=-0.05 dg
/TRANSCEIVER MENU/Transceiver-2 Menu/Athw.ship Offset=0.08 dg

Tranceiver 3 (18 kHz, hull mounted)

/TRANSCEIVER MENU/Transceiver-3 Menu/Mode=Active
/TRANSCEIVER MENU/Transceiver-3 Menu/Transducer Type=ES18-11
/TRANSCEIVER MENU/Transceiver-3 Menu/Transd. Sequence=Off
/TRANSCEIVER MENU/Transceiver-3 Menu/Transducer Depth=5.50 m
/TRANSCEIVER MENU/Transceiver-3 Menu/Absorption Coef.=3 dBkm
/TRANSCEIVER MENU/Transceiver-3 Menu/Pulse Length=Short
/TRANSCEIVER MENU/Transceiver-3 Menu/Bandwidth=Wide
/TRANSCEIVER MENU/Transceiver-3 Menu/Max. Power=2000 W
/TRANSCEIVER MENU/Transceiver-3 Menu/2-Way Beam Angle=-17.2 dB
/TRANSCEIVER MENU/Transceiver-3 Menu/Sv Transd. Gain=21.70 dB
/TRANSCEIVER MENU/Transceiver-3 Menu/TS Transd. Gain=21.50 dB
/TRANSCEIVER MENU/Transceiver-3 Menu/Angle Sens.Along=13.9
/TRANSCEIVER MENU/Transceiver-3 Menu/Angle Sens.Athw.=13.9
/TRANSCEIVER MENU/Transceiver-3 Menu/3 dB Beamw.Along=10.9 dg
/TRANSCEIVER MENU/Transceiver-3 Menu/3 dB Beamw.Athw.=10.9 dg
/TRANSCEIVER MENU/Transceiver-3 Menu/Alongship Offset=-0.04 dg
/TRANSCEIVER MENU/Transceiver-3 Menu/Athw.ship Offset=0.03 dg

ANNEX III

BENEFIT SURVEYS

Cruise Report No 10/99

Part 2: Application of multiple frequency acoustics for improvement of *in situ* target identification

6-17 September 1999

by

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Institute of Marine Research
Bergen, 1999

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CHAPTER 1 INTRODUCTION

1.1 BACKGROUND

Acoustic assessment of fish stocks requires successful identification of the ensonified scatterers. At present this identification relies heavily on adequate ground-truthing by targeted trawling. A number of factors determine the success of this identification, such as: the degree of species mixing in space, the selectivity of the gear and the ability of the gear to take spatially discrete samples.

At present, most acoustic surveys in the Benguela region are based on samples taken using 38 kHz transducers. However, several vessels in the area have multifrequency capabilities. Acoustic theory predicts that broad organism-type have a specific acoustic signature at different frequencies, depending on their size, shape and other scattering properties. It would therefore be potentially possible to use acoustic signatures at more than one frequency to identify the main scattering organisms.

The conventional means of obtaining samples from the acoustically surveyed population is trawling by means of pelagic or demersal sample trawl with a single codend. The major limitation of this way of sampling is the uncertainty associated with the representativeness off the samples caught by the particular sampling gear. In addition to the traditional problem of size- and species dependent avoidance from sampling gears, trawls have traditionally not been able to sample discrete depth intervals due to undesired fishing before and after it reaches fishing depth. This problem can be overcome today, using devices with multiple codends that can be opened and closed during operation, e.g *Multisampler* (Skeide et al. 1997). It is still, however, a time consuming process to sample vatious depths, and while surveying there is hardly the time to sample all observed schools, layers and other aggregations of fish at different times of day and night, and it is therefore essential to have some *a priori* knowledge of how scattering layers of different species appear acoustically, and how their acoustcial appearence chances from day to night time.

Acoustic records collected can also reveal spatial relationships between marine organisms, particularly in the biologically complex scattering layers of the northern and southern Benguela, where macrozooplankton, micronekton, and fish scattering layers aggregate and interact. Continuos monitoring by means of multifrequency acoustics and depth discrete sampling of plankton and nekton enables examination of structural patterns and trophic relations between different scattering layers.

The potential of these three lines of research were investigated during this survey.

1.2 OBJECTIVES OF THE SURVEY

The overall survey objective was to improve species identification techniques using multifrequency acoustics.

To carry out continous acoustic measurements of hake (*Merluccius capensis*, M. *paradoxus*) and associated pelagic species at 18, 38 and 120 kHz during 24 hour cycles to elaborate acoustical characteristics at different times of day and night. Species identification of recorded layera and schools were to be conducted using standard pelagic sampling trawl with *Multisampler*, enabling discrete samples to be obtained from various depths, and demersal trawl. CTD and ADCP profiles were to be taken for or mapping of environmental factors.

To compare the diurnal migration pattern of hake and related species at two or more differently located 24 hour stations.

To carry out studies of pelagic school in South-Africa and study intra- and inter school variation of species- and size distribution by means of *Multisampler* and Scanmar systems.

To take live samples of horse mackerel (*Trachurus capensis*) for anatomical studies of swimbladder allometric growth.

1.3 PARTICIPATION

The scientific staff consisted of:

From South Africa:
Shawn BERRY, Janet COETZEE, Rob COOPER, Sharon DU PLESSIS, Marc HENDRICKS, Stan PILLAR, Michael SOULE and Megan TERRY

From Namibia:
Angie KANANDJEMBO

From Norway:
Bjørn Erik AXELSEN (Cruise leader), Tore MØRK and Roar SKEIDE.

1.4 NARRATIVE

The “Dr. Fridtjof Nansen” departed from Walvis Bay 6 September at 15h30, heading west for selection of the first study site for the first of two 24 hour diel experiments emphasising trophic links between different scattering layers.

An appearently suitable location was found west of Walvis Bay (23°00’S 13°00’E), and a demersal trawl haul was carried out, indicating that hake (*Merluccius capensis* and M. *paradoxus*) were present in the area, and the experiment was started here. After the demersal haul was completed, a *Mutisampler* trawl haul series was executed, with the first sample caught just above the bottom, the second midwater, and the last one at the surface. The trawl was, however, severely torn from the *Mutisampler* and forewards due to large aggregations of jellyfish at the surface, and the 24 hour diel cycle experiment had to be interrupted and the trawl replaced. While the trawl was being replaced, the ship steamed southwards for selection of a new study site.

A more suitable area was found about 70 nautical miles (nm) south-west of Walvis Bay (24°46‘S 13°45’E), at approximately 340 m water depth, and the first experiment was carried out here from 7 to 9 September. After the completion of the first diel station, the ship steamed southwards for selection of a study site in South-African waters. The second diel station was conducted 60 nm south-west of Danger Point on the eastern Agulhas Bank (35°13’S 18°49’E) from 13 to 14 September. Each experiment lasted approximately 30 hours.

Two areas of high pelagic fish school abundance on the south-west coast of South Africa were located to investigate acoustic scattering properties of monospecific schools at different frequencies. The first study site was in St. Helena Bay, an area where anchovy was the dominant species. The second site was in Walker Bay, where sardine was dominant. At both sites, a transect of approximately 15 nm was sampled continuously using various trawl configurations.

The “Dr. Fridtjof Nansen” docked in Cape Town 17 September at 07h00.

CHAPTER 2 METHODS

2.1 HYDROGRAPHY AND WEATHER DATA

CTD- profiles were collected at regular intervals on all study sites using a Seabird 911+ probe/ Seasave software. For the 24-hour diel cycle stations, ADCP data (Acoustic Doppler Current Profiler) were logged during all trawls in 8-m bins from just below the surface to the bottom. All relevant meteorological information such as air and surface temperature, wind speed and direction and solar intensity was logged continously from the ANDREAA weather station.

2.2 SURVEY AREA

Two diel experiments were conducted to investigate trophic links between different scattering layers. The first took place about 70 nm south-west of Walvis Bay (24°46‘S 13°45’E) at approximately 340 m water depth from 7 to 9 September. The second experiment was conducted about 60 nm south-west of Danger Point on the eastern Agulhas Bank on the south coast of South Africa (35°13’S 18°49’E) from 13-14 September. Each experiment lasted approximately 30 hours.

Two areas of high pelagic fish school abundance were located on the south-west coast of South Africa to investigate acoustic scattering properties of monospecific schools at different frequencies. The first study site was in St. Helena Bay, an area where anchovy was the dominant species. The second site was in Walker Bay on the south-west coast of South Africa, where sardine was dominant. At both sites, a transect of approximately 15 nm was sampled continuously using various trawl configurations.

2.3 ACOUSTIC SAMPLING AND DATA ANALYSIS

Acoustic data were logged continuously from the EK 500 sounder, equipped with three split-beam transceivers operating at frequencies of 18, 38 and 120 kHz. The settings in the EK 500 tranceiver menu are given in **Annex I**. The Sonardata Echolog software was used to log data from the ethernet communications port of the EK 500. The data were logged simultaneously using the Bergen Echo Integrator (BEI). A Hewlett Packard Deskjet printer was set to print all frequencies simultaneously, with colour S_V minimum set to -90 dB. Another printer recorded an expansion of the 38 kHz echogram in periods of particular interest, i.e. the 30-hour experiments. Recordings from these experiments were scrutinized, using both software systems and trawl data.

Following the successful calibration of the EK 500 in St Helena Bay, post-processing of acoustic data was done using the corrected gain settings. A complete description of the calibration procedures and results are given in **Annex II**. A relatively low integration threshold (–75 dB) was used for all three frequencies. Integration limits were set to 5 m below the surface and 1 m off the bottom, without corrections for the difference in drift between the 18 kHz transducer and the other two keel-mounted transducers. In the initial analysis of data, no corrections were made, neither for differences in sampling volume nor for pulse duration of the three different systems.

2.4 TRAWL SAMPLING

Sampling trawls used included the large pelagic trawl (30 m vertical opening), the mid-sized pelagic trawl (15 m vertical opening) with *Multisampler* and a bottom trawl (5 m vertical opening), with floats for midwater trawling and without floats for bottom trawling. The *Multisampler* was equipped with three codends, which were remotely opened and closed to obtain discrete uncontaminated samples. Thyborøen 2000 kg trawl doors were used in all hauls. The trawl doors were chackelled for pelagic trawling, also during demersal trawling. Details of all sampling trawls and the *Multisampler* unit are illustrated in **Annex III**.

For each trawl station, catch size and species composition were determined from a random, representative sample of between five and 10 baskets**.** This data were entered into the NANSIS-database for all stations (356-513), following standard procedure. The size composition for selected species were determined as follows:

(i) Hake and horse mackerel: total length (all subsample, rounded down to the nearest 1.0 cm);

(ii) Anchovy and sardine: total length (100 individuals, rounded down to the nearest 0.5 cm);

(iii) Mesopelagic fish: total length (100 individuals, rounded down to the nearest 0.5 cm).

In addition, biological data were collected for hake, including stomach fullness, stomach content, prey composition and digestive state.

2.5 PLANKTON SAMPLING

For the 30-hour diel cycle experiments, all biological sampling was conducted along the same 5 nm section of track, commencing with a bottom trawl, followed by a midwater trawl sampling various depth strata by means of *Multisampler*, and finally a depth-stratified zooplankton haul by means of Hydrobios multinet. The Hydrobios sampler was fitted with five 405-µm mesh nets, and flowmeters mounted at the front of each net monitored the volume of water filtered by each net. The nets were hauled obliquely at a speed of as close as possible to 2 knots (1 m/sec). All samples were preserved in 4 % buffered formalin. Hydrographical sampling was carried out after each cycle. CTD casts obtained profiles of water temperature, salinity and dissolved oxygen, and depth-specific current speed and direction, including the vertical component, was measured throughout the experiments using an Acoustic Current Profiler (ADCP). Alltogether five and seven cycles were carried out during the first and second diel experiments respectively, consisting in total of 12 bottom trawls, 14 *Multisampler* trawls, 14 Hydrobios multinet hauls and 12 CTD casts.

Continuous acoustic records at 18, 38 and 120 kHz were logged throughout the diel experiments in order to determine the depths of and integrate the various pelagic scattering layers. The species compositions of the pelagic layers were identified from trawls, and size frequencies were obtained from the main fish species in the catch. On board, representative samples of each species of Cape hake (*Merluccius capensis*) and deepwater hake (*M. paradoxus*) were classified by stomach fullness. Subsamples of fish (usually 20 of each species per trawl) with stomachs containing food were analysed. Prey items were sorted into the lowest possible taxonomic group. Other fish species, such as horse mackerel (*Trachurus capensis*), anchovy (*Engraulis capensis*), sardine (*Sardinops sagax*), redeye (*Etrumeus whiteheadi*), and mesopelagic fish (Maurolicus spp. and Lampanyctodes spp.) were frozen whole for further processing ashore.

During the fish school compostion studies, Hydrobios multinet hauls and CTD casts to the bottom were carried out along the sampling transects at regular intervals.

CHAPTER 3 RESULTS

3.1 WEATHER CONDITIONS

Weather conditions were farily good with moderate wind, ranging from 0 to 25 m/s (**figure 1**). It was generally cloudy, and some rain during the cruise. The Solar intensity levels measured on top of the wheelhouse are given in **figure 2**. The temperature at the sea surface (**figure 3**) and in the air ranged from 12.2 to 17.1°C and from 10.4 to 17.0°C, respectively.

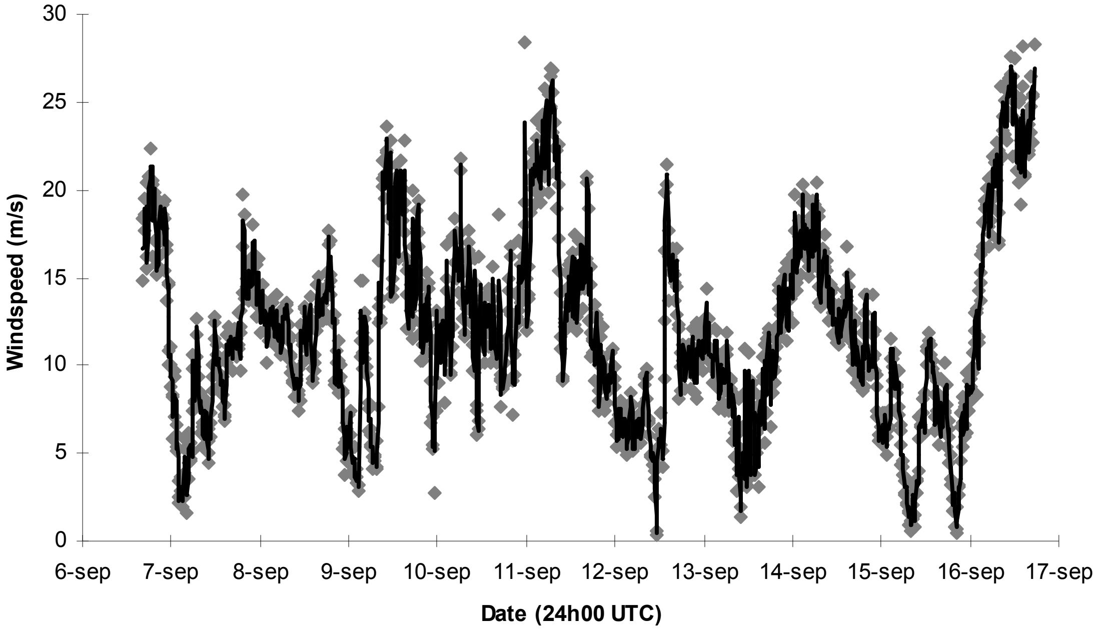


Figure 1 Wind speed recorded every 10 min with the Andreaa weather station throughout the cruise (−: moving average).

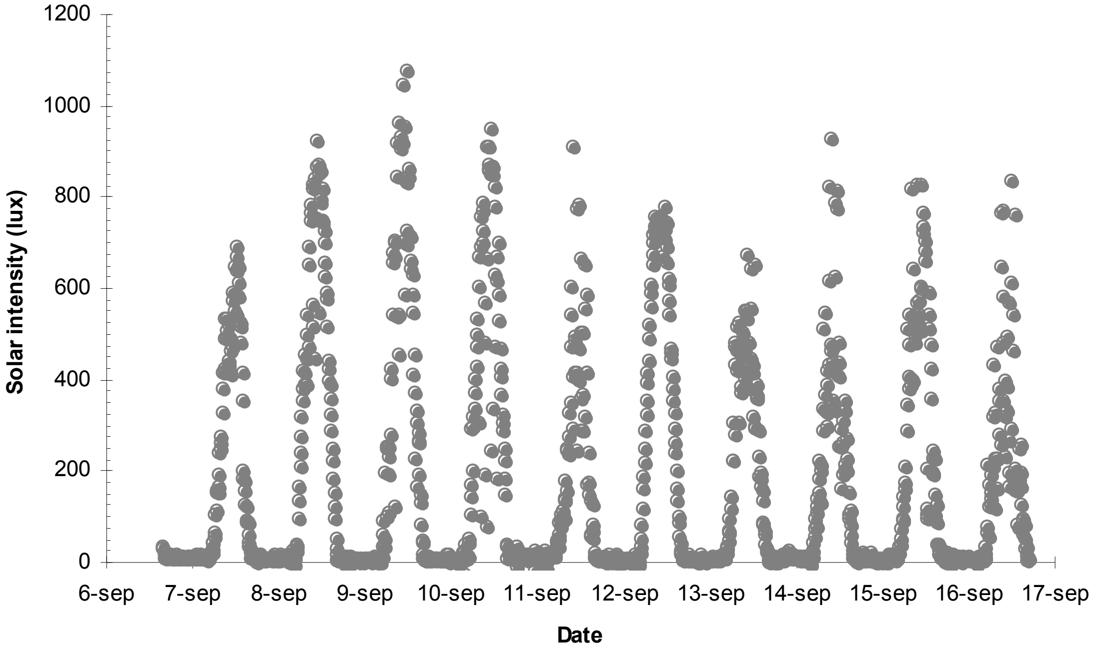


Figure 2 Surface solar intensity (lux) recorded every 10 min with the Andreaa weather station throughout the cruise.

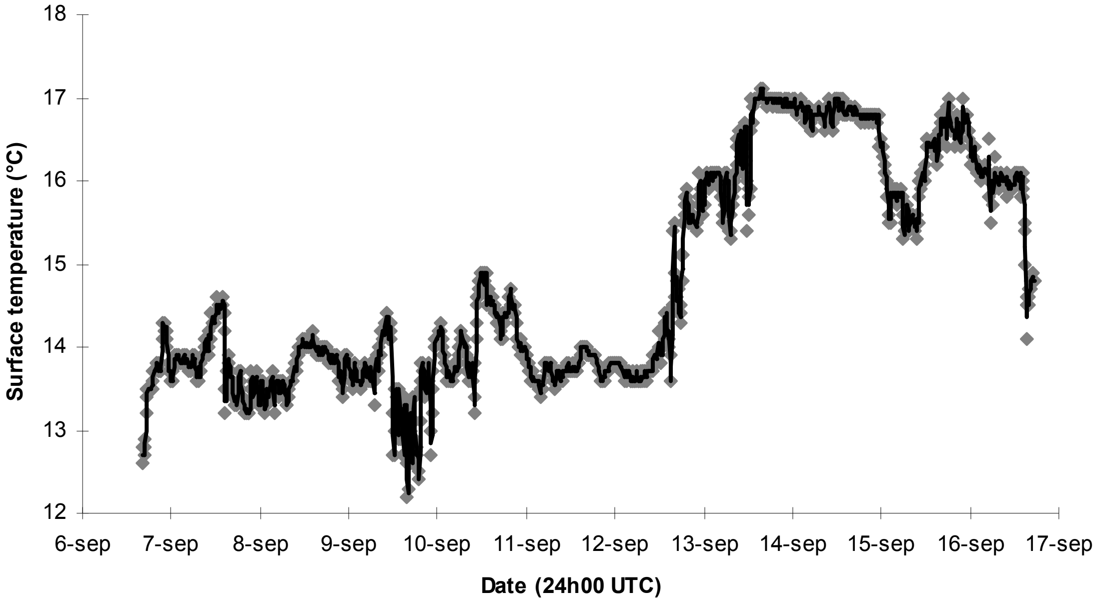
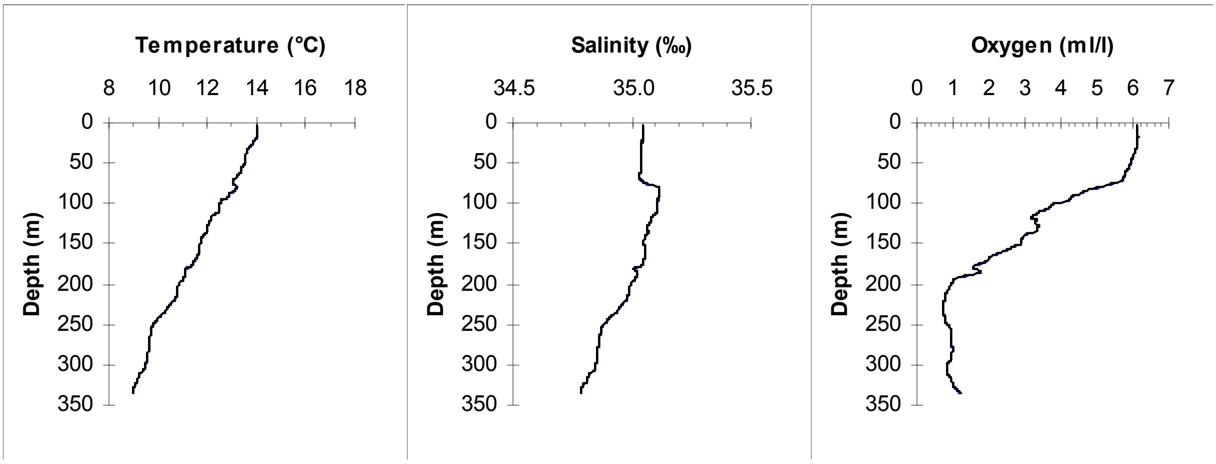


Figure 3 Surface temperature (˚C) recorded every 10 min with the Andreaa weather station throughout the cruise (−: moving average).

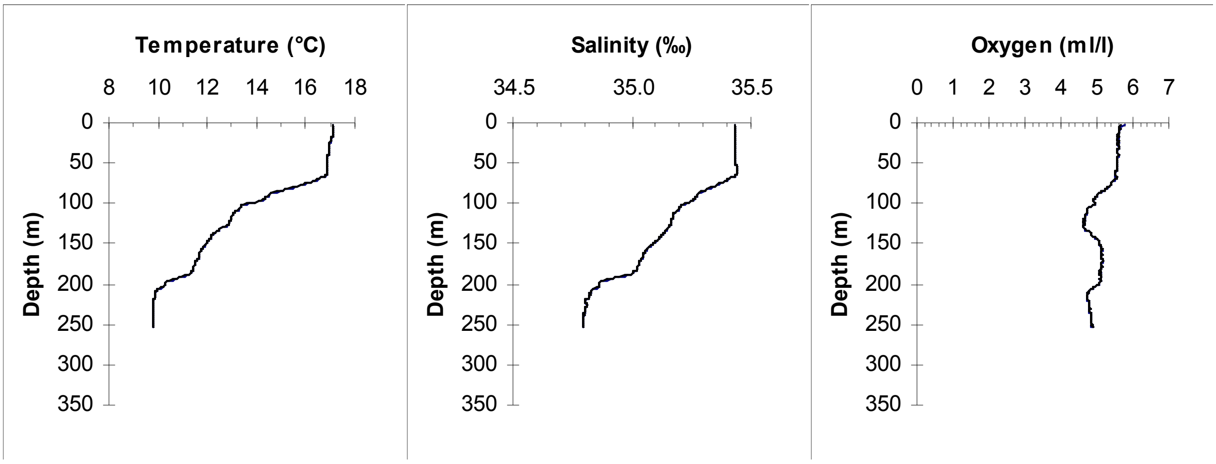
3.2 HYDROGRAPHY

Hydrographical profiles for both diel stations and for one of the pelagic stations (Walker Bay) are given in **Figure 4**.

a)



b)



c)

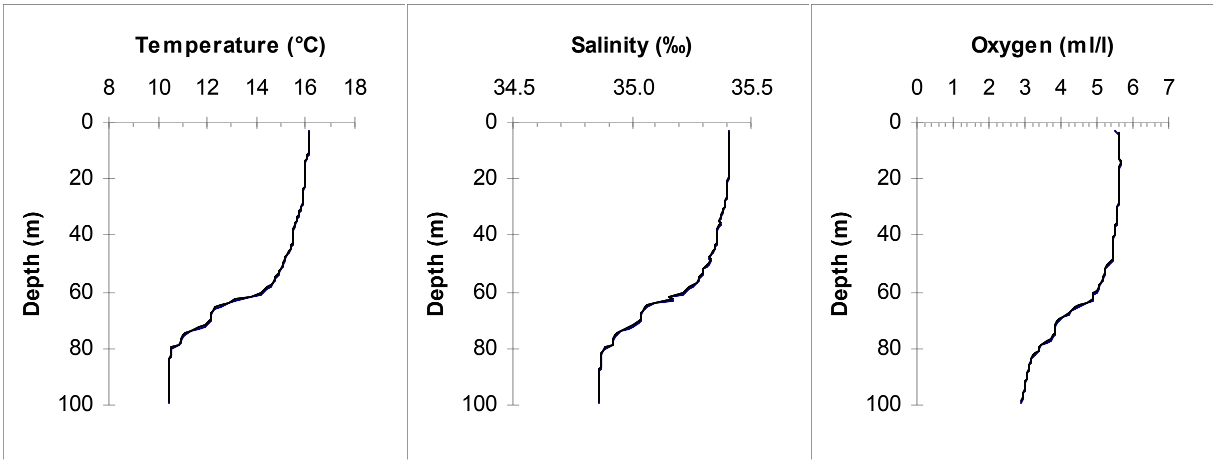


Figure 4 CTD profiles at a): diel station 1; b): diel station 2; and 3): Walker Bay (pelagic study site). Note that the depth scale in c) differs from that of a) and b).

3.3 MULTIFREQUENCY ACOUSTIC SCATTERING PROPERTIES

In this preliminary investigation of different scattering properties of various sized organisms at 18, 38 and 120 kHz, a very small sample was used because of time and data processing constraints. Initially, only 25 zooplankton (mostly copepod), 27 myctophiid (lanternfish) and 21 anchovy examples were used for the comparisons. The layers/schools were chosen in monospecific areas as indicated by trawl and multinet hauls. Integration regions ranged from 5 pings for anchovy schools, to 100 pings, in the case of zooplankton layers. In all cases, the depth ranges of the integration values were 5 or 10 m (to account for differences in pulse duration between the three frequencies). The shallower draft of the 18 kHz transducer was not taken into account. Furthermore, the difference in pulse volume as a function of range (**figure 5**) was not corrected for in the current preliminary analysis. The effect of the much larger pulse volume of the 18 kHz system at depths in excess of 60 m needs to be taken into account.

The volume scattering strengths (Sv) of the three groups; copepods (<5 mm), lanternfish (5 cm) and anchovy (9 cm) at 18, 38 and 120 kHz are shown in revealed a similar pattern between the zooplankton and mesopelagicstudied. Volume backscattering was highest at 18 kHz and lowest at 120 kHz. The higher backscatter at 18 kHz was probably a result of the larger pulse volume. An examination of these few examples revealed no single relationship between any of the Sv curves. There is no monotonous increase in scattering level with increasing frequency. It is important to note that more detailed analyses are required, including an analysis of the depth-dependence of volume scattering on frequency.

Further investigation of backscatter levels, using the ratio between the three frequencies, were however attempted (**figure 6**). In all three cases, no pattern was observed for the anchovy sampled. This is probably a result of non-overlapping pings between the 18 kHz transducer and the other two transducers because of their positioning. The problem is worse for schools in which the difference in the mean backscatter between adjacent pings is high. This issue will be dealt with in future analyses of the data. For zooplankton, the ratios between all three frequencies tended to be very similar, with peaks around 0.96, and within a relatively narrow range. For mesopelagics, there was a slightly lower peak mean ratio for all three frequencies, although the range and variability was higher.

3.4 SCATTERING LAYER STRUCTURE

The survey area of the first experiment was characterized by a mixture of both species of Cape hake near the seabed, and a large mesopelagic component, consisting of several species of mesopelagic fish, shrimps and smaller zooplankton. All the acoustic information scrutinized during the experiments were combined and is shown in **Figure 7**. In this experiment, a large

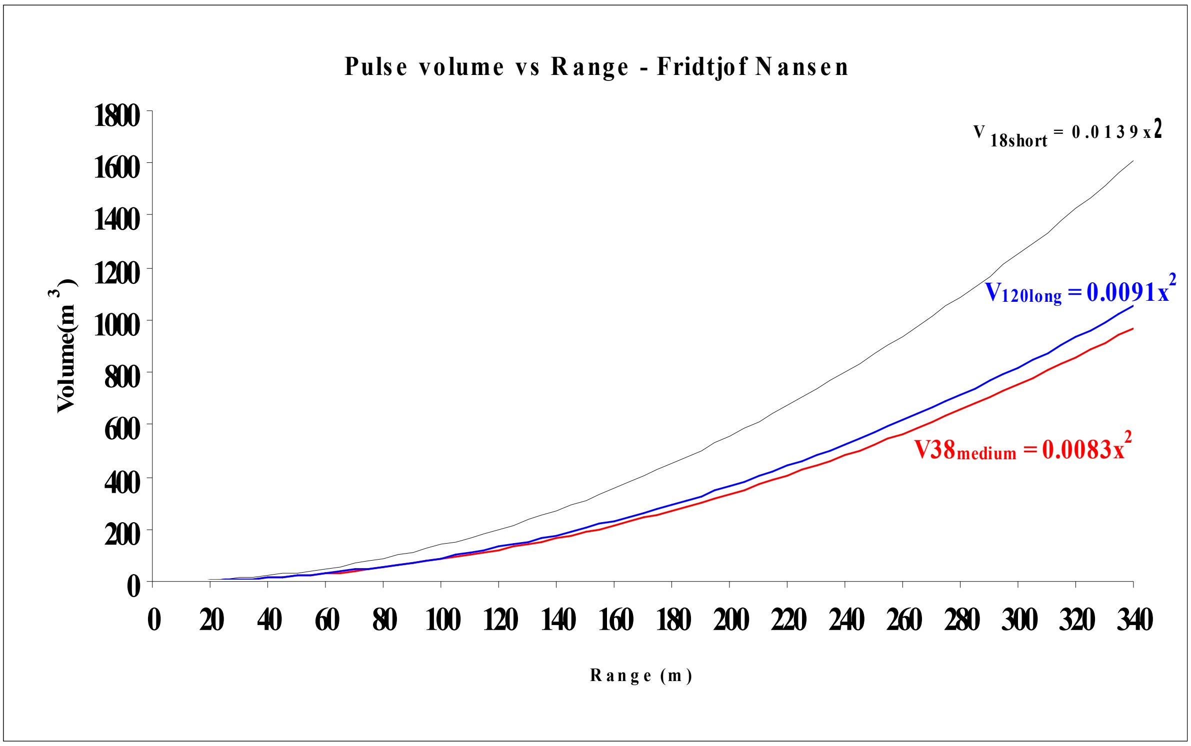


Figure 5 Pulse volume versus range of the 18, 38 and 120 kHz transducers on "Dr. Fridtjof Nansen".

component of the mesopelagic layers underwent an extensive diel vertical migration with the onset of daylight. At least three layers could be identified during the night (**Figure 8a**); a bottom layer (8-10 m off the bottom) consisting mainly of hake, a midwater layer between 100 and 200 m consisting of mesopelagic fish (mostly myctophids *Lampanyctodes hectoris*), and a zooplankton layer (mainly copepods *Calanoides* and *Metridia*) in the upper 100 m of the water column). Euphausiids and larger crustaceans, such as Sergestid and Pasiphaeid shrimps, were mostly common in the upper 100 m of the water column,.

The daytime acoustic distribution (**Figure 8b**) was characterized by at least five layers, excluding the hake layer, which was obscured by the bottom zooplankton layer. The surface zooplankton layer seemed to have split to form two layers, the deeper one consisting of a large proportion of euphausiids. Mesopelagic fish dominated the 150-300 m midwater layer, which appeared as an upper layer of small dense schools at about 200 m deep and a lower, more diffuse layer. Copepods dominated the near-bottom layer.

Figure 6 Frequency distribution of Sv ratios calculated the zooplankton, myctophids and anchovy at 18, 38 and 120 kHz.

Figure 7 A composite acoustic echochart showing the components of the scattering layers throughout the 30-h study in Experiment 1

The scattering layer configuration on the second night of Experiment 1 was similar to that of the first night (**Figure 8 a,c**). Mesopelagic fish were again found in the midwater zone (50-150 m), together with euphausiids and shrimps. Copepods dominated the upper 100 m. The hake layer consisted of both species and were found up to 30 m off the bottom.

The scattering layers in daylight in the second experiment included a bottom layer of hake (both species) and horse mackerel, a midwater layer of small zooplankters (mainly copepods), and several layers consisting of mesopelagic fish and sardine (**Figure 9a**). During the night, zooplankton dominated the midwater layer between 50 and 200 m, and pelagic fish were most abundant in the upper 50 m. Acoustic and trawl observations indicated that the hake and horse mackerel did not ascend any considerable distances above the seabed at night.

3.5 FEEDING

Generally, the hake studied during the first experiment did not migrate extensively into the water column. Summarizing the prey into major food groups from stomachs pooled over all the bottom trawls (**Figure 10**) shows that most of the diet consisted of fish and large crustaceans (mainly shrimps). Food consumption expressed as frequency of occurrence shows that most of the food ingested by *M. capensis* was mesopelagic fish (45 %), followed by shrimps (38 %) and hake (7 %). The dietary composition was different for *M. paradoxus*, with a lower occurrence of mesopelagic fish and higher incidence of shrimp in their stomachs. There was a low incidence of fresh food in the stomachs of both hake species and around one third of the fish sampled had empty stomachs. Larger hake everted their stomachs more frequently than did smaller fish.

About one-quarter of the stomachs of M. *capensis* taken in the second experiment were empty, whereas more than 95 % of the stomachs of M. *paradoxus* were empty. Pelagic fish were consumed most frequently (73 %) by M. *capensis*, with horse mackerel and hake occurring in about 20 % of their stomachs (**Figure 10**). By contrast, the few M. *paradoxus* with food in their stomachs consumed mostly mesopelagic fish. As in the first experiment, few hake had fresh food in their stomachs.

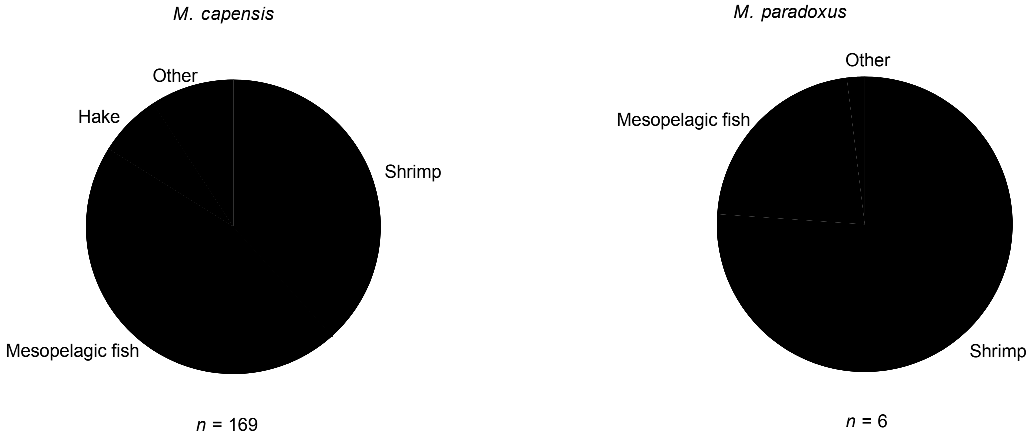
A qualitative examination of the horse mackerel stomachs revealed that few had fresh food among the contents. A more elaborate laboratory analysis of their stomach contents, together with those of the pelagic and mespelagic fish is required to investigate the different feeding patterns that have taken place during the course of the experiment.

Figure 8 Acoustic echochart showing the components of the scattering layers during the first experiment in (a) the first night, and (b) in daylight.

Figure 8c Acoustic echochart showing the components of the scattering layers during the first experiment in the following night.

Figure 9 Acoustic echochart showing the components of the scattering layers during the second experiment in (a) daylight and (b) at night.

Experiment 1



Experiment 2

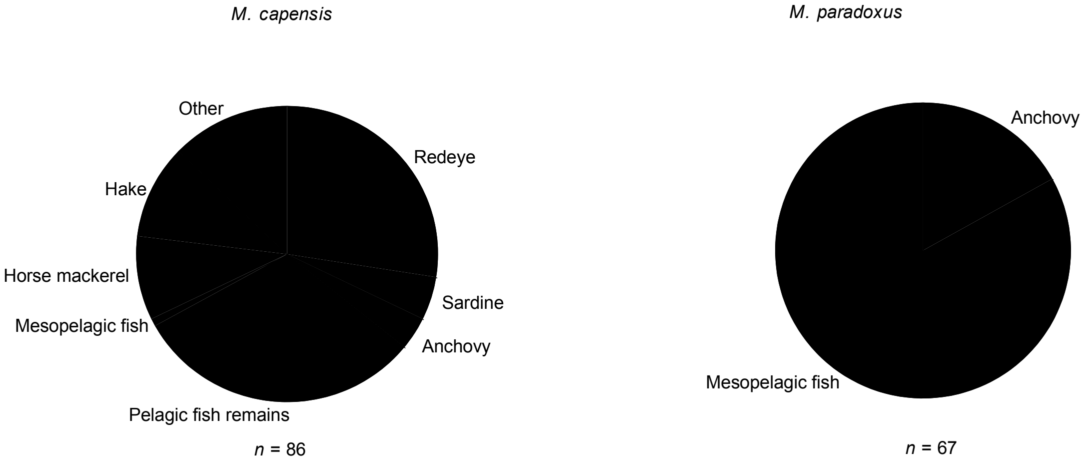


Figure 10 Frequencies of occurrence of different prey taxa in the stomachs of M. *capensis* and M. *paradoxus* from bottom trawls taken during experiments 1 (upper two diagrams) and 2 (lower to diagrams).

ANNEX I SIMRAD EK 500 TRANCEIVER MENU SETTINGS

Tranceiver 1 (38 kHz, keel mounted)

/TRANSCEIVER MENU/Transceiver-1 Menu/Mode=Active
/TRANSCEIVER MENU/Transceiver-1 Menu/Transducer Type=ES38B
/TRANSCEIVER MENU/Transceiver-1 Menu/Transd. Sequence=Off
/TRANSCEIVER MENU/Transceiver-1 Menu/Transducer Depth=8.00 m
/TRANSCEIVER MENU/Transceiver-1 Menu/Absorption Coef.=10 dBkm
/TRANSCEIVER MENU/Transceiver-1 Menu/Pulse Length=Medium
/TRANSCEIVER MENU/Transceiver-1 Menu/Bandwidth=Wide
/TRANSCEIVER MENU/Transceiver-1 Menu/Max. Power=2000 W
/TRANSCEIVER MENU/Transceiver-1 Menu/2-Way Beam Angle=-21.0 dB
/TRANSCEIVER MENU/Transceiver-1 Menu/Sv Transd. Gain=27.45 dB
/TRANSCEIVER MENU/Transceiver-1 Menu/TS Transd. Gain=27.65 dB
/TRANSCEIVER MENU/Transceiver-1 Menu/Angle Sens.Along=21.9
/TRANSCEIVER MENU/Transceiver-1 Menu/Angle Sens.Athw.=21.9
/TRANSCEIVER MENU/Transceiver-1 Menu/3 dB Beamw.Along=6.8 dg
/TRANSCEIVER MENU/Transceiver-1 Menu/3 dB Beamw.Athw.=6.7 dg
/TRANSCEIVER MENU/Transceiver-1 Menu/Alongship Offset=-0.03 dg
/TRANSCEIVER MENU/Transceiver-1 Menu/Athw.ship Offset=0.06 dg

Tranceiver 2 (120 kHz, keel mounted)

/TRANSCEIVER MENU/Transceiver-2 Menu/Mode=Active
/TRANSCEIVER MENU/Transceiver-2 Menu/Transducer Type=ES120-7
/TRANSCEIVER MENU/Transceiver-2 Menu/Transd. Sequence=Off
/TRANSCEIVER MENU/Transceiver-2 Menu/Transducer Depth=8.00 m
/TRANSCEIVER MENU/Transceiver-2 Menu/Absorption Coef.=38 dBkm
/TRANSCEIVER MENU/Transceiver-2 Menu/Pulse Length=Long
/TRANSCEIVER MENU/Transceiver-2 Menu/Bandwidth=Narrow
/TRANSCEIVER MENU/Transceiver-2 Menu/Max. Power=1000 W
/TRANSCEIVER MENU/Transceiver-2 Menu/2-Way Beam Angle=-20.6 dB
/TRANSCEIVER MENU/Transceiver-2 Menu/Sv Transd. Gain=25.62 dB
/TRANSCEIVER MENU/Transceiver-2 Menu/TS Transd. Gain=25.62 dB
/TRANSCEIVER MENU/Transceiver-2 Menu/Angle Sens.Along=21.0
/TRANSCEIVER MENU/Transceiver-2 Menu/Angle Sens.Athw.=21.0
/TRANSCEIVER MENU/Transceiver-2 Menu/3 dB Beamw.Along=7.6 dg
/TRANSCEIVER MENU/Transceiver-2 Menu/3 dB Beamw.Athw.=7.6 dg
/TRANSCEIVER MENU/Transceiver-2 Menu/Alongship Offset=-0.05 dg

/TRANSCEIVER MENU/Transceiver-2 Menu/Athw.ship Offset=0.08 dg

Tranceiver 3 (18 kHz, hull mounted)

/TRANSCEIVER MENU/Transceiver-3 Menu/Mode=Active
/TRANSCEIVER MENU/Transceiver-3 Menu/Transducer Type=ES18-11
/TRANSCEIVER MENU/Transceiver-3 Menu/Transd. Sequence=Off
/TRANSCEIVER MENU/Transceiver-3 Menu/Transducer Depth=5.50 m
/TRANSCEIVER MENU/Transceiver-3 Menu/Absorption Coef.=3 dBkm
/TRANSCEIVER MENU/Transceiver-3 Menu/Pulse Length=Short
/TRANSCEIVER MENU/Transceiver-3 Menu/Bandwidth=Wide
/TRANSCEIVER MENU/Transceiver-3 Menu/Max. Power=2000 W
/TRANSCEIVER MENU/Transceiver-3 Menu/2-Way Beam Angle=-17.2 dB
/TRANSCEIVER MENU/Transceiver-3 Menu/Sv Transd. Gain=21.70 dB
/TRANSCEIVER MENU/Transceiver-3 Menu/TS Transd. Gain=21.50 dB
/TRANSCEIVER MENU/Transceiver-3 Menu/Angle Sens.Along=13.9
/TRANSCEIVER MENU/Transceiver-3 Menu/Angle Sens.Athw.=13.9
/TRANSCEIVER MENU/Transceiver-3 Menu/3 dB Beamw.Along=10.9 dg
/TRANSCEIVER MENU/Transceiver-3 Menu/3 dB Beamw.Athw.=10.9 dg
/TRANSCEIVER MENU/Transceiver-3 Menu/Alongship Offset=-0.04 dg
/TRANSCEIVER MENU/Transceiver-3 Menu/Athw.ship Offset=0.03 dg

ANNEX II

ANNEX III ILLUSTRATIONS OF SAMPLING TRAWLS

ANNEX IV RECORDS OF FISHING STATIONS