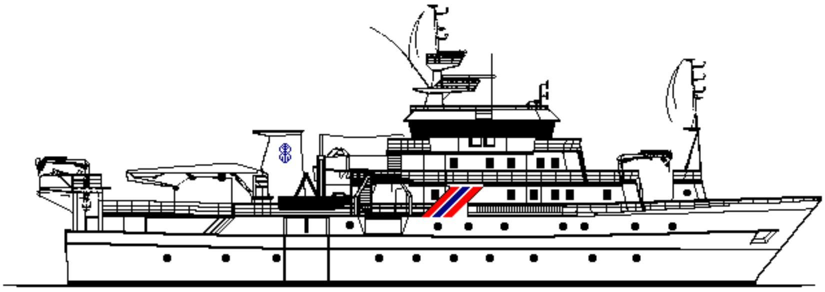
NORAD/FAO PROJECT GCP/INT/730/NOR CRUISE REPORTS DR. FRIDTJOF NANSEN



BENEFIT SURVEYS

SURVEY ERRORS IN CLUPEOIDS

Experimental survey

Studies of sardine schools and school groups

21 April – 2 May 2003

Marine and Coastal Management
Cape Town, South-Africa

Institute of Marine Research
Bergen, Norway

Ministry of Fisheries and Marine Resources
Swakopmund, Republic of Namibia

CRUISE REPORTS DR. FRIDTJOF NANSEN

BENEFIT SURVEYS

SURVEY ERRORS IN CLUPEOIDS

Experimental survey

Studies of sardine schools and school groups
21 April – 2 May 2003

by

Jens-Otto Krakstad[1], Dave Boyer[2], Ian Hampton[3], Mike Soule [3], Dagmar Merkle[4], Beau Tjizoo[2], Pandu Ilago[2], Adolf Mbaindjiikua[2], Margit Wilhelm[2]

[1.] Institute of Marine Research
P.O. Box 1870 Nordnes, N-5817 Bergen
Norway

[2.] National Information and Marine Research Centre
P.O. Box 912, Swakopmund
Namibia

[3.] Fisheries Resource Surveys
P.O. Box 31306 Tokai, 7966 Cape Town
South Africa

[4.] Marine and Coastal Management
P.Bag X2, Rogge Bay, Cape Town
South Africa

Institute of Marine Research
Bergen, 2003

TABLE OF CONTENTS

CHAPTER 1 INTRODUCTION

1.1 Background

Acoustic surveys are used throughout the region to produce abundance estimates on which TAC recommendations are based. An important question in these surveys is their accuracy, both as absolute and relative measures of abundance. Attempts to quantify survey errors to date have concentrated largely on estimating the random sampling error arising from the finite size of the sample. Other sources of random and systematic error arising, for example, from target strength uncertainty, the proportion of the population outside the surveyed area at the time of survey, and the variation in this proportion, have been largely ignored and not been quantified to any meaningful extent. For many surveys these errors may be large, potentially outweighing the random sampling error in importance and leading to over-optimistic impressions of survey accuracy, with potentially serious consequences for management strategies based primarily on these results.

The BENEFIT Workshop on Survey Errors in December 2000 identified a number of sources of error in acoustic and trawl surveys in the region, and made a first attempt to quantify their individual and combined effects on estimates of absolute abundance. A project was initiated to examine, the major sources of random and systematic error in acoustic surveys of the most important commercial clupeiform resources in the region (sardine, anchovy and sardinella), as currently practiced. The objective was to obtain more realistic estimates of survey accuracy and precision, and ultimately, to reduce survey error through the application of corrections and/or improvements in survey methodology.

In 2002, a survey was conducted on board the RV ‘Dr. Fridtjof Nansen’ off the South African coast in False Bay and Walker Bay. The primary objectives of this survey were to study the attenuation of acoustic backscatter in dense schools of sardine, collect target strength data and investigate the behaviour of individual schools, particularly with regard to vessel avoidance. The number of dense sardine schools found were not as high as had been expected prior to the survey. Nonetheless, a fairly large number were intercepted while scattered monospecific distributions of sardine at night allowed many hours of multi-frequency target strength data to be collected. The attenuation data have since been presented at the ICES Symposium on

Acoustics in Fisheries & Aquatic Ecology in Montpellier, France, in June 2002 and submitted to the ICES Journal of Marine Science (Coetzee *et al.* submitted). The multi-frequency target strength data has yet to be analysed, although a new TS project recently initiated by MCM will be making use of these data. Limitations with the sonar, and specifically the post-processing software (SODAPS), precluded the collection of any useful data on school behaviour.

The current survey was intended to build on the experiments conducted in 2002, while at the same time exploring other aspects previously identified as contributing significantly to errors in estimates of sardine abundance. The survey was conducted in Namibian waters to take advantage of the information gathered during the recently completed biomass survey on board the RV ‘Welwitchia’ which had estimated the sardine population at over half a million tonnes, providing more than sufficient fish to study.

1.2 Objectives of the survey

The overall aim of the survey was to investigate methods of improving the accuracy and/or precision of survey estimates for sardine based on errors identified at the BENEFIT Survey Errors Workshop (2000). The following objectives were prioritised for this specific survey:

- The lack of a valid target strength length relationship for southern African sardine has been recognised as potentially the most significant bias affecting the accuracy of abundance estimates. Therefore the estimation of *in situ* target strength for sardine using new multi-frequency single target recognition methods (Demer *et al.* 1999) was given a high priority for the survey.
- The widely dispersed and highly aggregated nature of sardine school-groups presents special challenges in designing a scientifically defensible and cost effective survey strategy. Observations of school-group dynamics, including the behaviour of individual schools within a school-group were therefore planned to provide data for a BENEFIT Project investigating the optimal survey design for Namibian sardine and other small pelagic species.

- The performance and efficacy of a recently designed shallow water towed body utilising a SIMRAD 38 kHz ES38B split beam transducer was to be investigated.
- Investigations of the reactions of sardine to the vessel, and in particular avoidance behaviour, were to be investigated using sonar in conjunction with the vessel and the Man-Over-Board (MOB) boat mounted vertical transducers.
- Investigation of the vertical diel migration of sardine using the towed body was to be attempted, in particular to ascertain whether the towed body would permit the collection of quantitative biomass data at night during routine surveys.
- Collection of further data relating to the attenuation of acoustic backscatter in dense, vertically extensive schools of sardine if and when the vessel transected such schools.

It was recognised prior to the survey that the list of objectives to be achieved was optimistic. Experiments such as the collection of multi-frequency target strength data for sardine; studies on school and school-group dynamics and vessel avoidance had not previously been attempted in the region. The deployment of a towed body, although offering potential solutions to some of the survey problems identified, presented a new set of technical challenges in terms of deployment and recovery strategies. A significant proportion of the work carried out during the current survey therefore related to the development of methodologies applicable to possible future experiments in these specific areas of research. As the second phase of the BENEFIT Project under which this survey was conducted ends later in 2003, it has been proposed that such investigations (improvements of survey methods) could possibly fall within the scope of the Benguela Current Large Marine Ecosystem (BCLME) Programme The work carried out during this survey will hopefully assist in the development of further experiments contributing towards the overall goal of improving the accuracy and precision of acoustic biomass estimates in the future.

1.3 Participation

The scientific staff consisted of:

From South Africa:

21/4/03 – 2/5/03	Ian Hampton, Mike Soule, Dagmar Merkle

From Namibia:

21/4/03 – 2/5/03	Dave Boyer (Local cruise leader), Beau Tjizoo, Pandu Ilago, Adolf Mbaindjiikua, Margit Wilhelm

From Norway:

21/4/03 – 2/5/03	Jens-Otto Krakstad (Cruise leader), Tore Mørk

1.4 Narrative

We left port Monday the 21st April at 16:30 after some delay with immigration. As 1000 m of new trawl warp had been wound onto the drums in Walvis Bay, we firstly sailed into deeper waters in order to spool out the cables and rewind them onto the drums under some tension. We finished spooling the new warps at 22:00 and headed back to shore to conduct a sphere calibration off Langstrand. We arrived at the calibration site at about 01:00 on the 22nd and finished calibrating both (38 kHz and 120 kHz) transducers successfully at 06:00.

It was decided to search for sardine in the south for up to 2 days, and if the search were unsuccessful, to continue searching in the north. Based on sardine aggregations found in the south on the Namibian sardine biomass survey three weeks before, a zigzag course track was set out between 23°00'S and 24°10'S and the 100 and 250 m isobaths. We broke off transect at 15:00 to trawl on some sardine-like shoals at the surface. However, there was no catch. Immediately afterwards, we repeated the trawl and caught 300 kg of snoek. Twenty snoek stomachs were opened, but all were empty. A tighter search grid was set out around the two trawl positions in order to find the sardine shoals. This mini-grid was completed at about 22:00 and we reverted to the original zigzag search pattern southwards.

At 03:00 on the 23rd, we found and identified several sardine shoals around 23°43’S and 13°56’S. A search grid was then conducted around this area to define the size of, and number of shoals in the area. Several large shoals were detected throughout the day. One trawl was conducted in the afternoon to identify the other pelagic fish in the area, juvenile horse mackerel.

A systematic survey grid, with 11 nautical miles (NM) long transects, 2 NM apart, was set out around 18:00 in order to record sardine shoals with the Echosounder and the SODAPS system, first during night time and then during the consecutive day. Very little was detected during the night time coverage. More shoals were detected in the northeastern part of the area in the morning of the 24th, but very few sardine shoals were detected during the course of the day, presumably because they had moved out of the area. After completion of the daytime coverage at 17:40 on the 24th, we started to search for sardine aggregations to trawl on. A CTD station was conducted at 18:20. At 22:36, we decided to go inshore and then northwards if we did not find any sardine again after searching the area.

At 6:15 on the 25th, a sardine shoal was detected and trawled on, and 2 tonnes of 10-12 cm sardines were caught. The search in the area continued and several more shoals were found. It was thus decided to map the area more thoroughly. A wider search grid was set out between Sandwich Harbour and Pelican Point, between 20-30 m bottom depth, and further into deeper water across to Wlotzkasbaken and we started logging raw data to the SODAPS system again at 10:10. After about 2h, we stopped to observe a single shoal to investigate if there was any consistent direction of movement. The shoal was followed for over an hour, showing little movement and change of integrity, with little dynamics in the shape of the shoal. We then started a search grid using E-W parallel transects, 2nm apart, starting from 22°44 and working northwards. A trawl was conducted at 15:00 after Transect 5, by which a lot of small but strong scatters showing on the sonar were determined to be mainly round herring.

Because there were not enough sardine shoals in the area to do a comprehensive study, the survey area was abandoned after Transect 6 at around 16:00, and we continued northwards. The towed body was tested on the way north, at 2 knots with gradually increasing speed until it reached survey speed at 10 knots. These tests showed that the body behaved well in the water. Very few sardine or other fish were detected on the sonar and echo sounder during the night.

At 06:00 on the 26th, we passed a purse seiner and the skipper reported having seen large shoals of sardine around Möwe Bay and northwards, and several days ago having seen large shoals at Sand Table Hill. We then started zigzag transects at 19°40 between 10-50 m bottom depths searching for sardine shoals. We found a few sardine shoals and some very dense horse mackerel shoals, north of Möwe Bay, but otherwise very little signs of life. We continued the search northwards along zigzag transects between 20-50 m bottom depths towards Cape Frio.
At 12:00 we conducted further towed body experiments, including tying the cable up using shackles so that the body could be lowered to 10 m. The experiments were successful.

During the early morning, 0:00-5:00 on the 27th, bioluminescence was observed at the bow of the vessel on the way north, with small patchy shoals being clearly visible on the surface. A surface trawl was done at about 04:00 to identify these fish. The trawl came up with mainly horse mackerel and jellyfish, and few round herring. The shoals we had observed were thus most probably horse mackerel. By 06:00 we still had found no sardine at Cape Frio, but after reports by three purse seiners, we decided to head back to the area south of Rocky Point. We searched the area between Rocky Point and just south of Möwe Bay, with zigzag transects between 15-30 m bottom depth without finding sardine during the day. A trawl was conducted at 15:30 to identify some dense patches visible on the sonar, which turned out to be horse mackerel. Observations of sardine-like shoals were made around 17:40 after sunset. A trawl at 17:45 gave only horse mackerel, but it was believed that we had missed the main target and we decided to search the shoal and try again. A second shoal was targeted at 20:00 with 5000 kg of fish being caught, about one half being sardine and the other half horse mackerel.

A mini survey was started at 21:30 on the 27th to map the distribution of sardine in the area, which ended at 03:35 on the 28th. We then turned back to find one of the previous sardine shoals to follow it into the coast at dawn. One shoal was found on the sonar, but lost very soon after that. Another shoal was found at about 0.5 NM inshore soon afterwards (possibly the same shoal). Once again we lost it almost immediately. A grid of tracks parallel to the coast working towards the south was started. During the 3rd transect, a purse-seiner reported on “good sardine shoals” about 1.5 NM south of our position in 65 m depth. We went there immediately and found a shoal, which we proceeded to lose and find three times. Eventually we gave up on this shoal and moved northwards searching between the transect lines, where we had seen shoals the night before. The whole day of the 28th was used to search for sardine shoals in shallow waters, 10-30 m depth. However, the few shoals that were detected disappeared from the sonar in a few minutes and we were not able to track them.

Since there were no sardine shoals in sight, we would not be able to do any work on sardine during the night. Thus, a target strength experiment on horse mackerel was initiated at 18:27, the experiment was ended at 00:44 on the 29th.

Two offshore transects were conducted from 01:00 to 05:30 on the 29th. Three sardine shoals were found and tracked for some time before they were lost. The direction of the shoals was consistently southwards during the tracking. A trawl was conducted in the morning on aggregations that looked like sardine, but turned out to be dense horse mackerel aggregations.

Another towed body trial was started at 8:00 to test the towed body during normal survey conditions, investigate differences in acoustic recordings between the two different transducers and to investigate vessel avoidance reactions recorded with the towed body. This was continued until the early afternoon, but despite transects extending far offshore and very close to the shore, very few fish were intercepted. It was therefore decided to terminate the towed body experiments and to leave this area, heading south along the coast in the hope of finding some suitable aggregations to work on during the final 30h of the cruise.

No shoals were detected on the Echosounder or Sonar by 06:00 on the 30th. However, after returning to Area 2 in the afternoon several small pilchard and anchovy schools where found, and the rest of the time of the survey was therefore spent in that area to map the distribution and school structure.After completing the survey midday on the 2nd of May the vessel arrived in Walvis Bay harbour around 19.30 in the evening.

1.5 Survey area

The survey area for the experiments was the Namibian shelf and coastal waters from 24°00'S to 18°00'S. The routine Namibian national acoustic sardine biomass survey had been completed just 7 days prior to the start of this cruise and therefore the information from this survey was used to determine the most likely areas where suitable concentrations of sardine would be found. Various search grids were conducted between Conception Bay (24°00'C) and Cape Frio (19°30'S). Three sets of experiments were conducted in areas where sardine were encountered (Figure 1). The first set was attempted in waters around 200-250 m deep south of Sandwich Harbour at 23°25'S (Area 1), while the second was conducted around 60 m bottom depth outside Swakopmund (Area 2). The final area (Area 3) was just south of Möwe Bay in 15 to 120 m bottom depth. Target strength experiments on horse mackerel were also conducted in Area 3 while the towed body experiments were conducted in Areas 2 and 3.

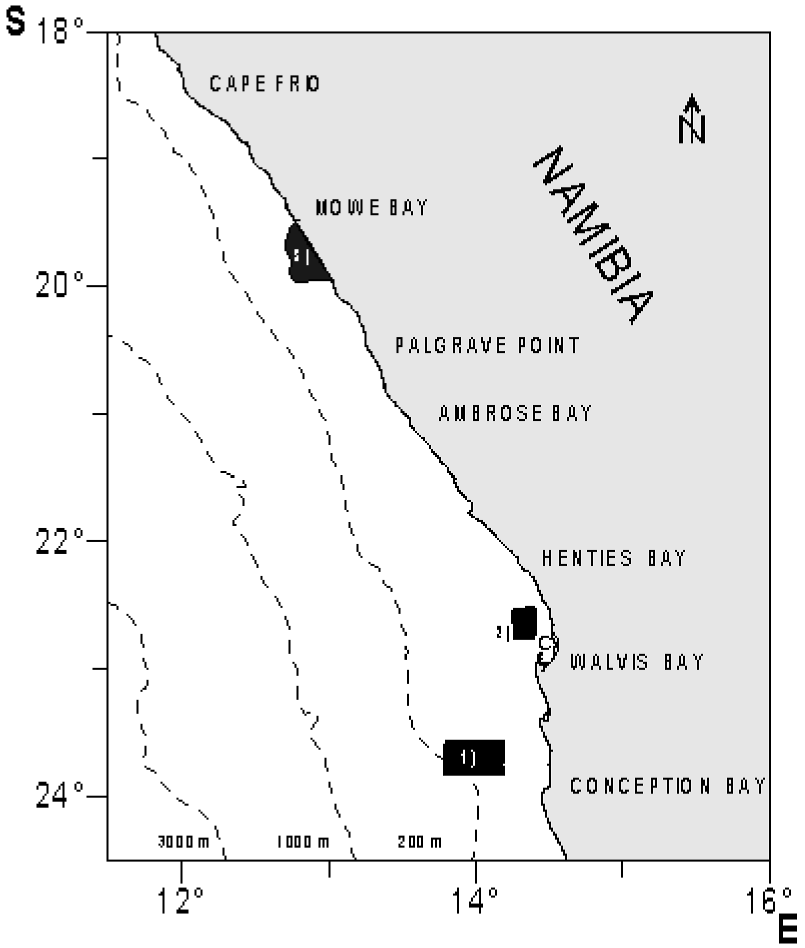


Figure 1. The Namibian coast. A calibration was conducted at Langstrand north of Walvis Bay (C). The squares indicate the positions of the three sonar mini survey experiments, the target strength experiment (2) and the towed body experiments (2 and 3).

CHAPTER 2 METHODS

2.1 Equipment and data collection

2.1.1 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 done regularly to obtain profiles of temperature, salinity and oxygen.

2.1.2 Multi-frequency echo sounder data sampling and analysis

Two SIMRAD EK500 echo sounders equipped with four acoustic transducers mounted on the submersible keel (Figure 2) operating at nominal frequencies of 18, 38, 120 kHz (split-beam, EK1) and 200 kHz (single-beam, EK 2) was available during the survey. The 120 kHz transceiver was disabled in shallow water because it interfered with the SF950 sonar. 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 first part of the survey until Sunday 27th April at 10h10 when it was retracted as the vessel entered shallow water. The offset on the EK500 was at the same time changed from 8 m to 5.5 m such that all acoustic data were referenced to the surface. All data were collected using GMT (local Namibian time minus 1)

The 38 and 120 kHz transceivers were calibrated at Langstrand on the 22/4 at the beginning of the survey. The technical specifications and the calibration reports are presented in Annex I.

The pulse duration and bandwidth of the 38, 120 and 200 kHz transceivers were set to medium/wide, long/narrow and short/wide respectively. The short pulse duration at 200 kHz was specifically selected to provide increased range resolution during target strength experiments. Logging of acoustic raw data was done using the Windows based SonarData_Echolog® Version 2.20.05 and the BEI system. Analysis and post processing of logged data was done using Sonardata_Echoview® Version 2.25.60 software.

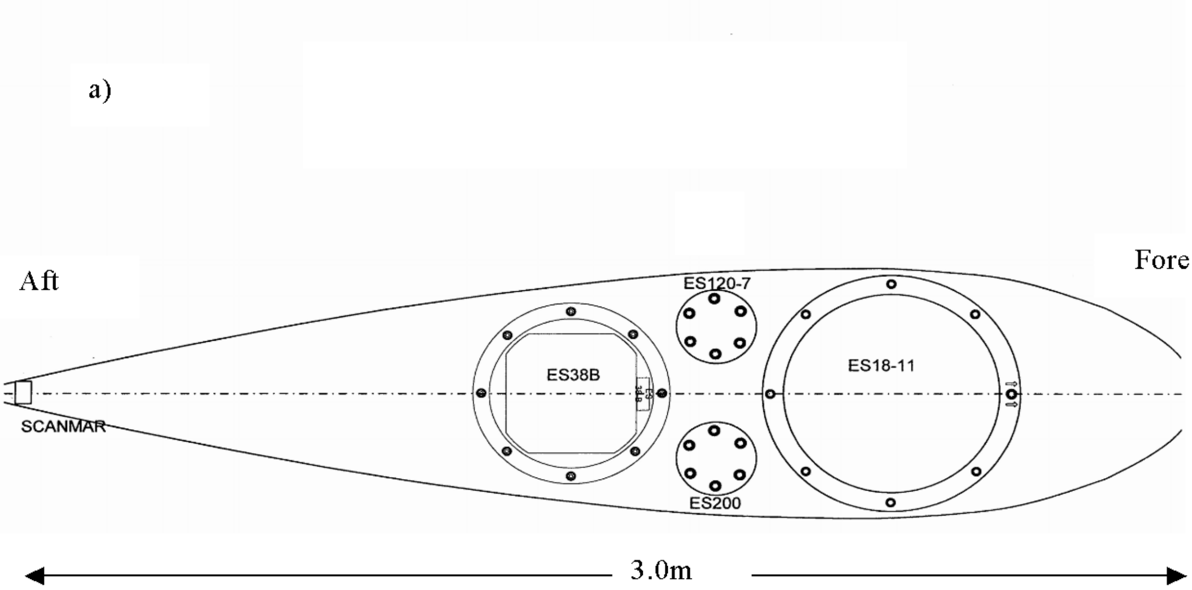


Figure 2. Transducer arrangement of the drop keel of R/V "Dr. Fridtjof Nansen" showing schematic illustration of the new orientation of the transducers on the keel (scale 1:10).

2.1.3 Sonar data sampling and analyses

Sonar data were recorded with the Simrad SF950 Fish School Detection Sonar operating at a frequency of 95 kHz in FM mode. The–SF950 is a high-resolution, multibeam, sector scanning sonar with sectorial transmission and multibeam reception. It can be operated in either single (CW) or multi-frequency (FM) modes and is capable of covering a 45° sector with 32 beams each 1.7° wide. The sector is mechanically trainable (± 200°) and tiltable (+10° to –90°). While surveying, the transducer was trained 90° to starboard with a tilt setting of –2°. A transducer gain of 3 was found to detect sardine shoals up to 600 m and effectively discriminated between these and other targets. The range setting was reduced on an ad hoc basis when used in shallow water or tracking individual fish schools.

The SODAPS (Sonar Data Processing System) was used for recording and post processing of data logged from the SF950 sonar. This UNIX-based system has been specified, modelled and coded during a co-operative R&D project between the IMR and Christian Michelsen Research AS (CMR), Bergen, Norway. The system is complex both in terms of its structure and performance. It runs comparative tests between every sample of the volume backscattering coefficient (s_v) for all 32 sonar beams and likewise between neighbouring beams - all in each ping return. During these detections it forms “echolines” and “echoblocks” and links consecutive pings to form echoblock chains or school candidates. Echolines, echoblocks and school candidates are all elements of potential schools. The software still requires further development and several problems were encountered making effective analyses of much of the data difficult (see Results and Discussion).

2.1.4 Trawl sampling

The sampling trawls used included the large pelagic trawl (30 m vertical opening), the small pelagic trawl (10 m vertical opening) and a bottom trawl (5 m vertical opening). The latter was often used in shallow waters with floats for midwater trawling. Tyborøn, 7.8 m^2, 1670 kg trawl doors were used in all hauls. The settings of the doors were those normally used during pelagic trawling. A summary of all trawl stations is found in Annex II.

A random sample of fish representative of the total catch was taken from the trawl, the size of the sample depending largely on the species mixture of the catch. In cases where the catch was small, the total catch was sampled. To determine the catch composition of the trawl the number and weight for each species in the random sample was recorded. This sample was then raised to the total catch. A random sample of about 100 fish per species, if available, was measured to the nearest 1 cm below total length to obtain the size composition of the catch. When the trawl data were used for identification purposes in the target strength experiments, standard biological data were also collected, viz. length-weight relationship (and hence condition factor), gonad and maturity states and stomach weights.

2.2 Experiments

2.2.1 *In situ* target strength experiments

It was not possible during the survey to obtain suitably dispersed pilchard layers for target strength experiments (see discussion). However, since these are important measurements for all pelagic species and the horse mackerel was well dispersed and perfect for such measurements, it was decided to conduct a target strength experiments in area 3 (Figure 1). The experiment was conducted in approx. 37 m of water over a period of 5 hours on the evening of 28 April. During this period three trawls (1284, 1285 and 1286) were conducted to confirm the species identity and provide length-frequency and biological data on species in the surveyed area (Figure 3). Oceanographic conditions were characterised by means of two CTD dips, one at the start and one at the end of the experiment. Of note was the strong oxycline evident at approx. 25 m. Echogram and echo trace data were simultaneously logged from both EK500 #1 (38 and 120 kHz) and EK500 #2 (200 kHz) using SonarData Echolog® software. Clocks on both EK500's were synchronised to GPS time during the course of the experiment to allow matching of ping time stamps at all three frequencies when post processing data. The ping rate was set to 1.2 seconds (the system default on the 'Dr. Fridtjof Nansen') and the sound speed to 1506 ms^{-1} in accordance with the results obtained from the CTD casts (Annex III, Station 523 and 524). A complete list of echosounder settings are provided in Table 1 while single target detector parameters, set in accordance with the goals of the experiment, are shown in Table 2.

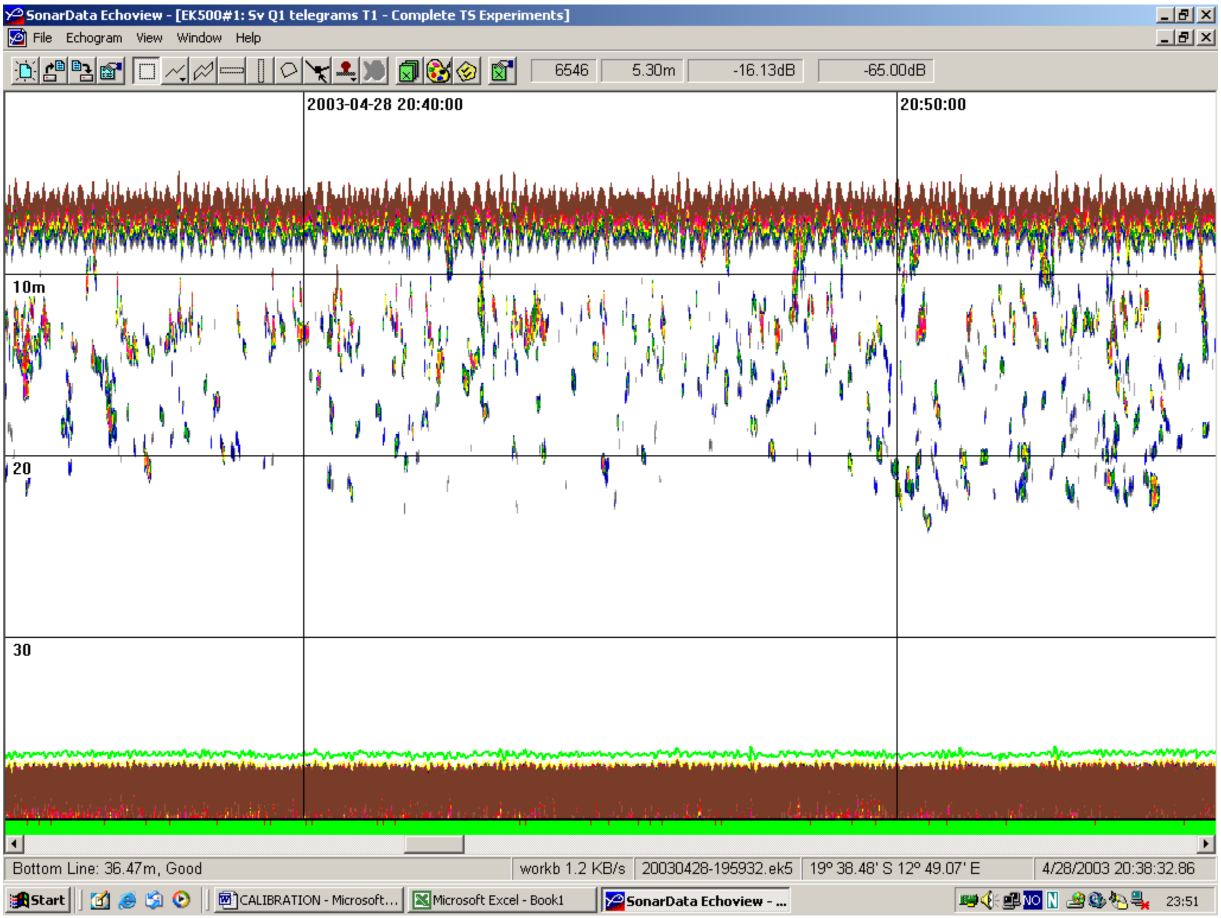


Figure 3. The dispersed layer of horse mackerel used for target strength investigations.

Table 1. EK500 transceiver settings during TS experiments.

PARAMETER	EK500#1			EK500#2
	1: 38 kHz	2: 120 kHz	3: 18 kHz[1]	1: 200 kHz
α (dB.km^{-1})	10,0	38,0	3,0	53,0
T_p (ms)	1,0	1,0	0,7	0,060
Bandwidth (kHz)	3,8	1,2	1,8	20,0
Power (W)	2000	1000	2000	1000
2-Way Beam Angle (dB)	-21,0	-20,6	-17,2	-20,5
SV Transducer Gain (dB)	27,01	25,75	23,86	24,62
TS Transducer Gain (dB)	27,14	25,90	23,61	25,95
Angle Sensitivity	21,9	21,0	13,9	
3 db Alongships Beamwidth (°)	6,8	7,3	11,1	
3 db Athwartships Beamwidth (°)	6,8	7,1	10,7	
Alongships Offset (°)	-0,05	0,00	0,07	
Athwartships Offset (°)	0,09	-0,24	-0,09	

1. Although 18 kHz data was logged, no data analysis is envisaged.

Table 2. Single target detector settings (all frequencies).

Parameter	Setting
Minimum threshold value (dB)	-65
Minimum echo length (normalised)	0,8
Maximum echo length (normalised)	1,5
Maximum gain compensation (dB)	6,0
Maximum phase deviation (phase steps)	5,0

The vessel was allowed to drift freely while target strength data was logged and data used for the preliminary analysis was confined to sectors corresponding most closely with the areas in which trawls were conducted.

Four techniques for estimating target strength from the recorded data will ultimately be considered during post processing. These are;

(i) Direct estimates using the internal single target screening algorithms of the EK500 echo sounder at 38 kHz applied to data logged in regions with low target densities.

(ii) Attempting to further reduce potential bias caused by the acceptance of overlapping echoes by testing the degree of correlation between the calculated and measured bearing of targets identified simultaneously at 120 and 38 kHz. Predicted positions at 120 kHz will be calculated with the bearing information obtained from targets detected at 38 kHz.

(iii) Using simultaneous target detections from the 200 kHz transceiver as a “range discriminator” to provide additional screening of targets logged at 38 kHz. Note that during the experiments, the 200 kHz system was set to operate at a pulse duration of 60 μs resulting in an approx. 17 fold improvement in the range resolution available when operating with a 1.0 ms pulse (as is the case at 38 kHz).

(iv) Applying the target screening algorithms implemented in the latest release (Version 3.0) of SonarData Echoview®.

For the purpose of this report, a preliminary target strength estimate was produced from EK500 (38 kHz) echo-trace data, screened in accordance with the single target detector settings shown in Table 2, and post processed via Echoview (i.e. as in (i) above). Additional visual screening to exclude regions where targets appeared to be more densely aggregated was applied during post processing.

2.2.2 School-group and school dynamics

Several areas of sardine schools (nominally defined as “school-groups”) were detected (see Section 2.2). In most instances, once the area of distribution of these school-groups was defined parallel east west transects were steamed across the region with a spacing of 2 NM. In each case an attempt was made to start and end the transects outside of the sardine school-group area. Coverages 2 and 3 of Area 2 were assessed using radiating square transects as there was insufficient time to define the area of distribution of the “school-group” prior to starting these surveys. This strategy seemed most appropriate in such a situation when the borders in all directions were unknown.

Standard echosounder data were collected at 38 kHz as per normal survey operations. These data were later scrutinised using Echoview and the biomass (total numbers and biomass per length-class) was calculated for each coverage of each area according to standard procedures (see Namibian sardine acoustic biomass survey reports for a full description of the methods).

The SF950 sonar was operated at a fixed range and bearing such that a swath to one side of the vessel was sampled (a belt transect as opposed to a line transect sampled with the vertical echosounder). The sonar data acquisition and processing software SODAPS was set to log aggregated information of all targets detected by the system. In addition, the sonar was continually monitored and the approximate size (small, medium or large), distance from vessel and position of all sardine targets was recorded manually.

The sonar data was scrutinised using SODAPS, although as noted in the Discussion, a number of bugs in the software precluded us from using this facility to its maximum capacity. The data recorded manually were used to assist the scrutinisation. In general, sardine schools were identified as those with clearly defined edges and giving a backscatter value above about -25 dB. However, given the low accuracy of such backscatter values (due to the considerable uncertainties in the scattering properties of fish assessed laterally – as opposed to vertically), these criteria were found to be rather imprecise and difficult to apply with any consistency. Trawling positively identified a number of large dense schools, but there was insufficient time to target weaker schools and hence the identity of such schools was uncertain.

Using the total estimated biomass for the area (from the echosounder data), the sonar data were analysed to estimate the mean surface density (kg/m^2) of the schools. Also the predicted numbers of interceptions of schools were compared with the actual interceptions by the vertical echosounder. This was based on the assumption that the cross-sectional areas of all schools were circular.

It must be noted that due to the problems encountered using SODAPS the scrutinisation process must be regarded as highly uncertain and needs to be thoroughly checked once the system is fully operational. The data from SODAPS reported in this report must therefore be considered preliminary, notably the area measurements of schools and hence all calculations of school density and interception rates.

2.2.3 Towed body trials

The FRS towed-body is a 1.6 m long depressor-controlled vehicle (Figure 4) fitted with an ES 38B 38 kHz split-beam transducer facing vertically downward. There is space in the vehicle for a number of higher frequency (e.g. 120 and 200 kHz) transducers, but none are fitted at this stage. The vehicle weighs approx. 140 kg in air (100 kg without the transducer) and is designed to be towed at speeds of up to 10 knots in the upper 50 m, depending on cable-handling capacity. In the present trials the vehicle was towed on a steel cable while electronic transmission was via a separate 9-core shielded conductor cable run directly from the transducer to the deck unit. The conductor cable (40 m long in this instance) was handled manually on deck; i.e. no winch was necessary. The vehicle is designed for target strength studies on pelagic species where it is necessary to shorten the range to the targets, and for use on vessels that are not fitted with adequate hull-mounted transducers for scientific work.

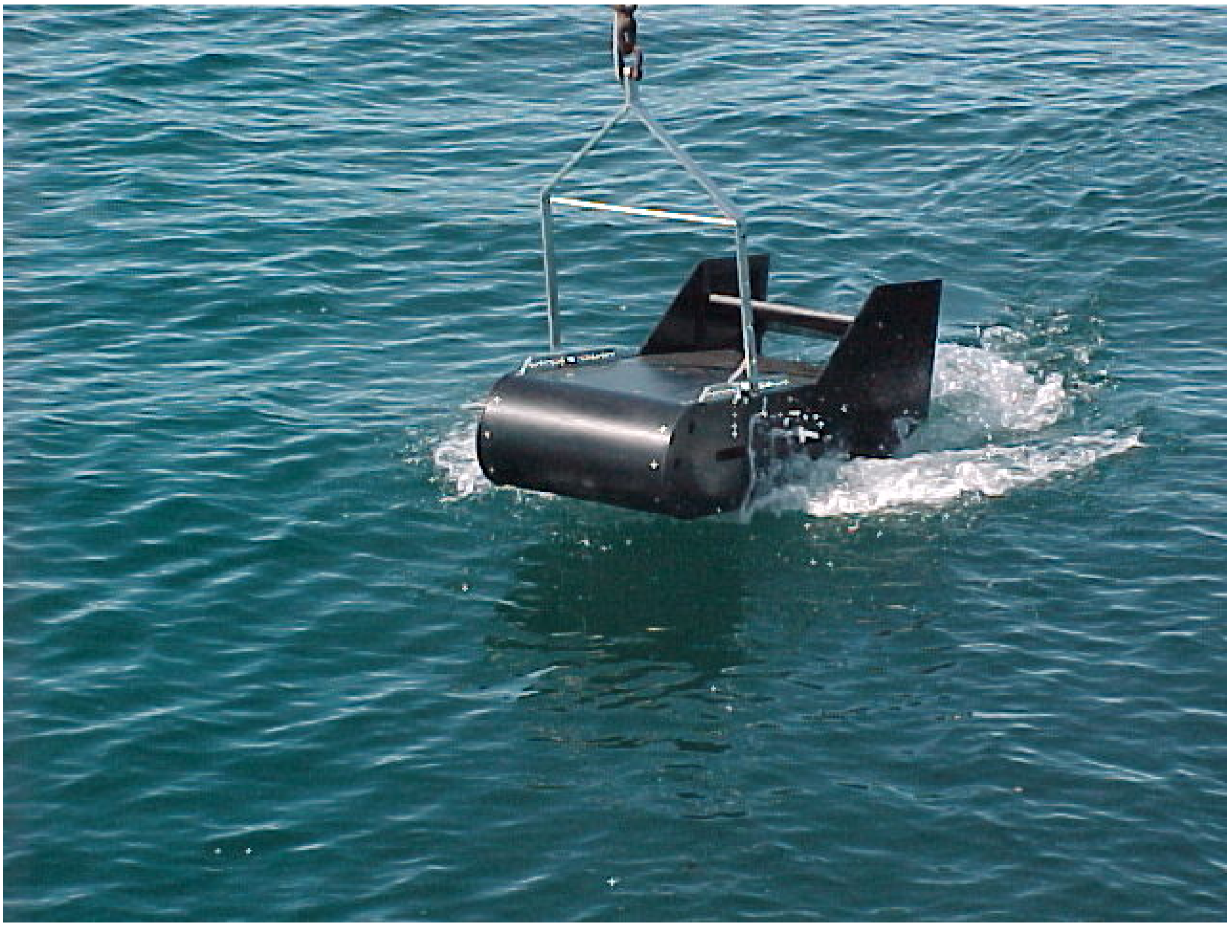


Figure 4. The towed body being retrieved.

2.2.4 Vessel avoidance

Experiments were planned to assess whether the sardine schools showed any reaction to an approaching vessel prior to being insonified by a hull-mounted echo sounder. It was planned to use the SF950 sonar to observe schools ahead of the vessel in conjunction with the MOB boat with a portable echo sounder (EY500). However due firstly to the general lack of sardine schools and secondly to the problems with the sonar these experiments were not attempted (see Discussion).

2.2.5 Signal attenuation

During the past two years an attempt has been made to assess the attenuation of the acoustic signal as it passes through dense sardine schools. The essence of this method is to estimate the level of attenuation from the reduction in the strength of the echo from the bottom beneath the school, taking the average bottom echo from areas around the school where there are no fish as a reference. This analysis has to date been conducted on about 250 suitable schools from both South Africa, but few have been extremely dense (with an $s_A > 1.000.000$ m^2 NM^{-2}).

Acoustic data were collected throughout the survey and a number of schools were transected that were extremely dense, often with maximum densities (s_V) greater than –15 dB and hence should provide useful information on extreme cases of attenuation. These were not analysed as it is planned that one of the Namibian students studying at Bergen University will use these data for her thesis.

CHAPTER 3

RESULTS

3.1 Fish distribution

Schools of sardine were found in all three areas, but they were widely dispersed and, few in number. It was not clear whether any of these areas could be considered a “school-group” in the normal sense. The number of schools of sardine found in the two areas surveyed with systematic transects, Area 1 and 2, was very low, with only 6 to 7 schools being intercepted by the vessel in each area, i.e. less than 1 school per hour, or 10 miles of transect (Figure 5). By comparison, the survey that preceded these experiments intercepted, on average, between 2 and 3 schools per hour in two regions close to Area 1. From previous surveys it is believed that schools in an area with ‘school groups’ in general are distributed in patchy clusters. There is however most probably more variation to this general observation and the schools during this survey did not clearly show this general pattern although some clustering inside the survey areas is evident from Figure 5.

The first area, offshore of Sandwich harbour in about 200 m water (Figure 5a and b), was centred between the two areas south of Walvis Bay where sardine were found during the preceding biomass survey, and it was therefore assumed that the schools were from one or the other of those areas. Only a few sardine were caught in this region. These had a similar length frequency distribution to the sardine sampled in this general area during the previous survey, which supports the conclusion that they were part of the same group. The estimated biomass in the region was around 5 000 t, a small fraction of the more than 200 000 t previously estimated for the area south of Walvis Bay, indicating that the main area of distribution in this region was not found.

A second group of sardine schools was found offshore of Swakopmund (Figure 5 c), in about 100 m of water in a region where no sardine were detected during the preceding survey. These fish had a modal length of 12 cm, a size class that was not found in the previous survey, confirming that this was a new “school-group” not previously detected.

The final area searched was around Möwe Bay (no Figure). During the previous survey it was estimated that there were almost 200 000 t of sardine just to the north of this region, but during these experiments only a few schools were found. They were distributed from just behind the surf zone to beyond the 100 isobath, covering a much greater depth range than in the previous survey, when the fish were concentrated closer inshore. Once again it could only be concluded that the main concentration found just two weeks previously was not found.

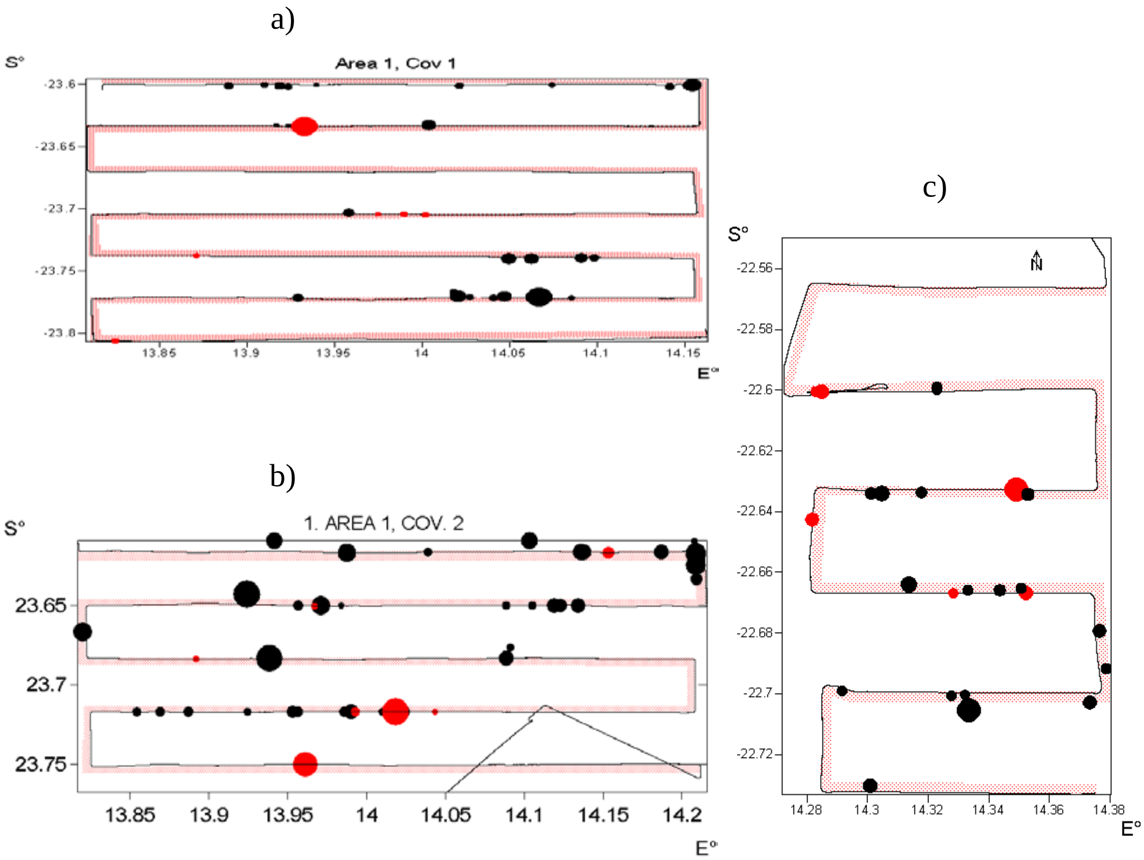


Figure 5. The cruise track in area 1, first a) and second b) coverage and in Area 2 coverage 1 c), The red layer show the area covered by the sonar while the positions of the detected schools are shown with black (Sonar) and red (Echo sounder) dots respectively.

3.2 Horse mackerel target strength experiments

The length frequency distributions of horse mackerel (*Trachurus capensis*) caught in the three trawls conducted during the course of the experiment are shown in Figure 6 below. Each trawl produced a bimodal distribution indicating the presence of at least two size classes measuring approx. 16 and 21 cm respectively. This split was not apparent in the TS distributions obtained however, and the overall mean length of fish measured in the three trawls (18.1 cm) was therefore used for calculation. In each case horse mackerel dominated the catch, both in terms of weight and number, generally exceeding the 95% limit - except for trawl 1285 where the “percentage by weight” was reduced to approx. 81% (Table 3). Other species present in the trawls included cape gurnard, pelagic gobies, west coast soles, bullrays and jellyfish.

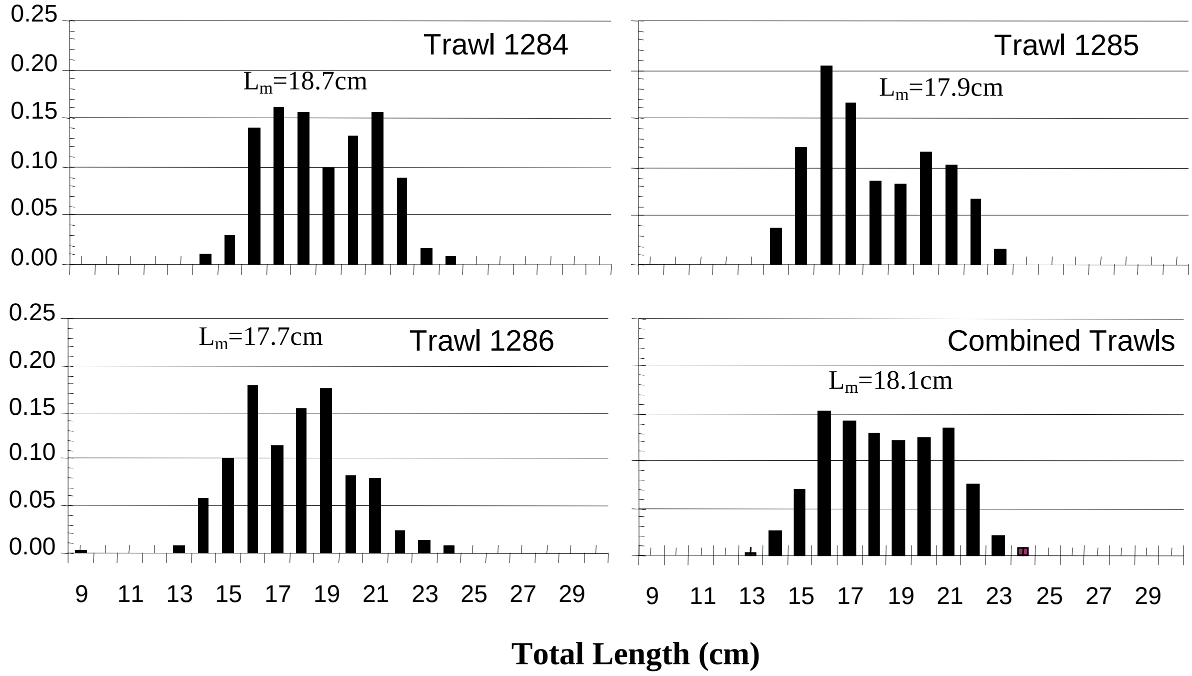


Figure 6. Individual and combined length-frequency distributions for horse mackerel obtained for the three trawls conducted during the target strength experiments. The mean (total) lengths for each distribution are also shown.

Table 3. Catch composition for the three trawls conducted during target strength experiments.

TRAWL	SPECIES	% by Weight	% by No.	Mean Weight (g)
1284	*T. trachurus capensis*	99,8	99,6	59,4
	Chelidonichthys capensis	0,2	0,4	33,3
1285	*T. trachurus capensis*	80,8	98,0	52,2
	Chelidonichthys capensis	3,3	1,0	210,0
	Myliobatis oquila	0,1	0,2	1900,0
	Sufflogobius bibarbatus	0,04	0,2	10,0
	Austroglossus microlepis	0,16	0,5	20,0
	Jelly	8,31	-	-
1286	*T. trachurus capensis*	95,4	99,0	53,5
	Chelidonichthys capensis	1,2	0,8	85,0
	Sufflogobius bibarbatus	0,7	0,2	200,0
	Jelly	2,8	-	-

The preliminary target strength distribution obtained is shown in Figure 7 below. The overall distribution is broad with primary peaks occurring at approx. –38.5 and –51 dB. The stronger of the two peaks (which can most likely be ascribed to horse mackerel targets) is pronounced, with a reasonably steep drop off either side of the peak. There are significant numbers of weaker targets present, which can most likely be ascribed to jellyfish and other small, unidentified scatterers.

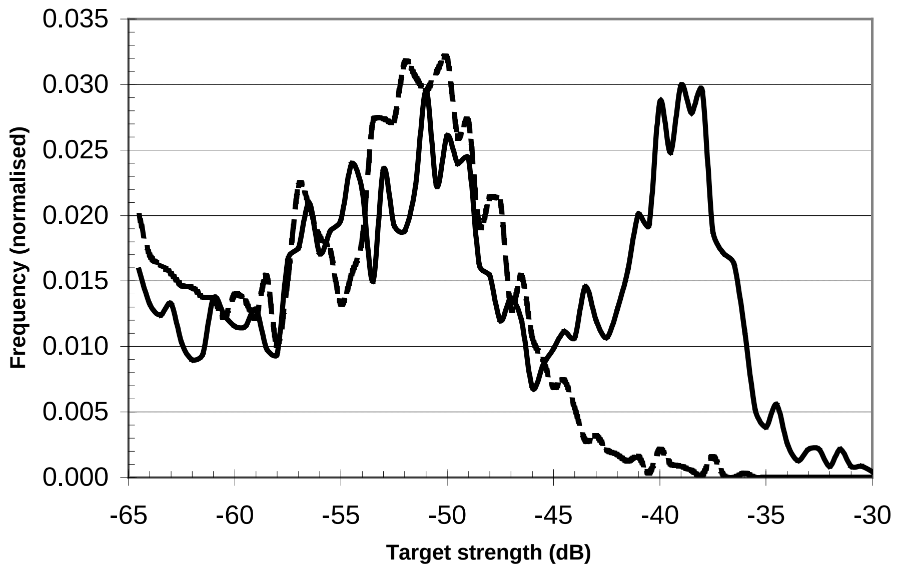


Figure 7. Target strength distributions obtained from TS experiments conducted on the evening of 28 April (solid curve) and from a weak background layer recorded during survey earlier on the same day (dashed curve).

Weak scattering layers with similar properties to those observed during these experiments were seen while surveying further offshore earlier on the same day. The recorded echogram (Figure 8) shows no evidence of horse mackerel targets in the vicinity of the observed layers. A rudimentary target strength distribution obtained from these layers was scaled and overlaid the overall TS distribution as shown in Figure 7 (dashed curve). The degree of correlation obtained is marked and tends to support the assumption that the weaker of the two peaks in the target strength distribution is not related to horse mackerel targets but to other weaker scattering organisms (jellyfish and plankton).

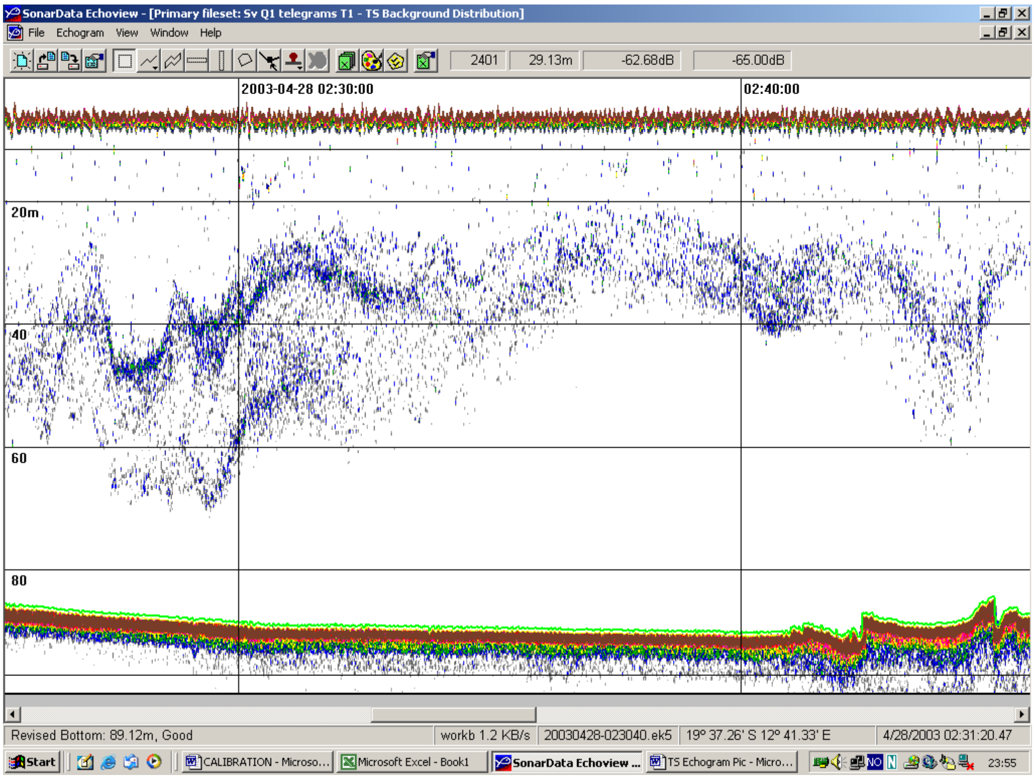


Figure 8. Weak scattering layers recorded during survey transects conducted during the day on 28 April.

As a result of these observations and to facilitate the calculation of a preliminary average target strength for the experiment, a decision was made to allocate the primary peak (at -38.5 dB) to horse mackerel. The lower end of the distribution was terminated at –46 dB to eliminate the influence of weaker targets on the overall result. This resulted in an average value of –38.9 dB (S.D. = 2.6 dB) with a B_{20} constant of. –64.1 dB which is approx. 1 dB above the highest value reported to date, viz. -65.2 dB by Svellingen and Ona, 1999. It should be noted however that this is a preliminary estimate which may be biased because of the presence of small numbers of larger scatterers in the distribution, (gurnard for example), or echoes arising from multiple targets which would lead to a positive bias in the estimate. Further analysis using multifrequency techniques, which provide improved rejection of overlapping echoes, will need to be completed before the validity of the estimate can be fully evaluated.

3.3 Comparison of sonar and echo sounder density estimates

The schools of sardine in both areas, although dense, were widely scattered. The sample size was therefore extremely low for this type of experiment and the results must be interpreted with this in mind.

As a consequence of the low number of schools intercepted by the echo-sounder, the echo-integration estimates of total biomass for these two areas was also very low (Table 4), while their CVs were rather high.

Table 4. Biomass estimates of the three areas surveyed calculated from the echo sounder recordings.

Area	Area 1, Coverage 1, Night	Area 1, Coverage 2, Day	Area 2, Day coverage
No. of schools	6	7	6
Biomass (t)	5783	8262	32946
CV (%)	57	44	55

The probability of school detection by the sonar seemed to be range dependent (Figure 9), although more samples are required to confirm this. The near range detection limit was set at 30 m and hence the number of schools detected at less than 50 m was naturally limited. The difficulty in identifying schools that are only in the beam for a short period further contributed to this low number. While the reduced beam volume close to the transducer may also have reduced the detectability close to the vessel, since at short range successive pings do not overlap, the schools tended to be so extensive that it is unlikely that any significant ones were missed between pings. Detection rates also seemed to decline beyond 150 m, this is consistent with earlier work on sardine schools in the region with this sonar.

Experiments conducted after Area 1 was surveyed indicated that sardine schools could be detected at a greater range than 300 m and indeed that this was one of the characteristics that permitted discrimination between sardine and other species. Therefore Area 2 was surveyed using a sonar range of 600 m.

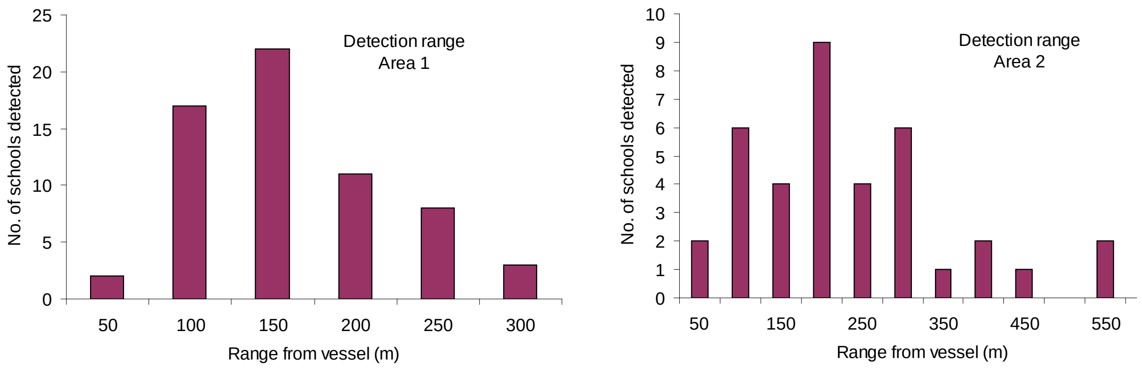


Figure 9. Range at which schools were detected by sonar.

Table 5 shows that the number of schools detected with the sonar in the three surveys varied from 16 to 33 and the average surface area from 159 to 679 m^2.

Table 5. Summary of the sardine schools detected using the SF950 sonar.

Area	Area 1, Coverage 1, Night	Area 1, Coverage 2, Day	Area 2, Day coverage
No. of schools	33	30	16
Average diameter (m)	14	13	26
Average surface area (m^2)	194	159	679
s.d.	31	21	181

Assuming that the schools were circular the average diameter ranged from 13 to 26 m. There is some indication that the diameter of schools detected tended to increase with range (Figure 10), suggesting that smaller schools were less detectable at greater ranges. However the sample size is small and, given the problems with SODAPS, such a finding needs more investigation.

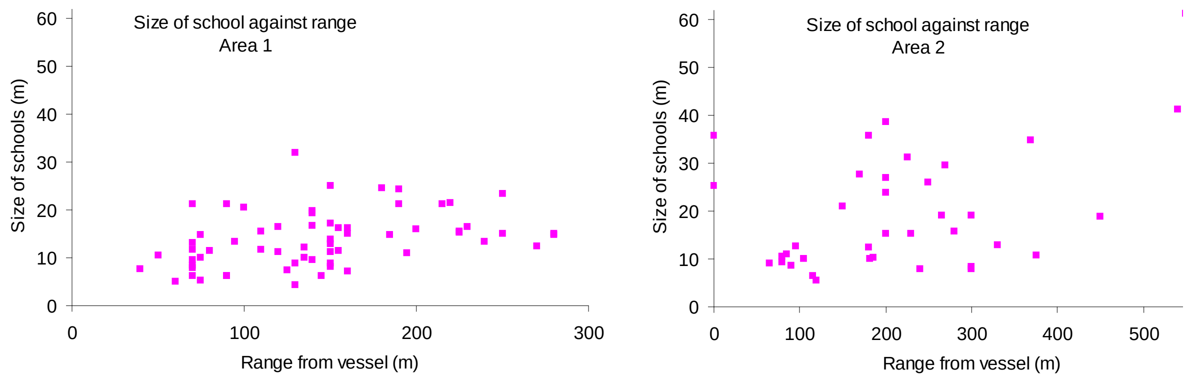


Figure 10. Diameter of schools detected by sonar vs range.

Taking the values in Table 5, and assuming the biomass estimated by the traditional vertical echo integrating method in each of the surveys to be correct, suggests that the mean surface densities of schools in the surveys ranged between 89 to 491 kg/m^2 (Table 6).

Table 6. Comparison between number of school interceptions and those predicted from sonar observations.

Area	Area 1, Coverage 1, Night	Area 1, Coverage 2, Day	Area 2, Day coverage
Mean density (kg/m^2)	115	89	491
Predicted number of echosounder interceptions	1.4	1.6	0.7
Actual number of echosounder interceptions	7	6	6
Predicted total number of schools per area	370	407	99

Table 6 shows that, based on the number of schools detected within the area searched by the sonar, the estimated total number in each area ranged from 99 to 407. From this, the expected number of school interceptions on the echo-sounder, assuming that all schools in the sonar range were detected, varied between 0.7 and 1.5 per survey. The actual numbers detected were some 5 to 10 times greater (Table 6). One possible interpretation is that the majority of the schools in the area were not detected by sonar, even within its optimum operating range. This appears to be a major question for further investigation.

A number of attempts were made to track individual schools in order to determine their movements, and interactions with other schools. The general lack of suitable schools meant that this type of experiment could not be attempted as frequently as had been hoped. It was also found that tracking individual schools with the SF950 sonar was difficult as the echo display tended to fade when a dense school remained in the beam for some time. It was suspected that a noise filter or thresholding software problem was occurring. In addition the system did not allow schools to be tracked automatically, or even the position of a school to be marked. Hence we found that it was rarely possible to follow a school for more than a few minutes at a time.

3.4 Towed body trials

Trial 1. 25 April.

The test was conducted in the late afternoon. The vehicle was towed 3 to 4 m from the ship's side from the after, starboard crane on 8 mm conductor-core steel rope. The environmental conditions were fine with sea state 2, 1 – 2 m swell. The conductor cable was strapped to the tow-rope over 3 m of its length and led to an EY 500 in the Fish Lab. The length of the strapping was limited by the height of the block above the gunwale.

The speed was varied in 5 steps between 2 and 10 knots over an approximately one hour period. Since the loose conductor cable had to be kept out of the water to avoid drag on the cable, the vehicle had to be kept shallower than 3 m. At this depth the vehicle appeared to track steadily approximately 3 m from the hull, with little lateral drift. Judging from the bottom echo, the depth varied by about a metre, which was probably due to periodic variations in height of the towing point with roll of the ship.

Rough measurements of towing angle made from the deck showed that the angle increased from about 20^o at 2 knots to about 35^o at 10 knots. The increase in angle from 6 to 10 knots was relatively slight (30 to 35^o), suggesting that the tow depth should remain relatively constant over this speed range, which is an attractive feature. These measurements suggest that with say 50 m of submerged conductor cable, a tow depth of 40 m should be achieved at 10 knots, although the additional cable drag may lift the vehicle somewhat. This suggests that the vehicle could be useful at full survey speed, and that there should be no difficulty in towing it at slow speed close to pelagic fish targets for target strength measurements in the upper 50 m or so. Some way of securing the conductor cable to the towing cable along the whole submerged length is necessary to reduce the drag on the cable. A fairing along a section of the cable close to the tow body may be necessary to reduce drag and cable-generated noise. This could also help to increase the towing depth at high speed.

Trial 2. 26 April.

The tests where conducted around midday, and the weather was still fine with sea state 2, 1 –2 m swell. Previous day's trials were repeated with 11 m of conductor cable strapped to the towrope. The first 3 m were tied to the towrope as before, and the remaining 8 m fixed to snap-hooks that slid along the cable. On launching these were collapsed at the top cable tie (3 m from the tow body), and then were pulled out by a rope fixed to the top hook as the tow-body was lowered, keeping the loose cable clear of the water at all times. This arrangement enabled the tow-body to be lowered to about 10 m from the surface.

With a fixed amount of towing cable, speed was varied between 6 and 10 knots. As speed increased, the tow-body depth decreased from 10m to 8m on average. The towing angle increased from about 33 to 37^{o}. The length of the conductor cable (about 40 m) limited the depth. There were short-term depth variations of 1 to 2 m, probably due to the roll of the ship. As speed increased the drag on the conductor cable (which was held by hand) increased to the point where it has difficult to hold. Some permanent way of relieving the strain is necessary Passive noise measurements were made at 10 knots and 4 knots, with the tow-body at 8 m and 10 m depths respectively. Noise started to show at –65 dB at around 500 m in both cases. It appeared to be reasonably constant, and was not obviously related to the propeller, which was probably within 10m of the tow-body. This test would have tended to over-estimate the noise since it was done in shallow water (30 m), where there would have been strong reflection of ship’s noise from the bottom. The tests should be repeated in deeper water.

Trial 3. 28 April.
The vehicle was towed at 10 knots for a continuous period of about 4 hours in the middle of the day, while steaming a survey grid consisting of west, south and east-going lines. The sea State was 3 to 4 with a south westerly swell, coming from the quarter except on the southerly line, which was almost into the sea.

The tow depth was approximately 3 m throughout the tow. The vehicle tracked steadily at this depth, and was not noticeably affected by the sea or the turns (to port). The strain on the conductor cable was relieved by a rope attached to the top ring, and was minimal. The bottom registration (at around 120 m) fluctuated by 1 to 2 m, again probably because of variations in the height of the towing point.

An attempt was made to inter-calibrate the EK500 and EY500 (towed transducer) systems using the bottom and scattering layers as references. For the first hour of the tow, s_A values from the bottom for the towed system were about 3 times lower than for the EK500, and then abruptly dropped to about 30 times lower (Figure 11), indicating a sudden loss of power and/or receiving sensitivity. The reason for this is not yet known, but on retrieval a crack was found in the cable, which is likely to have caused leakage. The transducer and cable need to be checked and the system fully calibrated before being used for quantitative work.

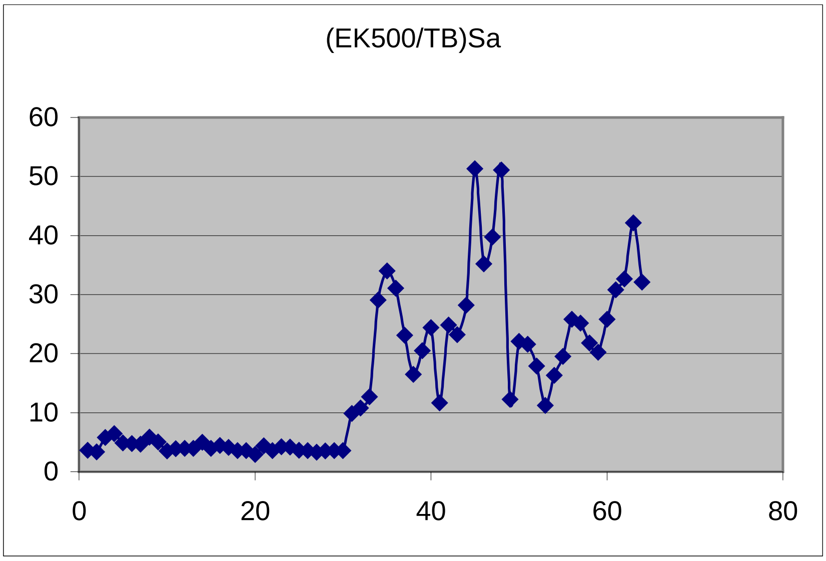


Figure 11. Ratio of s_A values for the bottom echo recorded by the hull and towed transducers, as a function of tow duration (in minutes).

An interesting observation (also observed on Trial 2) was that horse mackerel targets detected by the towed body were often steeply inclined, suggesting downward avoidance, which was not observed on the hull-mounted transducer. An example is shown in Figure 12**.** It is possible that the fish were reacting to the noise from the engine room as they passed between the hull and towed transducer. Also, in some of the records, scattering layers detected by the towed transducer were clearly deeper than when detected less than 10 seconds earlier by the hull transducer, possibly indicated rapid downward avoidance. These observations indicate that the towed transducer could be a useful tool in avoidance studies.

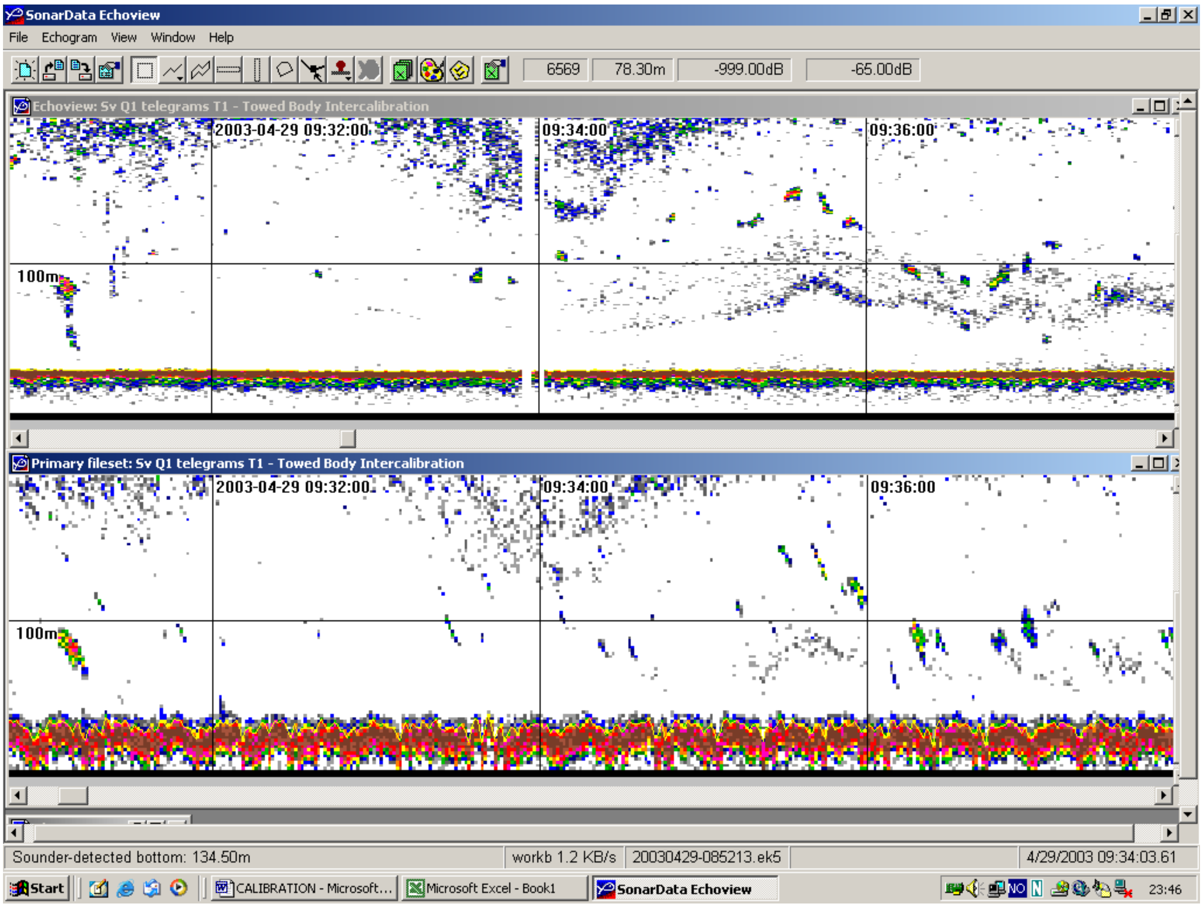


Figure 12. Comparison of echograms from EK500 (top) and towed body (bottom). Note slanted targets in bottom panel, indicative of downward avoidance. Targets are probably horse mackerel.

Noise measurements were made at 10 knots in about 120 m of water. The noise level at 600 m range was about -65 dB, slightly lower than that measured during Trial 1 in about 35 m of water. The tests need to be done in at least 200 m of water, and the towed body moved further from the propeller, either by towing it on a longer cable or by towing from further forward.

3.5 Vessel avoidance experiments

While specific experiments to observe the reaction of schools to the survey vessel could not be attempted, some interesting observations were noted on the towed body echograms (see Section 3.4 on towed body trails).

CHAPTER 4

DISCUSSION

Much of this survey was spent in trying to find suitable concentrations of sardine schools to conduct the experiments listed in the objectives. However, despite a number of school-groups having been found during the acoustic biomass survey immediately preceding the cruise, we were unable to find any such groups. Although sardine schools were found in three areas, in each case the schools were scarce and widely dispersed. It has to be concluded that the typical school-groups recorded just two to three weeks earlier were not found. In two of the areas where schools were found, the water was fairly deep (for sardine). While it is common for sardine schools to be more widely spread in deeper water, in this case the size of these areas, and in particular the scarcity of schools, was extreme.

The problems encountered on this cruise emphasized the need for a specialized survey design to enable valid biomass estimates to be obtained. The method currently used for sardine in Namibia, a two-stage adaptive design, with three vessels searching for school-groups, has addressed this. However, with the recent increase in the biomass and number of school-groups, this strategy urgently needs reviewing. Annex V proposes an alternative strategy combining aerial night time school detection with more traditional ship-borne acoustics. It is suggested that such a strategy may be a particularly cost-effective method of surveying widely dispersed schools occurring over large areas.

This survey also highlighted the necessity of having appropriate sonar for searching. The SF950 is designed to provide high-definition images of schools, but proved to be unsuitable for finding fish schools other than at relatively short range. A low-frequency omni-sonar would be more suitable, although of course such a unit would be largely unsuitable for behavioural studies. The problems of tracking individual schools with the SF950 sonar were also experienced in the previous sardine experimental survey in 2002. The instrument seems to have a number of software (and possibly hardware) problems that cause loss of signal from time to time. If these could be solved, it would make the unit much more useful. Additionally many of the options for tracking targets have been removed, or have not yet been activated. They should be re-instated and/or activated, since they are needed for behavioural experiments.

SODAPS has several software bugs that make it virtually unusable at present. The system has great potential for collecting and analysing extremely valuable data on school size and density, but the development of the system needs to be finalised first. A full report of problems experienced with the SF950 and SODAPS has been forwarded to IMR.

It is clear that in the northern Benguela densities in sardine schools at night are far too high to enable single fish to be resolved, even with multi-frequency single-target recognition systems. Thus precludes target strength estimation by conventional *in situ* techniques. Namibia and Angola will therefore have to rely on *in situ* target strength expressions developed in South Africa, where sardine tend to form scattering layers at night which are more suitable for target strength estimation.

In contrast, some very good *in situ* target strength data on dispersed horse mackerel were collected during the cruise. Preliminary analysis of these data gave target strengths which are much higher than those used at present to estimate the biomass of this species in Namibia. The TS of the physoclist horse mackerel might, however be expected to vary substantially. A range of other studies also supports this. See Axelsen et al. 2003 for a summary of published TS values for horse mackerel.

Vessel avoidance experiments were not possible due to the shortage of schools on which to conduct them. However some interesting information on vessel avoidance by horse mackerel schools was obtained with the towed transducer, which showed a clear diving reaction immediately towards the stern (and side) of the vessel. The fact that such behaviour was not evident from recordings made with the keel-mounted transducer, suggests that these fish were diving in reaction to the vessel passing over them. Whether this reaction had already started by the time the fish were insonified by the keel-mounted system (which would affect abundance estimates), is not clear.

Despite the general lack of sardine, which made it difficult (in some cases impossible) to conduct all of the planned experiments, and the problems experienced with the sonar and SODAPS, some useful results were achieved during this cruise. These include the successful trials with the towed body, the evidence of avoidance obtained from it, the apparently good data on horse mackerel target strength, and the progress made in implementing SODAPS, notwithstanding the problems encountered. Furthermore, the cruise was effective in highlighting the particular problems of surveying sardine in Namibia at present, and the need for new approaches.

ACKNOWLEDGEMENTS

This work was funded by the Benguela Environment Fisheries Interaction and Training Programme (BENEFIT) and the Nansen programme. We wish to extend warm thanks the crew onboard R/V 'Dr. Fridtjof Nansen' and to the skippers on the purse seiners who readily provided information on the distribution of fish throughout the survey.

REFERENCES

J. Coetzee, D. Boyer, I. Hampton, H. Boyer and A. Kreiner. Correcting acoustic estimates of fish density for absorption in dense schools. Submitted. *ICES J. mar. Sci.*

D.A. Demer, M.A. Soule and R.P. Hewitt, 1999. A multiple-frequency method for potentially improving the accuracy and precision of in situ target strength measurements. *J. Acoust. Soc. Am.* 105(4)

Axelsen, B. E., Bauleth-D'Almeida G., and A. Kanandjembo 2003. *In* situ measurements of the acoustic target strength of Cape horse mackerel *Trachurus trachurus capensis*. South African Journal of Marine Science. In press.

Svellingen, I. and E. Ona 1999. A summary of target strength observations on fishes from the shelf off West Africa. In Proceedings from The 137 Meeting of the Acoustical Society of America and The Second Convention of the European Acoustics Association. Berlin 14-19 March 1999. File: 2PAO_2.pdf (available on CD only).

Annex I Sphere calibration

A sphere calibration of the SIMRAD EK500 echo sounder was performed off Langstrand early on the morning of the 22nd April in near perfect conditions, the wind having abated considerably since the previous evening. The vessel was anchored fore and aft (after the weighted bowline was passed beneath the hull) in approx. 29 m water, the 38.1 mm tungsten carbide (WC) calibration sphere being deployed without incident and appearing almost immediately on the EK500 display. All equipment settings were checked; the draft offset was set to zero (for all transceivers) and the revised sound speed of 1503,6 ms^{-1} (obtained from the CTD) was entered into the *sound velocity* menu on both EK500's.

Calibration was confined to the 38 and 120 kHz split beam transceivers, which were used for multi-frequency target strength experiments during the cruise. The pulse duration and bandwidth settings for the two transceivers were *medium/wide* and *long/narrow* respectively. (These settings translate directly to a 1 ms transmitted pulse at both frequencies with corresponding receiver bandwidths of 3.8 and 1.2 kHz for the 38 and 120 kHz systems respectively). The 200 kHz transceiver was set to operate at the short (60 μs) pulse duration (wide, 20 kHz bandwidth) for the duration of the cruise and was used primarily to provide improved range discrimination when conducting target strength experiments. No quantitative backscatter information was derived from the 200 kHz system.

Conditions were sufficiently calm to allow calibration of both the TS and SV transducer gains at both frequencies. At 38 kHz the initial on-axis measurements of sphere TS (-42.55 dB) and corresponding S_A value (1301 m^2/NM^2 at 15m), indicated a slight decrease in sensitivity since the system was last calibrated (on 27-09-2002). After changing the gain settings and monitoring the results over a number of iterations, the transceiver TS and SV gain settings were revised to 27.14 and 27.01 dB respectively. A LOBE plot conducted with the 38 kHz beam offsets set to zero confirmed the TS_{gain} setting and resulted in a slight change to the previously measured beam parameters (Table A.1).

At 120 kHz the initial on-axis sphere TS was measured to be –40.4 dB, i.e. approx. 0.9 dB lower than the expected nominal value of –39.5 dB (C=1500 ms^{-1}). A corresponding drop of approx. 0.7 dB in the expected (theoretical) S_A value (2412 m^2/NM^2) was also noted. While shifts in transducer and transceiver sensitivity are to be expected with time (particularly at 120 kHz, which appears to be more prone to such variability), changes of this magnitude (a two-way error of approx. 38%) over a period of 7 months are cause for some concern and probably justify an investigation into the possible cause of the apparent instability. The final calibrated values for the 120 kHz transceiver were 25.75 and 25.90 dB for the SV and TS transducer gains respectively.

Calibration sheet I

Vessel: Dr. Fridtjof Nansen	Date: 22.04.2003	Place: Langstrand, Namibia
Echosounder: EK-500-1	Bottom depth: 28 m	Sphere depth: 15.0 m
Transducer ES38-B		T, Sphere depth 13.64 °C
Sound velocity: 1504 m/s	Sphere: WC 38.1	S, Sphere depth 35.3 ‰
Frequency: 38 kHz		TS sphere –42.3 dB

Parameter	Previous values	Values after calibration
Transducer depth	0.0	5.5
Absorption coefficient (dB/km)	10	10
Pulse duration (ms)	Medium	Medium
Bandwidth (kHz)	Wide	Wide
Transmission effect re. Terminals (W)	2000	2000
Equivalent beam width (10 log ψ) (dB)	-21	-21
Sv transducer gain (dB)	27.18	27.01
TS transducer gain (dB)	27.26	27.14
Angle sensitivity alongship	21.9	21.9
Angle sensitivity atwardship	21.9	21.9
3 dB beamwidth Alongship (deg)	6.9	6.8
3 dB beamwidth Atwardship (deg)	6.9	6.8
Alongship deviation from centre (deg)	0	-0.05
Atwardship deviation from centre (deg)	-0.12	0.09

TS reading Sphere before Calibration	-42.6 dB
Read s_A before calibration (m^2/NM^2)	1260
Theoretical s_A at sphere depth (m^2/NM^2)	1414
S_A sphere after calibration (m^2/NM^2)	1404

Kalibration conducted by: Mike Soule, Tore Mørk

Calibration sheet II

Vessel: Dr. Fridtjof Nansen	Date: 22.04.2003	Place: Langstrand, Namibia
Echosounder: EK-500-1	Bottom depth: 28 m	Sphere depth: 15.0 m
Transducer 120-7		T, Sphere depth 13.64 °C
Sound velocity: 1504 m/s	Sphere: WC 38.1	S, Sphere depth 35.3 ‰
Frequency: 120 kHz		TS sphere –39.6 dB

Parameter	Previous values	Values after calibration
Transducer depth	0.0	5.5
Absorption coefficient (dB/km)	38	38
Pulse duration (ms)	Long	Long
Bandwidth (kHz)	Narrow	Narrow
Transmission effect re. Terminals (W)	1000	1000
Equivalent beam width (10 log ψ) (dB)	-20.6	-20.6
Sv transducer gain (dB)	26.4	25.75
TS transducer gain (dB)	26.46	25.9
Angle sensitivity alongship	21.0	21.0
Angle sensitivity atwardship	21.0	21.0
3 dB beamwidth Alongship (deg)	7.3	7.3
3 dB beamwidth Atwardship (deg)	7.1	7.1
Alongship deviation from centre (deg)	0	0
Atwardship deviation from centre (deg)	-0.24	-0.24

TS reading Sphere before Calibration	-40.4 dB
Read s_A before calibration (m^2/NM^2)	1670
Theoretical s_A at sphere depth (m^2/NM^2)	2412
S_A sphere after calibration (m^2/NM^2)	2414

Kalibration conducted by: Mike Soule, Tore Mørk

Annex II Trawl stations

```
R/V "DR. FRIDTJOF NANSEN"        PROJECT:BE      PROJECT STATION:1272
DATE:22/ 4/03            GEAR TYPE: PT No: 2  POSITION:Lat   S  2324
         start   stop   duration                       Long  E  1346
TIME  :15:25:57 15:46:46  21  (min)  Purpose code:  1
LOG   :6267.70  6269.12  1.42        Area code    : 2
FDEPTH:     10       10              GearCond.code:
BDEPTH:    160      158              Validity code:
       Towing dir:  71ø  Wire out: 170 m  Speed: 40 kn*10

  Sorted:     Kg      Total catch:      6.36    CATCH/HOUR:     18.17
```

SPECIES	CATCH/HOUR weight	numbers	% OF TOT. C	SAMP
J E L L Y F I S H	14.29		78.65	
Thyrsites atun	3.86	3	21.24	
Trachurus capensis, juvenile	0.03	17	0.17	6182
Total	18.18		100.06	

```
R/V "DR. FRIDTJOF NANSEN"        PROJECT:BE      PROJECT STATION:1273
DATE:22/ 4/03            GEAR TYPE: PT No: 2  POSITION:Lat   S  2324
         start   stop   duration                       Long  E  1348
TIME  :16:30:23 17:13:32  31  (min)  Purpose code:  1
LOG   :6272.91  6274.99  1.91        Area code    : 2
FDEPTH:     25       25              GearCond.code:
BDEPTH:    162      159              Validity code:
       Towing dir: 251ø  Wire out:  90 m  Speed: 30 kn*10

  Sorted:     Kg      Total catch:    260.00    CATCH/HOUR:    503.23
```

SPECIES	CATCH/HOUR weight	numbers	% OF TOT. C	SAMP
Thyrsites atun	504.48	412	100.25	6183
Total	504.48		100.25	

```
R/V "DR. FRIDTJOF NANSEN"        PROJECT:BE      PROJECT STATION:1274
DATE:23/ 4/03            GEAR TYPE: PT No: 2  POSITION:Lat   S  2344
         start   stop   duration                       Long  E  1356
TIME  :03:02:00 03:02:14  17  (min)  Purpose code:  1
LOG   :6368.82  6369.94  1.07        Area code    : 2
FDEPTH:     10       10              GearCond.code:
BDEPTH:    182      185              Validity code:
       Towing dir: 155ø  Wire out: 160 m  Speed: 40 kn*10

  Sorted:     Kg      Total catch:    132.44    CATCH/HOUR:    467.44
```

SPECIES	CATCH/HOUR weight	numbers	% OF TOT. C	SAMP
J E L L Y F I S H	423.53		90.61	
Thyrsites atun	33.71	18	7.21	6185
Sardinops ocellatus	9.92	120	2.12	6184
Todarodes sagittatus	0.28	7	0.06	
Total	467.44		100.00	

```
R/V "DR. FRIDTJOF NANSEN"        PROJECT:BE      PROJECT STATION:1275
DATE:23/ 4/03            GEAR TYPE: PT No: 3  POSITION:Lat   S  2342
         start   stop   duration                       Long  E  1354
TIME  :05:02:59 05:04:20  30  (min)  Purpose code:  1
LOG   :6377.35  6379.13  1.78        Area code    : 2
FDEPTH:    150      150              GearCond.code:
BDEPTH:    179      176              Validity code:
       Towing dir:  90ø  Wire out: 450 m  Speed: 30 kn*10

  Sorted:     Kg      Total catch:     25.23    CATCH/HOUR:     50.46
```

SPECIES	CATCH/HOUR weight	numbers	% OF TOT. C	SAMP
J E L L Y F I S H	49.20		97.50	
Merluccius capensis	0.64	6	1.27	6186
Chelidonichthys capensis	0.50	2	0.99	6187
Todarodes sagittatus	0.08	2	0.16	
PHOTICHTHYIDAE	0.04	40	0.08	
Total	50.46		100.00	

```
R/V "DR. FRIDTJOF NANSEN"        PROJECT:BE      PROJECT STATION:1276
DATE:23/ 4/03            GEAR TYPE: PT No: 2  POSITION:Lat   S  2343
         start   stop   duration                       Long  E  1408
TIME  :14:07:56 14:09:28  30  (min)  Purpose code:  1
LOG   :6460.28  6462.21  1.92        Area code    : 2
FDEPTH:     10       10              GearCond.code:
BDEPTH:    149      150              Validity code:
       Towing dir: 344ø  Wire out: 160 m  Speed: 40 kn*10

  Sorted:  33 Kg      Total catch:   1000.00    CATCH/HOUR:   2000.00
```

SPECIES	CATCH/HOUR weight	numbers	% OF TOT. C	SAMP
Trachurus capensis, juvenile	1240.00	139662	62.00	6188
J E L L Y F I S H	726.88		36.34	
Etrumeus whiteheadi	20.26	490	1.01	6189
Total	1987.14		99.35	

```
R/V "DR. FRIDTJOF NANSEN"        PROJECT:BE      PROJECT STATION:1277
DATE:25/ 4/03            GEAR TYPE: PT No: 1  POSITION:Lat   S  2242
         start   stop   duration                       Long  E  1420
TIME  :05:49:29 05:57:55   8  (min)  Purpose code:  1
LOG   :6849.34  6849.94  0.59        Area code    : 2
FDEPTH:     20       20              GearCond.code:
BDEPTH:     69       68              Validity code:
       Towing dir:  10ø  Wire out: 150 m  Speed: 40 kn*10

  Sorted:  35 Kg      Total catch:   2000.00    CATCH/HOUR:  15000.00
```

SPECIES	CATCH/HOUR weight	numbers	% OF TOT. C	SAMP
Sardinops ocellatus	13651.80	729570	91.01	6191
J E L L Y F I S H	837.75		5.59	
Trachurus capensis, juvenile	429.53	81998	2.86	6192
Engraulis capensis	80.78	8925	0.54	6190
Total	14999.86		100.00	

```
R/V "DR. FRIDTJOF NANSEN"        PROJECT:BE      PROJECT STATION:1278
DATE:25/ 4/03            GEAR TYPE: PT No: 2  POSITION:Lat   S  2236
         start   stop   duration                       Long  E  1418
TIME  :14:54:39 14:54:49      (min)  Purpose code:
LOG   :6915.70  6915.71  0.01        Area code    :
FDEPTH:     10       10              GearCond.code:
BDEPTH:     69       69              Validity code:
       Towing dir:  90ø  Wire out: 160 m  Speed: 40 kn*10

  Sorted:  26 Kg      Total catch:    300.00    CATCH/HOUR:  18000.00
```

SPECIES	CATCH/HOUR weight	numbers	% OF TOT. C	SAMP
Etrumeus whiteheadi	15678.60	656340	87.10	6195
J E L L Y F I S H	1222.80		6.79	
Trachurus capensis, juvenile	472.20	25020	2.62	6194
Sardinops ocellatus	326.40	19440	1.81	6196
Engraulis capensis	298.80	20820	1.66	6193
Total	17998.80		99.98	

```
R/V "DR. FRIDTJOF NANSEN"        PROJECT:BE      PROJECT STATION:1279
DATE:27/ 4/03            GEAR TYPE: PT No: 2  POSITION:Lat   S  1834
         start   stop   duration                       Long  E  1202
TIME  :02:45:27 03:00:14  15  (min)  Purpose code:
LOG   :7260.77  7261.69  0.88        Area code    :
FDEPTH:      1        1              GearCond.code:
BDEPTH:     47       43              Validity code:
       Towing dir: 310ø  Wire out: 160 m  Speed: 40 kn*10

  Sorted:  33 Kg      Total catch:    750.00    CATCH/HOUR:   3000.00
```

SPECIES	CATCH/HOUR weight	numbers	% OF TOT. C	SAMP
Aequorea aequorea	1869.20		62.31	
Trachurus capensis	927.68	22220	30.92	6197
Etrumeus whiteheadi	194.76	10060	6.49	6198
Sardinops ocellatus	6.44	92	0.21	6199
Engraulis capensis	1.84	92	0.06	6200
Total	2999.92		99.99	

```
R/V "DR. FRIDTJOF NANSEN"        PROJECT:BE      PROJECT STATION:1280
DATE:27/ 4/03            GEAR TYPE: PT No: 1  POSITION:Lat   S  1927
         start   stop   duration                       Long  E  1244
TIME  :15:19:15 15:34:10  15  (min)  Purpose code:  1
LOG   :7365.83  7366.79  0.95        Area code    : 2
FDEPTH:      1        1              GearCond.code:
BDEPTH:     33       30              Validity code:
       Towing dir: 340ø  Wire out: 160 m  Speed: 40 kn*10

  Sorted:  29 Kg      Total catch:    150.00    CATCH/HOUR:    600.00
```

SPECIES	CATCH/HOUR weight	numbers	% OF TOT. C	SAMP
Trachurus capensis	306.80	2900	51.13	6201
J E L L Y F I S H	286.44		47.74	
Chelidonichthys capensis	3.96	84	0.66	6204
Etrumeus whiteheadi	1.44	40	0.24	6202
Engraulis capensis	1.04	40	0.17	6203
Trachipterus sp.	0.20	20	0.03	
Total	599.88		99.97	

```
R/V "DR. FRIDTJOF NANSEN"        PROJECT:BE      PROJECT STATION:1281
DATE:27/ 4/03             GEAR TYPE: PT No: 3  POSITION:Lat   S  1934
         start   stop  duration                          Long  E  1246
TIME  :17:54:07 17:58:55   5  (min)  Purpose code:  1
LOG   :7381.68  7382.05  0.36         Area code    : 2
FDEPTH:     10       10               GearCond.code:
BDEPTH:     39       39               Validity code:
       Towing dir:  40ø  Wire out: 130 m  Speed: 40 kn*10

  Sorted:  26 Kg      Total catch:    3000.00    CATCH/HOUR:  36000.00
```

SPECIES	CATCH/HOUR weight	numbers	% OF TOT. C	SAMP
Trachurus capensis	36000.00	459780	100.00	6205
Total	36000.00		100.00	

```
R/V "DR. FRIDTJOF NANSEN"        PROJECT:BE      PROJECT STATION:1282
DATE:27/ 4/03             GEAR TYPE: PT No: 3  POSITION:Lat   S  1931
         start   stop  duration                          Long  E  1244
TIME  :20:29:12 20:39:29  10  (min)  Purpose code:  1
LOG   :7397.41  7398.06  0.65         Area code    : 2
FDEPTH:     10       10               GearCond.code:
BDEPTH:     50       48               Validity code:
       Towing dir:     ø  Wire out: 150 m  Speed:380 kn*10

  Sorted:  60 Kg      Total catch:    5000.00    CATCH/HOUR:  30000.00
```

SPECIES	CATCH/HOUR weight	numbers	% OF TOT. C	SAMP
Trachurus capensis	16395.30	255390	54.65	6207
Sardinops ocellatus	12981.72	177102	43.27	6206
J E L L Y F I S H	617.94		2.06	
Engraulis capensis	4.98	498	0.02	6208
Total	29999.94		100.00	

```
R/V "DR. FRIDTJOF NANSEN"        PROJECT:BE      PROJECT STATION:1283
DATE:28/ 4/03             GEAR TYPE: BT No:    POSITION:Lat   S  1937
         start   stop  duration                          Long  E  1250
TIME  :12:27:50 12:35:55   8  (min)  Purpose code:  1
LOG   :7501.81  7502.27  0.46         Area code    : 2
FDEPTH:     18       16               GearCond.code:
BDEPTH:     18       16               Validity code:
       Towing dir: 340ø  Wire out: 100 m  Speed: 30 kn*10

  Sorted:  33 Kg      Total catch:    4000.00    CATCH/HOUR:  30000.00
```

SPECIES	CATCH/HOUR weight	numbers	% OF TOT. C	SAMP
Trachurus capensis	29633.03	631005	98.78	6209
Chelidonichthys capensis	247.65	8258	0.83	6210
Pterothrissus belloci	119.25	5505	0.40	6211
Total	29999.93		100.01	

```
R/V "DR. FRIDTJOF NANSEN"        PROJECT:BE      PROJECT STATION:1284
DATE:28/ 4/03             GEAR TYPE: PT No: 3  POSITION:Lat   S  1939
         start   stop  duration                          Long  E  1249
TIME  :18:27:36 18:29:19   2  (min)  Purpose code:  1
LOG   :7537.93  7538.02  0.09         Area code    : 2
FDEPTH:     10       10               GearCond.code:
BDEPTH:     36       36               Validity code:
       Towing dir: 340ø  Wire out: 120 m  Speed: 40 kn*10

  Sorted:  48 Kg      Total catch:    1500.00    CATCH/HOUR:  45000.00
```

SPECIES	CATCH/HOUR weight	numbers	% OF TOT. C	SAMP
Trachurus capensis	44905.50	755100	99.79	6212
Chelidonichthys capensis	94.20	2820	0.21	6213
Total	44999.70		100.00	

```
R/V "DR. FRIDTJOF NANSEN"        PROJECT:BE      PROJECT STATION:1285
DATE:28/ 4/03             GEAR TYPE: PT No: 3  POSITION:Lat   S  1938
         start   stop  duration                          Long  E  1249
TIME  :21:38:25 21:43:48   5  (min)  Purpose code:  1
LOG   :7541.00  7541.32  0.32         Area code    : 2
FDEPTH:     10       10               GearCond.code:
BDEPTH:     36       36               Validity code:
       Towing dir: 180ø  Wire out: 120 m  Speed: 38 kn*10

  Sorted:  26 Kg      Total catch:     300.00    CATCH/HOUR:   3600.00
```

SPECIES	CATCH/HOUR weight	numbers	% OF TOT. C	SAMP
Trachurus capensis	2909.28	55824	80.81	6213
J E L L Y F I S H	299.16		8.31	
Myliobatis aquila	267.00	144	7.42	
Chelidonichthys capensis	117.36	564	3.26	6214
Austroglossus microlepis	5.52	276	0.15	
Sufflogobius bibarbatus	1.32	132	0.04	
Total	3599.64		99.99	

```
R/V "DR. FRIDTJOF NANSEN"        PROJECT:BE      PROJECT STATION:1286
DATE:29/ 4/03             GEAR TYPE: PT No: 2  POSITION:Lat   S  1938
         start   stop  duration                          Long  E  1249
TIME  :23:57:31 00:12:29  15  (min)  Purpose code:  1
LOG   :7544.67  7545.55  0.88         Area code    : 2
FDEPTH:      5        5               GearCond.code:
BDEPTH:     37       37               Validity code:
       Towing dir: 160ø  Wire out: 160 m  Speed: 40 kn*10

  Sorted:  29 Kg      Total catch:     500.00    CATCH/HOUR:   2000.00
```

SPECIES	CATCH/HOUR weight	numbers	% OF TOT. C	SAMP
Trachurus capensis	1907.00	35656	95.35	6215
J E L L Y F I S H	56.04		2.80	
Chelidonichthys capensis	23.24	272	1.16	6216
Sufflogobius bibarbatus	13.64	68	0.68	
Total	1999.92		99.99	

```
R/V "DR. FRIDTJOF NANSEN"        PROJECT:BE      PROJECT STATION:1287
DATE:29/ 4/03             GEAR TYPE: BT No:    POSITION:Lat   S  1935
         start   stop  duration                          Long  E  1248
TIME  :06:39:46 06:54:56  15  (min)  Purpose code:  1
LOG   :7585.09  7586.05  0.95         Area code    : 2
FDEPTH:     24       18               GearCond.code:
BDEPTH:     24       18               Validity code:
       Towing dir: 345ø  Wire out: 120 m  Speed: 38 kn*10

  Sorted:  21 Kg      Total catch:    6000.00    CATCH/HOUR:  24000.00
```

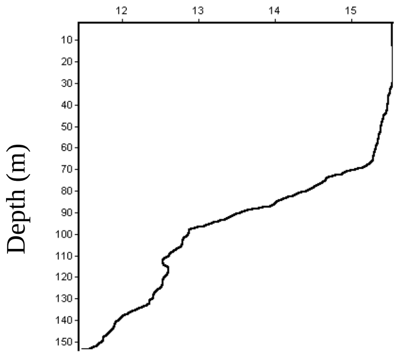
SPECIES	CATCH/HOUR weight	numbers	% OF TOT. C	SAMP
Trachurus capensis	24000.00	422664	100.00	6217
Total	24000.00		100.00	

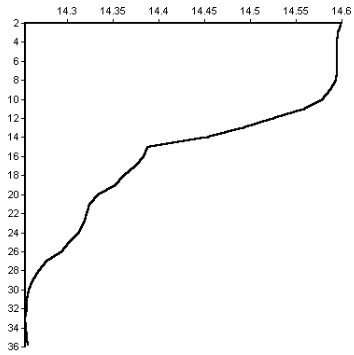
```
R/V "DR. FRIDTJOF NANSEN"        PROJECT:BE      PROJECT STATION:1288
DATE:30/ 4/03             GEAR TYPE: PT No: 1  POSITION:Lat   S  2232
         start   stop  duration                          Long  E  1416
TIME  :19:09:20 19:27:45  18  (min)  Purpose code:  1
LOG   :7939.38  7940.49  0.99         Area code    : 2
FDEPTH:      5        5               GearCond.code:
BDEPTH:     70       67               Validity code:
       Towing dir: 140ø  Wire out: 150 m  Speed: 36 kn*10

  Sorted:  62 Kg      Total catch:   10000.00    CATCH/HOUR:  33333.33
```

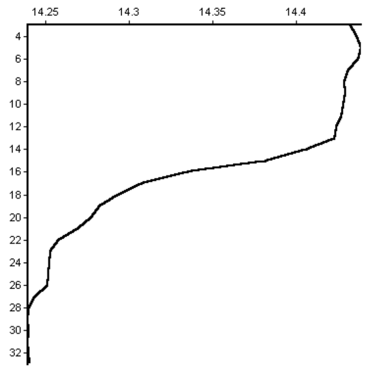
SPECIES	CATCH/HOUR weight	numbers	% OF TOT. C	SAMP
Sardinops ocellatus	18782.83	865877	56.35	6218
Engraulis capensis	14356.83	818290	43.07	6219
Engraulis capensis	14356.83	818290	43.07	6219
Trachurus capensis	193.63	11063	0.58	6220
Total	47690.12		143.07	

Annex III Hydrography data

Temperature °C

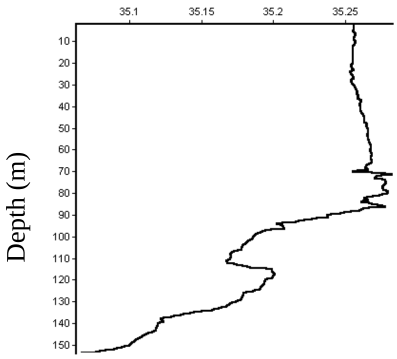


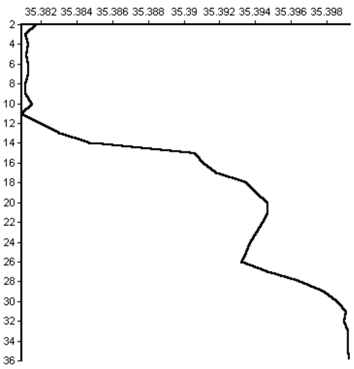


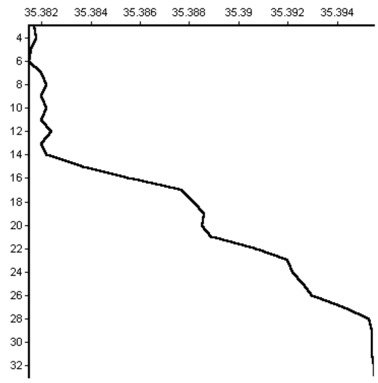


Station no: 522 523 524

Salinity ‰

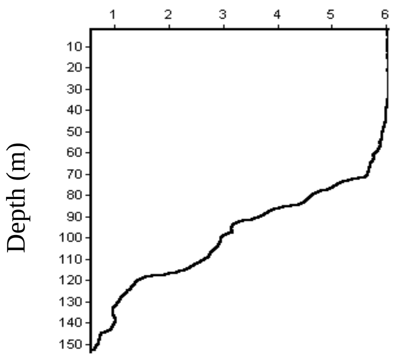


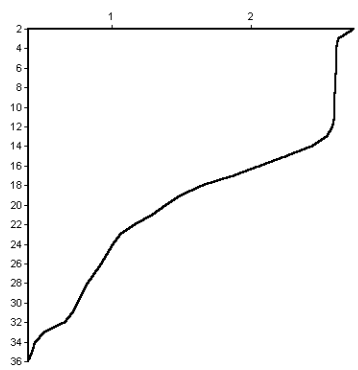


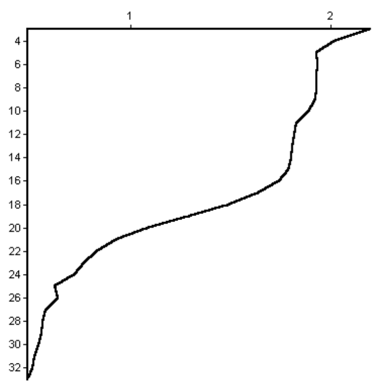


Station no: 522 523 524

Oxygen ml/l







Station no: 522 523 524

Annex IV Sonar observations of fish schools

AREA 1 COVERAGE 1

Lat	Long	Time (GMT)	Sonar/Echo	Discription (size, density, distance from vessel, etc
23 46.03	14 01.04	19:11	Sonar	Reasonable size, 3 different shoals came around. Distance = 270m
23 46.03	14 01.08	19:14	Sonar	1 medium shoal. Distance = 90m
23 46.03	14 02.09	19:19	Sonar	1 medium shoal. Distance = 220m
23 46.03	14 04.06	19:25	Sonar	Medium to large shoal. Distance = 158m
23 44.00	14 05.00	20:22	Sonar	135 to 160. Distance = 195m
23 44.00	14 04.00	20:27	Sonar	Small. Distance = 392m
23 44.00	14 03.00	20:30	Sonar	Small. Distance = 240m
23 44.00	14 02.00	20:38	Sonar	Small. Distance = 200m
23 42.00	13 59.00	22:55	Echo/Sonar	3= 10 to 19m. Distance =15m
23 40.00	14 05.00	00:15	Sonar	Small. Distance = 148m
23 40.00	13 60.00	01:32	Sonar	Small. Distance = 263m
23 38.00	13 52.00	02:37	Sonar	Small. Distance = 2m
23 38.00	13 56.52	02:38	Sonar	Small.
23 38.00	13 58.43	02:42	Sonar	Small. Distance = 184m
23 38.00	14 50.00	02:59	Sonar	Small. Distance = 96m
23 37.00	14 00.00	03:02	Sonar	Small. Distance = 292m
23 37.00	14 00.64	03:02	Sonar	Small. Distance = 54m
23 38.14	14 01.81	03:08	Sonar	Small. Distance = 171m
23 38.00	14 06.16	03:33	Sonar	Small. Distance = 117m
23 38.01	14 08.91	03:48	Sonar	Small. Distance = 91m
23 36.81	14 09.49	03:58	Sonar	Small. Distance = 66m
23 36.33	14 09.48	04:00	Sonar	Small. Distance = 200m
23 35.99	14 09.17	04:04	Sonar	Big. Distance = 193m
23 38.99	14 09.02	04:05	Sonar	Big. Distance = 255m
23 36.01	14 08.36	04:08	Sonar	Small. Distance = 253m
23 36.02	14 04.30	04:30	Sonar	Small. Distance = 153m
23 36.01	13 56.37	05:13	Sonar	Very Small. Size = <10m. Distance = 132m
23 36.01	13 55.03	05:19	Sonar	Small. Distance = 277m (2 shoals together)
23 36.01	13 55.00	05:21	Sonar	Small. Distance = 235m
23 36.01	13 53.04	05:31	Sonar	Small to Medium. Distance = 236m

AREA 1 COVERAGE 2

Lat	Long	Time (GMT)	Sonar/Echo	Discription (size, density, distance from vessel, etc
23 36.98	13 56.96	06:44	Sonar	Very long thin school. Size 50m top to bottom. Distance = 200m
23 36.98	13 59.04	06:59	Sonar	1 Medium school. Distance = 227m
23 36.98	14 06.03	07:38	Sonar	Small School. Distance = 136m
23 36.98	14 08.30	07:50	Sonar	Small school. Distance = 239m
23 36.98	14 11.47	08:07	Sonar	Small to Medium. Distance = 195m
23 38.00	14 12.00	08:17	Sonar	Small. Distance = 103m (Seals arround)
23 40.00	14 08.00	08:49	Sonar	Small. Distance = 171m
23 40.00	14 07.00	08:57	Sonar	Small. Distance = 164m (possibly Horse Mackerel)
23 40.00	14 07.00	08:59	Sonar	Small. Distance = 292m
23 40.00	14 06.00	09:03	Sonar	Small. Distance = 141m
23 40.00	14 05.50	09:08	Sonar	Small. Distance = 149m
23 39.02	13 58.95	09:43	Sonar	Very small. Distance = 132m
23 39.02	13 58.60	09:44	Sonar/Echo	3 Small shoals. Distances 1= 89m, 2 = 164m, 3=187m
23 39.00	13 57.00	09:50	Sonar/Echo	Medium. Distance = 118m (Small shoals on Echo)
23 38.97	13 55.69	10:00	Sonar	Large. Distance = 161m (Birds arround diving)
23 40.00	13 47.00	10:42	Sonar	Large. Distance = 164m
23 41.00	13 56.00	11:28	Sonar	Medium. Distance = 173 to 210m
23 41.00	13 57.00	11:33	Sonar	Small. Distance = 270m
23 41.00	13 59.00	11:44	Sonar	Small. Distance = 266m
23 41.00	14 00.00	11:48	Sonar	2 Small. Distance 1= 181m 2= 211m (Lots of birds arround at 11:51)
23 41.00	14 02.00	12:03	Sonar	Small and not dense. Distance = 158m
23 40.00	14 05.00	12:18	Sonar	Small. Distance = 155 to 162m
23 40.00	14 05.00	12:20	Sonar	Small. Distance = 159m
23 41.00	14 10.00	12:43	Sonar/Echo	3 Small following one another . Distance 1=103m, 2=121m, 3=118m (Shoal on echo)
23 41.00	14 10.00	12:46	Sonar	Small. Distance = 172m
23 41.00	14 10.00	12:47	Sonar	3 small shoals. Distances 1= 150m, 2 = 163m, 3=133m
23 41.00	14 10.00	12:48	Sonar	Small. Distance = 135m
23 41.00	14 10.00	12:49	Sonar/Echo	3 small shoals following each other. Distance 1=183m, 2=123m, 3=228m (also on echo)
23 41.00	14 11.00	12:51	Sonar	4 small shoals. Disatances 1=126m, 2=100m, 3=158m, 4=135m (#4 is larger depth 13m)
23 41.00	14 11.00	12:53	Sonar	Small. Distance = 155m
23 41.00	14 11.00	12:55	Sonar/Echo	Specks all over. Distance =117 to 133m another one at 246m
23 41.00	14 12.00	13:00	Sonar/Echo	Small specks again. Distance = 244m
23 41.00	14 12.00	13:01	Sonar	Small specks again. Distance 1=103m, 2=157m
23 42.00	14 12.00	13:08	Sonar	Bigger Blob. Distance = 157 to 180m
23 42.00	14 12.00	13:09	Sonar/Echo	Distance = 84 to 132m (Birds arround)
23 42.00	14 12.00	13:12	Sonar	Small. Distance = 144m
23 42.00	14 12.00	13:13	Sonar	Bigger. Distance = 70 to 107m followed by smaller at 212m

23 43.00	14 11.00	13:15	Sonar	Large but not dense. Distance = 69 to 143m followed by denser, smaller at 204m
23 43.00	14 11.00	13:19	Sonar	Lots of small red scratches. Distance = 55, 171m
23 43.00	14 09.00	13:25	Sonar	Medium density. Distance = 143m followed by one at 115m
23 43.00	14 09.00	13:27	Sonar	Medium density. Distance = 219m followed by one at 167m bigger
23 43.00	14 04.00	13:54	Sonar	Small but some red. Distance = 172m
23 43.00	14 01.00	14:10	Sonar/Echo	Medium density. Distance = 286m
23 43.00	14 00.00	14:14	Sonar	Small and narrow. Distance = 128m
23 43.00	14 00.20	14:18	Sonar	Medium. Distance = 290m
23 43.00	13 59.31	14:22	Sonar	Small. Distance = 150 and 155m
23 43.00	13 58.00	14:28	Sonar	Small following each other. Distance 1 =140m, 2=148m, 3=158m
23 43.00	13 57.00	14:32	Sonar	Small. Distance = 145m
23 43.01	13 57.00	14:34	Sonar	Small. Distance = 102m
23 43.03	13 55.00	14:42	Sonar	Small. Distance = 73m
23 43.03	13 53.00	14:55	Sonar	Small. Distance = 58m
23 43.02	13 52.02	15:02	Sonar	Small. Distance = 194m
23 43.02	13 51.37	15:05	Sonar	Small. Distance = 139m (two schools?)
23 43.03	13 49.00	15:15	Sonar	Small. Distance = 124m
23 44.52	13 49.51	15:25	Sonar	Big. Distance = 184m
23 45.03	13 51.27	15:39	Sonar	Big. Distance = 108 to 112m
23 45.03	13 53.58	15:52	Sonar	Small. Distance = 161m
23 45.24	13 56.35	16:08	Sonar	Small. Distance = 261m
23 45.00	13 56.79	16:10	Sonar	Small. Distance = 217m
23 45.00	13 56.93	16:11	Sonar	School. Distance = 132m
23 44.99	13 57.26	16:13	Sonar	School. Distance = 175m
23 44.99	13 58.31	16:19	Sonar	School. Distance = 67m
23 45.01	14 03.36	16:47	Sonar	Big. Distance = 137m followed by two small 1= 139m, 2=173m
23 45.00	14 06.70	17:04	Sonar	Small. Distance = 49m
23 45.00	14 07.07	17:07	Sonar	Small. Distance = 66m (five more minutes very small schools followed at around this range)
23 45.00	14 09.30	17:19	Sonar	Small. Distance = 46m
23 45.00	14 10.62	17:26	Sonar	Small. Distance = 53m and one small at 300m from vessel
23 45.00	14 11.58	17:31	Sonar	2 Small schools. Distance = 49m
23 45.00	14 12.64	17:37	Sonar	Medium school. Distance = 255m

Area 2 Coverage 1

Lat	Long	Time (GMT)	Sonar/Echo	Discription (size, density, distance from vessel, etc
23 03.87	14 22.02	03:14	Sonar	Small schools following each other. Distance = 173m
23 03.17	14 22.23	03:18	Sonar	Small Schools Distance = 82m
23 02.59	14 22.11	03:21	Sonar	Very big schools. Distance = 78m
22 59.53	14 21.34	03:39	Sonar	Small school. Distance = 279m
22 42.23	14 20.45	05:19	Sonar	Big school. Distance = 279m
				(Shoal trawled on = not recorded)
22 42.44	14 19.19	07:01	Sonar/Echo	Very small. Distance = 50m, very dense Distance = 600m went over but at surface.
22 42.56	14 19.21	07:02	Sonar/Echo	Middle size. Distance = 150m, very dense.
22 43.16	14 20.02	07:13	Sonar/Echo	Small school. Distance 293m
22 39.60	14 21.88	07:57	Sonar/Echo	2 Large weak schools. Distance = 282m
22 40.00	14 18.00	08:30	Sonar/Echo	Large.
22 42.00	14 19.00	08:51	Sonar/Echo	Large.
22 42.00	14 19.00	08:54	Sonar/Echo	2 Large.
22 42.00	14 19.00	08:54	Sonar/Echo	X Large.
22 42.00	14 18.00	09:07	Sonar/Echo	Large.
22 42.00	14 20.00	10:58	Sonar	Leave tracked school.ie left the school to go back to the track!
22 43.00	14 22.00	11:19	Sonar	Turning ship - wake?
22 43.00	14 17.00	11:48	Sonar	Medium school. Distance = 369m
22 42.09	14 17.10	12:02	Sonar	Testing system
22 41.94	14 17.69	12:07	Sonar	Red yellow at 182m (while turning)
22 41.98	14 19.75	12:18	Sonar	Small 186m
22 41.98	14 20.30	12:20	Sonar	Small 119 to 125m
22 40.02	14 21.02	12:52	Sonar/Echo	Very small 297m (Echo large)
22 40.01	14 20.58	12:55	Sonar	Medium 207m
22 40.01	14 19.93	12:58	Sonar	Small slither 309m (could be surface slick)
22 37.95	14 17.49	13:28	Sonar	Small green yellow features at 188m (while turning)
22 37.98	14 17.74	13:30	Sonar	148 to 219, 212, 262, 296 yellow features (school?)
22 37.98	14 18.13	13:32	Sonar/Echo	Large 166 to 312 followed by large at 274m (small schools on echo)
22 37.97	14 19.00	13:36	Sonar/Echo	Small 310m, 276m
22 37.97	14 19.24	13:38	Sonar	181m also small dense oh! dense schools on surface.
22 37.96	14 20.21	13:43	Sonar	Only yellow not red at 213m (dense school on echo) X2
22 37.98	14 21.23	13:49	Sonar/Echo	Very dense school!! and second school is at 277m
22 36.09	14 16.90	14:36	Sonar	Forondia scellings pog hilborke lil orginal
22 36.03	14 17.24	14:48	Sonar/Echo	Red yellow at 264m
22 35.97	14 18.34	15:15	Sonar	Big yellowish red school. Distance = 264m
22 36.03	14 17.51	15:21	Sonar	Yellowish with red. Distance = 209m

Annex V Thoughts on aerial pilchard surveys

THOUGHTS ON AERIAL AND/OR AERIAL/ACOUSTIC SURVEYS OF PILCHARD OFF NAMIBIA.

I. Hampton and D. Boyer

Acoustic surveys of pilchard off Namibia, as currently practised, are fraught with difficulties because of the highly patchy nature of the schools, and the fact that they are often too close inshore to be surveyed effectively by day, and too close to the surface to be adequately surveyed at night.

To overcome the patchiness problem, fishing vessels acting as scouts accompany the survey vessel RV 'Welwitchia' during the surveys, searching by sonar and echo-sounder for schools. When a group of schools is located by any of the vessels, an attempt is made to establish its boundaries, after which RV 'Welwitchia' steams an intensive survey grid in the remaining hours of daylight to obtain an estimate of the biomass in the group. Depending on the abundance, the group may be surveyed more than once, sometimes over a number of days. This form of design, although preferable to a conventional random stratified survey, is complex and difficult to implement effectively, particularly if time is short. One of the difficulties, particularly early in the survey, is to know how much additional time should be allocated to a group once found, when there is no knowledge of how many school-groups still lie ahead and where they are likely to be. It is also difficult to achieve the right balance between search and survey time without having some indication beforehand of the overall distribution of the population in the area to be surveyed (usually the entire Namibian coast between Hollamsbird Island and the Kunene River, and often extending into southern Angola).

There is also concern that as and when the biomass of the stock increases the number of school-groups may also increase, thus requiring the survey to be extended beyond the normal 20 days.

Another important concern is the cost of the current survey strategy whereby three vessels are at sea continuously for 20 days, often during peak fishing periods when the purse seiners could be much more profitably employed.

The consequence of these problems is that acoustic estimates of abundance, which are the main basis for management recommendations, are often rather imprecise, and in some cases have lacked credibility, resulting in the Industry not accepting the results or calling for the survey of some areas to be repeated several times, and even the final total biomass estimates to be questioned.

A statistician (Karl Stielau, University of Cape Town, Dept of Statistical Sciences) has recently been engaged using BENEFIT funds to examine aspects of the current design with a view to placing it on a firmer statistical footing. However, to make significant progress he needs more information than is currently available on the structure of schools within school groups in order to develop objective decision rules for allocating effort to the groups once found. Indeed, one of the objectives of the April 2003 BENEFIT experimental cruise on the RV 'Dr Fridtjof Nansen' was to gather information of this sort from sonar and echo-sounder observations of the sizes and distribution of schools within groups of pilchard schools.

Now that there are some signs of a recovery in the resource, it is more important than ever that the survey design, and indeed the whole approach to surveys of pilchard, be re-assessed. This memo proposes a practical and cost-effective method to improve these surveys.

Observations from April 2003 BENEFIT experimental cruise

The recent BENEFIT cruise investigating biases in surveys of pilchard in Namibia aimed to study, amongst other aspects, the behaviour and dynamics to pilchard schools and school-groups. A high-resolution multi-beam sonar (Simrad SF950 together with data acquisition and processing software - SODAPS) and both vessel-mounted and towed scientific echo-sounders (Simrad EK500 operating at 4 frequencies and EY500 respectively) were used. Throughout this cruise it proved extremely difficult to define the boundaries of any of the groups of pilchard schools encountered. In fact for none of the three groups found (off Sandwich Harbour, Swakopmund and Möwe Bay respectively) were the boundaries demarcated with any degree of confidence. Furthermore, in none of the areas were a substantial number of pilchard schools detected, even with the sonar scanning 300 – 600 m around the vessel. School densities in these areas were in fact considerably lower than during the RV 'Welwitchia' survey the previous month. The Möwe Bay area was particularly difficult to survey due to the fact that the few pilchard schools which were detected there were often shallow (where sonar detection was difficult), widely spaced, and apparently highly mobile. There were also many dense schools of horse mackerel in the vicinity making target identification difficult at times. No consistent picture of pilchard distribution in this area emerged even after 4 days of intensive study over what was a relatively small area. Under these circumstances, any abundance estimate derived from an acoustic survey of this area would have been highly inaccurate and of dubious value.

Potential value of aerial surveys

It was due to the problems outlined above that night-time aerial/acoustic surveys (Cram and Hampton 1976, Hampton *et al.* 1979) were introduced in the 1970s to survey the pilchard stock off Namibia, and were in fact used as the basis for managing the pilchard stock for a number of years in the mid 1970s. The aircraft was used to estimate the surface area of schools from measurements of the area of bioluminescence stimulated by the schools, which were generally clearly visible from the air under good viewing conditions. The average vertical extent of the schools was estimated from vessel-mounted echo-sounder observations, which when combined with the aerial estimate of total school surface area and estimates of volume density in schools from a number of catch experiments, provided an estimate of total biomass in absolute terms.

An advance on the method which was proposed (Hampton *et al.* 1979), but never put into practice, was for the vessel to estimate the average surface density of schools (g per m^2) acoustically using standard echo-integration methods and the best available estimate of pilchard target strength (as is done in the current acoustic surveys), which combined with the aerial estimate of total school area would give the biomass directly.

Several possible methods of combining aerial observations and acoustics could be investigated:

1) Aerial support to current survey strategy

A scouting plane could search the entire region and guide the RV ‘Welwitchia’ and purse seiners to school-groups after which each school-group would be surveyed as per the current survey strategy. Thus, the vessels would travel directly between school-groups and would not have to search the areas in between.

2) Combined aerial/acoustic biomass estimation

The plane would conduct the above type of search, but on finding a school-group would “survey” the area using fixed transects across the area while recording the surface area of the pilchard schools. Note that the RV ‘Welwitchia’ would then not need to conduct a survey *per se* of an area, but would be required to sample as many schools as possible from each school group to get the best possible estimate of mean school surface density within each group. A purse seiner may not be required to participate in this type of survey.

By these means the vessels would be almost continuously deployed in areas of high density, and would spend comparatively little time in low density areas, unlike in the present acoustic surveys, where a substantial proportion of the time is spent searching areas devoid of fish. The aerial surveys have a number of strong advantages over independent acoustic surveys, viz:

- Rapid (150-200 knot) coverage
- Wide (typically 1 mile) viewing swath
- Surface schooling an advantage (increased visibility)
- No avoidance problems
- Ability to map out horizontal distribution clearly on different scales
- Direct observations on the size and shape of individual schools –useful for survey design studies

Another key advantage would be a large reduction in costs. The current surveys are estimated to cost approximately N$2 000 000, while incorporating a plane into the survey methodology could reduce this by half (Table 1). It must be noted that the lost-opportunity costs of fishing to the purse seiners, which during the fishing season (i.e. the March/April survey) must be very large, need to be added to these costs.

Table 1 Approximate costs of various survey strategies. The daily costs are assumed to be N$ 40 000 for the RV 'Welwitchia', N$ 30 000/purse seiner (excluding lost-opportunity costs), N$ 30 000 for 8 hours flying/night and N$ 5 000 per night on standby (when conditions preclude flying).

	Current strategy	Aerial support	Aerial/acoustics
Welwitchia	20 days = N$ 800 000	15 days = N$ 600 000	15 days = N$ 600 000
Purse seiners	2 x 20 days = N$ 1 200 000	1 x 15 days = N$ 450 000	-
Plane – flying	-	5 nights = N$ 150 000	10 nights = N$ 300 000
-on standby	-	5 nights = N$ 25 000	5 nights = N$ 25 000
TOTAL	N$ 2 000 000	N$ 1 225 000	N$ 975 000

The chief difficulties are the susceptibility to poor viewing conditions (moonlight, fog, rough weather), the need for an operational base inland out of the fog zone, and occasional difficulties in detecting the schools if the bioluminescence is weak and/or the schools deep (at night, a comparatively rare occurrence in the 1970s). A further problem in the 1970s, which would not be a problem today, was the poor navigational facilities at that time, particularly off the coast of northern Namibia.

Aerial surveys were discontinued in 1977 for a number of practical reasons, but when combined with acoustic information, remain a potentially powerful and efficient method for estimating the size of the pilchard resource in Namibia, overcoming most of the difficulties of acoustic surveys. Technological advances in the past few decades would make the method more accurate and easier to apply today than it was in the 1970s. Specifically:

- Far better navigation (GPS) for both aircraft and vessel, making for more accurate aerial mapping and better synchronisation between the aircraft and the vessel
- Major advances in low-light-level image recorders and in image- processing systems needed for measuring school areas.
- Major advances in acoustic technology for estimating school surface density
- The ability of the acoustic survey vessel (RV 'Welwitchia') to identify acoustic targets by midwater trawling, which was not possible on the survey vessels used in the 1970s, requiring the chartering of catcher vessels

- Better understanding of the statistical aspects of both the aerial and acoustic sampling, and the development since then of more rigorous ways of estimating the precision of surveys

Proposal

It is proposed that a pilot study be conducted into the feasibility of using night-time aerial surveys either to support acoustic surveys of pilchard, or to provide a combined aerial/acoustic estimate of pilchard biomass. At the simplest level, the aircraft could be used merely to locate areas of high abundance and/or eliminate areas where there are no fish, enabling the vessel to survey more efficiently, and perhaps eliminating the need for one or more of the scouting vessels. At the opposite extreme, fully integrated aerial/acoustic surveys could be conducted according to the methods developed in the 1970s, or logical extensions of them, producing absolute estimates of biomass.

The pilot study would have to establish the following:

- Whether pilchard schools in high-density areas are still clearly and consistently visible from the air at night under good viewing conditions
- Whether they are sufficiently distinguishable from other sources of bioluminescence (especially horse mackerel schools) to enable them to be mapped from the air
- A suitable aircraft for the work, bearing in mind range, payload, viewing requirements, safety aspects and cost
- A suitable operational base, particularly for surveys in the far north where much of the pilchard resource is often concentrated
- The most suitable optical devices for recording images of fish schools at night, and appropriate methods for analysing the images
- Practical methods of surveying the schools from the air, building on the experience of the 1970s
- Practical ways of integrating the aircraft and vessel operations in an efficient and effective manner

If possible, the pilot study should be done well before the October 2003 pilchard survey, so that if the study is successful, the aircraft could be used in October to improve survey efficiency, even if initially by acting merely as a scout. Experience gained in October could then be used to make more or better use of the aircraft in subsequent surveys.

References

Cram, D. L. and I. Hampton 1976. A proposed aerial/acoustic strategy for pelagic fish stock assessment. *J. Cons. Perm. Int. Explor. Mer* 37(1): 91-97.

Hampton, I., Agenbag, J. J. and D. L. Cram 1979. Feasibility of assessing the size of the South West African pilchard stock by combined aerial and acoustic measurements. *Fish Bull. S. Afr*. 11: 10-22.