CRUISE REPORT

ACOUSTIC INVESTIGATION OF PILCHARD SCHOOLING BEHAVIOUR IN SOUTH AFRICAN WATERS

R.V. "Dr. Fridtjof Nansen"; 9-18 October 1995

Area: False Bay, between Cape Point and Cape Agulhas, South Africa

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BACKGROUND

The southern African pilchard, *Sardinops sagax*, supports major pelagic fisheries in South Africa, Namibia and (potentially) Angola waters, and is managed very largely on the basis of acoustic surveys. The results are highly sensitive to biases in caused by aspects of shoaling behaviour which affect the acoustic detectability of the fish. Particular problems are caused by reaction of the fish to the vessels and nets, near-surface schooling and the tendency for schools to concentrate close to the coast into areas where they may be inaccessible to large survey vessels. The aim of the proposed study is to observe such behaviour both directly and indirectly, quantify its extent and thereby assess the severity of the resultant biases in acoustic survey estimates. It is hoped that the results will give direction to the development of methods for reducing these biases in future surveys of pilchard in Southern Africa.

SPECIFIC ACTIVITIES

* Development of a relationship between school area and biomass (using available pilchard TS) for use in converting sonar estimates of school area to biomass.

* Comparison of biomass estimates obtained by sonar and vertical echointegration.

* Investigation of the shape and confirmation of schools.

* Investigation of the avoidance reaction of schools to the survey vessel (by sonar and ADCP).

* Investigation of the reaction of schools to midwater trawls.

* Tracking of the movement of individual schools, *inter alia* in relation to near-surface currents.

* Investigation of aggregation dynamics at dawn and dusk.

* Measurement of pilchard target strength *in situ*.

* Specific South African projects (Ichthyoplankton/environmental monitoring line, comparison of the zooplankton composition in the wake of moving school with that of the surrounding water).

EQUIPMENT

* Simrad SA950 truemotion sonar.

R/V "Dr. Fridjof Nansen" is equipped with a 95 kHz, high-resolution SIMRAD SA950 sector-scanning sonar. The operational mode of the sonar is sectoral transmisson and multi-beam reception. The sonar beam is transmitted in a 45^o sector and received by 32 adjacent single beams of 1.7^o each (between - 3 dB points). There is a fast digital processing system that utilizes the full dynamic range for signal processing and beam-forming. To reject unwanted noise signals and interference, the sonar can be operated with frequency-modulated (FM) transmission. In this mode the sonar transmits a combination code of two to eight different frequencies, and display only echoes that have the right frequency code. The transducer of the R/V "Dr. Friftjof Nansen" sonar is protected by an inflatable rubber dome.

* Simrad EK500 echointegrators (38 and 120 kHz).

* Bergen Echointegration postprocessing system.

* Simrad EY500 portable echosounder (38 kHz) and postprocessing software to be operated from workboat.

* Wesmar trawl mounted scanning sonar.

* Lowerable (38 kHz) splitbeam transducer.

* Highfrequency towed sidescan sonar (EG&G260).

* ADCP + software for measuring fish movement.

STRATEGY AND METHODS

The general strategy was first to locate a dense patch of pilchard schools from a small survey grid performed in False Bay, and to remain in the area, studying school behaviour intensively, for the whole period.

From this grid comparison of sonar and echointegrator estimates of biomass were made. Other works were done while either while drifting or steaming at low speed (school tracking, ADCP measurements, sidescan sonar imaging, TS measurements, support of observations from work boat). Midwater trawling were performed to identify and size acoustic targets, and to investigate the reaction of the fish to the trawl under different conditions. Some environmental sampling, both during underway and at fixed stations, were done.

Sonar data processing

A special software for computer-based detection and area measurement of school recordings by the sonar has been developed (Misund *et a*l., 1994). A program reads echo telegrams from the sonar and organizes the data in two separate tables that are updated for each transmission. The color code value of each pixel of the 32 beams and 512 range rings of the sonar is organized in an echo table that is updated for each ping. The first step in the detection of schools is a procedure that searches the echo table for identification of echo lines, which are defined in terms of a minimum number of successive pixels with color code values above a predetermined threshold. The position in the beam sector, horizontal extent and sum of color code values for each echo line detected are written to an echo-line table. The second step for school detection is a procedure that searches this table for identification of echo blocks, which are defined as adjacent echo lines that extend beyond a given width (Fig. 1). The horizontal extent, sum of color code values, depth and geographical position of echo blocks are written to an echo-block table together with information on time and vessel navigation. The final step is a procedure that searches the echo block table and identifies schools which are defined as echo blocks that occur in a minimum number of successive pings within an expected position. For each school detected, a specific school number is allocated to the underlying echo block in the echo-block table. A color printer for the SIMRAD SA950 has also been developed. The principle involved is to print the maximum color code value for each distance ring for each transmission. Continuous information on the tilt and train of the sonar is recorded.

Fish-density recording model

The sonar and echo sounder recordings made during the False Bay survey will be compred by the model outlined in the following. Assume that the fish schools are distributed below the upper blind zone of the hull-mounted echo sounder, but above the recording depth of the horizontal guided sonar, and that there are no vessel avoidance. Then the number of schools recorded ($N_{ECHO\ SOUNDER}$) within the sampling width of the echo-sounder ($SW_{ECHO\ SOUNDER}$) should be proportional to the number of schools (N_{Sonar}) recorded within the sampling width of the sonar (SW_{SONAR}). This is expressed through the equation;

$$N_{SONAR}/SW_{SONAR} = N_{ECHO\ SOUNDER}/SW_{ECHO\ SOUNDER} \tag{1}$$

The sampling width of a sonar directed sideways is the distance between the manual setting of the inner (R_1) and outer (R_2) sampling range. The sampling width of the echo sounder is found by means of the equation;

$$SW_{ECHO\ SOUNDER} = 2\ R \tan(\varphi/2) + D_{SCHOOL} \tag{2}$$

where

R = average vertical range from transducer to school
φ = beamwidth of echo sounder (~ between -3dB points)
D_{SCHOOL} = average school diameter

As the size of schools varies substantially, there is some uncertainty as to whether schools recorded within the rather narrow sampling width of an hull-mounted echo sounder are representative of the actual population. A better evaluation of the representativeness of the recordings made by the echo sounder and the sonar would therefore be obtained by comparing estimates of fish density (ρ). For a calibrated echo integrator unit, the number of fish per square nautical mile (ρ_A) can be found by (MacLennan and Simmonds, 1992);

$$\rho_{ECHO\ INTEGRATOR} = s_A / \langle\sigma\rangle \tag{3}$$

where

s_A= area backscattering coefficient (m^2/(nautical mile)^2)
$\langle\sigma\rangle$= average backscattering coefficient of the recorded fish (m^2)

Sonar recordings of school area (A) can be converted to estimates of fish density by linear relationships between school biomass (B) and school area (Misund et al., 1992);

$$B = aA \tag{4}$$

where a is the regression coefficient. If the recordings of school area are added and scaled to square nautical miles (ΣA), the number of fish per square nautical mile (ρ_{SONAR}) can be found by;

$$\rho_{SONAR} = a\,\Sigma A \tag{5}$$

If the assumptions for equation 1 are valid, the two measures of fish density should be equal;

$$\rho_{ECHO\ INTEGRATOR} = \rho_{SONAR} \tag{6}$$

SA-SARP Line

The environmental monitoring line operated by the South African team is a routine transect which is sampled weekly as part of the South African Sardine and Anchovies Recruitment Program (SA-SARP). The line is located off Slangkop Point (start position: 34^o 09.00´ S 18^o 17.80´E; end position: 34^o 22.30´ S, 17^o 41.30´ E). At 12 stations eggs and larvae are collected using a mini-Bongo net from the surface to 70 m (double oblique haul). A drogue is also deployed at each station and recollected in order to measure the surface current speed and direction. A Magnum sampler is used to obtain a depth/temperature/fluorescence profile. In addition a bottle is triggered at 5 m to obtain a water sample for chlorophyll, phytoplankton and nutrient analysis.

RESULTS

Biomass estimates in False Bay

Fig. 1 and 2 and Table 1gives the distribution and estimates of mean density and biomass of pelagic fish in the first and second surveys of False Bay (Lines A-1 to A-4, and A-5 to A-8 respectively).

Survey lines	Density (g m2)	Biomass (t) Eqn. 1	Biomass (t) Eqn. 2
A1 - A4	97.2	64 000	32 823
A5 - A8	176.0	116 000	84 519

Table 1: Pelagic fish biomass estimates from Survey Grid A in False Bay

The estimates have been made from Sa values per n. mile, from which weak echoes in the lower water column, believed not to be pilchard, were removed by the BEI post-processing system. The Sa values were converted to Mean Surface Back-Scattering Strength (MSBS) through the expression:

$$MSBS = 10 \text{ Log } Sa - 76.3 \quad .$$

MSBS values were converted to density using the weight-normalised TS expression used in all South African pilchard and anchovy surveys (Haldorsson and Reynisson, 1983)

$$TS/kg = -10.9 \text{ Log } Lt - 20.9 \quad , \quad (1)$$

with a fixed Lt of 16 cm from the trawls conducted in the Bay. Also shown in the Table are the biomass estimates using the most recent South African TS expression for pilchard (from Barange et al. in press):

$$TS/kg = -14.9 \text{ Log } Lt - 13.2 \quad , \quad (2)$$

which for Lt = 16 cm gives a TS/kg 2.9 dB higher than Eqn. 1. The two surveys of the Bay were both done partly at night, and partly by day. The lines were done as follows:

Line No.	Time
A - 1	day
A - 2	day
A - 3	day/night
A - 4	night
A - 5	night
A - 6	night
A - 7	night/day
A - 8	day

Comparison of sonar and echointegrator results

During the False Bay surveys, the sonar was directed 90^o to starboard and tilted to - 5^o. The gain function was set to step 9, the noise reduction filters (AGC, PP and Normalization) to step weak, and with frequency modulated transmission (FM-3). The school detection programe of the HP work station was run with the following settings; min range 25, max range 300, threshold 15, min range interval 8, min width 10, min gap 5, detection window 30, detection count 4.

The effective detection range of of schools by the sonar during the False Bay survey seemed limited to about 150 m. This is probably because of the rather shallow depth (about 25 - 50 m) in the area surveyed. Schools beyond the bottom detection by the sonar may therefore have been masked by bottom reverberation. During postprocessing of the sonar recordings, the maximum detection range were therefore set to 125 m.With a tilt of -5^o this mean that the sonar covered the upper 5 - 22 m of the water column.

The sonar recordings were analysed preliminary in a programe written in the SAS-software. For each school the maximum school area were identified and the number of schools and total school area summed at one nautical mile intervals. According to the equations given in the fish density recording model, the number of schools expected to be recorded by the echo sounder were estimated.

For comparing the number of schools expected to be recorded on the echo sounder based on those recorded by the sonar and the actual number recorded on the echo sounder, the daytime recordings in False Bay were selected (log 651-690, log 803-825). For these distance intervals the number of schools recorded by the echo sounder were counted manually within 5 m depth intervals down bottom for each nautical mile.

There was good correspondence (Fig. 3) and a significant correlation between the actual number of school recorded by the echo sounder down to 20 m depth and the number of school expected to be recorded by the echo sounder on the basis of the sonar recordings. This indicates that the echo sounder recordings were not influenced by avoidance or close to surface distribution.

The primary task, from the point view of estimating abundance from sonar data, was the development of a relationship between school area and biomass. This was done by recording and measuring schools by the sonar system and then pass over them by the vessel so that they were recorded by the EK500 echo integration system. During these measurments the vessel speed varied from about 4.0 - 6.0 knots.

The area of the schools was mesured by the sonar system ping by ping as the vessel approached. The instrument operator noted the allocated school number on the sonar echogram with the corresponding detection school number given by the school detection programe on the HP work station in brackets. This enabled specific identification of the respective schools in the data files produced by the school detection programe. During postprocessing of the sonar data by programes in the SAS software, the respective schools were identified by their detection school number. The maximum area measured by the school detection programe within 50 - 200 m in front of the vessel were then identified and printed for each school.

The allocated school number was also noted on the EK500 echograme. For each school the s_A - value, height and transect length were recorded. The target strength of the about 15 cm pilchard was found by use of the 20 log L - 71.9 relationship recommended for clupeoids. By use of these parameters the fish density of the schools were calculated. The volume of the schools by assuming circular shape and multiplying the school area by the height of the school. The school biomass was then found by multiplying fish density, school volume and average fish weight.

Preliminar analysis indicate that there were a certain correlation between school area and school biomass in the linear scale, and significant a regression between school area and school
biomass in the logaritmic scale (Fig. 4). A similar regression was apparent also between the school voulme and the school biomass (Fig. 5). A substantial variation in the density among the schools induced a large scattering in the school geometry-to-school biomass relationships.
Further analysis of the school geometry-to-school biomass relationships is required before application in comparison of sonar and echo sounder recordings. Similarly, the comparison between fish biomass as recorded by the sonar and by the echo integration system require detailed analysis with respect to the voulme covered by the respective recording systems.

School speed measurement below the vessel

In order to estimate the horizontal school avoidance reaction below the vessel, we have measured the time elapsed between the detection of a school by the sonar (tilted vertically) and the detection of the same school by the EK500 echosounder. The experiment was performed on 11/10/95 in the south-eastern part of False Bay, the mean depth was around 50 m, the vessel speed around 6 knots. The sonar settings were the usual ones (gain 9; AGC:weak; Ping to Ping filtering: weak; Normalization: weak). Since the transducers of these two acoustic devices are located along the same longitudinal line in the middle of the vessel and distant of around 10 m (this value must be checked accurately in Bergen), it is possible to calculate the relative horizontal speed between the school and the vessel. This require a precise measurement of the vessel speed relative to the water mass, a knowledge of the beam patterns of the two transducers and an accurate measurement of the time elapsed between two detections. None of these requirements was totally fulfilled since the vessel speed was estimated by the GPS and not corrected by the current speed (if any in the False Bay). The beam patterns was supposed identical (the -3dB beam angles given by Simrad are 10° and 8° for the sonar and the sounder respectively, but the effective beam angle for schools must be measured accurately in particular for the sonar, taking into account the AGC and FM systems). Moreover the precision of the time measurement was not totally accurate due to the relatively low ping rate of the devises (around 3 per second) and the difficulty in detecting the transmission which first detected the school. In addition, a bias could result from the ping to ping averaging (PPA) of the sonar which could increase the delay between the transmission and the display, eventhought the PPA was set to the "weak" position (the sonar user's guide do not precise how many pings at averaged; this information has to be obtained from SIMRAD). Finally, since all the observations were made along a single transect, we must assume that the observed swimming behaviour was not related to natural fish migrations. Therefore the results presented below are only tentative and must be confirmed by other measurements.

These preliminary results on 24 schools suggest that the delay of school detection between the two devices is too long to support the null hypothesis of a stable target (or random behaviour). The mean relative speed of the schools is 1.68 knots and it is significantly different from zero. There is no clear relationship between the school depth and this speed, but there is a small trend in the time series of school speed which can be due to observer training.

We repeat this experiment on 16/10/95 from 11:30 to 13:00 GMT, nearly at the same place; the mean depth was varying from 55 to 65 m, the vessel speed was around 6 knots. We tried to improve the methodology in the following way. The sonar settings were changed, specially we switched off the PPA in order to remove the delay between the transmission and the display (gain 8; AGC: weak; Ping to Ping filtering: off; Normalization: weak). At the same time an other observer was counting the school distribution in the 45º beam fan according to the depth and to 10º sub-sectors drawn on a transparency which was set on the screen (see below for details). We took advantage of this sub-sector drawing to focus our measurement only on the school located within the central 10º sub-sector which corresponds to the EK500 beam angle at -3dB. The last improvement was a measurement of the vessel speed with the Doppler, which presents the advantage of eliminating the GPS error and a possible

bias due to a current parallel to the vessel route.
Unfortunately the schools detected during this second experiment were not so appropriate for measuring the time elapsed between the two acoustical devices (surface schools, anamorphus shapes, low densities, layer of small schools, etc). It was obvious that the low density schools were only detected by the EK500 sounder. Moreover, some large schools with a dense core and a low peripherical density was detected simultaneously by the two equipments, or in some occasions first by the EK500. This was probably due to the difference in the detection thresholds of the EK500 and SA950.

We were able to estimate the relative velocity of 33 schools. The mean of the apparent relative speed of the school was not significantly different from zero (0.8 knots) due to the high variability in the observations (standard error 1.0).

Vertical and Horizontal School Avoidance

In order to evaluate the possible horizontal avoidance of schools during the survey, two separate experiments were carried out. One experiment (in the afternoon of 16/10) attempted to investigate trends in horizontal avoidance beneath the vessel, by observing the number of schools seen in several different parts of the (60 deg.) sector-scanning sonar beam, when directed athwartships and 90 deg. downwards. The number of schools seen in the central part of the beam (10 deg. +- 5 deg. of vertical) was also compared with the number of schools seen on the EK500 whose transducer is approx. 10m further aft, in line with the sonar dome.. The vessel speed was kept at about 6 knots.

A second experiment (in the morning of 17/10) was done with the sector-scanning sonar beam directed dead ahead with a downward tilt of 14 deg. Here the number of schools at a range of 100m was counted, divided into five 7.5 deg sectors, with one beam centred, and 2 on each side. Again, the number of schools seen in the centre beam was compared with the number of corresponding schools seen on the EK500. The vessel was run at a typical survey speed of 10 to 11 knots.

A first evaluation of the data obtained in the first experiment indicates an apparent significantly higher school density in the central beam of the sonar. This was most pronounced in the middle depth channel (25 to 50m). Surprisingly few schools were observed at depths less than 25m. taking into account that the shallowest schools were ignored due to the poor sector resolution at close distances. Perhaps these observations bear a relation to some downward migration of schools initially positioned in the upper depth strata. A comparison of the number of schools seen in the central part of the sonar beam, with the EK500 counts suggested that fewer than 10 % were missed.

Initial analysis of the data from the second experiment suggests that proportionally more of the schools in the two starboard sectors were detected on the sounder than in the two port sectors. This effect occured with three different observers, and may indicate an inclination of the horizontal axis of the beam due to, for example, a vessel list. 66% of the schools detected in the central sector of the sonar appeared on the echo sounder: a relatively high proportion considering the possibility of random movements out of the path of the vessel. Certainly, there was no strong evidence of avoidance at what is a typical survey speed. The schools on which most of the comparisons were based were large. well-defined schools in the upper 30 m or so. There were also deeper, usually smaller, schools which occasionally appeared in the sonar beam at some distance from the vessel, but whose reaction to the vessel was of lesser interest because of their depth.

Small boat experiment

In order to establish the validity of density estimates obtained of rather shallow schools by shipborne echosounders, an experiment was planned in which a small outboard engined boat (16'), equipped with a Simrad EY500 Echosounder (38kHz), passed over localized and selected schools, in advance of the research vessel.

In spite of a somewhat rough weather conditions an experiment was carried out (16.10.), allowing the small boat to pass over a number of surface schools of medium sized pilchard, where comparable recordings of echo abundance could be obtained (Fig. 6). Some subsequently identified shortcomings in the applied technique make it difficult to make comparisons of all the obtained density estimates with the desired degree of precision. A particular shortcoming was the inability to measure/estimate the exact speed of the boat during the periods of recording. In future trials, the speed measurements ougth to be improved, for instance by use of a portable GPS onboard the boat.

During the school passing operations, it was also observed that in spite of a slow and careful approach towards the schools, which could be observed at the surface, a pronounced avoidance reaction by school descendense or by school splitting, frequently took place.

It is therefor a question whether it is adviseable to carry out future similar experiments when schools are positioned so close to the surface, as the question of avoidance even of the small boat will have to be evaluated.

School tracking

To measure the swimming behaviour of fish schools in False Bay, 19 schools, presumably pilchard, were tracked by the Simrad SA950 sonar from 4 - 74 minutes. The school recordings choosen for tracking appeared as quite large, red spots on the sonar screen. The vessel speed was reduced gently, and the vessel manouvered carefully at a distance of about 50 - 250 away from the schools. Recordings were possible in weather conditions up to strong Southern gale because of the noise reduction capability of the SA950 sonar and because R/V "Dr. Fridtjof Nansen" is a remarkably stable vessel. During the observations the school detection programe were running, and the sonar data stored on separate files for later analysis. A record of events with drawings of changing school shapes were noted continously during the observations.

Preliminary analysis by use of programes developed in the SAS-software indicates that the schools were moving at an average speed from 0.67 - 1.59 m/s at an average depth of 23 - 48 m (Table 6). All schools were heading in southern directions, varying from South East to South West. The average area of the schools varied from about 70 - 210 m^2.

The tracking of a single school (no. 95, Table 6) is examplified in Fig. 7. The school were moving South East at an average speed of about 0.76 m/s. There were substantial variations in the swimming speed during the tracking, possibly due to the random GPS error. Also the area of the school varied substantially during the tracking.

The average intra school (change of shape) event rate was 0.48 min^{-1} which indicate a change of shape every 2 minute. The average inter school (splitt, join) event was 0.2 min^{-1} which mean that the schools splitt or joined everey fifth minute on average. No predator activity were noted from the sonar recordings, but in one occations diving ganets were observed diving on the schools. During the last trackings in good weather conditions, small echoes that possibly originated from seals were occationally recorded near the schools. 16/10 many schools were observed breezing at the surface during the small boat experiment, and seals were seen to be predating on the schools.

Side-scan Sonar Project

The work was done with an EG&G 260 100 kHz side-scan sonar (horizontal beamwidth 1.2 deg. , vertical beamwidth 50 deg. Inclination, 20 deg down). The towfish was streamed from the after Stbd. crane at a depth of about 5m, initially slightly aft of the vessel, and later (16/10) approximately opposite the crane, ahead of the propellor. In the first configuration the port beam fired through the wake, and in the latter, underneath (and partly into), the hull. Towing speed was generally between 3 and 4 knots. Time-marked data from both channels were captured on tape for re-analysis.. During all experiments the SA950 (trained either 90 deg. to stbd. or dead ahead), and EK500 were operated simultaneously. Attempts were made to relate EK500 and side-scan recordings through time signatures on the echo chart and data capture tape.

The instrument gave useful recordings out to about 100m, the port channel giving somewhat better recordings than the starboard channel, especially in the first two experiments (on 11/10 and 13 /10 respectively). Recordings made from the water column were usually better than those from targets beyong the range of the bottom, which varied from about 30 to 70m.

The best, and most numerous recordings were obtained on the 16th. This was probably because of a combination of good weather, the more forward towing position, the better performance of the stbd. channel and the abundance of suitable schools in the area.

There was a great variation in the size and shape of detected schools, ranging from small spots no more than a few m across, to spherical, elliptical or cescent-shaped (particularly common) schools a few 10's of m in the longest dimension, to amorphous or ribbon-shaped aggregations extending more than 100m in the longest dimension- in all, similar to the shapes that have been observed on the SA950, and at the surface, during this study. A few of the larger schools were recorded simultaneously in both the EK500 and side-scan beams. There seemed to be a tendency for the ribbon-shaped schools to be orented with their longest axis more or less parallel with the vessel - possibly indicating active orientation to the vessel. An impression, difficult to quantify, was that the detection rate on the SA950 was greater than on the sonar, either due to the lower detection threshold of the former, or to some avoidance out of the path between the two transducers. Generally, the best correspondence was observed when the school passed under the vessel, although even here, many schools detected on the EK were not detected on the side-scan.

Transition periods observations

During the False Bay grid survey, from EK500 observations, schools were observed to disperse in layer around half an hour after sunset and resume schooling in the morning around sunrise. Nevertheless some big dense shoals were observed inside the layer in the middle of the night (e.g. 10/10/1995 at 23:58 GMT), and also some tiny schools near the surface (e.g. 11/10/1995 from 01:04 to 01:49 GMT).

Four transitions periods were observed with the SA950 sonar and the vessel drifting or tracking at low speed (< 1.5 knots) in False Bay. The first one was the night-day transition on 14/10/1995 from 3:00 to 4:50 GMT. Inside a dense layer it was not possible to distinguish any clear pattern of fish aggregation before sunrise, eventhought from the EK500 echograms it was obvious that the layer became more structured. Just after sunrise small schools were detected by the sonar and several merging have been recorded. The second transition period was the day-night transition on 15/10/95 from 4:30 to 7:00 GMT. Just after sunset, some medium schools, not very dense, at 30 m depth, were observed to change their shape, split in several school, and disappear either on the bottom or inside a layer at 40 m depth. Then, from 17:30 to the end of the observation period, some big and dense schools were observed close to the surface, moving actively, changing shape, some times splitting but also merging. This last situation was not found very different from the day situation. It is speculated that the two groups of schools observed do not belong to the same species, or at least correspond to different size class of the same species. The catch made earlier in the same area was in majority of pilchards with small anchovies mixed.

An other day-night transition period was observed on 16/10/95 from 15:40 to GMT in the same area. Dense surface schools were observed, with some times some seals above them. Starting from a quarter of hour before sunset up to the end of the experiment, we observed a fast splittings and/or decreases in density and a dispersal of different schools. In some occasions it seemed that this dynamics was liked with the presence of seals, assuming that they appeared as small dense spots on the screen. A tentative conclusion from these observations could be that the relatively long time (> 1 hour) of the dispersion of a stock, usually described in the literature from successive observations on a great number of schools, could not necessarily results in all occasions from a long process for all schools, but on the contrary from a fast process for each individual school in addition to a large variability in the time of occurrence.

A last day-night transition period was observed on 17/10/95 from 3:10 to 4:10 GMT, in the same south-est area of False Bay, on 45 m ground depth. Before that period, the night echograms delivered by the EK500 sounder indicated a dense layer at 30 m depth, with dense shoals either in the middle of it, or in the upper part (most of the time) or above it at 10 m from the surface. We have first observed the dense layer with the sonar and were able to see a progressive increase of the school-schoals size and density, but the patchess merging was not obvious. On the EK500 echogram the layer was progressively disappearing and moving deeper. Only some medium size patches were remaining. Just before sunrise we have observed at around 10 m depth several very active school merging. In few minutes the schools increased in size and density. At the end of the observation period, typical day schools were observed between 10 and 30 m, and few small low density patchess in the deeper layet as well.

Of course of these observations must be confirmed by post processing (event rate, school area variation, school density variation, etc).

Annex I

Future Research

This cruise was very valuable for gaining a better understanding of the schooling behaviour of the South African pilchard, and of its reactions to a survey vessel of the size commonly used in Southern African acoustic surveys. Advances were made in quantifying biases in acoustic estimates arising from avoidance and near-surface schooling, in measuring the speed of schools in relation to the surrounding water, and in improving understanding of inter- and intra-school dynamics by direct sonar observation. Experience was also gained in imaging schools by side-scan sonar (from which an appreciation was gained of the large variation in the size and shape of schools), measuring school/layer speed by ADCP measurements (a new technique), and in using a small boat equipped with a portable echo-integrator to measure the size and density of schools. Most of the problems addressed have a direct or indirect bearing on the accuracy of acoustic estimates of population size, which are essential in managing pilchard stocks in the South East Atlantic. Much of this work would not have been possible without the multi-beam tracking sonar and associated custom-developed logging software available on *Nansen,* the presence on board of researchers skilled in the use of this equipment, and the support of local researchers experienced in acoustic surveys of South African pilchard.The work was also greatly facilitated by the other acoustic equipment on board, and the protruding transducer and sea-kindliness of the vessel, which allowed data collection to be continued during the long spells of bad weather which were encountered.

In view of the above, it is recommended that this work be continued in the future from *Nansen*. Some extensions/ improvements which could be considered are:

1. Repetition of the work on pilchard in different regions where conditions are markedly different (Namibia, Angola) to broaden understanding of behaviour.

2. Extension of work to anchovy, particularly in South African waters, where acoustic assessments of stock size are essential in managing a major anchovy fishery.

3. Introducing some means of capturing the SA950 video images to facilitate tracking of schools and combining sonar and echo-sounder information on their size and density.

4. Use of differential GPS to correct positions, either in real-time or post-cruise, to improve the accuracy of school tracking.

5. Environmental studies, and studies on activity within schools (with assistance of work boat) to gain understanding of biological and environmental factors responsible for observed behaviour patterns.

6. Investigation of pilchard and anchovy feeding by sampling zooplankton in the wake of schools tracked by sonar

7. *In situ* measurements of pilchard and anchovy target strength using new Simrad and/or SFRI single target-recognition software and hardware
8. Use of a larger workboat, operating from shore if necessary, to investigate near-shore distribution, abundance and school behaviour.

9. Incorporation of ADCP to make regular measurements of school horizontal movement, based on software to be developed from current results.

Annex II

Daily activty

9/10

09 - 13: Loading of equipment from SFRI, Cape Town and IMT, Simonstown, SFRI and IMT personel arriving, P. Freon (ORSTOM) arriving.
13 - 14:30: Cruise meeting, briefing on research programe and setting up watches,
15:00: Depature from Cape Town harbour, heading for first SARP position,
19:00: Start of SA- SARP (South African Sardine and Anchovy Recruitment Programme) weekly environmental monitoring line off Slangkop Point. Line consisted of 12 stations 3 miles apart. Temperature and fluoresence vertical profile at each station with Magnum/rosette sampler, double-oblique haul to 70m with mini-Bongo net to sample ichthyoplankton , and measurement of surface currents by drogue tracking for approx. half an hour. Water samples taken at 5 m for chlorophyll, phytoplankton and nutrient analysis.

10/10

06:00: Completion of SARP line

False Bay Survey, purpose to locate concentrations of *Sardinops*-schools for sonar and echo sounder measurments, survey for comparing number of schools and fish density recorded by sonar and echo sounder, sonar directed starbord, tilt -5, range 300,
- Start transect A01 at 08:40
- Pt19 at 11:40, small Aakra-trawl, buoys, Wesmar sonar (hanging incorrect), catch about 75 % *Sardinops ocellatus* and 25 % *Engraulis capensis*
- Start transect A02 at 12:55
- Pt20 at 14:40, small Aakra-trawl, buoys, Scanmar trawl-eye, about 65 % *Sardinops ocellatus* and 35 % *Engraulis capensis*
- CTD793 at 16:20
- Start transect A03 at 17:30
- Pt21 at 18:35, small Aakra-trawl, buoys, about 90 % *Sardinops ocellatus* and 10 % *Engraulis capensis*
- CTD794 at 18:50
- Start transect A04 at 20:50
- Repeat False Bay grid:
    - Start transect A05 (A01) at 23:45

11/10

- Start transect A06 (A02) at 01:50
- Start transect A07 (A03) at 03:20
- Start transect A08 (A04) at 05:15, finished at 06:40

-Pt22 at 07:40, small Aakra-trawl (new one), without buoys, Scanmar trawl eye, sonar guiding, followed school by SA950 from 150 m in front of vessel to behind vessel and saw school passed between the doors, school recorded at trawleye, trawl hauled imediately, little catch so school had probably swam out again.
-CTD755 at 08:20
-sailing towards Simonstown for picking up Dave Demer,
-D. Demer aboard at about 13:00

-Freon experiment by comparing detection time of schools at sonar tilted 90° and 38 kHz echo sounder south along line A01

-sonar logging programe not running, B.Totland consulted and programe repaired

-from 15:00, Side-scan sonar trial north along A01. Towfish streamed on starboard side at 4 knots about 5m from surface. Port channel (firing through wake) more sensitive than starboard channel. Six schools detected (all on port side), all corresponding to schools detected on echo-sounder. No/poor correspondence between SA950 detections to starboard and side-scan images. 1 school imaged at the end of side-scan experiment.

-18:00, School recording trial, given up at 18:20 because up air plume disturbance and wave reverberation

-from about 19:00 to 23:50; ADCP measurments while drifting southwards out of the bay. Extensive, dense targets in upper 30m suitable for experiment. Initial processing suggests an average horizontal fish velocity of around 1.25 knots in an ESE direction.

- at 23:50 sailing for more sheltered position near Simonstown, no programe for the night due to rough weather (northerly gale)

12/10

- 00:00 - 07:30 vessel drifting in sheltered position on western side of False Bay due to strong North Western gale,
- 08:00 - 09:00 tracking of School 1 -3 for 10 - 15 minutes, difficult to follow the schools due to rough surface waves and reverberation from air plumes caused by breaking waves,
- from 09:00 searching for schools near Western side of False Bay and along line A01, wind increasing,
- 12:30 anchored near Simonstown
- 18:00 wind decreasing, hauling anchor
- 18:15 - 20:00 measuring School 4 - 9 by Simrad SA950 and Simrad EK500 near Simonstown
- 20:00 - 23:50 surveying False Bay, diagonal from Simonstown to Cape Hangklip, rough waves and wind near Cape Hangklip, going north along A04, then to anchor position near Simonstown, due to strong Western Gale.

13/10

- wind decreased during the night
- lifted anchor at 07:50, started school measurement by Simrad SA950 and EK500, surveying out from Simonstown, south along A01, then east to between A04, and west to A03, recorded School no. 10 - 42,
- PT23, small Aakra trawl, no floats, Simrad trawl eye, caught a pilchard school by aimed trawling, catch about 1 ton of pilchard,
- 13:55-15:10, side scan excercise going north between A03 and A04, many schools recorded on both sonars, vessel speeed 4.0 knots
- 15:55, ADCP - measurments of school speed south between A03 and A04, vessel speed 3.0 knots, sonar and doppler log off to minimize interference.
- 18:00-20:00, sonar measurments of School no. 43-55, schools close to surface and

difficult to record by EK 500,
- PT24, small Akra trawl, buoys, Scanmar trawl eye, catch about 2-3 tons of pilchard,
- TS-sonde experiment, sonde lowered to 25-30m, Density considered too high for reliable TS-measurments, and experiment ended at about 22:00
- 22:00 - 24:15; ADCP-measurment of fish shoal movement. Continuous scattering layer plus some schools.

14/10

-00:00 - 05:00, vessel drifting in False Bay,
-05:00 - 07:00, transition period measurments of pilchard shoals by SA950 and EK500,
- 07:00 - 07:40, Sonar tracking of School no. 56
- 08:00 - 10:00, Measuremnts of School 58 - 72 by SA950 and EK500
- 10:00 - 14:45, Sonar tracking of School no. 73 - 79
- 14:45 - 15:00, CTD no.798 with ADCP measurment of current speed at location
- 15:00 - 17:30, Measurments of School no. 80 - 88 by SA950 and EK500
- durning the afternoon the wind increased to South Eastern Strong Gale
- ca. 19:00, anchoring in bay near Cape Hangklif

15/10

- lifting anchor 08:00, difficult conditions due to South Eastern Strong Gale
- 08:30 - 14:30, Sonar tracking of School no. 89 - 107, some school tracked for about 60 minutes despite the bad weather, "Dr. Fridtjof Nansen" is a remarkably stable vessel
- 14:30 - 14:45, CTD no. 797 with ADCP measurment of current speed at location
- 15:30 - 18:00, PT. 25. small, new Aakra-trawl, Wesmar sonar, Scanmar door-spread sensor and depth sensor on doors, Scanmar height sensor on headline, catch control sensor, weights 30 kgs, no buoys, warp length 150 m, vertical opening 20 - 16 m, footrope 15 m above bottom, catch ca. 700 kg pilchard, Wesmar sonar head hanging skewed because hook on sonde-cable attachment were broken.
- 18:15 - 21:00: Sonar tracking of Schools 108 - 120 during transition periode.
- 21:05: ADCP measurment of fish layer

16/10

- 00:30 ADCP measurment of fish layer
- 00:30-08:00, drifting in False Bay, wind decreased to Southern breeze during the night,
- 08:00 - 10:30, Side-scan sonar excercise, transducer towed from large deck crane directed forwards, transducer near starboard side of vessel at about 3 m depth, numerous recordings of schools and good correspondence with SA950 sonar and EK500 recordings.
- 10:45 - 12:15,PT. 26, small Aakra trawl, Wesmar sonar, Scanmar door-spread sensor and depth sensor on doors, weights 30 kgs, no buoys, warp length 150m, Wesmar sonar still hanging skewed, catch ca. 1 tons of pilchard.
- 12:15 - 15:30, vertical avoidance experiment

- 15:30 - 17-30, small boat with EY500 trial, successive recordings by small both and RV of surface schools,
- 17:30 - 20:00, transition periode observations of schools
- 20:00 - 00:00, ADCP measurments of fish layer

17/10

- 00:00 - 00:30, ADCP measurments of fish layer
- 00:30 - 05:00, vessel drifting in False Bay
- 05:00 - 06:30, transition periode observations
- 06:45 - 09:45, horizontal avoidance experiment
- 10:45 - 11:30, Pt. 27, in deep water, Wesmar sonar still hanging skewed, but school detected up to 800 m ahead of trawl.
- 12:00 - 16:00, Cruise report writing
- 16:00 - 17:30, Summing up meeting
- 16:30, start of SARP-line
- 22:00, Paper preparation meeting

18/10

- 09:30, Arriving Cape Town
- 11:30, Preliminary cruise report deadline
- **18:30, Final version of the cruise report**

Annex IV

Cruise lines, surface temperature distribution off South Africa, vertical temperature profiles, and ADCP - current profiles at CTD-stations in False Bay.

Annex V

Post-cruise Activities and Products

Proposed publications:

1. Comparison of echo-sounder and sonar estimates of pilchard (*Sardinops sagax*) biomass in False Bay, South Africa.

   Hampton, Misund, Coetzee, Olsen, Fréon & Svellingen

   Target date: Jan. 1996 (echo-sounder data analysis)
   April 1996 (sonar data analysis)
   Second half 1996 (submission)

2. Schooling behaviour of pilchard (*Sardinops sagax*) in False Bay, South Africa

   Misund, Fréon, Coetzee, Gardener, Olsen & Hampton

   Target date: Second half 1996 (submission)

3. Use of ADCP to measure the horizontal and vertical velocity of fish schools

   Demer

All papers to be submitted to ICES J. Mar. Sci.

Processing Required

Data/Processing	Publication	Responsibility
Sonar estimate of biomass, Grid A	1	Misund
Integrator estimate of biomass, Grid A	1	SFRI
School tracking	2	Misund

Transition period trackings and imagery	2	Fréon
Side-scan sonar imagery	2	SFRI/IMT
Timing experiments	1 & 2	Fréon
Horizontal and vertical avoidance from beam sectoring experiments	1 (separate section)	Olsen, Fréon
ADCP experiments	3	Demer
SARP data	-	SFRI
Trawl data	1 & 2	SFRI & IMR
CTD profiles	Cruise Report	IMR

Figure 1. Distribution of pilchard and anchovy in False Bay 10/10-95.

Figure 2. Distribution of pilchard and anchovy in False Bay 11/10-95.

Figure 3. Expected (full line) and recorded (stippled line) number of schools on echo sounder during the False Bay surveys.

Figure 4. School area to school biomass relationship for pilchard.

Figure 5. School volume to school biomass relationship for pilchard.

Figure 6. Recording of the same school, first by EY500 (left) on small boat, and then by EK500 on R/V "Dr. Fridtjof Nansen" (right).

Figure 7. Track of school 95, False Bay, 15/10-95.

Figure 8. Swimming speeds of school 95, False Bay, 15/10-95.