V. Data analysis methods

Improved mapping of schooling fish near the surface: comparison of abundance estimates obtained by sonar and echo integration

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A method is described for recording fish schools near the surface by means of a computerized sonar system, a conventional echo integration unit, and sampling by a near-surface trawl. The sonar system consists of a 95 kHz SIMRAD SA950 multi-beam sonar connected to a work station with software for automatic detection and measurement of schools, and logging of the sonar data. The technique for near-surface trawling is based on re-rigging a pelagic trawl by extending the upper bridles, removing the weights, and attaching two large buoys to each wing. Pelagic fish stocks were mapped in the north-eastern Atlantic and off Namibia. The abundance estimates obtained by the near-surface recording method were compared with that obtained by conventional echo integration alone for four different surveys. It is concluded that the near-surface recording method can provide more precise mapping and abundance estimates of pelagic fish stocks in schools near the surface.

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Introduction

Horizontal guided sonar can record fish schools that conventional echo integration cannot record due to vessel avoidance or upper blind zone distribution. The establishment of linear relationships between the geometric dimensions and biomass of fish schools (Misund et al., 1992) has given further encouragement to the use of sonar for absolute abundance estimation of schooling fish stocks. We have used a high resolution sonar system, an echo integration system, and a new pelagic trawl for sampling close to the surface on surveys of herring in the Norwegian Sea and the Barents Sea, and on small pelagic species off Namibia. We compare abundance estimates obtained by the sonar with those obtained by echo integration.

Materials and methods

The method of near-surface recording of pelagic fish was employed on surveys of herring (Clupea harengus) by RV "G. O. Sars" in the Norwegian Sea in July–August 1993 (covering North 68°30′ to 71°30′, East 18° to West 6°30′) and June 1994 (covering North 62°30′ to 72°, East 10° to West 10°), and in the Barents Sea in August 1994 (covering North 69°30′ to 72°30′, East 32° to 35°30′). A similar survey was conducted by RV "Dr. Fridtjof Nansen" off Namibia in June 1994 (covering South 17° to 26°, and out to about 60 nautical miles from the coast) on stocks of anchovy (Engraulis capensis), pilchard (Sardinops ocellatus), and round herring (Etrumeus whiteheadi). Both vessels are equipped with a 95 kHz, high-resolution SIMRAD SA950 sector-scanning sonar (Fig. 1) that is connected to a HP9000/720 computer with special software for the detection and measurement of school recordings (Misund et al., 1994). The sonar was operated at full transmission power, with a frequency-modulated pulse (FM-AUTO), gainstep 7, time-varied gain of 20 log R, and the AGC, PP, and Normalization filters set to "Weak". The tilt angle was set at −5° during the Norwegian Sea and Barents Sea

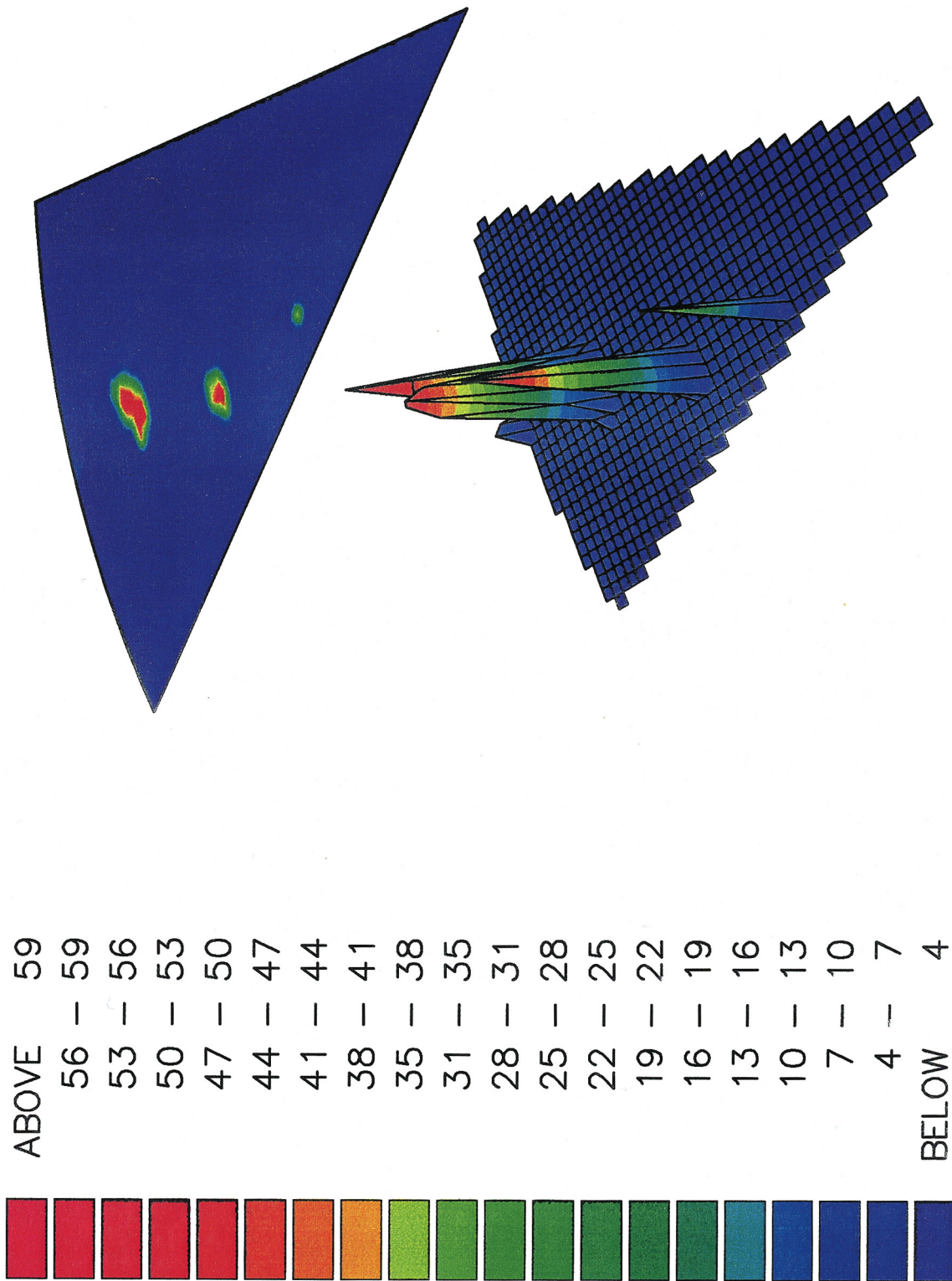| ABOVE	59
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BELOW	4

Figure 1. Two- and three-dimensional image of school recordings by the SIMRAD SA950 sonar as reproduced by the UNIRAS software. The sonar beam is transmitted in a 45° sector and received by 32 adjacent single beams of 1.7° each (between −3 dB points). The orthogonal beam width is 10° (−3 dB points). Recordings are displayed with a colour represented by a value from 0 to 63 (left column), and the number of the colour value increases with higher fish density. The school detection system is set to accept recordings with a colour value above 15, extending more than 5 m along the beams, and occurring in at least four consecutive pings.
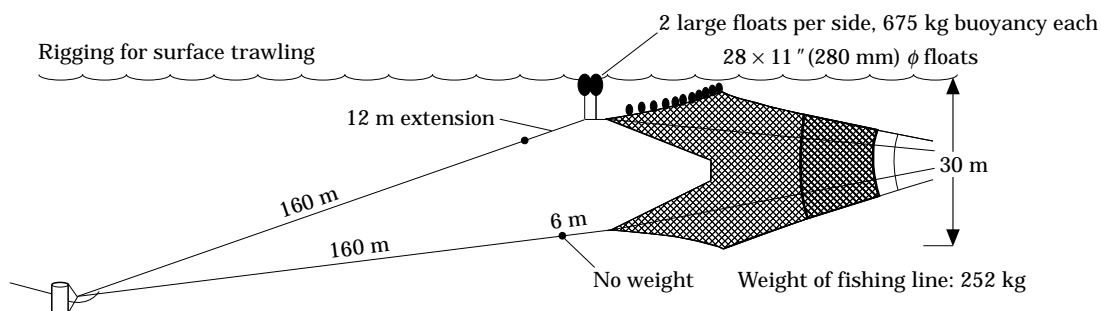
Figure 2. Rigging of the pelagic trawl for near-surface sampling. The trawl is made of four identical panels of black nylon netting, and the mesh size ranges from 3200 mm at the front to 20 mm at the codend. The trawl is normally operated with 7 m² Waco trawl doors, a towing speed of 1.8–2.0 m s^{-1}, warp lengths of up to 350 m, and slightly turning or zig-zagging of the vessel so that the trawl is towed out of the propeller wake.

surveys. During the Namibia survey, the tilt angle was adjusted from $-5°$ to $-10°$ depending on the depth distribution of the important pelagic species. The sonar was normally set with a train of $90°$ to the port or starboard side, but on a few occasions a train of $0°$ was used off Namibia.

The school detection system was set with a detection threshold at colour value 15, a lengthwise school extent of 5 m, and a minimum number of four detection pings (Fig. 1). On the RV "G. O. Sars", the inner and outer detection ranges were set at 50 m and 300 m, respectively, while on the RV "Dr. Fridtjof Nansen" they were set according to the bottom depth. The sonar recordings were post-processed by an application developed in SAS software (SAS, 1988). During this process, detections of unwanted echoes from the bottom, propeller wakes, whales, and surface air plumes during bad weather were removed. The Namibia recordings were processed with inner and outer detection ranges of 25 m to 65 m in shallow water, and 25 m to 150 m in deeper waters. The maximum area of each school detection was summed for each fifth nautical mile and the summed school area scaled to represent one square nautical mile. The sonar recordings were converted to fish biomass by using the relationship: school biomass=18.4 * school area. This had been established by measurements of herring schools using the SIMRAD SA950 sonar in the North Sea (Misund *et al.*, 1995).

Echo integration was carried out on all surveys using the BEI system (Foote *et al.*, 1991) connected to calibrated, 38 kHz SIMRAD EK500 echosounders operated with the 20 log R time-varied gain function. A new pelagic trawl (Valdemarsen and Misund, 1994) was used to sample pelagic recordings close to the surface (Fig. 2). In shallow waters off Namibia, RV "Dr. Fridtjof Nansen" towed a smaller version of the new sampling trawl. Subsamples of 100 fish of the target species were taken for measurements of length and weight. When converting the echo integration data allocated to the target species to biomass, the average

backscattering cross-section was computed from the target strength to length relationship TS=20 log L − 71.9, as recommended for clupeoids (Foote, 1987).

Results

On all surveys, the target pelagic species were mostly recorded at depths of less than 25 m and well within the observation volume of the sonar at the tilt angles applied. There were regions with large numbers of school recordings by the sonar and just a few on the echo-sounder (Fig. 3). This is caused by the small sampling width of the echo-sounder at a depth of 25 m, about 3 m, compared with the large sampling width of the sonar beam. In the example in Figure 3, the two schools recorded on the echo-sounder are as statistically expected when about 30 schools with an average diameter of about 15 m were recorded by the sonar for the same sailing distance.

The number of schools detected by the sonar correlated significantly with the fish density estimated from the sonar recordings (Table 1). However, there were significant but only weak correlations between the fish densities recorded by sonar and those recorded by echo integration for the cruises in the Norwegian Sea in 1994 and off Namibia (Table 1).

For the cruises in the Norwegian Sea and in the Barents Sea, there was a certain correspondence between the fish densities recorded by the sonar and echo-sounder, respectively, but there were regions in which herring schools were recorded by the sonar only. This is illustrated by vessel log 6450 to 6500 for the Norwegian Sea cruise in 1994 (Fig. 4). For the cruise off Namibia, the distributions of fish density recorded by the sonar show good correspondence with those of the echo-integrator.

In the Norwegian Sea and Barents Sea cruises, the average fish densities recorded by sonar were significantly higher than those recorded by echo-sounder (Table 1). In these cruises the ratios of fish densities
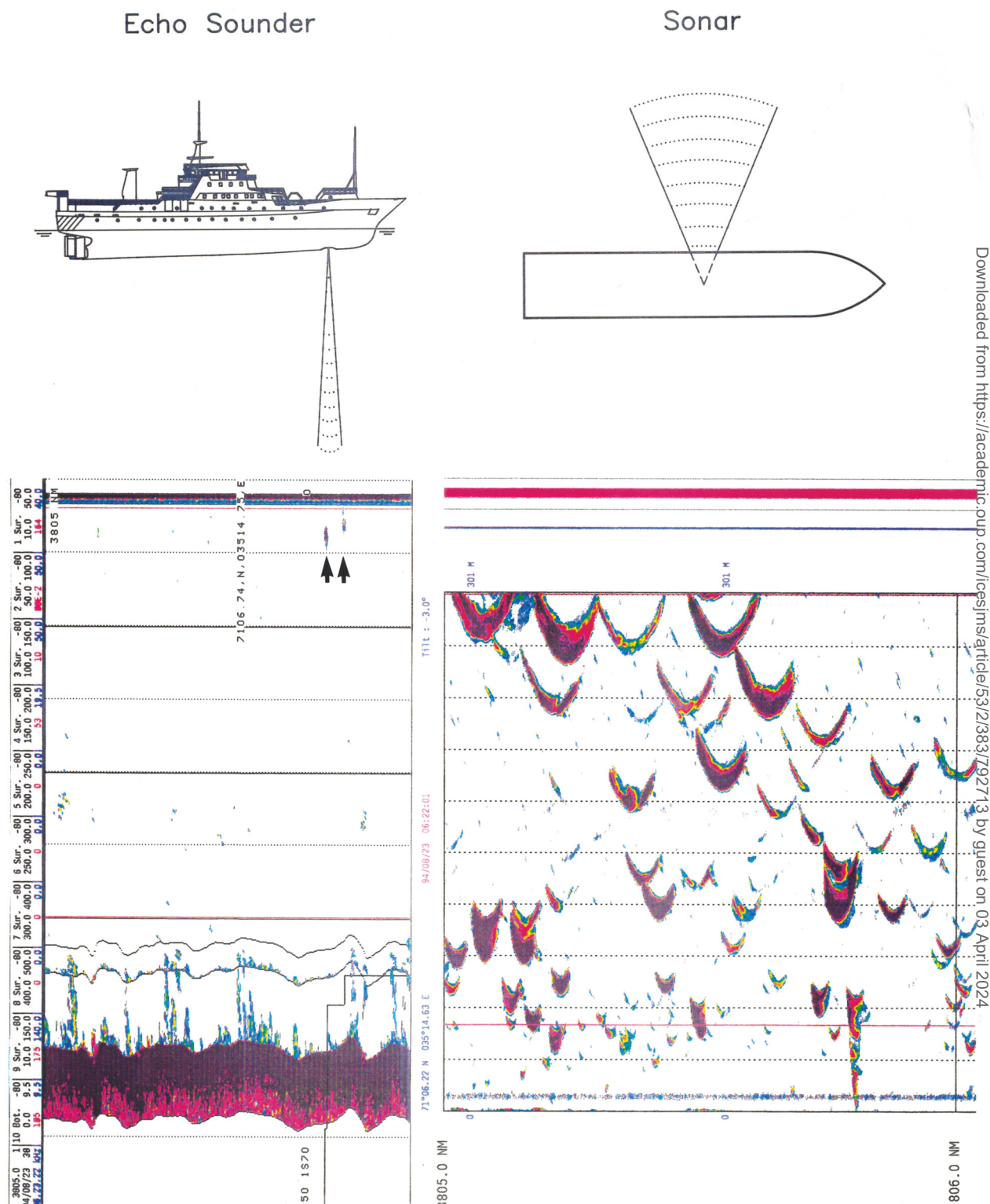
Echo Sounder

Sonar

Figure 3. Echo-sounder (left) and sonar recording (right) of schools for vessel log 3806 in the Barents Sea survey in 1994. Two schools (above the arrowheads) above 25 m depth are recorded by the echo-sounder, and 30 schools are detected by the sonar system within 50–300 m of the vessel. The sonar is directed 90° to port and tilted − 5°.

Table 1. Correlation analysis and average fish densities as recorded by sonar and echo-sounder on the different surveys (N_{sonar}=number of schools detected by the sonar; ρ_{sonar}=fish density as estimated from sonar recordings; $\rho_{E.I.}$=fish density as estimated from echo-integrator recordings; n=number of comparisons; r=correlation coefficient; NS: (p>0.05); Proportion=$\rho_{sonar}/\rho_{E.I.}$).

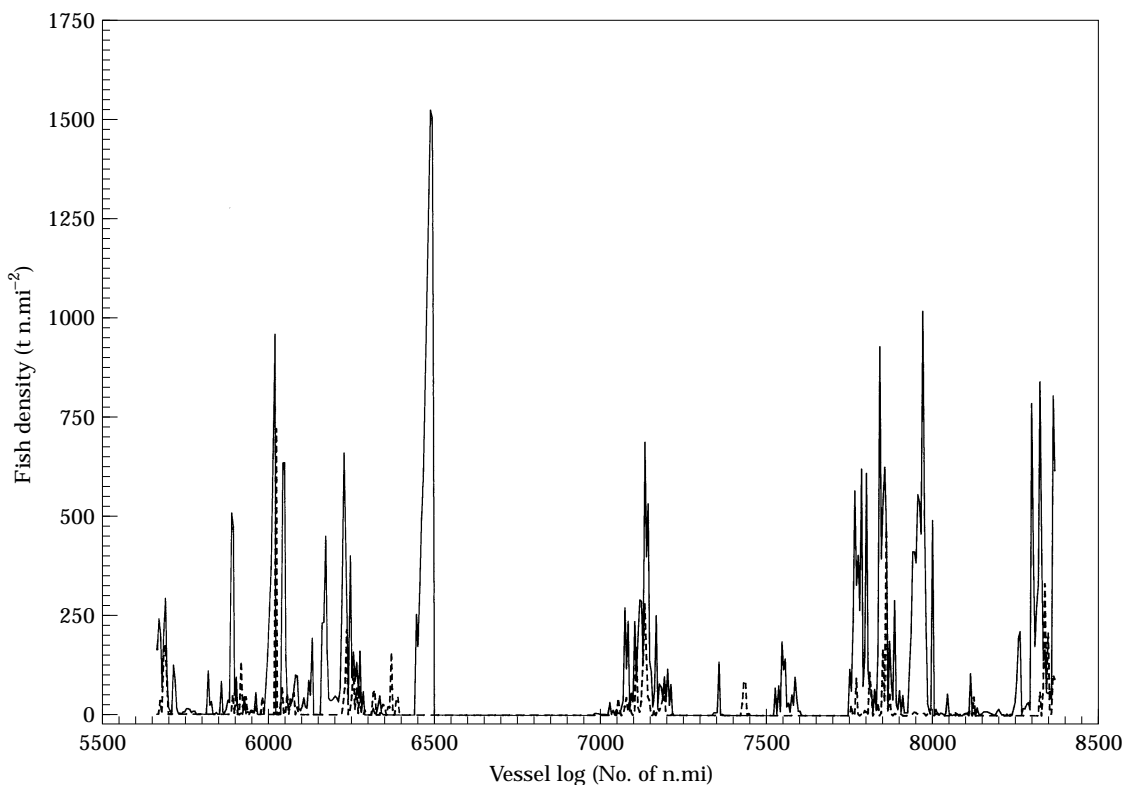| | Correlation analysis | | | | Average fish densities | | | |
	N_{sonar} vs ρ_{sonar}		ρ_{sonar} vs $\rho_{E.I.}$		ρ_{sonar} (t nmi^{-2})	$\rho_{E.I.}$ (t nmi^{-2})	Proportion	Wilcoxon 2-sample test (p)
	r	n	r	n				
Norwegian Sea 1993	0.90	89	0.10^{NS}	56	68.8	37.5	1.8	<0.05
Norwegian Sea 1994	0.44	301	0.24	111	175.4	51.8	3.4	<0.001
Barents Sea 1994	0.73	67	−0.01^{NS}	23	317.3	151.7	2.1	<0.001
Namibia 1994	0.85	262	0.38	258	62.9	69.2	0.9	<0.001

Figure 4. Distribution of fish density as recorded by sonar and echo-integrator for the survey in the Norwegian Sea in 1994. Solid line=fish density by sonar. Stippled line=fish density by echo integrator.

obtained by sonar to those obtained by echo integration ranged from 1.8 to 3.4. The highest average fish density, recorded by both sonar and echo-integrator, was observed on the herring cruise in the Barents Sea in 1994. On the cruise off Namibia the fish density recorded by echo integration was significantly higher than that of the sonar but the difference in the two estimates was only about 10%.

Discussion

Our study shows that a horizontally guided high-resolution sonar, which automatically detects and measures the size of fish schools near the surface, can locate more schools and thus give higher abundance estimates compared with conventional echo integration. This is because the sonar records fish schools missed by the

echo-sounder beam due to their position in the upper blind zone or to vessel avoidance by the fish. The extent to which these factors influence the mapping and measurement of fish densities may vary within and between surveys. For the surveys in the Norwegian Sea in 1993 and 1994 and in the Barents Sea in 1994, there were substantial regions in which the herring schools were recorded only by the sonar. The abundance estimates of herring from these surveys were therefore about two to three times higher when based on the sonar recordings rather than the echo-integrator data. Misund and Aglen (1992) observed significant vessel avoidance by herring schools close to the surface in the North Sea, but the effect of vessel avoidance on estimates of fish density obtained by echo integration was only about 20%. If there is no vessel avoidance and the fish schools are found within the observation volume of both the sonar and the echo-sounder, the recordings by these instruments should result in approximately similar estimates of fish abundance. This seems to have been the case for the Namibia survey. This indicates little or no vessel avoidance as has been reported for small clupeoids in tropical waters (Gerlotto and Freon, 1992).

Absolute estimates of the abundance of schooling fish by sonar require formulas by which the geometric dimensions or back-scattered sound intensity of schools can be converted to biomass. We have used a relationship between school area and school biomass established for schools of North Sea herring (Misund *et al.*, 1995). The relationship was based on measurement of school area by the SIMRAD SA950 sonar and subsequent echo integration of the schools with a 38 kHz SIMRAD EK500 to measure fish density and thereby to estimate the biomass. To convert the echo-integrator output into fish density, Misund *et al.* (1995) used the target strength equation of $20 \log L - 71.9$, as recommended by Foote (1987). The same equation was used to convert echo-integrator recordings to fish density in our surveys, and the sonar and echo-integrator estimates of fish density are therefore not completely independent. It is also likely that the relationship between school area and biomass may have been different for the herring recorded on our surveys, especially the pelagic species off Namibia, from the one derived for the North Sea herring. More reliable estimates of fish density by the sonar recordings might therefore have been obtained if relationships between school area and school biomass had been established for the target species during the respective surveys. The high correlations between the number of schools recorded by the sonar and the estimated fish density indicate that simple counts of schools by means of sonar may be used to develop relative estimates of fish density (Marchal and Petitgas, 1993).

To be detected by the sonar system, the relative echo intensity (colour code value) of the school must be above a certain threshold and the schools must be larger than a

certain horizontal extent. This implies that the system does not detect small and dense or large but loose schools. For the example given in Figure 3, the sonar detected 30 schools above 5 m in length, while a total of about 50 can be counted on the sonar echogram for log 3806. Obviously, missing the smallest schools implies that even the sonar estimates in our surveys are too low. However, it is quite possible that this underestimation is relatively unimportant because, for pelagic schooling fish, most of the biomass is concentrated in large schools (Freon *et al.*, 1993). The post-processing technique should therefore be further developed to enable redisplay and measurement of the sonar recordings with lower detection thresholds. In the present version of the sonar system there is no procedure for correcting the recorded school area for the range-dependent beam-width distortion. Nevertheless, the beam-width distortion seems to have negligible effect when recording schools with the rather high thresholds employed in our study.

References

Foote, K. G. 1987. Fish target strengths for use in echo integration surveys. Journal of the Acoustical Society of America, 82: 981–987.

Foote, K. G., Knudsen, H. P., Korneliussen, R. J., Nordbø, P. E., and Røand, K. 1991. Postprocessing system for echo sounder data. Journal of the Acoustical Society of America, 90: 37–47.

Fréon, P., Soria, M., Mullon, C., and Gerlotto, F. 1993. Diurnal variation in fish density estimates during surveys in relation to spatial distribution and avoidance reaction. Aquatic Living Resources, 6: 221–234.

Gerlotto, F., and Fréon, P. 1992. Some elements of vertical avoidance of fish schools to a vessel during acoustic surveys. Fisheries Research, 14: 251–259.

Marchal, E. and Petitgas, P. 1993. Precision of acoustic fish abundance estimates: separating the number of schools from the biomass in schools. Aquatic Living Resources, 6: 211–219.

Misund, O. A. and Aglen, A. 1992. Swimming behaviour of fish schools in the North Sea during acoustic surveying and pelagic trawl sampling. ICES Journal of Marine Science, 49: 325–334.

Misund, O. A., Aglen, A., Beltestad, A. K., and Dalen, J. 1992. Relationships between the geometric dimensions and biomass of schools. ICES Journal of Marine Science, 49: 305–315.

Misund, O. A., Aglen, A., and Frønæs, E. 1995. Mapping the shape, size, and density of fish schools by echo integration and a high-resolution sonar. ICES Journal of Marine Science, 52: 11–20.

Misund, O. A., Totland, B., Floen, S., and Aglen, A. 1994. Computer-based detection of schools by multi-beam sonar. *In* Proceedings of the 2nd European Conference on Underwater Acoustics, pp. 815–820. Ed. by L. Bjørnø. Elsevier, Amsterdam. 1099 pp.

SAS 1988. SAS Institute Inc. SAS/STAT® User's Guide, Release 6.03 Edition. Cary, NC: SAS Institute Inc., 1988. 1028 pp.

Valdemarsen, J. W. and Misund, O. A. 1994. Trawl designs and techniques used by Norwegian research vessels to sample fish in the pelagic zone. The Sixth Norwegian–Russian Symposium, Precision and relevance of pre-recruit studies for fishery management related to fish stocks in the Barents Sea and adjacent waters, Bergen, 14–17 June 1994. Paper 3.1. 17 pp.