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ACOUSTIC MEASUREMENTS OF SCHOOLING HERRING. ESTIMATION OF SCHOOL BIOMASS AND TARGET STRENGTH

by

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Abstract

The connections between reflected echo energy and dimensions of fatty herring schools were studied by a combination of multibeam sonar and a calibrated echo integration unit. A relation between the area and the biomass of the schools was established. A target strength relation was derived by preseining echo integration and sonar measurments of schools. Method deficiencies and improvements for school biomass estimation using sonar and preseining target strength measurements are discussed.

Introduction

Correct estimation of school biomass during purse seining is mostly dependent on the skipper's experience and intuition in relating echo recordings to biomass. During conventional echo integration surveys, schools avoiding the vessel will lead to significant underestimation of fish abundance (Olsen et. al. 1983). Use of sector scanning sonars may reduce this sampling error due to their greater volume coverage compared to single beam transducers (Ehrenberg 1980). Biomass measuring of schools with sector scanning sonars may increase the precision of abundance estimation of pelagic stocks, and be a helpful tool in tactical planning of purse seine operations.

Sector scanning sonars can be used to measure both horizontal and vertical school dimensions (Gunderson et. al. 1982, Wilkins 1986), and a computerized sonar can provide a scaled echo quantity of recorded schools (Bodholt 1982). However, relations to convert dimensions and echo quantity to absolute school biomass has been difficult to establish (Hewitt, Smith & Brown 1976).

To investigate possible connections between school dimensions and reflected echo energy, herring schools were measured by a multibeam sonar and a calibrated echo integration unit. Fish densities as measured by echo integration or estimated from purse seine capture of sonar measured schools were compared. By use of the density estimates from purse seining, a target strength relation of the herring was derived.

Materials and Methods

The investigations were made from M/V "Fjordfangst" in Romsdalsfjord, North Western Norway, in September 1987. The 42 feet vessel was rigged with a 320 m long and 45 m deep herring purse-seine, and equipped with an echo integration system (70 kHz Simrad EY-M echo sounder connected to a Simrad QM echo integrator) and a sonar (150 kHz Furuno CH-12). The acoustic system was calibrated according to standard methods (Foote et. al. 1987), and the instrument settings and calibration results are given in Appendix.

A total of 36 schools classified as herring were recorded. Temperature gradients in the Fjord (Fig. 1) caused deflection of the emitted sonar beams (Smith 1977), and the schools were detected < 300 m from the vessel. The vessel was turned towards the detected school, and when the recording appeared in the centre beam at a distance of 100 - 150 m away, the vessel was stopped. The sonar projection of the schools was measured perpendicular to the beams (cw) and along the beams (lw) by a ruler (Fig. 2). The horizontal distance vessel-school (R) was measured by the sonar marker. After dimensioning, the vessel was manoevered over the centre of the school at a speed (v) of approximately 2 m/s (4 knots) to record the reflected echo energy (M), echo transect length (tl), vertical extent (h), and average depth (D). Six of the schools were measured 4 - 5 times at intervals of 3 - 5 min. The dimensions and densities (method A, Johannesson & Losse 1977) were computed by:

(1) Crosswise extent : $CW = (cw\ s) - 2\ R \tan(BW_s/2)$ (m)
(2) Lengthwise extent : $LW = (lw\ s) - ((c\ t_s)/2)$ (m)
(3) Vertical extent : $H = h - ((c\ t_e)/2)$ (m)
(4) School area : $A = ((CW\ LW)/4)\ \pi$ (m^2)
(5) School volume : $V = 4/3\ A\ (H/2)$ (m^3)
(6) Transect length : $TL = (tl\ v/pv) - D\ (2 \tan(BW_e/2))$ (m)
(7) Fish density: $p = (C_i\ M\ k_{nm})/(4\ \pi\ \sigma_{bs}\ k_{nm}^2\ TL\ H)$ (n/m^3)

c : speed of sound (~ 1500 m/s)
BW_s : horizontal beam-angle of the sonar (6° at transmitter)
BW_e : beam-angle of the echo sounder (11°)
t_s : sonar pulselength (2.8 ms at sonar range of 200 m)
t_e : echo sounder pulselength (0.6 ms)
s : sonar scaling factor (sonar distance/screen distance)
pv : paper speed of the echo sounder (0.04 cm/s)
σ_{bs}: back scattering cross section of herring calculated by

target strength (38 kHZ) = 20 log L - 71.9 (Foote 1987)

k_{nm} : number of metres in one nautical mile

C_i : system calibration coefficient

The target strength of the herring was adjusted for the frequency of the echo sounder by addition of 4.5 (log f_a - log f_b) where f_a = 70 kHz and f_b = 38 kHz (MacCartney & Stubbs 1971). The school biomass was estimated by multiplying the school volume by the number of fish per unit volume and by the average fish weight (W) computed by:

(8) $$W = 1.508\ 10^{-3}\ L^{3.519}$$ (Simmonds et. al. 1986)

Two of the measured schools were captured by purse seine. The catch volumes were estimated visually by our skipper, and the fish densities estimated alternatively (method B) by dividing the catch volume with the average fish weight and the school volume. These densities enabled an independent calculation of the target strength (TS) of the herring by rearranging equation 7, and hence TS = 10 log σ_{bs} (MacCartney & Stubbs 1971).

RESULTS

The schools were recorded in daylight at depths from 7 to 58 m. The herring in sub-samples from four catches averaged 28.1 cm long (Fig. 3), were immature or slightly maturing, and with conciderable abdominal fat, and stomachs full of Calanus sp. At dawn the schools dispersed, too diffuse to enable dimensional measurement by the sonar.

Most of the schools seemed to avoid the approaching vessel sideways, and on eleven occasions the schools were not recorded on the echo sounder. The echo transect length was on average only about half the lengthwise extent as measured by the sonar (Table 1), and there was only a weak but significant correlation between these dimensions ($r = 0.39$, $p < 0.05$, $n = 52$).

The lengthwise and crosswise extent of the schools were on average about equal, but greater than the average vertical extent (Table 1). No correlation between the horizontal dimensions ($r=0.07$, $p>0.05$) indicates an elliptical or rectangular school shape. However, on one occasion a relatively large, parabolic shaped school was recorded, as swimming perpendicular to the convex side (Fig. 4). The vertical extent (H) seems to increase asymptotically with the area (A) of the schools (Fig. 5 A), expressed by:

$$H = 1.73\ A^{0.37} \qquad (r = 0.40,\ p < 0.05)$$

On average, the school areas amounted about 850 m^2, the school volumes about 14 000 m^3, but the school dimensions varied considerably (Table 1). The average fish density of the schools was 4.8 herring/m^3, but with high variance. There was considerable variation in repeated measurements of the six schools (Table 1), but average coefficient of variation (ACOVAR) was greatest for the echo trace length. The unstable dimensions induced great variation in estimated area, volume and densities of these schools with average coefficients of variation ranging from 0.55 to 0.89.

Both the reflected echo energy (M) and the calculated biomass (B) of the schools increased with school the area (A) (Fig. 5 B,C). The relationships are expressed by:

$$M = 0.0089\ (A) + 1.85 \qquad (r = 0.57,\ p < 0.05)$$

$$B = 0.02\ (A) - 0.25 \qquad (r = 0.68,\ p < 0.05)$$

Two schools, which had been dimensioned and measured for reflected echo energy were captured (Table 2). The difference in fish density as measured by the echo energy method (A) or estimated by the catch volume method (B) was < 1 herring/m^3. Calculated target strengths deviate 0.4 dB, but the largest herring gave the lowest target strength. Deduced 20 log L target strength relations indicate a difference of 1 dB in the two estimates. By linear averaging of these two estimates and refering to herring of 28.0 cm, the following target strength relation was derived:

$$TS\ (70\ kHz) = 20 \log L - 71.1$$

DISCUSSION

The schools were considered ellipsoid for the calculation of their area and volume. The equality in the crosswise and lengthwise extent, indicates a circular school shape when the sonar distortion is taken into account (Misund 1987). However, no correlation between the horizontal dimensions might also be explained with elliptic schools having random orientation of their axis relative to the vessel. This is different from other measurements of herring schools, where the elliptic shape of schools guided by the vessel was more apparent (Misund 1987). An elliptic shape of clupeidae and scombroidae schools are repeatedly reported (Bolster 1958, Cushing 1960, Anon 1974, Squire 1978), even if schools are claimed to be amorphous (Radakov 1973). The observed parabolic shape may be an adaption to combined feeding/migration behavior as reported for hunting bluefin tuna (Partridge, Johansson & Kalish 1983). Our method of measuring the school area would give erraneous estimates of parabolic schools.

The average proportion between the horizontal and vertical extent of the schools of about 1.6 : 1 is in accordance with similar proportions for herring, mullet, pilchard and saithe schools kept in aquaria or observed in nature (Breder 1959, Cullen et. al. 1965, Pitcher & Partridge 1979). However, the vertical extent seems to increase asymptotically with the area of the schools, indicating that the schools were enlongated more horizontally than vertically as they became bigger. This is in accordance with similar observations of capelin and haddock schools (Wrzesinski 1972), and points to influence of biotic and abiotic factors on school organizion.

The average area of the schools was about 850 m^2. This is less than the average school area of prespawning herring of the same stock and of summer-feeding North Sea herring schools, both sonar measured during purse seining (Misund 1987). This comparison is rather uncertain since small schools mostly are ignored during fishing. However, changes in biological conditions and sea environment may induce seasonal variations in school size (Devold 1969, Mohr 1971, Smith 1981).

Variation in dimensions from repeated measurements of the single school may be due to tightening or loosening of the school structure through changing swimming speed (Partridge et. al 1980), or because parts of the school are not insonified (Misund 1987). The relative variation in the crosswise extent was twice that of the lengthwise and vertical extent of the schools. As pointed out by Halvorsen (1985), the applied beamwidth correction is rather uncertain, and this might have induced the large variation in the crosswise extent. The school area measurements would have been improved substantially by methods for computerized picture analyzis of the sonar display.

The fish density in the recorded schools is one order of magnitude less than can be calculated from a school volume-to-average body length relation observed in aquaria (Pitcher & Partridge 1979). Comparisons between densities observed in nature and in a laboratory are probably doubtful since "aquaria" schools are organized in an environment with limited extent. The average fish density of about 4.8 herring/m^3 is comparable to 3.1 herring/m^3 as predicted by a relation between density and fish length (Serebrov 1976). Buerkle (1987) obtained densities from combined photograpic and acoustic measurements of a herring aggregation more than one order of magnitude lower, but his results may be biased by fish avoidance, and limitations of his camera system. Other studies of herring schools quote 1 fish/m^3 (Radakov 1973, Cushing 1977).

However, the measured densities may be biased by a too high frequency compensation (Ona 1982). Maybe the frequency compensation should have been negative since herring exhibit a falling frequency response from 27 to 54 kHz (Simmonds 1986). Errors in the measurement of the system calibration constant, absorbtion of the emitted sound beam in dense concentrations (Røttingen 1976), and sysematic vessel aviodance (Olsen et. al. 1983, Olsen 1987) may also have biased the results.

The great variation in the fish densities may reflect natural density variations caused by the internal school dynamic (Van Olst & Hunter 1971), or by lacunas between subunits in the schools (Pitcher & Partridge 1979, Serebrov 1984). In addition, variation in the fish densities may be induced by uncertainty in measuring the reflected echo energy from representative sections of the schools. This problem can be examplified by assuming a circular school shape which results in a probability to transect the diameter of schools proportional to $\pi/4$ (Olsen 1969). The uncertainty is increased with schools avoiding sideways, even if the direction of the vessel was adjusted to ensure passage over the centre of the school. This is supported by the proportion between the average echo trace length and average lengtwise extent of about 0.5, and also by the great relative variation in the echo trace length of the six schools measured repeatedly. In about 18 % of the occasions the schools avoided the approaching vessel strongly, and were not recorded on the echo sounder. The "stylus and ping errors" (Johannesson & Losse 1977) may also induce variation in the density measurements, but these sources of errors were reduced by a slow vessel speed and the relative large size of the schools.

Another serious source of variation is that some of the recorded schools might have been formed by species with a target strength different of herring. In the actual area saithe *(Pollachius virens)* were present, and one purse seine trial gave a 5 ton catch of about 35 cm long saithe. It is difficult to separate sonar and echo sounder recordings by species, and all recorded schools exccept the saithe school caught, were therefore considered to be herring.

The school area increased both with reflected echo energy and calculated biomass of the schools. This is in accordance with acoustic theory and the knowledge of schooling behaviour. Reflected echo energy from a recorded school section is proportional to the average target strength of the individuals plus 10 times the number of individuals in the recorded section (Mitson 1983). The volume of a school is proportional to the number of individuals multiplied by the cube of the average body length (Pitcher & Partridge 1979). Consequently, the area of a horizontal section through the school is proportional to the number of individuals in the section multiplied by the square of the average body length. The relation between the area and biomass of the schools is close to a similar relation for schools of North Sea herring of about the same size (Misund 1987), and comparable to a correlation between purse seine catches and echo integrator values of pacific herring shoals (Mulligan, Kieser & Gjernes 1987).

The difference in fish densities estimated by reflected echo energies or by catch volumes of two purse seine captured schools was less than 1 herring/m^3. Ignoring the frequency dependence, the derived target strength equation is close to the equation recomended by Foote (1987), but a bit different to a equation obtained by Hagstrøm & Røttingen (1983) with a method similar to ours. Since our target strength relation is based on uncontrollable catch volume estimates, the confidence of the relation is weak. However, even if an experienced skipper to some extent gives reliable catch estimates (Mulligan, Kieser & Gjernes 1987), accurate measurement makes the method confident.

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Table 1. Dimensions, area, volume and fish density by 52 measurements (totaly) of 36 recorded herring schools, and average coefficient of variation (ACOVAR) in repeated (4-5) measurements of 6 schools.

	Dimensions				Area	Volume	Fish density	
	CW(m)	LW(m)	TL(m)	H(m)	(m^2)	(m^3)	(n/m^2)	(n/m^3)
Average	31.3	33.4	19.4	20.8	852.2	13945	101.9	4.8
St. Dev.	20.1	20.2	20.2	9.2	921.0	18790	89.3	3.1
ACOVAR	0.53	0.20	0.69	0.31	0.55	0.69	0.77	0.89

Table 2. School dimensions, fish density and target strength of herring in two schools captured by purse seine (A: echo energy method, B: catch volume method).

	Catch volume (hl)	School area (m^2)	School volume (m^3)	Fish length (cm)	Fish weight (kg)	Fish density (n/m^3)		Fish TS (dB)
						A	B	
School 1	20	142	2461.3	27.0	0.164	4.4	4.6	-42.0
School 2	100	781.1	8331.7	28.9	0.209	4.6	5.3	-42.4

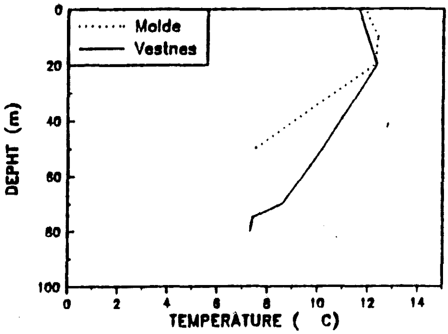

Fig. 1. Temperature profiles from the school recording area.

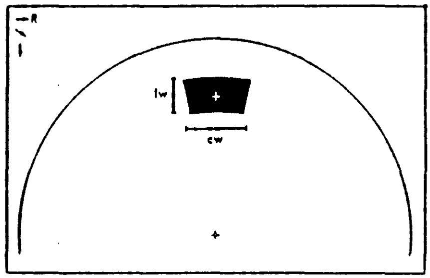

Fig. 2. Measurement of lengthwise (lw) and crosswise (cw) school extent, and horizontal distance vessel-to-school (R) at the sonar display.

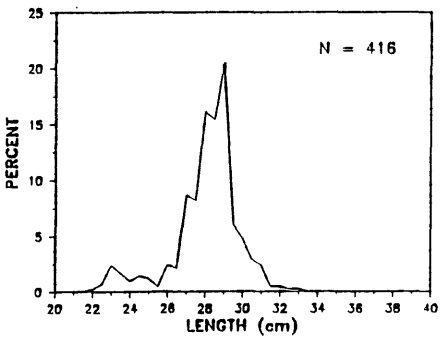

Fig. 3. Length distribution from four herring catches.

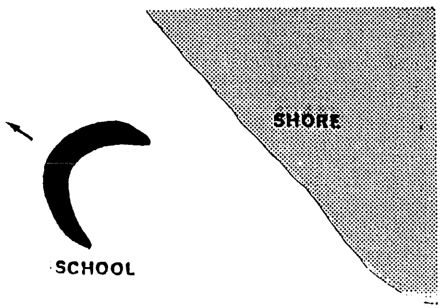

Fig. 4. Recorded parabolic shaped school with swimming direction as indicated by the arrow.

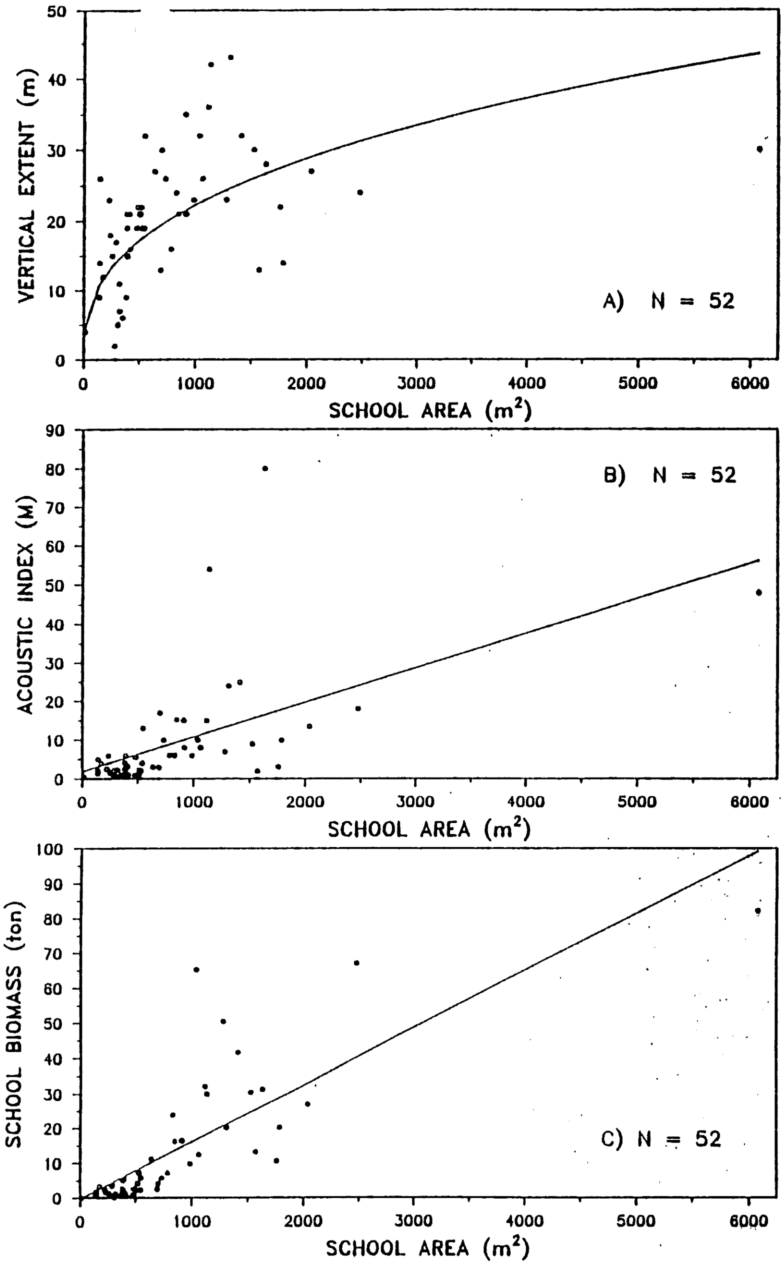

Fig. 5. Estimated school area related to vertical extent (A), acoustic index (M = integrator output, B), and calculated biomass (C).

APPENDIX

Instrument settings and calibration results

Simrad EY-M echo sounder	
Gain (step)	5
Scale (meter)	0 - 60
Source level (SL) + Voltage response (VR) (dB)	108
Simrad QM echo integrator	
Threshold (dB)	0
Gain (dB)	-20
Channel 1 (meter)	0 - 60
Channel 2 (meter)	60 - 120
System calibration constant (C_i)	328.6