Abundance estimation of fish schools based on a relationship between school area and school biomass

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Abstract

A method for acoustic abundance estimation by horizontal guided sonar of fish schooling close to surface is presented. The basic principle is to measure the horizontal area of schools in situ, and derive the school biomass subsequently through a school area to school biomass relationship. The application of the method is exemplified through a sonar survey in the eastern North Sea-Skagerrak in September 1990. The areas of recorded schools were measured by the estimate function of a Furuno CSH-70 sonar, and selected schools were captured by purse seine to establish a school-area to school-biomass relationship. In the actual region, the biomass of herring (*Clupea harengus*) and mackerel (*Scomber scombrus*) was estimated to about 90000 and 430000 tons, respectively. The accuracy of the method is discussed and improvements are suggested.

Keywords: Acoustic abundance estimation, fish schools, sonar, purse seine, herring, mackerel.

La biomasse des bancs de poissons estimée par la relation entre leur section horizontale et leur biomasse.

Résumé

On présente dans cet article une méthode d'estimation acoustique de l'abondance des poissons en bancs situés près de la surface en utilisant un sonar horizontal. Le principe de base consiste à mesurer *in situ* l'aire de la section horizontale du banc et d'en déduire sa biomasse à partir de la relation établie entre section et biomasse du banc. L'application de cette méthode est illustrée par une campagne de prospection au sonar effectuée dans l'est de la mer du Nord et le Skagerrak, en septembre 1990. Les sections des bancs détectés ont été établies d'après la fonction d'estimation du sonar Furuno CSH-70. Un certain nombre de bancs ont été capturés avec une senne tournante pour établir la relation entre la section des bancs et leur biomasse. Dans la région étudiée, la biomasse de hareng (*Clupea harengus*) a été estimée à 90000 tonnes, celle de maquereau (*Scomber scombrus*) à 430000 tonnes. La précision de la méthode est discutée et des améliorations sont suggérées.

Mots-clés : Estimation acoustique de l'abondance, bancs de poissons, senne tournante, hareng, *Clupea harengus*, maquereau, *Scomber scombrus*.

INTRODUCTION

Conventional acoustic abundance estimation by echo integration of fish schooling close to surface may be difficult due to vessel avoidance (Olsen, 1990) and the upper blind zone of the echo sounder (Aglen, 1989). Horizontal guided sonars can cope with these problems (Anon., 1974), but echo integration by use of a such equipment is not practised as relationships to convert school target strength to school biomass is difficult to establish (Hewitt *et al.*, 1976). Misund (1988; 1990 *a*) and Misund *et al.* (1992) have demonstrated that relationships exist between the geometric dimensions and biomass of schools. Based on acoustic dimensioning by sonar, this principle can be applied for abundance estimation of schooling fish.

In the North Sea, regular acoustic surveys are conducted to map the distribution and estimate the abundance of herring (Kirkegaard *et al.*, 1990). Conventional acoustic surveys for mackerel have also been attempted (Degnbol *et al.*, 1988), but the classification of echo recordings was associated with great uncertainties. This is because the mackerel is usually difficult to catch with standard sampling trawls, especially when schooling close to surface in summer (Misund and Aglen, 1992). There are also great uncertainties as to the applicability of recorded target strength values for mackerel (MacLennan *et al.*, 1989). The abundance of mackerel is therefore mainly estimated by indirect methods such as egg surveys, catch data analysis and tagging experiments (Anon., 1990).

To develop an alternative, direct abundance estimation method, an attempt has been made to measure the abundance of schooling fish by using a fisheries sonar (Furuno CSH-70) to quantify the area of recorded schools. To estimate the school biomass, a relationship between school area and biomass was established by purse seine capture of sonar measured schools. A similar method has been used for abundance estimation of herring in Newfoundland waters (Wheeler and Winters, 1990).

MATERIALS AND METHODS

The sonar method was tested during a survey in the Eastern North Sea-Skagerrak region (*fig.* 1) by the purse seiner M/V "Endre Dyrøy" (799 GRT). The vessel was well equipped with acoustic instruments for fish detection (*table* 1) and a conventional herring purse seine (735 × 167 m).

Table 1. – Acoustics instruments, M/V "Endre Dyrøy".

		kHz	Beamwidth	Pulse-length (s)
Sonar	Furuno CSH-70	180	5-10° × 6° (a)	0.005 (400 m)
	Simrad SU	24	8.5° × 9° (a)	0.015 (1 250 m)
Echo Sounder	Skipper CS 119	200 50		
	Simrad EQ 50	49	8° × 18° (b)	0.003

(a) horizontal × vertical.
(b) alongship × athwartship.

The upper 40 m of the water column was searched for schools during daytime by operating the Furuno CSH-70 sonar in a 180° mode with a 400 m search radius and a tilt angle of –3°. The gain functions of the sonar were given a setting (*table* 2) that, according to the skipper's experience, were favourable for mackerel recording. A relative estimate of each school recorded was obtained by using the estimate function of the sonar when the schools were in the range interval of 100 to 300 m away from the vessel. The estimate function gives a relative size from 0 to 100 of a recording within an octagonal area with cross-section equal to 1/4 of the search range chosen (*fig.* 2). The relative estimate (a') is a function of the extent and target strength of the school. By assuming circular school shape and proportionality between school target strength and school area, an estimate of school area can be calculated by:

$$A' \,(\mathrm{m})^2 = a' \times s$$
$$= 2 \times (R_i \times LW' \times n \times \tan(\varphi/2))$$

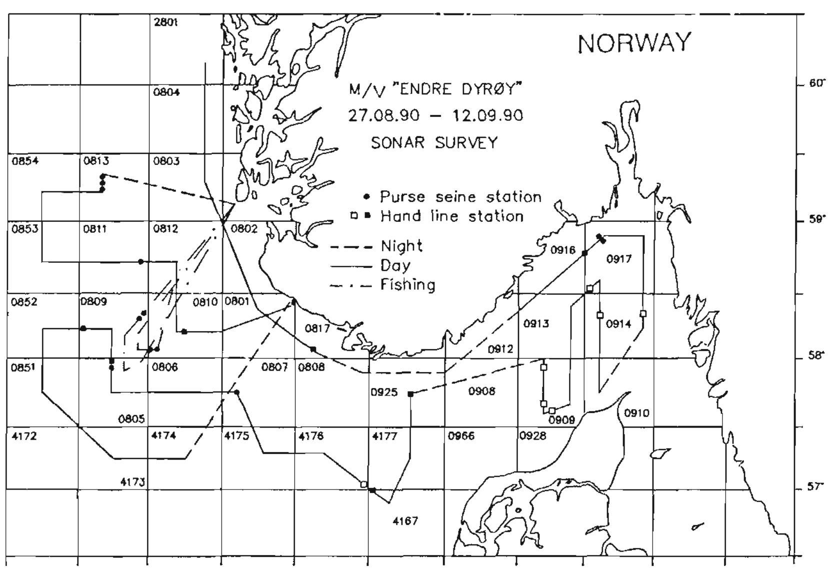

Figure 1. – Transects, purse seine and hand line stations during the sonar survey 27/8-12/9 1991. The number in each square is according to the ICES system for statistical areas, and is used to identify the squares in *table* 4 (filled symbols: stations with catch, open symbols: no catch).

Table 2. – Setting of the Furuno CSH-70 (the possible range of all functions is 0-9).

	TVG			Gain	AGC	HOR
	Near	Medium	Far			
Setting	0	5	5	7	2	0

TVG: time varied gain.
AGC: automatic gain control.
HOR: horizontal beamwidth adjustment.

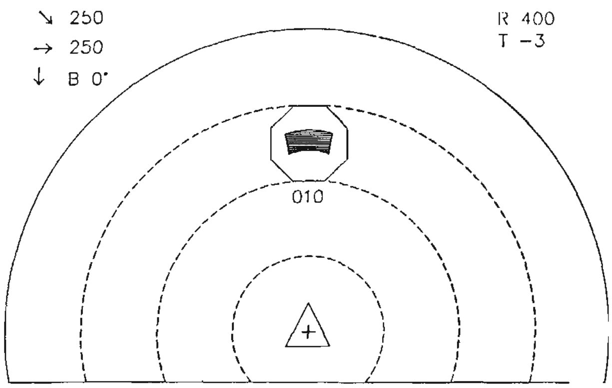

Figure 2. – Estimate function of the Furuno CSH-70 (R: search range of sonar, T: tilt angle, arrows: slant, horizontal and vertical distance to marker, B: direction of bearing to marker).

$$LW\ (m) = A'/2 \times (R_i \times n \times \tan(\varphi/2)) - c\tau/2$$
$$A\ (m)^2 = \pi/4 \times (LW)^2$$

A' = uncorrected school area;
LW' = uncorrected school diameter;
s = scaling factor (converting sonar estimate to m^2);
R_i = horizontal vessel-to-school distance (m);
LW = school diameter (m);
n = number of beams covered by the school projection;
φ = horizontal beam-width of the sonar (6°);
c = speed of sound (m/s);
τ = pulse-length (ms).

The classification of the recorded schools to species was based on frequent fishing with hand lines and purse seining of selected schools. During hand line fishing the vessel was manoeuvered carefully to a position straight on top of recorded schools.

For schools captured by purse seine, the relationship between school area and school biomass was investigated. The sonar picture was video taped during circling of these schools, and the crosswise (extent perpendicular to the sonar beams) and lengthwise (extent along the sonar beams) dimensions of the schools measured by a ruler on the screen during still picture playback as described by Misund (1990 *a*). The biomass of whole schools caught was estimated from the volume occupied in the holding tanks, and control-measured during delivery. The school area-to-school biomass relationship of these schools was compared with similar measurements of mackerel schools in the Northern North Sea (Misund, 1988) and in a Norwegian fjord.

The biomass of recorded schools was estimated using the area-to-biomass relationship established to convert the school area estimate to school biomass. The sailed distance, area searched, and total recorded school biomass were estimated for statistical squares of 30 × 30 nautical miles (*fig.* 1). By multiplying the total recorded biomass with a real-to-searched area proportion for each square, an estimate of the total biomass in these squares was obtained.

The horizontal beam-width of the Furuno CSH-70 sonar is not explicitly stated as the operator manual claims it to be adjustable in the interval 5° to 10°. According to Misund (1990 *b*), measurements of schools should be corrected for a horizontal beam-width that results in a range-dependent proportion between the crosswide and lengthwise extent of the school projections. The measurements of crosswise extent for the schools selected for purse seine capture were therefore corrected for beam-widths in the actual interval, and the effects on the crosswise-to-lengthwise proportion studied (*table* 3). Range independence was obtained at beam-widths of 5° and 6°, and in the following analysis a horizontal beam-width of 6° is used.

RESULTS

Measurements on two herring schools (mean fish length 22 cm) circled in Skagerrak confirmed the basic assumption of proportionality between the school area and the relative abundance estimate (*fig.* 3), as there was a significant correlation between the school

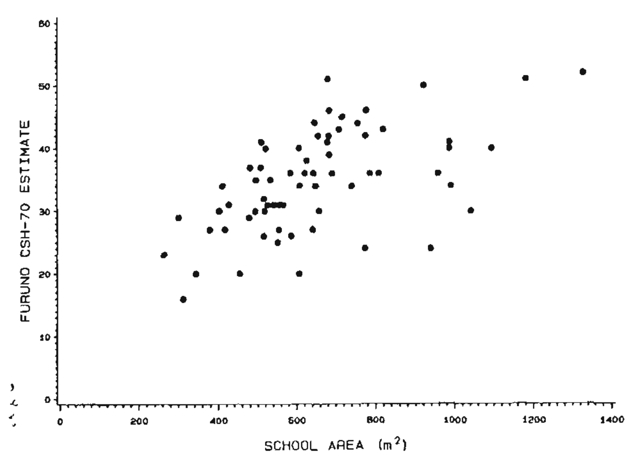

Figure 3. – Relationship between the school area measured as described by Misund (1990 *a*) and the Furuno-estimate for two herring schools circled during purse seining in Skagerrak.

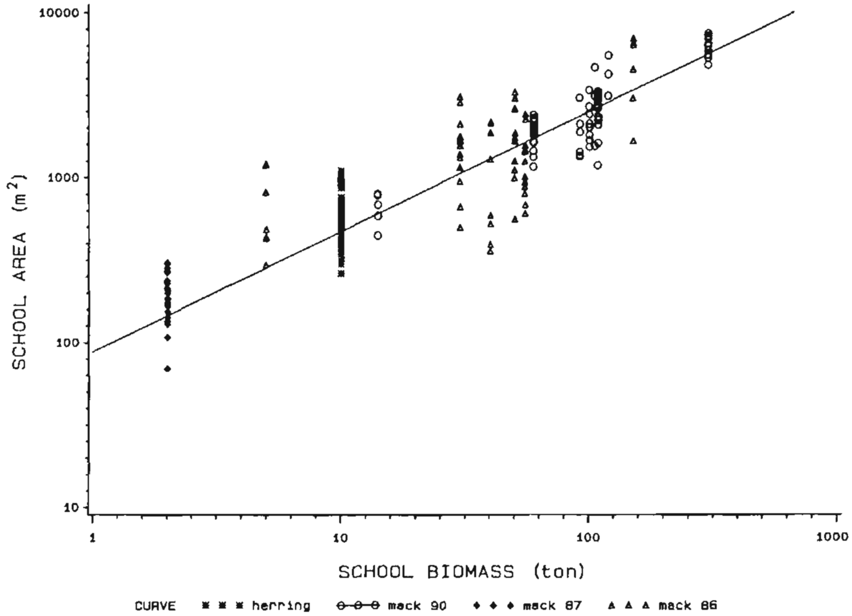

Figure 4. – Relationship between the school area and biomass for mackerel schools (mack 90) caught by M/V "Endre Dyrøy", 1990. Data for a herring school are included, and measurements of mackerel schools conducted by M/V "Libas" (mack 86) in 1986 (Misund, 1988) and R/V "Fjordfangst" (mack 87) in a Western Norway fjord in 1987 are also presented.

Table 3. – Average crosswise/lengthwise (CW/LW) extent of the schools related to beam width and distance (r_s: Spearman rank correlation coefficient for CW/LW and distance).

Beam width	Herring			Mackerel		
	CW/LW	r_s	N	CW/LW	r_s	N
5°	1.35	−0.10	68	2.00	0.16	81
6°	1.22	−0.14	68	1.92	0.15	81
8°	0.98	−0.25*	68	1.75	0.11	81
10°	0.73	-0.40*	68	1.62	0.04	81

* $p<0.05$.

area and the Furuno estimate ($r=0.58$, $p<0.001$, $n=67$). The second assumption of circular school shape was acceptable for the circled herring schools (average crosswise-to-lengthwise proportion = 1.22, *table* 3), but not for the mackerel schools (mean fish length 37 cm) circled during purse seining (average crosswise-to-lengthwise proportion = 1.92).

There was a clear relationship between the area and biomass of eight mackerel schools from 14 to 300 tons caught by purse seine (*fig.* 4). The area of a 10 ton herring school fits well to this relationship also. The relationship between school area and school biomass for the herring and mackerel schools is expressed by:

$$\log(\text{biomass}) = 1.329 \times \log(\text{school area}) + 0.428$$
$$r = 0.94$$

This relationship was used for the conversion of school area estimates to school biomass for the schools recorded during the sonar survey.

Mackerel schools were recorded along the coast of Southern Norway, in Skagerrak only a few herring schools were detected, while both herring, mackerel and horse mackerel schools were recorded in the Eastern North Sea. Most of the recorded schools were rather small, and average school area was 300 m² and 220 m² for the herring and mackerel schools, respectively. This corresponds to average biomasses for the herring and mackerel schools of 7.5 tons and 5.5 tons, respectively. The average school area (565 m²) of the few horse mackerel (*Trachurus trachurus*) schools recorded was larger than that of herring and mackerel.

Based on the sonar recordings, the total abundance of herring was estimated to 30 000 tons in Skagerrak and 60 000 tons in the Eastern North Sea (*fig.* 5, *table* 4). Only a small amount of mackerel seemed to be present in Skagerrak (*fig.* 5), but the total estimate for the Eastern North Sea was 430 000 tons (*table* 4).

DISCUSSION

The school-area to school-biomass relationship established for mackerel fits well to a similar relationship reported by Misund (1988) on the basis of sonar measurements and subsequent purse seine capture of marckerel schools by M/V "*Libas*" in 1986 and a single observation by R/V "*Fjordfangst*" in 1987 (*fig.* 4). These relationships indicate a biomass of 25 tons for a school of 1 000 m², which is also comparable to the level of a relationship established by a similar method for North Sea herring (Misund, 1990).

However, the area-to-biomass relationships estimated by purse seine capture of sonar measured schools give estimates about 5 times that of area-to-biomass relationships established by echo integration of sonar measured schools (Misund *et al.*, 1992). This discrepancy may be the result of different sampling strategies, as the few schools singled out for purse seining may be larger and denser than average, while echo integration may have been conducted on schools within a greater interval of variation both in size and density. If this is the case, the abundance of herring and mackerel is severely overestimated. However, most sources of errors connected to the echo integration method tend to result in underestimated fish densities (Aglen, 1989), especially of schools due to absorption (Toresen, 1991).

There is a rather large scattering (by a factor of about 10) in the school area to school biomass relationship. This indicates that the predictability of school biomass based on a single measurement of the area of a recorded school is affected with substantial uncertainty. However, the fish abundance was estimated from measurements of a large number (about one thousand) of schools. This will probably give an acceptable degree of precision in the total biomass estimate as the randomness in the measurements of the single schools will be smoothed out.

A substantial fraction of the large scattering in the area to biomass relationship is probably induced by the measurement procedure. The recording of the actual schools was made when the vessel circled around them before shooting the purse seine. The schools were therefore measured from different aspect angles so that the total target strength of each school probably varied substantially. Since mackerel has no swimbladder and therefore a low target strength, this may have caused that fractions of the school with a low fish density were not displayed when the fish were recorded in unfavourable aspect angles. Similarly, the schools may not have been properly insonified on all occasions due to imprecise tilting of the sonar and since the sonar beam was not stabilized in relation to the pitch and roll motions of the vessel.

However, some of the variation in the size of the school area is probably real, and caused by internal dynamics of the schools (Misund, 1990 *b*). Schooling fish pack denser when swimming faster (Partridge, 1981), and changes in swimming speed will thereby influence the school area. Formation and disappearance of empty spaces in the school may also affect the school area. Nevertheless, the size of the school area may be relative stable for periods up to one hour despite substantial changes in external shape (Fréon *et al.*, 1992).

A major uncertainty with the applied method is the estimation of school area *in situ* by the estimate function of the Furuno CSH-70 sonar. The assumption of circular schools is not met, at least for the mackerel schools. School shape is dependent on swimming depth, with more circular schools midwater and flattened discoids close to surface and bottom (Misund, 1990 *b*). Squire (1978) argues that circular school shape is rather uncommon in nature. Basing the estimation of school area to an assumption of circular school shape is therefore not satisfactory. An alternative would be to use a relation between school area and the relative Furuno estimate directly. Unfortunately, this was not possible during this survey, as the area of six of the mackerel schools caught exceeded that of the estimate octagon so that the direct relation between the Furuno extimate and the school biomass could not be studied. The school area could also have been calculated from measurements of the crosswise and lengthwise extent of the school projection (Misund, 1990 *b*). This would have required continuous video recording of the sonar, and the subsequent video analysis of recordings from a 14-day survey would have been very laborious and time consuming.

A critical procedure of the applied method is the *in situ* classification of recorded targets, especially

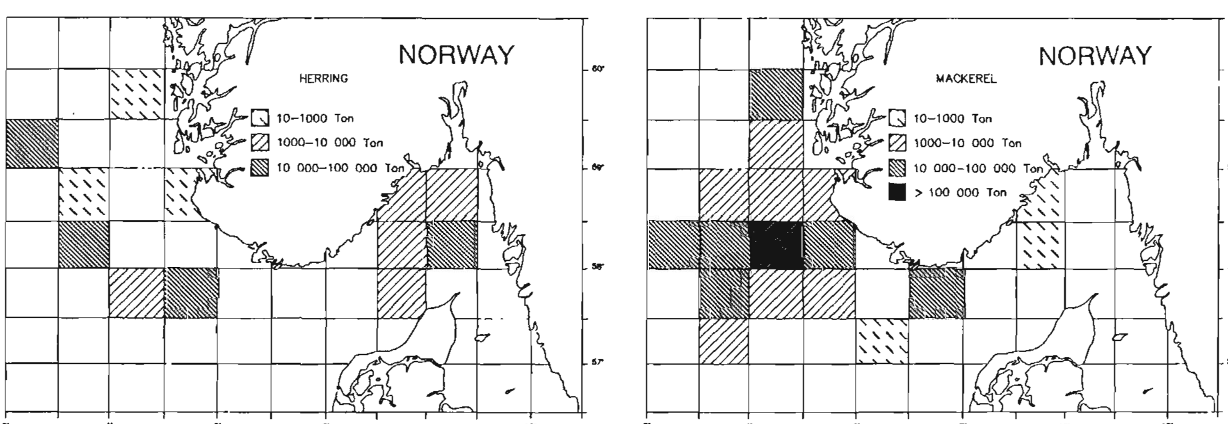

Figure 5. – Abundance distribution of herring and mackerel as recorded by the Furuno sonar, September 1990.

Table 4. – Biomass estimates for herring and mackerel in Skagerrak and Eastern North Sea, September 1990 (x: average school size; Σ: total estimate; RA: area of statistical square; SA: searched area.).

Square	Sailed distance (nm)	SA (nm^2)	RA/SA	N	Herring Biomass (ton)		N	Mackerel Biomass (ton)	
					x	Σ		x	Σ
Skagerrak									
0916	28	9.07	50.00	2	21.0	2 107	7	0.3	99
0917	80	25.92	34.23	15	7.4	3 797			
0914	48	15.55	57.88	53	3.5	10 860			
0910	20	6.48	138.89	–	–	–			
0913	52	16.851	53.41	14	11.0	8 237	19	0.3	275
0909	67	21.712	41.46	18	7.1	5 314			
Σ				102		30 315	26		374
North Sea									
0802	33	10.69	42.10	1	0.2	10	111	1.7	8 166
0801	50	16.20	55.56				119	3.5	23 214
0817	20	6.48	48.23						
0925	13	4.21	213.76				40	1.6	13 470
4177	32	10.34	87.04						
4167	14	4.54	198.24						
4176	37	11.99	75.06				3	0.9	219
4175	27	8.75	102.86						
0807	22	7.13	126.23	6	14.9	11 296	18	3.0	6 881
0806	30	9.72	92.59	10	5.6	5 190	5	17.7	8 215
0805	30	9.72	92.59				29	17.6	47 277
0809	30	9.72	92.59	19	12.5	22 055	75	12.9	89 569
0852	30	9.72	92.59				31	15.1	43 226
0851	35	11.34	79.37						
4173	35	11.34	79.37				5	15.3	6 080
4174	15	4.86	185.19						
0810	35	11.34	79.37				188	9.4	139 867
0812	25	8.10	111.11				53	1.0	5 798
0811	30	9.72	92.59	4	0.4	174	39	2.5	8 834
0859	30	9.72	92.59	14	1.9	1 969	13	0.1	149
0854	30	9.72	92.59	18	15.2	25 455			
0813	12	3.89	231.36						
0803	33	10.69	84.19				56	1.2	5 763
0804	30	9.72	92.59	1	0.2	16	121	2.2	25 194
Σ				73		66 165	906		431 922

under difficult sonar conditions with much surface reverberation. In such a situation, the vessel speed was reduced to enhance the probability of detecting and classifying targets. Despite intensive sampling and frequency response judgement of the recorded schools, allocation to species could be difficult. This is illustrated by the fact that a large school assumed to be mackerel turned out to be 12 ton horse mackerel when caught by the purse seine. In some of the areas covered, a significant amount of the schools was probably misjudged to be mackerel instead of horse mackerel.

The vertical distribution of the mackerel in the region seemed to be within the sampling interval of the sonar as no mackerel schools were recorded deeper than 40 m by the echo sounder. It was different for the herring schools which were frequently recorded close to bottom and therefore not detected by the nearly horizontal tilted sonar. The abundance of herring in the region is therefore severely underestimated. This illustrates that the potential of this method is as a supplement to conventional echo integration to record the abundance of fish schooling chose to surface. The method may be improved by an algorithm for automatic detection and area measurements of the schools applied on a sonar with narrow horizontal beam-width (Misund, 1991).

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