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ON THE RELATION BETWEEN ECHO INTENSITY AND FISH DENSITY

By

INGOLF RØTTINGEN
Institute of Marine Research, Bergen

ABSTRACT

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Integrated echo intensities for a wide range of fish densities were measured. The experiments were cariied out on live saithe (*Pollachius virens*) and spıat (*Sprattus sprattus*) which were kept in a net cage. Echo intensities were measured at 38 kHz and 120 kHz and pulse lengths ranging from 0.1 ms to 0.6 ms. The echo intensity was proportional to fish density below certain density limits. At high fish density a shadowing effect was observed. Factors encountered during survey work on schooling fish which indicate shadowing are also discussed.

The exact density values at which shadowing occurs, appear to depend on parameters such as fish species, size, orientation, and probably also the vertical extention of the school.

INTRODUCTION

The basic principle of acoustic fish stock estimation when using echo integration is that the relation between the integrated echo intensity, M, and the fish density, ϱ, is (MIDTTUN and NAKKEN 1971)

$$\varrho = C \cdot M$$

where C is the density coefficient. It expresses the number of fish per unit area which contributes to one unit of the integrated echo intensity. It is dependent upon fish species and size and the characteristics of the sounder and integration system (NAKKEN 1975). In dense schools one may expect, due to acoustic interaction of the individual fish, that the members of the deeper part of the school are shadowed by the members which are nearer the transducer. This may take form of scattering and absorption of sound energy by the nearer members, and consequently the lower fishes will reflect less sound energy per density unit. This will lead to an underestimation of fish density.

Little is known about the effects of acoustic interaction of fish in a school (MCCARTNEY, STUBBS and TUCKER 1965). Some teoretical work on scatterers have been done, the scatterers usually being point scatterers or small bubbles, and WESTON (1967) has applied the results for bubbles to fish schools. However, little experimental work has been done in this field (LOVE 1971).

The aim of the present investigation has been, by means of acoustic measurements of live fish, to examine if the proportionality between fish density and integrated echo intensity is valid at all fish densities.

MATERIALS AND METHODS

The materials treated in this investigation is:

1) Echograms and oscilloscope readings obtained during survey on schooling fish with a research vessel.
2) Fully controlled measurements of echo intensity from known densities of fish.

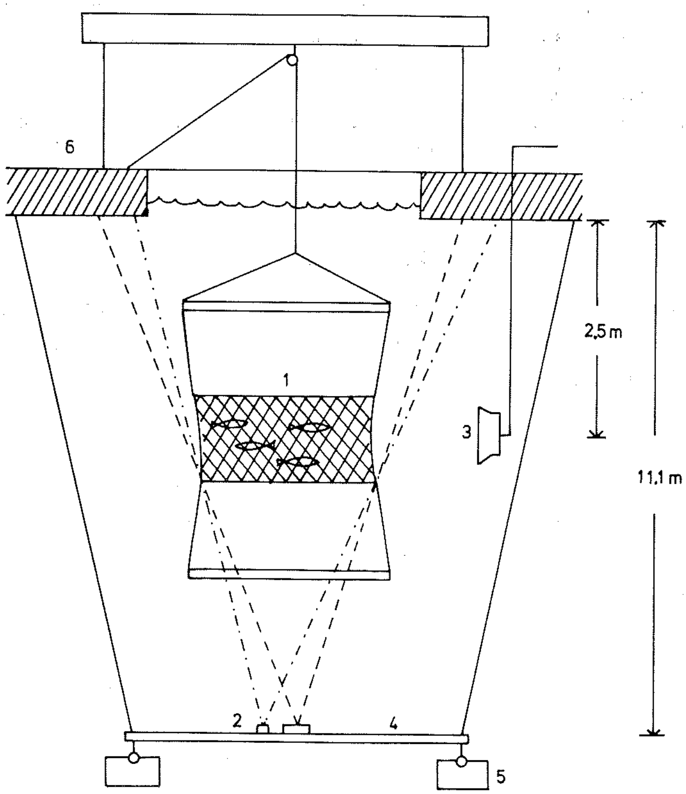

Fig. 1. Experimental arrangement (not to scale). 1) Net cage, 2) transducers, 3) camera, 4) transducer base, 5) load, 6) raft.

Table 1. Data for the net cages.

	Distance between supporting rings (m)	Height of net cage (m)	Diameter of net cage at top and bottom (m)	Diameter of net cage at the centre (m)	Mesh size (mm)	Volume of net cage (m^3)
Net cage 1 (saithe)	3.80	1.80	1.45	1.40	14	2.87
Net cage 2 (sprat)	3.40	2.40	1.50	1.40	26	3.96

Table 2. Mean length ($\bar{l}$), standard deviation (SD), mean weight ($\bar{w}$) of fish used during the acoustic measurements.

Species	$\bar{l}$ (cm)	SD (cm)	$\bar{w}$ (g)
Saithe	35.1	0.6	375
Sprat	12.1	1.7	12

The controlled measurements were carried out from an anchored raft. A diagram (not to scale) of the experimental arrangement is shown in Fig. 1. The upward looking transducers were mounted on a heavily loaded steel frame submerged from the raft in adjustable wires. The net cage was suspended on a line on the acoustic axis of the sound beam at a mean depth of 2.5 m. Table 1 gives data for the two net cages. The upper and lower metal supporting rings were placed at some distance from the net cage; thus the echoes from these rings were not included in the integration interval. Before an acoustic measurement was made, the net cage was hoisted to the surface, and the desired amount of fish was transferred through an opening on the top of the net cage. Then the net cage was lowered to the desired depth.

The acoustic measurements were carried out on two species, saithe (*Pollachius virens*) and sprat (*Sprattus sprattus*). Length and weight data of the fish are shown in Table 2. Before the measurements the fish were kept in floating pens where the fish were acclimatized to the depth at which the measurements were made.

The mean depth of the net cages during the measurements was 2.50 m. At the mean depth the diameter of the net cages was 1.40 m (Table 1), and the sound level at the rim of the cage was measured to be approximately one dB down compared with the sound level at the acoustic axis.

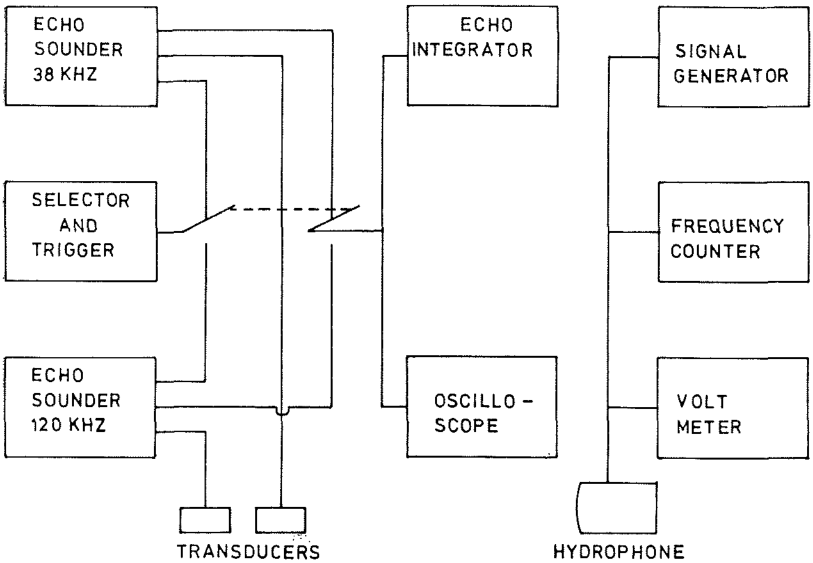

Fig. 2. Block diagram of instrumentation.

A block diagram of the instrumentation is shown in Fig. 2, and Table 3 gives instrument data and control settings.

RESULTS

Fig. 3 shows drawings of four oscilloscope readings of capelin (*Mallotus villosus*) schools. The volt scale is horisontal and the time scale vertical, the vertical extention of the schools being in the order of 30—40 m.

Fig. 4 shows a echogram recording of large schools of spawning capelin on the coast of Finnmark, Northern Norway. The vertical extention of the schools varies from 25 m to 70 m.

Fig. 5—8 show the integrated echo intensities (sum of 1200 pulse transmissions) obtained during the controlled experiments for the different fish densities. In order to compare the different frequencies and pulse lengths, the echo intensities are given in relative values, i.e. the maximum value for each series is set at 1.0. The densities at which the proportionality between integrated echo intensity and fish density is no longer valid, here called shadowing densities, are summarized in Table 4.

For saithe there was only one series of measurements, but for sprat the series was repeated. The values in Fig. 5 and 6 are mean values. The variation of the integrated echo intensities of single pulse transmissions from constant fish densities will be discussed in a later paper.

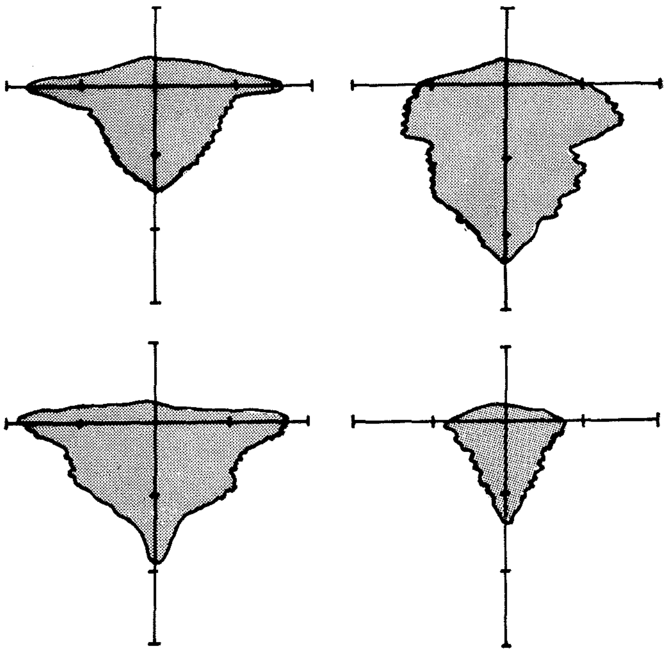

Fig. 3. Oscilloscope readings of capelin schools, Barents Sea, February 1974. 38 kHz 0.6 ms. Volt scale horisontally, time scale vertically.

Table 3. Instrument data and control settings.

Echo sounder:	
Type:	Simrad EK 38A and EK 120A
Frequency:	38 kHz and 120 kHz
Transducers:	10 cm × 10 cm (38 kHz). Circular, diameter 5 cm (120 kHz)
Mode:	WL
Discriminator:	1
Pulse lengths:	0.3 ms and 0.6 ms (38 kHz), 0.1 ms and 0.6 ms (120 kHz)
Bandwidth:	Wide
Output power:	1/10
Repetition rate:	4 pulses per second
Echo integrator:	
Type:	Simrad QM Mk II
Mode:	1 (Channel A. Sounding, Channel B. Nautical mile)
Speed Comp.:	10 knots
Reset:	Manually after 5 minutes (1200 pulses)

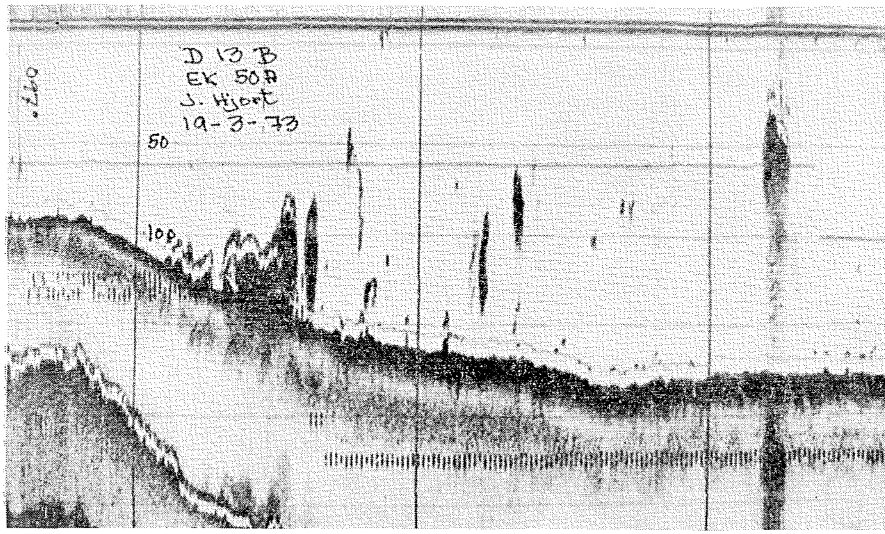

Fig. 4. Echogram of school of spawning capelin, Finnmark coast, March 1973. Depth scale in meters.

Table 4. Shadowing densities for saithe and sprat.

Species	Frequency (kHz)	Pulse length (ms)	Shadowing density	
			Fish/m³	kg/m³
Saithe	38	0.3	110– 130	41–49
	38	0.6	100– 120	38–45
	120	0.1	130– 140	49–53
	120	0.6	120– 130	45–49
Sprat	38	0.3	1800–2100	22–25
	38	0.6	1800–2000	22–24
	120	0.1	2700–2900	32–35
	120	0.6	2400–2600	29–31

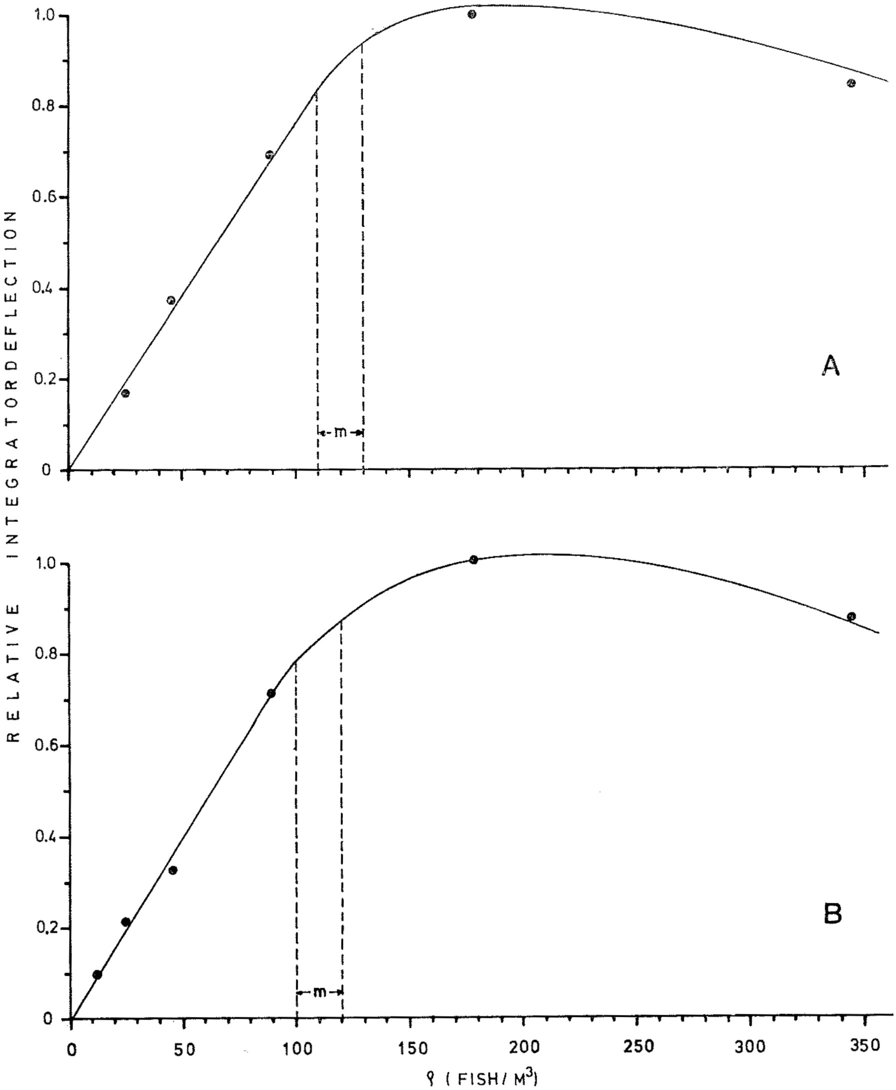

Fig. 5. Observations of relative integrator deflection on densities of saithe at 38 kHz. A) 0.3 ms, B) 0.6 ms, m) density values at which shadowing was encountered.

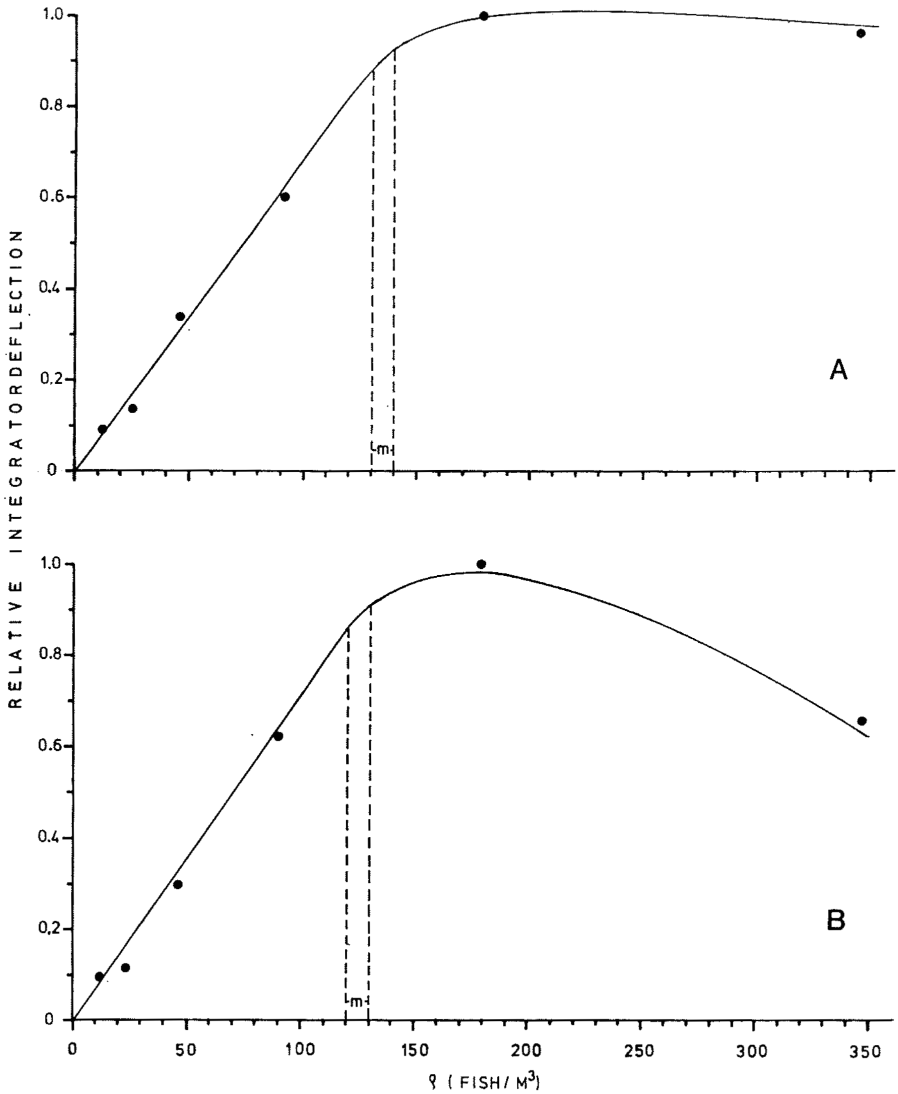

Fig. 6. Observations of relative integrator deflection on densities of saithe at 120 kHz. A) 0.1 ms, B) 0.6 ms, m) density values at which shadowing was encountered.

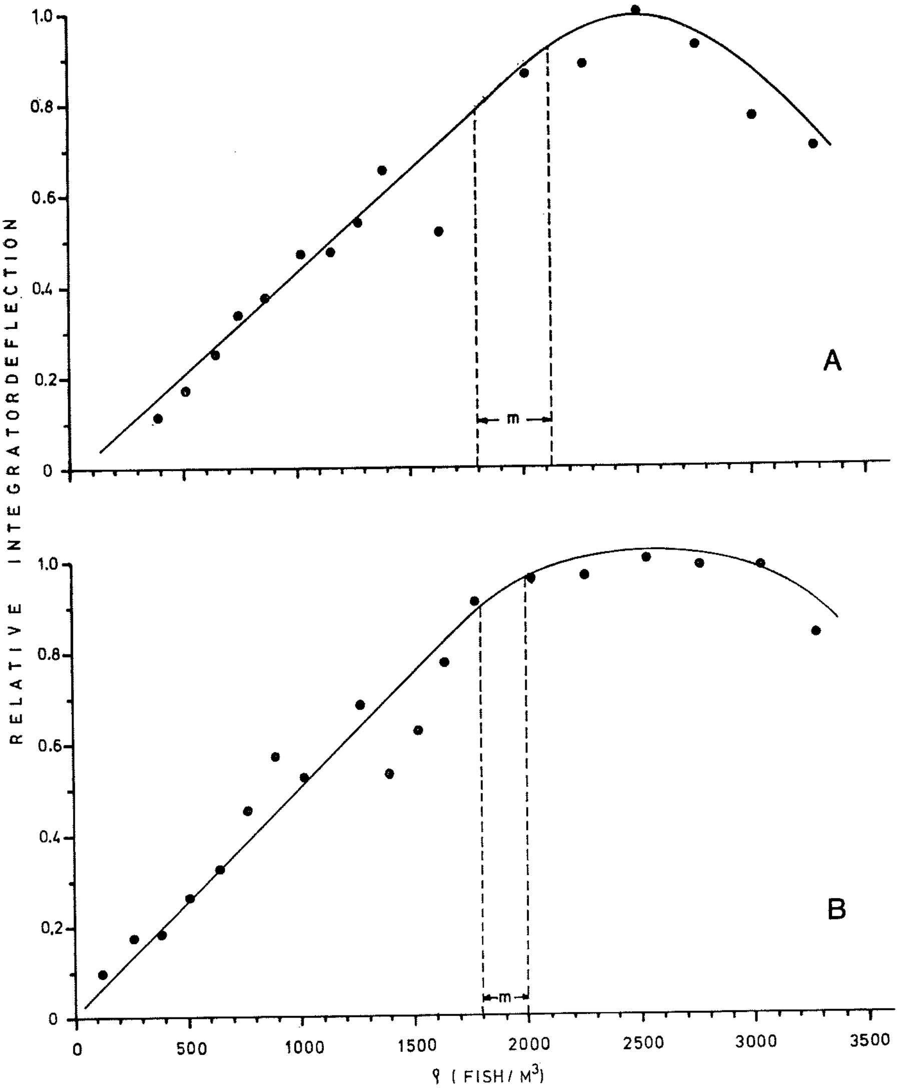

Fig. 7. Observations of relative integrator deflection on densities of sprat at 38 kHz. Legend as in Fig. 5.

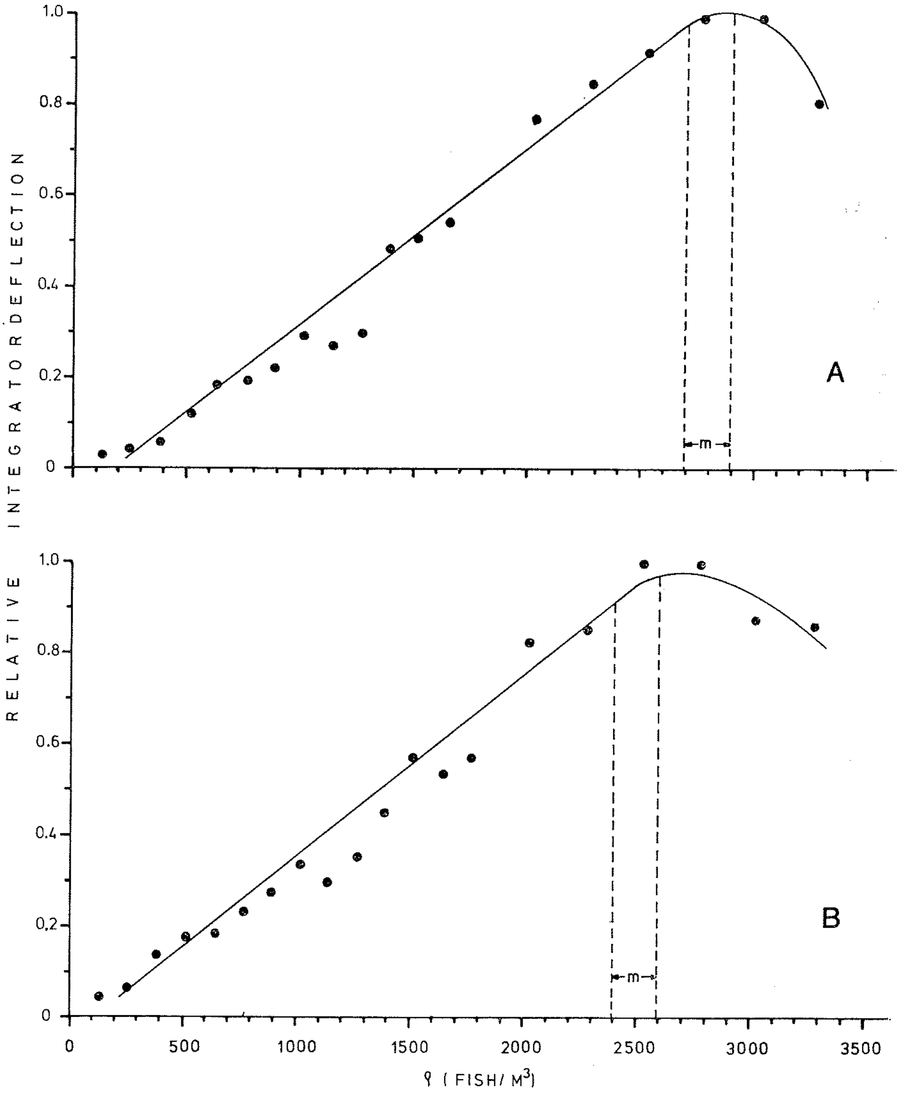

Fig. 8. Observations of relative integrator deflection on densities of sprat at 120 kHz. Legend as in Fig. 6.

DISCUSSION

There are strong reasons to believe that shadowing effects are encountered during surveys on fish schools. The schools in Fig. 3 all show less sound reflection from the deeper layers. The echo sounder has an automatic depth compensator, and it is doubtful if the oscilloscope readings show the actual physical structure of the school, i.e. with greater fish density in the upper layers of the school. A more plausible explanation would be that sound energy is attenuated within the school.

The modern echo sounder is equipped with a white line function. The purpose of this function is to make it easier to discriminate fish which are close to the bottom, and, of great importance when making fish stock assessments with integrator techniques, to prevent strong bottom signals from being integrated. The bottom has a clear white line in areas with no capelin in Fig. 4. However, below the capelin school this bottom white line disappears. This means that the strength of the bottom echo is considerably reduced, and it is therefore probable that the echo of lower fishes will also be reduced. This is the shadowing effect which was discussed in the introduction of this paper. The figure shows also that the echo from the upper part of the schools is so strong that it is blocked.

By using integrator technique the density in the capelin school will be considerably underestimated due to

A. Blocking of the uppermost layer;
B. Shadowing of the lower fishes by the members of the school which are nearer the transducer.

A can be avoided by an appropriate altering of the discriminator level, while the quantitative effects of B are much more difficult to estimate.

The large school in Fig. 4 is a spawning school of capelin. The structure of these spawning schools has been well studied by direct observation by SCUBA divers (BAKKE and BJØRKE 1973, SÆTRE and GJØSÆTER 1975). The densities of these schools are tabulated in Table 5 together with other direct or indirect observations of fish density.

As discussed earlier there is a reduction of the bottom signal below the large capelin school in Fig. 4. This type of spawning school is what SÆTRE and GJØSÆTER (1975) call a "first type school", and these schools consisted of more or less regularly oriented capelin swimming forward or in circles. BAKKE and BJØRKE (1973) and SÆTRE and GJØSÆTER (1975) give densities in distances between fishes. A distance of 15 cm (Table 5) between capelin of 15 cm length will give a density of about 150—200 fish/m^3. This is considerably lower than the shadowing densities given for sprat in Table 4. The sprat is only a little smaller than capelin, and this

Table 5. Natural fish densities.

Species	fish/m³	kg/m³	Interfish distance (cm)	References
Mallotus villosus			40–80 Spawning schools (first type)	BAKKE and BJØRKE (1970)
M. villosus			10 Spawning schools (second type)	BAKKE and BJØRKE (1970)
M. villosus			15–30 Spawning schools (first type)	SÆTRE and GJØSÆTER (1975)
M. villosus			5 Spawning schools (second type)	SÆTRE and GJØSÆTER (1975)
Clupea harengus.......	0.7–1.0			TRUSKANOV and SCHERBINO (1966)
C. pallasi		0.2–0.8		RADAKOV (1973)
C. pallasi		30–32 (2–3 days before spawning)		RADAKOV (1973)
C. pallasi	9.0–10.4 (day)			THORNE (1973)
C. pallasi	0.012–1.0 (night)			THORNE (1973)
Engraulis encrasicholus	650			JOHANNESSON and LOSSE (1973)
E. mordax	50–75			MAIS (1973)
Sardina pilchardus	2		80	CUSHING (1957)
Merluccius productus ..		0.04–0.05		THORNE (1973)
Gadus morhua	$1.0–8.0 \cdot 10^{-5}$			TRUSKANOV and SCHERBINO (1966)
Trachurus mediteranus	110			JOHANNESSON and LOSSE (1973)
Scomber japonicus	20			VAN OLST and HUNTER (1970)

seems to suggest that the shadowing effect is not due to density as such, but rather to the total number of fish or scatterers within the sound beam. In schools with a great vertical extention, such as the spawning school in Fig. 8, shadowing effects may then well be encountered at lower densities than in schools with a short vertical extention like those observed during the experiment.

The problem of estimating densities at which shadowing occurs at different school extentions may be approached by an application of the mathematical theory of multiple scattering. By using the same number of fish which gave a shadowing effect during the experiments, one could make a density reduction by analysing reflection from the same number of scatterers at different fictive extentions of the net cage.

To apply such results to field work, one would probably need exact information of species, sizes of the schools, length distribution, absorption patterns of the fish etc. In addition, behavioral information would be needed, such as orientation and mobility of the fish. At present, much of this information is lacking.

The curves obtained by using different pulse lengths and frequencies do not seem to have significant differences within the same species. There may be a tendency that the shadowing effect first occurs at higher densities when using higher frequencies (Table 4). The curves show decreasing echo intensity for the highest densities. The exact reason for this is unknown.

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