International Council for
the Exploration of the Sea

Fish Capture Committee
C.M. 1986/B:44
Sess. U

SOUND ATTENUATION WITHIN SCHOOLS OF HERRING

by

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ABSTRACT

Sound attenuation within dense aggregations of fish may cause a problem for abundance estimation by echo integration. Indications of the occurense of this phenomenon may frequently be observed as changes in the bottom echo when a dense school of fish is recorded. Sound attenuation within schools of herring has been measured and the possible impact on survey results is discussed.

RÉSUMÉ

Attenuation de son dans des denses aggrégations de poisson a pu causer un problem au cours de l'éstimation d'abondence de poisson avec la méthode integration d'échos.

Souvent l'occurence du phénoméne se manifeste par des changements du echo de fond pendant l'enrégistrement d'un banc de poisson trés dense.

Attenuation de son dans des bancs d'hareng a été mesuré, et ce monographe discute l'impact possible du phénoméne sur les resultates des études.

INTRODUCTION

In the "echo-integration" method one basic assumption is that the received echo signal is directly proportional to the number of fish insonyfied at any depth independent of the number of fish in the sound beam at intermediate depths.

When echo recordings of dense fish schools are obtained an apparent dimishing in the bottom echo signal is frequently seen. One logical explanation of such an observation is that a significant sound attenuation has taken place within the school. Consequently, the back scattering strength in the deeper part of the school may also be significantly reduced due to this effect.

Such "shaddowing effects" in echo sounding, caused by sound absorption, or perhaps by multiple scattering, have been investigated by Røttingen (1976) in an experiment with live fish in a cage. Such effects have also been discussed, from a theoretical point of view, by Foote (1982) and Lytle and Maxwell (1983). All authors accept the existence of the phenomenon of "weakening of signals", but the basis for this is still debated.

Quantitative *in situ* measurements of sound attenuation in relation to fish aggregations are, difficult to obtain. This would require measuring of the sound intensity of the transmitted sound pulse to be made, simultaneously, both above and beneath a fish school.

A possible approach to solving this problem may be to measure the "two way" sound attenuation, similar to the situation of recording bottom echoes. This would require both a school of fish and a stable reference bottom echo. An easier solution might be to undertake experiments by measuring the variations in target strength of a special reference target in the presence and absence of a school of fish. This paper describes some experiments conducted using such a method.

MATERIALS AND METHODS

A sketch of the experimental rig is shown in Fig. 1. The rig consists of a steel frame for holding both a submersible transducer and a suspension system. The purpose of the suspension system is to keep a reference target (a 12.5 cm diameter steel sphere) in a fixed position in the acoustic beam at 40 m distance from the transducer. The rig is operated by attaching it to the hydrografic winch system on board the vessel. The transducer is connected to a SIMRAD EYM (70 kHz) echo sounder which also allows tape recordings of echo signals to be made.

An experimental run consists of continuous measurements of the back scattering strength of the reference sphere both alone and in the presence of a school of fish within the acoustic beam. By recording the received echo signals for later "echo integration" a method for quantitative analysis of signal variation is obtained.

Suitable conditions for the experiments were found in a sheltered fjord and where a number of schools of herring were registered at relatively shallow depths. When a herring school was observed on the research vessel sonar, the vessel was stopped carefully in the vicinity of the school and the measuring rig lowered to an appropriate depth. If current drift/swimming direction of the school had been correctly estimated, the school would soon appear passing beneath the vessel and could be registered by the rig echo sounder.

Data prosessing consists of feeding the tape recordings into an echo integrator, and prints out of the mean integrals of successive transmissions are observed (pulse rep.rate: 4 pr. sec.). Depth intervals were varied from 1 m for the reference target channel, to 5 m for fish recordings for a total of 12 channels.

The reference target is assumed to have a target strength of -26.4 db (Foote, 1981). By comparing the integrator readings both and absolute fish densities within the schools and area fish densities have been calculated.

Fish density per unit area (ρ) within a particular depth interval can be expressed as:

$$\rho = \frac{1}{\langle \sigma_{BS} \rangle} \cdot C_i \cdot M \qquad \text{(I)}$$

$\langle \sigma_{BS}^{*)} \rangle$ is the effective back scattering cioss section of the fish including the effect of behaviour and the beam pattern of the applied transducer. M is the integrater reading and C_i is a system calibration factor (Dalen & Nakken, 1983).

Since the back scattering cross section of this sphere (σ_{ST}) was known from an earlier experiment (Foote, 1981), C_i was determined from the back scattering measurement of the steel sphere when alone in the beam.

$$C_i = \frac{\sigma_{ST}}{M_{ST}\, D_{ST}^2 \cdot \psi} \qquad \text{(II)}$$

M_{ST} is the integrator reading of the sphere echo, D_{ST} is the distance between the tranducer and sphere (41 m) and ψ is the equivalent solid angle of the beam ($\psi = 0.022$ sterad

Substituting (II) into (I) gives:

$$\rho = \frac{M}{M_{ST}} \cdot \frac{\sigma_{ST}}{\langle \sigma_{BS} \rangle} \cdot \frac{1}{D_{ST}^2 \cdot \psi} \qquad \text{(III)}$$

Alternative estimates of fish densities within the schools have been obtained by flash-photography. A camera was lowered carefully into a fish school and when the fish had clustered around the camera (controlled by a separate echo sounder transducer attached to the camera), shots were made. By using a method based on fish counts from the pictures and assuming approximately equal fish lengths (Olsen, 1980), volume fish density within the schools was estimated.

*) $\langle \sigma_{BS} \rangle = 10^{0.1\ TS}$, $TS_{herring} = 19.1 \log l - 74.5$ (annon., 1985).

Results

In Fig. 2a and Fig. 2b are shown examples of paper recordings obtained when schools passed through the echo sounder beam. Fig. 2a shows a recording of a school of medium-sized herring ($\overline{l}$ = 20 cm) observed during daytime in winter and Fig. 2b shows a school of adult herring ($\overline{l}$ = 35 cm) observed in autumn, also during the day. In both situations, the echo of the steel sphere was considerably reduced when the school was present in the acoustic beam.

Table 1 shows print outs of the integreated tape recording of the esperiment illustrated in Fig. 2a. Each numerical value given in the table represents the mean of 8 successive transmissions. Despite this averaging both the back scattering estimates of fish abundance and of the back-scattering of the reference target varied markedly. When the school was present, the echo intensity of the reference sphere could be reduced up to 75 - 85%. This is shown in Fig. 3a in which the back scattering of the steel sphere is plotted against the total fish echo abundance. The results shown in Fig. 3a are from an experimental run where medium-sized herring passed through the beam. Fig. 3b shows a similar plot for the results of two experimental runs in which adult herring passed through the beam.

If it is assumed that there is an insignificant sound attenuation in the uppermost part of the fish schools, a "real" volum fish density may be estimated (calculated on the basis of "the average" area fish density in the upper or second 5 m depth interval). For the school of medium-sized herring (Fig. 2a) a "real" volume fish density of 35-39 fish per m^3 was estimated (average integration value; 1800-2000 per 5 m depth interval).

For the two schools of adult herring a "real" volume fish density of 6-7 fish per m^3 was estimated (average integrator value; 800-900 per 5 m depth interval).

Mean fish density estimates from the underwater photographs (3) taken of the medium-siqed herring schools gave density estimates of 20-25 fish per m^3. Mean fish density estimates from photographs (video film pictures) of the adult herring schools gave density estimates of 10-15 fish per m^3.

A mean sound attenuation coefficient (α_b) is estimated by dividing the "two-ways" loss in back scattering strength of the sphere by 2. For the situation shown in Fig. 2a this gives an estimate of α_b in the order of 0,2 dB/m ($\approx$ 40% loss over the 20 m depth spane of the school).

Similar calculations conducted on the data collected for the schools of adult herring (Fig. 2b), coefficient of 0,15 dB/m.

Estimates of the mean extinction cross section of the fish (σ_e):

$$\sigma_e = \frac{\alpha_b}{434.N} \quad \text{(Clay \& Medwin, 1977)} \qquad \text{(VI)}$$

where (N) is the number of scatters (fish) per m^3, give estimates of σ_e: 1.2 10^{-3} and 4.9 10^{-3} (m^2) respectively.

Foote (1982) gives an expression for an approxemate calculation of total fish abundance ($\mathcal{E}_{TOT}$) in a fish school if sound attenuation occurs:

$$\mathcal{E}_{TOT} = \frac{1- \exp(-2\gamma \Delta z \sigma_e)}{2\gamma \Delta z \sigma_e} \sum_{i=1}^{N} \mathcal{E}_i$$

where γ is the fish density, Δz is the depth extension of N fish uniformerly distributed and $_i$ is the mean echo intensity from the i - th fish, were there no extinction.

Combining equation (VI) and (VII) makes $\mathcal{E}_{TOT}$ only a function of a measured (or calculated) sound attenuation coefficient (α_b) and the depth extinsion of a school (Δz) (γ=N):

$$_{TOT} = \frac{1-\exp\left(\frac{-\alpha_b \cdot \Delta z}{2.17}\right)}{\frac{\alpha_b \cdot \Delta z}{2.17}} \sum_{i=1}^{N} \mathcal{E}_i$$

In Fig. 4 is shown a plot of the expected reduction in the fish abundance estimations for given school depths spans as a function of the sound attenuation coefficients calculated from the experimental data (0.2/0.15 dB per m). For a 10 m deep school the abundance estimate will be reduced by 35% and 20% respectively, and for a 50 m deep school the reduction in the echo abundance may as high as 79% and 61%.

Discussion

A problem with these experiments would arise if the repherence sphere "swung" out of the acoustic beam e.i. movements due to currents or due to fish "pushing" the sphere out of position.

These problems are overcome by careful monitoring of the position of the lowering wire, and the design of the rig ought to ensure that the transducer "orientates" towards the sphere even if a positional disturbance of the sphere takes place.

The great variation in back scattering of both fish and sphere is probably due to physical reasons as well as to the fish behaviour (Røttingen, 1977). From the UTV observations of the schools of adult herring (during a feeding period) it was evident that there was both great variations in tilt orientation and also considerable variation in schooling density.

Both orientation and density would be expected to be more consistent for the medium-siqed herring observed in a typical "hibernation" area, as seem to be confirmed be earlier investigation and pictorial evidence (Olsen, 1980).

The apparent great difference in fish density between the hibernating schools and the "feeding" schools is perhaps surpricing, but some similar high density observations of herring have been reported by Olsen (1980) who observed hibernating adult herring of more than 50 fish per m^3. Herring schools of 10 fish per m^3 or less, seem, however, to be more common (Truskanov & Scherebino 1966, Thorne 1973).

The reason for the discrepancies in the fish density estimates from the echo intergration method and photographic method is unclear. The few photographs used (3) for the purpose and the rather poor obtainable quality of the "still-pictures" made from video records obviously introduce uncertainty in the estimates.

On the other hand, the target strength/length equation used for calculating the effective back scattering cross section of the herring, may not be appropriate for the situations observed. If the tilt distribution of the hibernating herring was particularely narrow, as indicated on the photographs taken, a rather high mean TS is to be expected (Olsen & Angell, 1983). In accordance with equ, III and equ, IV, the estimated fish density would then have been reduced and the mean extiction cross section increased.

Herring in a feeding situation, however, is expected to show a much wider tilt orientation and this would generate a greater variance in TS and consequently a less mean TS. Compared with the more "over-all" TS/length equation applied, this may have lead to a somewhat increased fish density estimate and a reduced mean extinction cross section.

The difference in mean extinction cross section may then become more in accordance with what could perhaps have been expected from comparisons of fish sizes and expected schooling densities.

The measured sound attenuation will clearly be of significance in survey situations where fish frequently aggregate in dense schools. A model which could compensate, at least approxemately, for the underestimation in biomass, would have to consider both fish density, fish size and vertical school extension. The results obtained, may indicate that providing some more empirical data on schooling densities and schooling behaviour is collected, an approximate calculation of "biomass loss" is possible.

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Table 1. Echo integraror print outs of recording obtained during the experimental run shown in Fig. 1a. The reference target echo is positioned in the 41 - 42m depth channel. (Print outs: mean values of 8 transmissions).

R/V " JOHAN RUUD " DATE: 86 07 08 ECHOSOUNDER: 38 KHZ / B TRANSDUCER: 8 X 8 TRANSMITTER: EXT.

INSTR. CONSTANT: 1.00 BOT.TEST: 3 0 TVG/GAIN: 20 LOG R -20 DB BANDWITH: 3.3 KHZ REC. RANGE: 250

INTEGRATOR-CHANNEL:	1	2	3	4	5	6	7	8	9	10	11	12	13
TVG-JUSTIFICATION :	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
THRESHOLD (VOLTS) :	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017
BOTTOM-DISCRIMIN. :	5.89	5.00	4.59	4.34	4.04	3.84	3.70	3.70	3.70	3.70	3.70	3.70	3.70

HOUR	LOG	5	10	15	20	25	30	35	39	40	41	42	43	50	100
00 29 57	632.8	0	2	1	661	2343	1358	953	253	11	8	14	9	13	1698
00 29 57	632.8	0	2	1	661	2343	1358	953	253	11	8	14	9	13	1698
00 29 59	632.9	0	3	2	1646	2733	1468	984	120	9	8	18	4	18	1198
00 30 01	633.0	0	1	8	1794	2070	1207	1002	49	5	5	17	5	14	1263
00 30 03	633.1	0	2	318	2565	2342	1282	1069	44	4	4	23	4	15	1532
00 30 05	633.2	0	1	767	1954	1570	954	569	25	4	3	17	3	11	1703
00 30 07	633.3	0	1	845	1863	1500	1425	544	16	3	2	15	1	7	1329
00 30 09	633.4	0	1	969	2033	1392	1561	1076	16	3	1	10	2	7	1552
00 30 11	633.5	0	2	1263	2523	2059	1960	1191	23	3	3	8	2	10	1512
00 30 13	633.6	0	1	1359	2840	2187	2245	1295	27	3	3	9	3	9	1476
00 30 15	633.7	0	1	1798	2726	2354	2449	1411	37	4	2	16	2	11	1476
00 30 17	633.8	0	1	1978	1566	1199	2037	1442	48	5	4	16	2	13	1498
00 30 19	633.9	0	2	1537	1594	807	1908	1234	51	4	3	13	2	13	1229
00 30 21	634.0	0	1	1125	1609	563	1562	1021	51	5	3	8	3	10	1312
00 30 23	634.1	0	2	1585	1737	875	1089	1163	66	4	4	9	3	12	1047
00 30 25	634.2	0	1	1868	1156	894	1568	1449	81	8	6	10	3	11	1584
00 30 27	634.3	0	1	1492	728	470	1172	694	88	5	3	8	3	9	1263
00 30 29	634.4	0	2	1757	708	266	1164	628	49	5	3	14	3	14	1493
00 30 31	634.5	0	4	1443	755	383	765	726	56	4	3	6	3	12	1328
00 30 33	634.6	0	9	1201	725	653	904	828	56	7	6	8	3	12	1015
00 30 35	634.7	0	36	1674	861	1008	1223	1134	123	6	6	9	4	12	1139
00 30 37	634.8	0	44	1947	590	2130	1732	1378	230	10	7	7	4	20	1073
00 30 39	634.9	0	76	2189	906	1046	1583	1576	198	8	6	9	5	18	913
00 30 41	635.0	0	394	1964	965	1018	1256	1529	182	7	7	16	4	19	1334
00 30 43	635.1	0	518	2547	821	1235	1287	776	193	12	9	16	5	21	1182
00 30 45	635.2	0	772	2571	517	1450	2122	352	92	10	6	15	5	25	932
00 30 47	635.3	0	1038	1985	827	1081	1390	542	150	8	8	12	6	24	863
00 30 49	635.4	0	1018	1481	714	504	479	536	192	7	7	19	5	17	828
00 30 51	635.5	0	985	1888	676	590	379	339	127	5	4	9	3	13	1040
00 30 53	635.6	0	1175	1808	587	241	242	101	46	3	3	8	3	9	968
00 30 55	635.7	0	1121	1332	728	628	178	116	35	4	3	9	2	9	730
00 30 57	635.8	0	1465	1585	619	301	169	222	63	4	3	7	2	9	1100
00 30 59	635.9	0	970	1400	274	268	231	143	38	3	2	7	1	5	914
00 31 01	636.0	0	902	1469	289	196	213	139	25	2	2	5	2	5	946
00 31 05	636.2	0	1064	273	261	342	156	82	13	1	+	6	1	3	981
00 31 14	636.6	0	1995	603	529	917	306	129	24	3	3	12	2	164	944
00 31 15	636.7	0	2438	906	1011	1373	582	133	23	4	3	13	3	13	1757
00 31 17	636.8	0	3252	2912	1592	1624	820	94	28	5	4	15	4	19	2309
00 31 19	636.9	0	2907	4724	3291	840	343	66	27	5	4	14	5	25	2291
00 31 21	637.0	0	1592	6223	3922	600	211	49	26	4	4	14	4	25	2410
00 31 23	637.1	0	159	5490	3274	331	123	44	20	4	3	35	4	24	2963
00 31 25	637.2	0	7	2436	1168	210	63	28	13	3	3	59	2	14	2849
00 31 27	637.3	0	7	174	109	113	34	22	11	2	2	55	2	11	3001
00 31 29	637.4	0	12	61	94	58	28	24	12	3	2	59	3	15	3230
00 31 31	637.5	0	7	22	42	22	19	23	9	1	1	50	2	8	2668
00 31 33	637.6	0	8	15	25	20	18	18	9	2	2	56	2	9	3139
00 31 35	637.7	0	11	15	22	21	17	14	10	2	2	61	2	13	3659
00 31 37	637.8	0	5	8	20	12	10	11	5	1	1	59	2	6	2803
00 31 39	637.9	0	7	7	20	15	10	13	6	1	1	60	1	7	2739
00 31 41	638.0	0	6	6	14	11	10	11	7	1	1	58	2	8	2740
00 31 43	638.1	0	10	9	12	14	13	13	8	2	2	61	2	10	2737
00 31 45	638.2	0	4	5	9	10	15	13	6	2	1	58	2	8	2922
00 31 47	638.3	0	3	2	3	5	11	11	3	1	1	56	1	4	3176
00 31 49	638.4	0	6	7	6	12	13	13	9	1	2	73	2	9	2909
00 31 51	638.5	0	7	6	8	15	14	11	7	2	1	54	1	8	3368
00 31 53	638.6	0	3	5	4	12	12	9	7	1	1	51	1	6	3280
00 31 55	638.7	0	6	3	3	11	12	11	4	1	1	44	1	3	2859
00 31 57	638.8	0	4	5	5	11	16	13	5	1	+	51	1	5	3243
00 31 59	638.9	0	7	7	9	12	12	18	5	1	1	51	2	6	2842
00 32 01	639.0	0	3	3	3	4	7	9	5	+	1	43	+	3	2894
00 32 03	639.1	0	8	8	9	8	11	14	7	2	1	47	2	9	2980
00 32 05	639.2	0	7	9	8	9	14	14	10	2	2	51	3	10	3426
00 32 07	639.3	0	5	3	2	6	7	9	4	1	1	41	1	4	2658
00 32 09	639.4	0	3	3	3	2	7	8	3	+	+	44	1	4	2848
00 32 11	639.5	0	8	6	6	8	9	11	6	1	1	49	1	6	3694
00 32 13	639.6	0	9	8	8	8	11	15	7	2	2	49	2	9	3152
00 32 15	639.7	0	5	4	5	5	7	10	5	2	1	38	1	5	3399

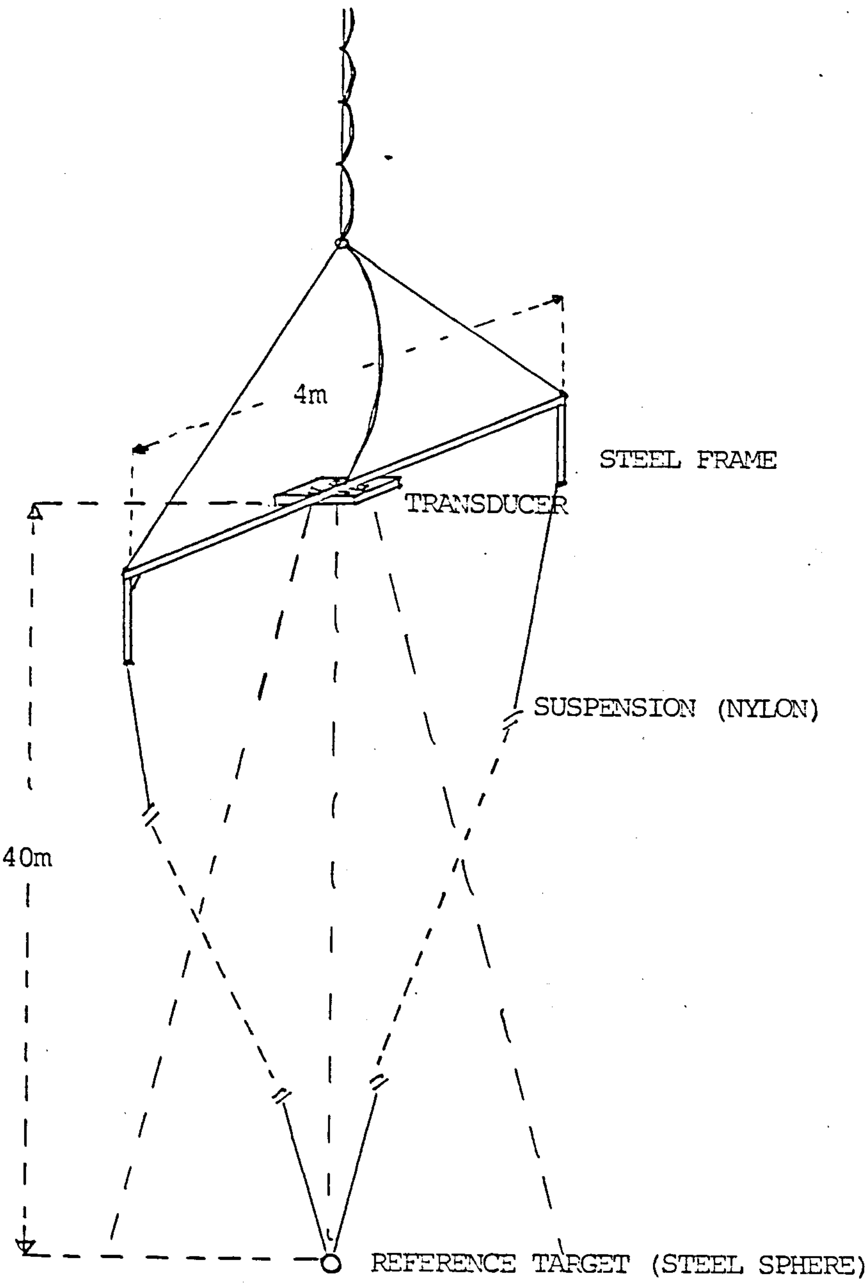

Fig. 1. Expermental set up for sound attenuation measurements. Reference target: Stainless steel sphere, 12.5 cm in diameter (TS = - 26.4 dB).

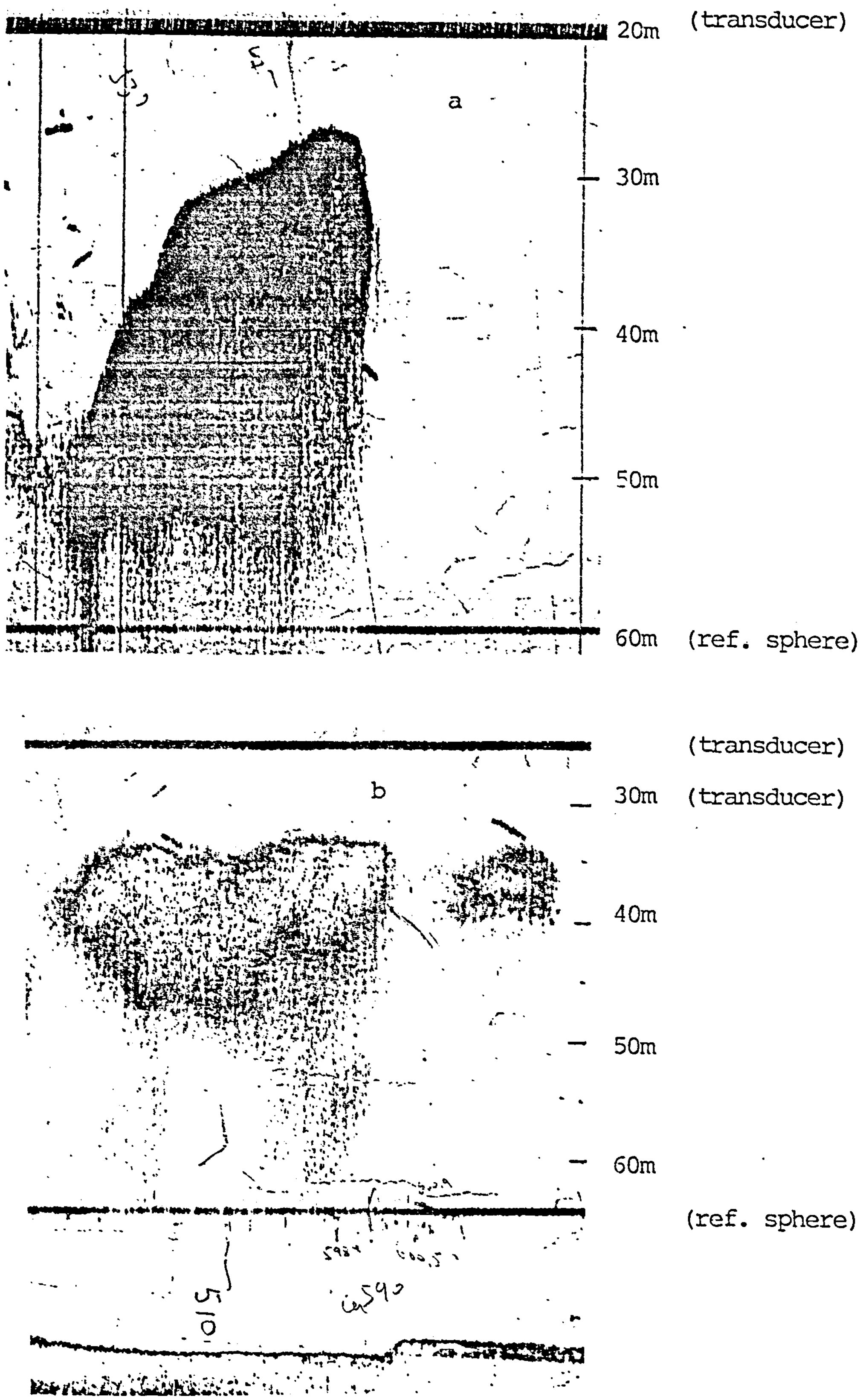

Fig. 2. Echo recordings obtained when schools of herring is passinf through the acoustic beam of the rig transducer. Fig. 1a , school of meadium-sized herring ($\overline{l}$ = 20 cm), transducer depth 20m. Fig. 1b, school of adult herring ($\overline{l}$ = 35 cm), transducerdepth 25m.

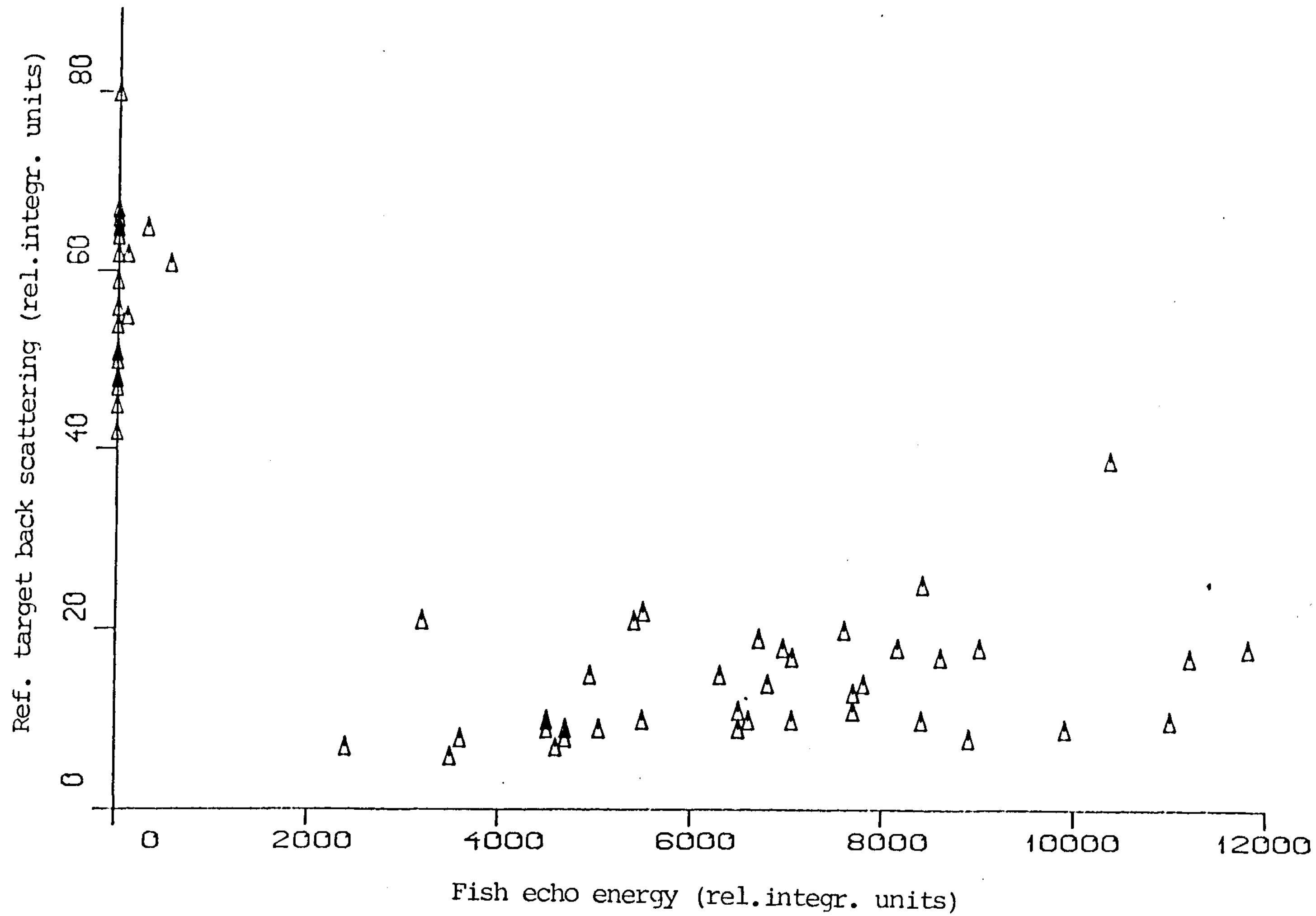

Fig. 3a. Plot of back scattering strength of the reference target (stainless steel sphere, 12.5 cm diameter) against the total integrated fish echo abundance of a school of meadium-sized herring $\overline{I}$ = 20cm). Daytime observations (mean values of 8 transmissions).

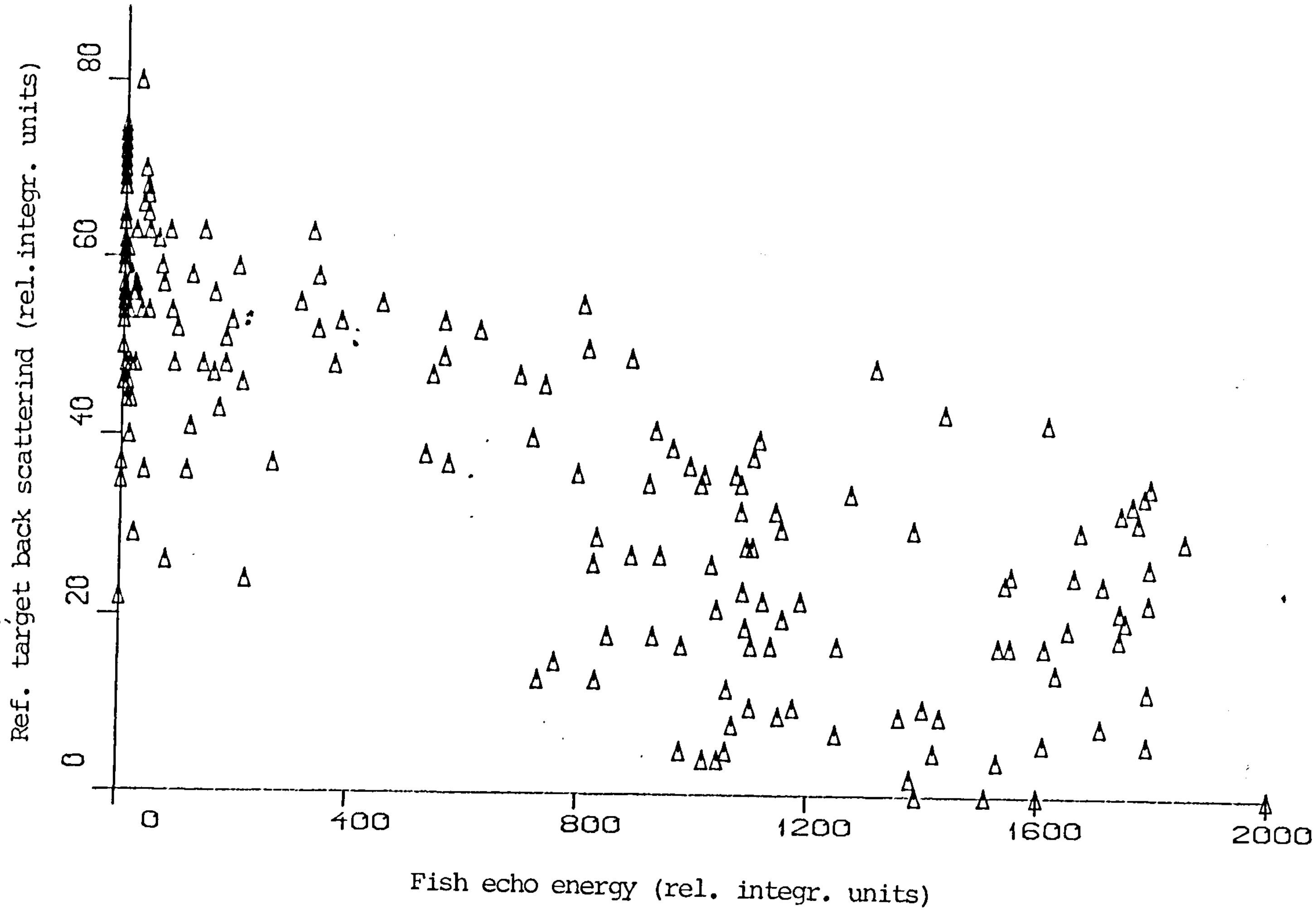

Fig. 3b. Plot of back scattering strength of the tererence target (stainless steel sphere, 12.5 cm diameter) against the total integrated fish echo abundance of two schools of adult herring ($\bar{l}$ = 35 cm). Daytime observations (mean values of 8 transmissions).

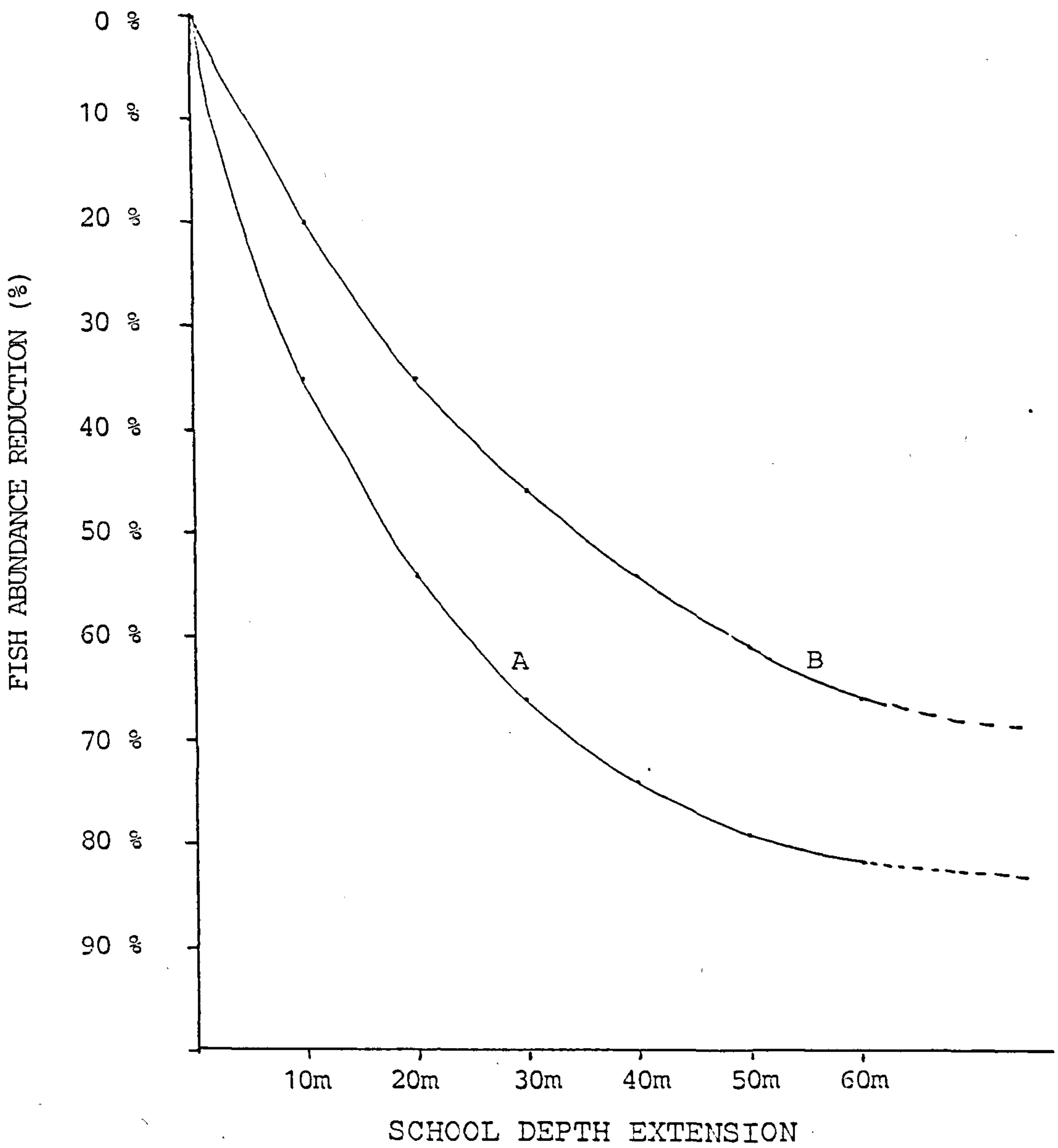

Fig. 4. Plot of expected reduction i fish abundance estimation (%) with increasing school depth extension (m), calculated on basis of the observed sound attenuation coefficients: 0.2 dB per m (A) and 0.15 dB per m (B).