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Measurements of the Reflection of Sound by Fish

By

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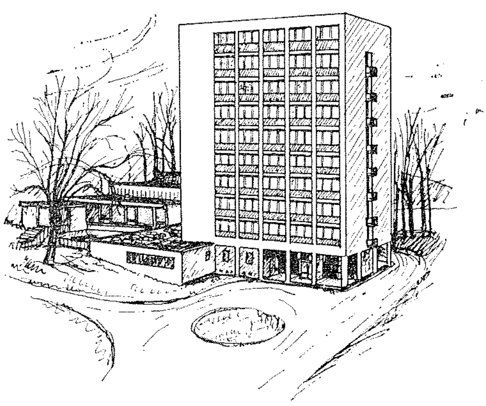

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INTRODUCTION

Echo sounding is now widely used in fish detection and sounders are constructed especially for such purposes. In fishery research echo-surveys are regularly undertaken in order to study the distribution of fish. Today one is interested in knowledge of how far echo sounding can be used also as a method for estimating fish abundance. At the Institute of Marine Research, Bergen, new types of calibrated sounding equipment have recently been used, with which it was possible to measure the absolute values of echoes received.

At present comparatively little is known about absolute values of the sound reflectivity of fish, either as regards single fish or shoals of fish. Cushing and Richardson (1955), Jones and Pearce (1958), and Richardson *et al.* (1959) have found that the airbladder is responsible for the major part of sound reflected from fish, while Tucker and Stubbs (1958) discussed theoretically the reflecting power of some models approximating fish for different frequencies of sound. Hashimoto and Maniva (1952 and 1955) have also made some studies in this subject, but their reports are in Japanese. Smith (1954) measured the target strength of some smaller marine organisms, including that of a sea bass.

The general theory concerning sound in the sea is given in «Physics of Sound in the Sea» (1945).

The present investigation was of the sound reflectivity of some commercial fish under natural conditions, especially that of their dorsal reflectivity as a function of orientation, measured in absolute units.

This investigation has partly been financed by Fiskerinæringens Forsøksfond. We wish to express our thanks to this foundation. Part of the equipment has been loaned by SIMRAD of Oslo and Horten, RADEX, Bergen, and Sandviken Slipp, Bergen. We are greatly indebted to those firms, and to the SIMRAD-engineers, *Mr. T. Gerhardsen* and *Mr. P. Pettersen* for valuable advice.

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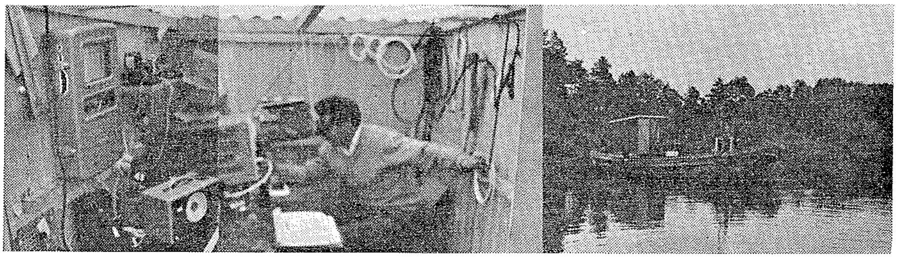
EXPERIMENTAL TECHNIQUE



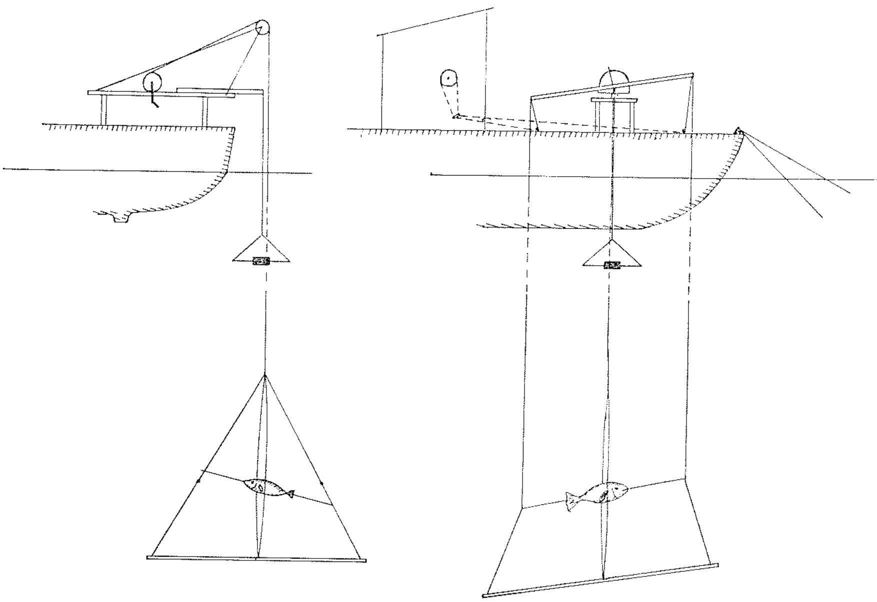


Fig. 1. The arrangements in the Grimseidpollen.

The experiments described were carried out in Grimseidpollen bay, near Bergen, which has a very narrow entrance so that the sea there is always smooth. Since there is nearly 30 m of water close in shore, the 40 ft lighter used could be anchored near to land, and electric power taken from shore by a cable through the water.

The electronic equipment was mounted in a small laboratory built on the deck of the lighter and the underwater equipment was hung outboard in such a manner that the plane of the oscillator was horizontal. The fish to be measured was placed in a frame which could be lowered by a hand winch to the depth chosen, 15 m or 10 m below the oscillator.

Two types of frame were used, which are illustrated in Fig. 1. Apart from the cross-bars at the bottom of the frames, the units consisted of thin nylon gut which did not affect the sound signals.

When using the triangular type of frame it was necessary to haul up the frame and lower it again every time the position of the fish had to be adjusted. We therefore changed later to the other type of frame, with which the inclination of the fish could be controlled by a wheel from the instrument house on deck. A pointer showed the angle of inclination of the fish whose reflectivity was measured. This pointer was adjusted to zero at maximum echo by using a rubber tube suspended in the frame in place of a fish. The rubber tube gave a distinct maximum echo indicating the horizontal position to the nearest degree of angle.

Electronic equipment

A 38 kc/s echosounder (SIMRAD, Type 512-12) was used as transmitting apparatus producing signals, the duration of which were 2 millisec. The oscillator had a size of (8x10) cm^2 and was used both as transducer and receiver. The echo signals were amplified by a specially built amplifier with linear characteristics within the interval of echo strength in question. When amplified the echoes where displayed on an oscilloscope (Tektromix 515 A) where they were read by visual observation. The pulse repetition could be triggered either automatically or manually, the latter method being used when echo traces were recorded.

Variations in voltage on the net were compensated for by means of a voltage regulator.

Both the intensity of the outgoing pulse (source level) and the response of the receiving system were calibrated several times during the experimental period. The source level was measured by means of a calibrated hydrophone (BC-32 C Atlantic Research Corp.) arranged in the centre of the beam 1 m. from the transducer and connected to the oscilloscope. A variable resistance inserted in the cable to the transducer could be adjusted to keep the source level at a constant value. Only very small adjustments were made. Thus, the source level can be regarded as constant and equal to *100 db // 1* μ *Bar* for all the runs. The receiving response was calibrated using the hydrophone as a transducer. The input voltage was produced by a generator (Philips G. M. 2317) and measured by a tube voltmeter (R. V. 34 a). The resultant incoming voltage from the amplifier was measured on that same tube voltmeter. The calibration curves did not vary more than $\pm$ 1 db from linearity and at this accuracy the variation from run to run was insignificant.

The measurements

Apart from some fish measured during preparatory tests, 13 fish, including 11 cod of different sizes and 2 coalfish, 40,5 cm and 46 cm long were examined using the following technique:

The airbladder was assumed to be of great importance regarding the reflectivity of sound. Therefore in order to measure the fish with their airbladders in the normal condition they were acclimatized in a cage at the measuring depth for about one week. When a fish was to be measured, it was quickly brought to the surface and killed, then, still kept under water, it was transferred to the frame and suspended fixed to the four nylon guts at marked points. The frame was then lowered into position using a hand winch.

The angle of inclination of the fish was then changed in steps of about 3 degrees, (later 1 degree), and the echo strength at each position was computed on the basis of the mean value from a series of readings on the oscilloscope. The variation between readings within the same series was very seldom more than $\pm$ 1 db in intensity.

As a control, the echo from a 4,1 cm diameter steel ballbearing sphere was measured several times during the experimental period. The results are given below.

The background noise was found to be about — 53 db// 1 μ Bar during all our measurements.

Temperature and salinity in the water at the oscillator depth and at the target depth were also measured both before and after the experiments. Results are given in Tab. 1.

Table 1.

Temperature, salinity, density, sound velocity and wavelength of the transmitted sound

Date	depth (m)	t(°C)	S (‰)	σ_t	e(m/s)	(cm)
3/7—61	2	13,70	30,36	22,36	1494,2	3,9
«	12	11,33	32,39	24,71	1488,6	3,9
22/7—61	2	15,98	30,14	22,04	1501,4	3,9
«	12	11,82	32,27	24,53	1490,4	3,9

RESULTS OF MEASUREMENTS

Sound reflection is usually reported in two ways (Physics of sound in the sea 1945).

Target strength, T. measured in decibells and defined as

$$T = 10 \log I_r - 10 \log F + H$$

where I_r is the intensity of the reflected sound measured at the sound source, F is the intensity of the transmitted sound measured 1 m from the source, and 2 H is the transmission loss during sound propagation from the source out to the target and back again. In these experiments the

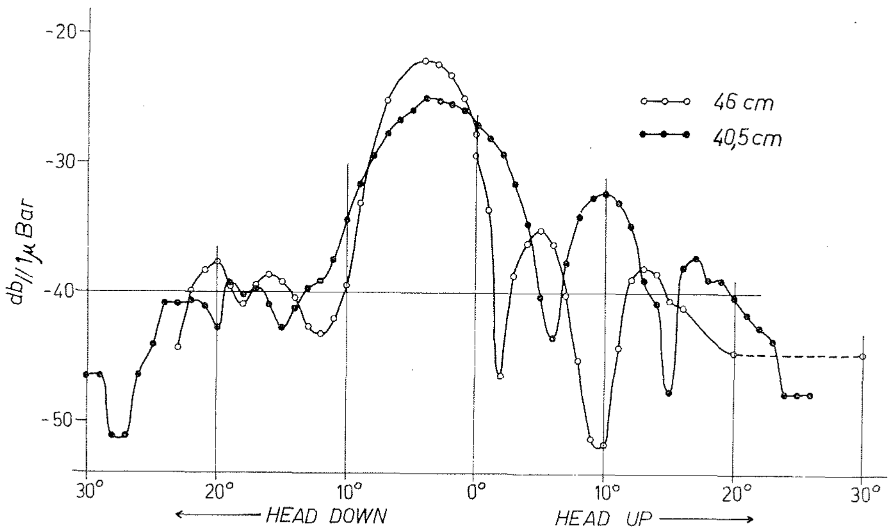


Fig. 2. Reflectivity pattern-diagrams of coalfish. Dorsal target strength as function of inclination.

distance between the source and the target was only 10 m (on two occasions 15 m). Therefore, one can put the transmission loss equal to the geometric intensity drop, viz: $2\,H = 40 \log r$, where r is the distance in metres from source to target.

Effective target area, also called the scattering cross section, τ, defined as follows: If the echo received was reflected by a total reflecting target with uniform spherical reflectivity pattern, the area of this target normal to the incident sound beam would be equal to τ.

A large, completely reflecting sphere has an effective target area equal to its projected area.

The target strength and effective target area are related to each other by the expression:

$$T = 10 \log \frac{\tau}{4\pi}$$

Target strength of the sphere

During the period of the experiment we measured the echoes from the steel sphere mentioned 20 times. The results are given in Table II, from which the accuracy of the measurements can be seen to be $\pm$ 1 db.

Table II.

Target strength of a 4,1 cm diameter steel sphere.

No. of obs.	Target strength db.			Area in cm²	
	Min. val.	Max. val.	Mean val.	Mean τ	Projection
20	37,1	39,1	38,1	19,5	13,2

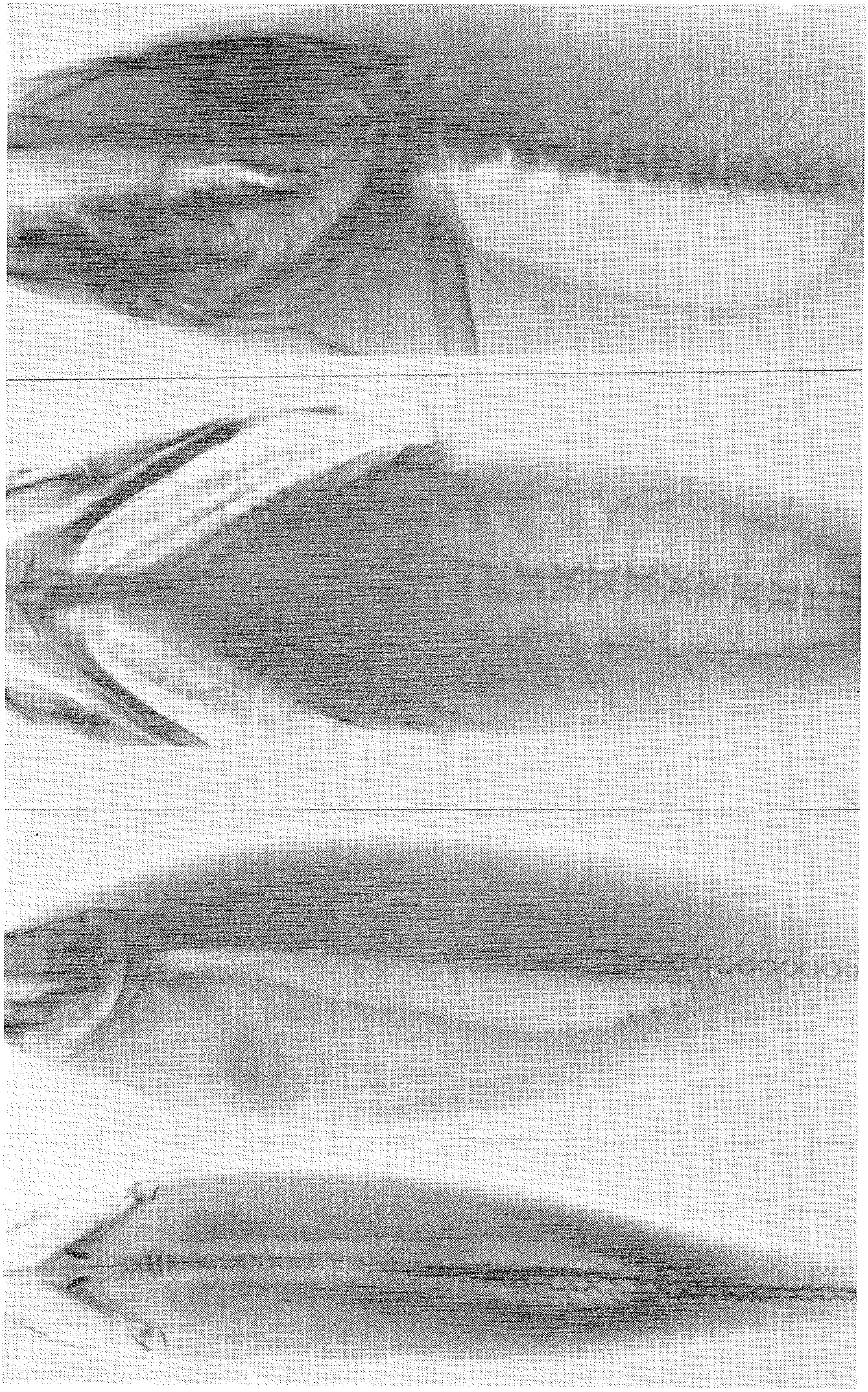


Fig. 3. Roentgenphotographs in two planes of:
1. (above) A 81 cm cod.
2. (below) A 55 cm coalfish.

The difference between the effective target area and the projected area equals 1,7 db, or a little greater than the accuracy of observations. This is a very reasonable differance, because, our sphere can not be regarded as large compared to the wavelength of the sound. (Circumference is only 3,3 times wavelength). Reflection by spheres of this magnitude can be computed from theory (Morse 1948, p. 354).

Target strength of coalfish (Pollachius virens)

The target strength values obtained for the two coalfish measured are given in Fig. 2. The target strength is greatly influenced by the inclination of the fish, thus for the larger fish, a variation of not more than 6 degrees in angle could change the target strength by as much as 24 db.

The two reflectivity curves in Fig. 2 show the same pattern even in details. The maxima were found when the fish had an angle of inclination equal to 4 degrees (head downwards). On either side of the main peak each curve has also two further peaks, only half as broad. They are directivity patterns typical of diffraction spreading. The direction of minimum sound reflection fairly is theoretically given by the equation:

$$\sin a = N \frac{\lambda}{2\,D}$$

where a is the inclination angle of the reflecting surface, λ the wavelength of sound and D is the length of the reflecting body measured parallel to the reflecting surface, N represents the successive interference 1, 2, etc. The magnitude of D calculated from this formula was about 17 cm for the largest fish and about 12,5 cm for the other one, which value should be related to the dimension of the airbladder. Roentgen photographs of coalfish (Fig. 3) showed that the lengths of the airbladders must have been about 19 cm and 16,5 cm respectively. Fig. 3 also showed that the airbladder were inclined 4 degrees (head downwards) relative to horizontal position of the fish suspended in our measuring frame.

Tucker and Stubbs (1948) give a formula for the effective target area of a finite cylinder, viz: $a = \frac{2\,\pi}{\lambda}\, r\, b^2 \mu^2$.

Table III.

Measured maximum target strength of coalfish compared to computed reflection from airbladder.

Fish length	Measured target strength db.	Computed target strength of airbladder db.
40,5 cm	— 25,0	— 25,6
46 ,,	— 22,0	— 24,1

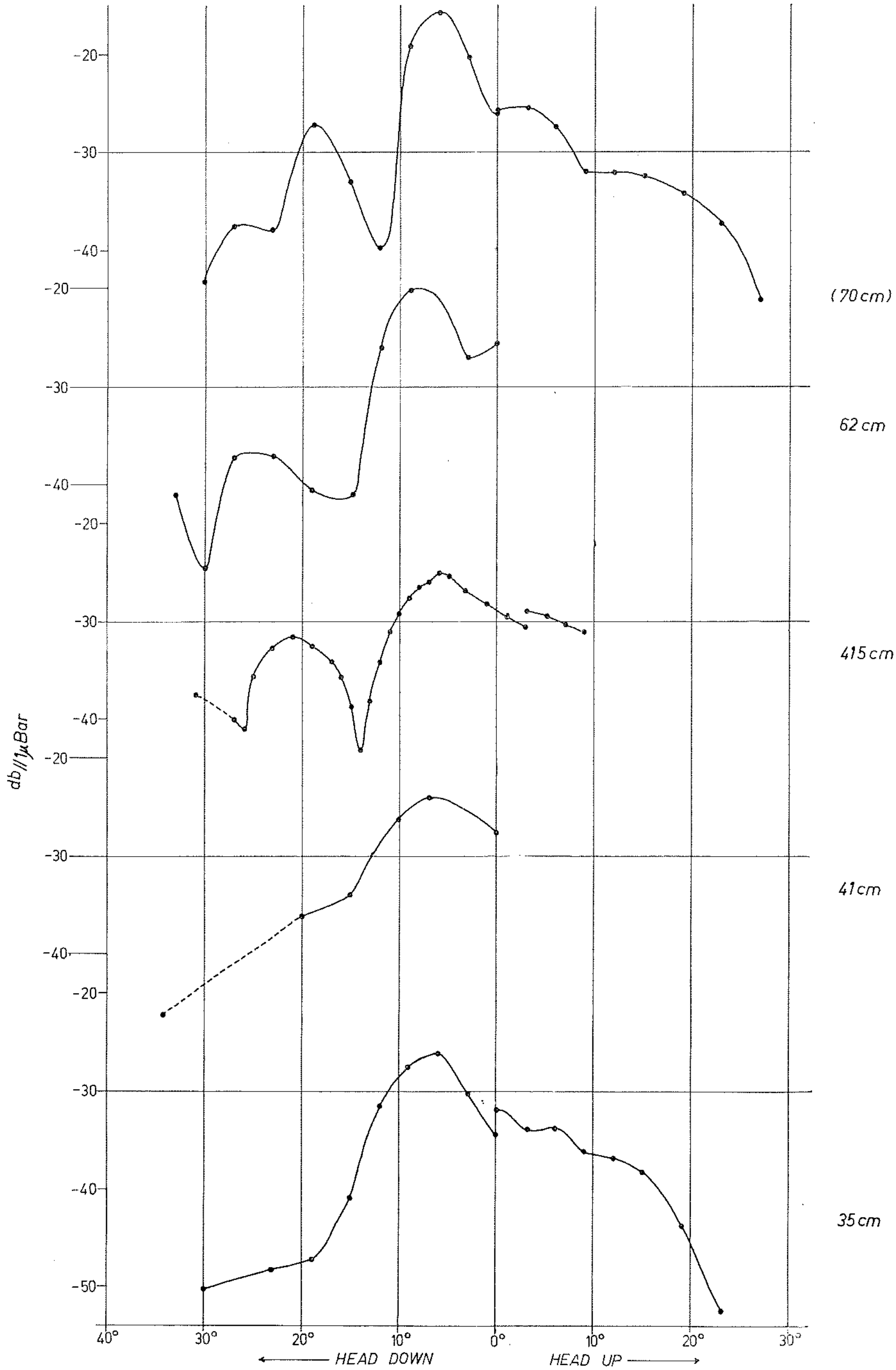


Fig. 4. Reflectivity pattern-diagrams of cod. Dorsal target strength as function of inclination.

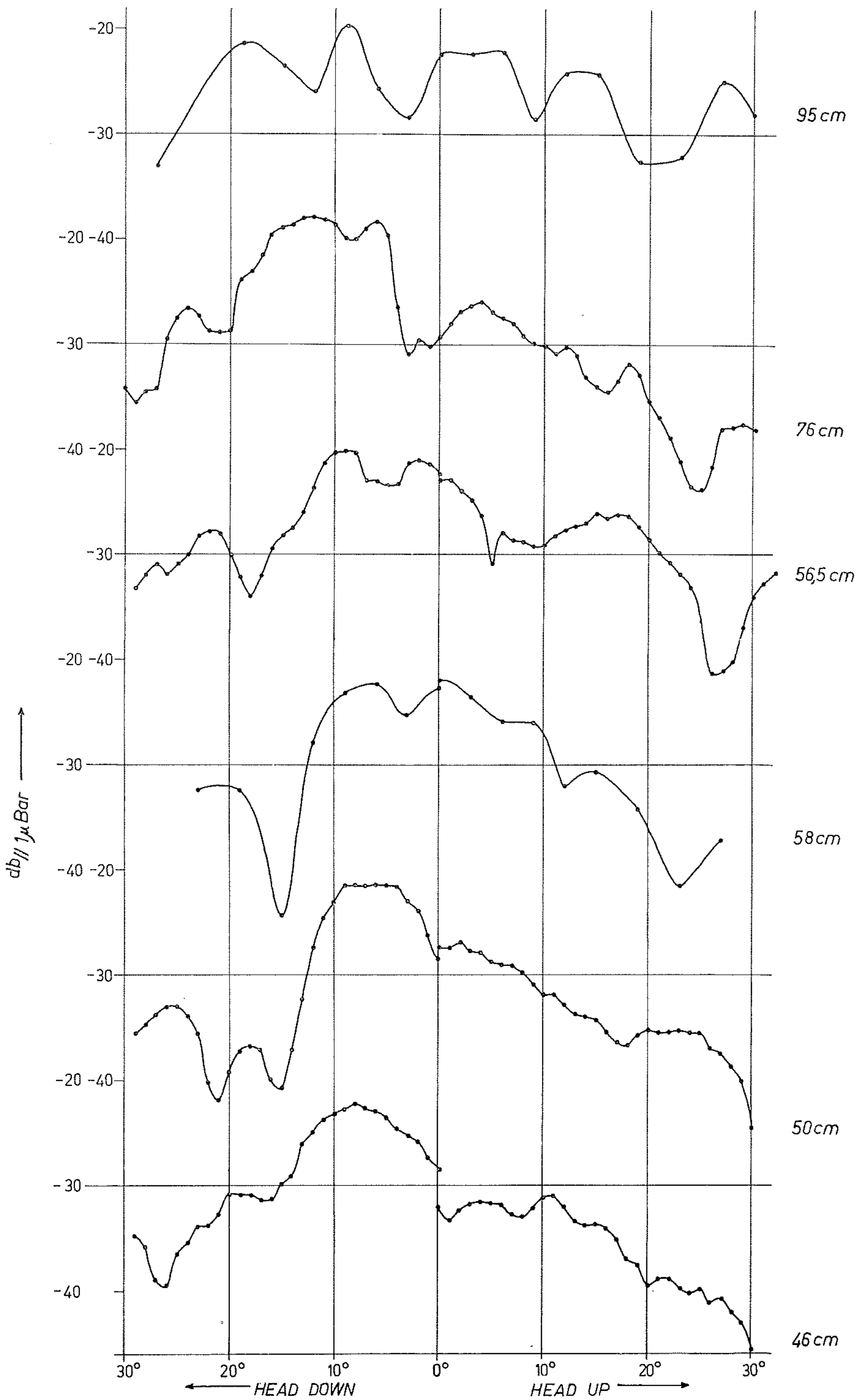

-20
-30
-20 -40
-30
-40 -20
-30
-20 -40
-30
-40 -20
-30
-20 -40
-30
-40
db// 1μ Bar
95 cm
76 cm
56,5 cm
58 cm
50 cm
46 cm
30°
20°
10°
0°
10°
20°
30°
HEAD DOWN
HEAD UP

Fig. 4 (cont.).

λ is the wavelength of sound, r the radius and b the length of the cylinder, and μ is the coefficient of reflectivity. The present authors do not know how far this formula may be applicable to a cylindrical model with the dimensions of the airbladder, but the calculated values (putting $\mu = 1$) are in good agreement with those measured. (Tab. III).

Target strength of cod (Gadus morhua)

The target strength diagrams for the 11 cod measured are given in Fig. 4. The size of the 70 cm cod was inadvertently not measured, but its length has been estimated and is given in paranthesis in later diagrams. The patterns are not so uniform as those given by the coalfish already shown, but there are some main features common to all of them, thus the maximum values occurred at a head downwards inclination of roughly 7°, which is identical to horizontal position of the dorsal surface of the airbladder. The largest fish (95 cm long) gave a pattern a little different from that of the others as the directivity of the reflected sound was less pronounced.

In order to test how far the maximum target strength was related to the dimensions of the fish, we have compared the maximum target strength to 20 log (fish length), since this is the scale and dimension of T (Fig, 5). In order to compare our results with those obtained by Jones and Pearce (1958) on the target strength of perch measured in a fresh water tank using 30 kc/s sound, the results obtained with one of their fishes (No. 6, 20.6 cm) is entered in the diagram. There is obviously a rectilinear relation between the maximum target strength and the size of the fish, including the perch. The slope of this straight line is greater than 45 degrees, indicating increasing directivity of the reflected sound with increasing fish size up to a value of about 70 cm of fish length. Above this value the directivity decreases. This is in accordance with the reflectivity pattern of the 95 cm cod in Fig. 4a.

It is difficult to compute theoretically the reflection of sound given by fish, but in order to examine more closely the question of directivity, we have compared this to the directivity of the sound reflected by a plane of the same size as the projection of the airbladder.

The «gain» of a reflecting plane can be expressed approximately by

$$G = \frac{I'_r}{I'_{r,s}} = \frac{4\pi A}{\lambda^2}$$

where I'_r is intensity reflected by the plane, $I'_{r,s}$ is the intensity by spherical reflection of the same incident sound. Both I'_r and $I'_{r,s}$ are measured at distance r and normal to the plane, which is also the direction of

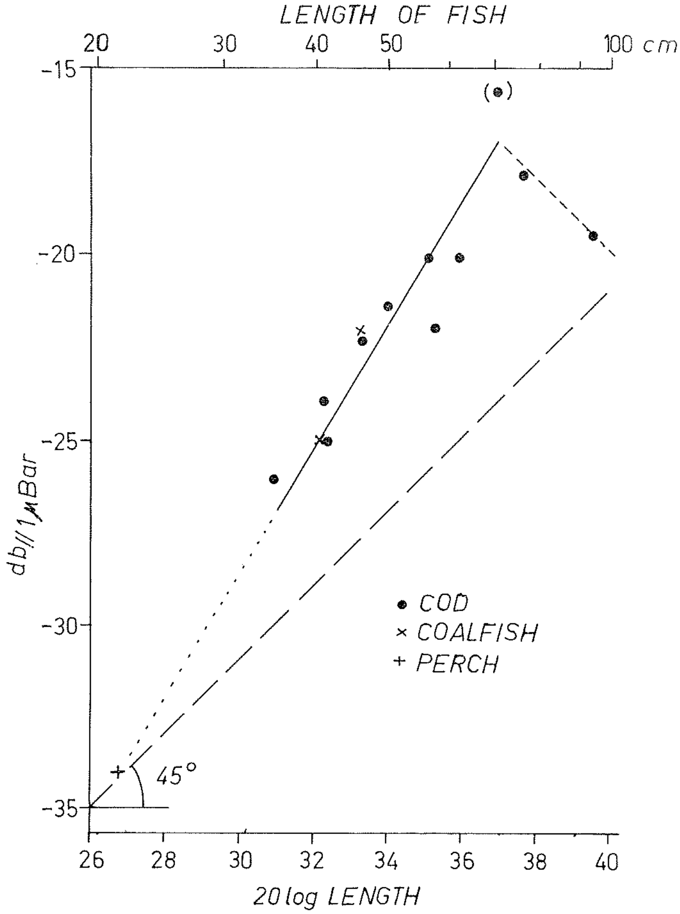


Fig. 5. Comparison of maximum target strength and fish length (see text).

incident sound. A is the area of the plane and λ the wavelength of sound. When I'_r and $I'_{r,s}$ are measured at the sound source

$I'_r = k' \frac{F}{r^4}$ and $I'_{r,s} = \frac{FA}{4\pi r^4}$, where F is the transmitted sound intensity.

Substituting these expressions into the equation above, we obtain

$$k' = \frac{A^2}{\lambda^2}$$

or

$$T' = 10 \log k' = 20 \log \frac{A}{\lambda}$$

which gives the target strength of the plane.

Values of A are computed on the basis of Roentgenphotographs of two cod (55 cm and 81 cm) and two coalfish (38 cm and 50 cm).

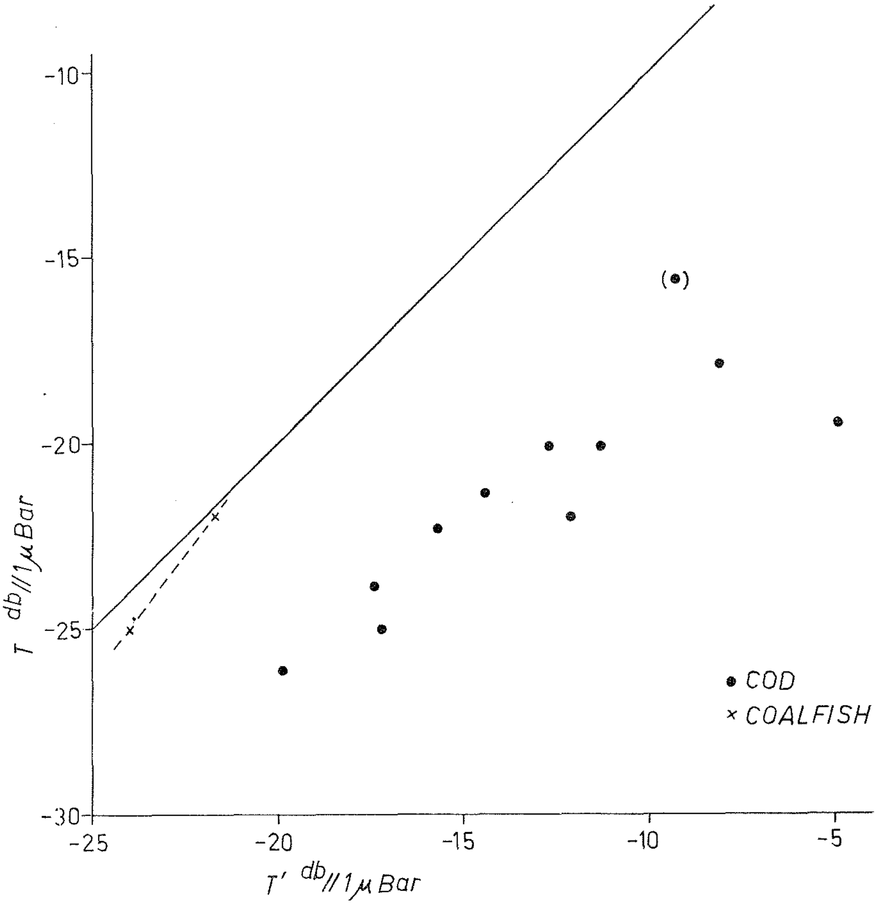


Fig. 6. Comparison of reflectivity of fish (T) and the reflectivity of a plane corresponding to the projected area of the airbladder (T′).

In Fig. 6 T' is compared to the measured T_{max} from the fishes. A heavy line indicates the target strength of the corresponding plane (T'). The coalfish have a directivity very close to that of the plane whereas the cod show much lower directivity. In our opinion this is explained by the shape of the airbladder of the cod which is different from that of a coalfish of the size of those measured. This is clearly seen from the Roentgenphotographs in Fig. 3. Whereas the airbladder of the coalfish is nearly cylind

Table IV.

Ratios of total length to bladderaxis length for two cod 81 cm and 55 cm long. (a length, b width and c height of airbladder).

L_1/L_2	a_1/a_2	b_1/b_2	c_1/c_2
1,47	1,20	1,62	1,67

rical, that of the cod has the shape of a short ellipsoid which becomes more spherical as the size of the cod increases. Table IV gives the ratios of fish length to that of the airbladder axis for the two cod photographed.

SUMMARY

This paper describes the measurements of the target strength of some commercial fish; cod and smaller coalfish. The dorsal reflectivity was found to vary strongly with angle of inclination, which can be explained by regarding the airbladder as responsible for the major part of the reflection. The directivity of the reflected sound seems to be a function both of the size of the fish and the geometry of the airbladder.

The airbladder length (a) has the smallest increase and the airbladder height (c) has the greatest increase.

In Fig. 7 the differences in target strength between the fish and the relative theoretical plane, (T—T') are compared to the ratio length/height of the airbladders of the different cod. The target strength difference shows an accelerating decrease when this ratio in airbladder is also decreased.

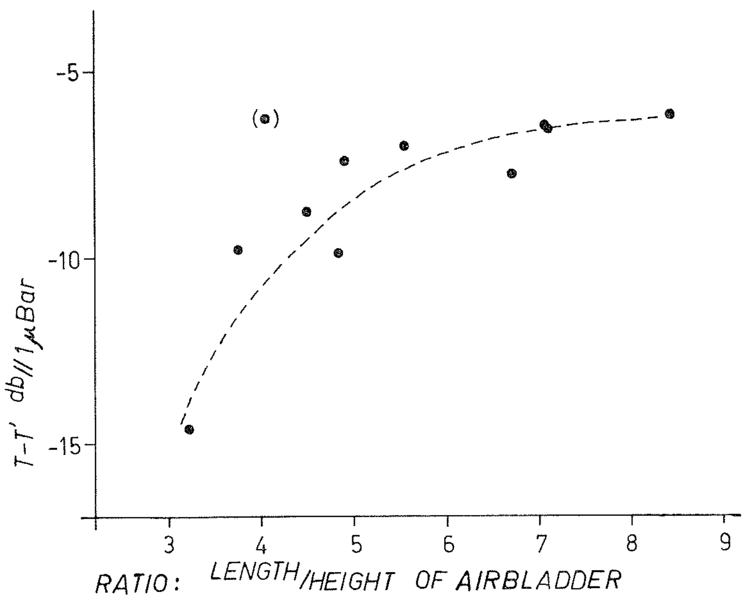


Fig. 7. Difference in the target strength between the plane and the fish, compared to the ratio length/height of the airbladder.

REFERENCES

Cushing, D. H. and Richardson, I. D. 1955. Echo sounding experiments on fish. *Fish. Invest.*, Ser. 2, 18 (4): 1–34.

Hashimoto, T. and Maniva, Y. 1952. Study on school finder. *Tech. Rep. Fish Boat.* 3: 177–234.

— 1955. Study on reflection loss of ultrasonic wave on fish-body by millimeter wave. *Tech. Rep. Fish. Boat.* 8: 113–118.

Jones, F. R. Harden, and Pearce, G. 1958. Acoustic reflection experiments with perch. (*Perca fluviatilis* Linn.) to determine the proportion of the echo returned by the swimbladder. *J. exp. biol.*, 35: 437–450.

Morse, P. M. 1948. *Vibration and sound*, (2. edition). Mc Graw-Hill. New York. XIX + 468 p.

Physics of sound in the sea 1–4, 1945. (Originally issued as NDRC Summary technical reports 6(8)). Murray printing Co., Wakefield, Mass.

Richardson, I. D., Cushing, D. H., Jones, F. R. Harden, Beverton, R. J. H. and Blacker, R. W. 1959. Echo sounding experiments in the Barents Sea. *Fish. Invest.* Ser. 2, 22(9): 1–57.

Smith, P. F. 1954. Further measurements of sound scattering properties of several marine organisms. *Deep-Sea Res.*, 2(1): 71–79.

Tucker, M. J. and Stubbs, A. R. 1958. The reflection of sound by fish. *N.I.O. Internal Report*, No. A 12. 1–12 Surrey (mimeographed).