International Council for
the Exploration of the Sea

C.M. 1976/B: 37
Gear and Behaviour Committee
Ref. Pelagic Fish (Northern)
Committee

TARGET STRENGTH MEASUREMENTS AND ACOUSTIC BIOMASS ESTIMATION OF CAPELIN AND 0-GROUP FISH

by

John Dalen, Askjell Raknes and Ingolf Røttingen
Institute of Marine Research, Bergen

INTRODUCTION

Echo integration is now widely used to obtain estimates of abundance of fish populations (THORNE et al 1971, JOHANNESSON and LOSSE 1973, MIDTTUN and NAKKEN 1973 among others). Earlier estimates have mostly been worked out under the assumption that the scattering cross section of the fish is proportional to its weight (URICK 1967). This assumption introduces a bias which is dependent on the size distribution of the fish (NAKKEN 1975). However, this is overcome if one introduces a length dependent scattering cross section (BUZETA and NAKKEN 1975, NAKKEN and DOMMASNES 1975).

At Institute of Marine Research acoustic biomass estimation of the stock strength of capelin has been carried out in September - October each year since 1971 and in June - July since 1973. The echo integration system applied during these cruises together with the results are given in NAKKEN & DOMMASNES 1975. The last year this methodology has also been applied to cod (DALEN, HYLEN and SMEDSTAD, in press). Back scattering properties of capelin were not known, and it has hitherto been assumed that the dependency of the density coefficient (C) on fish length for capelin was similar to that of sprat. Back scattering data for sprat are given in NAKKEN and OLSEN (1973).

During late summer and early autumn O-group fish of many species occur pelagically in the Barents Sea. Knowledge of the pre-recruitment stock is essential in attempts to predict and control fisheries, and the advantage of knowing yearclass strength for all species in a region before they are subject to finishing is obvious (DRAGESUND 1971). However, this knowledge is in the Barents Sea area so far limited to relative values (abundance indices) for each species each year (ANON. 1975).

The method of obtaining these indices has improved. At present, a method described by HAUG and NAKKEN (1973) is used. Here a certain number of fish of each species in the trawl catch is used to discriminate between areas of scattered and dense concentrations. But information on the contributions to the total biomass from different species can, only to a small extent, be extracted from the abundance indices values.

The aim of the present paper is to give information on the back scattering properties of some pelagic and O-group fish in the Barents Sea, in order to improve the acoustic biomass estimations of the above mentioned categories of fishes.

METHODS

Experimental set-up

The work took place in a sheltered bay at Skogerøya, South Varanger in Finnmark.

An anchored ship with a raft alongside the ship constituded the power station, the laboratory and the accomodation facilities (Fig. 1).

The upward looking transducers were mounted in a loaded aluminum frame submerged from the raft in adjustable wires. The fish was kept in an upside down position by a small float attached to the fish belly in the central part of the sound beam by a suspension of thin nylon gut. A hoisting device made it possible to hook the fish to the suspension at the surface and then lower it to the measuring position at 2.5 m depth (Fig. 1).

The aspect angle of the fish could be continously changed in the pitch plane. The fish was automatically tilted between -45° and + 45° to the horizontal. The overall accuracy was found to be ± 2° with the worst case of deviation to be ± 5°.

The equipment was calibrated three times during the field period by means of a hydrophone. To check the short time variations of the performance, three or four daily calibrations were carried out by measuring the target strength of a rigid steel sphere, 5 cm in diameter, that was lowered into the actual position.

Each fish to be measured was killed by hitting the frontal part of the brain by a sharp tool. When suspending the fish, care was taken to avoid air in gills and stomach. The measurements started immediately after the fish had reached the measuring position if no other fishes were in the close neighbourhood. Wild fish within the sound beam were however often a problem which caused considerable delays in the experiments.

Instrumentation

Fig. 2 shows a block diagram of the instrumentation which also listed below.

Echosounder EK 38 A,	SIMRAD A/S
Echosounder EK 120 A,	SIMRAD A/S
Transducer, 38 kHz, dim. 10 x 10 cm	SIMRAD A/S
Transducer, 120 kHz, dim. Ø 5 cm	SIMRAD A/S
Trigger (electronic)	Institute of Marine Research
Tiltangle indicator and control, sensor and motor	Institute of Marine Research

Oscilloscope Dual trace 1217 B	Hewlett - Packard
Echo Integrator QM II	SIMRAD A/S
Recorder 7702 B	Hewlett - Packard
Signal generator Model 116	Wavetec
Signal generator PF 1101	Marconi
Frequency counter 5306 AM. meter/counter	Hewlett - Packard
Electronic voltmeter Model 2606	Brüel & Kjær
Hydrophone LC 32	Atlantic Research

The transmitted pulselengths were 0.6 ms for both sounders. The sounding repetition was approximately 3.4 pulses per second (200 pulses per minute).

Data processing

The information recorded on paper consists of signal voltage amplitudes as function of frequency, tiltangle, aspect, species and size.

During the analysis the following parameters were to be read (R) and calculated (C) from each fish, species and aspect.

L (R) : Fish length (cm)

U (R) : Maximum observed voltage amplitude (V)

FV (R) : Interval of tiltangle within which $TS \geq TS_{max} - 6$ dB (degrees)

TS_{max} (C) : Maximum observed target strength

Target strength, TS, was calculated from the following equation

$$TS = 20 \log \frac{U}{U_r} + TS_r \qquad (1)$$

where U is observed voltage amplitude, U_r is the observed voltage amplitude from the reference sphere which has the target strength TS_r. TS_r is - 38.1 dB at ideal conditions which was the value used in (1).

RESULTS

Besides values of the target strength it is of importance to find the dependency between target strength and length of the fish. To establish this we assume a linear relation between target strength and the logarithm of the fish length, that is

$$TS = m \log L + b \qquad (2)$$

m and b are determined by linear regression analysis.

It was originally planned to measure target strength of all length groups of capelin. However, due to difficulties in catching and transporting the smaller capelin from the fishing grounds in the Barents Sea south to the measuring site at Varanger, target strength measurements could only be made for length groups 13 cm to 18 cm. This was considered to few data to apply a linear regression, and it was decided to combine these data with previously measured target strength data from other fish of the order Clupeiformes. Pertinent data for following species of Clupeiformes were included.

	Species	Reference
Capelin	(Mallotus villosus)	(present measurements)
Herring	(Clupea harengus)	NAKKEN & OLSEN(1973)
Salmon	(Salmo salar)	RØTTINGEN, unpublished
Sprat	(Sprattus sprattus)	NAKKEN & OLSEN (1973)

These data have been combined and plotted in Fig.3, and results from the linear regression are shown in Table 1.

The observations and the results of the linear regression for cod (Gadus morhua), saithe (Pollachius virens) and sand eel (Ammodytes sp.) are shown in Figs. 4, 5 and 6, and Table 2.

Target strength measurements of 10 specimens of haddock (Gadus aeglefinus) were made. NAKKEN and OLSEN (1973) also measured target strength of haddock (15 specimens) but the measurements were only published as mean values (Table 3, NAKKEN and OLSEN 1973) because they felt the observations to few to make a linear regression. Fig. 7 and Table 2 combine the present measurements of haddock with those of NAKKEN and OLSEN (1973).

Fig. 8 shows the relation between maximum dorsal aspect target strength and mean angle between points of half maximum amplitude (6 dB points) for cod, haddock and saithe.

DISCUSSION

We would like to pay some specific attention to how to reduce the data by linear regression analysis i.e. what regression to use (RICKER 1973). In order to make a decision one should discuss;

1 - what kind of variability and error which are involved in the variates,
2 - what distributions the variates make,
3 - what has the sampling method been and
4 - is the regression used to describe a relationship, or to make predictions, or both.

Most of the variability in target strength-length observations we find to be inherent in the material more than in the process itself of measuring length and measuring and calculating target strength.

The observations are from a non-random sample which forms an open-ended non-normal distribution.

Primarily the regressions are needed to decribe a certain relationship, secondarily however, they will be used to predict target strength from length observations.

These statements lead to the conclusion that functional regression (least geometric mean regression) is preferable to predictive regression (least mean square regression). The functional regression represents the line which minimizes the sum of the products of the vertical and horizontal distance of each point from the line. The slope of the line is

$$v = \pm \sqrt{\frac{\sum y^2}{\sum x^2}} \qquad (3)$$

x and y represent the quantities as measured from their means, i.e. $x = X - \overline{X}$ and $y = Y - \overline{Y}$.

NAKKEN (1975) shows that observations of maximum dorsal aspect target strength can be used to obtain reliable ratios of echo intensity between species and length groups.

The dorsal target strength is

$$TS_{max} = m \log L + b \tag{4}$$

Or applied for the density coefficient (NAKKEN 1975)

$$C = C_I \cdot C_s \cdot L^{\frac{-m}{10}} \tag{5}$$

C_I is a instrument constant and C_s is a constant for a given species.

Unfortunately the data obtained during the present measurements were to few to give length dependency of the density coefficient based on data from capelin only. However, the capelin belongs systematically to the order <u>Clupeiformes</u>, and in general, with the exception of certain deep-sea species (MARSHALL 1960), clupeiform fish have physostomus swim bladders (FAHLĒN 1967, 1968), osseous bone tissue, intermuscular bones, comparatively many vertebrae, fins without spines and cycloid scales. Clupeiform fish therefore have common structural components that are acoustically important, and one feels that this justifies treating the acoustic data for several <u>Clupeiformes</u> together. The obtained values of m for a number of species of 0-group fish are listed in Table 2. The value for cod shows a decrease in dB/decade compared to that of larger fish measured by NAKKEN and OLSEN (1973), while the value for saithe shows a increase in dB/decade.

It is well known (LOVE 1971, SHIBATA 1970) that there is a change in the directional reflection of fish as the fish size, or rather L/λ (where L is fish length and λ is wave-length), decreases. There will be a reduction in the number of lobes, and consequently an increase of the FV-angle. Fig. 8 shows the relation between maximum dorsal aspect target strength and the angle between the

6 dB points in the directivity pattern for the measured cod and saithe. The relations found by NAKKEN and OLSEN (1973) are also indicated. The angle between the 6 dB points for cod increases with decreasing fish size, (or decreasing L/λ), for saithe the angle does not seem to exceed 25^o. This may be due to different structure and reflecting properties of the swim-bladders of cod versus that of saithe, a phenomenon already indicated by MIDTTUN and HOFF (1962) and MIDTTUN and NAKKEN (1971). The tilt angle distribution will thus be of greater importance in abundance estimation of 0-group saithe than for 0-group cod.

Abundance estimation

When different categories of fish, i.e. size groups and species are mixed and thus simultaneously contribute to the echo, then the integrated echo intensity M can be written

$$M = M_{11} + M_{12} + \dots + M_{1n} + M_{21} + M_{22} \dots + M_{2n} + \dots + M_{p1} + \dots + M_{pn} \qquad (6)$$

M_{11} is the contribution to the integrated echo intensity from length group 1 of species 1, M_{12} is the contribution from length group 2 of species 1 and so on, altogether n length groups from each of the p species. We must assume that frequent sampling, usually with a pelagic trawl, shows the true density ratios between different length groups and species. Following NAKKEN and DOMMASNES (1975):

$$k_{ai} = \frac{{}^{\rho}A_{ai}}{\sum_{a=1}^{p} \sum_{i=1}^{n} {}^{\rho}A_{ai}} \qquad (7)$$

k_{ai} is the proportion of the length group of species of the total catch, (Total n length groups from each of p species) and ${}^{\rho}A_{ai}$ is the density per unit area of that particular category of fish.

Further

$$K = \frac{1}{\sum_{a=1}^{p} \sum_{i=1}^{n} \frac{k_{ai}}{C_{ai}}} \qquad (8)$$

where C_{ai} is the density coefficient for length group i of species a.

The relationship between the fish density and integrated echo intensity is linear below a certain density (THORNE and WOODEY 1970, MIDTTUN and NAKKEN 1973, RØTTINGEN in press.). This leads to:

$$\rho_{ai} = k_{ai} \cdot \frac{M}{\sum_{a=1}^{p} \sum_{i=1}^{n} \frac{k_{ai}}{C_{ai}}} \qquad (8)$$

By applying this method absolute fish density can be calculated for the different species where the density coefficients are known (eq. 5, Table 1 and 2).

Table 1. Functional regression ($TS_{max} = m \log_{10}L + b$) for *Clupeiformes* for frequencies 38 kHz and 120 kHz m) calculated slope, b) constant of regression, r) correlation coefficient, N) number of fish measured.

Frequency kHz	N	m	b	r
38	103	19.1	64.0	0.89
120	83	18.4	62.7	0.90

Table 2. Calculated slope (m) and constant (b) of regression lines, $TS = m \log_{10}L + b$, the correlation coefficient (r) and the number of fish measured (N).

Species	Frequency kHz	N	m	b	r	Length range measured (cm)
Cod	38	32	21.9	63.5	0.81	4.7 - 20.5
	120	7	39.4	87.1	0.90	9.0 - 16.5
Saithe	38	25	37.1	78.0	0.94	7.1 - 14.5
	120	11	34.8	78.6	0.84	7.1 - 14.5
Haddock	38	24	18.7	59.4	0.95	7.2 - 48.0
	120	20	28.9	74.0	0.97	7.6 - 48.0
Sand eel	38	22	45.5	97.1	0.60	9.2 - 18.5

REFERENCES

ANON. 1975. Report of a meeting to consider young fish surveys. Coop.Res.Rep.Ser.A.,int.Coun.Explor.Sea, 52: 1-37.

BUZETA, R. and NAKKEN, O. 1975. Abundance estimates of the spawning stock of blue whiting (Micromesistius poutassou (Risso, 1810)) in the area west of the British Isles in 1972-1974. FiskDir.Skr.Ser. HavUnders., 16: 245-257.

DALEN, J., HYLEN, A. and SMEDSTAD, O. 1976. Acoustic abundance estimates of cod and haddock in the Barents Sea in February 1976. (In press).

DRAGESUND, O. 1971. Comparative analysis of year-class strength among fish stocks in the North Atlantic. FiskDir. Skr.Ser.HavUnders., 16: 49-64.

FAHLÉN, G. 1967. Morphological aspects on the hydrographic function of the gas bladder of Clupea harengus L. Acta.Univ.Lund. II(1): 1-49.

FAHLÉN, G. 1968. The gas bladder as a hydrostatic organ in Thymallus thymallus L., Osmerus esperlanus L. and Mallotus villosus Müll. FiskDir.Skr.Ser.HavUnders., 14: 199-228.

HAUG, A. and NAKKEN, O. 1973. Echo abundance indices of 0-group fish in the Barents Sea 1965-1972. Int.Coun.Explor. Sea Symp.Acoustic Methods in Fisheries Research. Bergen 1973 (26): 1-13. [Mimeo.]

JOHANNESON, K.A. and LOSSE, G.F. 1973. Some results of observed abundance estimates in several UNDP/FAO resource survey projects. Int.Coun.Explor.Sea Symp.Acoustic Methods in Fisheries Research. Bergen 1973 (3): 1-77. [Mimeo.]

LOVE, R.H. 1971. Dorsal aspect target strength of an individual fish. J.Acoust.Soc.Am., 49: 816-823.

MARSHALL, N.B. 1960. Swimbladder structure of deep-sea fishes in relation to their systematics and biology. *Discovery Rep.*, 31: 1-122.

MIDTTUN, L. and HOFF, I. 1962. Measurements of reflection of sound by fish. *FiskDir.Skr.Ser.HavUnders.*, 13: 1-18.

MIDTTUN, L. and NAKKEN, O. 1971. On acoustic identification, sizing and abundance estimation of fish. *FiskDir. Skr.Ser.HavUnders.*, 16: 36-48.

MIDTTUN, L. and NAKKEN, O. 1973. Some results of abundance estimation studies with echo integrators. *Int.Coun. Explor.Sea Symp.Acoustic Methods in Fisheries Research.* Bergen 1973 (38): 1-10. [Mimeo.]

NAKKEN, O. 1975. On the problem of determining the relationship between integrated echo intensity and fish density. *Coun.Meet.Int.Coun.Explor.Sea*, 1975 (B:26): 1-8. [Mimeo.]

NAKKEN, O. and DOMMASNES, A. 1975. The application of an echo integration in investigations on the stock strength of the Barents Sea capelin (Mallotus villosus, Müller) 1971-1974. *Coun.Meet.Int.Coun.Explor.Sea*, 1975 (B:25): 1-13. [Mimeo.]

NAKKEN, O. and OLSEN, K. 1973. Target strength measurements of Fish. *Int.Coun.Explor.Sea Symp.Acoustic Methods in Fisheries Research.* Bergen 1973 (24): 1-33. [Mimeo.]

RICKER, W.E. 1973. Linear regression in fishery research. *J.Fish.Res.Board Can.* 30: 409-434.

RØTTINGEN, I. 1976. On the relation between echo intensity and fish density. *FiskDir.Skr.Ser.HavUnders.*, (in press).

SHIBATA, K. 1970. Study on details of ultrasonic refluction from individual fish. *Bull.Fac.Fish.Nagasaky Univ.* 29: 1-82.

THORNE, R.E. and WOODEY, J.C. 1970. Stock assessment by echo integration and its application to juvenile Sockeye salmon in Lake Washington. *Univ.of Wash. Coll.Fish.Circular no. 70 - 2.* 1970.

THORNE, R.E., REEVES, J.E. and MILLIKAN, A.E. 1971. Estimation of the Lake population in Port Susan, Washington, using an echo integrator. J.Fish.Res.Board Can. 28 (9): 1275-1284.

URICK, R.J. 1967. Principles of underwater sound for engineers. Mc Graw-Hill Book Company. New York. 342 p.

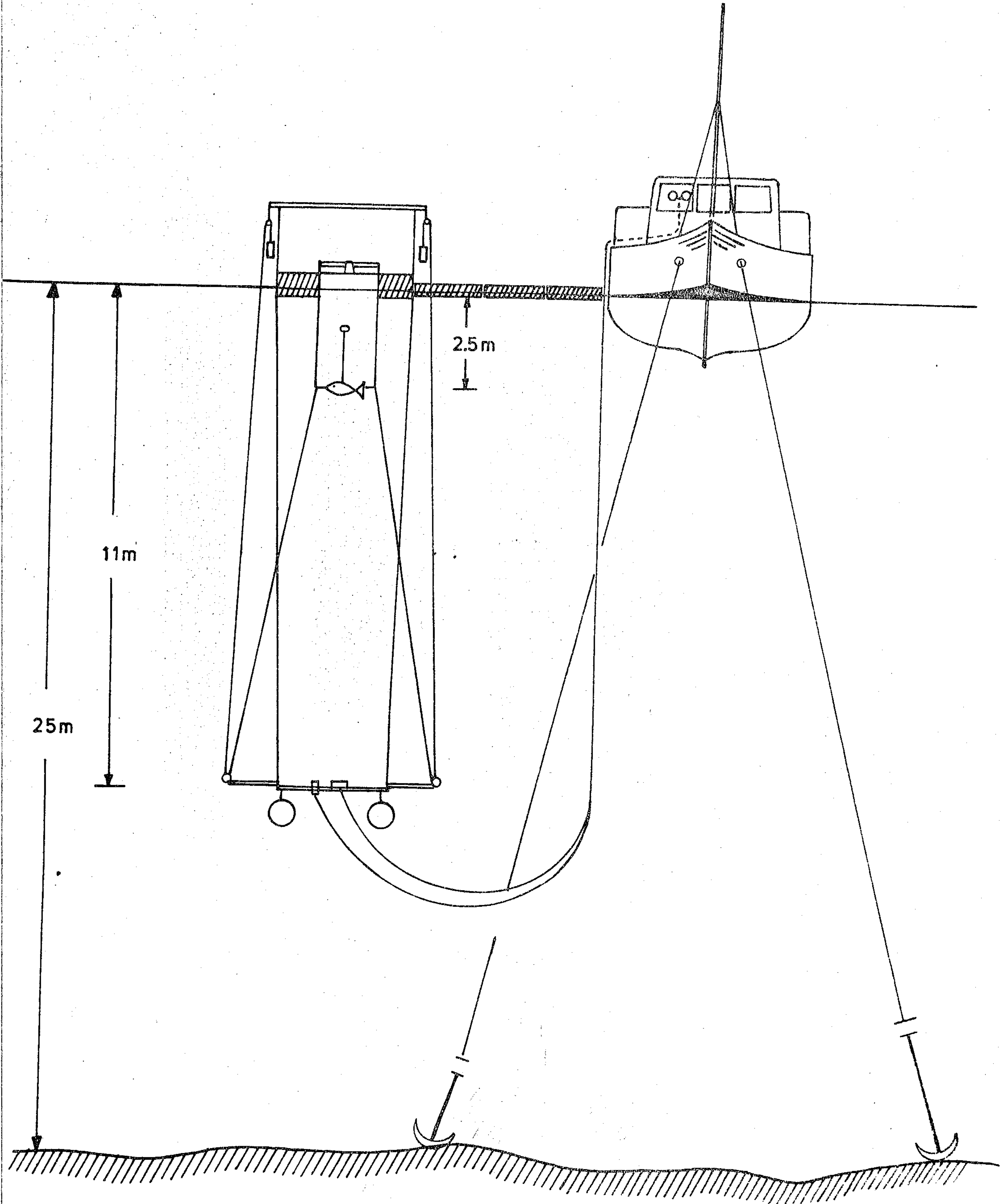

Fig. 1. Experimental set-up vessel, raft, framemounted transducers and surpension arrangement.

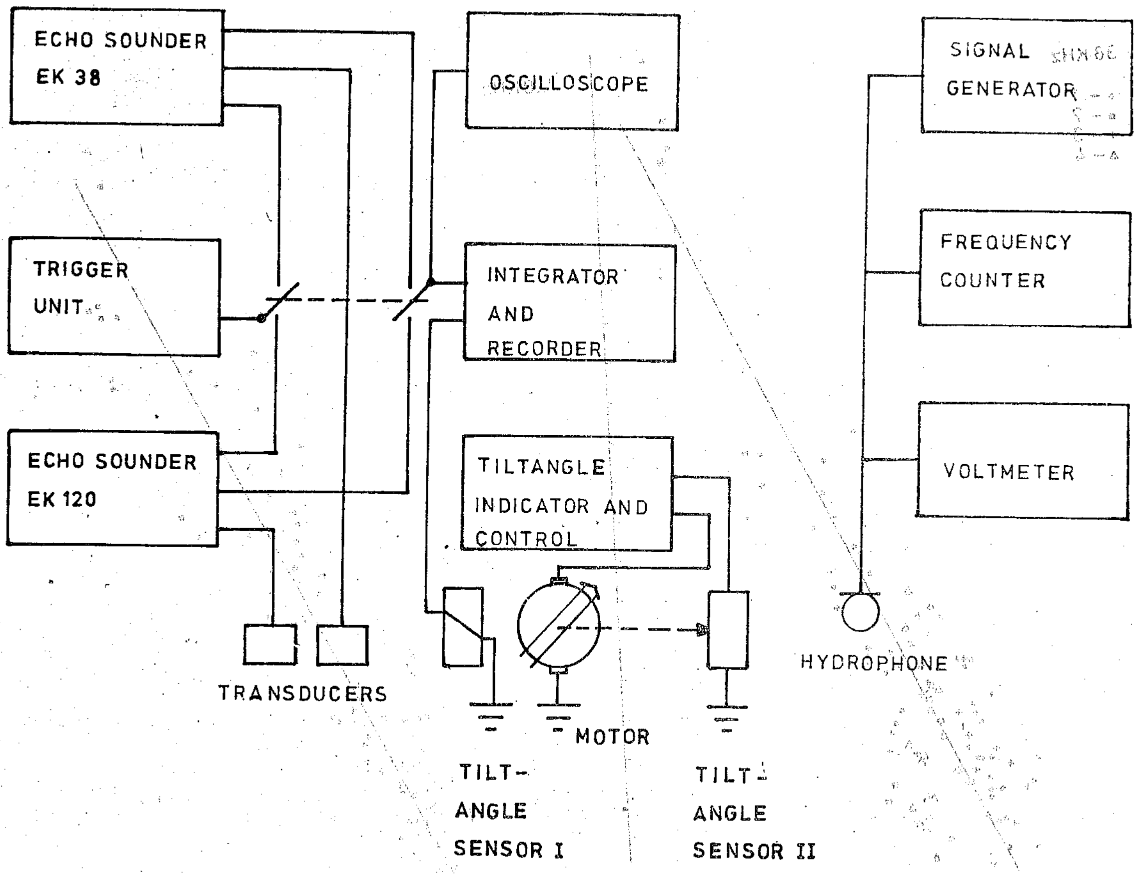

Fig. 2. Composition of instruments.

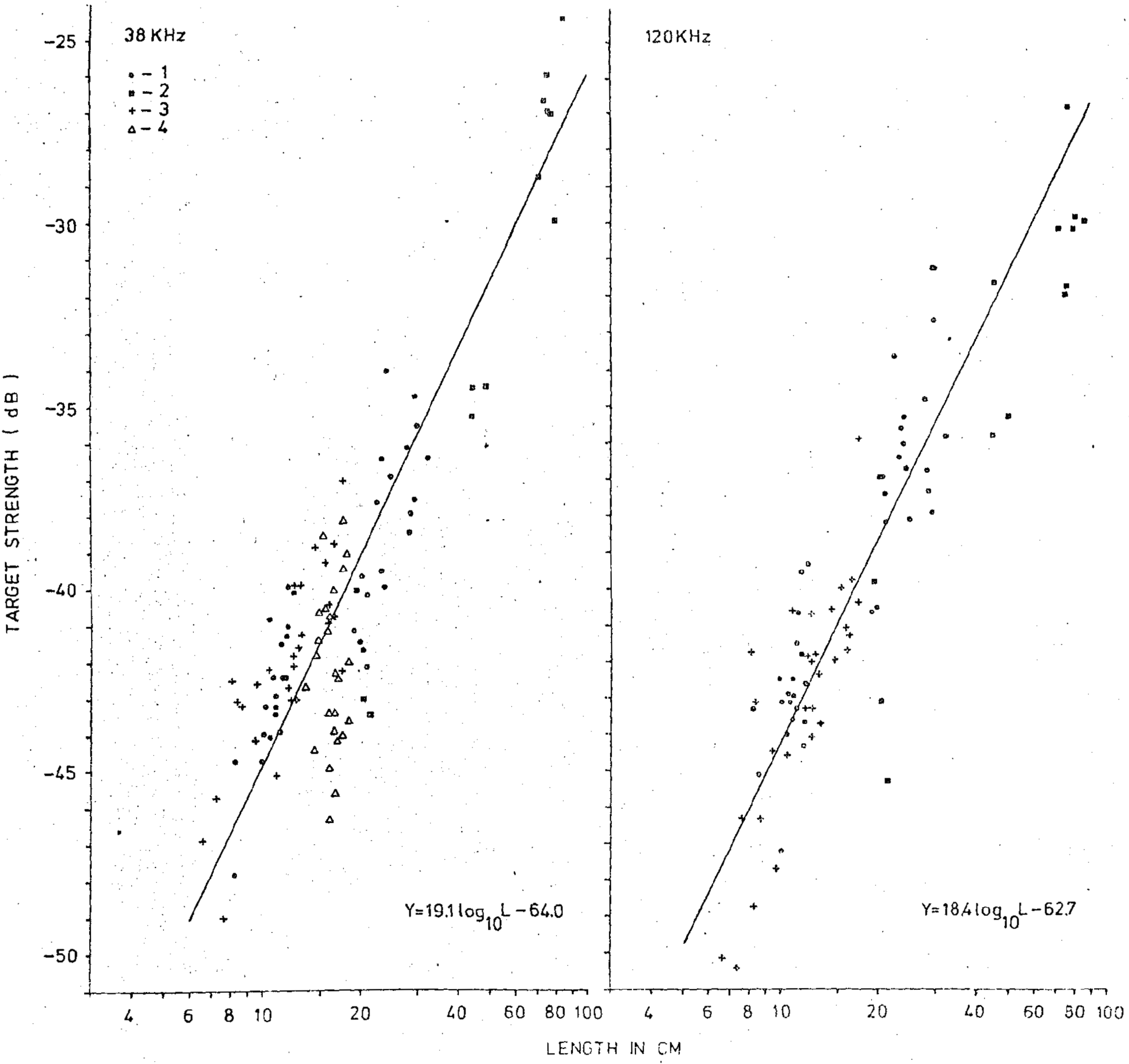

Fig. 3. Maximum dorsal target strength versus length of Clupeiformes. 1) Herring, 2) Salmon, 3) Sprat and 4) Capelin. Observed values and regression line.

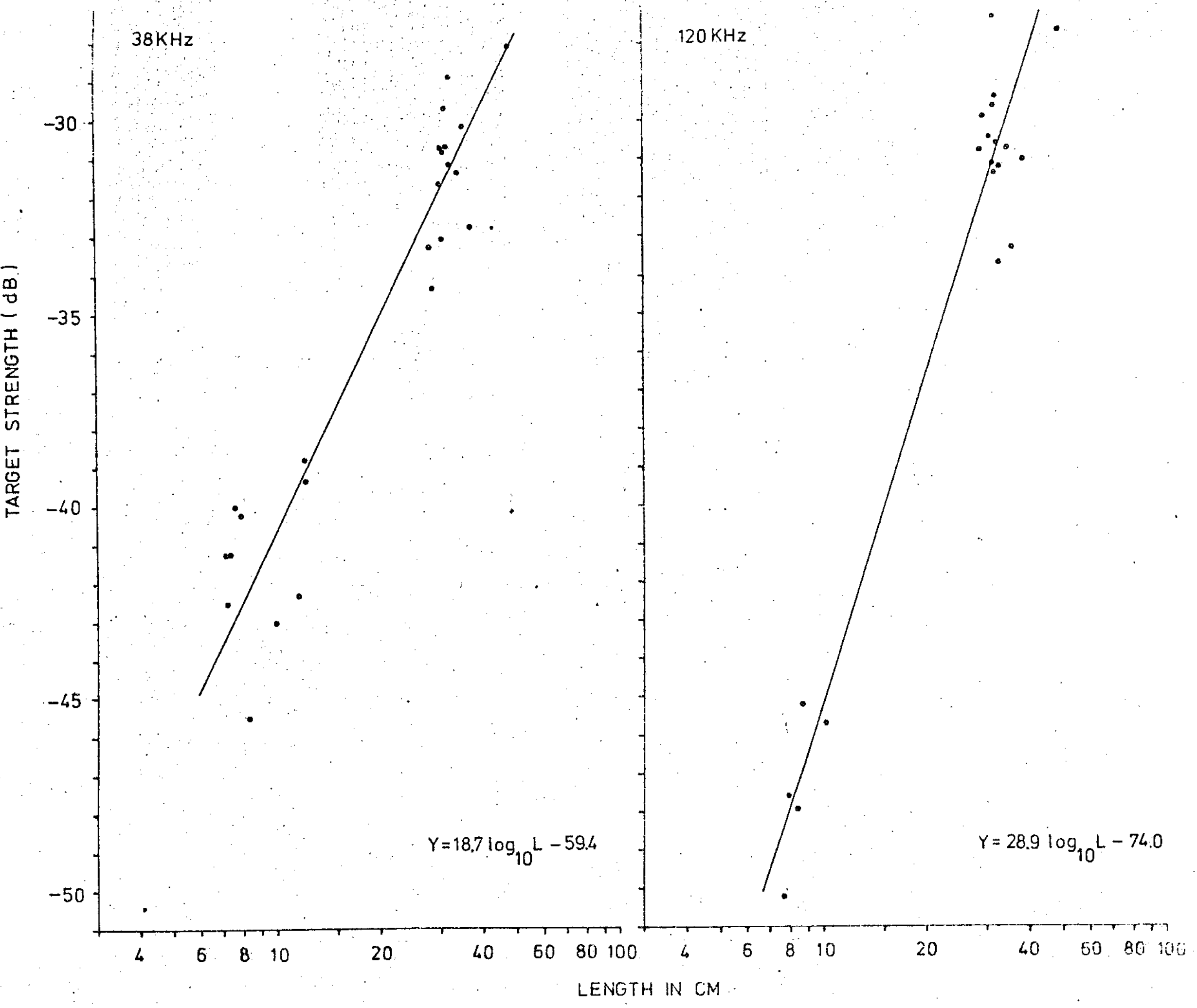

Figure 7. Maximum dorsal target strength versus length of haddock. Observed values and regression line.

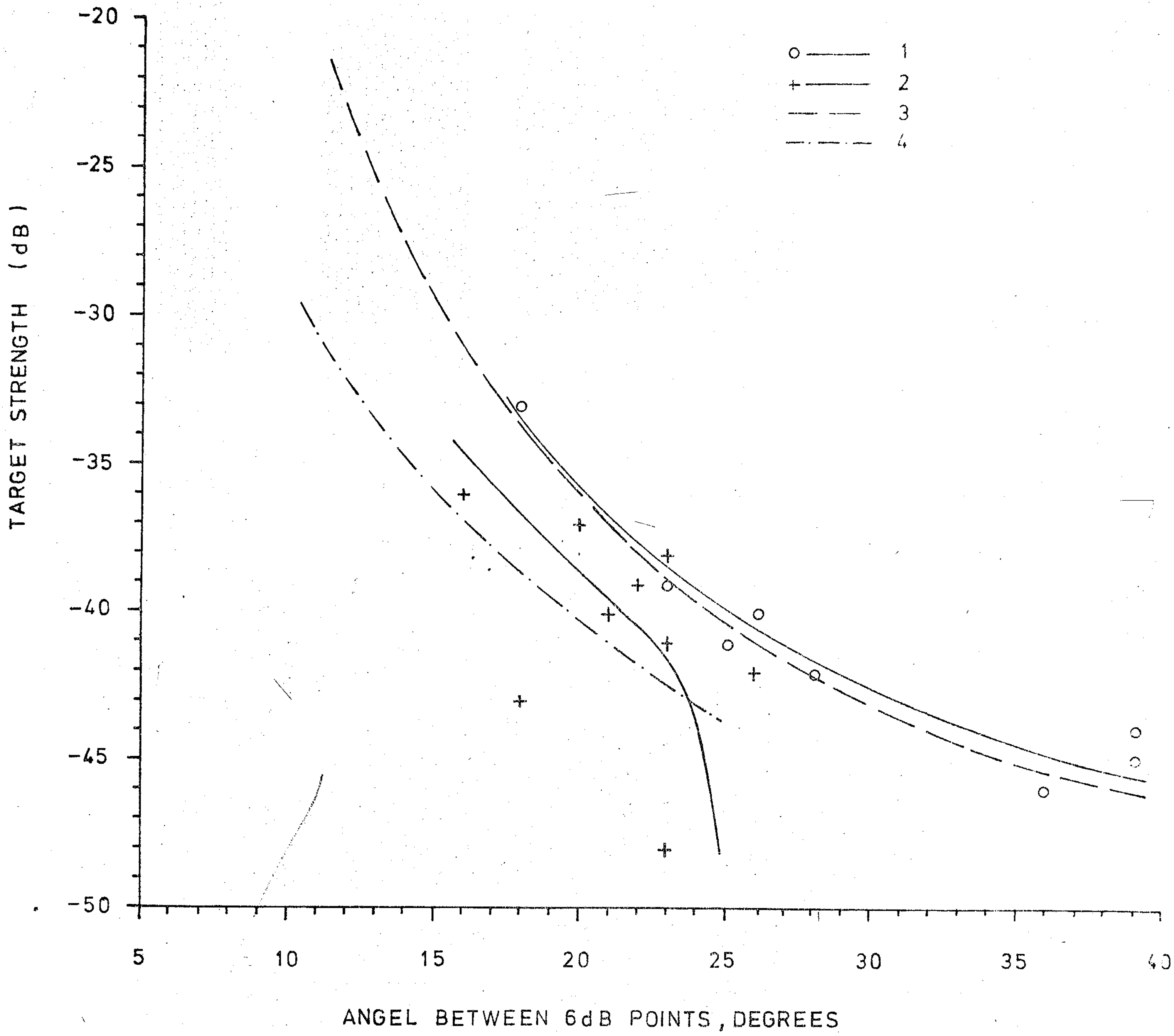

Fig. 8. Corresponding values of maximum dorsal target at 38 kHz strength and angel between point of half maximum amplitude (6 db points).
1) cod, 2) saith, 3) and 4) cod and saithe (NAKKEN and OLSEN 1973).