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TARGET STRENGTH MEASUREMENTS OF FISH

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During the summer of 1971, target strength measurements of fish were made at two frequencies, 38 kHz and 120 kHz. The relationships between dorsal aspect target strength and fish length were worked out for four species. The results for the gadoid fishes were in accordance with the results reported from previous studies and also in accordance with observations from field measurements. For fish of lengths 6–12 cm, the dorsal aspect target strengths of gadoids and clupeoids are approximately equal. For bigger fish the dorsal aspect target strength of clupeoids was found to be lower than of the gadoids. No significant differences in side aspect target strengths were found between the two groups. As the dorsal aspect target strength of fishes depends heavily on the inclination of the fish, more information on fish behaviour will improve both abundance estimation and length determination by acoustic equipment.

tilvangle

INTRODUCTION

Methods of fish sizing using the reflected sound signal from individual fish have been developed (Cushing, 1968; Craig and Forbes, 1969; Midttun, 1966). It has also been suggested that discrimination between species might be possible by studying the change in target strength when individual fishes pass through the sound beam (Midttun and Nakken, 1971). Several workers have studied the frequency responses of fish in order to find methods of identification and sizing (McCartney and Stubbs, 1971; Holliday, 1972), but, as yet, the relationships between target strength and fish species and between target strength and fish size are not well enough known to permit accurate sizing and reliable identification to be done as routine work at sea.

Due to the complexity of factors governing the reflection of sound from fish, it is impossible to calculate the scattered sound field. Thus the relationships between target strength and fish parameters (i.e. species and size) have to be established empirically. There are two approaches to this. Firstly, series of target strength measurements can be made with calibrated echo-sounders at sea provided that the fish under observation within each series are of only one species and of equal size, and that representative fish samples can be caught. The target strength observed by this method will be an 'average dorsal aspect target strength' depending on the unknown average inclination distribution of the fishes under observation. Secondly, the target strength can be measured under fully controlled conditions in laboratory experiments;

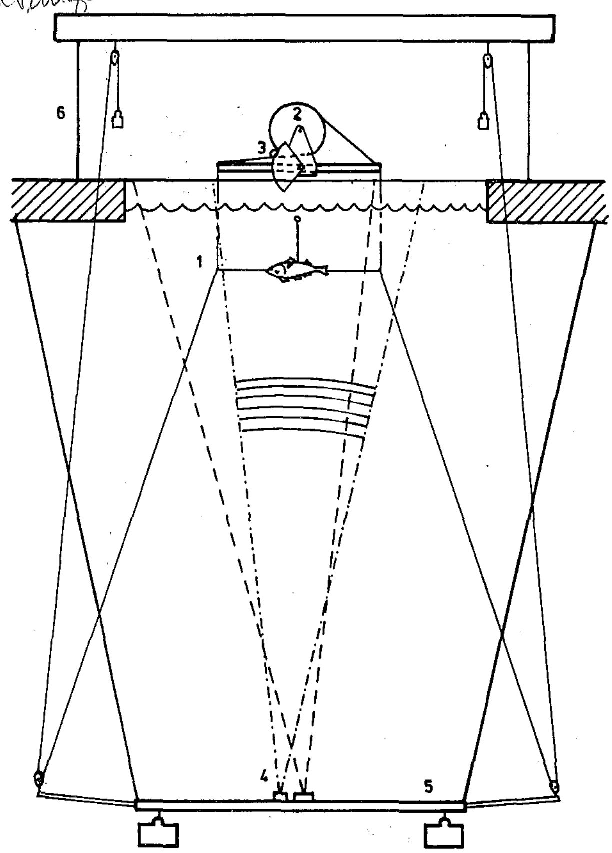


Figure 36. Experimental set-up. 1 fish suspension; 2 hoisting system; 3 tilting system; 4 38 kHz and 120 kHz transducer; 5 transducer base; and 6 raft.

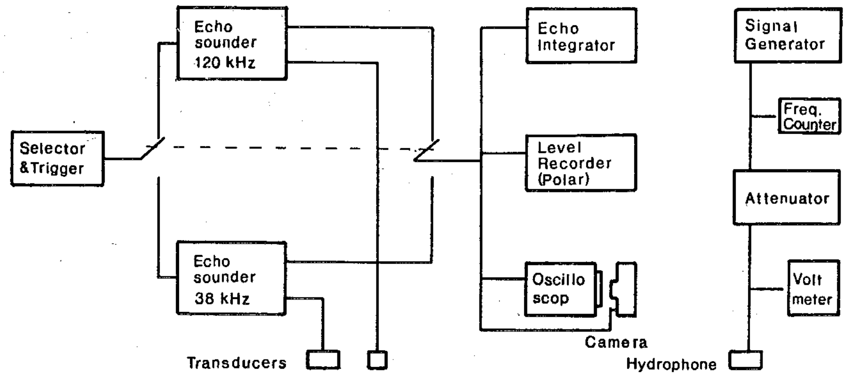


Figure 37. Block diagram of instrumentation.

several works of this kind have been reported (Love, 1969 and 1971; Haslett, 1969; McCartney and Stubbs, 1971; Midttun and Hoff, 1962; Shibata, 1970). However, as the average inclination of the fish in the field has not been considered, the results from such experiments might bias the estimates of fish lengths made at sea (Midttun and Nakken, 1971). Therefore, to support such measurements observations of fish inclinations should be available (Olsen, 1971; Barham, 1970; Beltestad, 1973).

In order to obtain more knowledge of the back scattering properties of the fish species which are most commonly recorded in the north-eastern Atlantic, studies of the target strength of individual fish were carried out during summer 1971. The experiments employed two frequencies which are commonly used in field work. Results of these studies are reported here. Estimates of target strength which are to be expected at sea are obtained by combining the experimental results with field observations of fish inclination.

MATERIALS AND METHODS

EXPERIMENTAL SET-UP

The experiments were carried out in a sheltered inlet 200 m wide, 12–14 m deep and with a soft bottom. The arrangement of apparatus is shown in Figure 36. An anchored raft carried both the laboratory and the accomodation for the staff.

The upward looking transducers were mounted in a heavily loaded steel frame submerged from the raft on adjustable wires. The fish were kept in an upside down position in the central part of the sound beam by a frame of thin monofil nylon. A special hoisting

Table 13. Length distributions of observed fish

Species	Length groups, cm 5–7	8–10	11–13	14–16	17–19	20–24	25–29	30–39	40–49	50–59	60–69	70–79	80–89	90–99	100–130	Total
Cod	4	6	2	–	–	3	8	16	8	7	15	2	1	1	–	73
Saithe	–	3	14	8	–	–	3	17	2	18	3	–	–	–	–	68
Pollack	–	–	–	–	1	19	10	10	2	3	1	–	–	–	–	46
Mackerel	–	–	–	–	–	–	1	36	2	–	–	–	–	–	–	39
Herring	–	9	11	–	1	11	7	2	–	–	–	–	–	–	–	41
Sprat	3	7	10	7	2	–	–	–	–	–	–	–	–	–	–	29
Haddock	–	–	–	–	–	–	2	12	1	–	–	–	–	–	–	15
Blue whiting	–	–	–	–	–	–	–	10	–	–	–	–	–	–	–	10
Whiting	–	–	–	–	–	–	6	2	–	–	–	–	–	–	–	8
Spiny dogfish	–	–	–	–	–	–	–	–	–	–	–	–	1	–	2	3
Wrasse	–	–	–	–	1	1	–	–	–	–	–	–	–	–	–	2
Ballan wrasse	–	–	–	–	1	1	–	–	–	–	–	–	–	–	–	2
Trout	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	2
Horse mackerel	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	1
Lumpsucker	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	1
Poor cod	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	1
Prawn	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–	2
Total	8	26	37	15	6	35	39	108	15	28	19	2	2	1	2	343

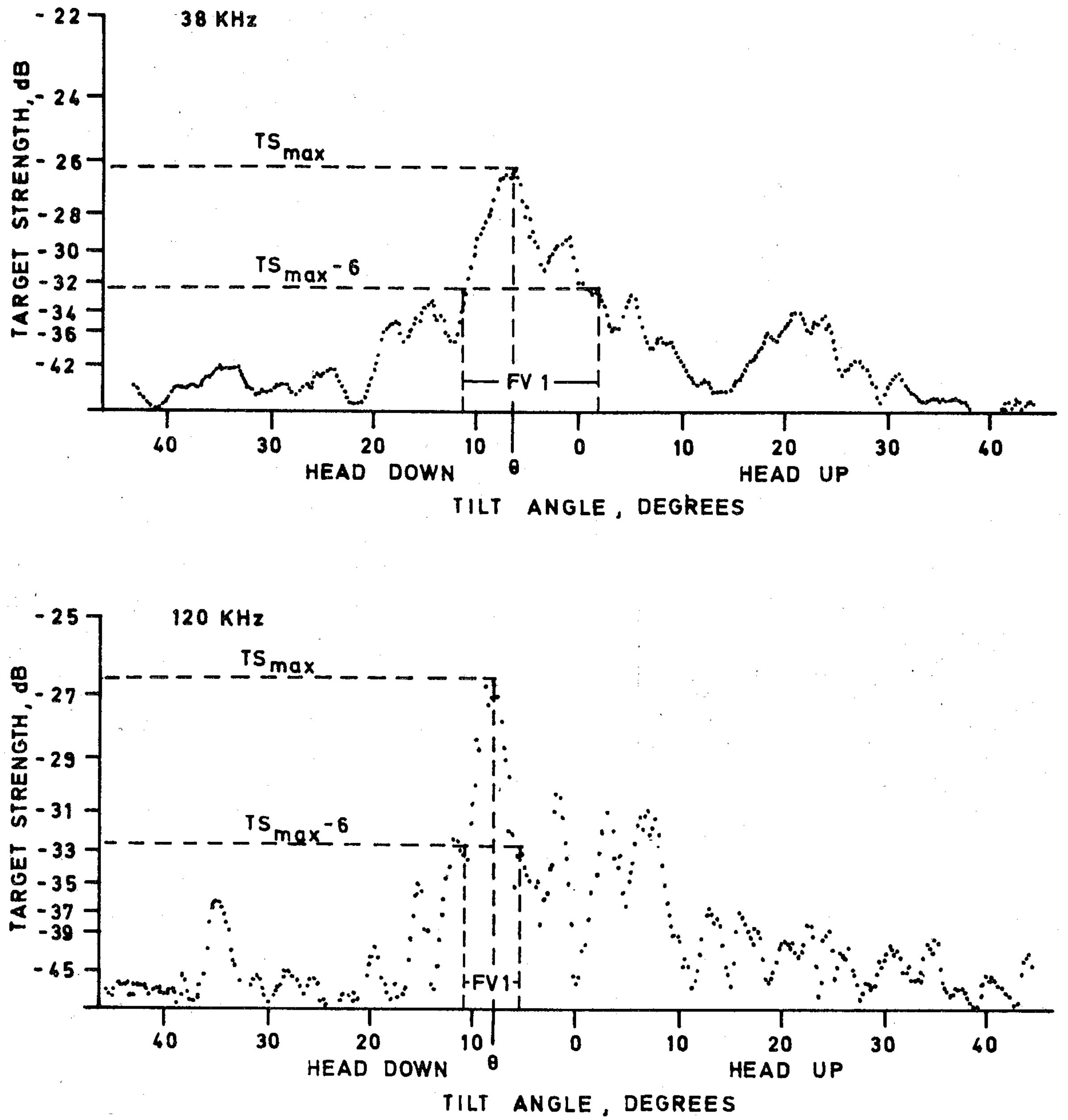


Figure 38. Recordings of dorsal aspect target strength (TS) as a function of tilt angle (φ) for a 45 cm cod at 38 kHz and 120 kHz. FV 1 is the interval of φ within which $TS \geq TS_{max} - 6$ dB.

device made it possible to hook the fish to the frame at the surface and then lower it to the measuring position at 2·4 m depth. The aspect of the fish could be continuously changed in two planes, tilt and roll, without any re-hooking. The fish was tilted between $-45°$ and $+45°$ from horizontal position with $\pm 1°$ accuracy by operation of the automatic 'tilting bar'. The tilting speed was 1° per second. When only tilt variations were wanted, a stable upside-down position was obtained by small floats attached to the belly of the fish. When roll variations were also wanted, the floats were replaced with thin nylon strings from the fish sides to a small wheel which was operated manually and worked normal to the tilting bar. For complete change of aspect, the fish was hauled to the surface and the points of hooking changed.

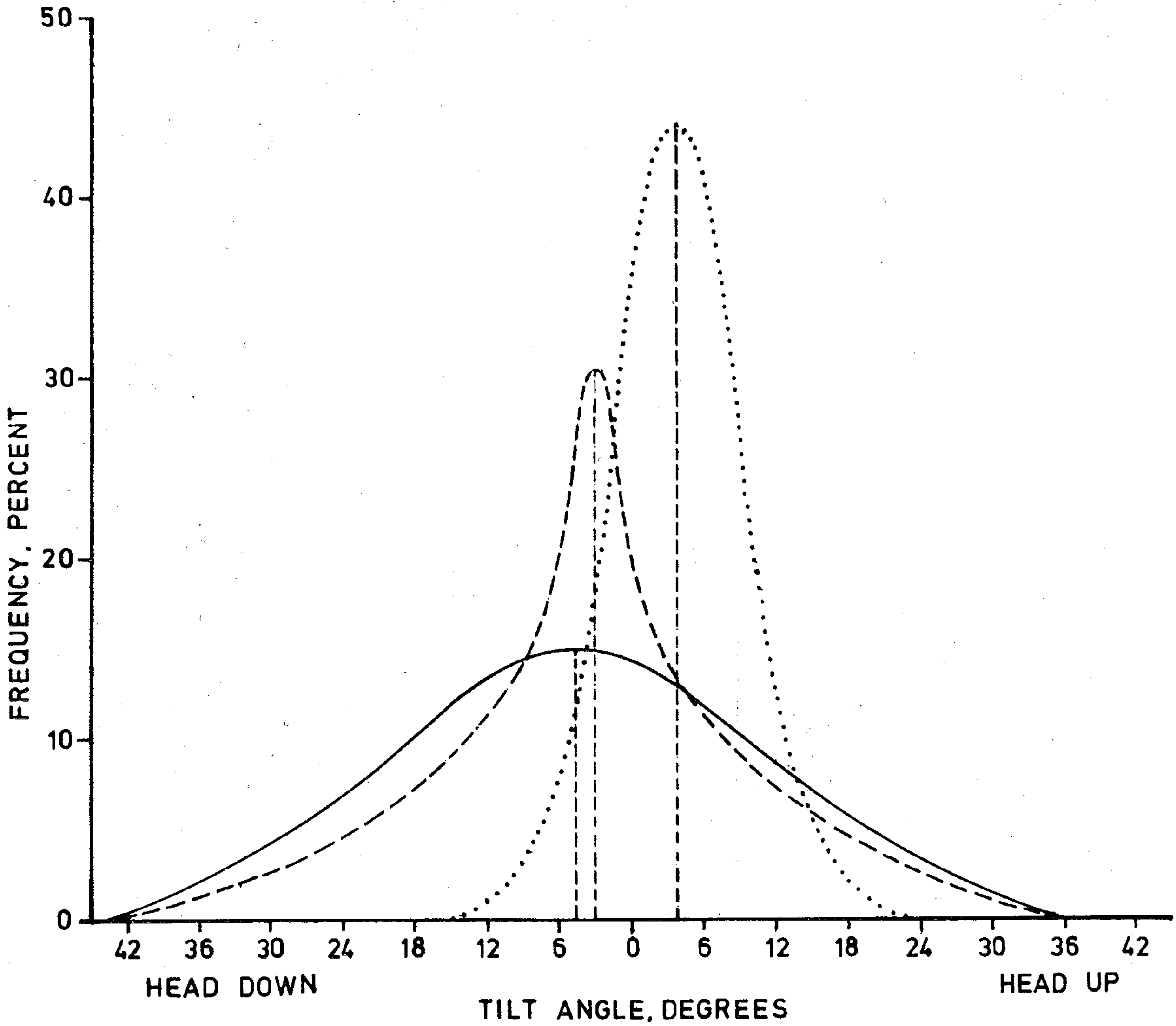


Figure 39. Distribution of field observations of tilt angle.—cod (mean length 80 cm), day and night (Olsen, 1971); --- herring (mean length 13 cm), night; .... herring, day (Beltestad, 1973).

INSTRUMENTATION AND DATA RECORDING

A block diagram of the instrumentation is shown in Figure 37. Two echo-sounders working at frequencies 38 kHz and 120 kHz (Simrad Ek 38 A and Ek 120 A) with transducers respectively 10×10 cm and 5 cm diam. were used. The transmitted pulse lengths, measured at half amplitude, were 0·6 ms for both sounders. The repetition rates of the sounders were increased to 4 pulses per second. For measuring and recording of data, a Hewlett Packard 141 A, a two-channel oscilloscope, a Simrad QM echo integrator with a Hewlett Packard 7702 B two channel recorder and a Brüel and Kjær 2304 polarplot level recorder were used. One channel of both the oscilloscope and the integrator recorder was used for presentation of echo amplitudes, while the corresponding tilt angles were recorded on the other channel. A film camera triggered by the echo-sounders was attached to the oscilloscope.

An Atlantic Research LC 32 hydrophone was used for calibration of the equipment. In addition, a daily calibration was carried out by measuring the target strength of a rigid steel sphere, 5 cm diam., which was lowered into the measuring position.

The sequence in one measuring programme was that the tilting bar started from the horizontal position,

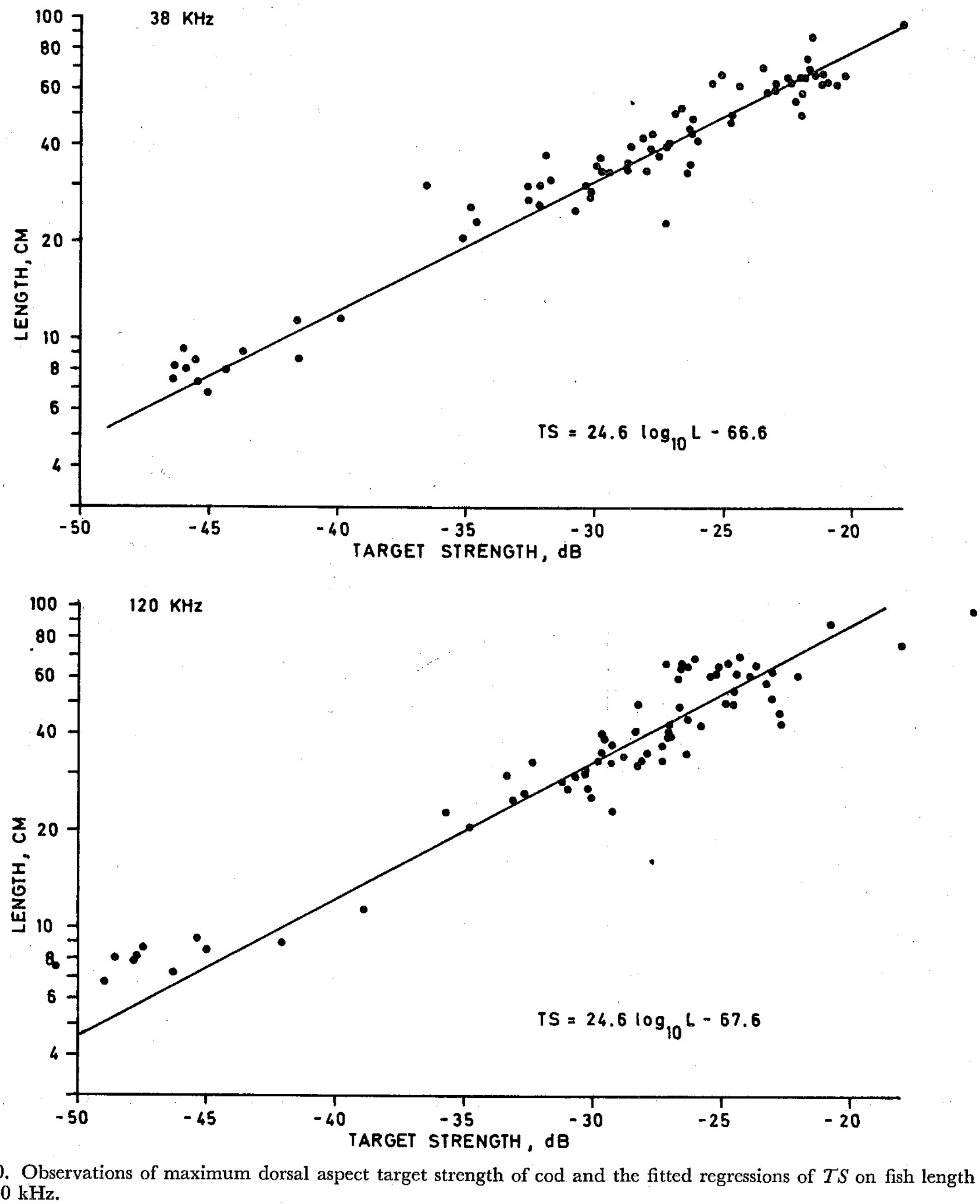


Figure 40. Observations of maximum dorsal aspect target strength of cod and the fitted regressions of *TS* on fish length at 38 kHz and 120 kHz.

moved to +45°, back again through the horizontal to −45° and then back to horizontal. During the first quarter of this cycle, suitable gain settings were selected. The data collected during the complete half cycle between +45° and −45° was used for further treatment. Figure 38 shows examples of recordings.

The fish was stunned or killed by hitting the frontal part of the brain by a sharp tool. When suspending the fish, care was taken to avoid air being enclosed in the gills and stomach. The measurements were started immediately after the fish had been lowered into the measuring position. In order to obtain necessary information about the relation between target strength characteristics of dead and live fish, measure-

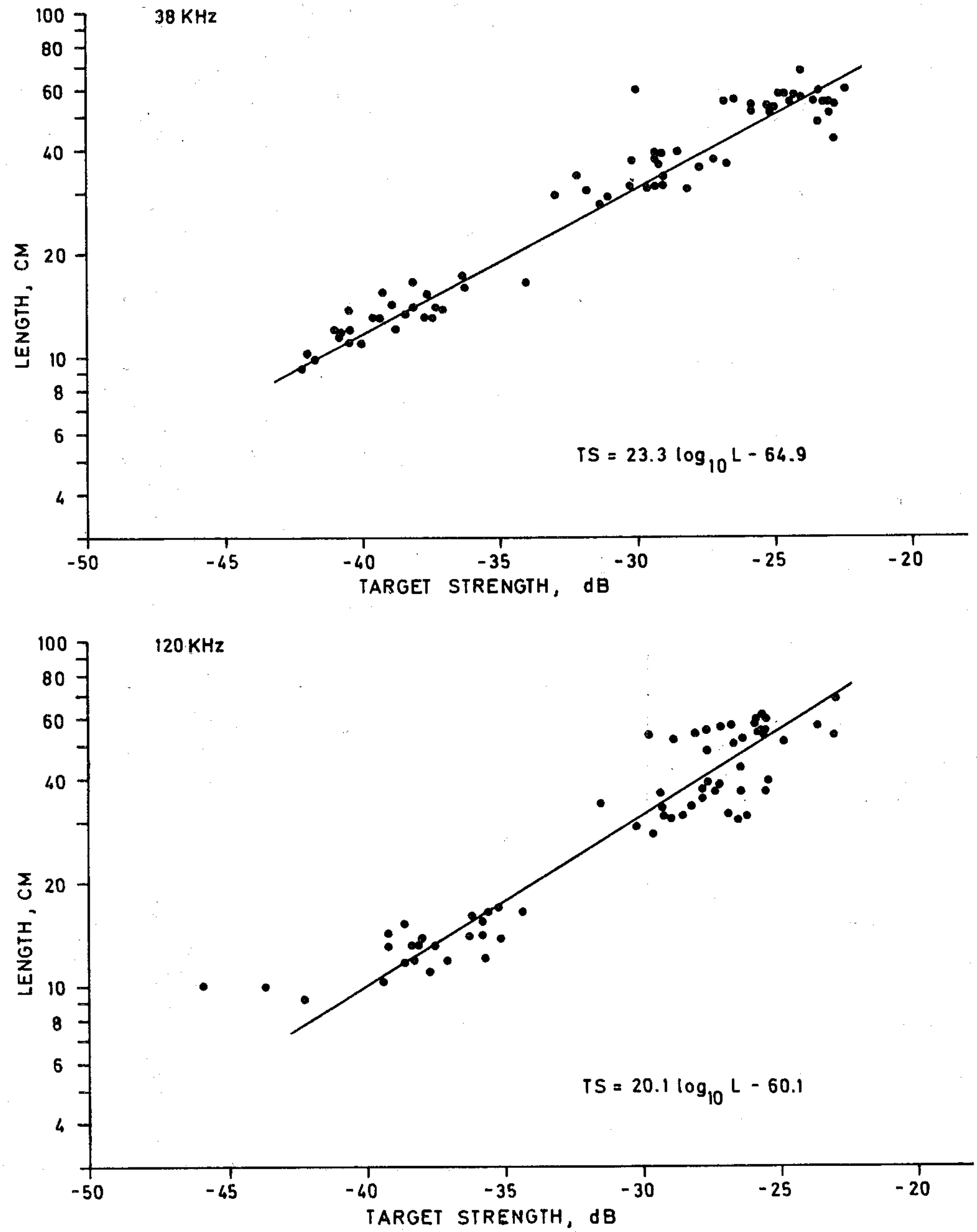


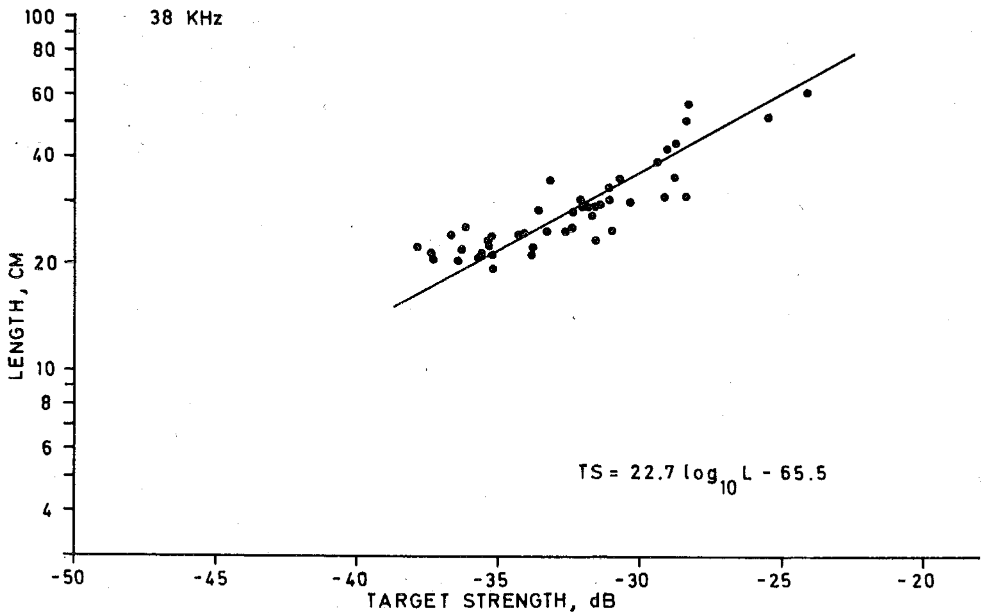
Figure 41. Observations of maximum dorsal aspect target strength of saithe and the fitted regressions of *TS* on fish length at 38 kHz and 120 kHz.

ments were made on a few live fish; these were allowed to move their tails and bodies without changing their positions within the sound beam.

DATA PROCESSING

The recorded data consisting of corresponding values of voltage, V, and tilt angle, φ, (Fig. 38) were transferred to punch-cards. The amount of data punched from each observation series was enough for production of adequate diagrams. The calculations of target strength, TS, were done by computer from equation

$$TS = 20 \log \frac{V}{V_r} + TS_r \qquad (1)$$



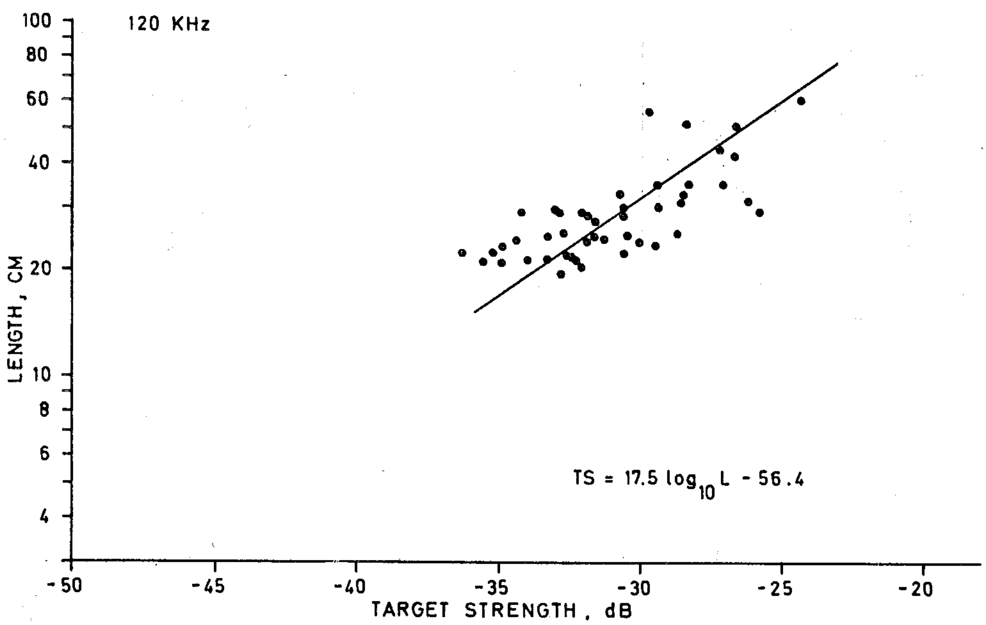


Figure 42. Observations of maximum dorsal aspect target strength of pollack and the fitted regressions of TS on fish length at 120 kHz.

where V is the observed voltage, V_r is the voltage from the reference sphere and TS_r is the target strength of the reference sphere in decibels. The theoretical value of TS_r is $-38 \cdot 1$ dB and the measured values, using the data obtained by hydrophone calibration, were -38 dB and $-38 \cdot 5$ dB respectively for the 38 kHz and the 120 kHz echo-sounders. When computing TS, the measured values of TS_r were used.

As a first step in the analysis of the material, outprints of the following parameters from each fish, species and aspect were made:

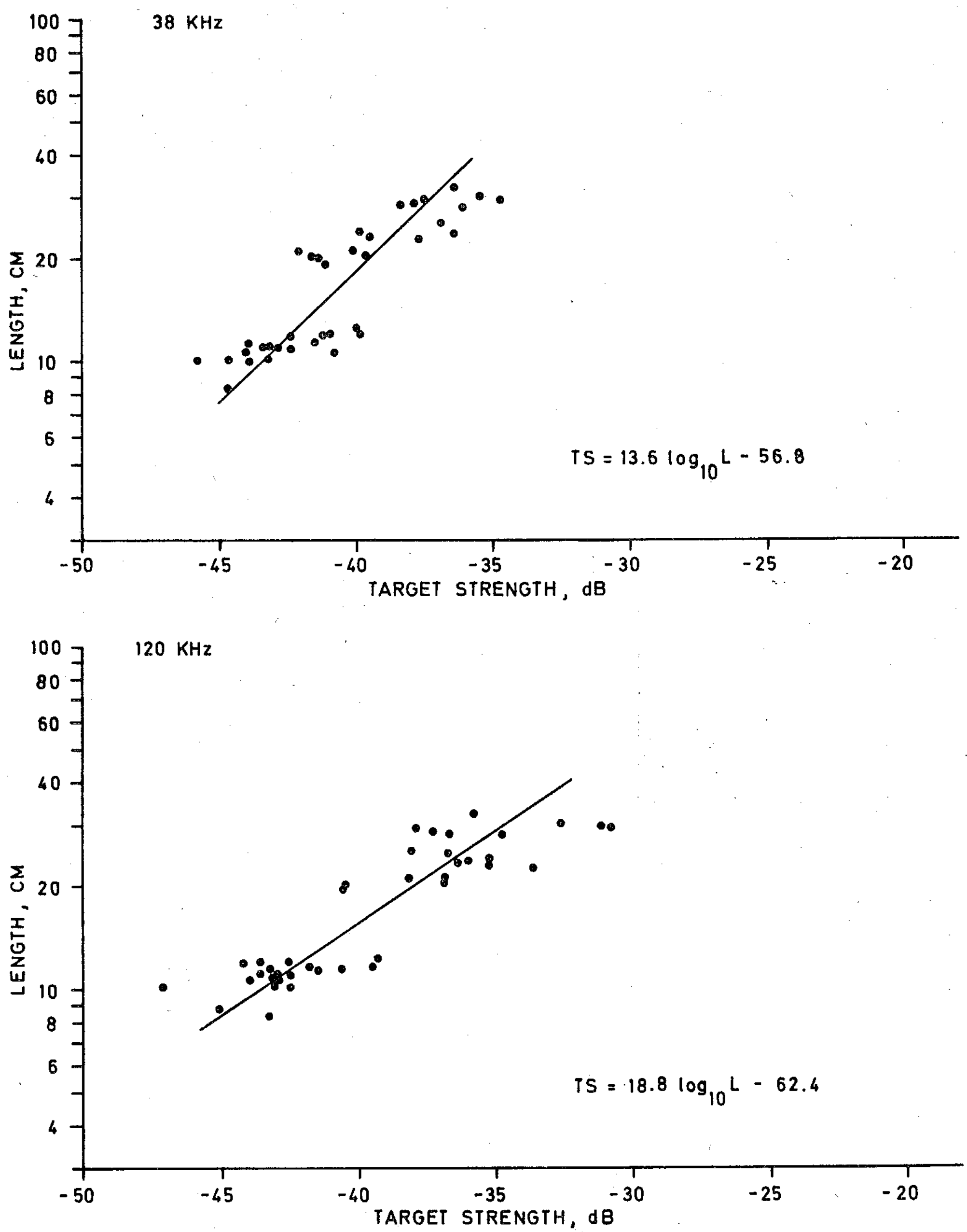


Figure 43. Observations of maximum dorsal aspect target strength of herring and the fitted regressions of TS on fish length at 38 kHz and 120 kHz.

No	:	fish reference number
L	:	fish length (in cm)
TS_{max}	:	maximum observed target strength (dB)
θ	:	tilt angle, φ, (in degrees), at TS_{max}. θ is negative for head down, positive for head up.
FV_1	:	interval of φ within which $TS \geq TS_{max} - 6$ dB
FV_2	:	interval of φ within which $TS \geq TS_{max} - 10$ dB
FV_3	:	interval of φ within which $TS \geq TS_{max} - 20$ dB

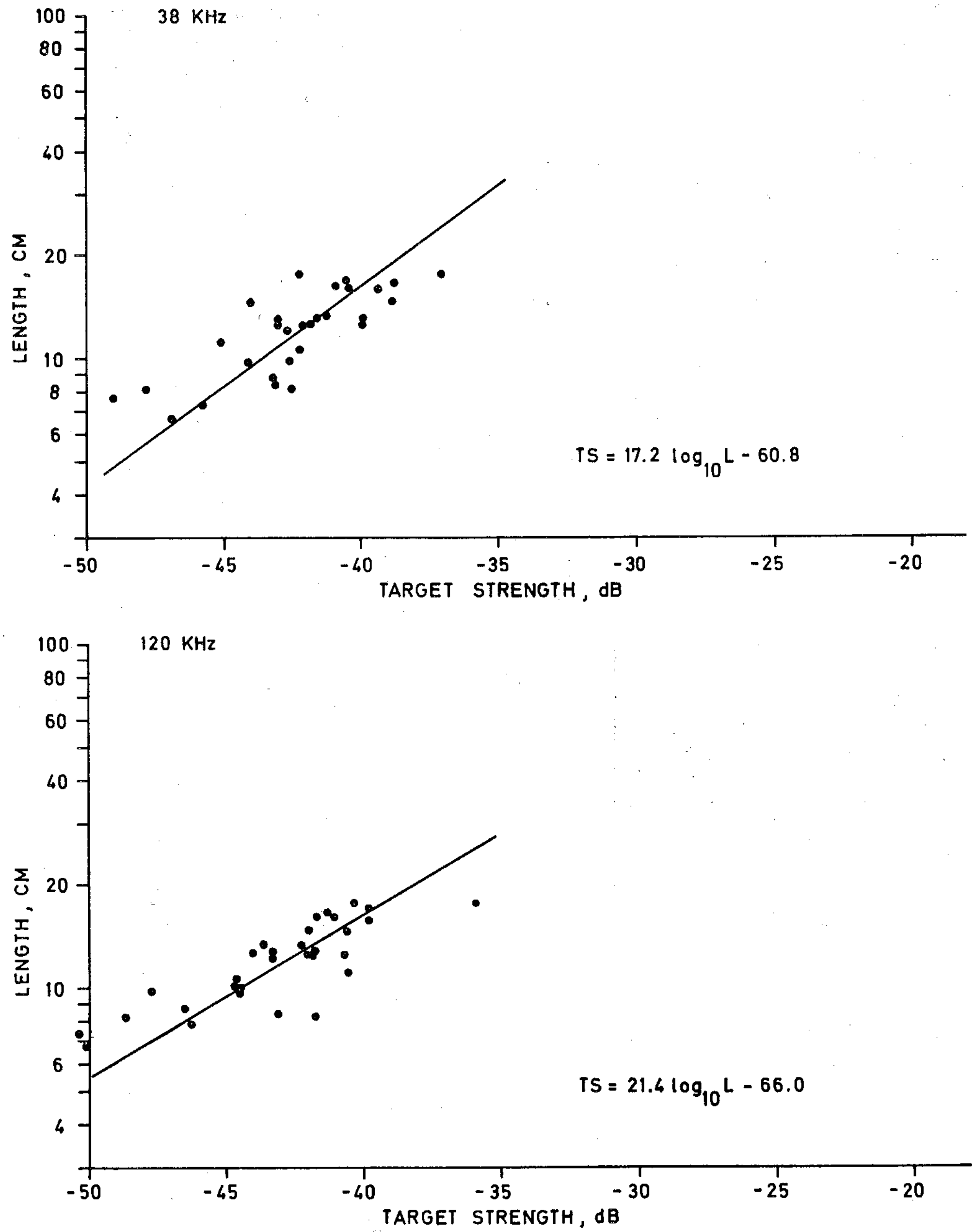


Figure 44. Observations of maximum dorsal aspect target strength of sprat and the fitted regressions of TS on fish length at 38 kHz and 120 kHz.

n_1 : total number of lobes where $TS \geq TS_{max} - 6$ dB

n_2 : total number of lobes where $TS \geq TS_{max} - 10$ dB

n_3 : total number of lobes where $TS \geq TS_{max} - 20$ dB

V_1 : mean amplitude within FV_1

V_2 : mean amplitude within FV_2

V_3 : mean amplitude within FV_3

A : running mean of amplitudes, calculated from the formula

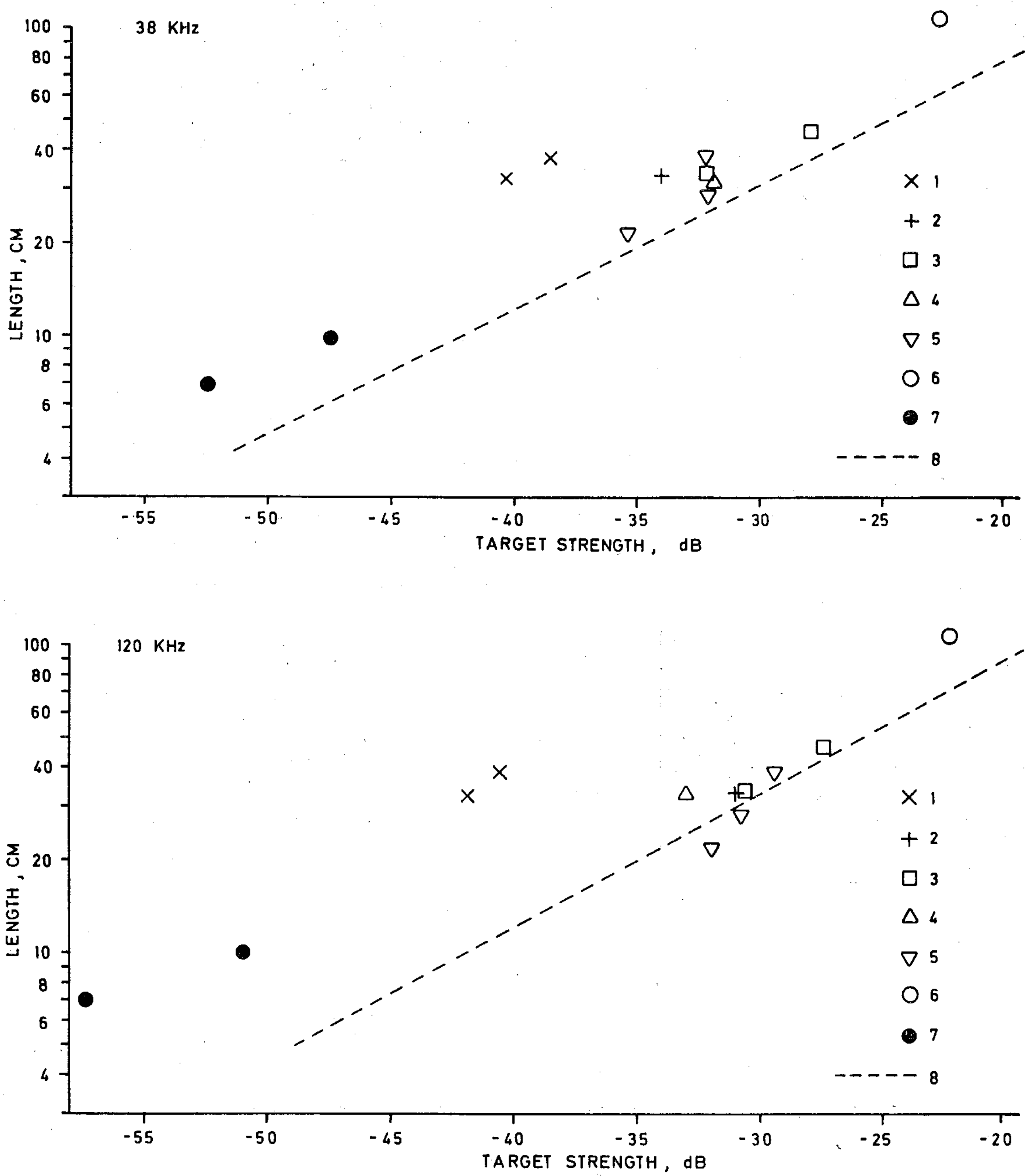


Figure 45. Mean observed values of maximum dorsal aspect target strength against mean size for: 1 mackerel; 2 horse mackerel; 3 haddock; 4 blue whiting; 5 whiting; 6 spiny dogfish; 7 prawn; with 8 the cod *TS*/length regression line.

$$A = \frac{1}{6} \int_{\varphi}^{\varphi+6^\circ} V \cdot d\varphi$$

when φ was running from -45° to $+45^\circ$. A was printed out for $= -21, -15, -9, -3, 3, 9, 15$ and 21°.

A_3 : maximum value of A

FI : value of φ when $A = A_3$.

A linear relationship between maximum dorsal aspect target strength (TS_{max}) and fish length (L)

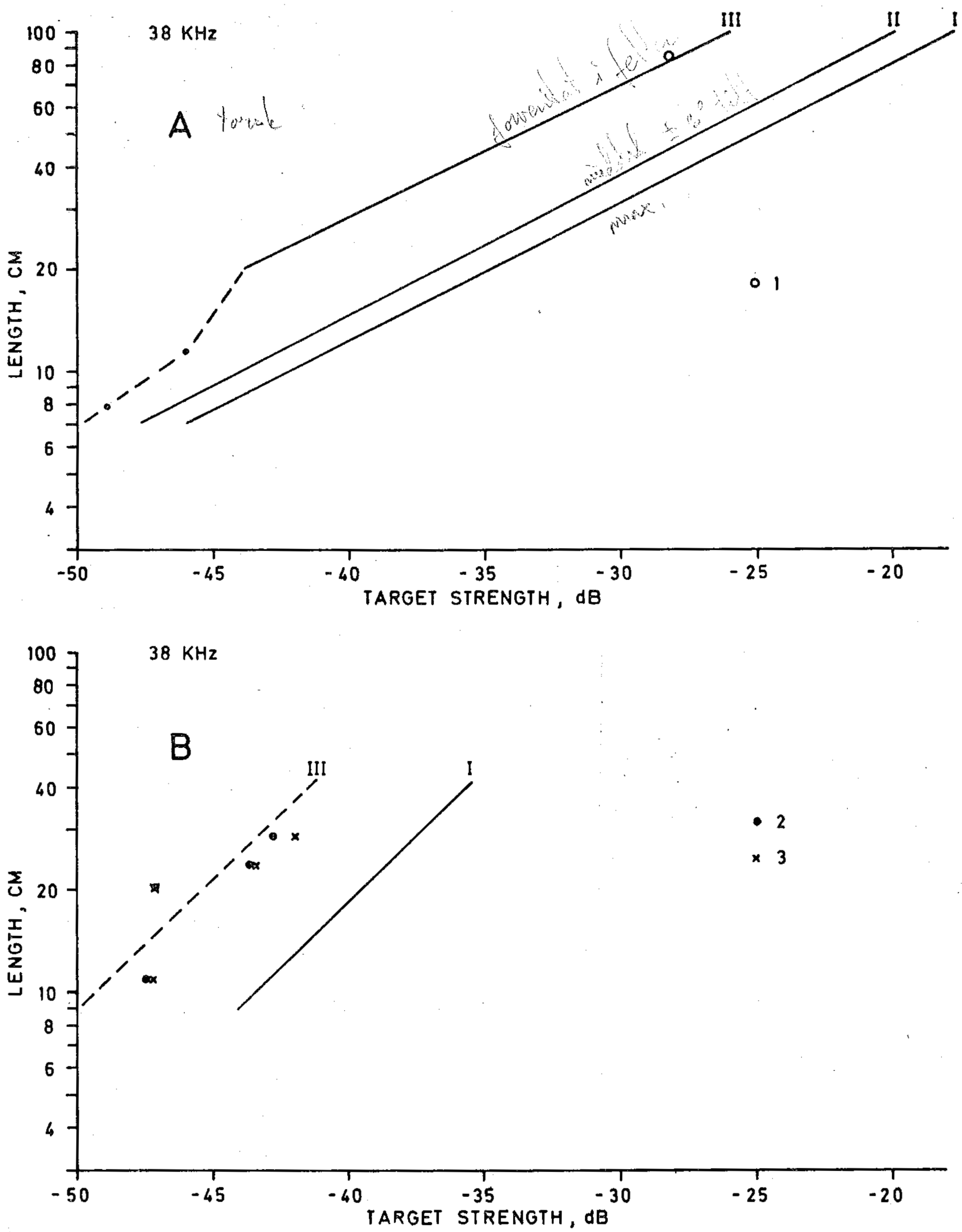


Figure 46. Dorsal aspect target strength/length relationship at 38 kHz for A) cod and B) herring. I, observed maximum values; II, mean values for tilt angles within ± 3° of angle of maximum value (corresponds to 6° transducer beam width); III, expected values in the field (derived from Fig. 39). 1 field observation of mean value (Midttun and Nakken, 1971); 2 day and 3 night observations of tilt angle.

$$TS_{\max} = m \log_{10} L + b \qquad (2)$$

was assumed to exist for each species and frequency and the coefficients m and b were calculated by least mean square regression analyses.

TS / length relationships were computed for two species, cod and herring, at 38 kHz, taking into account distribution of the tilt angle, φ, which have been observed at sea, (Fig. 39). The following formulae were used:

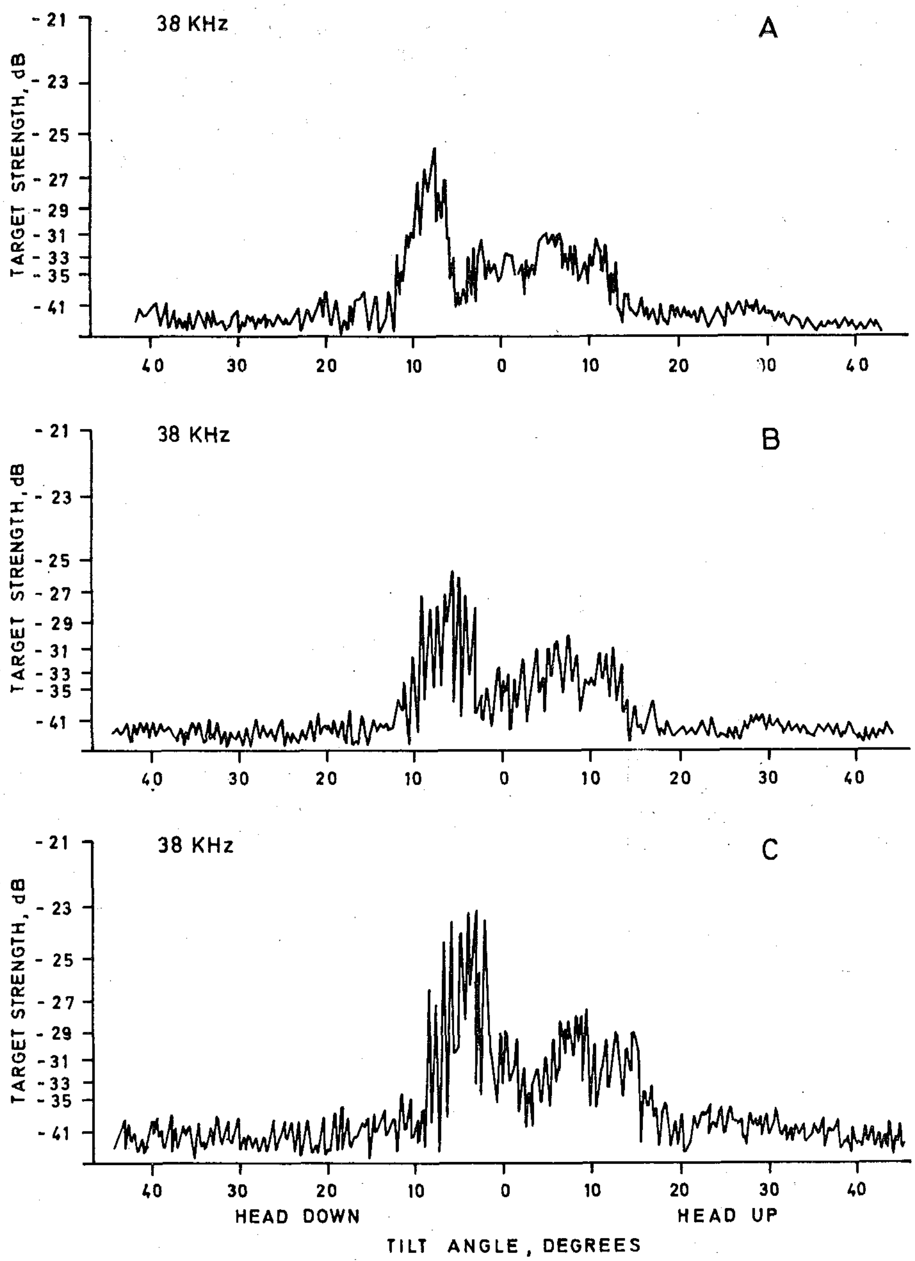


Figure 47. Observations of dorsal aspect target strength of a swimming saithe at various tilt angles and three levels of swimming activity: A) low; B) moderate; and C) high.

$$V_{\text{sea}} = \left. \begin{array}{l} \dfrac{\sum\limits_{\varphi=-21}^{\varphi=+21} \sum\limits_{\mathcal{J}=1}^{n} k_{\varphi} \cdot A_{\varphi \mathcal{J}} +}{n \cdot 100} \\ \dfrac{+ \sum\limits_{\mathcal{J}=1}^{n} \left(\dfrac{A_{\varphi=21,\mathcal{J}} + A_{\varphi=-21,\mathcal{J}}}{2} \cdot \left(100 - \sum\limits_{\varphi=-21}^{\varphi=+21} k \right) \right)}{n \cdot 100} \end{array} \right\} \quad (3)$$

and $$TS_{\text{sea}} = 20 \log \frac{V_{\text{sea}}}{V_r} + TS_r \qquad (4)$$

where k_{φ} are the frequencies given in Figure 39 (in 6 degree classes of φ), $A_{\varphi \mathcal{J}}$ is the amplitude of the $\mathcal{J}$th fish at tilt angle φ (averaged in 6 degree classes of φ) and n is the number of fish in each investigated length group (Table 13).

Table 14. Regressions of target strength on fish length ($TS_{max} = m \log_{10} L + b$) for five species at two frequencies

Species	Freq. (kHz)	No. of fish	Slope m (dB)	Constant b (dB)	Correlat. coeff.	Stand. error (dB)
Cod	38	73	24·5	– 66·6	0·972	2·02
	120	72	24·6	– 67·6	0·955	2·28
Saithe ...	38	68	23·3	– 64·9	0·975	1·44
	120	68	20·1	– 60·1	0·948	1·85
Pollack ..	38	46	22·7	– 65·5	0·879	1·50
	120	46	17·5	– 56·4	0·754	1·86
Herring ..	38	38	13·6	– 56·8	0·851	1·51
	120	41	18·8	– 62·4	0·890	1·79
Sprat	38	29	17·2	– 60·8	0·874	1·66
	120	29	21·4	– 66·0	0·819	1·83

RESULTS

The observations and the results of the least mean square regressions ($TS_{max} = m \log_{10} L \times b$) are shown in Table 14 and Figures 40–44. It appears that the regression lines for cod, saithe and pollack almost coincide, while those for sprat and herring are different. The two latter species have lower maximum dorsal aspect target strengths than the gadoids. The other measured fish were either too few in number or the length range was too narrow for application of a least mean square

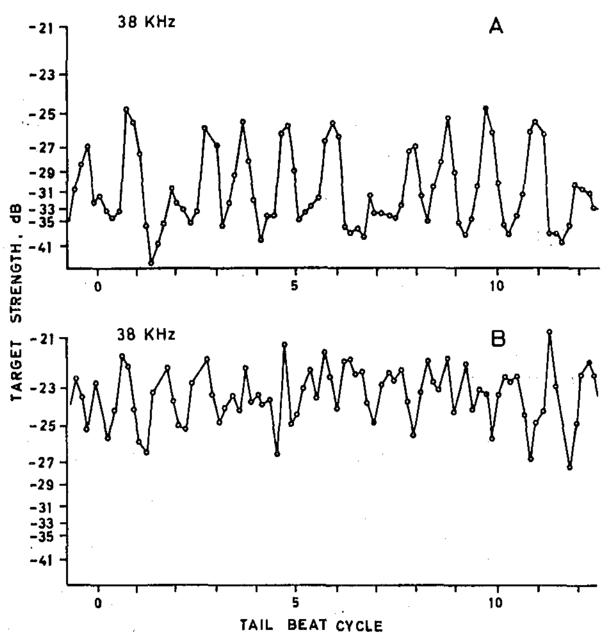


Figure 48. Observations of dorsal aspect target strength of a swimming cod (69 cm). A) at zero tilt angle; and B) at tilt angle of maximum target strength (5°).

Table 15. Mean values ($\overline{TS}$) and standard deviations (s.d.) of target strength according to length (L). N is the number of fish measured

Species	Freq. (kHz)	N	L (cm)	$\overline{TS}$	s.d. (dB)
Mackerel	38	16	29–34	– 40·3	2·7
	38	23	35–41	– 38·6	3·0
	120	16	29–34	– 41·9	4·0
	120	22	35–41	– 40·6	3·6
Horse mackerel	38	1	33	– 34.0	–
	120	1	33	– 30·9	–
Haddock	38	13	28–38	– 32·1	1·8
	38	1	48	– 28.0	–
	120	14	28–38	– 30·7	1·5
	120	1	48	– 27·6	–
Blue whiting ..	38	10	31–35	– 32.0	1·8
	120	9	31–35	– 33·3	2·7
Whiting	38	4	21–22	– 35·4	0·4
	38	1	28	– 32·2	–
	38	2	38, 38	– 32·3	1·9
	120	5	21–22	– 32·0	1·9
	120	1	28	– 30·8	–
	120	2	38, 38	– 29·5	0·7
Spiny dogfish.	38	3	81, 120, 120	– 22·8	0·4
	120	3	81, 120, 120	– 22·1	4·2
Prawn	38	1	7	– 52·4	–
	38	1	10	– 47·4	–
	120	1	7	– 57·2	–
	120	1	10	– 51·2	–
Ballan wrasse.	38	2	19, 20	– 36·8	0·1
	120	2	19, 20	– 35·5	0·5
Wrasse	38	2	17, 24	– 36·0	2·0
	120	2	17, 24	– 35·0	2·5
Trout	38	2	31, 32	– 33·2	0·2
	120	2	31, 32	– 32·6	0·1
Lumpsucker ..	38	1	29	– 32·6	–
	120	1	29	– 31·5	–
Poor cod	38	1	23	– 34·4	–
	120	1	23	– 35·7	–

regression and the results for these fish are shown in Table 15 and Figure 45. In Figure 45 the regression line for cod is shown for comparison. The maximum dorsal aspect target strength of these species is approximately 1–3 dB less than that of cod, except for mackerel, dogfish and prawns which all show considerably lower values. The mean values for mackerel are 10–11 dB lower than those for cod, and 3–4 dB lower than for herring.

The TS/length relationships which are to be expected for cod and herring at sea, at 38 kHz, with the distributions of tilt angle (Fig. 39) applied to all length groups, are shown in Figure 46. Figure 46 A shows that the expected mean value of a target

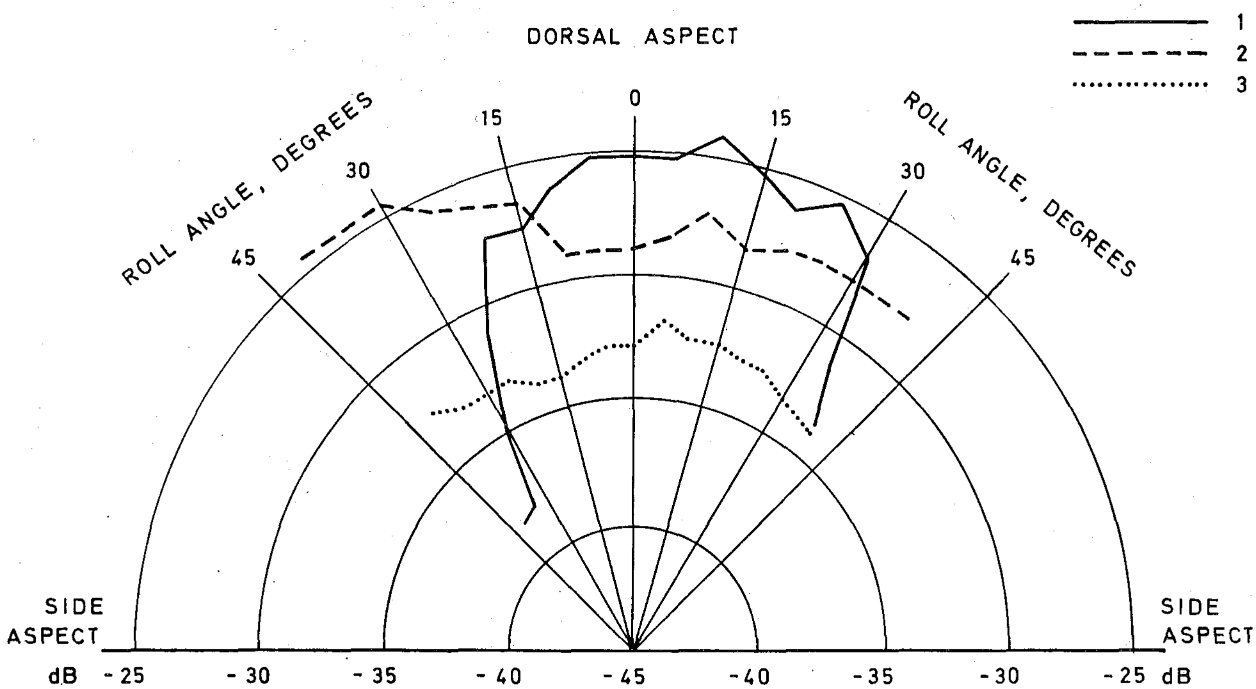


Figure 49. Target strength as a function of roll angle for three species of fish: 1 cod; 2 saithe; and 3 herring.

strength distribution of cod will be 8–9 dB lower than the corresponding maximum values. The results are compared with the field observations made by Midttun and Nakken (1971). Assuming all fish observed to be horizontal, the expected *TS*/length relationship for observations with a 6° transducer beamwidth will be as indicated by line II in Figure 46 A. For herring, the expected target strengths at sea will be 6 dB lower than the corresponding maximum values (Fig. 46 B) The differences between day and night values are insignificant. The relatively small difference between the expected and the maximum observed values of

Table 16. Dorsal aspect target strength (*TS* in dB) of individual fish (a) swimming and (b) after death. Measurements on swimming fish are at tilt angles for maximum obtainable *TS*. Figures in parentheses are 95% confidence limits

Species, length in cm	Mean *TS*, swimming	Max *TS*, dead	Corresponding *TS* from *TS*/length regression
Cod, 59	– 24·3 (+ 5·0) (– 3·2)	– 24·6	– 32·2 (± 4·0)
Cod, 69	– 23·5 (+ 3·5) (– 2·5)	– 23·9	– 21·5 (± 4·0)
Saithe, 53	– 27·0 (+ 8·0) (– 2·5)	Not obs.	– 24·5 (± 2·8)

Table 17. Mean values ($\overline{\Delta TS}$) and standard deviations (s.d.) of the difference between maximum dorsal and maximum side aspect target strength (ΔTS). N is the number of fish measured

Species	Freq. (kHz)	N	$\overline{\Delta TS}$ (dB)	s.d. (dB)
Cod	38	7	4·0	3·0
	120	7	2·5	2·6
Saithe	38	29	0·1	1·6
	120	29	1·0	2·4
Pollack	38	11	– 0·4	1·2
	120	11	– 1.7	2·5
Herring	38	6	– 3.5	1·6
	120	6	– 1·2	2·2
Sprat	38	4	– 3·0	1.0
	120	4	– 2·8	2·5
Mackerel	38	6	– 1·5	2,9
	120	5	– 3·0	1.6

TS at small fish lengths (Fig. 46 A) is caused by the lesser directivity of small fishes.

The effect of swimming on target strength is shown in Figures 47 and 48. The movements of the fish introduced a variation in target strength and this variation increases with increasing swimming activity. Table 16 shows that there was no significant change in mean values of swimming and still fish. Figure 48

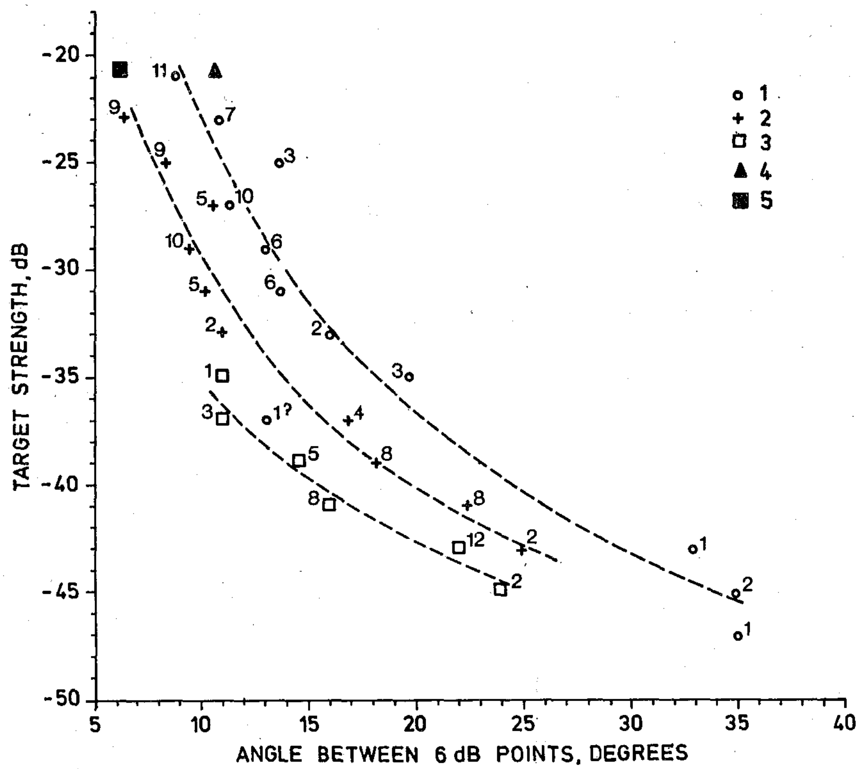


Figure 50. Values of maximum dorsal aspect target strength for various angles between points of half maximum amplitude (6 dB points). 1 cod; 2 saithe; 3 herring; 4 and 5, field observations of cod and saithe respectively (Midttun and Nakken, 1971). The values are averaged over the indicated number of fish.

indicates a periodic relationship between target strength and tail beat.

Table 17 compares the maximum dorsal with the maximum side aspect target strength. None of the species observed shows a larger mean difference than 4 dB and significant differences are obtained only for cod, herring and sprat. Figure 49 presents target strength as a function of roll angle; it indicates that cod may have considerably lower target strengths at roll angles larger than approximately 30°.

The relationship between mean values of maximum dorsal aspect target strength in each length group and the angle between 6 dB points in the directivity pattern (Fig. 38) is shown in Figure 50. The three curves are significantly separated and the obtained values correspond to the field observations made by Midttun and Nakken (1971).

A comparison of all the observed target strengths for the two frequencies is made in Figure 51; it indicates a frequency difference of 2·4 dB (derived from the McCartney & Stubbs (1971) equation $TS = 24{\cdot}5 \log_{10} L - 4{\cdot}5 \log \lambda - 26{\cdot}4$). Figure 51 also indicates that the difference in target strength between 38 kHz and 120 kHz varies with the magnitude of target strength (fish length).

DISCUSSION

The slopes of the regression lines at 38 kHz for cod, saithe and pollack are in accordance with the results reported by McCartney and Stubbs (1971), as is also the slope at 120 kHz for cod. The lines for saithe and pollack at 120 kHz show smaller slopes, comparable to the finding of Love (1971). The difference in the slopes between 38 kHz and 120 kHz for pollack may, however, not be significant because the length range of the observed fishes was narrow and the variation from specimen to specimen was large. The slopes for herring and sprat are both smaller than those found for the gadoid species. The apparent differences between herring and sprat are not significant and the data could probably have been treated as being from one species, resulting in slopes of approximately 16·0 and 20·5 dB/decade at 38 and 120 kHz respectively. For fishes of lengths 6–12 cm, the dorsal aspect target strengths of gadoids and clupeoids are approximately

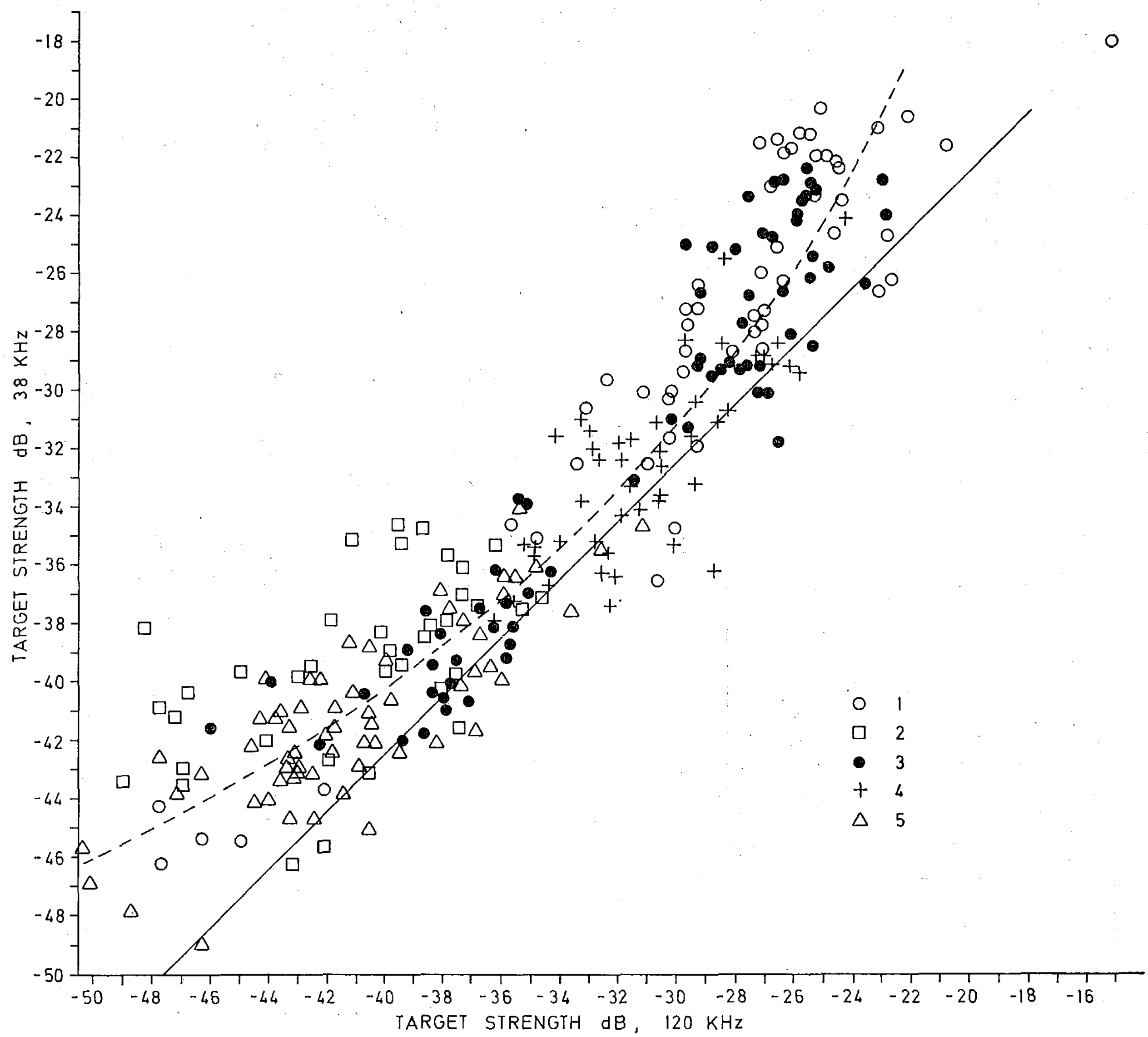


Figure 51. Maximum dorsal aspect target strength of individual fish at two frequencies, 38 kHz and 120 kHz: 1 cod; 2 mackerel; 3 saithe; 4 pollack; 5 herring and sprat. Full line: McCartney and Stubbs, 1970 [4·5 logλ]; broken line: curve fitted to the data.

equal. For bigger fish, the dorsal aspect target strength of the clupeoids will be lower than that of the gadoids, the difference between a 35 cm cod and a 35 cm herring being 7–8 dB. Table 17 shows that the side aspect target strength of cod is 4 dB lower than the dorsal aspect target strength, while herring seem to have a 3·5 dB difference the opposite way at 38 kHz. This indicates that herring and cod have approximately equal side aspect target strengths and consequently are equal as targets for horizontal working sonars.

The small differences between the calculated values which are to be expected at sea and the field observation of target strengths (Fig. 46 A) are well within the limits of calibration accuracy. However, as both the field observations of target strength and the data on tilt angle distribution are obtained on spawning cod, good agreement should be expected. Line III in Figure 46 is based on the assumption that all length groups have equal tilt angle distributions. To what extent this holds good is not known as data on tilt angle distribution according to length, species and season is lacking.

Figure 46 B shows that the change in the expected target strengths for herring from day to night was insignificant, although both the mean and the spread of the tilt angle distributions changed from day to night. As the mean value of the day observations of tilt angle is much closer to the angle of maximum dorsal aspect target strength than is the mean of the night observations (Fig. 39), this will compensate for the greater spread at night than in the day.

From Figure 46 it is seen that changes of tilt angle distributions both for herring and cod may have considerable effects on mean values of target strength. This is a matter which can lead to serious errors both in sizing and abundance estimation. Reliable estimates of target strengths of individual fish at sea can only be obtained when the fishes are scattered. When such estimates are used to calculate densities of schooling fish, the density estimates will be correct if the tilt angle distributions are equal for scattered and schooling fish. If not, large errors might be introduced. More information on tilt angle distributions related to the density of fish concentrations will therefore improve the abundance estimation by acoustic equipment.

It is important to know if the target strength observations made on stunned or dead fish are valid for free swimming individuals. In the experiments done with live fish, the body movements of the fish were observed to be similar to free swimming fish. Most of the recordings were obtained when the swimming activity of the fish was comparable to a 'fast cruising' situation. For purposes of sizing, identification and abundance estimation, the average value of target strength is the important parameter. Although the fish observed (Table 16) are too few for safe conclusions, there were no indications that the observed periodic target strength variation influenced the mean value significantly. What seems probable, however, is an increased variance on target strength due to swimming. This is particularly clear for the observed saithe. The question of why the target strength variations (Fig. 48) seem to be related to each tail beat cycle and not to each half cycle, cannot be answered from these investigations.

The relationships between maximum dorsal aspect target strength and the angle between the 6 dB points in the directivity pattern (Fig. 50) show significant differences between the three species (cod, saithe and herring) when mean values are plotted. The values for large cod and coalfish are in close agreement with the field observations made by Midttun and Nakken (1971). The variations from specimen to specimen within the same species are, however, large and a similar plot to that of Figure 50 for individual fish would show a large degree of overlap. Midttun and Nakken (1971) suggested that such plots might be used for identification according to species. Figure 50 indicates that this should be feasible for the three species under consideration when they are unmixed. When mixed recordings occur, it will probably be extremely difficult or impossible to discriminate between species by this method.

Figure 50 shows also that, at 38 kHz, the decrease with tilt angle of the dorsal aspect target strength is less for individual cod than for saithe and herring. This means that variation in tilt angle distributions might lead to larger errors in sizing and abundance estimation for the two latter species than for cod. For small fish (low L/λ), changes in tilt angle are of less importance for all three species, due to the relatively low directivity of small fish.

The data plot in Figure 51 will fit a straight line relationship ($k \log\lambda$, where k is a constant) at target strengths below -30 dB if the mackerel is excluded. The curved shape of the plot considering all observations is probably caused merely by the fact that all our data are within the region of interference effects.

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