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IN SITU FISH TARGET STRENGTHS DERIVED WITH A SPLIT-BEAM ECHO SOUNDER

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ABSTRACT

In situ target strengths of six fishes were determined with a split-beam echo sounder during cruises about Lofoten in March 1984 and the Shetland Islands in July 1984. The species and lengths, mean and standard deviation, are the following: cod (*Gadus morhua*), 82 ± 11 cm, saithe (*Pollachius virens*), 57 ± 6 cm; Norway pout (*Trisopterus esmarki*), 18 ± 2 and 15 ± 1 cm; herring (*Clupea harengus*), 28 ± 2 cm; redfish or ocean perch (*Sebastes marinus*), 20 ± 9 cm; and greater silver smelt (*Argentina silus*), 37 ± 4 cm. Extraction of unbiased mean target strengths by a method of threshold compensation is described.

RÉSUMÉ: In-situ détermination d'index de réflexion obtenue avec un sondeur vertical à faisceau scindé

Détermination d'index de réflexion in-situ grâce à un sondeur vertical à faisceau scindé au cours de campagnes effectuées autour des Lofoten en mars 1984 et des îles Shetland en juillet 1984. Les espèces étudiées avec leur taille moyenne/écart type sont les suivantes: morue (*Gadus morhua*), 82 ± 11 cm; lieu noir (*Pollachius virens*), 57 ± 6 cm; tacaud norvégien (*Trisopterus esmarki*) 18 ± 2 et 15 ± 1 cm; hareng (*Clupea harengus*), 28 ± 2 cm; sébaste (*Sebastes marinus*), 20 ± 9 cm; et grande argentine (*Argentina silus*), 37 ± 4 cm.

INTRODUCTION

The need for knowledge of fish target strengths is well known (Midttun 1984). *In situ* measurements are particularly valuable for representing the acoustic scattering properties of fish under the actual conditions of their surveying. Such data acquire a greater significance when used to determine the length dependence of target strength, as the resulting relation can then be used on fish of different lengths than originally observed and also, under certain circumstances, on fish of different species.

Development of the first commercial split-beam echo sounder, by SIMRAD, was thus welcomed for its evident usefulness in determining *in situ* target strengths. By providing a means of direct measurement, the split-beam technique avoids many of the problems intrinsic to indirect methods (Ehrenberg 1983). It is additionally superior in principle, if not in practice too, to the only other direct *in situ* method, that of dual beams (Ehrenberg 1974, 1979).

The simple purpose of this paper is to present some results from the first applications of the new split-beam echo sounder. This was, in fact, the first model of the ES380 system, which was specially adapted for research use (Foote, Kristensen and Solli 1984). However, while the basic single-fish echo data were easy to gather, the presence of both weak- and strong-signal thresholds, or cutoffs, in the processing complicated the analysis. It is hoped that description here of the method of threshold compensation will aid other current or potential users of the new split-beam echo sounder - or other threshold-affected systems or techniques for that matter - if only by urging caution in the interpretation of ostensibly unambiguous data.

MATERIALS

The primary materials consist of the acoustic and biological data collected on a number of species during cruises with R/V G.O. SARS about Lofoten in March 1984 and the Shetland Islands in July 1984. The form of the acoustic data gathered with the SIMRAD ES380 split-beam echo sounder has already been described in detail (Foote, Kristensen and Solli 1984). In brief, each single-fish echo is characterized by three data: the ping number, echo range to the nearest decimeter, and target strength. Each of these numbers is recorded for each resolved single-fish echo. The target strength is expressed as one of 80 target strength classes evenly spaced over the range from -50 to -20 dB, hence with 0.375 dB resolution. The split-beam echo sounder, with 38 kHz operating frequency, was calibrated with the 60 mm copper sphere (Foote et al. 1981, Foote 1982) at least once during each cruise.

The acoustic data are valuable only when accompanied by good biological data on rather pure fish aggregations. For present purposes, the purity is sufficient for unambiguous assignment of the acoustic data to the responsible fishes in either of two situations: a clearly dominant single species, or two species of distinct length groups. Thus, of the 11 data series with split-beam echo sounder measurements of fish during the March Lofoten cruise, only five are usable for determining mean target strengths. Of the 14 data series during the July Shetland Islands cruise, only four are usable, and of the seven series during the March and April cruise to survey blue whiting (*Micromesistius poutassou*) west of the British Isles, none is considered usable because of suspected problems with species and length selectivity of the trawling gear.

Table 1. Biological data accompanying in situ target strength measurements made during two 1984 cruises.

Data series	Survey date	Fish	No. specimens		Fish length (cm)				Assumed length distribution in simulations: N(mean,s.d.)		Truncation limits	
			Caught	Sized	Mean	S.D.	Min.	Max.	Mean	S.D.	Min.	Max.
1	12/3	Norway pout	223	223	17.6	1.6	10	21	17.6	1.6	14.4	20.8
		Saithe	52	52	59.7	4.9	48	69	57.2	6.0	45.2	69.2
2	13/3	Saithe	1863	73	57.2	6.0	45	91	57.2	6.0	45.2	69.2
3	13/3	Redfish	92	92	19.7	8.7	9	43	19.7	8.7	11.0	37.1
		Saithe	15	15	56.3	5.1	46	65	57.2	6.0	45.2	69.2
7	15/3	Cod	13	13	81.7	10.6	60	98	81.6	11.4	58.8	104.4
8	15/3	Gr. s. smelt	1813	1813	37.2	4.4	25	50	37.2	4.4	28.4	46.0
11	18/3	Cod	[Unspec.	953	81.6	11.4	50	105+]	81.6	11.4	58.8	104.4
15	25/7	Herring	165	165	28.8	2.0	24	34	28.5	2.0	24.5	32.5
25	29/7	Herring	22	22	28.0	2.7	25	34	28.5	2.0	24.5	32.5
26	30/7	Norway pout	2250	107	14.8	1.1	12	19	14.8	1.1	12.6	17.0

A summary of the biological data is presented in Table 1. In every case except one the length distribution is apparently normal. It is assumed to be normal in modeling the threshold effect, with mean and standard deviation generally equal to the corresponding sample values, and with truncation at two standard deviations from the mean. In the exceptional case, that of redfish, the distribution was rather elongated, and is characterized by a normal distribution truncated at one standard deviation below the mean and two standard deviations above the mean.

All of the length data in the table were determined directly from catches obtained during simultaneous measurement with the split-beam echo sounder except for those of cod on 18 March. Because these measurements were made in an area of intensive, commercial cod fishing, trawling was impossible. Recourse was therefore had to Danish-seine catch data collected at Svolvær and Henningsvær over the period 8-14 March. The similarity of these data with those determined by trawling by R/V G.O. SARS on 15 March is noted.

Because of the smallness of the herring catches shown in Table 1, the parameters of the assumed length distribution were determined on the basis of five catches. These included those taken during data series 15 and 25 and the other three catches from the same period and area.

When trawling during the March Lofoten cruise, a bottom trawl, the so-called shrimp trawl, was used for all reported catches except that of cod on 15 March, for which the pelagic trawl was used. For the reported catches from the July Shetland Islands cruise, the pelagic trawl was used.

The acoustic data are summarized through the histograms of in situ target strengths in Fig. 1. Additional data in the form of ping number

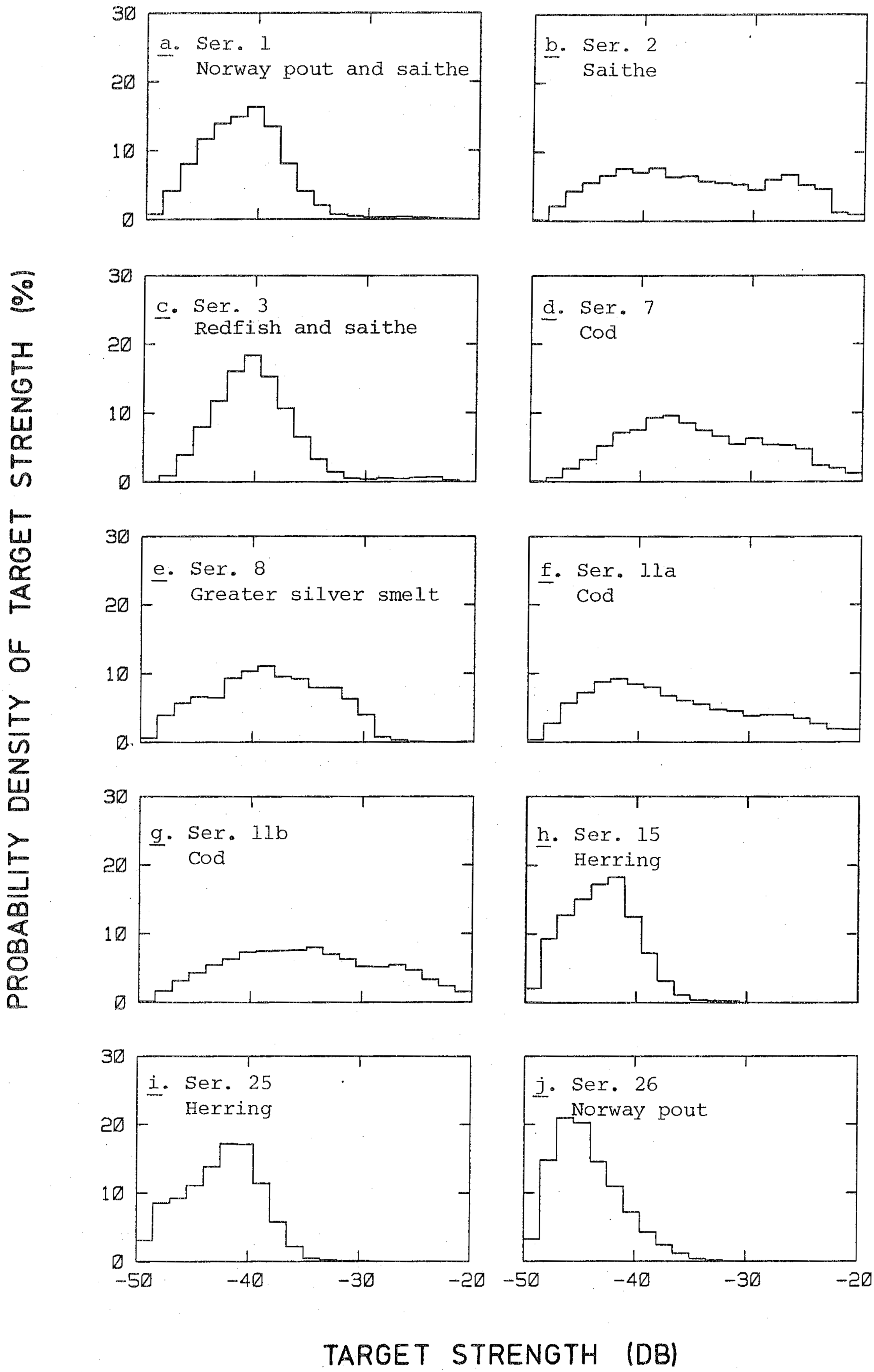

Fig. 1. Target strength histograms of ten data sets derived with the split-beam echo sounder. See Tables 1 and 2 for further details.

and depth, which are attached to each respective target strength datum, are neglected here. Thus, according to Fig. 7 in Foote, Kristensen and Solli's paper (1984), some of the measurements included in the histograms derive from the same fish, observed repeatedly during passage of the vessel and echo sounder beam. Such multiple observations, which may involve from about 15% or less to more than 50% of the total number of single-fish data, are not expected to bias the results, although reference to the original data and recomputation could decide the matter if necessary.

Some circumstances of the acoustic data collection are given in Table 2. Both the depth range and boat speed refer to the analyzed data. The depth is actually the sum of the depth of hull-mounted transducer, which is about 5 m, and the target range. However, since targets are accepted by the ES380 system only if lying within 4.94 deg of the acoustic axis, the depth estimate is only negligibly biased.

Often fewer data were analyzed than were available. Reasons for this included the desire to maintain a homogeneous data set, as, for example, by limiting the vessel speed to a narrow range, or by limiting the fish echoes to a narrower depth range than was actually employed during the observations.

Table 2. Conditions of acoustic data collection.

Data series	Measuring time			Starting position		No. single-fish data		Depth range (m)		Boat speed (knots)	
	Date	Hour	Period (min)	Lat. (°N)	Long. (°)	Total	Analyzed	Min.	Max.	Mean	S.D.
1	12/3	2103	81	68.73	12.86 E	10400	9800	105	240	3.9	2.6
2	13/3	0031	23	68.54	12.43 E	3400	3000	105	130	2.9	0.2
3	13/3	1837	78	67.43	10.30 E	8600	8400	165	225	4.4	3.0
7	15/3	1912	48	68.11	14.58 E	5400	4400	70	165	2.7	0.2
8	15/3	2217	47	67.97	14.60 E	7800	2600	265	360	2.4	0.1
11a	18/3	1736	87	68.10	14.52 E	9600	9600	85	160	11.3	0.4
11b	18/3	2155	65	68.10	14.46 E	9000	9000	85	160	3.3	0.3
15	26/7	0021	104	59.96	1.14 W	10600	6545	65	95	7.1	2.9
25	29/7	2353	99	60.24	0.70 W	5800	2687	15	45	5.5	3.8
26	30/7	2248	104	60.61	0.63 W	24000	4201	85	115	4.2	3.7

METHODS

Two basic problems must be addressed in analyzing the data presented in Fig. 1. In the case of those data consisting of mixed species, namely data series 1 and 3, the target strength data in Figs. 1a and c must be assigned to the individual fishes. The solution to this problem is referred to below as the method of "separation". The second problem, that of extracting the mean target strength, is common to all data sets. This would be trivial indeed if the data were unaffected by thresholding, but this is patently not the case. Consideration of the range in fish sizes and likely corresponding target strengths (Nakken and Olsen 1977, Foote and Nakken 1978) suggests that the target strengths of the largest cod have not been represented because of the upper threshold, or cutoff, of -20 dB. Similarly, the target strengths of fish shorter than 30 cm often lie well below the lower threshold of -50 dB. Thus the effect of thresholding must be considered in computing mean target strengths from the split-beam measurements if, for example, it is intended to use these in typical echo integration work. The reason is simply that standard echo integrators register fish echoes over a much greater dynamic range than the 30 dB of final registration in the SIMRAD split-beam system.

Separation of composite target strength histograms

This applies to the data of series 1 and 3. It is apparent from Table 1 that the saithe length distributions resemble that of series 2. In fact, the geographical areas of the three series are essentially the same, being the fishing banks west of Lofoten, where saithe spawn in the spring. Thus the relative contribution of the saithe to the composite target strength histograms of Figs. 1a and c are known. Because the second species of the two data series, Norway pout and redfish, respectively, are smaller than the saithe, the greatest target strengths of the largest Norway pout and redfish, will undoubtedly be substantially less than the greatest target strengths of the largest saithe (Nakken and Olsen 1977).

The difference in peak target strengths of the several fishes can be estimated by reference to Nakken and Olsen's target strength data. The appropriate equations share the common form

$$TS_{max} = m \log \ell + b \quad , \tag{1}$$

where TS_{max} is the maximum dorsal aspect target strength in units of decibels, ℓ is the fish length in centimeters, and the coefficients m and b are determined by a least-mean-squares regression analysis. For saithe the result is

$$TS_{max} = 23.4 \log \ell - 65.1 \tag{2a}$$

or, requiring that m=20,

$$TS_{max} = 20 \log \ell - 60.2 \quad . \tag{2b}$$

If a nominal length of 70 cm is used for the largest saithe in each of data series 1 and 3, then the maximum dorsal aspect target strength is expected to be about -23 or -22 dB. This agrees exactly with the observations in Figs. 1a and c.

Norway pout was not measured by Nakken and Olsen. It is a gadoid, hence for present purposes might be represented as having a target strength roughly comparable to that of other gadoids of similar length. For want of a closer kinship, the maximum target strength relation for Norway pout is based on the combined cod, saithe and pollack data of Nakken and Olsen. It is

$$TS_{max} = 24.5 \log \ell - 67.1 \qquad (3a)$$

or, requiring m=20,

$$TS_{max} = 20 \log \ell - 60.5 \quad . \qquad (3b)$$

Thus for the largest observed Norway pout, with ℓ=21 cm, the maximum target strength is expected to be about -35 or -34 dB.

Redfish was also omitted by Nakken and Olsen in their measurements. Were the gadoid data appropriate, although redfish is not a gadoid, a maximum target strength of about -28 or -27 dB could be expected from the largest caught specimen of 43 cm. However, comparison of the target strength histograms of Figs. 1b and c suggests a possible greatest redfish target strength of -30.5 dB.

Separation of the saithe contribution from the composite histograms in Figs. 1a and c is accomplished by attributing all data above the likely greatest target strength of the second fishes to saithe. The number of represented saithe data above this cutoff represents the same fraction of the entire saithe distribution as does the comparable part of the pure-saithe target strength histogram in Fig. 1b. The pure-saithe histogram can thus be scaled absolutely, and the part below the cutoffs in Figs. 1a and c can be subtracted directly from the composite histogram. The result of applying this procedure to the composite data in Figs. 1a and c is shown in Figs. 2a and b, respectively.

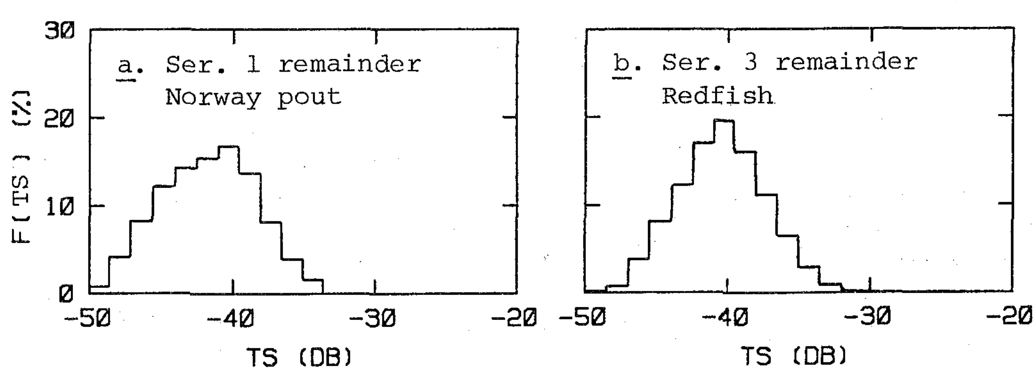

Fig. 2. Target strength histograms derived from Figs. 1a and c by removal of the saithe contributions.

Threshold compensation

The effect of thesholding by the split-beam echo sounder at -50 and -20 dB is estimated by comparing the pure-species target strength histograms of Figs. 1b, d-j, and 2 with target strength histograms simulated for comparable species from Nakken and Olsen's data, but without imposition of thresholds. The empirical distribution is then extended by appending the tails of the simulated histogram: those parts lying below about -50 dB and above -20 dB, while the original empirical histogram is scaled down in proportion to the central part of the simulated histogram, namely that lying between the two thresholds.

The target strength simulation data were derived directly from Nakken and Olsen's data. To form a uniform basis having the same length distribution as the observed, only those target strength functions were used with fish lengths lying within the truncation limits shown in Table 1. The measured target strength functions were then scaled both in magnitude and angle to simulate a series of fish spanning the length range. Target strength values lost by contraction of the original functions were replaced by values derived from the very approximate relation $TS_{min}=30 \log \ell - 100$, where ℓ is the simulated fish length in centimeters. Computed target strength histograms for each of these were subsequently compounded according to a truncated normal distribution having the mean and standard deviation given in the same table.

Representation of the several fishes in the simulation was one-to-one for cod, saithe and herring. For both Norway pout and the non-gadoid but physoclistous redfish, Nakken and Olsen's combined data for cod, saithe and pollack were used. The non-clupeoid, phyostomous greater silver smelt was represented initially by herring, but the applicable data were so few that the simulation was repeated on the basis of the gadoid data, and the separate results were averaged.

In attaching the lower tail of the simulated histogram to the split-beam histogram, either -50, -48.5 or -47 dB was used as the attachment point. The exact choice was made to optimize the agreement of the two histograms. Three higher cutoffs, -45.5, -44 and -42.5 dB, were also examined but were clearly excessive as the agreement was much poorer.

Another ingredient for simulating the target strength distribution is knowledge of the fish behaviour as expressed through the tilt angle distribution. Notwithstanding a feverish interest in the subject (Foote 1980a, Foote and Ona 1985), and rumours of development of a transponding tilt-angle-measuring tag, tilt angle distributions have been determined at sea for only three species (Olsen 1971, Carscadden and Miller 1980, Buerkle 1983). Given the sensitivity of the tilt angle distribution to behaviour, for example, directed horizontal swimming versus feeding versus diving, this is clearly unknown for the observed fish.

The state of nearly total ignorance of fish behaviour was remedied by assuming a range of behaviour modes, performing the described computations for each, and averaging the results over the entire set. A single assumption was made about the behaviour: that it was not extreme. This hypothesis was theoretically sustained, in fact, for simulated target strength distributions for mean tilt angles greater than 10 deg from the horizontal generally lack or underrepresent the largest observed target strengths. Therefore, if the target strength measurements of Nakken and Olsen (1977) and their applicability (Foote 1983) can be believed, then strong avoidance reactions with diving (Olsen 1979, 1981) are simply incompatible with the observations.

The non-extreme behaviour modes were characterized by normal distributions in tilt angle with means of -10, -5, 0, 5 and 10 deg and standard deviations of 5, 10 and 15 deg. In averaging the target strengths with respect to the normal distributions, the effect of perspective (Foote 1980b) was incorporated by increasing the first two standard deviations to 5.5 and 10.2 deg, respectively, while leaving the third unchanged. These values were determined for a circular beam pattern whose edge is 5 deg from the acoustic axis assuming an equally likely probability of occurrence anywhere in the horizontal plane (Foote 1985).

Computation of the mean target strength $\overline{TS}$ for a particular behaviour mode was accomplished in the intensity domain. Thus

$$\overline{TS} = 10 \log \frac{\overline{\sigma}}{4\pi} \quad , \tag{4}$$

where the average backscattering cross section $\overline{\sigma}$ is determined from the set of probabilities $\{h_i, i=1,2,...,n\}$ describing the extended empirical histogram according to

$$\overline{\sigma} = \sum_{i=1}^{n} h_i \sigma_i \quad , \tag{5}$$

where σ_i is the average backscattering cross section for the particular target strength interval. If this extends from TS_i to TS_{i+1}, then

$$\sigma_i = \frac{40\ \pi}{\ln 10} \frac{10^{TS_{i+1}/10} - 10^{TS_i/10}}{TS_{i+1} - TS_i} \tag{6}$$

Computation of the mean target strength TS* with respect to all 15 investigated non-extreme behaviour modes is also effected in the intensity domain. The sample variation in this mean value was estimated by computing the standard deviations $\Delta\sigma^*$ of the averaged average backscattering cross section σ^*, and then computing

$$TS^*_{\pm} = 10 \log \frac{\sigma^* \pm \Delta\sigma^*}{4\pi} \quad . \tag{7}$$

RESULTS

Threshold-compensated mean in situ target strengths derived with the new split-beam echo sounder are shown in Table 3. The standard deviations in target strength reflect uncertainty over the exact behaviour mode, or tilt angle distribution, assumed in the course of complementing the

Table 3. Threshold-compensated mean in situ target strengths derived with the SIMRAD ES380 split-beam echo sounder.

Fish	Length (cm)	Depth (m)	Boat speed (knots)	No. data	Target strength (dB)	b_{20}^* (dB)	Data series
Cod	81.6 ± 11.4	70 - 165	2.7 ± 0.2	4400	-28.7 ± 0.8	-66.9	7
Cod	81.6 ± 11.4	85 - 160	11.3 ± 0.4	9600	-29.0 ± 0.8	-67.2	11a
Cod	81.6 ± 11.4	85 - 160	3.3 ± 0.3	9000	-28.5 ± 0.7	-66.7	11b
Saithe	57.2 ± 6.0	105 - 130	2.9 ± 0.2	3000	-30.3 ± 0.0	-65.5	2
Norway pout	17.6 ± 1.6	105 - 240	3.9 ± 2.6	9800	-42.0 ± 0.8	-66.9	1
Norway pout	14.8 ± 1.1	85 - 115	4.2 ± 3.7	4201	-44.7 ± 1.0	-68.1	26
Redfish	19.7 ± 8.7	165 - 225	4.4 ± 3.0	8400	-40.4 ± 0.4	-66.8	3
G. s. smelt	37.2 ± 4.4	265 - 360	2.4 ± 0.1	2600	-36.5 ± 0.4	-67.9	8
Herring	28.5 ± 2.0	65 - 95	7.1 ± 2.9	6545	-43.3 ± 0.4	-72.4	15
Herring	28.5 ± 2.0	15 - 45	5.5 ± 3.8	2687	-42.5 ± 0.4	-71.6	25

original, generally truncated data sets. The standard deviation was computed as the arithmetic mean of TS_+^* and TS_-^*, which incurred no error because of the similar smallness of the excursions from the mean TS^*. For comparison purposes the quantity

$$b_{20}^* = TS^* - 20 \log \bar{\ell} \quad , \tag{8}$$

where $\bar{\ell}$ is the mean fish length, is included.

The mean target strength derived by equal weighting of the three cod data is -28.7 dB. If this is used together with the tabulated data for the other gadoids, then the result of regressing target strength on the logarithm of mean fish length $\bar{\ell}$ is

$$\overline{TS}_{gadoids} = 21.9 \log \bar{\ell} - 69.7 \quad , \tag{9a}$$

which obtains with a standard error of 1.0 dB. If the length dependence is constrained to be 20 log $\bar{\ell}$, then

$$\overline{TS}_{gadoids} = 20 \log \bar{\ell} - 66.8 \quad , \tag{9b}$$

with standard error of 1.1 dB. In case each of the tabulated cod data is weighted equally with each of the other three gadoid data, then the resulting equations are $TS=21.1 \log \bar{\ell} - 68.7$ and $TS=20 \log \bar{\ell} - 66.9$, which obtain with the respective standard errors of 0.9 and 1.0 dB.

If the matter of the depth dependence of the herring data is ignored, and the two target strengths are accorded equal weight, then the average target strength of 28.5 cm herring is -42.9 dB. If this single datum is allowed to determine the coefficient b in the equation $\overline{TS}=20 \log \bar{\ell} + b$, then

$$\overline{TS}_{herring} = 20 \log \bar{\ell} - 72.0 \quad . \qquad (10)$$

DISCUSSION

The aim of this paper has been a simple presentation of in situ target strengths, derived with the new split-beam echo sounder, for application in echo integration. However, the difference in thresholding practices between the split-beam system and typical echo integrators is substantial: echo integrators typically register far weaker signals than those corresponding to the lower, -50 dB threshold of the split-beam system, and saturation occurs at typical detection ranges only for much stronger signals than those corresponding to the upper, -20 dB threshold or cutoff of the split-beam system. Thus a careful examination of the thresholding has been necessary.

Compensation for the threshold effects has been achieved through a combined comparison and extrapolation procedure based on simulated target strength distributions. These depend on the validity of the basis target strength data, presumed established (Foote 1983), and knowledge of the fish behaviour as expressed through the tilt angle distribution. Given nearly complete ignorance of the particular behaviour patterns, a range of non-extreme behaviour modes has been assumed. Averaging of the respective mean target strengths has revealed a rather low variance, with no standard deviation exceeding 1.0 dB according to Table 3. This is fortunate, for indicating a basic insensitivity of threshold-compensated in situ target strengths to the particular behaviour mode, which is both unknown and difficult to know.

There is, however, clear support for the exclusion of extreme behaviour patterns from the analysis of each data series here. It is the absence of relatively large target strengths in the simulated distributions. If the mean tilt angle were, for instance, to deviate from the horizontal by more than about 10 deg, then it would be difficult, if not impossible, to explain the large target strengths that were observed. In a word, the present analysis indicates that fish detected within the acoustic beam were not seriously affected by the passage of the vessel. It is important to note that most of the data were collected at moderate speeds. In the case of cod, however, data were collected at each of several distinct speeds, varying from less than 3 knots to more than 11 knots, yet neither systematic nor significant differences in target strength were found.

Justification for the threshold compensation is provided by a comparison of the compensated mean target strengths with the corresponding mean target strengths computed directly from the uncompensated split-beam data. Only in the case of saithe are the estimates identical, which indicates that the observed target strength distribution for saithe is expected to lie wholly within the acceptance range of the echo sounder. For the other fishes, the effect of compensation, as based solely on the mean values, varies from -1.8 to 1.8 dB.

While preparing the split-beam data for averaging, two instances of mixed-species data were encountered. In each of these, the distribution form of the component with the larger target strengths, namely saithe, was well known. This allowed subtraction of the entire large-fish contribution, leaving the small-fish distribution as the remainder for further analysis. A degree of justification for this procedure lies in the final results: the target strengths of the Norway pout of 17.6 cm mean length and the redfish are in line with other physoclist *in situ* target strengths, both as determined in this study and as determined elsewhere. Exemplary, independently derived target strength data are provided by a series of measurements of walleye pollock (*Theragra chalcogramma*) with the dual-beam echo sounder (Traynor and Ehrenberg 1979, Ehrenberg et al. 1981, Ehrenberg 1983, Traynor and Williamson 1983, Traynor 1984).

It is tempting to compare the present results with other *in situ* data in systematic fashion, but this exceeds the scope of this work. Two other comparisons ought, however, to be made before passing.

(1) Gadoid target strength. The relation derived on the sole basis of 13 pollack swimbladders and 2 saithe swimbladders, and assumption of cod behaviour as described by Olsen (1971), is (Foote 1985)

$$\overline{TS}_{gadoids} = 20 \log \bar{\ell} - 66.9 \quad , \tag{11}$$

which is to be compared with Eq. (9b).

(2) Herring target strength. The relation recommended by the 1983 Planning Group on ICES-Coordinated Herring and Sprat Acoustic Surveys (Anon. 1983) is

$$\overline{TS}_{herring} = 20 \log \bar{\ell} - 71.2 \quad , \tag{12}$$

which is to be compared with Eq. (10).

Much more remains to be done with the data analyzed here. Three examples of studies for future prosecution include the following: (1) determination of the depth dependence of the herring target strength, (2) compensation for thresholding on the basis of data simulated from swimbladder morphometries, and (3) investigation of avoidance reactions through a statistical analysis of echo trace lengths (Midttun 1984, Aksland 1985). Another study which could be profitably undertaken in the future, were better behavioural data forthcoming in the interim, is a refinement of the present target strength values based on more certain specification of the applicable tilt angle distributions.

It is interesting retrospective of the introduction of the split-beam echo sounder one year ago (Foote, Kristensen and Solli 1984) to note that the potential of the instrument is being realized. However, it is exceedingly important too to call the attention of current and future users of the equipment to the hazards of ignoring the thresholds, the Scylla of -20 dB, the Charybdis of -50 dB.

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