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# *In situ* target strength measurements of Icelandic summer spawning herring in the period 1985-1992

by

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**Abstract**

Data on the target strength of several length groups of Icelandic summer spawning herring have been obtained with 38 kHz split-beam echo sounders in the period 1985-1992. In 1992 a target strength distribution of 0-group capelin was acquired as well.

The results on herring are expressed through equations of the form $\overline{TS} = m \log \bar{l} + b$ and $\overline{TS} = 20 \log \bar{l} + b_{20}$, where $\overline{TS}$ is the mean target strength in decibels, $\bar{l}$ is the mean length of the fish, and $m$, $b$ and $b_{20}$ are constants of a least-mean-squares regression. In both cases the relationship was found to be highly significant. For herring with mean lengths ranging from 7 to 34 cm, $m$=20.5, $b$=-67.7 dB and $b_{20}$= -67.1 dB. Significant dependence of target strength on depth or vessel speed was not found. For adult herring a trend toward lower target strength with higher fat content was observed. The data indicate that for 1% increase in fat content, the target strength is lowered by about 0.2 dB.

For 0-group capelin with mean length 46 mm, the mean target strength was estimated at -61.5 dB.

## 1. Introduction

The stock of Icelandic summer spawning herring has been monitored annually by acoustic methods since 1973 (Jakobsson 1983). In order to obtain information on the acoustic properties of this species, a programme for studying its target strength was started in 1980. The first series of target strength measurements were carried out in the period 1980-1982 (Halldórsson and Reynisson 1983). An ordinary single-beam echo sounder transmitting at 38 kHz was used and the data were analysed in accordance with the method introduced by Craig and Forbes in 1969. In 1985 the more precise split-beam method was adopted as instruments utilizing this technique became available. In the period 1985-1992 *in situ* target strength data have been obtained from several distinct and relatively narrow length distributions of herring, with mean lengths ranging from 7 cm to 34 cm.
A review of the methods mentioned for measuring target strength has been given by, for instance, Ehrenberg (1983) and Foote (1991).

## 2. Material and methods

The primary material consists of the acoustic and biologigal data, collected on the Icelandic summer spawning herring, during the stock assessment cruises conducted by the Marine Research Institute in Iceland. These cruises are carried out on a yearly basis during the winter season, usually in November and December, but sometimes in January and February as well. All measurements were made at night when the fish are occasionally found in sufficiently disperse scattering layers to allow detection of single fish echoes. In each case, trawling was undertaken in order to get information on species and length composition as well as other biological data. Only target strength data, accompanied by a rather narrow length distribution, were accepted. In most cases, herring was the only species present in the catch, with the exception of 0-group capelin and a few specimens of cod, which were observed from time to time. All data collection was carried out in sheltered fjords under ideal weather conditions and state of sea.

### 2.1 Instrumentation

In the period 1985-1990 an ES400 split-beam echo sounder was used for the acoustic data collection, but was replaced by an EK500 system in 1991 (Foote *et al.* 1984, Bodholt *et al.* 1989). A 38 kHz working frequency was used in all measurements, 1 ms pulsewidth and a bandwidth of 3.5 and 3.8 kHz. Useful data were collected in 1985, 1988 and 1992, but each time with some differences in the data logged.

<u>a) ES400 serial data.</u> In 1985 the data were collected from the serial output of the ES400, the data consisting of pingnumber, target strength and depth for each echo

pulse, accepted as a single fish echo by the selection criteria of the ES400 internal software. The threshold was set at -56 dB.

b) ES400 parallel data. In 1988 improvements in the data logging equipment had been made. This allowed the raw split-beam data to be sampled from the parallel output of the ES400, giving information on pingnumber, depth, echo-level and angular position of the target, for each 10 cm of the water column.

c) EK500 serial data. In 1992 the split-beam data, present on one of the serial interface of the EK500, were logged for further scrutiny. These data consist of the depth and angular positions of the target and target strength before and after beam pattern compensation. The criteria used for single-echo detection by the internal software were set as follows: The signal threshold was set at -68 dB for small herring (≤ 20 cm) and -60 dB for adult herring (≥ 30 cm). Echo length was required to be within 70% and 140% of the transmit pulse duration. The maximum phase deviation, allowed between samples within a pulse, was 2.0 and only echoes within the -6 dB level of the two-way beam pattern were accepted.

A more specific information on the afore mentioned interfaces and data formats is given in the Simrad operation manuals P2092E and P217E for the EK400 and EK500 respectively.

**2.2 Calibration**

Prior to, or during each survey, the echo sounder system was calibrated in accordance with recommendations in the ICES Cooperative Research Report, 144 (Foote *et.al.* 1987). Apart from the on-axis calibration, split-beam data of echoes from a 60 mm diam. copper sphere were collected from at least three transects through the sound beam in order to check the performance of the directivity compensation of the split-beam system.

a) The serial data from the ES400 give target strength values which have been internally corrected for the beam pattern. The accuracy of this correction was checked thoroughly by measurements of the calibration sphere throughout the beam, disclosing a compensation error of as much as -2 dB in certain areas of the beam. Due to these irregularities, an overall adjustment of the mean target strength by -0.9 dB had to be applied. These measurements have been described by Reynisson (1987).

b) The unprocessed split-beam data from the ES400 allowed a look-up table to be generated, containing beam pattern correction values for all angular coordinates within certain limits (Reynisson 1988). This reduced the correction errors considerably, and within the -6.0 dB limits of the two-way beam pattern, 95% of all echoes received from the calibration sphere were within ±0.5 dB of the expected target strength.

c) In the case of the EK500, a mean target strength value was calculated within each 1 dB level of the two-way beam pattern. The result is shown in Figure 1 and indicates that within the -6 dB limit the mean target strength is within ±0.1 dB of

the on-axis value.
The error of the on-axis calibration was estimated to be ±0.3 dB with 95% confidence in all cases. The combined error due to the on-axis value and the overall beam-pattern correction is estimated at ±0.6 dB in a) and ±0.4 dB in b) and c) with 95% confidence.

**2.3 Data analysis**
Visual inspection of echograms was used as the basis of the primary selection of useful data sets. If shoaling or clumping of echoes was not observed and definite single fish echoes were abundant the corresponding target strength data were processed further. This primary selection was especially important in the case of the serial data, in order to minimize the probability of multiple echoes. The selected data were processed as follows:
a) ES400 serial data. Target strength distributions were scrutinized visually for obvious multiple echoes. In some cases these could be avoided, either by setting an upper limit on the target strength or by choosing certain depth limits. For the data sets, passing this inspection, a mean target strength was calculated and the correction of -0.9 dB was added.
b) ES400 parallel data. In processing of the raw split-beam data a special program was developed. The criteria used for the detection of a single fish echo were as follows. The threshold was set to -68 dB, maximum phase deviation, allowed on the leading edge of the pulse, was 3 angle units, pulsewith was required to be within 80% and 140% of the transmitter pulse duration, distance between adjacent pulses should be at least 1 m and only echoes within the -6 dB level of the two-way beam pattern were accepted. The effectivity of the selection program and the criteria used has been reported in detail by Reynisson (1988). Similar criteria have been used by Degnbol and Levy (1987) in post-processing of raw split-beam data.
c) EK500 serial data. The target strength data were examined visually, and in some cases an upper limit had to be applied in order to exclude values obviously lying outside the main distribution. At some locations, where 0-group capelin and possibly krill mixed with the small herring, a peak at the lower end of the overall target strength distribution was observed. This peak was clearly separated from the upper peak, originating from the herring, and could be excluded by using a lower-end threshold of about -56 dB, leaving the herring target strength distribution to a large degree intact. In Figure 2, three target strength distributions are shown, one from a mixture of herring and capelin and the other two from practically pure herring and capelin records.
A mean target strength was calculated in the intensity domain for each data set. The target strength values were examined for dependence on fish length, mean depth and boat speed, using a least-mean-squares analysis. Where data on the fat content of the herring were available, the possible influence of this factor on the observed mean target strength was considered.

## 3. Results

The results of each separate measurement are summarized in Table 1. The 95% confidence limit given for the target strength in Table 1 was derived by combining the error of calibration and the uncertainty due to the large scatter of individual target strength values through the root-mean-square operation. For comparison purposes the quantity $b_{20} = TS - 20\log\bar{l}$, where $\bar{l}$ is the mean fish length, is included in the table. Least-mean-squares regression of target strength on the logarithm of fish length results in

$$\overline{TS} = 20.5\log\bar{l} - 67.7$$

with a standard error of 0.8 dB and a correlation coefficient $r$=0.99. This relation is shown in Figure 3 with a 95% confidence belt for the regression line. If a $20\log\bar{l}$ relationship is assumed, then

$$\overline{TS} = 20\log\bar{l} - 67.1,$$

with the same standard error. Significant dependence of target strength on mean depth and boat speed was not found. The correlation coefficients were $r$=0.05 and $r$=0.22 respectively.

Measurements of the fat content of the fish are only available for the adult herring. A trend toward lower target strength with higher fat content is indicated. Tentatively, one can say that the target strength is lowered by about 0.2 dB for a 1% increase in fat content of the herring. Figure 4 shows how $b_{20}$ varies with fat content.

A mean target strength of 0-group capelin of mean length 46.4 mm (st.dev. 4.5) was found to be -61.5 dB with a 95% confidence limit of ±0.4 dB.

## 4. Discussion

The target strength data reported are all collected using the split-beam technique, but on the basis of the differences in data logging and processing the data are divided in three categories: a) the ES400 serial data, b) ES400 parallel data and c) the EK500 serial data.

The mean values of $b_{20}$ and their 95% confidence limits are as follows for each category: a) -67.2±0.5, b) -66.9±0.9, c) -66.7±0.5. These values are not significantly different, which is further validated by examining mean values ($\bar{b}_{20}$) obtained within a certain depth interval or at a certain vessel speed. The values of $\bar{b}_{20}$ within 10 m depth intervals, and each vessel speed recorded, are shown in Figure 5 and 6 respectively. The variation of $\bar{b}_{20}$ with depth and vessel speed is seen to be in the order of 1 dB. The possible effect of the fat content of the fish has also to be considered. The conclusion is, that the difference in the mean values for each category can only to a small extent be ascribed to differences in data sampling and processing of the split-beam data. Figure 7 shows how $b_{20}$ varies with fish length. The different data logging methods are indicated.

The precence of other species than herring was minimal at the time of the target strength measurements, except for 0-group capelin and some stray cod. At some locations, and within certain depth intervals, target strength data were obtained separately from capelin and herring as shown in Figure 2. Comparison to mean target strength values, obtained from pure herring records, indicated that using a lower limit of about -56 dB had a minimal effect on the mean value, or within ±0.1 dB. In the uppermost distribution, shown in Figure 2, a few large target strength values occurred. These most probably originate from feeding cod, and are not included in the averaging process.

The trend toward lower target strength with higher fat content of the herring is in agreement with the findings of Ona (1990). Ona has shown that the size of the swimbladder in herring is inversely related to the fat content of the fish and states that acoustic estimates could be biased both ways by as much as 30-40% if variance in target strength due to fat content is not taken into account. The fat content shown in Figure 4 is the result of measurements on the flesh of the fish only. The available data on the fat content of the flesh are more detailed, with regard to fish length and time period than the analysis of the total fat content of the fish. In Table 1 both values are given. It should be noted that the measurements of the fat content are not based on samples taken by the research vessel at the time of the target strength measurements but are the mean values obtained from several samples taken each month from the catch by the fishing fleet. In our future assessment work and target strength measurements, it is important that more attention be paid to analysis of fat content and stomach fullness of the herring, both juvenile and adult fish.

In the following text table the result from several *in situ* single fish target strength measurements on herring in different parts of the world are briefly summarized. For the purpose of comparison, $TS = 20\log + b_{20}$ is assumed, and in the table $b_{20}$ is shown as well as the mean length of the fish and the measurement area in each case. These measurements are carried out under different conditions and reflect the variability of the target strength of herring. The range of values of $b_{20}$ is about 12 dB which emphasizes the neccessity to record and analyse the conditions of the acoustic data collection and the biology of the fish in question.

| *Author* | $b_{20}$ *(dB)* | $\bar{l}$*(cm)* | *Area* |
|---|---|---|---|
| This paper: | -67.1 | 6.5-34.0 | Iceland |
| Halldórsson and Reynisson 1983, recalculated in the intensity main * | -69.4 | 9.4-32.8 | Iceland |
| Degnbol *et al.* 1985 | -72.6 | 21.0 | Skagerak/Kattegat |
| Lassen and Stæhr 1985 | -70.8 | 14.6 | Baltic Sea |
| Foote *et al.* 1986 | -72.1 | 28.5 | Shetland Islands |
| Kautsky *et al.* 1990 | -60.5 | 15.0 | Strait of Georgia |

In the acoustic stock estimates of the Icelandic herring, the relationship which has been used since 1980 for the conversion of integrated echo intensities into number of fish, is $TS = 21.7\log l - 75.5$ dB (Halldórsson and Reynisson 1983). In 1986, Halldórsson *et al.* studied the relationship between acoustic and VPA estimates of the adult component of the Icelandic herring and concluded that an optimal fit, although not significantly better, was obtained by increasing the target strength values used by about 1 dB. Recent investigations by Jakobsson *et al.* (1993), on all available pairs of acoustic and VPA estimates of 5-ringers and older herring, indicate strongly that a 1 dB increase will indeed give a significantly better 1:1 relationship. For 30 cm herring this results in an optimum target strength of -42.5 dB or assuming a $20\log l$-relationship, $b_{20}$=-72 dB. According to the results presented, this still leaves a difference of about 5 dB. There is a possibility that the whole stock is not covered in the acoustic surveys. This has, on occations, been the case to such a degree as beeing quite obvious, and the results had to be discarded and the survey would be repeated if possible. In general, one would expect an underestimation of this kind to be of a varying degree from year to year and make any comparison to VPA difficult. Another explanation, at least to some extent, could be sound extinction in the herring schools since during surveying the fish are usually aggregated in large schools. According to what is known about the extinction of sound in schools of herring and the echo intensities usually observed, this probably accounts for less than 15% of the difference (Foote *et al.* 1991). The assumption of similar tilt angle distribution of the fish during the target strength measurements, and when in dense aggregations, may not be correct. This could account for the difference as a relatively small change in tilt angle can result in dramatic changes in target strength. As very little is known about the the tilt angle distribution in each case this is purely speculative, and any information with regard to this problem, would be a great step forward. More realistic values for assessment work on fish, occurring in dense aggregations, might be obtained from measurements carried out on schools of fish. An example is the experiment reported

* In the paper by Halldórsson and Reynisson (1983) the averaging of the target strength data was done in the logarithmic domain. This is incorrect and in the table the value -69.4 was obtained by recalculation of the data in the intensity domain. A least-mean-squares regression of TS on log*l* of the originally published data resulted in TS=21.7log*l*-75.5 dB. Using the recalculated data gives TS=21.9log*l*-72.1 dB.

by Hagström and Røttingen (1992), in which a small school of herring was surveyed by acoustic means, and subsequently, more or less, caught by a purse seiner. In this way a mean target strength of herring with mean length 34.6 cm was estimated at - 42.7 dB or, equivalently, $b_{20}$ = -73.5 dB.

Using the target strength values, presented in this paper, results in biomass estimates of the Icelandic herring which are far too low to sustain the catch of about 100.000 tonnes, taken the last few years. We have, therefore, what we believe to be high quality in-situ single-fish target strength data of the Icelandic herring, which show that the $20 \log l$-relationship is highly significant, but the fact remains that these data are not applicable in our assessment work without further information on *e.g.* tilt angle and extinction cross section .

**References**

Bodholt, H., H. Nes and H. Solli 1989. A new echo sounder system. Proc. IOA 11(3), 123-130.

Craig, R. E. and S. T. Forbes 1969. Design of a sonar for fish counting. FiskDir Skr. Ser. Havunders., 15 (3): 210-219.

Degnbol, P., H. Lassen and K. -J. Stæhr 1985. In situ determination of target strength of herring and sprat at 38 and 120 kHz. Dana 5, 45-54.

Degnbol, P. and P. Lewy 1987. Interpretation of target strength information from split-beam data. International Symposium on Fisheries Acoustics, June 22-26, 1987. Seattle, Washington, USA.

Ehrenberg, J. E. 1983. A review of in situ target strength estimation techniques. FAO Fish. Rep., 300: 85-90.

Foote, K. G., F. H. Kristensen and H. Solli 1984. Trial of a new split-beam echo sounder. ICES C. M. 1984/B:21

Foote, K. G., A. Aglen and O. Nakken 1986. Measurement of fish target strength with a split-beam echo sounder. J.Acoust. Soc. Am. 80, 612-621.

Foote, K. G., H. P. Knudsen, D. N. MacLennan and E. J. Simmonds 1987. Calibration of acoustic instruments for fish density estimation: a practical guide. Coop. Res. Rep. Cons. int. Explor. Mer. no 144.

Foote, K. G. 1991. Summary of methods for determining fish target strength at ultrasonic frequencies. ICES J. mar. Sci., 48:211-217.

Foote, K. G. 1990. How to correct fish densitiy estimates for extinction. ICES C. M. 1990/B:24.

Foote, K. G., E. Ona and R. Thoresen 1991. Determining the extinction cross section of aggregating fish. J. Acoust. Soc. Am. 91(4), 1983-1989.

Hagström, O. and I. Röttingen 1982. Measurements of the density coefficient and average target strength of herring using a purse seiner. ICES C. M. 1982/B:33

Halldórsson, Ó and P. Reynisson 1983. Target strength measurements of herring and capelin "in situ" at Iceland. FAO Fish. Rep. 300: 78-84.

Halldórsson, Ó., P. Reynisson and G. Stefánsson 1986. A method for estimating terminal F's from a series of acoustic surveys - comparison of VPA and acoustic estimates of the Icelandic herring. ICES C. M. 1986/H:62.

Jakobsson, J. 1983. Echo surveying of the Icelandic summer spawning herring 1973-1982. FAO Fish. Rep. 300: 240-248.

Jakobsson, J., Á. Guðmundsdóttir and G. Stefánsson 1993. Stock related changes in biological parameters of the Icelandic summer spawning herring. ICES C. M. 1993/H:47.

Kautsky, G. A., N. A. Lemberg and E. Ona 1990. In situ target strength measurements of Pacific herring in eastern Strait of Georgia using dual-beam and split-beam sonar. Proc. Int. Herring Symp. Oct. 1990, Anchorage, Alaska, 163-182.

Lassen, H. and K. -J. Stæhr 1985. Target strength of Baltic herring and sprat measured in situ. ICES C. M. 1985/B:41

Ona, E. 1990. Physiolocical factors causing natural variations in the acoustic target strength of fish. J. mar. biol. Ass. U. K. (1990), 70, 107-127.

Reynisson, P. 1987. Measurements of the beam pattern and the compensation errors of split-beam echo sounders. International Symposium on Fisheries Acoustics, June 22-26, 1987. Seattle, Washington, USA.

Reynisson, P. 1988. Experiments with target strength data from an ES400 split-beam echo sounder. ICES C. M. 1988/B:45.

Table 1. Summary of split-beam target strength data of Icelandic herring in the period 1985-1992. Note that a vessel speed of 3 knots also indicates that the measurements are carried out during trawling. A speed of zero indicates that the ship was drifting during the measurements.

| Year/ month | Fish length (cm) | | Fat content (%) | | Depth (m) | | Vessel sp. (knots) | Number of data | Target strength (dB) | | b20 (dB) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | St. dev. | Flesh | Total | Interval | Mean | | | Mean | 95% conf. | |
| 85/11 | 8.4 | 0.5 | | | 30 - 45 | 37 | 3 | 1239 | -49.2 | 0.7 | -67.7 |
| 85/11 | 8.6 | 0.6 | | | 30 - 45 | 37 | 9 | 667 | -48.8 | 0.7 | -67.5 |
| 85/11 | 8.6 | 0.6 | | | 25 - 40 | 33 | 3 | 1183 | -48.8 | 0.7 | -67.5 |
| 85/11 | 8.6 | 0.6 | | | 30 - 45 | 38 | 5 | 1016 | -49.8 | 0.7 | -68.5 |
| 85/11 | 8.7 | 0.5 | | | 25 - 45 | 33 | 7 | 457 | -49.1 | 0.8 | -67.9 |
| 85/11 | 8.7 | 0.5 | | | 45 - 70 | 56 | 3 | 1283 | -47.4 | 0.7 | -66.2 |
| 85/11 | 10.1 | 1.5 | | | 18 - 30 | 23 | 3 | 2166 | -47.9 | 0.7 | -68.0 |
| 85/11 | 10.6 | 0.8 | | | 15 - 25 | 19 | 3 | 1841 | -46.5 | 0.7 | -67.0 |
| 85/11 | 10.6 | 0.8 | | | 20 - 25 | 22 | 5 | 812 | -47.1 | 0.7 | -67.6 |
| 85/11 | 10.6 | 0.8 | | | 15 - 25 | 19 | 9 | 1863 | -45.5 | 0.7 | -66.0 |
| 85/11 | 11.0 | 1.8 | | | 9 - 20 | 12 | 3 | 718 | -44.7 | 0.7 | -65.5 |
| 85/12 | 11.0 | 1.8 | | | 15 - 25 | 21 | 7 | 625 | -46.4 | 0.8 | -67.2 |
| 85/12 | 17.9 | 1.7 | | | 10 - 35 | 21 | 3 | 2449 | -42.3 | 0.7 | -67.4 |
| 85/12 | 17.9 | 1.7 | | | 15 - 30 | 24 | 0 | 4421 | -44.1 | 0.6 | -69.2 |
| 85/12 | 31.5 | 1.8 | 18.2 | 19.6 | 10 - 30 | 18 | | 5467 | -37.1 | 0.6 | -67.1 |
| 85/12 | 32.0 | 1.8 | 18.2 | 19.6 | 35 - 55 | 46 | | 2722 | -37.5 | 0.7 | -67.6 |
| 85/12 | 32.9 | 2.0 | 18.2 | 19.6 | 25 - 45 | 29 | | 2227 | -36.9 | 0.7 | -67.2 |
| 85/12 | 33.0 | 2.1 | 18.2 | 19.6 | 25 - 40 | 31 | | 5420 | -36.5 | 0.6 | -66.9 |
| 88/02 | 31.9 | 1.9 | 13.2 | 14.8 | 40 - 60 | 18 | 9 | 281 | -36.2 | 0.7 | -66.3 |
| 88/02 | 33.0 | 2.2 | 14.6 | 14.8 | 20 - 40 | 26 | 0 | 1093 | -35.7 | 0.5 | -66.1 |
| 88/11 | 9.0 | 1.2 | | | 5 - 20 | 49 | 0 | 344 | -48.9 | 0.7 | -68.0 |
| 88/11 | 10.2 | 1.3 | | | 10 - 25 | 30 | 0 | 2312 | -47.6 | 0.9 | -67.8 |
| 88/11 | 17.6 | 1.8 | | | 14 - 39 | 13 | 0 | 482 | -42.0 | 0.6 | -66.9 |
| 88/11 | 34.0 | 2.3 | | | 20 - 43 | 31 | 3 | 1253 | -35.9 | 0.6 | -66.5 |
| 92/11 | 6.6 | 0.5 | | | 20 - 40 | 32 | 3 | 2345 | -50.1 | 0.5 | -66.4 |
| 92/12 | 6.5 | 0.6 | | | 10 - 45 | 22 | 3 | 662 | -51.0 | 0.4 | -67.3 |
| 92/12 | 7.0 | 0.5 | | | 30 - 70 | 54 | 3 | 1343 | -49.5 | 0.4 | -66.4 |
| 92/12 | 7.0 | 0.5 | | | 30 - 70 | 52 | 9 | 1135 | -49.8 | 0.4 | -66.7 |
| 92/12 | 33.1 | 2.3 | 15.4 | 17.1 | 100 - 150 | 131 | 9 | 3755 | -36.0 | 0.4 | -66.4 |

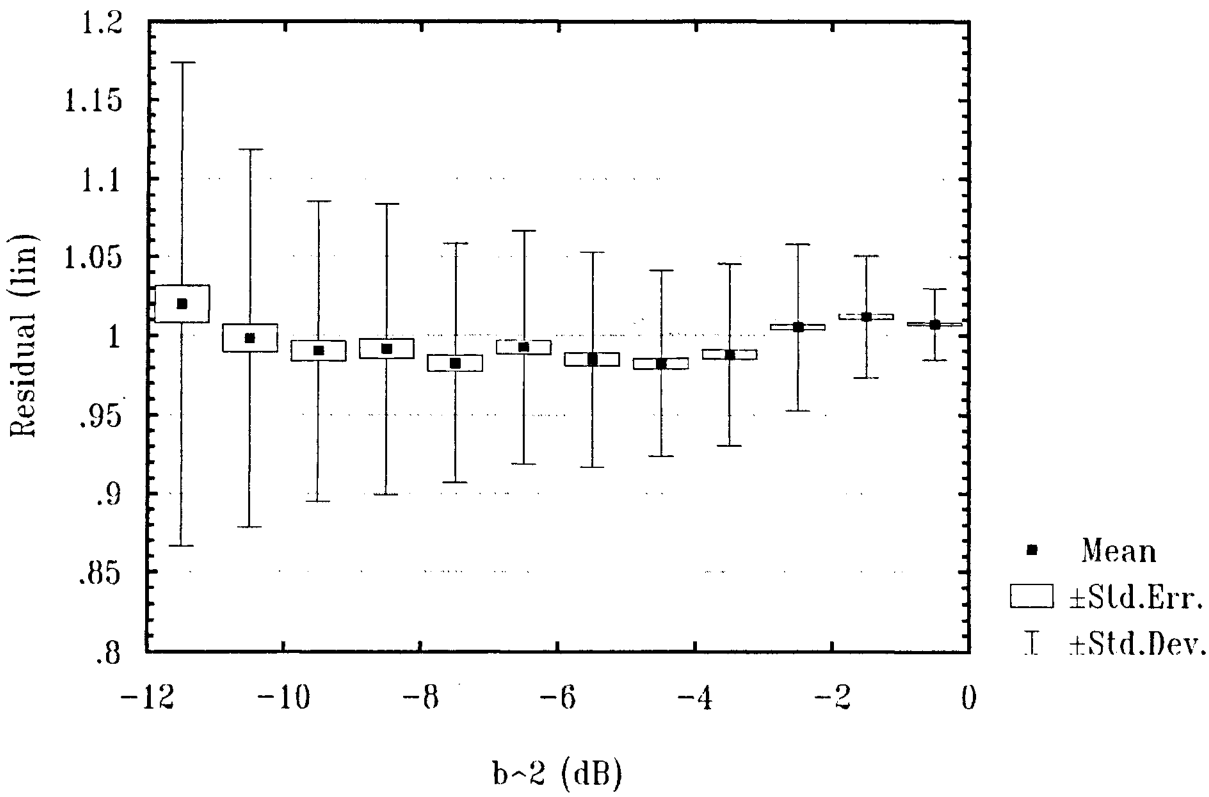


Figure 1. Residual of split-beam correction within 1 dB intervals of the two-way beam pattern obtained from standard sphere calibration of EK500.

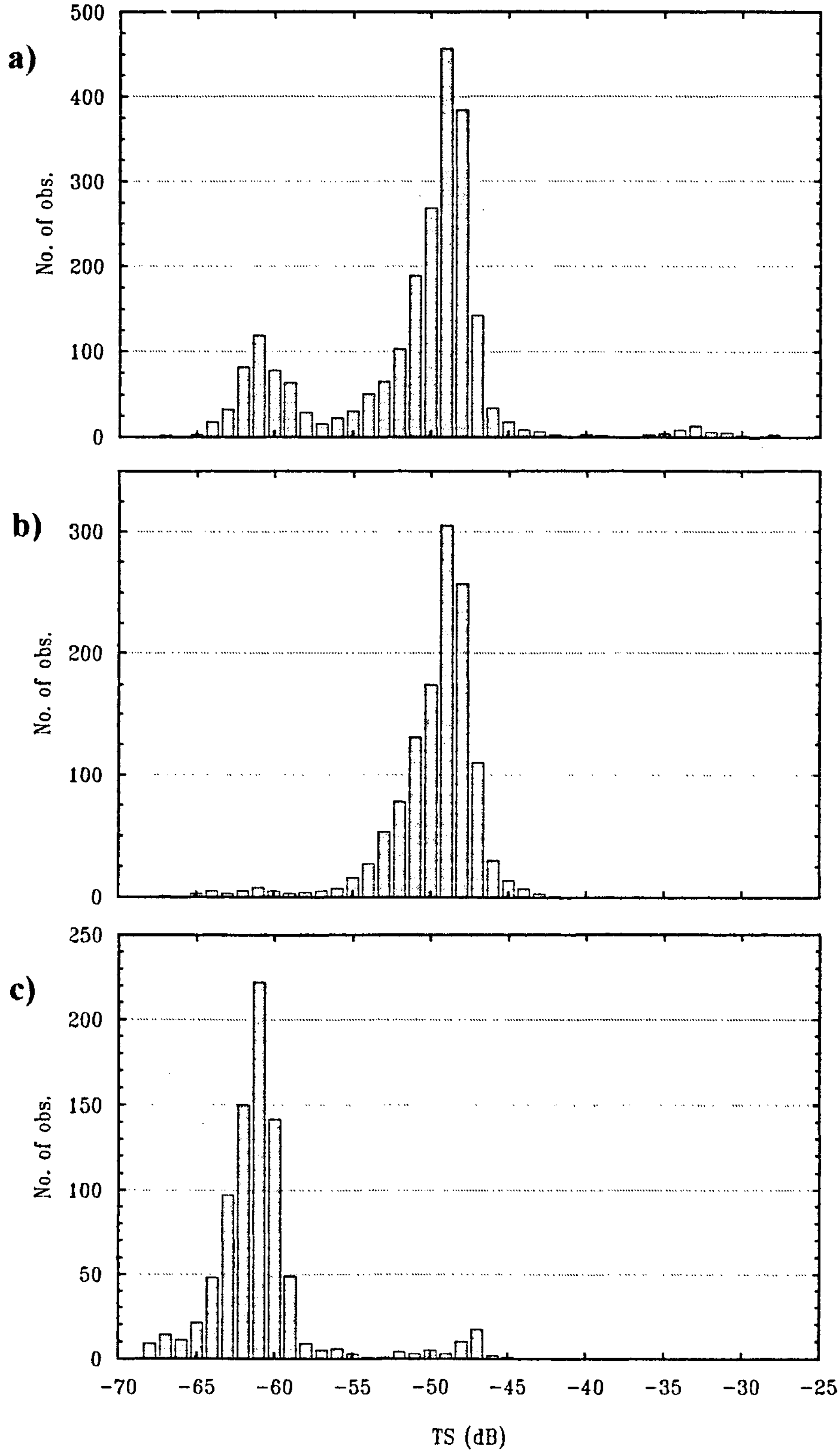


Figure 2. Target strength distribution of a) small herring and 0-group capelin, b) small herring and c) 0-group capelin. Note the few large Ts-values in a) which most likely originate from cod.

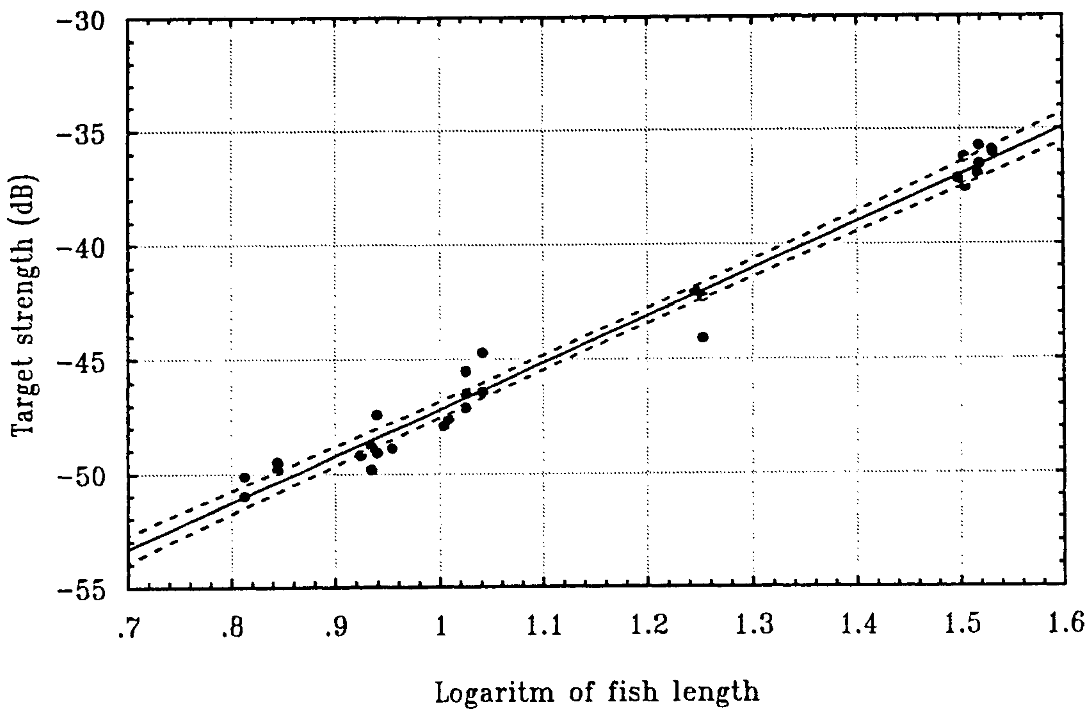


Figure 3. Mean target strength related to the logarithm of mean fish length with 95% confidence belt for the regression line. $\overline{TS} = 20.5\log\bar{l} - 67.7$, standard error=0.8 dB and correlation coefficient $r$=0.99.

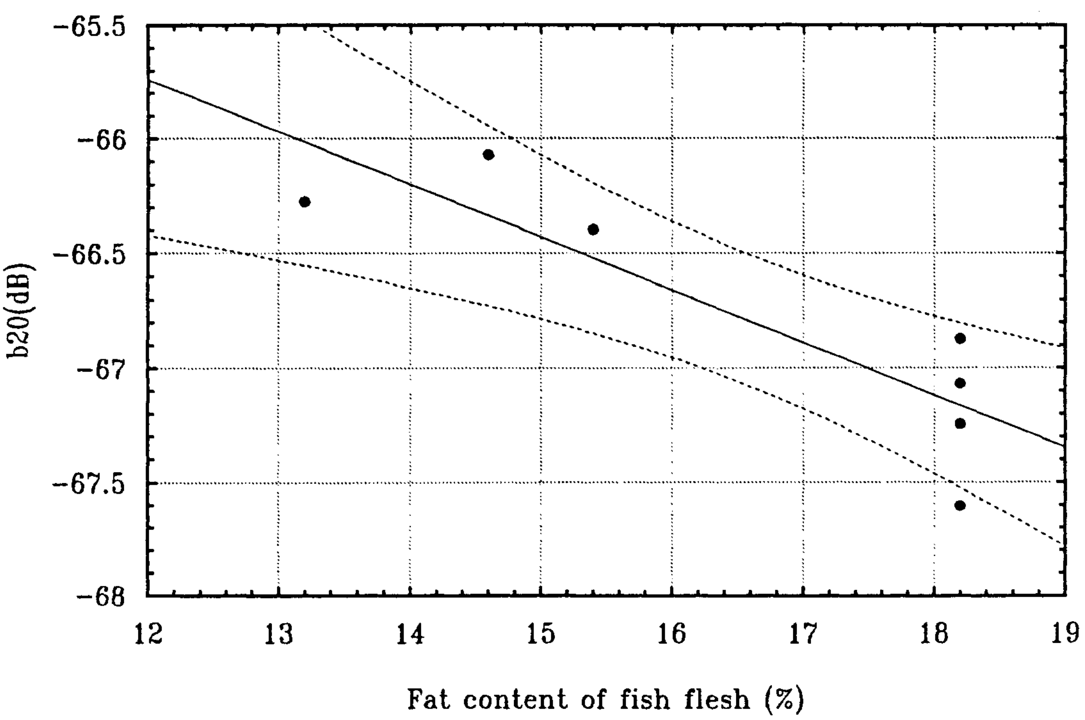


Figure 4. $b_{20}$ related to the fat content of the flesh of herring with 95% confidence belt for the regression line. $b_{20} = -0.2F.c.(\%) - 63.2$, with standard error=0.3 dB and correlation coefficient $r$=0.87.

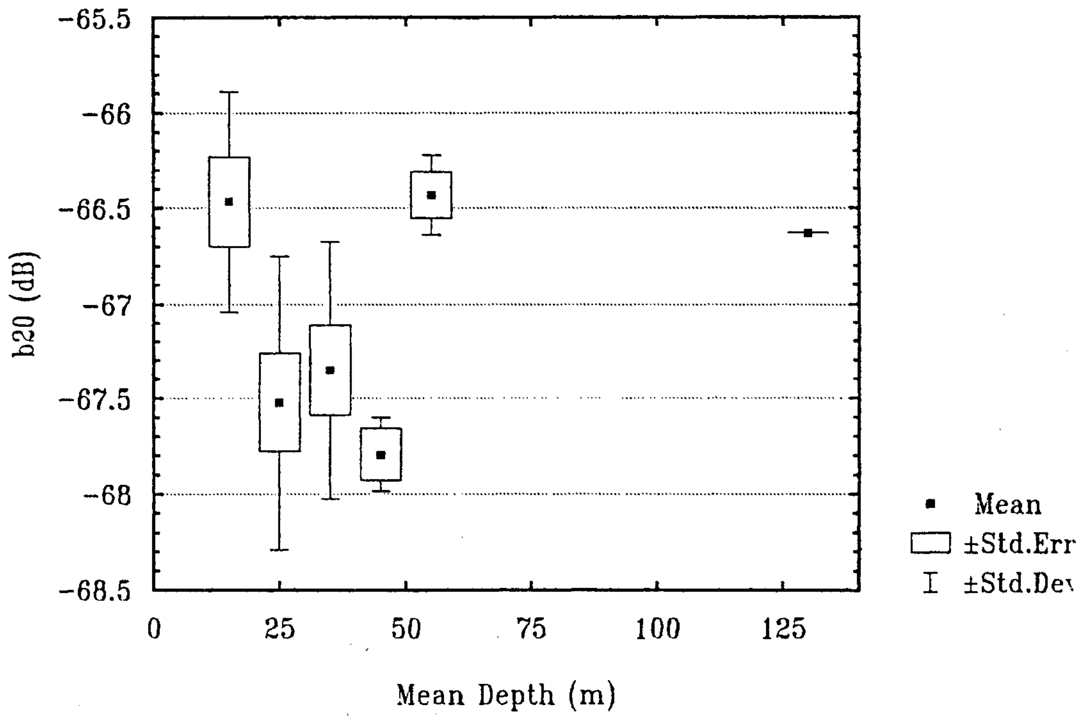


Figure 5. Mean values of $b_{20}$ obtained within each 10 m depth interval.

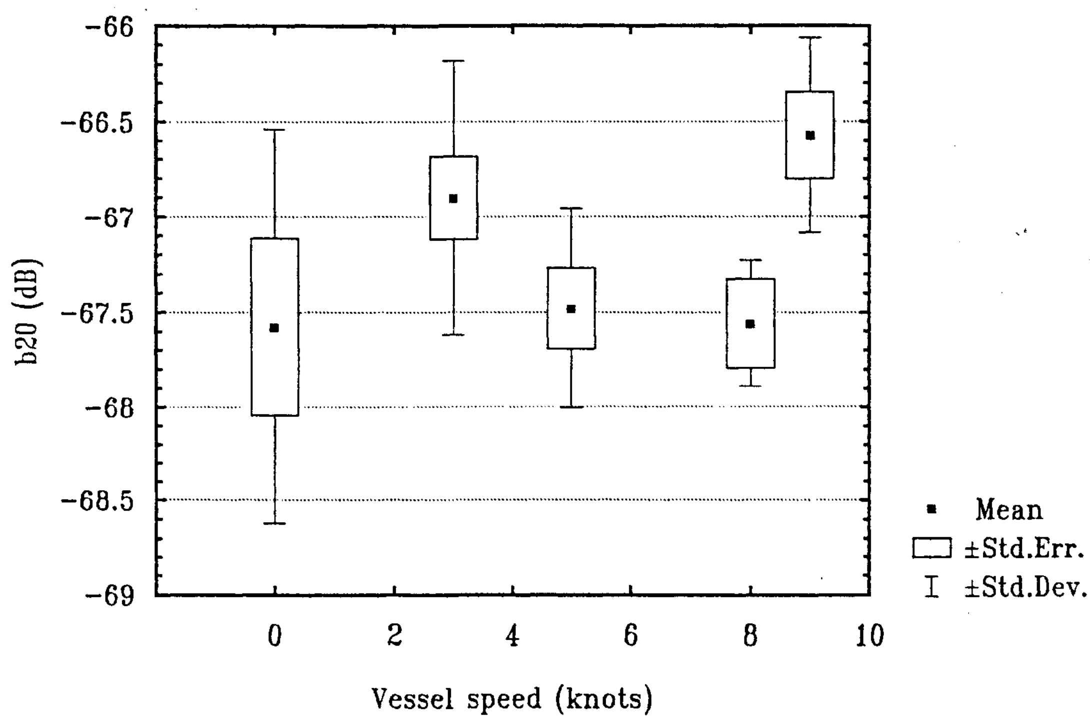


Figure 6. Mean values of $b_{20}$ obtained for each recorded vessel speed.

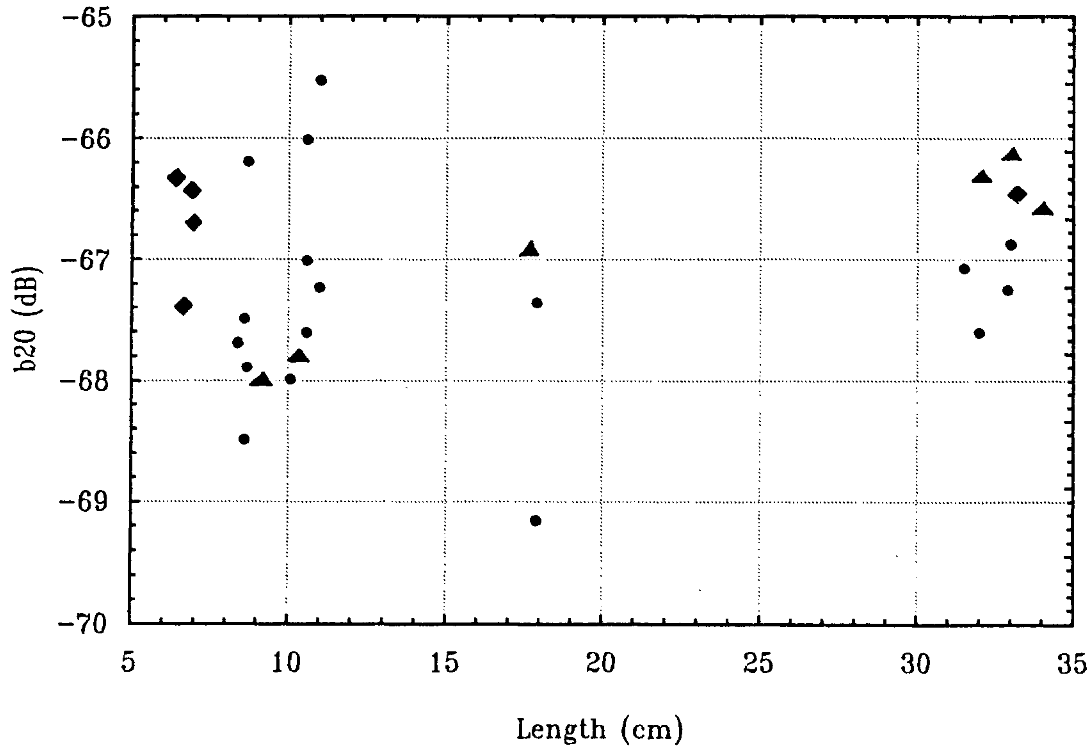


Figure 7. $b_{20}$ versus fish length with the type of data indicated.
●: ES400 serial data, ▲: ES400 parallel data and ◆: EK500 serial data.

Fjölritunarstofa
Daníels Halldórssonar