Dana, vol. 5, pp. 45-54, 1985

In-situ determination of target strength of herring and sprat at 38 and 120 kHz

Poul Degnbol, Hans Lassen & Karl-Johan Stæhr
The Danish Institute for Fisheries and Marine Research,
Charlottenlund Castle, DK-2920 Charlottenlund, Denmark

Abstract

Target strength of herring is estimated as 20 log Length −72.6 dB at 38 kHz and for herring and sprat combined as 20 log Length −73.1 dB at 120 kHz. An indirect *in-situ* technique based on a single beam transducer is used. Deconvolution for finding the target strength distribution is done through a least square fit to the observed echolevel distribution. The herring/sprat peak is identified using cross-correlation between the target strength distribution and the logarithmic length composition.

The least square fitting technique is more robust to sampling errors in the high energy peaks than the Craig-Forbes algorithm which has been used in similar studies.

Introduction

Fish stock assessment surveys for pelagic species are often undertaken using hydroacoustical integration methods and the Danish Instute for Fisheries and Marine Research at present participates in annual hydroacoustical surveys for herring (*Clupea harengus*) in Skagerrak/Kattegat and the southern Baltic.

Conversion of the measured acoustical mean volume back scattering strength to number of fish by species and agegroup involves an estimate of the species composition in the ensonified water volume and the target strength by species.

Target strength data on herring have been obtained through ensonification, of anaesthetized fish, Nakken & Olsen (1977), of herring confined in cage, Edwards & Armstrong (1983) and through *in-situ* techniques Reynisson & Haldorsson (1983). These *in-situ* techniques have been reviewed, Ehrenberg (1983).

The data presented in this paper have been obtained using the indirect *in-situ* target strength technique.

A single beam transducer is used to obtain an echolevel distribution from which the target strength distribution can be found under the assumption that fish are randomly dispersed in the ensonified water volume. The fish composition is assumed to be constant over the time necessary to obtain an echolevel distribution with several thousand single fish echoes.

Algorithms for conversion of echolevel distribution into target strength distribution include linearization of the basic integral equation, Craig & Forbes (1969), introduction of an assumed functional form of the echolevel distribution, Peterson *et al.* (1976), least square fitting, Robinson (1982) and the use of z transforms, Clay (1983). The approach presented here is a least square fit to the Craig-Forbes equations under the restriction that only non-negative solutions are considered.

The indirect *in-situ* technique has been used for obtaining target strength of a species when these fish occur unmixed with other species, e.g. for blue whiting, Robinson (1982) and herring, Halldorsson & Reynisson (1983) and Halldorsson (1983), However, such situations rarely occur in the waters surveyed by Danish research vessels. Identification of the relevant proportion of the target strength distribution is in this paper based on cross-correlation between the length distribution obtained by trawling and the entire target strength distribution.

The least square approach combined with cross-correlation between the length and target strength distributions should overcome the problem of the estimated mean target strength being strongly influenced by a few very big echoes, see e.g. Robinson (1982).

The data presented are obtained in the Skagerrak/Kattegat area in August-September 1983 and 1984 (38 kHz) and in the Southeastern Baltic Sea in October 1983 (120 kHz). The echolevel recordings were done either during trawling or immediately prior to or after fishing. The depth interval covered by the trawl and the peak selection algorithm were chosen to correspond. The trawlhauls selected for analysis are those dominated by herring and sprat. All trawl hauls showed other species as well.

Material and methods

Data material

Fishing was done with the research vessel *Dana* rigged with a pelagic trawl with 16 mm streched mesh in the cod-end. Information on hauls is summarized in Table 1.

Table 1. Summary of data included in the analysis. The position is given as ICES square. The echo-distributions are presented by start time (GMT), duration (min) and the number of echoes identified.

					Echo distribution					Trawling					Weight percent	
Echo dist. no.	Freq. kHz	Haul no.	Date	ICES square	Start GMT	Duration min.	Upper, m	Range, m	No. of echoes	Start GMT	Duration min.	Upper, m	Opening, m	Tot. catch, kg	Herring	Sprat
585	38	560	13/08-83	42/G2-3	01.56	c.150	16	10	6974	04.50	60	15-20	15	4889	100	–
620	38	600	12/08-83	41/G1-2	15.46	99	26	7	1849	18.25	60	15	15	657	100	–
650	38	660	12/08-83	42/G1-4	12.14	98	21	15	12337	14.01	60	20	15	1375	99	–
7717	38	300	24/08-83	44/F9-2	19.12	54	50	35	1804	18.47	60	70	15	447	83	–
7075	38	28	5/09-84	45/F9-3	20.17	105	16	30	2225	20.30	70	20	15	272	37	–
7081	38	28	5/09-84	45/F9-3	20.02	120	16	30	3883	20.30	70	20	15	272	37	–
9601	120	2	20/10-83	38/G3-4	22.40	50	16	10	3945	23.30	60	15	15	348	32	53
9608	120	2	20/10-83	38/G3-4	23.35	70	16	20	9797	23.30	60	15	15	348	32	53
9730	120	3	21/10-83	40/G5-4	18.48	77	40	25	2527	18.40	60	40	15	119	81	7
9757	120	4	21/10-83	40/G6-3	23.10	110	21	20	1061	23.05	60	20	15	112	80	6
9882	120	5	22/10-83	39/G6-1	19.38	82	21	20	2912	19.20	60	20	15	240	22	14
9900	120	6	22/10-83	40/G6-4	23.05	80	16	20	10180	23.05	60	15	15	374	34	33
0201	120	8	24/10-83	40/H0-3	23.28	88	41	25	22470	23.28	60	40	15	106	7	39
0324	120	9	25/10-83	39/G8-2	18.20	75	46	20	7718	18.09	60	45	15	328	45	43
0607	120	10	27/10-83	39/G3-4	18.17	43	21	20	2593	18.08	60	20	15	624	92	7

The pelagic trawl hauls are all from the upper part of the water column, mainly from 20-40 m. Both day and night hauls are presented from the Kattegat/Skagerrak area (38 kHz) while all hauls from the southeastern Baltic are taken during night.

The Kattegat/Skagerrak samples showed herring and no sprat while both herring and sprat were caught in the Baltic.

The echolevel distributions analyzed were all recorded either during pelagic trawling or immediately before or after fishing. The echolevel sampling covers the same part of the water column as that of the pelagic trawl. Hauls where herring and sprat did not dominate in numbers were discarded.

The material presented in Table 1 covers 6 hauls with 38 kHz and 8 hauls with 120 kHz echolevel distributions. Haul no. 28 showed herring and blue whiting in almost identical proportions. However the blue whitings were significantly larger than the herring and the target strength for these herring and blue whiting should be well separated, Nakken & Olsen (1977).

Instrumentation and signal analysis

38 kHz and 120 kHz Simrad EK 400 sounders were used for data collection. The sounders were calibrated against standard copper spheres. Settings and calibration parameters during TS measurements are shown in Table 2.

The calibrated output ($40 \log r + 2\alpha r$ TVG compensation) was envelope detected and digitized with a frequency of 30 kHz and a resolution of 3.45 mV peak i.e. 12 bits, by a Simrad QX integrator preprocessor.

The digitized signal was transferred to a PDP 11/23 computer via a DRV11-R DMA interface. Pings were alternately transferred into two 3200 element buffers corresponding to a depth interval of 80 m.

The signal in one buffer was analyzed simultaneoulsy with the transfer of the next ping into the other buffer. Depending on the depth range selected for analysis and the complexity of the signal no loss of pings was noted for ping rates up to 1-2 pings/sec.

Table 2. Setting and calibration of echosounders during echolevel sampling.

	EK 400, 38 kHz	EK 400, 120 kHz
Transducer	SIMRAD Ceramic 38-29/25 8° × 8°	SIMRAD Ceramic 68 AA 4.5° × 4.5°
Platform	stabilized	stabilized
Output power (W)	1729	622
SL + VR*c* (1983) (dB)	133.2	115.8
(1984) (dB)	132.8	–
TVG*c* 1983	99.2	89.0
1984	98.8	–
(Attenuation) dB/m	0.008	0.0137
Pulse length (msec)	1.01	0.98
Band width (kHz)	1	1

The identification of echo peaks to be included in the echo distribution is based on the position and amplitude of minima and maxima in the detected signal. Real time signal processing is performed in two steps: 1) identification and tabulation of minima and maxima and 2) echoidentification on basis of maxima and minima. Each step involves a number of criteria. These were adjusted to accomplish the best possible reproduction of the selection of echoes achieved by running cross-correlation between the signal and a single echo as reference. The criteria used in the analysis are listed below with the parameter values actually used shown in brackets.

Identification of maxima and minima

It is not possible to extract maxima and minima related to echoes from the signal without some means of eliminating the effect of small deviations due to noise. The method to exclude the effect of noise consisted of:

1. A threshold. Signal values below this threshold were ignored. Minima were defined when the signal passed the threshold from above and from below. (20 mV).
2. A moving average of the last values was used on a reference to check whether the signal was increasing or decreasing (mean over last 3 values).
3. A minimum number of subsequent de/increases had to take place before it was accepted that the sign of the slope had changed. (3).
4. When the signal level was unchanged minima were defined at the beginning and end of the horizontal piece if the horizontal piece was a trough and not a shoulder or a maximum. In the presence of noise equality was defined as being within preset limits. Horizonitality was only accepted after a minimum number (3) of subsequent values had been within the preset limits (of ± 12 mV).

Echoidentification

Echoes were selected on basis of the maximum-minimum table according to three criteria similar to those outlined by Robinson (1978). The purpose of these criteria is to exclude overlapping echoes and to ensure a similarity between actual echolength and the pulselength.

1. The ratio of the amplitude of a maximum and the adjacent minima should exceed a preset minimum (2).
2. The distance between the two minima adjacent to a maximum should be less than a preset multiplum of the pulselength (2).
3. The distance between a maximum and the adjacent maxima should exceed a preset fraction of the pulselength (0.5).

TVG amplification

The TVG amplifier used in the Baltic corresponds to 10°C and 10‰ salinity for 120 kHz.

The TVG amplifier used in Kattegat/Skagerrak for 38 kHz corresponds to 10°C and 35‰ salinity.

The TVG corrections to the actual temperature and salinity profiles are thus small and were ignored in the present analysis.

Solving for target strength distribution

The echolevel distribution, $n(e)$, is the convolution of the sampling volume and the fish target strength distribution

$$n(e)\,de = N_f \int_0^1 dx * \frac{w_T(x)}{x} * w_f\left(\frac{e}{x}\right) de \qquad (1)$$

$n(e)$ is the number of echoes with echolevel equal to e, N_f is the number of fish per m^3, $w_T(x)$ is the sampling volume with the two-way radiation pattern equal to x and $w_f(ts)$ is the fraction of fish with back scattering cross section equal to ts. Eq. (1) is transformed into logarithmic values $EL = \log e$, $y = \log x$ and becomes

$$n(10^{EL})\,dEL = N_f \int_{-\infty}^{0} dy\, w_T(y) * w_f(EL - y)\,dEL$$

The echolevel distribution is observed in discrete intervals and therefore the integral is replaced by a summation

$$n(EL_i) = N_f \sum_j \Delta y_j * w_T(y_j) * w_f(EL_i - y_i)$$

which is the Craig-Forbes equation for $\Delta y = 1$, Craig & Forbes (1969). This equation is linear and directly solvable. The solution is however extremely dependent on the few echoes with high amplitudes and the determinant tends to be very small, Robinson (1982).

An alternative approach to solve eq. (1) may be to investigate the least square problem

$$\sum_i [n(EL_i) - \sum_j w_T(y_j) * w_f(EL_i - y_j)]^2 = \min$$

with the restrictions

$$w_f(x) \geqq 0 \text{ for all } x$$

and

$$\sum w_f(x) = 1$$

The numerical problems of solving this least square problem is discussed by Lofstedt (1983). This approach is preferable to the Craig-Forbes algorithm since sampling errors are partly accounted for and since the influence of a few large echolevels on the solution is less than in the Craig-Forbes algorithm.

Estimation of sampling volumes

The sampling volume $w_T(x)$ is calculated from the theoretical expressions for a circular transducer (120 kHz) and for a rectangular transducer (38 kHz), see e.g. Clay & Medwin (1977). The parameters of these expressions are: (k is the wavenumber) $k \times$ radius for the circular, and $k \times$ width/2 and $k \times$ height/2 for the rectangular transducer. These parameters were fitted to radiation pattern diagrams supplied by SIMRAD for the two transducers. This procedure reduces the variation introduced when reading radiation pattern diagrams.

Only the main lobes are considered when calculating the sampling volumes. The range of target strength distribution should be 10-15 dB under the assumption of TS = 20 log $L + b$ where L is the length of the fish and b is a constant for the observed range of herring sizes from 8 cm to 32 cm. The first side lobes are −19 dB for the circular and −20 dB for the rectangular transducer, one-way transmission. Echolevel distributions with a range up to 50 dB will therefore only include contributions from the main lobe. The analyses presented cover only echolevel distributions with ranges about 30 dB.

The transducer parameters are fitted for the main lobe only and were found as:

	fore-aft		sidewards
circular		39.56	
rectangular	17.83		17.58

The equivalent transducer dimensions to these parameters are 7.9 cm radius for the circular and 22.4 cm, width equal to breadth for the rectangular transducer. The actual transducer dimensions are 10 cm for the circular and 25 cm for the rectangular transducers. These dimensions include the casing.

Sonar equation

The echolevels obtained, EL dB, are dependent on target strength, TS, and the electronic system. The pertinent sonar equation is

$$\mathrm{EL} = \mathrm{SL} - \mathrm{TL} + \mathrm{TS} - \mathrm{TL} + 2\mathrm{DI} + \mathrm{VR}$$

where SL is the source level, TL is the one-way loss and DI the one-way directivity, VR the voltage response. The loss at range R is

$$\mathrm{TL} = 20 \log \mathrm{R} + \alpha\, \mathrm{R}$$

where α is the absorption in sea water per m. The voltage response, of the system including the TVG amplifier, is

$$\mathrm{VR} = \mathrm{VR}c - \mathrm{TVG}c + 40 \log \mathrm{R} + 2\alpha\, \mathrm{R}$$

where VR*c* and TVG*c* are apparatus constants. Table 2 shows the SL + VR*c* and TVG*c* constants for both transducers.

Mean TS estimation

The target strength distribution is the sum of contributions from all organisms ensonified. The TS of herring and sprat are found to be almost identical, Nakken & Olsen (1977). It is thus not possible to separate the contribution from herring and sprat to the TS distribution and therefore only a combined mean target strength can be estimated, when these species occur together.

The target strength TS is considered to be a function of fish length L through TS = a log L + b, see Anon. (1984) for a number of examples for herring. The parameter a is often found to be around 20, implying that the target strength is related to the surface of the fish.

Assuming that other species present in the ensonified water volume have mean target strengths, which differ from that of herring and sprat, cross-correlation analysis between the logarithmic length distribution of herring and sprat combined and the estimated TS distributions should separate the various contributions, see e.g. Burdic (1984). The cross-correlation technique requires that the length distribution is fairly broad. Otherwise there is little information available for identifying the appropriate mean target strength.

The cross-correlations are confined to −40 dB to −52 dB for 38 kHz and to −45 dB to −55 dB for the 120 kHz data since this appears to be the relevant target strength intervals for herring and sprat of the sizes recorded, Anon. (1984). When the cross-correlation reveals several peaks in this interval they are all shown in Table 3.

Results

Table 3 shows the mean target strength estimated for herring (38 kHz) and for herring and sprat combined (120 kHz) for which the cross-correlation coefficient is at maximum in the chosen window. The mean logarithmic lengths of herring and sprat are also shown for each haul.

Since some target strength data are presented as per kg rather than per individual the weight-length relationships for herring and sprat for the Kattegat/Skagerrak

Table 3. Estimated mean target strength, TS, for herring (38 kHz) and herring and sprat combined (120 kHz). The cross-correlation coefficient r and mean logarithmic length log *L* for the corresponding trawl haul are given. All dominating peaks in the cross-correlation diagram are shown. The window applied for the 38 kHz data is −40 to −52 dB and −45 to −55 dB for the 120 kHz data.

38 kHz

Echo dist. no.	Day/ night	log *L* (cm)	TS (dB)	r
585	night	1.290	−46.4	0.89
620	day	1.329	−46.1	0.50
650	day	1.284	−46.0	0.83
7717	night	1.333	−44.9	1.00
			−46.9	0.68
7075	night	1.410	−43.7	0.80
			−48.7	0.74
7081	night	1.410	−47.2	0.33
			−50.2	0.63
Mean		1.323	−46.2	
Mean length		21.0 cm		

120 kHz. (r>0.4) all hauls taken at night

Echo dist. no.	log *L* (cm)	TS (dB)	r
9601	1.107	−49.6	0.63
		−51.6	0.40
9608	1.107	−50.2	0.43
		−51.2	0.43
9730	1.281	−48.1	0.44
9757	1.207	−48.1	0.51
		−51.1	0.46
9882	1.248	−54.2	0.80
9900	1.149	−50.4	0.51
0201	0.893	−49.9	0.92
		−51.9	0.85
0324	1.145	−53.2	0.57
0607	1.143	−48.7	0.55
		−45.7	0.48
Mean	1.142	−50.3	
Mean length	13.8 cm		

Table 4. Length-weight relationships for herring estimated for the trawl hauls corresponding to 38 kHz and to the 120 kHz target strength distributions. Weight in grammes and length in cm.

38 kHz	Weight $= 5.431\ 10^{-3} \times \text{length}^{3.135}$,	$n = 4642$,	$r = 0.99$
120 kHz	Weight $= 7.055\ 10^{-3} \times \text{length}^{2.970}$,	$n = 4217$,	$r = 0.98$

and southeastern Baltic as obtained during these cruises are presented in Table 4.

The mean length range is very narrow for both the 38 kHz data and the 120 kHz data and no relationship between target strength and logarithmic length is obvious in these data. A simple mean target strength value is therefore considered appropriate to represent these observations. Only one peak from each haul is included, that which showed the highest correlation coefficient, Table 3.

The mean target strength for a herring of 21.0 cm is found as −46.2 dB for 38 kHz. The target strength at 120 kHz for herring and sprat is found as −50.3 dB for a mean length of 13.8 cm. The results are summarized below:

	Mean length (cm)	Mean TS dB
38 kHz	21.0	−46.2
120 kHz	13.8	−50.3

This implies the relationships:

$$TS = 20 \log L - 72.6 \quad (38\ \text{kHz})$$
$$TS = 20 \log L - 73.1 \quad (120\ \text{kHz})$$

Taking the scatter of target strength values into account the two estimates probably do not differ significantly.

Discussion

The estimated target strength for 38 kHz corresponds reasonably well with estimates given by other authors, Table 5. The data presented by Nakken & Olsen (1977) are obtained at maximum dorsal aspect which in general are about 6 dB above data obtained *in-situ.*

Table 5. Target strength (TS) for a 21.0 cm herring at 38 kHz calculated from the estimated target strength-length relationships given by various authors.

	TS dB per individual
Nakken & Olsen (1977)	−38.8
Dalen *et al.* (1976)	−44.8
Edwards & Armstrong (1983)	−45.1
Edwards & Armstrong (1983)	−47.8
Halldorsson & Reynisson (1983)	−46.8
Halldorsson (1983((at 20 m depth)	−44.9
This paper	−46.2
	TS dB per kg
Hagstrom & Røttingen (1982)	−33.2
This paper (mean weight 75.9 g)	−35.0

Table 6. Target strength (TS) for a 13.7 cm herring at 120 kHz calculated from the estimated target strength-length relationships given by two authors.

	TS dB per individual
Nakken & Olsen (1977)	−41.0
This paper	−50.3
	TS dB per kg
Aglen *et al.* (1981)	−38.3
This paper (mean weight 16.9 g)	−32.5

Comparison between the estimated target strength at 120 kHz and those of Nakken & Olsen (1977) and Aglen *et al.* (1981), Table 6 shows a much larger difference, about 3 dB per kg than that of Aglen *et al.* Both Nakken & Olsen (1977) and Aglen *et al.* (1981) are controlled experiments on confined herring. Further our estimate is for herring and sprat combined. The length composition in our samples did show that the smaller size groups were dominated by sprat. However Nakken & Olsen (1977) found for a 13.8 cm herring −41.0 dB and for a 13.8 cm sprat −41.6 dB at 120 kHz.

The accuracy with which the TS for herring/sprat can be obtained may be judged by comparing those echo distributions which have been sampled immediately prior to or after one another. These echo distributions are compared below:

Echo distance:	7075	7081	9601	9608
TS for max. correlation:	−43.7	−50.2	−49.6	−50.2

The estimates appear to have some random error or it is critical that sampling of echo distribution and trawling are closely linked suggesting that the allocation of

Table 7. Effect of removing the upper 7 dB part of the echolevel distribution on the mean of the estimated target strength distribution

Echo dist. no.	No. of echoes	No. of echoes removed	Change in mean TS Least square	Change in mean TS Craig-Forbes
585	6974	31	0.00	0.53
620	1849	5	0.02	0.08
650	12337	3	0.01	0.00
7717	1804	24	0.23	1.01
7075	2825	4	0.64	2.15
7081	3883	214	0.77	3.24
9601	3945	21	0.05	0.37
9608	9797	22	0.04	0.17
9730	2527	89	0.46	3.69
9757	1061	59	0.69	2.07
9882	2912	16	0.07	0.59
9900	10180	100	0.03	0.84
0201	22470	73	0.12	0.20
0324	7718	7	0.01	0.03
0607	5216	77	0.15	0.73

trawl hauls to echointegration used in acoustical surveys could be the main source of error in these types of surveys.

The estimation of the target strength distribution through the Craig-Forbes algorithm is very dependent on the correct sampling of the few very high energy peaks, e.g. Robinson (1982). The least square approach applied in this paper is much less so. This is illustrated by calculating the mean of the estimated TS distribution for the echolevel samples using both methods. Table 7 shows the change in mean of the target strength distribution when the echoes in the upper 7 dB intervals are removed. This illustrates the better robustness of the least square approach.

References

Aglen, A., O. Hagstrom & N. Håkanson, 1981: Target strength measurements and *c*-values determinations of live Skagerrak herring and cod. – ICES C.M. 1981/B: 12.

Anon., 1984: Report of the Working Group of the Fisheries Acoustic Science and Technology. – ICES C.M. 1984/B: 41.

Burdic, W.S., 1984: Underwater Acoustic System Analysis Prentice-Hall processing series Prentice-Hall, Inc. Englewood cliffs N.J. 07632.

Clay, C.S. & H. Medwin, 1977: Acoustical Oceanography: Principles and Applications. – J. Wiley & Sons.

Clay, C.S., 1982. Deconvolution of the fish scattering PDF from the echo PDF for a single transducer sonar. – J. Acoust. Soc. Am. *73*(6): 1989-1994.

Craig, R.E. & S.T. Forbes, 1969: Design of a sonar for fish counting. – Fisk Dir. Skr. Ser. Havunders. *15*: 210-219.

Dalen, J., A. Raknes & I. Røttingen, 1976: Target strength measurements and acoustic biomass estimation of capelin and 0-group fish. – ICES C.M. 1976/B: 37.

Edwards, I. & F. Armstrong, 1983: Target strength measurements on herring, sprat and mackerel. – ICES C.M. 1983/B: 23.

Edwards, J.I. & F. Armstrong, 1983: Measurement of the target strength of live herring and mackerel. – *In* O. Nakken & S.C. Venema (eds): Symposium on fisheries acoustics. Selected papers of the ICES/FAO symposium on fisheries acoustics. Bergen, Norway 21-24 June 1982. Paper no. 104 FAO Fish Rep. (300): 331 pp.

Ehrenberg, J., 1983: A review of *in-situ* target strength estimation techniques. – *In* O. Nakken & S.C. Venema (eds): Symposium on fisheries acoustics. Selected papers of the ICES/FAO symposium on fisheries acoustics. Bergen, Norway 21-24 June 1982. Paper no. 104 FAO Fish Rep. (300): 331 pp

Halldorsson, O., 1983: On the behaviour of the Icelandic summer spawning herring (*C. harengus* L.) during echo surveying and depth dependence of acoustic target strength *in-situ*. – ICES C.M. 1983/H: 36.

Halldorsson, O. & P. Reynisson, 1983: Target strength measurements of herring and capelin 'in-situ' at Iceland. – *In* O. Nakken & S.C. Venema (eds): Symposium on fisheries acoustics. Selected papers of the ICES/FAO symposium on 21-24 June 1982. Paper no. 104 FAO Fish Rep. (300): 331 pp.

Hagstrom, O. & I. Røttingen, 1982: Measurements of the density coefficient and average target strength of herring using purse seine. – ICES C.M. 1982/B: 33.

Lofstedt, P., 1984: Solving the minimal least square problem subject to bounds on the variables. – Bit *24*: 206-224.

Peterson, M.L., C.S. Clay & S.B. Brandt, 1976: Acoustic estimates of fish density and scattering function. – J. Acoust. Soc. Am. *60*: 618-623.

Robinson, R.J., 1978: *In-situ* measurements of fish target strength. – Proceedings of the Institute of Acoustics Conference on Acoustics in Fisheries, Hull.

Robinson, B.J., 1982: An *in-situ* technique to determine fish target strength with results for blue whiting (*Micromesistius poutassou* Risso). – J. Cons. int. Explor. Mer *40*: 153-160.