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ON THE FREQUENCY DEPENDENCE OF TARGET STRENGTH OF MATURE HERRING

by

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ABSTRACT

Mature herring (Clupea harengus), hibernating in Ofotfjord in December 1991, was measured simultaneously at each of three frequencies: 18, 38, and 120 kHz. Measurements of the mean volume backscattering coefficient were integrated over the water column and averaged over 0.1-nautical mile intervals. Through a regression analysis of the resulting values of area backscattering coefficient, performed for pairs of frequencies, the ratio of backscattering cross sections σ was determined. By using the standard target strength-length relationship for clupeoids at 38 kHz, $TS=10 \log \sigma/4\pi=20 \log \ell - 71.9$, where ℓ is the mean length in centimeters, the TS values at 18 and 120 kHz are determined. For $\ell=34.3$ cm, TS=-42.9 dB at 18 kHz and -42.6 dB at 120 kHz. The nominal precision of the measurements is ±1.0 and ±0.5 dB, respectively.

RESUME: SUR L'INCIDENCE DE LA FREQUENCE SUR L'INDICE DE REFLEXION DU HARENG ADULTE

Du hareng adulte qui hibernait dans le fjord Ofot en décembre 1991 a été simultanément mesuré à 3 fréquences différentes: 18, 38 et 120 kHz. Les mesures de l'indice de réflexion volumique ont été intégrées le long de la colonne d'eau et moyennées sur des intervalles de 0.1 mile nautique. Sur les indices de réflexion surfaciques ainsi obtenus, on a procédé à une regression portant sur les couples de fréquence, ce qui a permis la determination du rapport des contours apparents. Au moyen de la relation qui lie l'indice de réflexion à la longueur des harengs a 38 kHz, $TS= 10 \log \sigma/4\pi=20 \log \ell -71.9$, où ℓ désigne la longueur moyenne des poissons en centimetre, les indices de réflexion ont été déterminés à 18 et 120 kHz. Pour $\ell=34.3$ cm, l'indice vaut -42.9 dB à 18 kHz et -42.6 dB à 120 kHz. La précision des mesures est respectivement de l'ordre de ±1.0 et ±0.5 dB.

INTRODUCTION

Knowledge of fish target strength is generally recognized to be important, but there are surprisingly few published data. In fact, in one summary of target strengths (Foote 1987), only data at 38 kHz are presented. A reason for this then, and now, is the scarcity of in situ measurements at other frequencies.

Were the frequency dependence of target strength known, if indeed it exists, extrapolation from measurements at 38 kHz to other frequencies would be straightforward. This dependence is not known however. According to Love (1977), the frequency dependence must be rather weak over the following relative range of length ℓ to wavelength λ ratio: $\ell/\lambda=1-100$. For fish longer than about 35 cm, there may be no systematic frequency dependence at ultrasonic frequencies (Haslett 1969).

Thus, a new study might supplement current in situ measurements while contributing to knowledge of the frequency dependence of target strength. This is the aim of the present study, which reports in situ measurements of herring at 18, 38, and 120 kHz.

THEORY

The fundamental measured quantity is the area backscattering coefficient s_A. In terms of the mean volume backscattering coefficient s_v,

$$s_A = 4\pi\, 1852^2 \int_{z_1}^{z_2} s_v \, dz \quad , \tag{1}$$

where the integration is performed over depth from z_1 to z_2, assuming a directional downward-looking transducer. Since $s_v=\rho\sigma/4\pi$, where ρ is the volume density of scatterers and σ is the mean backscattering cross section,

$$s_A = \rho_A \sigma \quad , \tag{2}$$

where ρ_A is the area density of scatterers with respect to 1 NM^2.

If s_A is measured simultaneously for the same aggregation over the same depth range at each of two frequencies, then

$$\sigma_1/\sigma_2 = s_{A,1}/s_{A,2} \quad , \tag{3}$$

where the subscripts denote the respective frequencies. Since $s_{A,1}$ and $s_{A,2}$ are measured, if one of the backscattering cross sections is known, then the other can be immediately determined.

DATA COLLECTION

An aggregation of mature herring was observed in Ofotfjord in early December 1991. Data were collected with the SIMRAD EK500 echo sounder (Bodholt et al. 1989) at each of three frequencies, 18, 38, and 120 kHz. The echo sounder and Bergen Echo Integrator (Foote et al. 1991) were calibrated by means of standard spheres (Foote et al. 1987) in separate calibration exercises performed during the present cruise at 38 and 120 kHz and on an earlier cruise at 18 kHz.

The particular data set analyzed here was collected on board R/V "JOHAN HJORT" at night on 5 December. The vessel sailed the length of Ofotfjord, from the outer end near (68°20'N,16°1'E) to Rombaken, an inner reach at (68°27'N,17°40'E), where it swung about in a large loop, then sailed part way out to conclude the measurement series near (68°26'N,17°13'E). The average speed was 8 knots.

The primary acoustic data were collected with two EK500 echo sounders. Some operating parameters of the transducers are shown in Table 1. The data were expressed as s_V-values spanning the total depth range, with scale 0-1000 m relative to the transducer depth, which is about 5.5 m. The data were logged by means of the Bergen Echo Integrator.

Table 1. Some transducer operating parameters.

Nominal frequency (kHz)	Pulse duration (ms)	Receiver bandwidth (kHz)
18	2	1.8
38	1	3.8
120	0.3	1.2

A previous investigation in November 1991 showed the aggregation to be almost entirely composed of mature herring. A single pelagic trawl haul made in Ofotfjord on 5 December confirmed this, while disclosing the length distribution.

ANALYSIS METHOD

The acoustic data were interpreted in the usual manner by means of the Bergen Echo Integrator. Values of s_A were accumulated over 100-m-thick depth channels and averaged over 0.1-NM intervals of sailed distance. The results were stored in a database for later retrieval.

In order to express the unknown backscattering cross section, say σ_2, in terms of the assumed known cross section σ_1, equation (3) was rewritten in the form of a regression equation,

$$s_{A,2} = a\, s_{A,1} \quad , \tag{4}$$

where the coefficient a is determined by regressing $s_{A,2}$ on $s_{A,1}$. For the particular data, the reference frequency is 38 kHz, hence

$$\sigma_2 = a\, \sigma_1 \quad , \tag{5}$$

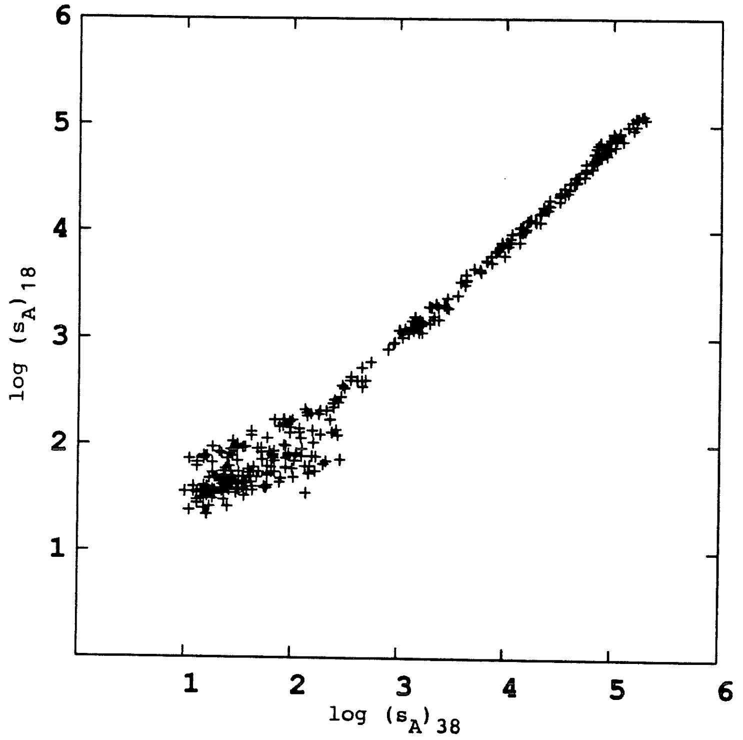

Fig. 1. Scatter diagram of paired s_A-values at 38 and 18 kHz from the upper 100 m.

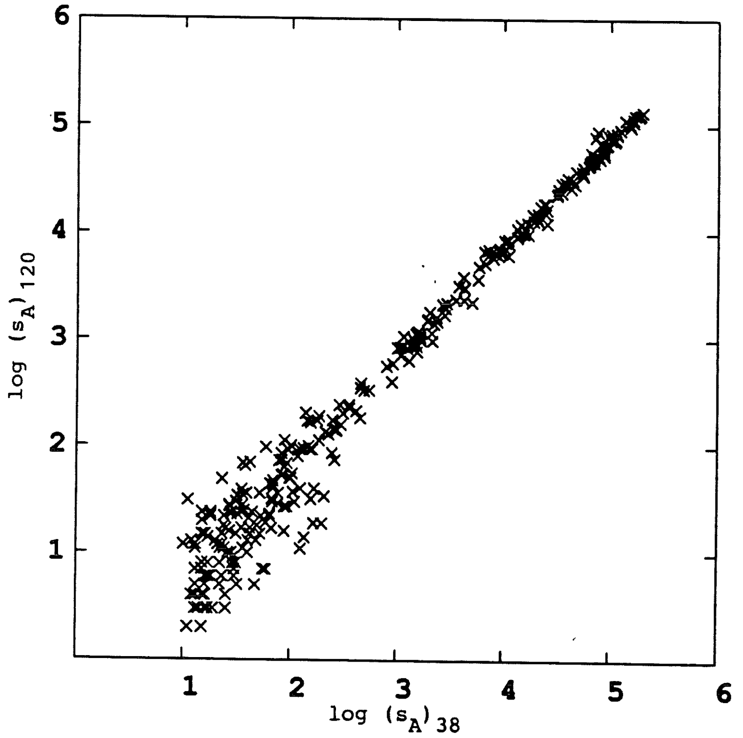

Fig. 2. Scatter diagram of paired s_A-values at 38 and 120 kHz from the upper 100 m.

Table 2. Histograms and simple statistics of s_A-values for herring at three frequencies, collected in Ofotfjord on 5 December 1991. Histogram values are percentages.

$s_{A,min} \le s_A < s_{A,max}$		Frequency (kHz) 18	38	120
zeroes		0	0	14
2	4	0	0	2
4	8	0	0	6
8	16	0	7	8
16	32	4	19	11
32	64	29	12	6
64	128	16	10	6
128	256	7	7	5
256	512	3	4	1
512	1024	2	1	5
1024	2048	9	7	5
2048	4096	2	3	3
4096	8192	5	3	4
8192	16384	5	5	6
16384	32768	6	5	5
32768	65536	8	5	7
65536	131072	6	9	7
131072	262144	0	3	0
No. samples		360	360	360
Average		11781	16943	12262
Standard dev.		24819	36263	26289
Coef. variation		2.11	2.14	2.14

Table 3. Regression analyses of s_A-values according to equation (4), where s_A at frequency y is regressed on s_A at frequency x. The number of 0.1-NM sample intervals is denoted n. The standard error of the regression coefficient a is denoted se(a).

Selection criteria		Frequency (kHz)				
z_{max}	$s_{A,min}$	x	y	n	a	se(a)
100	1000	38	18	145	0.683	0.008
100	1000	38	120	130	0.720	0.010
100	0	38	18	360	0.683	0.004
100	0	38	120	360	0.720	0.005
Bottom	1000	38	18	173	0.769	0.011
Bottom	1000	38	120	155	0.715	0.008
Bottom	0	38	18	360	0.769	0.006
Bottom	0	38	120	360	0.715	0.004

where

$$\sigma_1 = 4\pi 10^{TS_1/10} \quad , \tag{6a}$$

and, according to a general equation for clupeoids (Foote 1987) that is applied to Norwegian spring-spawning herring,

$$TS_1 = 20 \log \ell - 71.9 \quad . \tag{6b}$$

Uncertainty in σ_2 derives from both the calibration and σ_1 itself.

Two criteria were imposed a priori on the data to be analyzed. These are that data only be selected from the upper 100 m of the water column and that s_A-values exceed 1000 m^2/NM^2 in this depth channel. Other selection criteria were also imposed on the data, but principally out of curiosity and not with the intention of being used.

RESULTS

The collected data are presented pairwise in scatter diagrams of $s_{A,2}$ and $s_{A,1}$. Figure 1 applies to the data collected at 18 and 38 kHz, while Fig. 2 applies to data at 120 and 38 kHz. The full data ranges are shown, but the a priori selection criteria restrict the useable data to those in the upper right quadrant. The basis data are further quantified through histograms and simple statistics presented in Table 2.

The results of the regression analysis in equation (4) are presented in Table 3. A subset of these, derived for the mentioned selection criteria with depth less than 100 m and s_A-values exceeding 1000 m^2/NM^2 for the same depth range, is further analyzed. For the observed mean fish length ℓ=34.3 cm at 38 kHz, TS=-41.2 dB and σ=9.55 cm^2 according to equations (6a and b). Thus, from equation (5), TS estimates are derived at 18 and 120 kHz. These are presented in Table 4. The nominal estimates of precision are, respectively, ±1 dB and ±0.5 dB.

Table 4. Estimates of σ and TS for herring of approximate normal length distribution N(34.3,2.2) cm, at three frequencies, where the estimates at 38 kHz are computed from equations (6a and b). Also presented is the intercept term b in the equation TS=20 log ℓ + b.

Frequency (kHz)	σ (cm^2)	TS (dB)	b (dB)
18	6.52	-42.9	-73.6
38	9.55	-41.2	-71.9
120	6.87	-42.6	-73.3

DISCUSSION

The results are succinctly expressed in Table 4. Examination of the several sets of data in Table 3 is revealing for showing a general similarity of results at 120 kHz, but a tendency for target strength to increase with depth at 18 kHz. The reason for this is unknown, but it is suggested that the composition of the scatterers may also have changed with depth, which could have been sensed more strongly at the lowest frequency, where the medium absorption coefficient is least.

Although the present results strictly apply to data that satisfy conservative selection criteria, further analysis suggests a wider applicability. Specifically, relaxation of the requirements that the data lie within the upper 100 m and that the s_A-values exceed 1000 m is accompanied by rather small changes in derived TS values. Data collected on mature herring in Ofotfjord on 4 December, in the middle of the day, show a very similar pattern of dependence on frequency.

It is interesting to compare the new results in Table 4 with those derived by Degnbol et al. (1985) for a mixed aggregation of herring and sprat (Sprattus sprattus) at 120 kHz. For a mean length of 13.8 cm, the coefficient b in the standard equation $TS=20 \log \ell + b$ was determined to be -73.1 dB. Degnbol et al. compared this value to the corresponding one for herring of mean length 21.0 cm at 38 kHz, namely -72.6 dB. The above value, -73.3 dB for herring of length 34.3 cm, is also less than values at 38 kHz, namely -71.9 dB for clupeoids (Foote 1987) and -71.2 dB for herring assessed in ICES-coordinated surveys (Anon. 1983). Further understanding of differences in results with Degnbol et al. may be sought in the inverse relationship between swimbladder volume and fat content (Ona 1989). This is assumed to explain the connection between swimbladder volume and salinity, which is less in the Baltic region, where Degnbol et al. made their measurements, than along the Norwegian coast.

As with the Degnbol et al. results, the observed difference in frequency, especially between 38 and 120 kHz, may not be significant. It is the authors's intention, therefore, to perform new measurements on a similar aggregation of herring in a northern Norwegian fjord in December this year. An extended calibration exercise may also enable data from greater depths or with lower s_A-values to be used. This would immediately make available for analysis many other data from the cruise reported here. It may also improve the relative estimate of precision, which is presently dominated by calibration and not the spread of the data themselves, which are highly correlated about a straight line through the origin.

Use of the general linear regression equation, with two terms, instead of that in equation (4), only marginally improves the fit. This attests to the quality of both the instrumentation and the method of measurement. Some insight into the frequency dependence of target strength may indeed be expected from future similar investigations.

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