Fol. 41 B

Fiskeridirektoratet
Biblioteket

International Council for the
Exploration of the Sea

C.M. 1993/B:30
Fish Capture Committee
Ref. H - Pelagic Fish
Committee

MORE ON THE FREQUENCY DEPENDENCE OF TARGET STRENGTH OF MATURE HERRING

by

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ABSTRACT

The hibernating stock of Norwegian spring-spawning herring has been acoustically surveyed in a fjord system in northern Norway in December 1992. The survey frequencies are 18, 38, 120, and 200 kHz. When the corresponding echo sounders were operating, the fundmental measurements of volume backscattering strength were simultaneous. By comparing integrated measures of these, the several backscattering cross sections are related. New results are compared with those obtained from a cruise in the same area in December 1991, when the same herring stock was observed.

RESUME: DONNEES COMPLEMENTAIRES SUR LA VARIATION FREQUENTIELLE DE L'INDEX DE REFLEXION DU HARENG MATURE

Le stock hivernal de hareng norvégien, frayant au printemps, a été évalué par acoustique dans un fjord au nord de la Norvège en décembre 1992. Les fréquences utilisées étaient 18, 38, 120 et 200 kHz et des mesures simultanées d'index de réverbération de volume ont ainsi pu être obtenues. Par comparaison des valeurs écho-intégrées, les différentes surfaces de rétrodiffusion ont été extraites. Ces nouveaux résultats sont comparés à ceux obtenus en décembre 1991 sur le même stock de hareng.

INTRODUCTION

In December 1991, Norwegian spring-spawning herring (Clupea harengus) hibernating in Ofotfjord were measured simultaneously at each of three frequencies, 18, 38, and 120 kHz (Foote, Hansen and Ona 1992). From measurements of the area backscattering coefficient, relative backscattering cross sections were determined. The particular measurement series was quite limited, however, hence the authors's announced intention of performing similar measurements on the same target species one year later.

Thus, in December 1992, two of the coauthors (KF and KH) returned

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to Ofotfjord, where they measured hibernating herring simultaneously but at each of four frequencies, 18, 38, 120, and 200 kHz. Results from a statistical analysis are presented here.

THEORY

As earlier described, the principle of measurement derives from the fundamental equation of echo integration, namely

$$s_A = \rho_A \sigma \quad , \qquad (1)$$

where s_A is the area backscattering coefficient, ρ_A is the area density of observed scatterers, and σ is the mean backscattering cross section of the scatterers. If two echo sounders operate simultaneously, with proximate transducers oriented in the same direction, then separate echo integration performed on the two echoes will yield two equations in the form shown above. Since the area density ρ_A is the same,

$$s_{A,1}/s_{A,2} = \sigma_1/\sigma_2 \quad , \qquad (2)$$

where the subscripts denote the respective frequencies. If one of the backscattering cross sections is known a priori, say σ_1, then the other is directly determined. Extinction is neglected here, with justification.

DATA COLLECTION

Both instrumentation, platform, venue, target species, biology, and other measurement conditions closely resembled those of the preceding study in December 1991. These are briefly described here.

Instrumentation The primary acoustic measurements were made with two SIMRAD EK500 echo sounder systems (Bodholt et al. 1989), with common trigger signal. Each system controlled two transducers and associated circuitry, with operating parameters as shown in Table 1. Values of the volume backscattering strength were stored by the Bergen Echo Integrator (Foote, Knudsen, Korneliussen, Nordbø and Røang 1991), or BEI, for postprocessing, including echo integration. The absoluteness of the measurements was ensured by conducting a standard-target calibration in the standard way (Foote et al. 1987), in advance of the fish measurements. Estimated figures for the measurement uncertainties are also shown in Table 1.

Platform This was R/V "JOHAN HJORT", as in December 1991. Its speed was nearly constant at 8 knots throughout the measurements.

Venue Measurements were made both in Ofotfjord and nearby Tysfjord. So far, only the measurements from the first fjord have been analyzed, but the others are not expected to differ significantly from these.

Table 1. Operating parameters of the four SIMRAD transducers used in the measurements, together with estimated figures for the uncertainties in calibration.

Frequency (kHz)	Pulse duration (ms)	Receiver bandwidth (kHz)	Measurement uncertainty (dB)
18	2.0	1.8	±1.0
38	1.0	3.8	±0.2
120	0.3	12.0	±0.5
200	0.2	20.0	±0.5

Target species The major component of the Norwegian spring-spawning herring stock has been hibernating in the Ofotfjord-Tysfjord system in recent years. The dominant year class has been that from 1983, but the proportion of younger fish recruited to the stock has been increasing. Other pelagic fish in the fjord tend to lie in deeper water, often separated vertically from the herring but otherwise showing a distinctly different pattern of echo traces. Demersal fish are similarly distinguished from the target species.

Biology Information about the target species was acquired by trawling. Because of the generally concentrated state of the herring aggregation, trawling was performed with an open cod end. Analysis of the catch at the five pelagic trawl stations shows a bimodal distribution, with dominant peak at 36 cm and secondary peak at 30 cm. The relative proportions represented by the two peaks are 2:1. The overall mean length is 34 cm, with standard deviation of 3.2 cm. The rms length is 34.1 cm. Extreme lengths in the distribution are 21 and 38.5 cm.

Other measurement conditions Conditions were typically excellent for the place and time of year. The onset of a storm in the middle of the measurements required caution in navigation on the downwind side of the fjord, but the consequent change in area coverage is negligible. The sun did not rise at all during the cruise, but a period of civil twilight prevailed in the middle of the day for about 2½ hours.

DATA ANALYSIS

Initial analysis of the acoustic data was conducted in the manner of an echo integration survey, as indeed it was, if of experimental type. The Bergen Echo Integrator was thus used to retrieve and display the data on a workstation screen. These were interpreted, that is, identified or sorted by class of scatterer, for example, herring or non-herring. Resulting discriminated values of the area backscattering coefficient were stored in the BEI database, with resolutions of 0.1 nautical mile in sailed distance and 10 m in depth.

These stored data became the raw material for a statistical analysis. Equation (2) was essentially solved by regression s_A at one frequency on that at another, reference frequency, namely

$$s_{A,2} = c\, s_{A,1} \quad , \tag{3}$$

where c estimates σ_2/σ_1, that is, σ_2 relative to σ_1. The more general linear regression, with two coefficients, was also examined, but gave only insignificant improvement in the fit of the data. The simpler form in equation (3) was retained. The method of solution was that of linear least-mean squares.

RESULTS

In analyzing the data, four subsets are considered at each frequency. These are differentiated by depth range and s_A-threshold value. The treated depth ranges are the upper 100 m of the water column and the entire water column, from surface to bottom. In the event, computed values of c for the thresholds 0 and 1000 m^2/NM^2, or square meters of backscattering cross section per square nautical mile, for the same depth range are indistinguishable. The restriction that s_A be at least 1000 m^2/NM^2 reduces the number of data n by about 50%, and the associated standard error se(c) is correspondingly larger. Both c, se(c) and n are presented in Table 2 for each frequency, where the reference is 38 kHz. Also included in the table are the corresponding results from the 1991 cruise.

Table 2. Results of the regression analysis in equation (3), where the reference frequency is 38 kHz. A threshold value for s_A of 1000 m^2/NM^2 has been applied.

	Depth	18 kHz			120 kHz			200 kHz		
Year	range	c	se(c)	n	c	se(c)	n	c	se(c)	n
1992	0-100 m	0.670	0.004	1386	0.686	0.003	1277	0.754	0.005	1032
1992	0-bottom	0.712	0.004	1684	0.787	0.006	1554	0.810	0.005	1147
1991	0-100 m	0.683	0.008	145	0.720	0.010	130	-	-	-
1991	0-bottom	0.769	0.011	173	0.715	0.008	155	-	-	-

The results in Table 2 are further reduced by translating the regression coefficient into an absolute value of backscattering cross section. In doing this, the reference value at 38 kHz, denoted σ_1, is assumed to be given by the standard equation,

$$TS_1 = 20 \log \ell - 71.9 = 10 \log \sigma_1/4 \quad , \tag{4}$$

where TS_1 denotes the target strength, and ℓ is the mean fish length in centimeters. For general purposes of comparison with data on other mean lengths or species, the new target strength value TS_2 is also expressed in terms of the intercept b_2 in the equation

$$TS_2 = 20 \log \ell + b_2 \quad . \tag{5}$$

Results are given in Table 3 for the criteria that the data derive from the upper 100 m of the water column and that the threshold value of s_A be 1000 m^2/NM^2. Corresponding results from 1991 are also presented.

Table 3. Estimates of σ, TS, and b for herring, where the reference values at 38 kHz are derived from equation (4) assuming the mean length in the appropriate normal length distribution, N(34.0,3.2) cm for 1992 and N(34.3,2.2) cm for 1991. The assumed depth range is 0-100 m and s_A-threshold value is 1000 m^2/NM^2.

	1992			1991		
Frequency (kHz)	σ (cm^2)	TS (dB)	b (dB)	σ (cm^2)	TS (dB)	b (dB)
18	6.28	-43.0	-73.6	6.52	-42.9	-73.6
38	9.38	-41.3	-71.9	9.55	-41.2	-71.9
120	6.43	-42.9	-73.5	6.87	-42.6	-73.3
200	7.08	-42.5	-73.1	-	-	-

DISCUSSION

The quantities of data underlying the several regression analyses represented in Table 2 are actually much larger than suggested by the numbers. The primary reason is imposition of the requirement that the s_A-values be at least 1000 m^2/NM^2. As mentioned in the previous section, removal of the threshold does not change the basic results for the ratio of backscattering cross section, the regression coefficient c in equation (3). With the approximate doubling in number of data pairs when the threshold is removed, the value for the standard error is reduced, which reflects the increase in range of s_A-values. That the results are essentially identical is due to the high concentration and linearity of the data, with correlation coefficient in the range 0.96-0.98.

Comparison of the new data with those gathered in 1991, as presented in Table 2, also reveals a strong similarity for the two frequency pairs that can be compared. Differences, if observable, are not highly significant, at least for the conditions that the data be restricted to the upper 100 m of the water column and that s_A-values less than 1000 m^2/NM^2 not be considered. This similarity is strikingly reinforced by inspection of Table 3. Apropos of the intrinsic measurement uncertainties in Table 1, there are no significant differences to be found here.

An interesting feature of the data, including both new frequencies of the first study, 18 and 120 kHz, and the frequency introduced in 1992, 200 kHz, is the evident peak in the four-frequency spectrum at 38 kHz. Whether this is mere chance or a more significant phenomenon associated with the precise animal size and echo sounder frequency remains to be seen. Perhaps application of an acoustic model can help resolve this issue, as with the frequency dependence of krill target strength (Foote et al. 1990, Chu et al. 1993). If experience with fish scattering models, e.g., Foote (1985) and Foote and Traynor (1988), is a guide, however, knowledge of swimbladder morphometry will be required. Since _Clupea harengus_ is a primitive fish, the form of the swimbladder is relatively simple, hence the swimbladder-mapping process may be much simpler than for the cited case of gadoids.

Another interesting, potentially valuable feature of the 1992 data is a dependence on depth. The current presentation is not designed to emphasize this, but the fact that respective values of c increase with increasing depth range, from upper 100 m to the entire water column, may reveal a deeper phenomenon. Whether this is connected with the effect of pressure on the swimbladder form or on orientation, as through the light level, also remains to be seen. Again, it may be anticipated that scattering models may contribute to the elucidation of this phenomenon. New measurements on light levels in the water column may also contribute to a fundamental understanding.

Essential to the application of acoustic scattering theory to the new multiple-frequency measurements is the correctness of the experimental data. Given the size of the uncertainties in Table 1, especially that at 18 kHz, caution must be exercised. Fortunately, development of a new 18-kHz ceramic transducer by SIMRAD, transducer type 18-11, may provide a rather simple remedy apropos of planned future measurements.

In the light of these anticipated measurements, not to mention the general incorporation of multiple-frequency echo sounding into ordinary echo integration surveys, a particular software development should probably be undertaken. This would effect the simultaneous interpretation of corresponding echo records at different frequencies when the echogram at the first-chosen frequency is interpreted. Whether or not the interpretation applies completely or at all to the others, the one interpretation may serve as a model, or template, or proposal, as it is variously called, to be confirmed or modified when the echograms at other frequencies are displayed. A like development has already been effected in BEI, but laterally, with respect to sailed distance. What is determined as the interpretation scheme for one echogram is automatically transferred to the succeeding echogram - for acceptance or rejection by the operator. A similar process should be feasible for rationalizing the interpretation of multiple-frequency echograms.

At the same time, data-checking routines might also be incorporated in BEI. In any case, they are necessary in post-postprocessing, i.e., in data analysis. Error avoidance at the earliest stages in data collection and processing should, of course, always be a guiding principle.

Biological measurements could also be improved in future work by analysis of fish specimens for fat content. According to Ona (1990), this is related to swimbladder volume, in inverse proportion. Such measurements would supplement swimbladder morphometry.

The possibility of measuring resolved single-fish echoes is another attraction of continued observation of herring in the Ofotfjord-Tysfjord system. Direct measurement of in situ target strength could provide an independent test of the basic theory underlying the present work, at least in the weak-scattering limit when extinction is demonstrably negligible. The present application of theory may be justified from the smallness of the effect, which on average overall causes an underestimate in area fish density of about 5%. While it is possible to correct for extinction (Foote 1990), the extinction cross section must be known. This is known, to an extent, for herring at 38 kHz (Foote, Ona and Toresen 1992), but not at the other frequencies. It may be possible that information on the frequency dependence of the extinction cross section can be obtained from the kind of measurements described here, again in conjunction with the exercise of scattering models.

ACKNOWLEDGEMENTS

I. Røttingen is thanked for communication of detailed information on the state of herring aggregations in advance of the cruise. A. Romslo, B. Kvinge, and H. P. Knudsen are thanked for diverse contributions to data collection and cruise preparations. Discussions with R. A. Bullis, D. Chu, I. Huse, and T. K. Stanton are acknowledged. N. Diner is thanked for rendering the abstract.

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