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ON THE PROBLEM OF DETERMINING THE RELATIONSHIP BETWEEN INTEGRATED ECHO INTENSITY AND FISH DENSITY

by

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INTRODUCTION

Echo integration is now widely used to obtain estimates of abundance of fish populations (DRAGESUND and OLSEN 1965, BODHOLT 1969, JOHANNESSON and LOSSE 1973, MIDTTUN and NAKKEN 1971, THORNE et.al 1971). The fundamental background for the integration method is given in FORBES and NAKKEN (1972) and can be summed up as follows: when a time varied gain, compensating for one way geometrical spreading and two ways absorption of the sound, is applied, and the echo voltage is squared before it is integrated, then the output of an echo integrator bears a linear relationship to fish density. The linear relationship between echo intensity and fish density empirically shown by SCERBINO and TRUSKANOV (1966), is dependent on the scattering cross section or target strength of the fish and is thus a constant for a given species and size (CRAIG 1973). In order to obtain estimates of absolute density of fish from integration values, this relationship must be quantified, i.e. the slope and the intersect of a straight line must be determined.

Target strengths for a large number of fish from various species were investigated during the summer 1971. The main results from these experiments are reported elsewhere (NAKKEN and OLSEN 1973). The present paper deals with some results from the measurements which may simplify the determination of the numerical values of the relationship between echo intensity and fish density in practice.

MATERIAL AND METHODS

The relation between the integrated echo intensity, M, and the number of fish per unit area, P_A, is (THORNE and WOODEY 1970, MIDTTUN and NAKKEN 1973):

$$P_A = CM + d \tag{I}$$

The density coefficient, C, expresses the number of fish per unit area which contribute to one unit of the integrated echo intensity. The density, d, is the lowest density which can be recorded and can thus be regarded as a threshold density.

The density coefficient, C, depends on fish species and size and on the characteristics of the sounder and integration system. It is therefore convenient to write C as a product (NAKKEN and VESTNES 1970, CRAIG 1973).

$$C = C_f \cdot C_i \tag{II}$$

where C_f now depends only on fish specie and size and C_i is an "instrumentation constant" which can be determined by calibration of the instruments.

As C_f is inversely proportional to the scattering cross section one arrives at

$$C_f = C_s \cdot l^{-b} \tag{III}$$

where l is the length of the fish and both C_s and b are constants for a given species. Numerical values of b are given by several authors (LOVE 1969 and 1971, MIDTTUN and HOFF 1962, Mc CARTNEY and STUBBS 1971, GODDARD and WELSBY 1973, NAKKEN and OLSEN 1973). Equations II and III give

$$C = C_s \cdot C_i \cdot l^{-b} \tag{IV}$$

When C_s, b and C_i are known, C can be calculated for any length, l. Examples of such calculations are given by CRAIG (1973). NAKKEN and DOMMASNES (1975) and BUZETA and NAKKEN (1975) use a different approach. They determined one (or a few) set of corresponding values of C and l by doing integration on individual fish and count the number of traces on the recording paper (MIDTTUN and NAKKEN 1971, and 1973). Using the observations of C and l in equation IV, together with an empirically determined value of b (NAKKEN and OLSEN 1973) they arrived at estimates of $C_s \cdot C_i$ for the species and integration system under consideration. Next, equation IV was used to obtain estimates of C for all length groups in question.

In stead of using equation IV in the calculations of C, a suitable table can be made which contain the empirical information on C_s and b. The "fish dependent" part of the density coefficient C can in such a table then be found for as many species and size groups as there are sufficient knowledge of. Introducing a reference target with a density coefficient $C = C_{ref}$ in equation II one get:

$$\frac{C}{C_{ref}} = \frac{C_f}{C_{ref}} \cdot C_i \qquad \text{(V)}$$

and putting $\frac{C_f}{C_{ref}} = r$ one finally has:

$$C = C_i \cdot C_{ref} \cdot r \qquad \text{(VI)}$$

From this equation relative values of C are found when values of r are available.

Values of r were obtained from the data collected by NAKKEN and OLSEN (1973). In that paper the instrument set up as well as the working procedure of the experiment were described in detail and here just a few remarks will be given. For the dorsal aspect of each fish an average echo intensity A, was calculated as a running mean according to the following formula

$$A = \frac{1}{6} \int_{\varphi}^{\varphi + 6} V \, d\varphi \qquad \text{(VII)}$$

where φ is the angle between the perpendicular to the acoustic axis of the transducer and the long axis of the fish in degrees. V is the observed echo voltage. The maximum values of these running means were grouped according to species and length and mean values and confidence limits for each group were calculated. Finally r was calculated by inverting the relative intensities, multiplying them with 100, and then select C_{ref} equal to C_f for a 100 cm cod.

RESULTS AND DISCUSSION

Fig. 1 shows the mean value of the relative echo intensity per individual fish as a function of fish length for the observed species. The 95 per cent confidence limits are indicated. The curves are fitted by eye, and except for the interval 15-25 cm were they show a downward bend, they are similar to those fitted to the observations of the maximum dorsal aspect scattering cross sections by a linear regression analyses (NAKKEN and OLSEN 1973). Observations of maximum dorsal aspect target strength can therefore be used to obtain reliable ratios of echo intensity between species and length groups. In other words, the numerical values of the power b determined for the maximum dorsal aspect scattering cross section, can also be applied for the density coefficient C. The deviations from a smooth logarithmic curve in the interval 15-20 cm are probably caused by interaction in the reflection from the different parts of the fish body. In this interval where the ratio between fish length and wave length are 4-5, there is a transition zone with respect to the nature of the back scattering.

In order to compare density coefficients for different species and lengths instead of the echo intensities in Fig. 1, Table 1 were made. The values in the table are arrived by inverting the values in Fig. 1, multiplying them by 100 and using $C_{ref} = C_f$ for a 100 cm cod. Table 1 expresses then how many fishes of the different species and sizes which must contribute to the integrated echo intensity in order to equal the contribution from a 100 cm cod. When Table 1 is used to arrive at absolute values for the density coefficient C, the value of C must be known for one specie and size. When so is the case, the combination of equation II and Table 1 give the absolute density coefficients for all the other categories in Table 1. For example: If, for a given integration system, the density coefficient C for a 60 cm cod is found to be $6.4 \cdot 10^6$ $\frac{\text{number}}{(\text{nm})^2 \cdot \text{mm}}$, then all values in Table 1 must be multiplied by $\frac{6.4 \cdot 10^6}{3.4}$. The new table arrived at by this operation then contains absolute values for the density coefficient for that particular integration system for all species and lengths covered by Table 1.

REFERENCES

BODHOLT, H. 1969. Quantitative measurements of scattering layers. Simrad Bull., (3): 1-11.

BUZETA, R. and NAKKEN, O. 1975. Abundance estimates of the spawning stock of blue whiting (Micromesistius poutassou Risso, 1810) in the area west of the British Isles in 1972 - 1974. FiskDir. Skr. Ser. HavUnders., 16: [In press].

CRAIG, R.E. 1973. The quantitative use of echo sounders. Introductory notes. FAO Fisheries Circular, October 1973: 1-15 [Mimeo.]

DOMMASNES A., NAKKEN, O., SÆTRE, R. and FRØILAND, Ø. 1974. Lodde- og polartorskundersøkelser i Barentshavet i september - oktober 1973. Fiskets Gang, 60: 73-77.

DRAGESUND, O. and OLSEN, S. 1965. On the possibility of estimating year-class strength by measuring echo abundance of 0-group fish. FiskDir.Skr.Ser.HavUnders., 13 (8): 47-75.

FORBES, S.T. and NAKKEN, O. 1972 (Editors). Manual of methods for fisheries resource survey and appraisal. Part 2. The use of acoustic instruments for fish detection and abundance estimation. FAO, Rome 1972.

GODDARD, F.C. and WELSBY, V.G. 1973. Statistical measurement of the acoustic target strength of live fish. Acoustic Methods in Fishery Research, ICES/FAO/ICNAF Symp. Bergen 1973 (40): 1-9 [Mimeo.]

JOHANNESSON, K.A. and LOSSE, G.F. 1973. Some results of observed abundance estimations in several UNDP/FAO resource survey project. Acoustic Methods in Fisheries Research. Symp. ICES/FAO/ICNAF, Bergen 1973 (3): 1-77 [Mimeo.]

LOVE, R.H. 1969. Maximum side aspect target strength of an individual fish. J.Acoust.Soc.Am., 46: 746-752.

LOVE, R.H. 1971. Dorsal aspect target strength of an individual fish. J.Acoust.Soc.Am., 49: 816-823.

McCARTNEY, B.S. and STUBBS, A.R. 1971. Measurements of the acoustic target strengths of fish in dorsal aspect including swinbladder resonance. J.Sound Vile. 15(3): 397-420.

MIDTTUN, L. and HOFF, I. 1962. Measurements of the reflection of sound by fish. FiskDir.Skr.Ser.HavUnders., 13 (3): 1-18.

MIDTTUN, L. and NAKKEN, O. 1971. On acoustic identification, sizing and abundance estimation of fish. FiskDir.Skr.Ser. HavUnders., 16: 36-48.

MIDTTUN, L. and NAKKEN, O. 1973. Some results of abundance estimation studies with echo integrators. Acoustic Methods in Fishery Research, ICES/FAO/ICNAF Symp. Bergen 1973 (38): 1-10, 1 Tab., 4 Figs. [Mimeo.]

NAKKEN, O. and OLSEN, K. 1973. Target strength measurements of fish. Acoustic Methods in Fishery Research, ICES/FAO/ ICNAF Symp. Bergen 1973 (24): 1-33 [Mimeo.]

NAKKEN, O. and VESTNES, G. 1970. Ekkointegratoren. Et apparat for å måle fisketetthet. Fiskets Gang, 56: 932-936.

SCHERBINO, M.N. and TRUSKANOV, M.D. 1966. Determination of the density of fish consentrations by means of hydroacoustic apparatus. Coun.Meet.Int.Coun. Explor.Sea. 1972 (F.3.): 1-6, 3 Figs. [Mimeo.]

THORNE, R.E., REEVES, J.E. and MILLIKAN, A.E. 1971. Estimation of the hake population in Port Susan, Washington, using an echo integrator. J.Fish.Res.Bd.Canada 28(9): 1275-1284.

THORNE, R.E. and WOODEY, J.C. 1970. Stock assessment by echo integration and its application to juvenile Sockeye salmon in Lake Washington. University of Washington, College of Fisheries, Circular no. 70 - 2. 1970.

Table 1. Relative density coefficients, r, at 38 kHz, according to species and length. Numbers in brackets are extrapolated.

	SPECIES				
Length CM	Cod, saithe, pollack	Haddock, blue whiting	Herring, sprat	Mackerel	Prawn
07	526.3	(526.3)	625.0		
08	384.6	(384.6)	416.7		1250.0
09	270.3	(270.3)	303.0		833.3
10	208.3	(208.3)	277.8		625.0
11	161.3	(161.3)	204.1		
12	128.2	(128.2)	175.4		
14	82.0	(100.0)	147.1		
16	58.8	(71.4)	133.3		
20	41.7	50.0	116.3		
25	26.7	34.5	84.7	200.0	
30	17.2	24.1	53.2	149.3	
35	12.2	17.9	(35.7)	111.1	
40	8.9	12.5	(25.0)	(80)	
45	6.8	8.3			
50	5.3	7.1			
60	3.4				
70	2.3				
80	(1.7)				
90	(1.3)				
100	(1.0)				

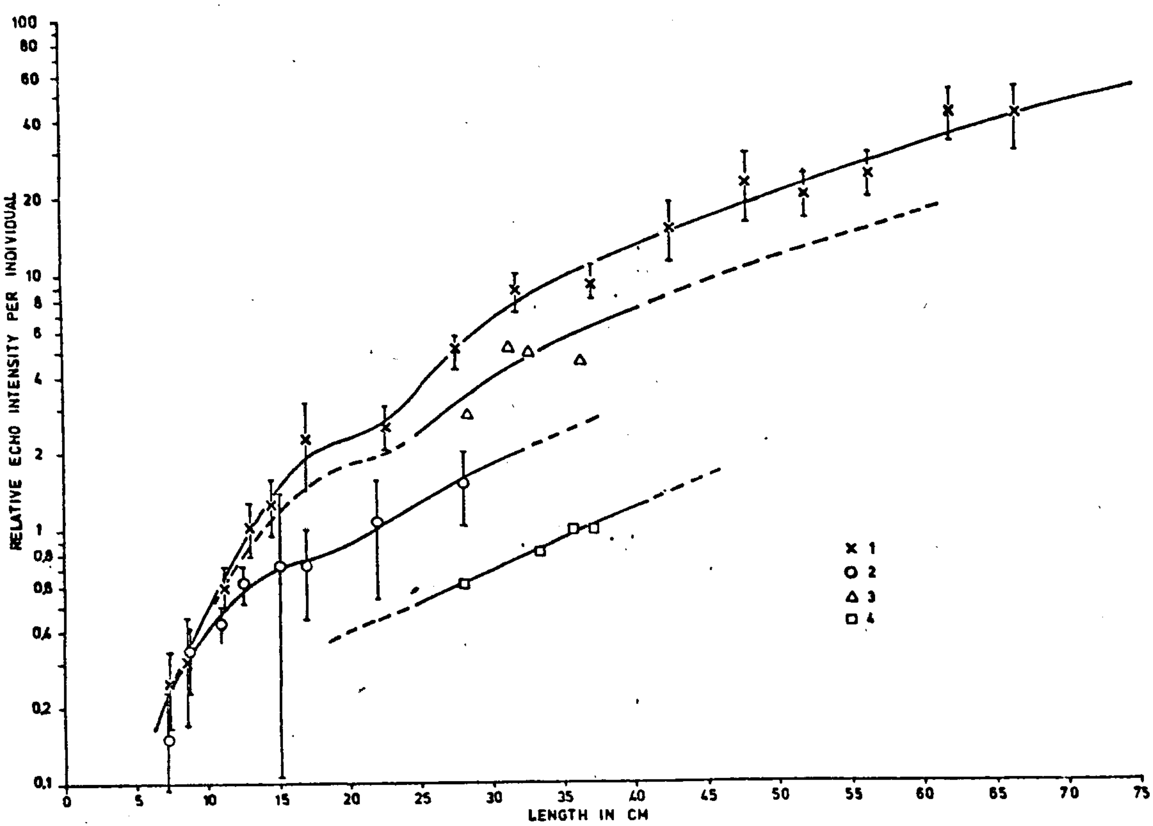

Fig. 1. Relative echo intensity per individual at 38 kHz (percent of the echo intensity of a 100 cm cod) as a function of fishlength for some species. 1) Cod, Pollack and Saithe, 2) Herring and Sprat, 3) Haddock and Blue whiting and 4) Mackerel. 95 percent confidence limits are indicated.