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Methods and Results of *In situ* Measurements of the Average Target Strength of Pelagic Fishes

by

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ABSTRACT

The paper considers methods and results of measurements of the average target strength of blue whiting made on scattered aggregations of freely swimming fish in the Norwegian Sea in 1982-1984. The measurements were taken aboard the RV"Persey-III" during echometric surveys of blue whiting in different parts of the Norwegian Sea. A compact two-channel echo integrating and echo counting device EI-2 connected to the EK-S-38 was used for target strength measurements and echometric surveying. Average target strengths of single fish $\langle TS \rangle$ and of 1 kg biomass $\langle TS_{kg} \rangle$ in different feeding periods of blue whiting were determined.

SPECIAL SESSION ON BIOLOGICAL STUDIES

INTRODUCTION

Echometric surveys of blue whiting were conducted west and north-west of Ireland and Great Britain in March-April. Fish migrating after spawning to feed as well as immature fish were then surveyed in the northern Norwegian Sea. In March-April blue whiting forming dense aggregations were recorded primarily at the depth of 300-500 m. From late April onwards blue whiting went up to the depths of 150-300 m at night and in the upper part of aggregations fish were recorded by the echo sounder individually. In July both at night and in the daytime blue whiting in northern parts of the sea were recorded in scattered aggregations at depths 120-150 m.

Precisely in those periods when fish were recorded individually echo signals from single fish were measured, blue whiting in the surveyed layer were fished and size composition of fish, their average length $\bar{L}$, mean weight $\bar{W}$, absolute calibration coefficient C of echo integrator readings M, average target strength $\langle TS \rangle$ of single fish and that of 1 kg biomass were determined.

MATERIAL AND METHODS

It is known that the average target strength of fish *in situ* may be measured with instrumental constants of the echo sounder C_{ES} and echo integrator C_{EI} as well as absolute calibration coefficient C of echo integrator readings M estimated on aggregations of freely swimming fish first determined. In this case the average target strength of fish $\langle TS \rangle$ and of 1 kg biomass $\langle TS_{kg} \rangle$ are calculated by the formulae (Burczynski et al., 1982):

$$\langle TS \rangle = 10 \log 3430 \cdot 10^3 + C_{ES} - C_{EI} + \Delta TVG - 10 \log C;$$

$$C_{ES} = -(SL+VR) - 10 \log \frac{c\,\tau}{2} + 20 \log r_o + 2\alpha r_o - 10 \log \Psi;$$

$$C_{EI} = 10 \log M - 20 \log U_{RMS} - 10 \log H;$$

$$\langle TS_{kg} \rangle = \langle TS \rangle - 10 \log \bar{W} \qquad (1)$$

where SL - transmission level of the echo sounder, db/μPa/m;

VR - sensitivity of the echo sounder, db/V /μPa;

c - sound velocity in water, m/s;

τ - length of transmitted pulse, s;

Δ TVG - difference between theoretiwal and actual TVG function at surveyed depth;

r_o - maximum depth of TVG function, m;

α - coefficient of sound absorption in water, db/m

Ψ — equivalent width of the directivity diagramme of the echo sounder, steradian;

H - thickness of the integrated layer, m;

$\bar{W}$ - average weight of fish, kg;

U_{RMS} - effective voltage at echo integrator input, V

Constants C_{ES} and C_{EI} may be estimated accurately enough: C_{ES} is usually determined with the help of a hydrophone (Bodholt et al., 1979) or calibrated sphere (Foote et al., 1982), C_{EI} is calculated using standard electric instruments. There are several methods (echo counting and photogrammetric methods, using cages with live fish, basing on catch size within integration range) to calculate the coefficient C at present, each of which has its shortcomings and advantages. Major advantages of the echo counting method are: coefficient C and target strength are estimated during surveying real aggregations of freely swimming fish with their behaviour and spacial orientation, a great number of measurements per a short time interval. The target strength of blue whiting was measured with the aforesaid method, which is based on simultaneous echo integration and counting of signals from fish in scattered aggregations, when almost all fish are recorded individually (Ermolchev, 1977 1979; Ermolchev et al., 1980). For this purpose "calibration" regime is implemented in the echo integrating and echo counting device EI-2, when echoes are divided into those from single fish and from groups of fish and simultaneously a set of parameters of echo signals is measured: total energy of echoes M, number of echoes from single fish K_o and from groups of fish K_g. Measurements were made within a thin layer (H=20-40 m). Values of M, K_o and K_g were automatically recorded both in digital form by standard electronic pulse counters (Ermolchev, Zaferman, 1983) and in analogue form directly on the echo sounder echogramme.

The density of aggregations was determined from readings of the echo counting system (K_o, K_g):-

$$\rho_S = 3.43 \cdot 10^6 \, \frac{K_o + K_g \cdot \bar{X}}{Nn \cdot \bar{S}_E} \qquad (2)$$

where $\bar{X}$ - mean number of fish in groups;

$\bar{S}_E$ - effective section of the sonified volume in a sampled layer at depth $\bar{r}$, sq.m;

Nn - number of pings of the echo sounder per a selected interval of measurements

The mean number of fish in groups $\bar{X}$ was determined theoretically from the ratio K_g/K_o under the assuption that the fish were Poisson-distributed in the sonified volume within the layer sampled: at $K_g/K_o \leq 0.5$ $\bar{X}$ = 2.0 (Ermolchev, 1979). The effective angle of the antenna directivity diagramme θ, diameter D_E and section S_E of the sonified volume were determined by the horizontal extent of echo traces 1 (mm) from single fish on the echogramme at a maximum transmission frequency of the echo sounder Q_m(pulse/min.), maximum tape speed V_p (mm/min.) and at a constant ship speed (3-4 knots).

$$tg\,\theta = \frac{D_E}{2r}; \quad D_E = \frac{1852 \cdot V_s \cdot 1}{V_p \cdot 60}; \quad S_E = \frac{\pi D_E^2}{4} \qquad (3)$$

Simultaneously size-weight composition of blue whiting was determined in catches taken by pelagic trawl at the surveyed depth.

Values of ρ_s were compared with measured echo intensities M and coefficient C was then calculated using the method of regression analysis. A mean geometric estimate of the functional relationship (GM regression) between ρ_s and M was used to exclude a feasible bias in the estimate of C due to non-uniform distribution of different values of ρ_s in samples (Ricker, 1973).

RESULTS AND DISCUSSION

Realizations were processed containing echo signals from groups of fish ($K_g = 0.1 \div 0.5\, K_o$) and those without them ($K_g = 0$). The number of echoes from single fish in each realization was $K_o = 500 \div 2500$. Absolute calibration coefficients in the two cases appeared to be close in value. The total number of echoes in each calculation of the coefficient C was ≥ 10000. Echo sounder instrumental constant was determined from measurements on calibrated sphere. An internal integrator with transmitted pulse length of $\tau = 1.0$ ms, TVG function - 20 log r/"0"db, 29/25E antenna with directivity diagramme angles of 8° x 8°(10 log $\psi = -19.6$db) were used in the EK-S-38. The total value (SL+VR) according to measurements on calibrated sphere was found to be 130.4db. The value of ΔTVG in the echo sounder for different depths within 3-500 m was calculated from electric measurements, with $\alpha = 8$db/km for the Norwegian Sea. To calculate the coefficient C the following parameters are measured: number of echoes from fish, their energy M, ship speed V_s and horizontal extent of echo traces from fish 1.

At ΔK_o=5%, ΔM=10%, ΔV_s=5%, Δl=10% and $n \geq 10$ (number of samples of ρ_s and M) it may be expected that $\Delta C \leq 18\%$ (at $n > 20$ $\Delta C \to 12\%$).

In estimation of the average target strength of fish $\langle TS \rangle$ the measured parameters are (SL+VR), τ, C_{EI}, Δ TVG, C. If (SL+VR)= 10-12%, $\Delta\tau$=5%, ΔC_{EI}=10-12%, $\Delta(\Delta TVG)$=5%, ΔC=12%, the error in the average target strength measurement by the aforesaid method will not exceed 20-25% and in particular in those cases when the variation of fish size is insignificant (S_L).

Table 1 shows the results of measurements of the average target strength of blue whiting of different size in different parts of the Norwegian Sea. Table 2 and Figs.1,2 and 3 present expected errors in estimates of C and $\langle TS \rangle$.

CONCLUSIONS

The average target strengths <u>in situ</u> of single blue whiting $\langle TS \rangle$ and of 1 kg biomass $\langle TS_{kg} \rangle$ were measured on scattered aggregations of freely swimming fish primarily in the period of their post-spawning feeding. All echoes from single fish and from groups of fish in the sonified volume at surveyed depths were measured. However, the behaviour and orientation of fish remain unknown as well as wether the values of $\langle TS_{kg} \rangle$ and $\langle TS \rangle$ are constant at other stages of life cycle of blue whiting: before spawning, during spawning, in dense aggregations, at other depths.

To answer this questions the employment of hydroacoustic systems in complex with other deepwater facilities (for instance, photographing and television) is to our opinion rather promising and allows to determine the density ρ_v and spacial orientation of fish in the sonified volume in dense aggregations of fish (Carscadden, Miller, 1980; Ermolchev, 1978; Ermolchev, Zaferman, 1981; Guzman et al., 1982; Olsen, 1981),

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Table 1. Measurements of the average target strength of blue whiting in different periods of their post-spawning feeding in 1982-1984 (f=38kHz)

Area, period	$\bar{L}$ cm	$\bar{W}$ kg	$\bar{r}$ m	⟨TS⟩ db	⟨TS$_{kg}$⟩ db	R*	n*
North of Great Britain							
May 1982	3I,7	0,I70	260	-39,6	-3I,9	0,97	522
May 1983	25,I	0,I0I	I90	-44,0	-34,I	0,99	5I7
- " -	29,0	0,I35	250	-4I,3	-32,6	0,95	43I
- " -	3I,4	0,I59	250	-40,3	-32,3	0,9I	469
May 1984	20,2	0,048	"	-43,4	-30,2	0,93	386
- " -	24,6	0,089	260	-4I,9	-3I,4	0,99	474
- " -	26,0	0,I05	I40	-4I,0	-3I,2	0,97	456
- " -	24,2	0,I20	260	-42,5	-33,3	0,98	52I
- " -	28,5	0,I32	220	-40,5	-3I,7	0,90	5II
- " -	24,5	0,096	260	-42,4	-32,2	0,93	5I8
East of the Faeroes							
May 1982	32,0	0,I59	270	-40,8	-32,8	0,9	5I5
- " -	32,0	0,I59	2I0	-40,6	-32,6	0,96	482
- " -	32,3	0,I54	2I0	-39,9	-3I,8	0,98	438
East of Iceland							
July 1982	3I,0	0,I87	200	-40,5	-33,2	0,98	53I
- " -	3I,I	0,I98	205	-39,5	-32,5	0,88	478
- " -	30,5	0,I88	I35	-40,7	-33,4	0,96	463

* R - correlation coefficient ρ and M

n - number of fish in the estimation of $\bar{L}$ and $\bar{W}$.

Table 2. Errors of in situ measurements of the average target strength of blue whiting in 1984

L, cm	Size composition of catches, %					
I6	0,2					
I7	9,0	2,0	0,8	–	–	–
I8	I9,8	3,0	4,4	0,8	–	–
I9	30,I	2,0	4,6	I,I	0,6	–
20	6,8	I,4	7,6	3,3	4,7	0,3
2I	3,4	0,9	2,2	0,5	I,9	0,3
22	3,6	I,4	I,6	3,8	5,3	0,9
23	9,0	5,3	9,5	9,6	9,7	2,4
24	9,9	II,0	I4,4	29,0	26,8	II,8
25	7,2	II,9	27,8	33,9	29,5	29,9
26	0,5	5,0	7,9	I0,9	II,9	24,3
27	0,5	2,6	6,3	4,4	3,5	I8,I
28	–	I,2	2,5	0,8	0,6	4,2
29	–	0,3	0,5	–	0,9	I,5
30	–	3,2	0,5	–	0,6	0,9
3I	–	6,7	I,9	–	0,3	0,6
32	–	II,7	I,6	0,5	I,3	2,4
33	–	I0,5	I,9	I,6	0,9	2,I
34	–	9,6	I,4	0,3	0,9	0,3
35	–	5,7	I,2	–	0,3	–
36	–	2,6	0,8	–	–	–
37	–	I,7	0,3	–	0,3	–
38	–	0,3	0,3	–	–	–
$\bar{L}$, cm	20,2	28,5	24,2	24,5	24,6	26,0
$\bar{W}$, g	47,8	I3I,6	I20,0	95,7	88,5	I05,I
ΔC, %	4,4	I4,0	I0,0	7,8	8,0	4,0
$\langle TS \rangle$, db	-43,4	-40,5	-42,5	-42,I	-4I,9	-4I,0
$\langle TS_{kg} \rangle$, db	-30,2	-3I,7	-33,3	-3I,9	-3I,4	-3I,2
Δ TS , db	$\pm$0,83	$\pm$0,96	$\pm$0,90	$\pm$0,86	$\pm$0,86	$\pm$0,83
Δ TS , %	$\pm$2I,0	$\pm$24,8	$\pm$22,8	$\pm$2I,9	$\pm$22,0	$\pm$2I,0
S^2_L	6,7	27,9	I3,5	II,0	5,5	4,0

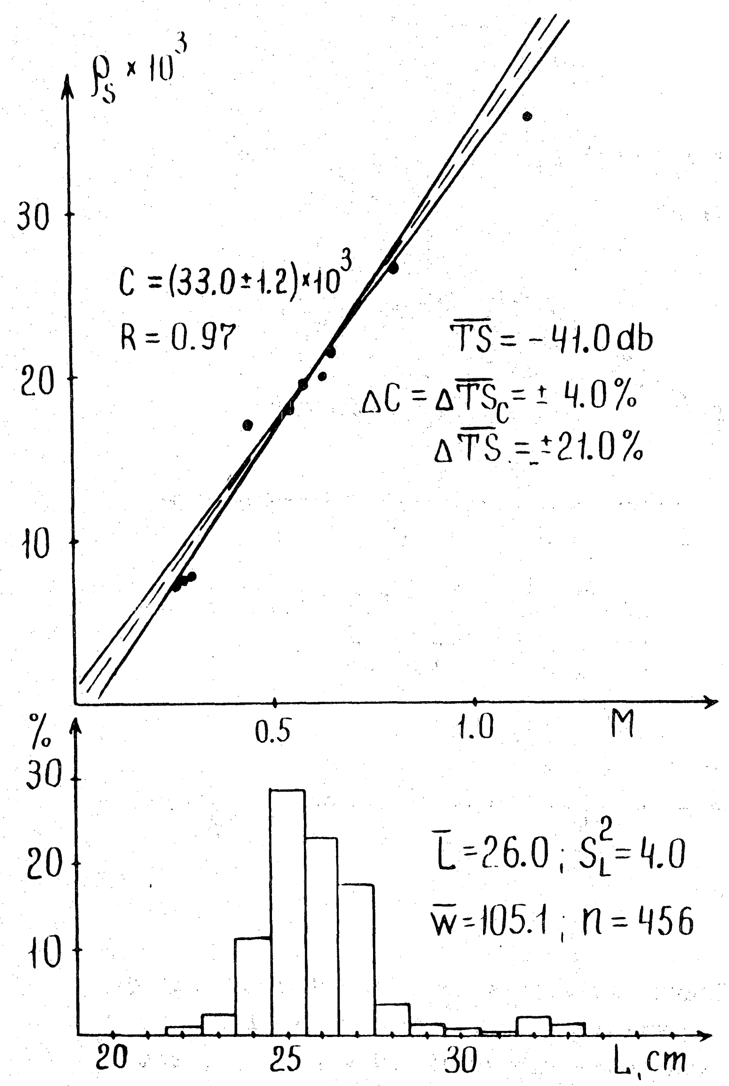

Fig.1. Statistical relationship between density of fish aggregation $\rho_s \times 10^3$ (in number of fish per sq.mile) and total energy of echoes M; size composition of catches from surveyed layer. C_{EI} = 16.2db.

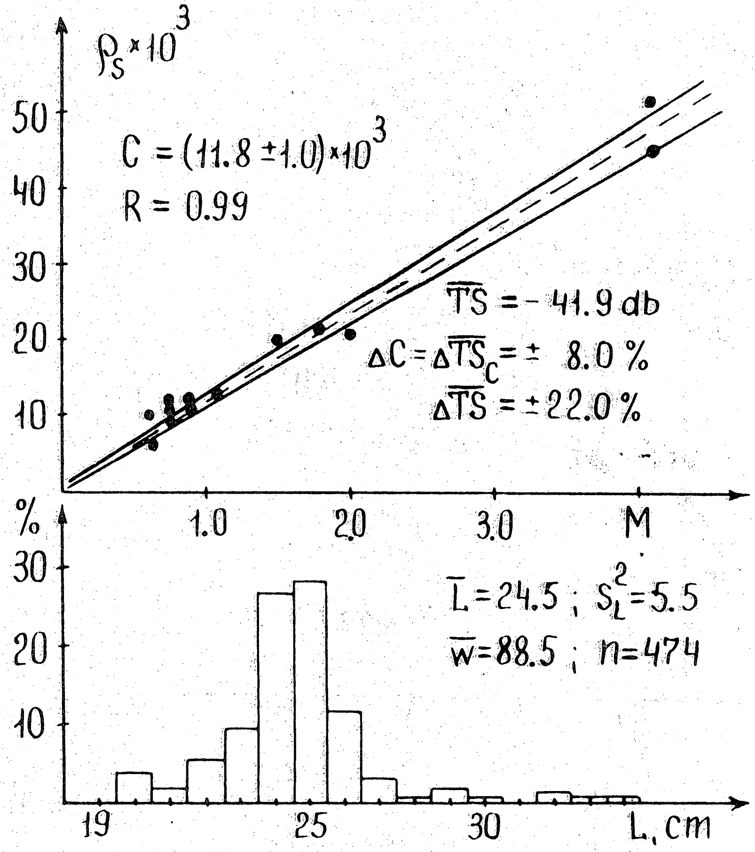

Fig. 2. Statistical relationship between density of fish aggregation $\rho_S \times 10^3$ (in number of fish per sq.mile) and total energy of echoes M; size composition of catches from the surveyed layer. $C_{EI} = 21.4$db.

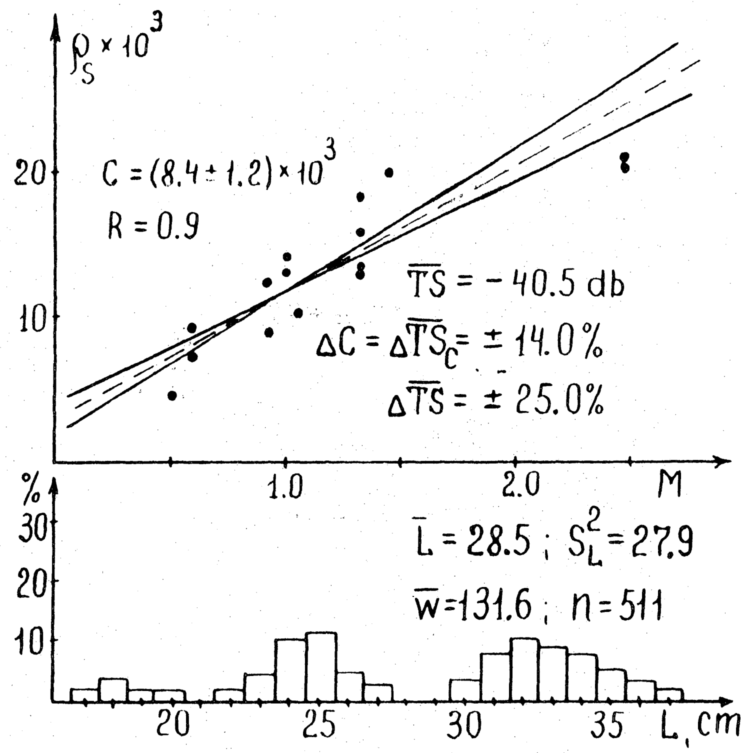

Fig. 3 Statistical relationship between density of fish in aggregation $\rho_s \times 10^3$ (in number of fish per sq.mile) and total energy of echoes M; size composition of catches from the surveyed layer C_{EI} = 21.4db.