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SOME RESULTS OF ABUNDANCE ESTIMATION STUDIES WITH ECHO INTEGRATORS

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Two examples of acoustic fish stock abundance estimation are given. The first is the estimation of the exploited Barents Sea capelin stock; the second is measurement of the size of the unexploited blue whiting stock. Surveys of both species were undertaken at the time of the year when conditions were favourable i.e. the fish were located as pelagic scattering layers and unmixed with other species.

When the echo-sounder is operated with a TVG equal to $20 \log R + 2\alpha R$, the integrated echo intensity is proportional to the number of fish per unit area. To obtain absolute values, the system is calibrated on scattered recordings when single fish can be counted.

INTRODUCTION

The use of acoustic methods for fish abundance estimation is now in a state of progressive improvement. Such methods have already provided valuable information on stock size of both exploited and unexploited fish populations (Blindheim & Nakken, 1971; Dragesund, 1970a and b; Dragesund et al., 1973; Midttun & Nakken, 1972; Thorne & Woodey, 1970; Thorne et al., 1971). The success of an acoustic abundance estimation depends very much on the behaviour and distribution of the species in question. The best conditions for the echo integration technique applied by the Institute of Marine Research, Bergen, are when the fish stock in question is distributed within a defined area, unmixed with other species and in continuous scattering layers at moderate depths in midwater. Estimation is more complicated when the fish are in dense schools or are mixed with other species. When the fish are distributed close to the bottom or near the sea surface, conditions for estimation are unfavourable.

In practical application it is therefore most important to take into consideration fish behaviour and to carry out the abundance estimation surveys when conditions are as favourable as possible. This may be related to special seasons.

Here we shall give two examples of acoustic fish stock abundance estimation. The first is the estimation of an exploited fish stock, namely the Barents Sea capelin. The second is measurement of the size of the unexploited blue whiting stock. The surveys of both species were undertaken at the time of the year when the conditions favoured the technique.

METHOD

The method applied has been described by Forbes & Nakken (1972).

When a $20 \log R + 2\alpha R$ time varied gain is used, the integrated (or averaged) echo intensity is proportional to the number of fish per unit area.

$$\varrho_A = mM + b \tag{1}$$

where ϱ_A is the number of fish per unit area and M is the integrated echo intensity. In practical application, M is accumulated over each nautical mile sailed. The constant b can be regarded as a threshold density below which no contribution to the integrated echo intensity occurs.

In estimating stock size, the two main points to be considered are:

1. determination of m and b in Equation (1), so that relative densities, M, can be converted to absolute densities ϱ_A.
2. collection of observations of M throughout the total area where the stock under consideration is distributed.

In order to determine m and b in Equation 1, corresponding values of ϱ_A and M are needed. Thorne & Woodey (1970) obtained estimates of ϱ_A by pelagic trawling. Midttun & Nakken (1971) suggested a different approach: when the fish species in question are recorded as individuals the number of fish traces which appear on the recording paper are counted; this gives a series of observations of M and N (number of fish within the depth interval of integration) from which

Table 59. Echo integrator deflections M (mm per nautical mile) and corresponding densities of fish ϱ_A (number of fish per square mile) obtained by counting fish traces, N, on the recording paper. N_1 and N_2 are obtained from the same fish traces by the personel on different watches. The results of a least mean square regression, $\varrho_A = mM + b$, are shown at the bottom of the table.

	Blue whiting							Capelin		
	Jan 1973				Mar 1973			Sep 1971		
M	N_1	ϱ_{A1}	N_2	ϱ_{A2}	M	N	ϱ_A	M	N	$\varrho_A \cdot 10^{-5}$
24	259	43 512	301	50 568	3	86	13 244	2·1	282	333
23	215	36 120	317	53 256	1	41	6 314	1·4	240	258
13	160	26 880	173	29 064	0	23	3 542	1·2	182	238
4	69	11 582	59	9 912	0	23	3 542	1·6	263	238
4	54	9 072	59	9 912	0	24	3 696	2·3	337	340
5	72	12 096	62	10 416	1	36	5 544	1·4	172	223
21	265	30 210	291	33 174	1	43	6 622	1·4	232	235
17	225	25 650	220	25 080	1	47	7 238	1·5	291	287
18	177	20 178	201	22 914	2	58	8 932			
7	101	11 514	93	10 602	4	81	9 639			
6	94	10 716	104	11 856	9	132	15 708			
9	129	14 706	114	12 996	8	121	14 399			
9	112	12 768	119	13 566	8	136	16 184			
7	99	11 286	102	11 628	4	88	10 472			
7	110	10 230	117	10 881	4	94	11 186			
12	150	13 950	137	12 741	8	143	17 017			
2	64	5 952	44	4 092	5	108	12 852			
12	121	11 439	121	11 253	6	91	10 829			
15	225	20 925	158	14 695						
	r = 0·9236		0·8905			r = 0·9391			r = 0·8960	
	m = 1535		1823			m = 1345			m = 106·10³	
	b = −313		−1750			b = 4976			b = 96·10³	

ϱ_A is obtained by dividing the number of fish, N, by the sampling area of the sounder, within the interval of counting and integration. The sampling area of the sounder can be found in two ways. When the echosounder used has a calibrated recorder gain switch, the difference between the recorder gain at normal setting and the gain giving a just visible marking of the paper for the fish in question is used to find the sampling angle in the directivity diagram. The sampling angle (detection angle) can also be found by counting the number of echoes from each fish. (Midttun & Nakken, 1971).

It should be noted that it is not necessary to make the observations of ϱ_A and M with the same echosounder. When using two sounders, the one which is used to obtain estimates of N should have a 40 log R + $2\alpha R$ time varied gain, as this will simplify the later calculations.

The total amount of fish, T, of a given species within an area, A, can be written

$$T = \int_A \varrho_A \, dA = m \int_A M dA + b \cdot A. \qquad (2)$$

The most convenient way to calculate T is therefore to do an area integration of the integrated echo-intensity ($\int_A M dA$). Then a relative measure of fish abundance is achieved. If estimates of m are available, absolute estimates of fish abundance, T, can be calculated.

When mixed recordings occur, it is necessary to discriminate between the species and to find the contribution to the integrator recordings from each species. On board the Norwegian research vessels it is therefore routine procedure to identify the echo recordings by trawl catches whenever the recordings apparently change. It is also routine to scrutinize the acoustic data each day and to decide which species of fish have contributed to the integrated echo intensity. This analysis is done by experienced people on the basis of examination of trawl catches and echo recordings.

During the investigations reported in this paper, the six echo integrators on board the "G. O. Sars" were connected to the Simrad EK 38 scientific sounder. The five upper channels were normally adjusted to integrate in 50 m depth slices down to 250 m, while the sixth channel worked between 250 and 449 m. During the blue whiting surveys a slightly different setting was adopted in order to include the deeper part of the fish layers. All channels have a bottom stop function which stops the integration just above bottom.

The integrated echo intensities were read per nautical mile, averaged for each 25 nautical miles (running means) and plotted along the course line.

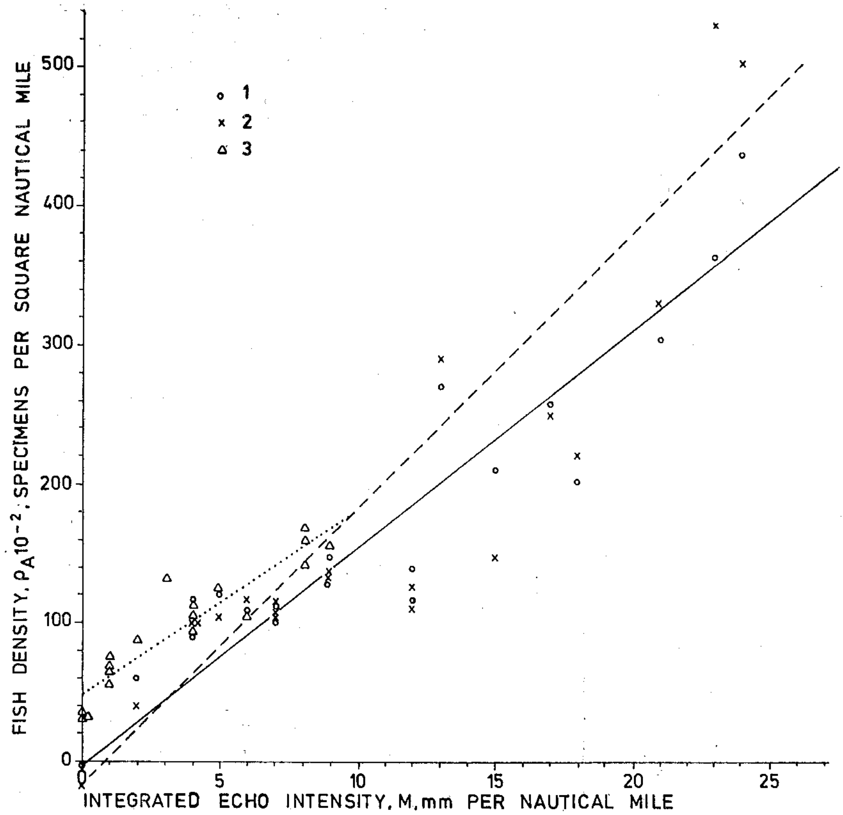

Figure 222. Corresponding values of integrated echo intensity, M, and fish density, ϱ_A, (calculated from counts on the recording paper) for blue whiting. 1) and 2) estimates from two different watches counting the same recording paper in January 1973, 3) estimates from March, 1973.

RESULTS AND DISCUSSION

DETERMINATION OF m AND b

Table 59 and Figures 222 and 223 show some results of the determination of the constants m and b for blue whiting and capelin. The differing values for the constant b for blue whiting are caused by the difficulty of defining the 'just visible mark' on the recording paper. The difference in the slopes, m, from January to March are harder to explain. In March a relatively narrow range of fish density observations was used and the values from January may be the more reliable. The mean of all three slopes is 1570 individuals/mm per nautical mile·nautical mile², corresponding to approximately 0·4 ton/mm per nautical mile·nautical mile².

For capelin the calibration run shows a slope of $106 \cdot 10^3$ individuals/mm per nautical mile·nautical mile² which corresponds to approximately 1·4 ton/mm per nautical mile·nautical mile². The difference between the slopes for blue whiting and capelin indicates that the capelin has a much lower target strength (5–6 dB) than blue whiting of the same size. Observations at sea indicate that a 15 cm capelin has a target strength of – 50 dB while a 15 cm cod (Nakken & Olsen, 197~~6~~7) has an expected target strength of – 45 dB Further, the results obtained by Nakken & Olsen (197~~6~~7) indicate that the blue whiting has a dorsal aspect target strength which is slightly lower than that of cod. The difference between blue whiting and capelin shown by our observations is therefore reasonable. Since the calibration results for the "G. O. Sars" show no significant differences in equipment characteristics between 1971 and 1973, the results obtained within this period are comparable.

The bias introduced in the estimates of m, by other species mixing with the blue whiting and capelin during the calibration runs is believed to be small. Pelagic trawl catches indicated that both species were in 'pure' concentrations.

It is seen from Equation (2) that, even if the magnitude of the constant b exceeds that of m, b will have a quite insignificant influence on the total amount of fish plotted in the distribution charts (Figs. 224 and 225). In calculating the amount of fish present within the

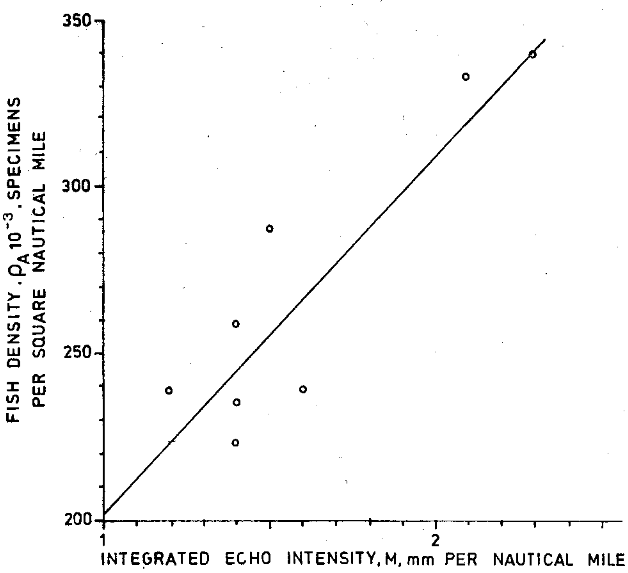

Figure 223. Corresponding values of integrated echo intensity, M, and fish density, ϱ_A, (calculated from counts on the recording paper) for capelin.

charted distribution areas, the following forms of Equation (2) were therefore used:

$$\text{Blue whiting: } T = 0{\cdot}4 \cdot \int_A M \mathrm{d}A \text{ (ton)}$$

$$\text{Capelin : } T = 1{\cdot}4 \cdot \int_A M \mathrm{d}A \text{ (ton)} \qquad (3)$$

The magnitude of the variances associated with the estimates obtained from Equations (3) are to some extent unknown. As the variance will vary from species to species and from year to year the estimates for the two species will be discussed separately.

CAPELIN

The resulting abundance estimates from the two capelin surveys are tabulated below:

1971		1972	
Rel. ($\int M\mathrm{d}A$) mm·n mile^2	Abs. (T) ton	Rel. ($\int M\mathrm{d}A$) mm·n mile^2	Abs. (T) ton
$4{\cdot}8 \cdot 10^6$	$6{\cdot}7 \cdot 10^6$	$6{\cdot}5 \cdot 10^6$	$9{\cdot}1 \cdot 10^6$

The absolute values in this table are lower than those reported by Midttun & Nakken (1972). The reason for this discrepancy is the lower values of m. The values of m reported in 1972 were found by taking the ratios between the arithmetic means of ϱ_A and M in Table 59. The magnitude of this ratio depends on the magnitude of b and the procedure may lead to serious errors especially when many low values of M and ϱ_A are used.

The capelin survey in 1971 (Fig. 224) was carried out under favourable conditions. The fish were distributed over wide areas in scattering layers and thin schools well above the bottom and practically unmixed with other species. Excluding all uncertain values of M (disregarding the reason for the un-

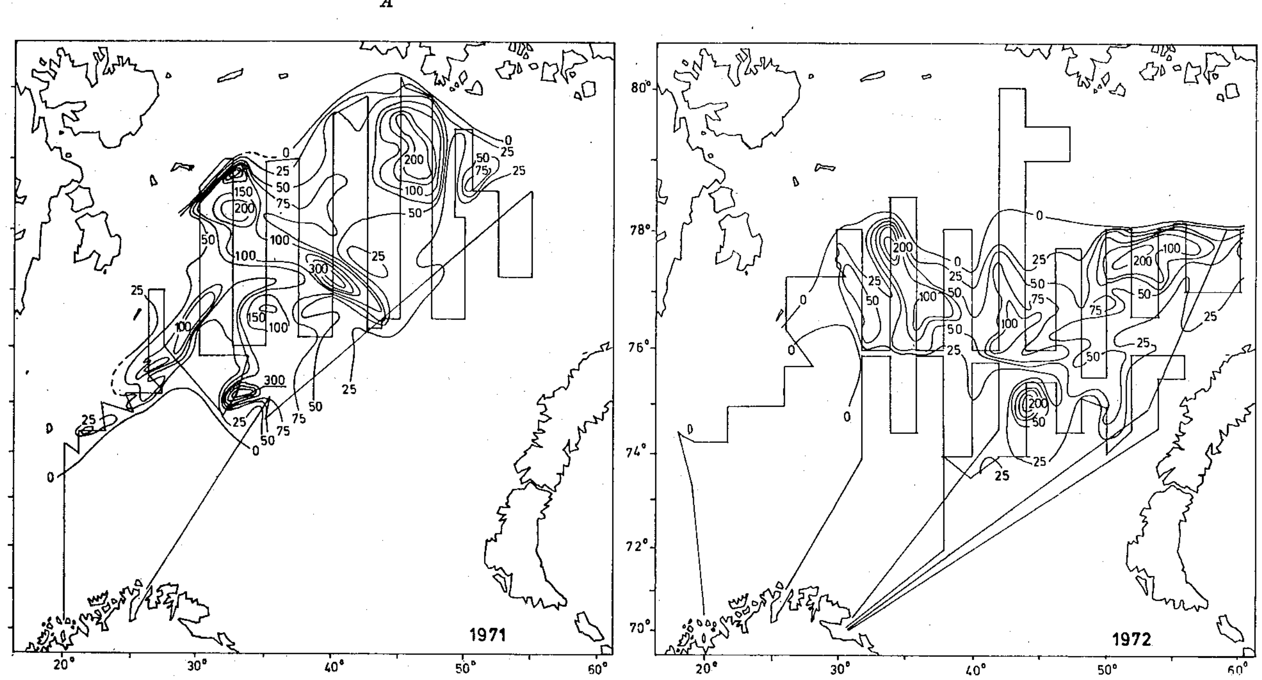

Figure 224. Integrated echo intensity (mm deflection) of capelin in 12–29 September 1971 and 5–20 August 1972. The survey routes are indicated.

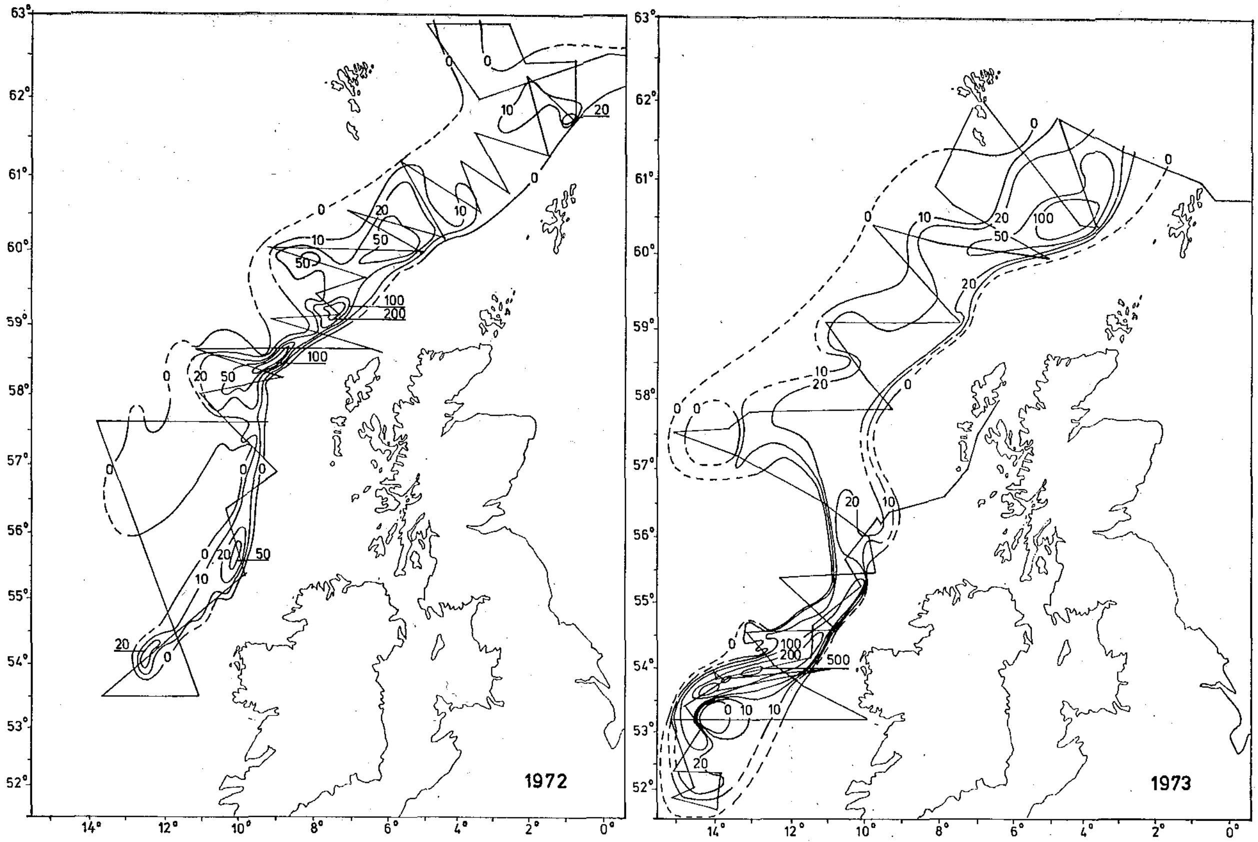

Figure 225. Integrated echo intensities (cm deflection) of blue whiting in 1972 and 1973. The survey routes are indicated.

certainty), the estimate of T decreased by 8%. The value of m for capelin was obtained during this survey and is based on mean values of N from four different observers. When m is calculated for each of these four sets of data, the highest and lowest values will be 1·6 and 1·3 ton/mm per nautical mile · nautical mile² respectively. Using the above information, upper and lower values of T are calculated at $7{\cdot}7 \cdot 10^6$ ton and $5{\cdot}7 \cdot 10^6$ ton respectively. Mature fish were found to constitute 35–40% of the trawl catches (Dragesund & Nakken 1972), so the spawning stock amounted to something between $2{\cdot}0 \cdot 10^6$ tons and $3{\cdot}1 \cdot 10^6$ tons. These figures agree very well with estimates from egg and larval surveys and tagging experiments (Dragesund, Gjøsæter & Monstad, 1973).

The conditions for doing echo integration in August 1972 (Fig. 224) were more difficult than in September 1971. In the western part of the area the capelin were distributed close to the bottom over wide areas. Farther to the east, capelin and polar cod were very often extensively mixed, and at times it was impossible to discriminate between the two species on the recording paper. The proportion of mature fish in the trawl catches was estimated to be 75–80% (Gjøsæter et al, 1972) leading to estimates of $6{\cdot}8 \cdot 10^6$ tons and $7{\cdot}2 \cdot 10^6$ tons for the spawning stock. Observations made by Monstad & Kovalyov (1973) in November-December 1972 indicated a much lower percentage of mature fish (30–40%); use of this value will reduce the estimate of the spawning stock considerably.

BLUE WHITING

Surveys for estimating the spawning stock of the blue whiting were carried out in 1972 and in 1973, just before or during the spawning season, March-April, in both years. In this period the blue whiting is distributed within a rather well defined area northwest of the British Isles (Fig. 225). The fish are mostly concentrated in pelagic scattering layers at depths between about 350 and 550 m and are not mixed with other species. In both 1972 and 1973 two independent surveys were carried out. The results are presented below:

	Rel. ($\int MdA$) mm·n mile^2	Abs. (T) ton
1972 1. survey 28.2–15.3	$11{\cdot}0 \cdot 10^6$	$4{\cdot}4 \cdot 10^6$
1972 2. survey 12.3–26.3	$6{\cdot}8 \cdot 10^6$	$2{\cdot}7 \cdot 10^6$
1973 1. survey 12.3–30.3	$25{\cdot}9 \cdot 10^6$	$10{\cdot}4 \cdot 10^6$
1973 2. survey[1] 31.3– 7.4	$10{\cdot}0 \cdot 10^6$	$4{\cdot}0 \cdot 10^6$

The values obtained on the 1972 surveys are much lower than those reported by Jakupsstovu & Midttun (1972) and by Midttun & Nakken (1972). This is because the calibration results now are more reliable than those of 1972. The second 1973 survey did not cover the whole area of distribution because it was conducted partly as a service to find the best areas for fishing operations for the small fleet of vessels doing trial fishing there. Furthermore the two surveys in 1972 did not include the whole Porcupine Bank, and this may be part of the reason why the 1972 results are lower than those of 1973. On the other hand the high value from the first 1973 survey is based on a rather open grid and could be an overestimate.

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[1] Excluding the Rockall Bank and the Porcupine Bank south of 54° latitude.