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Symposium
on
Acoustic Methods in
Fisheries Research.
No. 38

SOME RESULTS OF ABUNDANCE ESTIMATION STUDIES WITH ECHO INTEGRATORS

by

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INTRODUCTION

The use of acoustic methods for fish abundance estimation is now in a state of progressive improvement. Already at present such methods have proved to give valuable informations on stock size of both exploited and unexploited fish populations (BLINDHEIM and NAKKEN 1971, DRAGESUND 1970a and b, DRAGESUND et al. 1973, MIDTTUN and NAKKEN 1972, THORNE and WOODEY 1970, THORNE et al. 1971). The success of an acoustic abundance estimation depends strongly on the behaviour and the distribution of the species in question. The best conditions for the echo integration technique applied by the Institute of Marine Research, Bergen, are given when the fish stock in question is distributed within a defined area, unmixed with other species and in continous scattering layers at moderate depths in mid-water. Conditions are more complicated when the fish are forming dense schools or are mixed with other species, and unfavourable situations are found when the fish are distributed close to the bottom or near the sea surface.

In practical application it is therefore of the greatest importance to take into consideration fish behaviour and to carry out the surveys aiming at an abundance estimation when conditions are as favourable as possible. This may be related to special spawning or feeding seasons.

In the following we shall give two examples of acoustic fish stock abundance estimation. The first one is the estimation of an exploited fish stock, namely the Barents Sea Capelin. The second example is size measurement of the unexploited blue whiting stock. The surveys of both species are undertaken at the time of the year when the conditions seem to favour the technique used.

METHOD

The method applied is described by FORBES and NAKKEN (1972).

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

$$\rho_A = m\,M + b \qquad (I)$$

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 treshold density below which no contribution to the integrated echo intensity occurs.

When aiming at an estimate of stock size, the two main points to be considered are:

1. Determination of m and b in equation (I), so that relative densities, M, can be converted to absolute densities ρ_A.

2. Collect observations of M throughout the total area of distribution for the stock under consideration.

In order to determine m and b in equation (I), corresponding values of ρ_A and M are needed. THORNE and WOODEY (1970) obtained estimates of ρ_A by pelagic trawling. MIDTTUN and NAKKEN (1971) suggested a different way of approach: When the fish species in question are recorded as individuals the number of fish traces which appear on the recording paper are counted. A series of observations of M and N (number of fish within the depth interval of integration) are then obtained. The number of fish, N, are divided by the sampling area of the sounder, within the interval of counting and integration, giving ρ_A. 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, are 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 and NAKKEN 1971).

It should be noted that it is not necessary to do 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

$$T = \int_A \rho_A dA = m \int_A M dA + b \cdot A \qquad \text{(II)}$$

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

When mixed recordings occur, it is necessary to discriminate between the species, and 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 basis of examination of trawl catches and echo recordings.

During the investigations reported in this paper the 6 echo integrators onboard the G.O.Sars were connected to the Simrad scientific sounder EK 38. The 5 upper channels were normally adjusted to integrate in 50 m depth slices down to 250 m, while the 6th channel worked between 250 and 449 m. During the blue whiting surveys a slightly different setting was adopted in order to include also 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.

RESULTS AND DISCUSSION

Determination of m and b.

Table 1 and Figs 1-2 show some results of the determination of the constants m and b for blue whiting and capelin. The difference in the constant b for blue whiting are caused by the difficulty of defining the "just visible mark" on the recording paper. The differences in the slopes, m, from January to March are harder to explain. In March a relative narrow range of fish density observations were used and it might be that values from January are the most reliable. The mean of all three slopes is 1570 individuals/mm per nautical mile·nautical mile^2 corresponding to approximately 0,4 ton/ mm per nautical mile·nautical mile ^{2}.

For capelin the calibration run shows a slope of $106 \cdot 10^3$ individuals/ mm per nautical mile·nautical mile^2 which corresponds to approximately 1,4 ton/mm per nautical mile·nautical mile^2. The difference between the slopes for blue whiting and capelin indicates that the capelin has a much lower target strength (5-6 dB) than equally sized blue whiting. Observations at sea indicates that 15 cm capelin has a target strength of -50 dB while a 15 cm cod (NAKKEN and OLSEN 1973) has an expected target strength at sea of -45 dB. Further, the results obtained by NAKKEN and OLSEN (1973) 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 which appears from 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 area 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 trawlcatches indicated that both species were in "pure" consentrations.

It is seen from equation (II) 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 which appear in the distribution charts (Figs 3 and 4). In calculating the amount of fish present in the distribution charts the following forms of equation II were therefore used:

$$\text{Blue whiting: } T = 0{,}4 \cdot \int_A M dA \text{ (ton)}$$

$$\text{Capelin: } T = 1{,}4 \cdot \int_A M dA \text{ (ton)} \qquad \text{(III)}$$

The magnitude of the variances associated with the estimates obtained from equations (III) are to some extent unknown, and as the variance will vary from species to species and from year to year the estimates for the two species will be discussed seperately.

Capelin

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

1971		1972	
Rel. ($\int$ MdA) mm·(nm)^2	Abs. (T) ton	Rel. ($\int$ MdA) mm·(nm)^2	Abs. (T) ton
$4,8 \cdot 10^6$	$6,7 \cdot 10^6$	$6,5 \cdot 10^6$	$9,1 \cdot 10^6$

The absolute values in this table are lower than those reported by MIDTTUN and NAKKEN (1972). The reason for this discrepancy is the lower values of m. The values of m reported in the above mentioned paper were found at by taking the ratios between the arithmetic means of ρ_A and M in table 1. The magnitude of this ratio is depending 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.3) were 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 M-values (disregarding the reason for the uncertainty), the estimate of T decreased with eight per cent. 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·square nautical mile respecitvely. Using the above information to calculate an upper and lower values of T one arrives at $7,7 \cdot 10^6$ ton and $5,7 \cdot 10^6$ ton respectively. The percentage mature fish in the trawlcatches were found to be 35-40 per cent (DRAGESUND and NAKKEN 1972) and accordingly the spawning stock amounted to somewhat between $2{,}0 \cdot 10^6$ tons and $3{,}1 \cdot 10^6$ tons. These figures coincide very well with estimates from egg and larval surveys and tagging experiments (DRAGESUND, GJØSÆTER and MONSTAD 1973).

The conditions for doing echo integration in August 1972 (Fig.3) were more difficult than in September 1971. In the western part of the area the capelin was distributed close to the bottom over wide areas. Farther to the east, capelin and polar cod very often were extensively mixed, and at times it was impossible to discriminate between the two species on the recording paper. The portion mature fish in the trawlcatches were estimated to be 75-80 per cent (GJØSÆTER et al. 1972) resulting in estimates of $6{,}8 \cdot 10^6$ tons and $7{,}2 \cdot 10^6$ tons for the spawning stock. Observations made by MONSTAD and KOVALYOV (1973) in November-December 1972 indicated a much lower percentage of mature fish (30-40 per cent) a matter which will reduce the estimates 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, both years just before or during the spawning season, March-April. In this period the blue whiting is distributed within a rather well defined area northwest of the British Isles (Fig.4). The fish are mostly consentrated in pelagic scattering layers at depths between about 350 and 550 metres and unmixed with other species. Both in 1972 and in 1973 there were actually carried out two independant surveys each year and the results are presented below:

				Rel. ($\int$MdA) $mm \cdot (nm)^2$	Abs. (T) ton
1972	1.survey	28.2-15.3		$11{,}0 \cdot 10^6$	$4{,}4 \cdot 10^6$
"	2. "	12.3-26.3		$6{,}8 \cdot 10^6$	$2{,}7 \cdot 10^6$
1973	1. "	12.3-30.3		$25{,}9 \cdot 10^6$	$10{,}4 \cdot 10^6$
"	2. "	31.3-7.4	x)	$10{,}0 \cdot 10^6$	$4{,}0 \cdot 10^6$

x) excluding the Rockall Bank and the Porcupine Bank south of 54°latitude.

The results need some comments: The values obtained by the 1972 surveys are much lower than reported by JAKUPSSTOVU and MIDTTUN (1972) and by MIDTTUN and NAKKEN (1972). This is because the calibration results now are more reliable than those obtained during the 1972 survey. The second survey 1973 did not cover the whole area of distribution since it was conducted partly as a service to the small fleet of vessels doing fishing trials here, in order to find the best areas for fishing operations. But also 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 survey 1973 is based on a rather open grid net and could be a bit overestimated.

ACKNOWLEDGEMENTS

We wish to thank colleagues at the Institute of Marine Research and officers and crew onboard the research vessels G.O.Sars and Johan Hjort for help during the collection of data. It is a great pleasure to acknowledge the invaluable help of S.H. Jakupsstovu with whom we have cooperated during the work on blue whiting.

REFERENCES

BLINDHEIM,J. and NAKKEN,O. 1971. Abundance estimation of the spawning Lofoten cod 1971. Coun.Meet.int.Coun. Explor.Sea 1971. (B 15): 1-5,3tabs.,2 figs. [Mimeo].

DRAGESUND,O. 1970 a. Distribution,abundance and mortality of young and adolescent Norwegian Spring spawning herring (*Clupea harengus* Linné) in relation to subsequent year-class strength. Fisk.Dir.Skr.Ser. HavUnders., 15 (4): 451-556.

DRAGESUND,O. (ed.) 1970 b. International 0-group fish surveys in the Barents Sea 1965-1968. Coop.res.rep.int. Coun.Explor.Sea, 1970, Ser.A (18): 1-81. [Mimeo].

DRAGESUND,O. and NAKKEN,O. 1972. Lodde- og polartorskundersøkelser i Barentshavet i august-september 1971. [Capelin and Polar cod investigations in the Barents Sea in August-September 1971]. Fiskets Gang, 58: 145-148.

DRAGESUND,O., GJØSÆTER,J. and MONSTAD,T. 1973. Estimates of stock size and reproduction of the Barents Sea Capelin in 1970-1972. Fisk.Dir.Skr.Ser.HavUnders., (in press).

FORBES,S.T. and NAKKEN,O. (ed.) 1972. Manual of methods for fisheries resource survey and appraisal. Part 2. FAO Manual in Fisheries Science, No.5, 1972.

GJØSÆTER,J., MIDTTUN,L., MONSTAD,T., NAKKEN,O., SMESTAD,O.M., SÆTRE,R. and ULLTANG,Ø. 1972. Undersøkelser av fiskeforekomster i Barentshavet og ved Spitsbergen i august-septmeber 1972. [Investigations on fish distribution and abundace in the Barents Sea and off Spitsbergen in August-September 1972]. Fiskets Gang,58: 1010-1021.

JAKUPSSTOVU,S.H. and MIDTTUN,L. 1972. Kolmuleundersøkelser nordvest for De Britiske Øyer i februar-mars 1972. [Blue whiting surveys northwest of the British Isles in February-March 1972]. Fiskets Gang, 58. 428-433.

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

MIDTTUN,L. and NAKKEN,O. 1972. Application of acoustic stock abundance estimation on capelin and blue whiting. Coun.Meet.Int.Coun.Explor.Sea 1972 (B:16) 1-8, 6 Figs. [Mimeo].

MONSTAD,T. and KOVALYOV,S.M. 1973. Loddeundersøkelser i Barentshavet i november-desember 1972. [Capelin investigation in the Barents Sea in November-December 1972]. Fiskets Gang, 59: 350-353.

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. Echo integrator deflections M (mm per nautical mile) and corresponding densities of fish ρ_A (number of fish per square mile) obtained by counting of 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, $\rho_A = mM+b$, are shown at the bottom of the table.

Blue whiting — Jan. 1973

M	N_1	ρ_{A1}	N_2	ρ_{A2}
24	259	43512	301	50568
23	215	36120	317	53256
13	160	26880	173	29064
4	69	11582	59	9912
4	54	9072	59	9912
5	72	12096	62	10416
21	265	30210	291	33174
17	225	25650	220	25080
18	177	20178	201	22914
7	101	11514	93	10602
6	94	10716	104	11856
9	129	14706	114	12996
9	112	12768	119	13566
7	99	11286	102	11628
7	110	10230	117	10881
12	150	13950	137	12741
2	64	5952	44	4092
12	121	11439	121	11253
15	225	20925	158	14695
	r =	0,9236		0,8905
	m =	1535		1823
	b =	-313		-1750

Blue whiting — March 1973

M	N	ρ_A
3	86	13244
1	41	6314
0	23	3542
0	23	3542
0	24	3696
1	36	5544
1	43	6622
1	47	7238
2	58	8932
4	81	9639
9	132	15708
8	121	14399
8	136	16184
4	88	10472
4	94	11186
8	143	17017
5	108	12852
6	91	10829
	r =	0,9391
	m =	1345
	b =	4976

Capelin — Sept. 1971

M	N	$\rho_A \cdot 10^{-5}$
2,1	282	333
1,4	240	258
1,2	182	238
1,6	263	238
2,3	337	340
1,4	172	223
1,4	232	235
1,5	291	287
	r =	0,8960
	m =	$106 \cdot 10^3$
	b =	$96 \cdot 10^3$

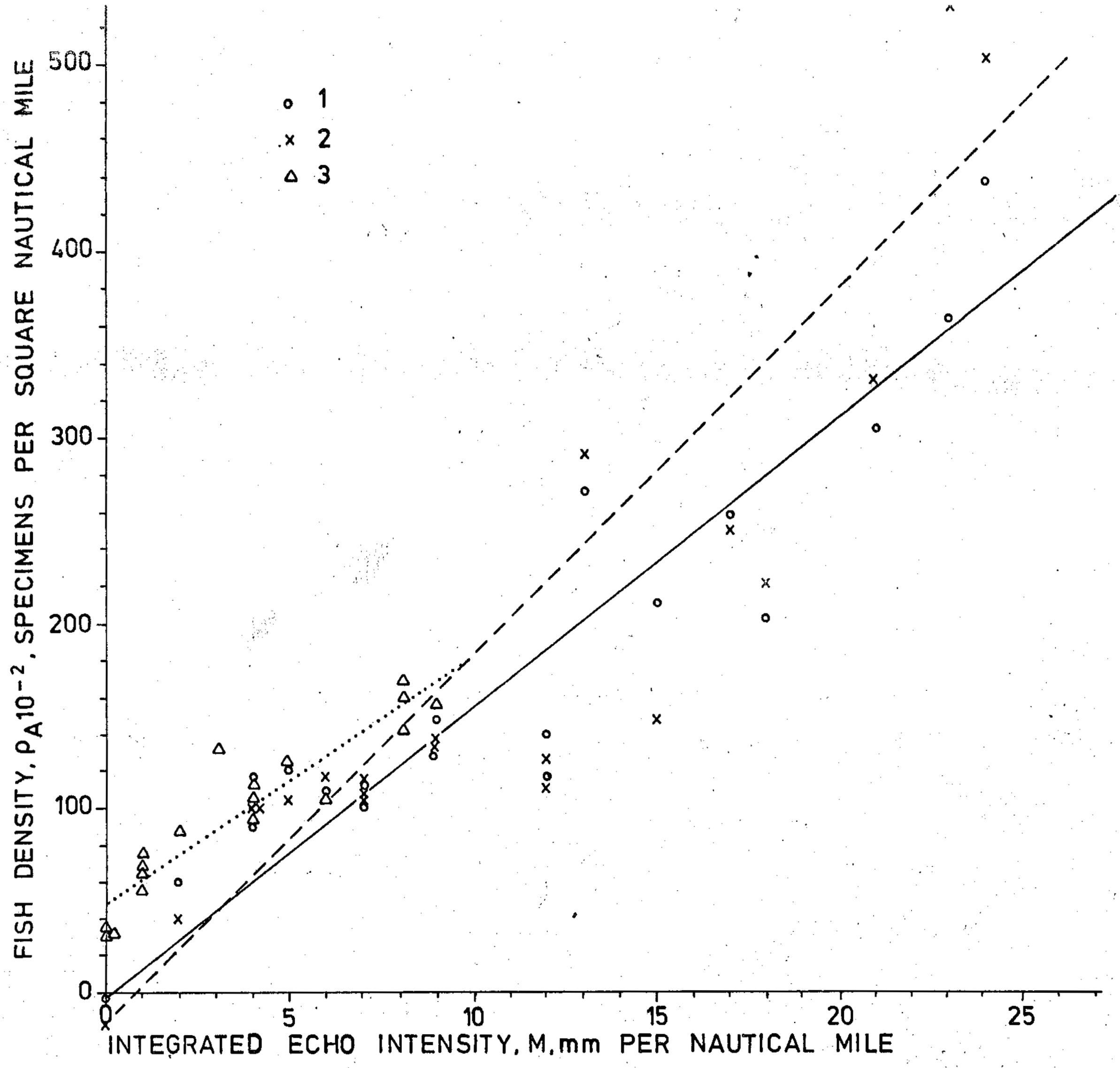

Fig. 1. Corresponding values of integrated echo intensity, M, and fish density, ρA, (calculated from counts on the recording paper) for blue whiting. 1) and 2) estimates from two different watches counting the same recording paper in January 1973, 3) estimates from March 1973.

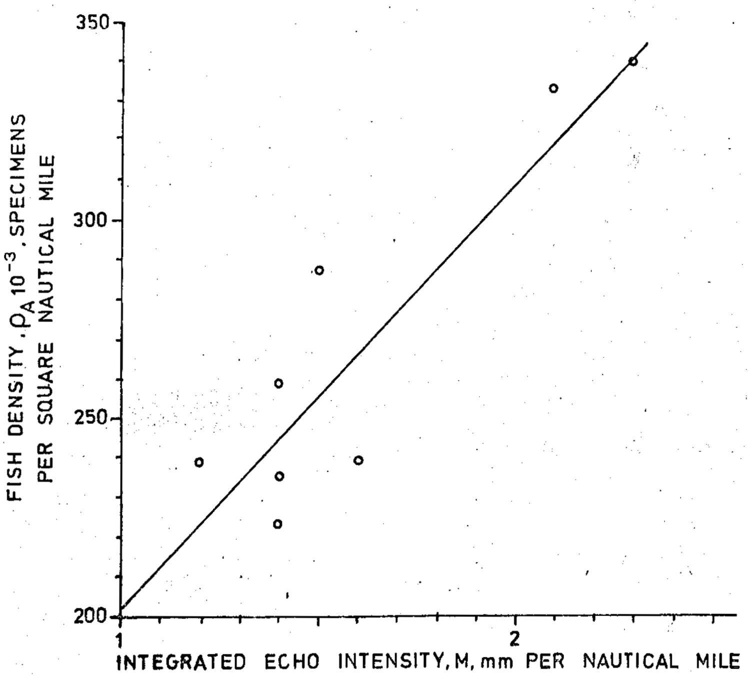

Fig. 2. Corresponding values of integrated echo intensity, M, and fish density, ρA, (calculated from counts on the recording paper) for capelin.

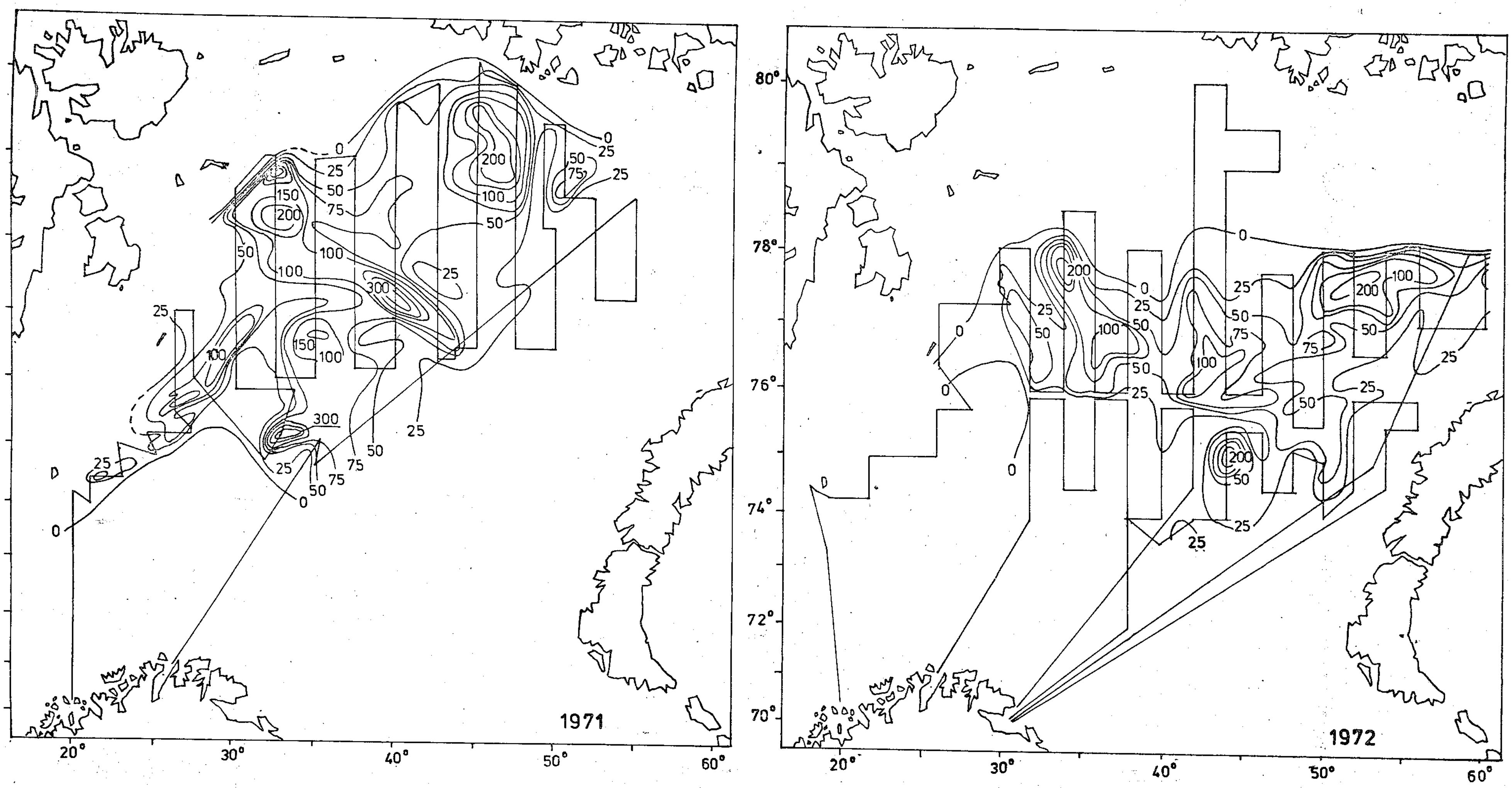

Fig.3. Integrated echo intensity (mm deflection) of capelin 12-29 September 1971 and 5-20 August 1972. The survey routes are indicated.

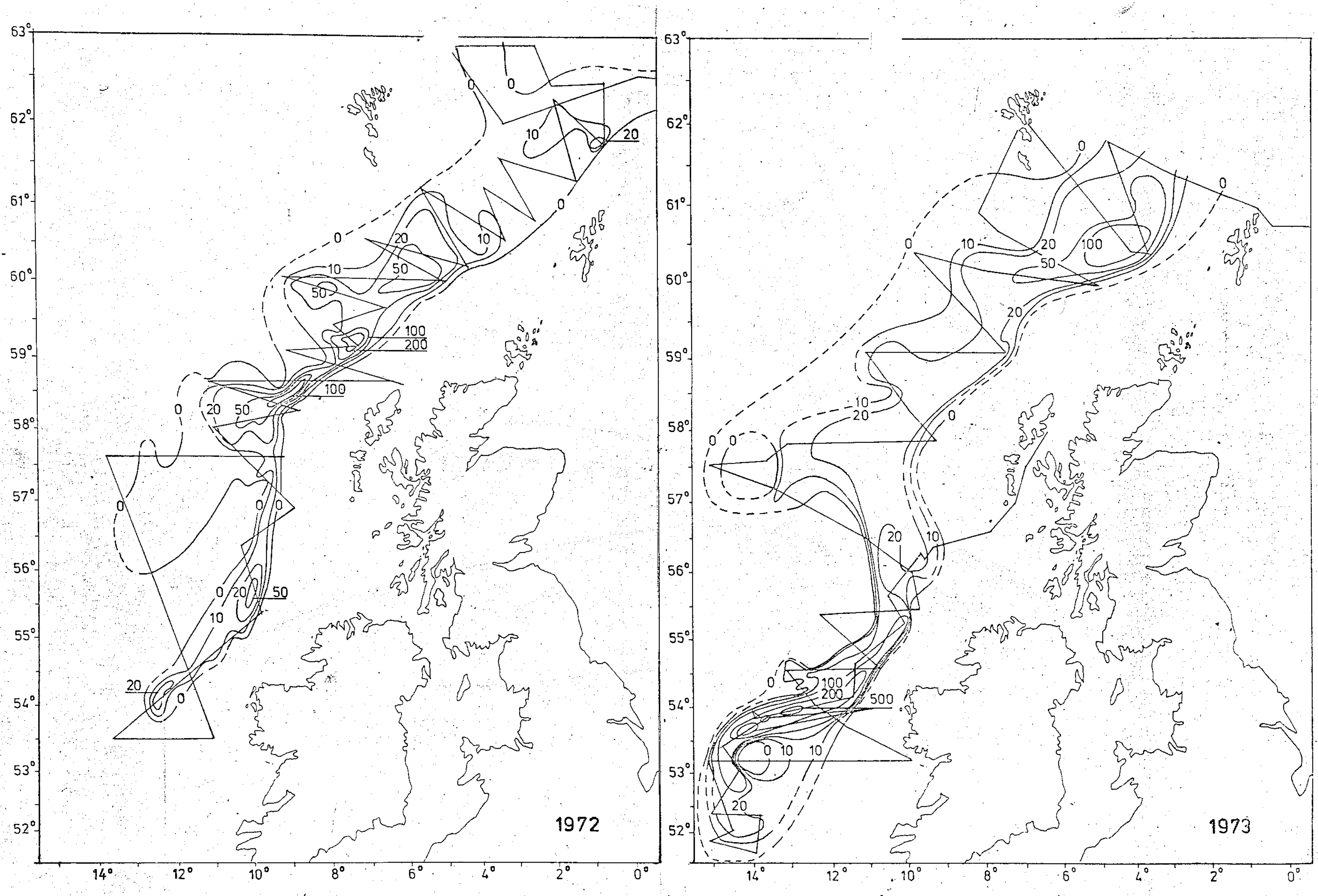

Fig. 4. Integrated echo intensities (cm deflection) of blue whiting 1972 and 1973. The survey routes are indicated.