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THE APPLICATION OF AN ECHO INTEGRATION SYSTEM IN INVESTIGATIONS ON THE STOCK STRENGTH OF THE BARENTS SEA CAPELIN (MALLOTUS VILLOSUS, MÜLLER) 1971 - 1974

by

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INTRODUCTION

During the last decade acoustic methods for fish abundance estimation have been largely improved (BODHOLT 1969, CRAIG and FORBES 1969, CUSHING 1968, DRAGESUND and OLSEN 1965, FORBES and NAKKEN 1972, SCHERBINO and TRUSKANOV 1966, THORNE and WOODEY 1970 and THORNE 1973). At present such methods are widely used to obtain information on stock size on both exploited and unexploited fish populations (BLINDHEIM and NAKKEN 1971, BUZETA and NAKKEN 1975, DOWD et al. 1970, DRAGESUND et al. 1973, JOHANNESSON and LOSSE 1973, MIDTTUN and NAKKEN 1973, THORNE et al. 1971). The reliability of the acoustic abundance estimates of fish depends on a number of factors, some of which have been discussed by EHRENBERG and LYTLE 1973, BODHOLT 1973 and RØTTINGEN 1975. Estimates have most often been worked out under the assumption that the scattering cross section of the fish is proportional to its weight (URICK 1967). This assumption introduces a bias which is dependent on the size distribution of the fish in question (CRAIG 1973, NAKKEN 1975). The estimates of abundance which are presented here are worked out using the observed length dependent scattering cross sections (NAKKEN and OLSEN 1973).

Since 1971 the Institute of Marine Research has carried out acoustic surveys each autumn with the aim of assessing the stock strength of the Barents Sea capelin (DRAGESUND et al. 1973, MIDTTUN and NAKKEN 1973). Some preliminary results from these cruises are given in earlier reports (DRAGESUND og NAKKEN 1972, GJØSÆTER et al. 1972, DOMMASNES et al. 1974, BUZETA et al. 1974). Since 1973 the institute has also carried out acoustic surveys in May - June for stock assessment of capelin (HAUG og MONSTAD 1974, DALEN og DOMMASNES 1974, AKSLAND et al.1975).

The present paper describes the technique used during these surveys and the results achieved during the autumn surveys in the period 1971 - 1974.

MATERIAL AND METHODS

Fig.1 shows the survey routes and fishing stations in 1973 and comparison of Fig.1 and Table 1 indicates the approximate coverage the other years. In the following we shall first establish a set of formulas for later use. Thereafter we shall consider the practical aspects of both the observation techniques and the computations.

When four categories (age groups, size groups or species) of fish are mixed and thus simultaneously contribute to the echo, then the integrated echo intensity, M, can be written (FORBES and NAKKEN 1972):

$$M = M_1 + M_2 + M_3 + M_4 \qquad (I)$$

M_1, M_2, M_3 and M_4 are the contributions to the integrated echo intensity from each category. The relationship between the fish density and integrated echo intensity is linear:

$$\rho_{A_i} = C_i M_i + d_1 \qquad (II)$$

where ρ_A is the number of fish per unit area, C is the density coefficient, d is a threshold density and i denotes the category. When d is neglected equation II reduces to:

$$\rho_{A_1} = C_1 M_1 , \quad \rho_{A_2} = C_2 M_2 , \quad \rho_{A_3} = C_3 M_3 , \quad \rho_{A_4} = C_4 M_4 \qquad (III)$$

Assume now that frequent sampling shows the true density ratios between the different categories of fish. When k_i expressed the i-th category's proportion of the total catch, then:

$$k_i = \frac{\rho_{A_i}}{\sum_{i=1}^{i=4} \rho_{A_i}} \qquad \text{(IV)}$$

and

$$\frac{k_1}{k_2} = \frac{C_1 M_1}{C_2 M_2}, \quad \frac{k_1}{k_3} = \frac{C_1 M_1}{C_3 M_3}, \quad \frac{k_1}{k_4} = \frac{C_1 M_1}{C_4 M_4} \qquad \text{(V)}$$

Combination of I and V will now give M_i as a function of k, C and M, and by using equation III the density of each category of fish can be expressed by observed quantities only. The result is:

$$\rho_{A_1} = k_1 KM, \quad \rho_{A_2} = k_2 KM$$
$$\rho_{A_3} = k_3 KM \quad \rho_{A_4} = k_4 KM \qquad \text{(VI)}$$

$$K = \frac{1}{\sum_{i=1}^{i=4} \frac{k_i}{C_i}} = \frac{C_1 C_2 C_3 C_4}{k_1 C_2 C_3 C_4 + k_2 C_1 C_3 C_4 + k_3 C_1 C_2 C_4 + k_4 C_1 C_2 C_3}$$

By these formulas the absolute fish density ρ_A (number per unit area) can be computed, provided that corresponding values of M, k and C are known. The computations above can easily be carried out for both a less and a larger number of fish categories.

Integrated echo intensity, M.

The vessels used in the surveys were all equipped with Simrad scientific sounders and Simrad echo integrators (BODHOLT 1969, VESTNES 1969, GERHARDSEN et al. 1968, NAKKEN og VESTNES 1970, DRAGESUND et al. 1968). The main advantage of the scientific sounder is the calibrated time varied gain function. This function was used in the mode 20 logR for all the observations. The six echo integrator channels onboard "G.O. Sars" and the 4 channels onboard "Havdrøn" and "Johan Hjort" were set to cover the depth column from 10 m depth to 300 m or bottom. The outputs of the integrators were stored for each nautical mile and the average outputs per nautical mile were logged for every five nautical miles sailed (Fig. 2). Continuous watches were kept on the acoustic instruments throughout the entire cruise and whenever the recording - as it appeared on the echo sounder recorder - changed, a sample was taken with the appropriate gear. The echograms and integrated echo intensities were scrutinized each day, and contributions fr "false" echoes (wakes and false bottoms) were removed. The contributing species were identified and their contributions to the integrator readings were determined on the basis of the composition of the trawl catches and the patterns of the echograms. (Fig. 3). The contributions from the different depth channels were added and the "species" column in Fig. 2 were filled in.

The three years when two ships were used in the investigations, intercalibration runs were carried out in order to have comparable values of M. The two ships sailed one behind and slightly to the side of the other for 20-35 nautical miles, thus observing the same fish concentrations. Care was taken so the second ship did not come into the wake of the first. A straight line (Equation VII) was fitted to the observed integrator outputs by a least mean square analysis:

$$M_A = aM_B + b \qquad \text{(VII)}$$

M_A and M_B are integrator readings in mm deviation per nautical mile for the two ships A and B. a and b are constants. "G.O. Sars" was always taken as ship A. Values for a, b and the correlation are given in Table 1.

Catch composition proportion, k.

The total numbers of fishing stations in the different years are given in Table 1. Fishing was carried out whenever the pattern of the echo recording changed or when the need for biological data made it necessary. The trawls used were all of commercial sizes with an innernet of meshsize 7 mm bar in the codend. The pelagic trawls had square openings with a circumference of 1100 to 1600 meshes 200 mm mesh size; the bottom trawls were of the Granton type. All ships were equipped with net sondes thus allowing very precise depth positioning of the pelagic trawls. Standard towing time was 20 minutes, but when the net sonde indicated that a sample of reasonable size (several baskets) was caught the trawl was hauled earlier. The catches were sorted immediately according to species, and length measurements as well as an examination of sex, maturity stage and stomach contents were carried out for all samples. In selected samples, observations on length/weight relations of individual fish were collected and otoliths were preserved for later age determination. Age/length keys were then made and used to transform the observed length distribution on each station to distributions of age. From these distributions the proportions which each yearclass contributed to the total catch, k, were found.

Density coefficient, C.

Numerical values of the density coefficient, C, were determined by the method described by MIDTTUN and NAKKEN (1971 and 1973). Corresponding values of ρ_A and M (equation II) were obtained by counting of traces on the paper record when fish were recorded as individuals. The relation between the number of fish traces on the paper record, N, and the number of fish per unit area, ρ_A, when no overlapping between successive transmissions occurs, is (FORBES and NAKKEN 1972):

$$\rho_A \approx \frac{N}{(\bar{R} \cdot \theta)^2 \cdot \pi \cdot n} \qquad \text{(VIII)}$$

where $\bar{R}$ is the mean depth of the counted specimens, θ is the sampling angle of the beam and n the number of transmissions over 1 nautical mile. The sampling angle, θ, was determined in the directivity diagram as the angle corresponding to the different between the gain setting during the counting run and the gain setting at which the counted capelin gave a just visible mark on the paper record. Finally a straight line was fitted to the observed values of M and ρ_A by means of a least mean square analysis whereby the numerical values of the density coefficient C and the threshold density d were determined (Equation II). Such counting runs were always followed by a fishing station to get the length distribution of the counted fish. The dependency of C on fish length for capelin was assumed to be similar to that for sprat. Data for sprat are available (NAKKEN and OLSEN 1973, NAKKEN 1975) and give:

$$C = C_I \cdot C_s \cdot l^{-1.72} \qquad \text{(IX)}$$

The numerical value of $C_I C_s$ was determined from

$$C_I \cdot C_s = \text{antilog}_{10} \; (\log_{10} C + 1.72 \log_{10} \bar{l}) \qquad \text{(X)}$$

The density coefficient, C, was found from the least mean square analysis of the counting observations, and the mean length $\bar{l}$ of the fish from the corresponding trawlstation. Values of C for different length groups were thereafter determined by equation IX.

Computations.

The surveyed area was divided into suitable subareas corresponding to those used for statistical purposes by the Norwegian Directorate of Fisheries (Fig. 4). Within each subarea, mean values of M and k_1, k_2, k_3 and k_4 as well as mean values of C_1, C_2, C_3 and C_4 were calculated and the computations (in VI) were carried out.

RESULTS AND DISCUSSION

Figs 5-8 show the distribution of the integrated echo intensities for capelin in the four years. The estimates of $C_I C_s$ to be used in equation IX are given in Table 2. Figs 9-12 show the density distribution of the four yearclasses of capelin in autumn 1974 as computed from equations VI. Estimates of the number of specimens in each yearclass the different years are given in Table 3, where also the total stock and the maturing part of the stock are given. The maturing stock in Table 3 is the portion of the capelin stock which on the basis of observations of maturity stage was expected to spawn during the following winter. The estimates are of course subject to various errors and we will now discuss the most important sources of error and their influence on the results.

Integrated echo intensity, M.

The variance error involved in the estimate of M is considered theoretically by BODHOLT (1973) and EHRENBERG and LYTLE (1973) and on the basis of those investigations it seems fair to conclude that errors of this type are negligible. This conclusion is supported by the high correlation between the observations of M from the two different ships during the intercalibration runs (Table 1). If the integrator output was subject to large variance errors, one should expect the correlation coefficient to be lower.

Within the area surveyed, capelin was the main contributor to the echo recordings. In the eastern part of the area scattered concentrations of polar cod at times occurred in mixture with capelin, especially in 1972, but according to the trawlcatches the total contributions of other species no year exceeded 5 percent of the contribution from capelin, and the error due to mixed recordings is therefore considered to be negligible for the area as a whole. In smaller parts of the area, however, this type of error will be of significance some years.

Fish concentrations which are shallower than 10 m depth or less than 2-3 m from the bottom at 200 m depth will not contribute to M. It has been shown (BELTESTAD, NAKKEN and SMEDSTAD 1975) that 0-group capelin will stay close to the surface during the day, above the depth of the echo sounder transducer. This was also experienced during the present investigations from observations with sonar and side-looking echo sounder (VESTNES og NAKKEN, 1971). Consequently the contributions to the integrated echo intensity from O-group capelin were systematically too small. Older capelin were usually not distributed so close to the surface that they avoided the echosounders, but on some occasions concentrations of adult capelin were found close to, and partly on, the bottom. However, the eventual underestimate caused by this behaviour was believed to be negligible.

Catch composition proportion, k.

The assumption that the sampling showed the true density ratios between the different yearclasses of capelin does not hold good. The behaviour of the O-group has to some extent prevented it from being fished by the trawls (BELTESTAD, NAKKEN and SMEDSTAD, 1975). In addition the trawl itself will be selective and under-sample the smaller fish due to mesh selection. A considerable amount of capelin gets gilled along the entire trawl in each trawl haul and 50 percent or more of a three baskets catch might be entangled in the meshes. Variations in mesh selection with fish size and fish behaviour are therefore important sources of error and they will lead to an underestimate of the O-group fish which is clearly demonstrated in Table 3.

Density coefficient, C.

The result of the determinations of the density coefficient, C, are shown in Table 2. The variation from year to year in $C_I C_s$ is partly due to changes in the performance and partly to changes in the gain settings of the integration system onboard the "G.O.Sars" Numerical values of C were worked out only for the counting runs where the corresponding trawlcatches showed that the capelin were uniform in size and that no other species of similar size, jellyfish, pelagic shrimps, etc. were mixed with it.

The assumption that the scattering cross section of capelin shows a similar length dependency as that of sprat is probably not completely met with. However, from the extensive target strength measurements which were carried out by NAKKEN and OLSEN (1973) it can be suggested that the power in equation IX cannot be far from 2.0. As the length range of the capelin will be relatively small, 6-18 cm, a small error in the power in equation IX will not have much influence on the density coefficient C if the value of C has been correctly determined from fish in the middle of the length range. If, however, C has been determined for one end of the length range, then the bias at the other end of the length range might be considerable when a wrong power is used in equation IX. Experiments on the target strength/ length relationship for capelin will clarify this point.

Reliability of the results.

Several possible sources of errors have been mentioned, but it has not yet been possible to work out statistical estimates of the precision of the results. In order to have some knowledge of the confidence which can be given to the numbers in Table 3, they should be compared to estimates of stock size obtained by other methods. From Table 3 it is seen that on the basis of the acoustic survey carried out in September 1973 the spawning stock of capelin in the winter of 1974 was expected to be 1.0-1.5 million metric tons. These values correspond to one of the estimates which were obtained from tagging experiments during the spawning season in 1974 (DOMMASNES 1975).

A comparison of yearly estimates of the number of fish in each yearclass (Table 3) indicates a reasonable reduction between the second and the third year. The amount of 0-group fish will as a rule be underestimated, especially in 1971 when only a small part of the 0-group distribution area was surveyed.

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Table 1. Acoustic surveys for assessing the stock strength of Barents Sea capelin 1971-1974.

Years	Periods of investigations	Vessels	Total numbers of fishing stations		Total nautical miles sailed	Relations between integrator values for the vessels ($M_A = aM_B + b$ x)		
			Pelagic trawl	Bottom trawl		a	b	r
1971	12-29 Sept.	G.O.Sars	23	6	2600	-	-	-
1972	5-20 Aug.	G.O.Sars Johan Hjort	56	6	4000	3.0	0	-
1973	16 Sept.-18 Oct.	G.O.Sars Johan Hjort	100	10	5500	2.0	13.6	.98
1974	15 Sept.-18 Oct.	G.O.Sars Havdrøn	115	4	6000	8.2	20	.96

(x "G.O.Sars" is always taken as vessel A)

Table 2. Estimates of the density coefficient C_i and the treshold density d_i ($\rho_{A_i} = C_i M_i d_i$) for capelin, obtained by a least mean square analysis. r is the correlation coefficient, $\bar{l}$ is the mean length of the fish.

Years	$\bar{l}$ cm	C $\frac{\text{number}}{\text{mm}\cdot(\text{nautical miles})^2}$	d $\frac{\text{number}}{(\text{nautical miles})^2}$	r	C_I C_s $\frac{\text{number}}{\text{mm}\cdot(\text{nautical miles})^2}$ Estimates	Values used
1971	13.6	$106\cdot10^3$	$96\cdot10^3$	.89	$9.40\cdot10^6$	$9.4\cdot10^6$
1972	-	-	-	-	-	$9.4\cdot10^6$
1973	10.5	$45\cdot10^3$	$28\cdot10^3$	.95	$2.56\cdot10^6$	$3.0\cdot10^6$
	11.1	$55\cdot10^3$	$34\cdot10^3$	.96	$3.45\cdot10^6$	
	15.5	$26\cdot10^3$	$14\cdot10^3$	.73	$2.93\cdot10^6$	
1974	10.8	$30\cdot10^3$	$23\cdot10^3$	.96	$1.80\cdot10^6$	$1.8\cdot10^6$

Table 3. Estimates of the total number of specimens, N, and the total weight, W, of each yearclass of Barents Sea capelin during the acoustic surveys in the years 1971-1974. The total stock and the maturing part of the stock are also indicated.
N: Numbers x 10^{-11}, W: tons x 10^{-6}.

Time	Yearclass 1968		1969		1970		1971		1972		1973		1974		Total Stock	Maturing stock
	N	W	N	W	N	W	N	W	N	W	N	W	N	W	W	W
1971 Sep	0.5	0.9	1.3	1.3	2.2	3.5	0.2	0.04							5.7	1.7
1972 Aug-Sep			0.4	0.8	1.4	2.2	1.8	1.8	6.4	1.8					6.6	3.7
1973 Sep-Oct					0.11	0.27	0.23	0.45	2.4	1.7	4.1	1.4			3.8	1.0-1.5
1974 Sep-Oct							0.03	0.05	1.6	1.3	5.5	2.9	4.7	1.6	5.8	0.75

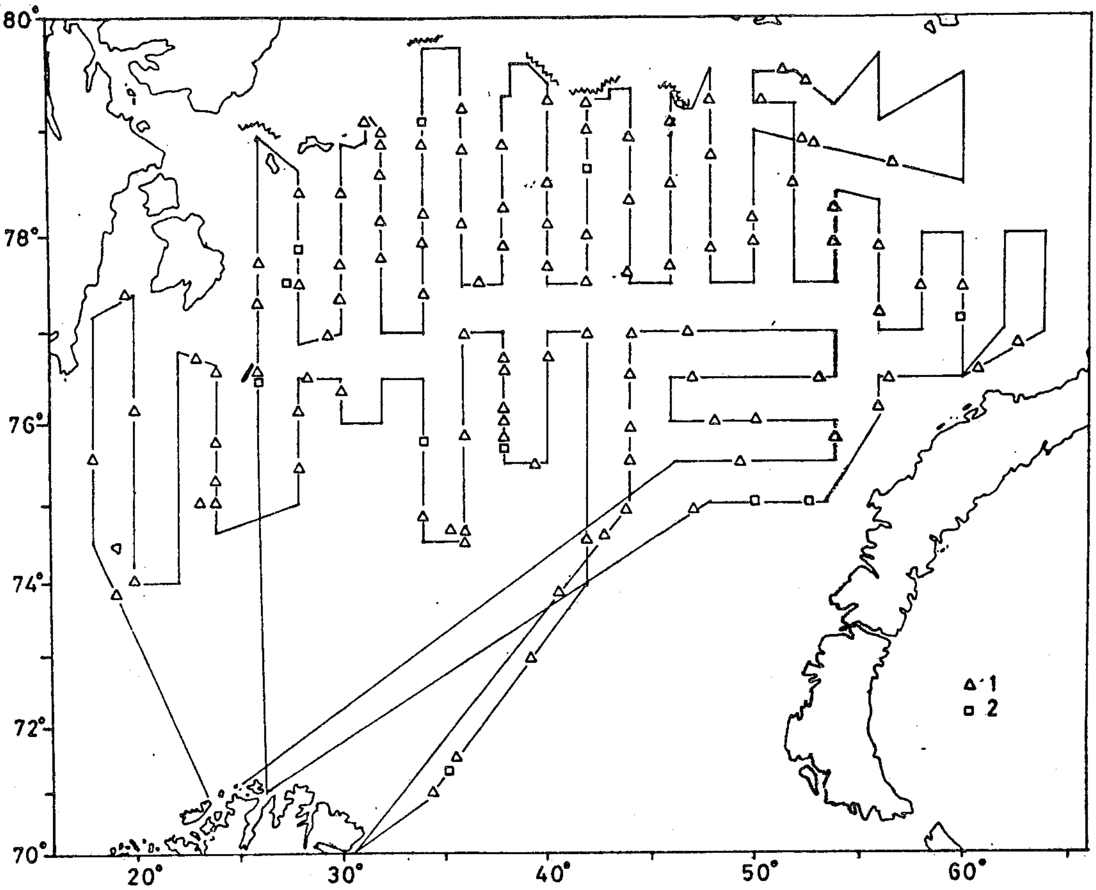
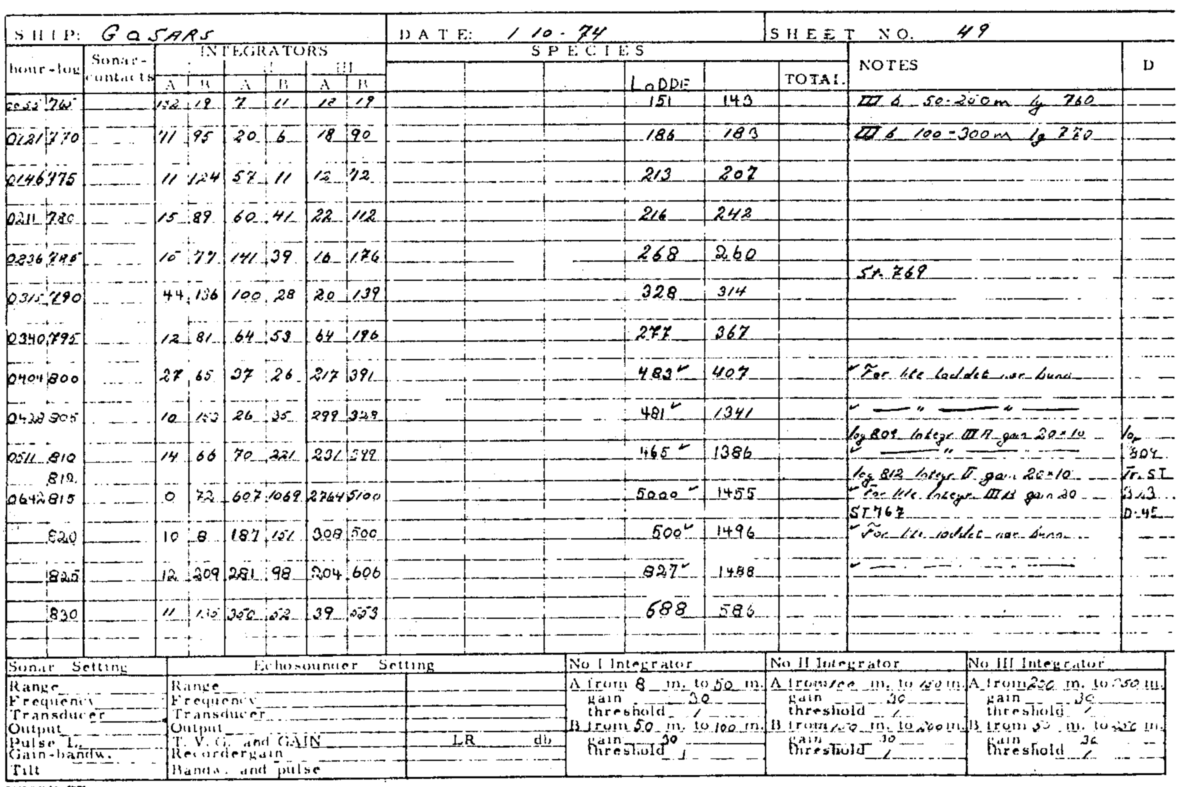


Fig.1. Survey routes and fishing stations 16 September-8 October 1973. 1) Pelagic trawl 2) Bottom trawl



SHIP: G. O. SARS | DATE: 1-10-74 | SHEET NO. 49

hour	log	Sonar-contacts	Integrators I A	I B	II A	II B	III A	III B	Species: Lodde		TOTAL	NOTES	D
0052	765		152	19	7	11	12	19	151	143		III b 50-200m lg 760	
0121	770		11	95	20	6	18	90	186	183		III b 100-300m lg 770	
0146	775		11	124	57	11	12	72	213	207			
0211	780		15	89	60	41	22	112	216	242			
0236	785		10	77	141	39	16	176	268	260		St. 769	
0315	790		44	136	100	28	20	139	328	314			
0340	795		12	81	64	53	64	196	277	367			
0404	800		27	65	37	26	217	391	483 ✓	407		✓ [illegible]	
0428	805		10	[illegible]	26	35	299	329	481 ✓	1341		✓ — " — " —	
												log 804 Integr. III B gain 20→10	log
0511	810		14	66	70	221	231	[illegible]	465 ✓	1386		✓ — " —	804
	810											log 812 Integr. II gain 20→10	Tr. ST
0642	815		0	72	607	1069	2764	5100	5000 ✓	1455		✓ [illegible] Integr. III B gain 20	343
												ST 767	D: 45
	820		10	8	187	151	308	500	500 ✓	1496		✓ [illegible]	
	825		12	209	281	98	204	606	827 ✓	1488		✓ — " —	
	830		11	[illegible]	300	[illegible]	39	[illegible]	688	586			

Sonar Setting	Echosounder Setting	No I Integrator	No II Integrator	No III Integrator
Range	Range	A from 8 m. to 50 m.	A from 100 m. to 150 m.	A from 200 m. to 250 m.
Frequency	Frequency	gain 30	gain 30	gain 30
Transducer	Transducer	threshold 1	threshold 1	threshold 1
Output	Output	B from 50 m. to 100 m.	B from 150 m. to 200 m.	B from 50 m. to 250 m.
Pulse L.	T. V. G. and GAIN LR db	gain 30	gain 30	gain 30
Gain-bandw.	Recordergain	threshold 1	threshold 1	threshold 1
Tilt	Bandw. and pulse			

Fig.2. Logsheet for acoustic data.

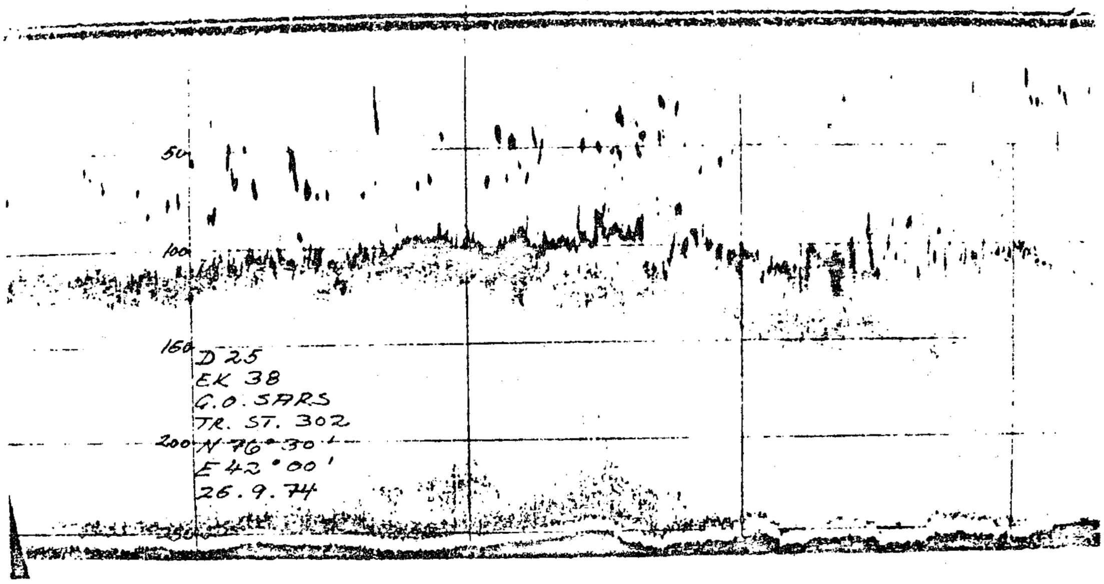


Fig.3. Echogram showing scattering layers of capelin. The integration intervals of the different channels, 50m in depth and 1 nautical mile in distance, are indicated.

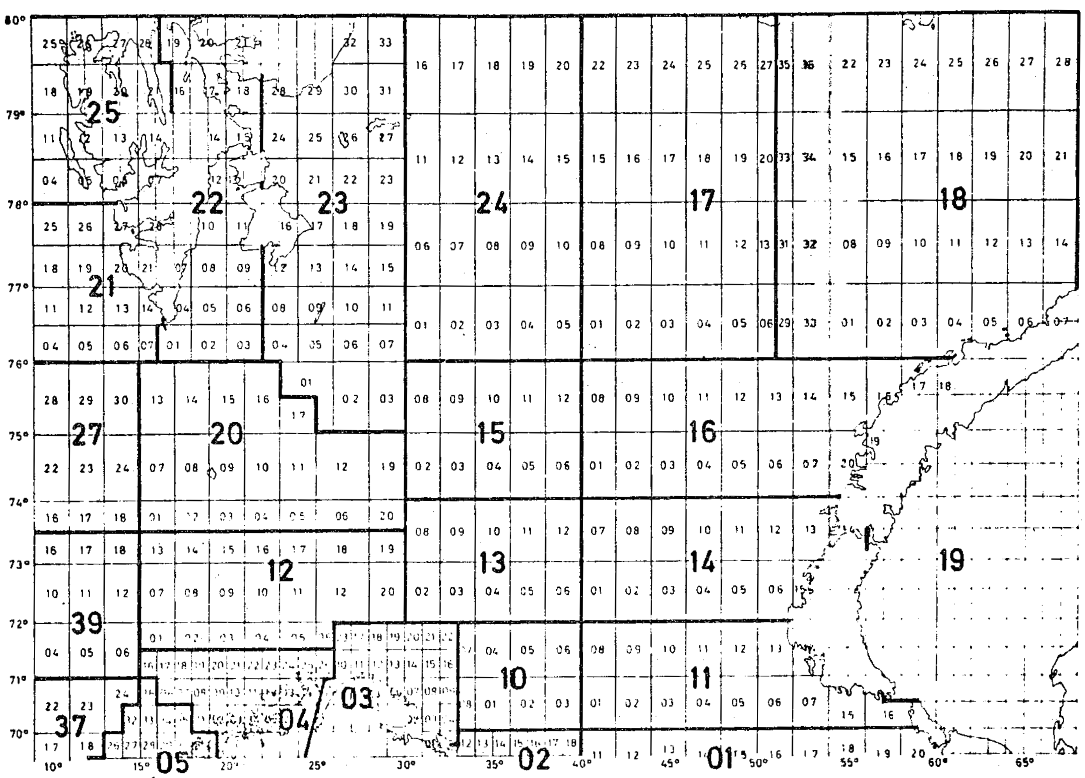


Fig.4. Areas and subareas in the Barents Sea, used by the Directorate of Fisheries for statistical purposes.

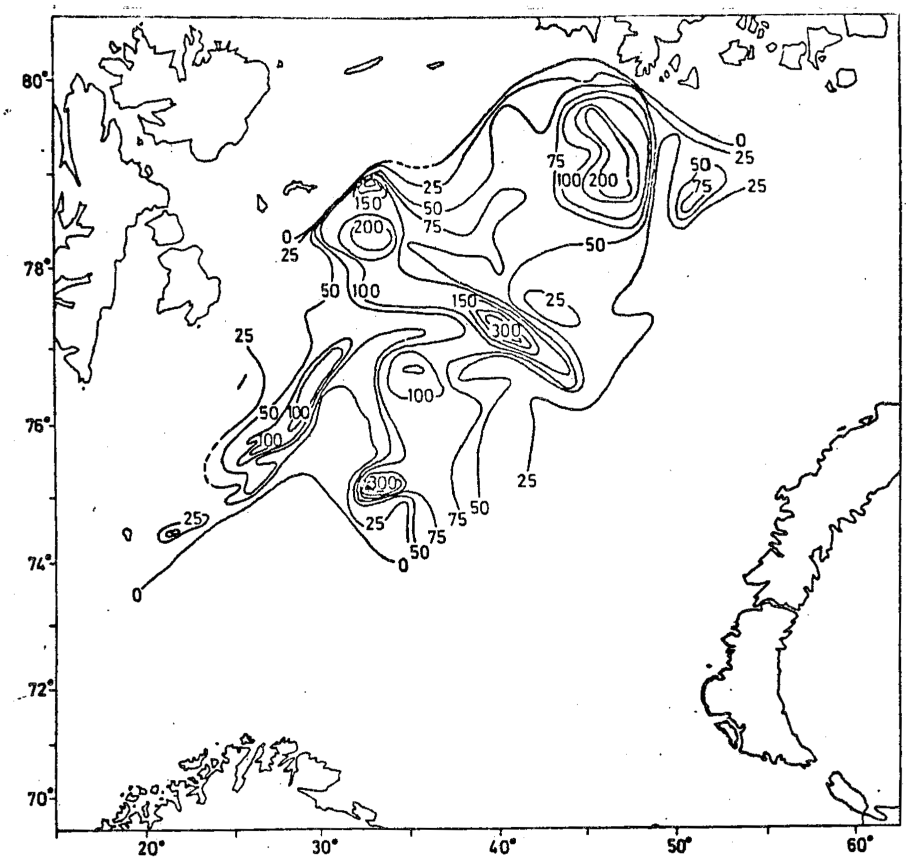


Fig.5. The distribution of integrated echo intensities for capelin 12-29 September 1971.

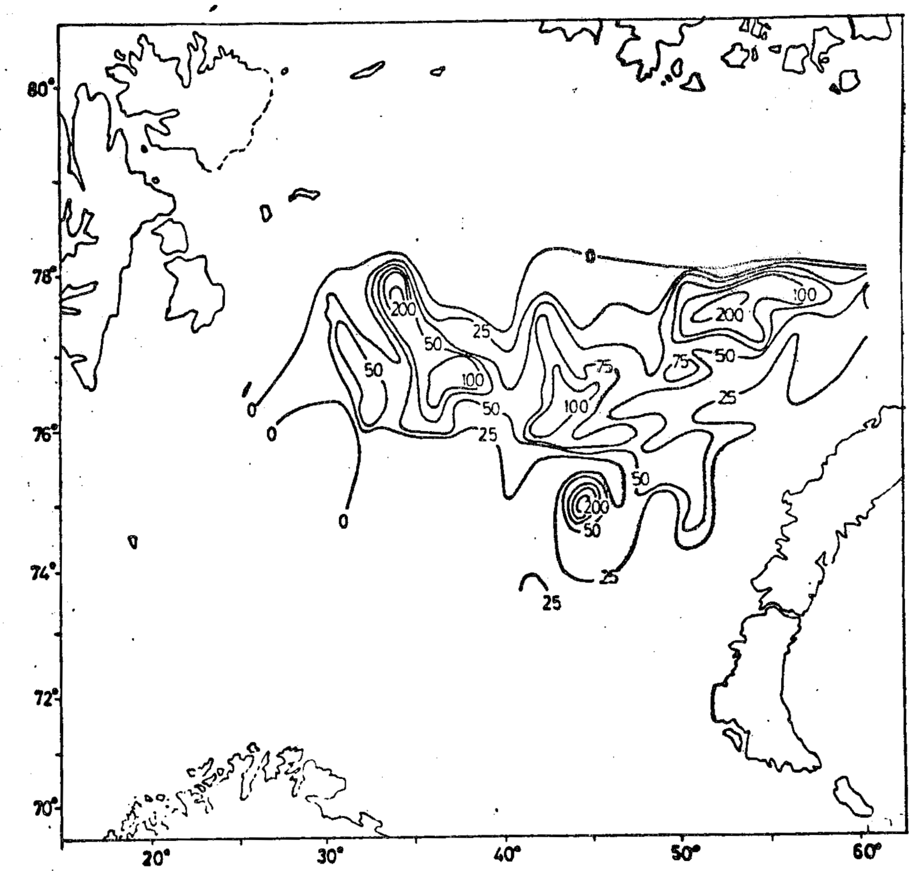


Fig.6. The distribution of integrated echo intensities for capelin 5-20 August 1972.

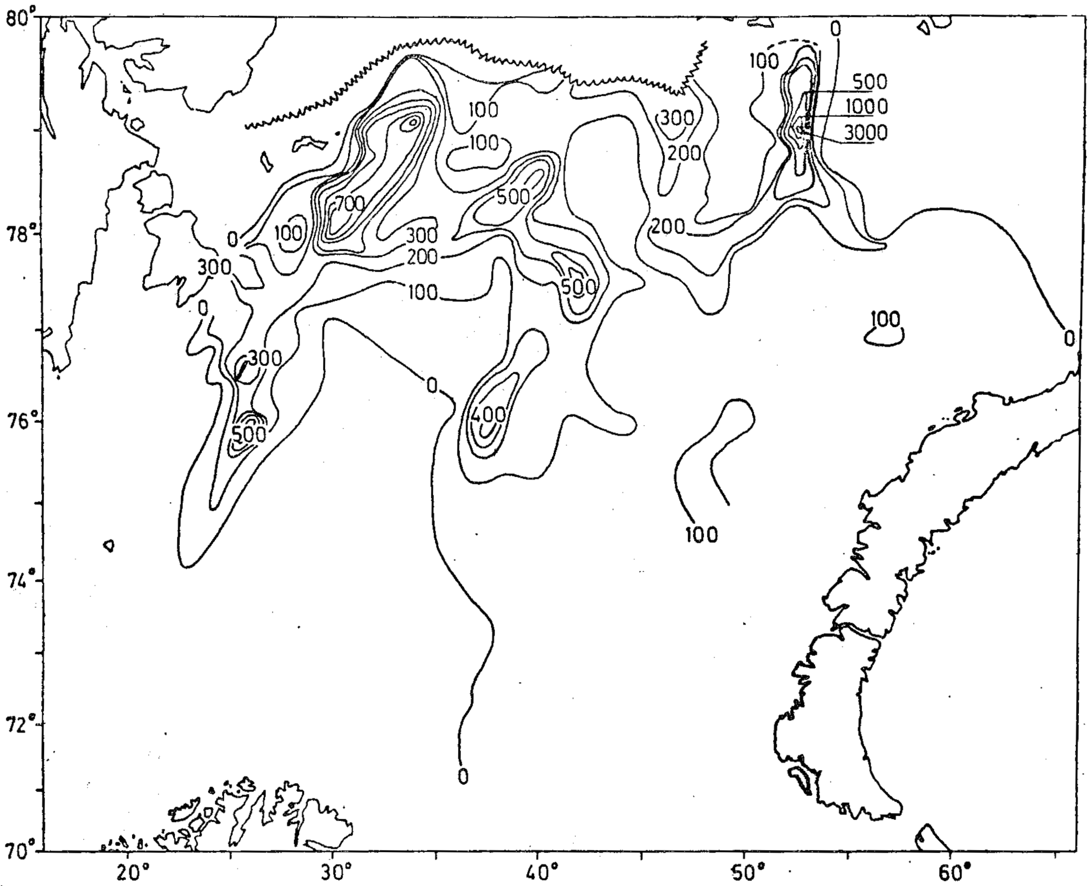


Fig.7. The distribution of integrated echo intensities for capelin 16 September-8 October 1973.

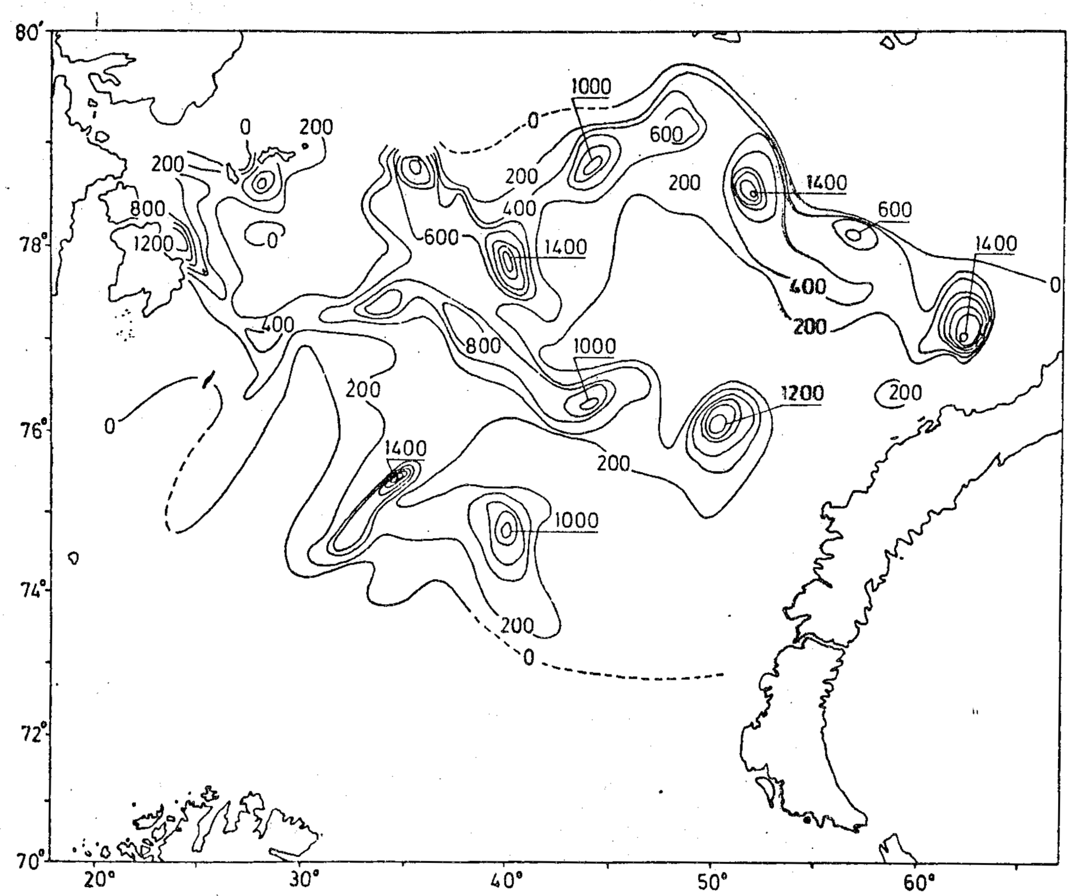


Fig.8. The distribution of integrated echo intensities for capelin 15 September-12 October 1974.

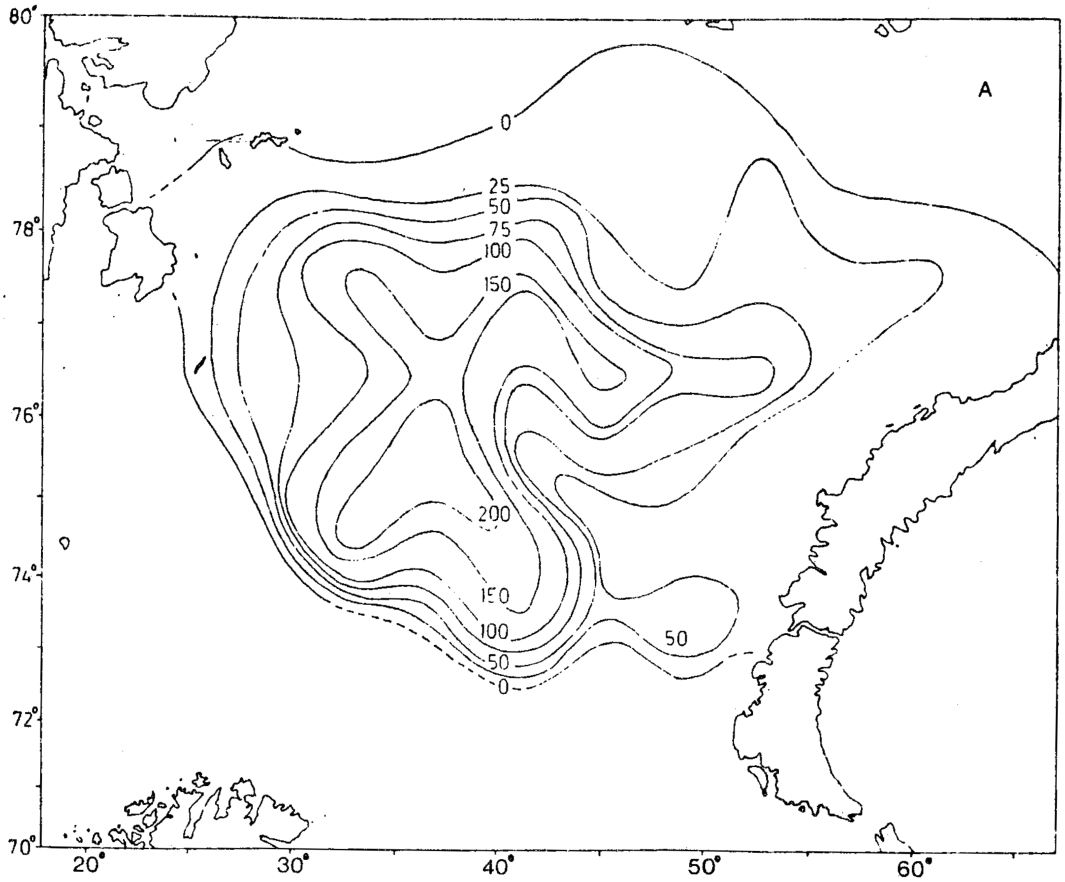


Fig.9. Density distribution (hectolitres/(nautical mile)^2) of 0-group capelin.

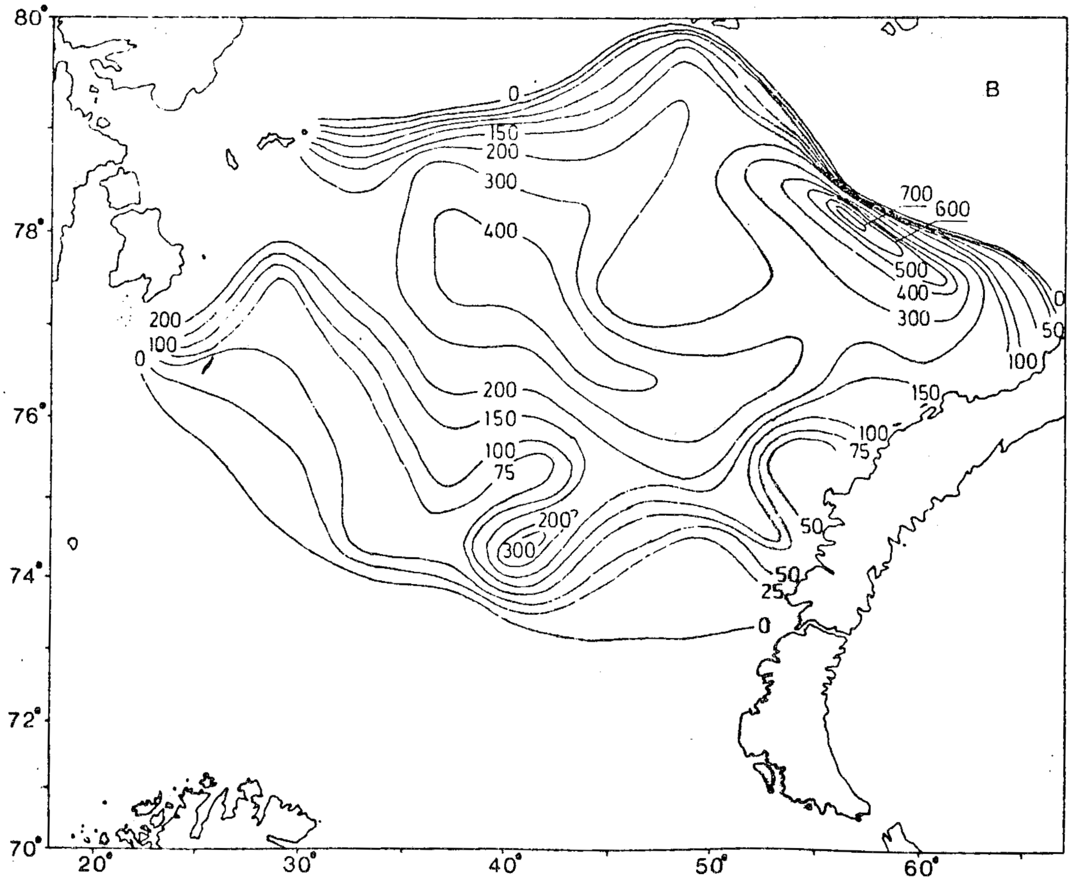


Fig.10. Density distribution (hectolitres/(nautical mile)^2) of 1 year old capelin.

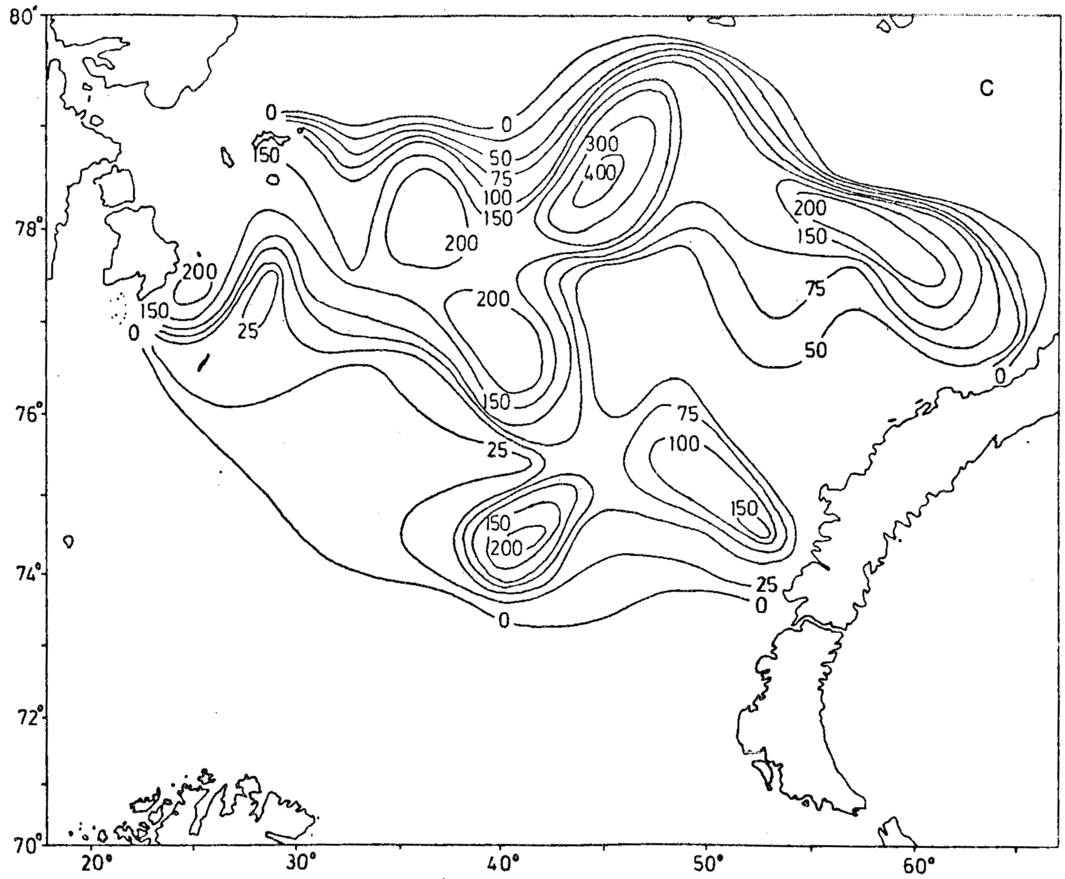


Fig.11. Density distribution (hectolitres/(nautical miles)^2) of 2 years old capelin.

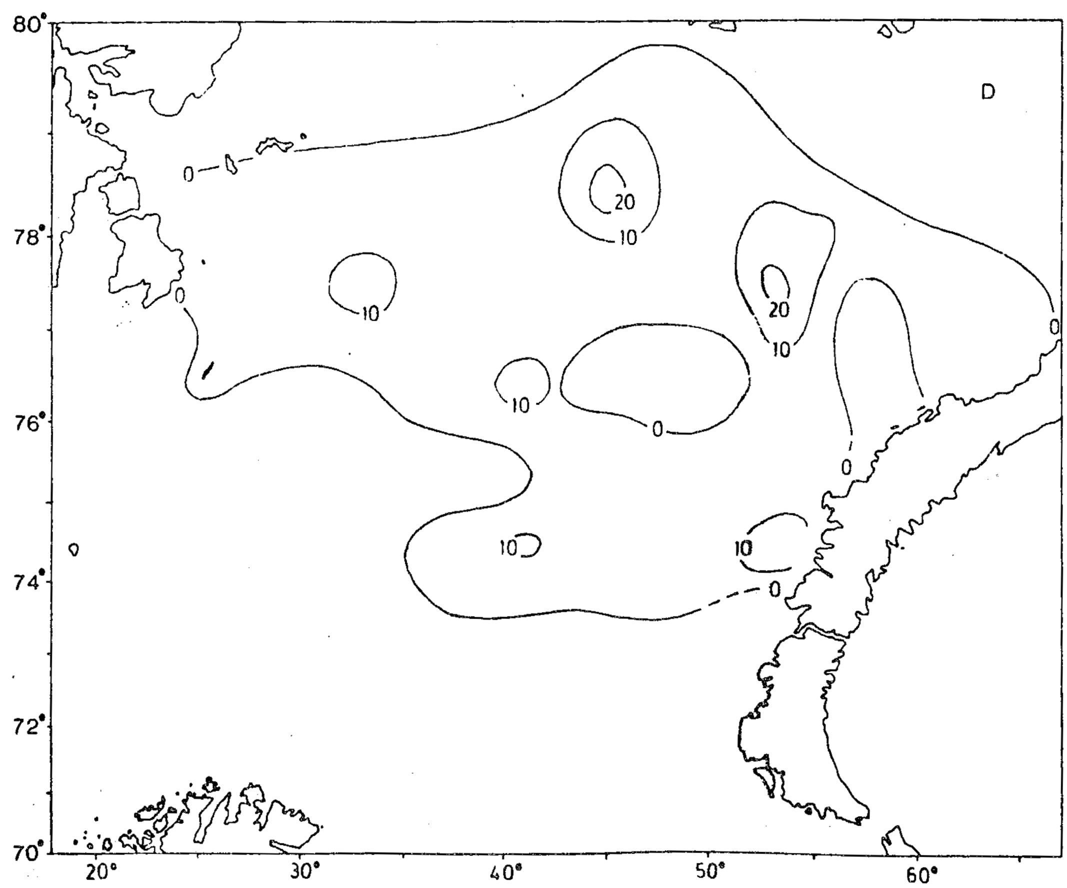


Fig.12. Density distribution (hectolitres/(nautical mile)^2) of 3 years old capelin.