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Distribution and abundance of sprat in the North Sea in winter 1979-1980 determined by acoustic methods

by

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ABSTRACT

To estimate the size of the North Sea sprat stock acoustically two cruises were carried out in November 1979-January 1980. The method is described and the size of the sprat stock was estimated to about 1 million tons. This is probably an underestimate due to the fact that some of the sprat stock were distributed close to the bottom or sea surface and therefore out of range of the acoustic equipment, and also due to the fact that the applied average target strength possibly is too high.

METHODS

A 38 KHz scientific echo sounder and a computer system was used for echo integration. Sampling of fish recordings were done with a pelagic trawl. Hydrographic measurements were made with CTD-zonde. All stations and the survey grids are shown in Fig.1 (November 1979) and Fig.2 (January 1980).

Average integrated echo intensities per nautical mile were computed each fifth nautical mile steamed. The values were given in mm integrator deflection referred to 40 dB integrator gain.

During daily scrutinizing of the echo recordings these values were allocated to three main categories: plankton, fish recordings containing sprat and other fish recordings. The allocation was based on the results of the trawl catches and the appearance of the recordings. In January plankton recordings were scarce and fairly easy to distinguish from fish recordings. In November more plankton was observed, frequently mixed with fish recordings especially at night. In such cases the integrator values were split by applying the ration between plankton and fish contribution obtained in neighbouring areas where fish and plankton were clearly separated.

The echo intensity contribution from sprat relative to the contribution from the category "fish recordings containing sprat" was calculated by applying the formula:

$$\text{Echo fraction of sprat} = Ef_s = \frac{k_s \sum_{i=1}^{n_s} (f_i \cdot L_i^2)}{\sum_{j=1}^{m} \left[a_j k_j \sum_{i=1}^{n_j} (f_i \cdot L_i^2) \right]}$$

where k_j = fraction (by numbers) of species j

k_s = fraction (by numbers) of sprat

f_i = fraction of length group i in the length distribution of species j

L_i = fish length (cm) in group i

n_j = number of length groups of species j

n_s = number of length groups of sprat

m = number of species

a_j = 1.0 for species with swimbladder
= 0.25 for species without swimbladder

Ef_s was estimated by counting the number and measure the length distribution for each species in each trawl catch. The echo intensity values for sprat, M_s, were then calculated as

$$M_s = \overline{Ef}_s \cdot M$$

where $\overline{Ef}_s$ is the average Ef_s for the nearest trawl stations,

and M is the value for fish recordings containing sprat.

Experimental measurements of target strength of sprat of different sizes and tilt angles (NAKKEN & OLSEN, 1977) are used to calculate an average target strength as function of length. When tilt angles are assumed to be normally distributed with an average of 3.8^{o} and a standard deviation of 6.0^{o}, the average target strength: $\overline{TS}$ = 20 log L-65 dB per individual or $\overline{TS}_{kg}$ =- 10 log L -15 dB per kilogram. (The basic calculations were made by K.G. Foote, Institute of Applied Mathematics, University of Bergen). The additional spread of tilt angles caused by the transducer beam angle, and the performance data of the equipment give the following conversion factors (L):

November 1979

1 mm/n.mile = $3.5 \cdot 10^{6} \cdot L^{-2}$ individuals per $(n.mile)^2$ or
$21 \cdot L$ kilograms per $(n.mile)^2$

January 1980

1 mm/n.mile = $5.6 \cdot 10^{6} \cdot L^{-2}$ individuals per $(n.mile)^2$ pr.mm per n.mile or
$34 \cdot L$ kilograms per $(n.mile)^2$ pr. mm per n.mile

The difference between November and January is caused by a 2 dB reduction of the source level in the echo sounder.

The density of sprat was calculated as

$$\rho_s = M_s \cdot C$$

In November average densities was calculated within area rectangles of 15 x 30 nautical miles. Interpolated values were assigned to uncovered rectangles laying between covered rectangles.

For the January survey smoothed averages were calculated running over 25 nautical miles. These were plotted and isolines of sprat abundance were drawn (Figs. 4 and 5).

RESULTS

Table 1 and 2 show the composition of the trawl catches. The density distributions of the 1979 year class and the older sprat are shown separately in Figs. 3, 4 and 5. Because of incomplete coverage in November, density-isolines are not drawn. The 35 $^{o}/oo$ isoline at surface is shown in Figs. 3 and 4.

The average length distributions of sprat within different areas are shown in Figs.6 and 7. These are calculated as an unweighted average of the length distributions obtained within the respective area (disregarding samples of less than 50 fishes).

The major part of the 1979 year-class seems very small in size. Most of the samples from November 1979 had a modal length of 3.5 - 4.0 cm and an average volume of 0.5 ml per individual. Some larger 0-group (5-7 cm) occured in the coastal areas. The samples of the 1979 year-class taken in January 1980 had a modal length from 4.5 to 5.5 cm and an average volume of 1.0 ml. Assuming 8.0 cm as the upper limit for the length of the 1979 year-class taken in November 1979, the estimates within the surveyed area (division IIIa excluded).

190 000 tons or $370 \cdot 10^9$ individuals of the 1979 year-class
150 000 tons or $26 \cdot 10^9$ individuals of the older sprat.

Using 8.5 cm as the upper limit for the 1979 year-class taken in January 1980, the estimates (for the North Sea, outside division IIIa) are

660 000 tons or $660 \cdot 10^9$ individuals of the 1979 year-class
350 000 tons or $55 \cdot 10^9$ individuals of the older sprat

DISCUSSION

The main sprat concentrations seem to have been distributed unusually far to the south-east during the winter 1979/80. This is possibly caused by the influx of Atlantic water from the north. Figs. 3 and 4 indicate that both the 35 $^{o}/oo$ isohaline and the main sprat concentrations moved south-eastward during the period November 1979-January 1980. A similar shift occured in the Norwegian sprat fishery (Fig.8).

During the November cruise the sprat in some areas showed a tendency to stay close to the surface or close to the seabed. This means that some fish occured outside the integrator range and the total abundance of sprat may be underestimated. It is difficult to assess to what extent this happened. Comparisons of echo intensities obtained along the same track lines during day and night in Moray Firth showed a 50% reduction from night to day. The main reason for this is assumed to be that the fish tended to stay close to bottom at daytime, while a more suitable distribution for the acoustic system was found at night.

In January these tendencies were evident only in the shallowest areas (less than 25 m bottom depth), which represents just a minor part of the observed distribution area.

The separation of mixed recordings of fish and plankton is based on the assumption that the ratio of fish and plankton contribution is the same during day and night and the assumption that the ratio is not significantly different in neighbouring areas. These assumptions are not verified, and it is very difficult to assess whether the possible errors may lead to an underestimation or an overestimation.

During January the problems with the plankton was of minor importance. This, together with good weather conditions and convenient vertical distribution of the sprat, give reasons to rely on the obtained values for echo-abundance of sprat. In November the results were influenced both by dense plankton recordings and to certain extent also on unfavourable vertical distribution of the sprat.

The formula applies for calculation of the echo fraction of sprat is a simplification of the formulas given by NAKKEN & DOMMASNES (1975). The simplifications are based on the following assumptions:

All fish species with swimbladder have equal average back scattering cross-section at equal fish length.

Fishes without swimbladder have 1/4 of the average back scattering cross-section of equal-sized fish with swimbladder (reflected by the factor, a_j, in the applied formula).

The average back scattering cross-section is proportional to the square of the fish length.

Target strength measurements made by NAKKEN & OLSEN (1977) indicates that those assumptions do not lead to serious errors in the sprat estimate as long as sprat is the dominating species.

The use of trawl catch composition as an estimate of the true composition of species and size groups in the sea is likely to be biased, due to trawl selection. Larger fish may swim too fast and thereby avoid the trawl. Further, the smallest fish may be retained only by the inner small-meshed cover-net (8 mm strecthed meshes) in the cod end. Therefore they are sampled from a much smaller volume than the bigger fishes are. The fish of intermediate size may be retained or swept into the trawl by the large meshes in the front of the trawl, without being able to avoid the trawl. Because of this size-dependent behaviour the intermediate sized fishes tend to be overrepresented relative to small and large fish in the catches.

In addition to such systematic errors the trawl catches introduce random errors due to inhomogenous distribution of species and size-groups, both horizontally and vertically. This is not believed to be too serious in this investigation due to small variation in the composition of neighbouring trawl hauls.

Random errors in the estimate of echo abundance mainly depends on fish behaviour and survey grid density. The applied survey grid in January gives a "degree of coverage" of 12 when defined as the ratio between number of n.miles steamed (within the observed distribution area) and the square root of the distribution area. Experiences from similar surveys on small pelagic fish give reason to expect the estimate of echo abundance to have a coefficient of variation of about 0.2 when the "degree of coverage" is 12 (AGLEN 1979). Therefore the estimate is expected to be less than 20% from the "true value".

In November the distribution area was partly covered. The "degree of coverage" for the covered area is 9, when Division IIIa is excluded. This corresponds to an expected coefficient of variation of 0.2. In Division IIIa the most dense area (inner Kattegat) was incompletely covered. The results for this area may therfore be unreliable and are not further discussed here.

The suggested "confidence limits" only applies to the estimates of echo abundance, not to the absolute estimates in tons (or number of individuals). The reason for this is the uncertainty of the applied conversion factors. This is directly dependent of how representative the assumed average target strength is. The average traget strength is based on the measurements made by NAKKEN and OLSEN (1977) and the tilt angle distribution observed by BELTESTAD (1974) on "undisturbed", encaged young herring. Later behaviour studies (OLSEN 1979) show that the average target strength of fish beneath a steaming vessel may be well below the average target strength of undisturbed fish. Therefore the applied conversion factor and the resulting abundance estimate may be too low.

In spite of this it shoulbe be possible to compare the results from the two surveys. The estimates from January are clearly higher than those from November. This may simply be explained by the incomplete coverage in November. In addition some unfavourable vertical distribution of the sprat in November has possibley reduced the estimate. If the entire distribution area had been covered during both surveys, one should expect the January estimate of number of individuals to be the lowest, because of natural and fishing mortality. (About 50 000 tons were taken by Norwegian fishermen during the period between the surveys).

CONCLUSION

The 1979 year-class seems to be rather strong, but slowly growing. This year-class was calculated to represent 92% (by numbers) of the total stock in January. Because of the trawl selectivity it may be even more dominating.

The total estimate of about 1 mill. tons is possibly and underestimate, because the applied average target strength is possibly too high, and because sprat close to bottom or sea-surface is not measured acoustically.

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Table 1 Composition of pelagic trawl catches taken during 7-27 January 1980. (Number of fishes and litres of Euphausiids pr.naut.mile towed). 1-28 November.

St.number	Date	Time GMT	Trawl depth (m) (depth of headrope)	1-group sprat	≥2-group sprat	1-group herring	≥2-group herring	Cod	Whiting	1-group other fishes	≥2-group other fishes	Euphausiids
1	8	09	25	400	-	12	-	3	-	117	-	0.5
2	8	17	0	192	-	-	-	-	-	-	-	120.0
3	9	03	150	-	-	-	-	-	-	-	-	+
4	9	18	0	5170	52	-	1	-	12	30	3	-
5	10	02	25	3523	39	-	-	-	2	93	14	-
6	10	09	40	2550	22	330	4	-	1	3	4	11.0
7	11	04	30	-	-	-	-	-	-	-	164	-
8	11	14	60	29	-	1	-	-	2	1	1	0.8
9	12	10	23	4176	-	55	1	-	3	-	-	5.0
10	12	15	30	600	-	67	-	-	-	7	-	0.9
11	13	20	0	-	3	-	-	-	4	505	3	-
12	14	04	25	-	1	-	-	1	22	18	-	1.0
13	14	23	16	-	18	-	-	-	-	2032	10	0.5
14	15	07	14	2920	60	37	-	3	12	65	21	-
15	15	15	25	3840	-	-	13	-	7	-	10	0.4
16	15	20	30	6762	-	-	1	2	3	10	239	-
17	16	02	12	580	-	-	-	-	4	91	2	-
18	16	08	34	3300	30	153	10	-	-	12	7	-
19	16	15	20	6667	-	-	65	-	17	4	-	-
20	16	22	20	5418	660	-	207	70	245	850	42	-
21	17	05	15	15510	690	96	112	2	105	2	17	-
22	17	12	25	10300	1150	-	43	-	8	15	1	-
23	17	15	30	1596	62253	-	272	-	80	-	-	-
24	17	20	22	234000	-	-	-	-	-	3	57	-
25	18	00	20	60711	15172	-	246	-	6	162	198	-
26	18	05	16	-	54	-	10	17	250	51	111	-
27	18	15	20	3220	2835	-	19	-	18	-	8	-
28	18	20	12	8460	1275	-	4	-	3	13	169	-
29	19	00	20	-	126	-	-	-	2784	168	28	-
30	20	10	25	2165	1083	2	-	-	314	82	16	-
31	20	05	10	17145	4030	-	-	-	26	264	20	-
32	20	16	15	36690	158	68	2	22	-	648	18	-
33	23	23	30	117	4	3	-	-	1	32	18	-
34	24	02	30 1)	-	-	-	-	-	-	-	-	-
35	24	06	25	3975	48	-	-	-	-	550	32	-
36	24	14	30	1500	-	27	-	-	-	1091	-	-
37	24	22	30	12950	58	292	3	-	-	1164	38	+
38	24	14	45	-	-	-	-	-	-	-	1	-
39	25	19	28	10692	308	-	3	1	1	1	71	-
40	26	02	20	4343	-	-	26	1	3	27	11	-

1) The trawl did not operate properly

Table 1. continued

St. number	Date	Time GMT	Trawl depth (m) (depth of headrope)	0-group sprat	≥1-group sprat	0-group herring	≥1-group herring	0-group mackerel	0-group whiting	Blue whiting	Norway pout	Maurolicus mülleri	Euphausiids
421	13	18	60,80	250	-	-	1	-	60	-	9	-	-
22	13	22	60,70	1950	-	-	-	-	3	-	-	-	-
23	14	11	0	800	-	-	-	-	25	-	-	-	-
24	15	10	50	17100	-	-	162	-	21	-	-	-	-
25	15	14	0	-	-	-	-	-	-	-	-	-	-
26	16	19	50,60	-	-	-	-	-	-	-	-	-	-
27	16	14	65,70	670	-	-	-	-	4	-	4	150	2.3
28	17	02	30	250	-	-	-	-	13	-	3	-	3.0
29	19	20	10	400	-	-	25	-	50	-	-	-	-
430	20	03	23	900	-	-	-	1	120	-	9	-	-
31	20	09	60,30	6100	-	-	-	5	2	-	-	-	1.1
32	20	11	0	-	-	-	-	-	-	-	-	-	-
33	20	16	25	910	-	-	-	-	-	-	-	-	-
34	20	21	25	1000	10	-	-	-	-	-	-	-	-
35	21	08	0	4800	-	-	-	-	-	-	-	-	0.8
36	21	08	15	125	-	-	-	-	-	-	-	-	-
37	21	16	15	12	-	-	-	1	-	-	-	-	+
38	21	21	0	-	-	-	-	-	1	-	-	-	30.0
39	22	08	0	-	-	-	-	-	-	-	-	-	-
440	22	11	50	12480	-	-	-	-	1	-	-	-	6.4
41	22	18	25,40	250	-	-	-	-	-	-	-	-	0.3
42	22	24	50	4700	-	-	-	-	40	-	-	-	-
43	23	05	33	-	1	-	1	-	70	-	-	-	-
44	23	09	45	130	-	6	-	-	11	-	-	-	-
45	23	14	0	2250	-	11500	-	-	4	-	-	-	-
46	23	21	50	6300	20	-	17	-	100	-	-	-	+
47	24	00	0	90	-	-	10	-	25	-	-	-	-
48	24	06	30,50	70	18	-	30	-	470	-	-	-	+
49	24	12	60	750	1500	-	-	-	60	-	-	-	-
450	24	19	30	100	-	-	-	-	2800	-	-	-	-
51	25	01	33	1600	-	176	-	1	120	-	-	-	-
52	25	15	40,70	350	20	-	-	-	5	-	-	-	-
53	26	06	70	1150	30	-	13	-	160	-	-	-	-
54	26	20	70	-	-	-	-	-	6	-	5	-	-
55	27	08	40,60	-	-	-	-	-	-	-	-	312	-
456	27	15	47	1000	-	17	-	-	2	-	-	-	+

Table 2 Composition of pelagic trawl catches taken during 7-27 January 1980. (Number of fishes and litres of Euphausiids pr.naut.mile towed).

St.number	Date	Time GMT	Trawl depth (m) (depth of headrope)	1-group sprat	≥2-group sprat	1-group herring	≥2-group herring	Cod	Whiting	1-group other fishes	≥ 2-group other fishes	Euphausiids
1	8	09	25	400	-	12	-	3	-	117	-	0.5
2	8	17	0	192	-	-	-	-	-	-	-	120.0
3	9	03	150	-	-	-	-	-	-	-	-	+
4	9	18	0	5170	52	-	1	-	12	30	3	-
5	10	02	25	3523	39	-	-	-	2	93	14	-
6	10	09	40	2550	22	330	4	-	1	3	4	11.0
7	11	04	30	-	-	-	-	-	-	-	164	-
8	11	14	60	29	-	1	-	-	2	1	1	0.8
9	12	10	23	4176	-	55	1	-	3	-	-	5.0
10	12	15	30	600	-	67	-	-	-	7	-	0.9
11	13	20	0	-	3	-	-	-	4	505	3	-
12	14	04	25	-	1	-	-	1	22	18	-	1.0
13	14	23	16	-	18	-	-	-	-	2032	10	0.5
14	15	07	14	2920	60	37	-	3	12	65	21	-
15	15	15	25	3840	-	-	13	-	7	-	10	0.4
16	15	20	30	6762	-	-	1	2	3	10	239	-
17	16	02	12	580	-	-	-	-	4	91	2	-
18	16	08	34	3300	30	153	10	-	-	12	7	-
19	16	15	20	6667	-	-	65	-	17	4	-	-
20	16	22	20	5418	660	-	207	70	245	850	42	-
21	17	05	15	15510	690	96	112	2	105	2	17	-
22	17	12	25	10300	1150	-	43	-	8	15	1	-
23	17	15	30	1596	62253	-	272	-	80	-	-	-
24	17	20	22	234000	-	-	-	-	-	3	57	-
25	18	00	20	60711	15172	-	246	-	6	162	198	-
26	18	05	16	-	54	-	10	17	250	51	111	-
27	18	15	20	3220	2835	-	19	-	18	-	8	-
28	18	20	12	8460	1275	-	4	-	3	13	169	-
29	19	00	20	-	126	-	-	-	2784	168	28	-
30	20	10	25	2165	1083	2	-	-	314	82	16	-
31	20	05	10	17145	4030	-	-	-	26	264	20	-
32	20	16	15	36690	158	68	2	22	-	648	18	-
33	23	23	30	117	4	3	-	-	1	32	18	-
34	24	02	30 [1]	-	-	-	-	-	-	-	-	-
35	24	06	25	3975	48	-	-	-	-	550	32	-
36	24	14	30	1500	-	27	-	-	-	1091	-	-
37	24	22	30	12950	58	292	3	-	-	1164	38	+
38	24	14	45	-	-	-	-	-	-	-	1	-
39	25	19	28	10692	308	-	3	1	1	1	71	-
40	26	02	20	4343	-	-	26	1	3	27	11	-

1) The trawl did not operate properly

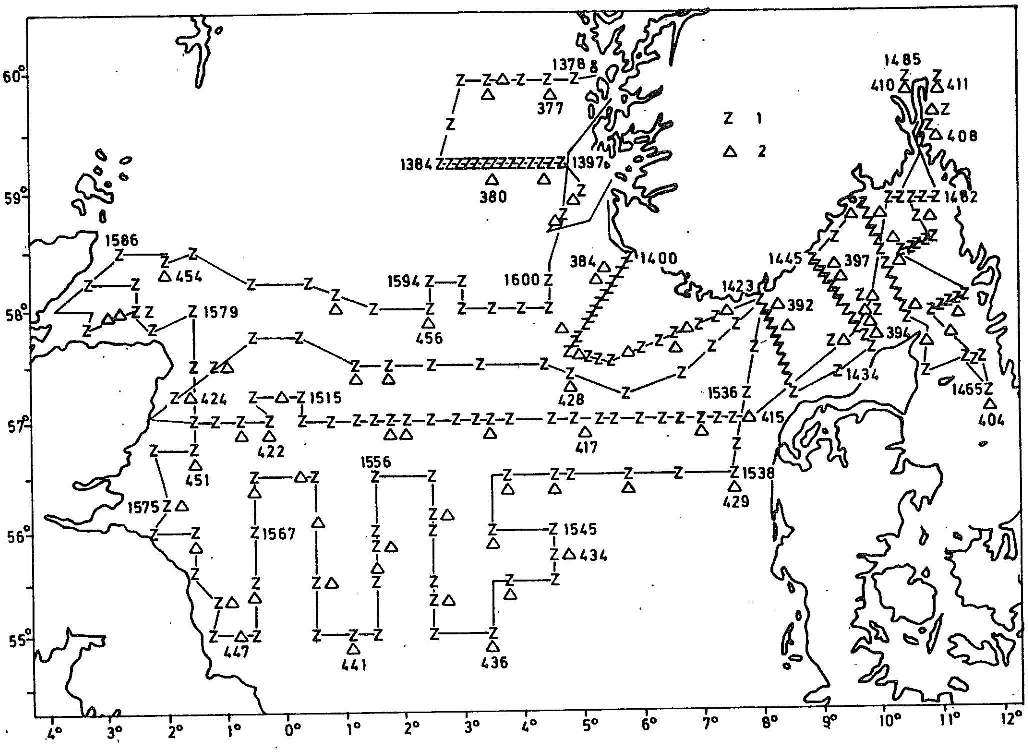

Fig. 1. Survey grid and stations, "Johan Hjort", 1 - 28 November 1979. 1) CTD sonde, 2) Pelagic trawl.

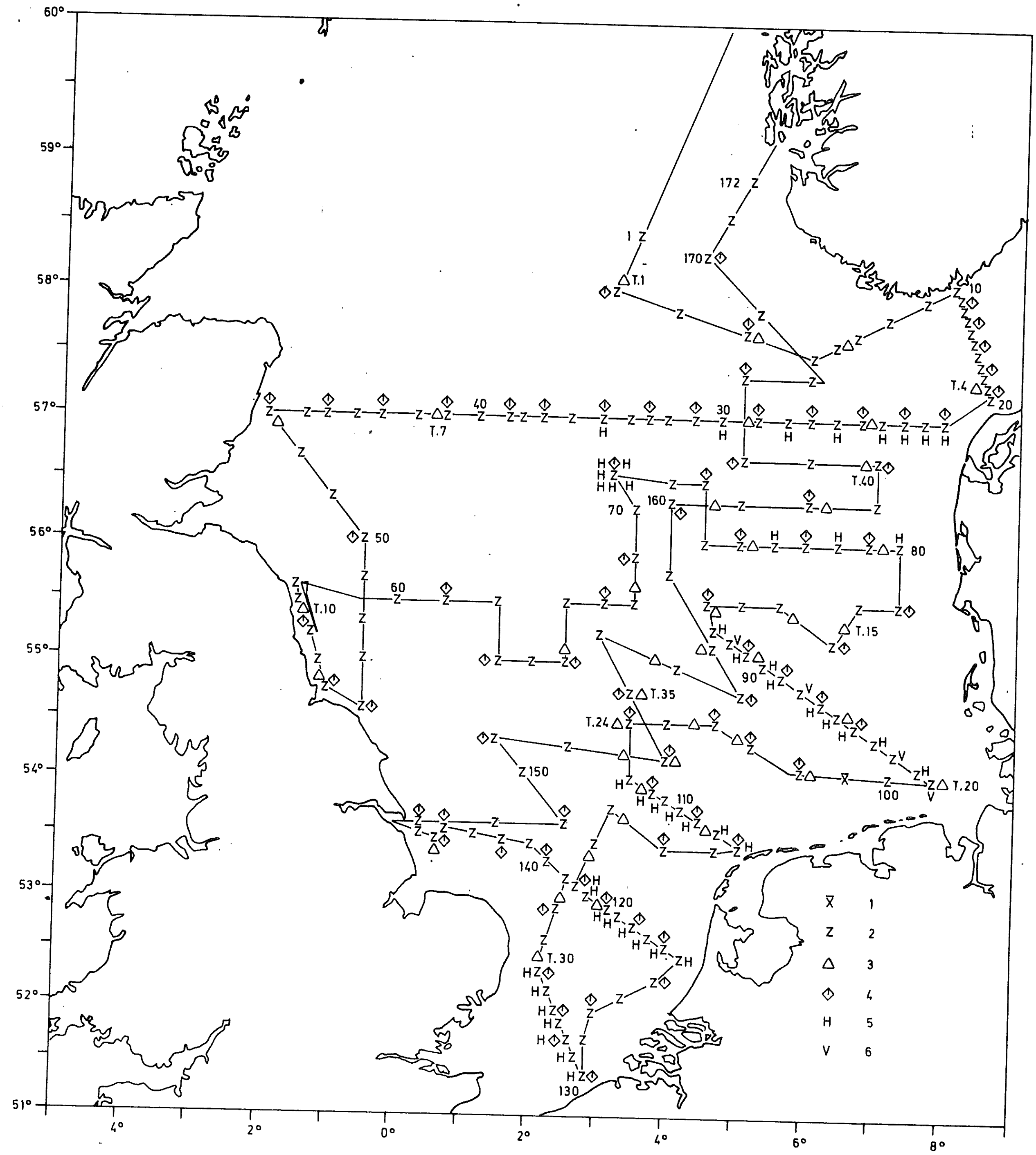

Fig. 2. Survey grid and stations, "Johan Hjort", 7 - 28 January 1980. 1) Classical oceanographic station, 2) CTD sonde, 3) Pelagic trawl, 4) Plankton station, 5) Sample from 1 m depth for hydrocarbon analysis, 6) Samples from 1, 10, 20 and 30 m depth for hydrocarbon analyses.

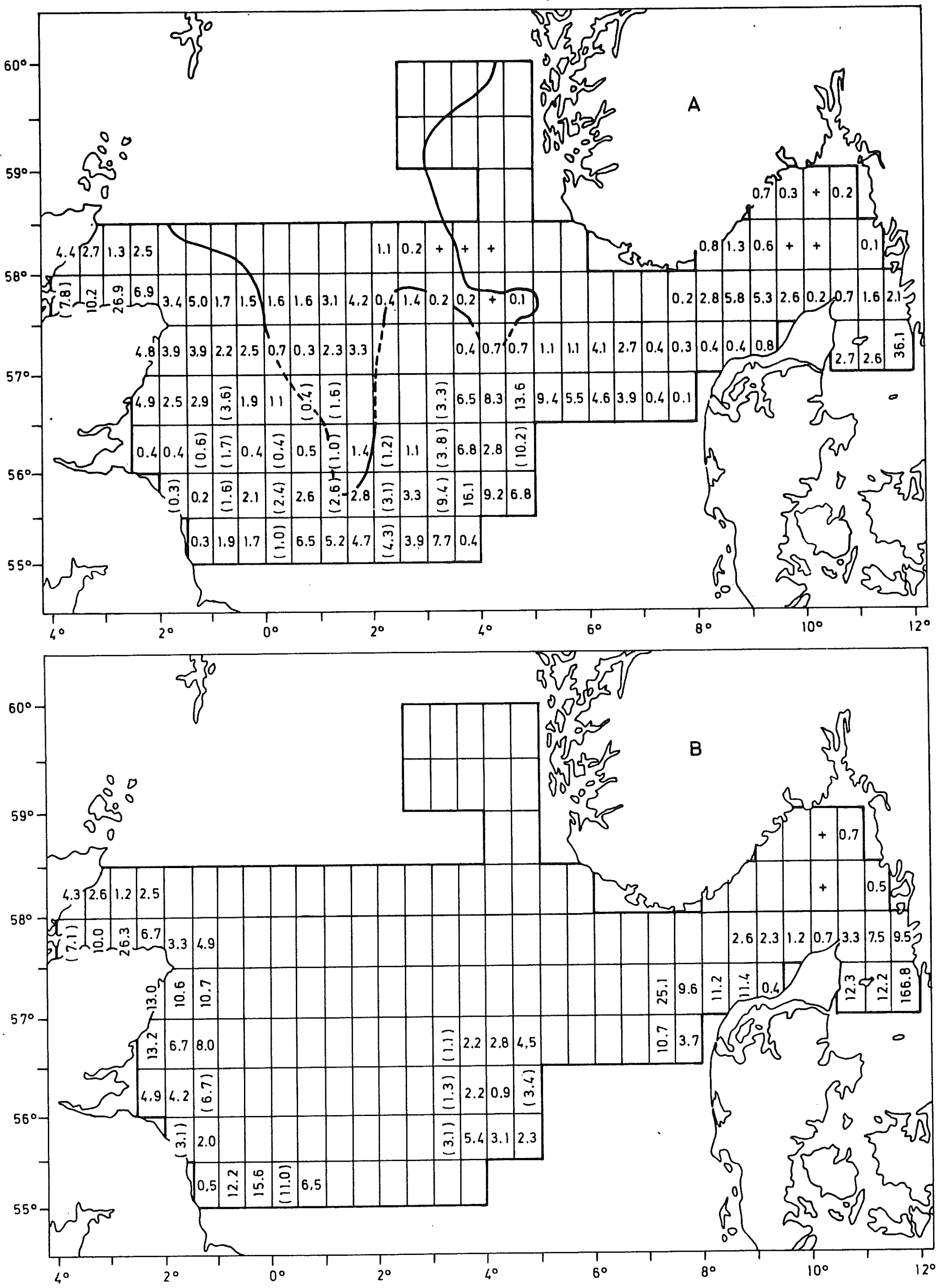

Fig. 3. Average density of sprat in tons per square nautical mile within statistical squares in November 1979. Interpolated values are given in parantheses. A) The 1979 year-class of sprat and the 35 per mille isohaline at surface, B) older sprat.

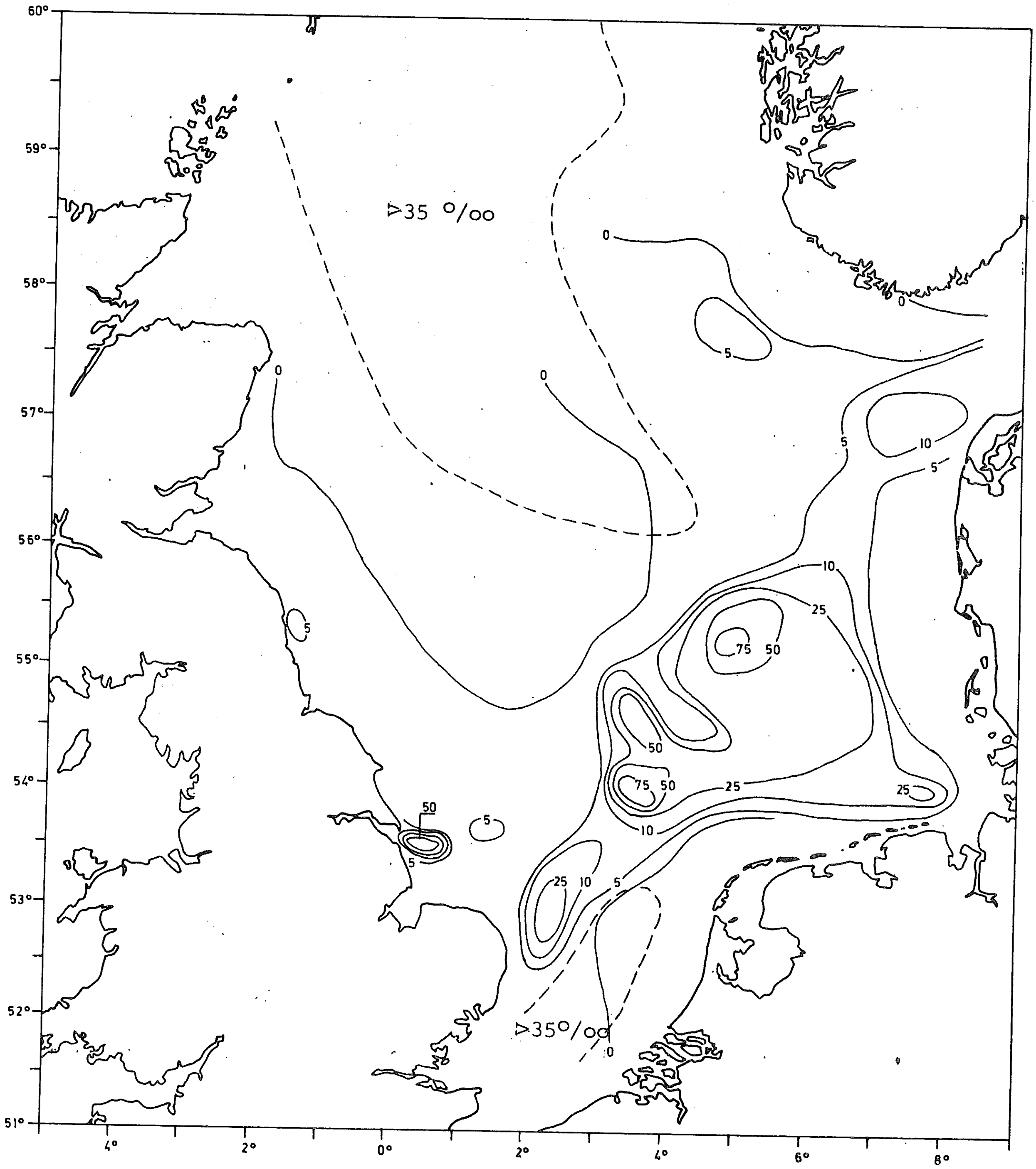

Fig. 4. Distribution of the 1979 year-class in January 1980.
Densities given as tons per square nautical mile.
Broken line: 35 per mille isohaline at surface.

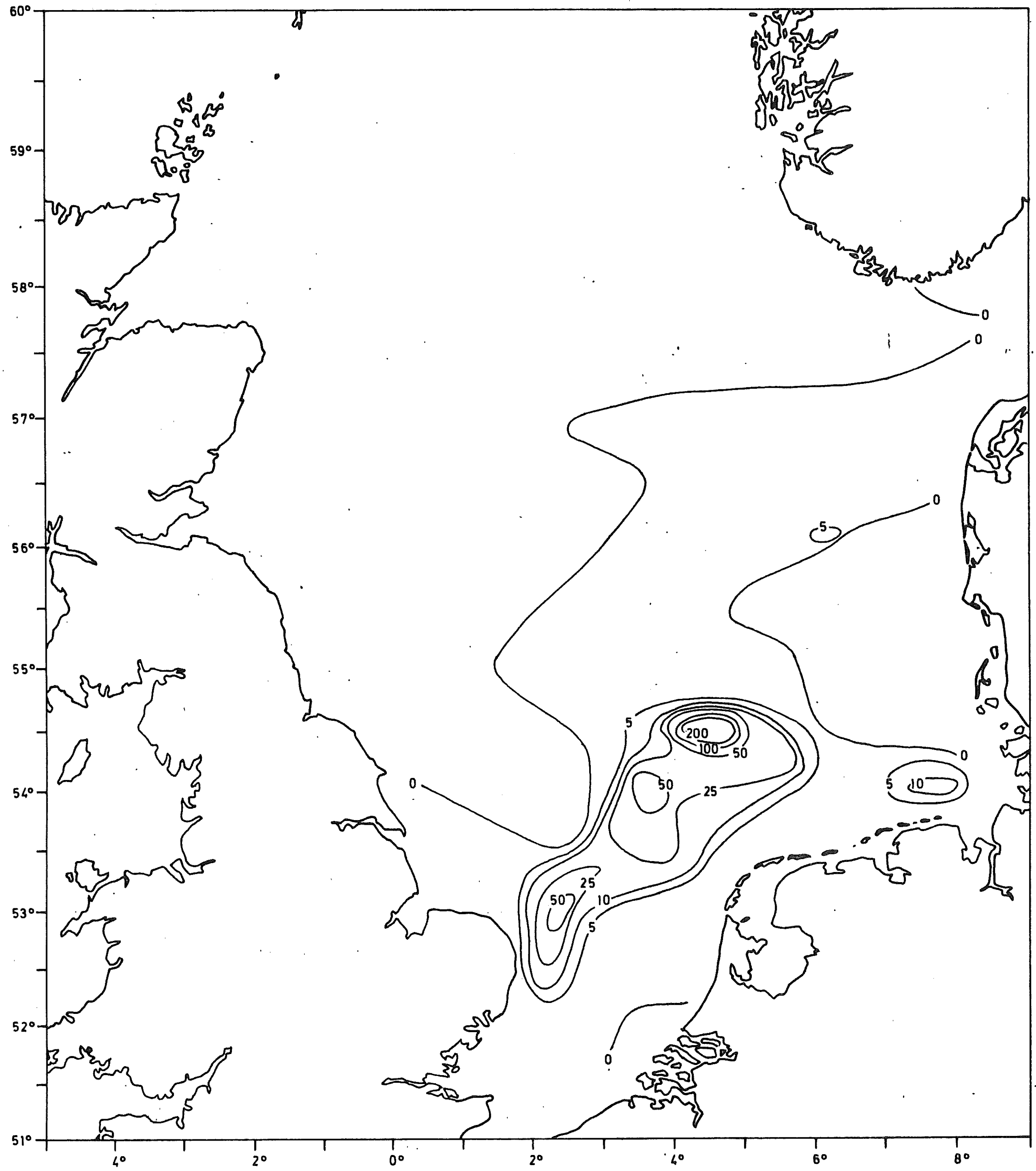

Fig. 5. Distribution of older sprat in January 1980. Densities given as tons per square nautical mile.

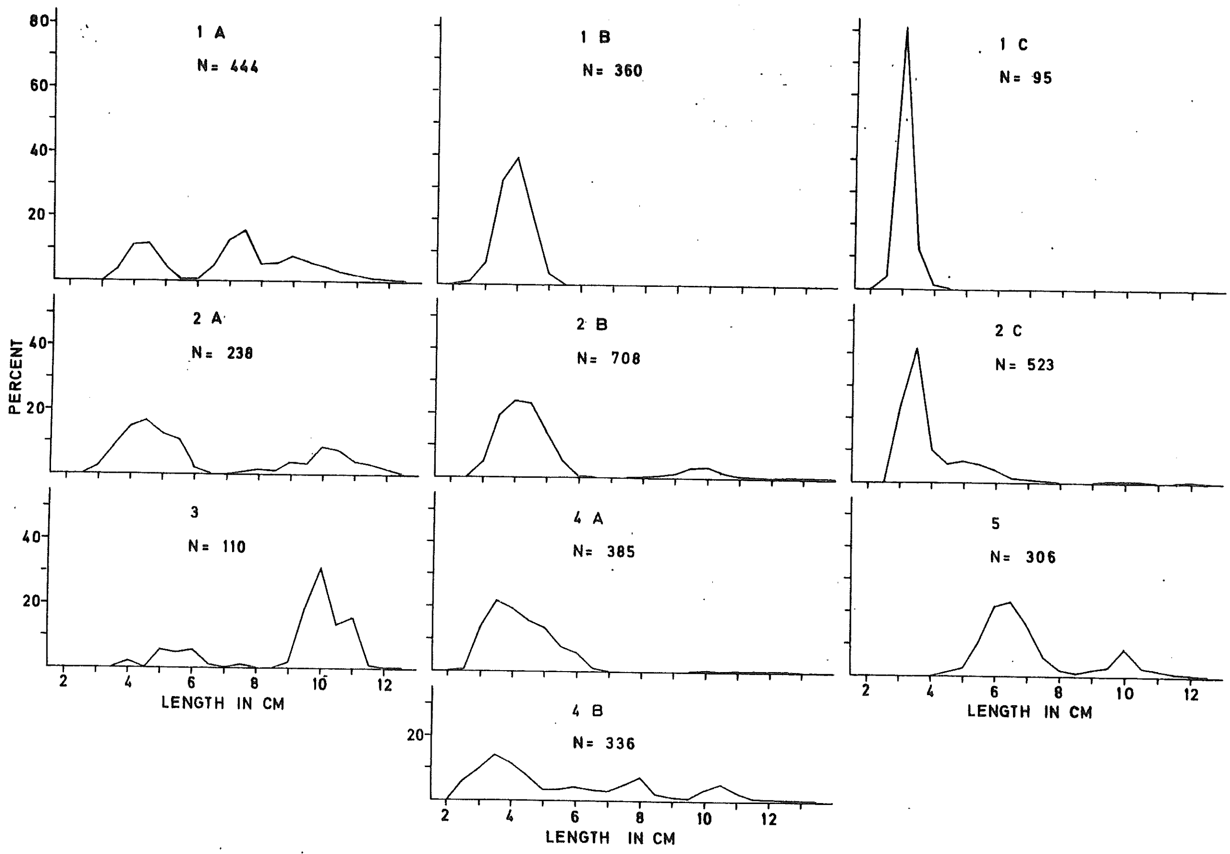

Fig. 6. Average length distribution of sprat (total length measured to nearest half centimeter below) within different areas in November 1979. N = number measured.

1A: North of N 56°45', west of W 1°
1B: " between W 1° and E 3°
1C: " between E 3° and E 7°
2A: South of N 56°45', west of W 1°
2B: " between W 1° and E 3°
2C: " between E 3° and E 7°
3 : West coast of Denmark
4A: Outer Skagerrak
4B: Inner Skagerrak and Kattegat
5 : The Oslofjord

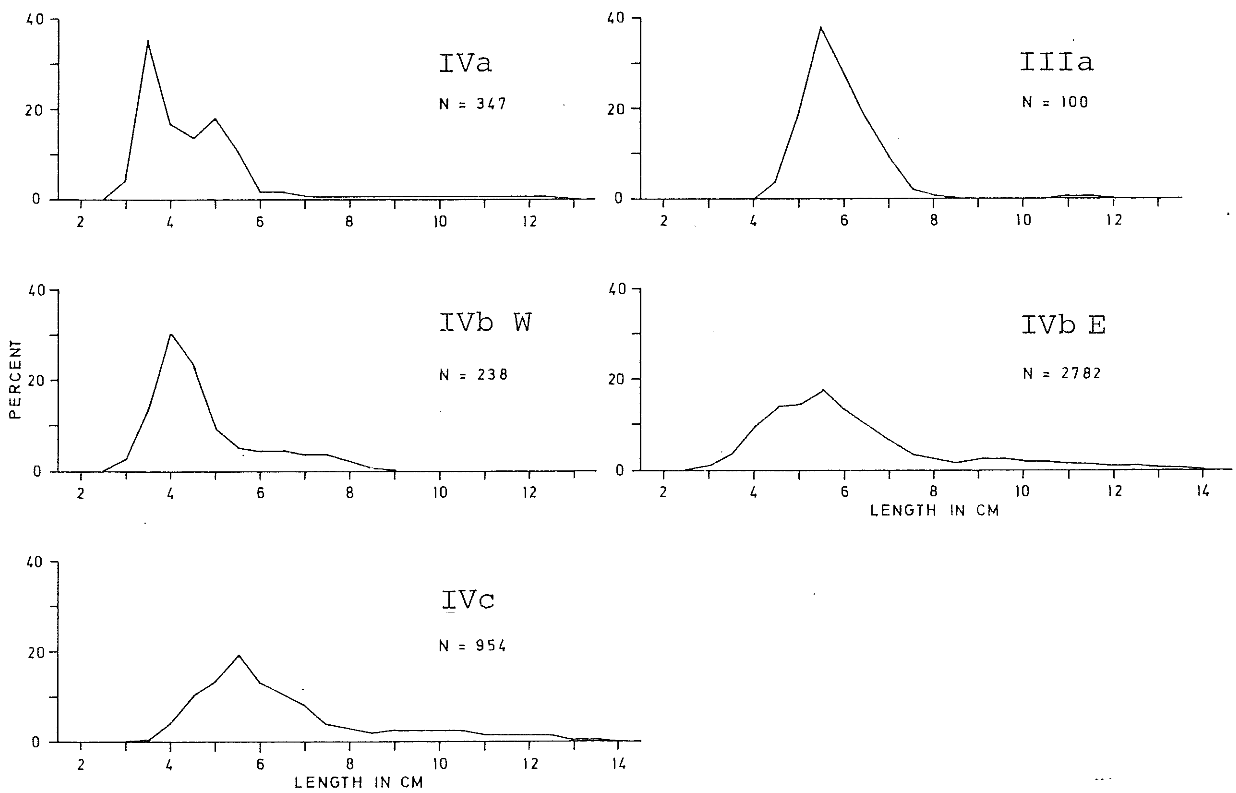

Fig.7 Length distributions of sprat within different ICES-areas in January 1980. Area IVb is divided along 3°E. Total length measured to neares half cm below. N = Number measured.

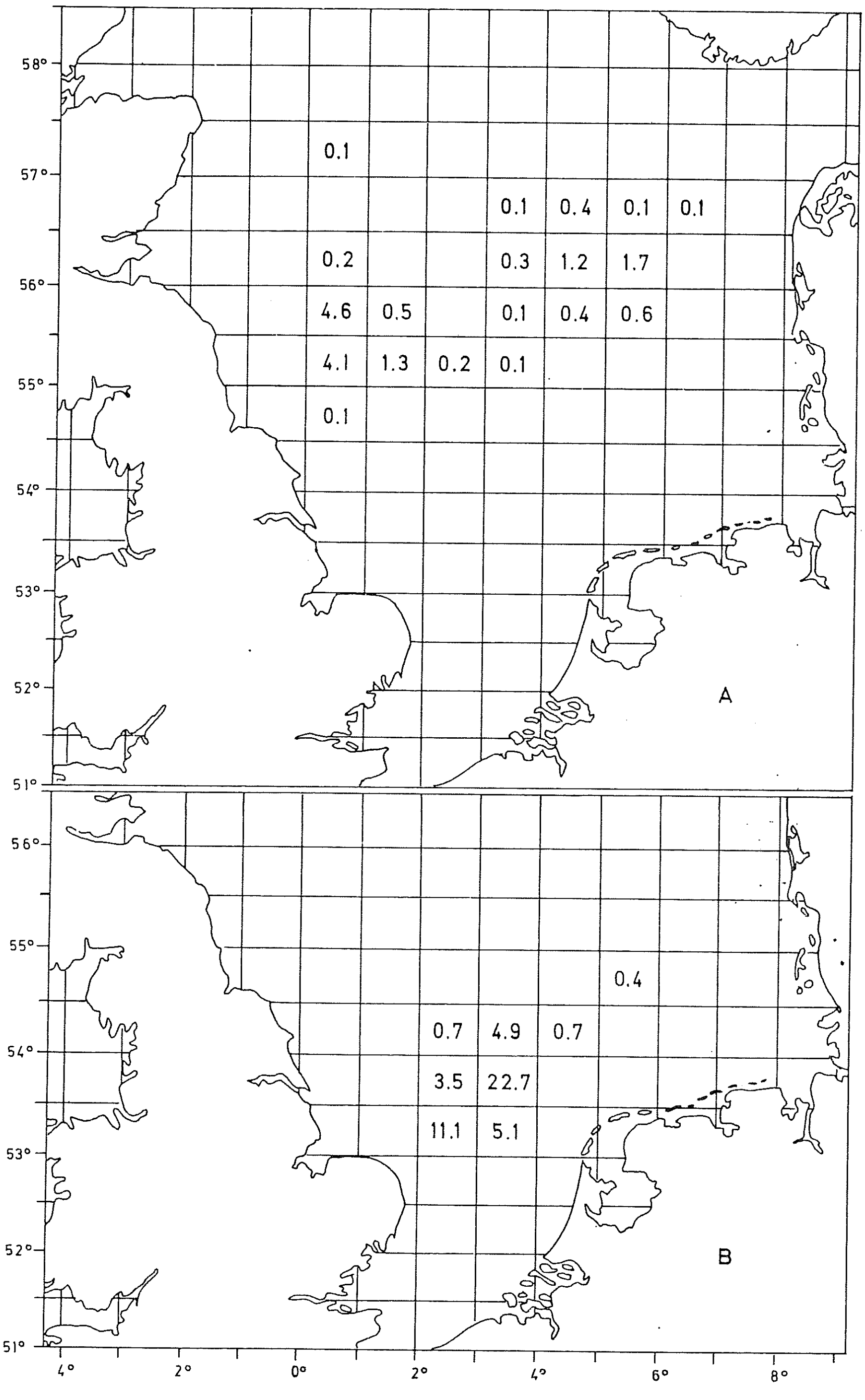

Fig. 8 . Norwegian purse seine catches of sprat (1000 tonnes) in different areas. A) 1-7 November 1979, B) 1-13 January 1980.