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ABUNDANCE ESTIMATION OF NORWEGIAN SPRING SPAWNING HERRING WINTERING IN THE VESTFJORD SYSTEM, DECEMBER 1996

by

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ABSTRACT

The spawning stock of Norwegian spawning herring has been surveyed when wintering in the Vestfjord, Tysfjord, and Ofotfjord, in northern Norway in December 1996. The basic method is that of echo integration, with compensation for acoustic extinction. Physical capture has been effected by means of the Multisampler pelagic trawl, which allows remote opening and closing of each of three codends at arbitrary depths. This has shown essentially thorough mixing of the dominant year classes except in the two fjord arms, where the samples contained a larger proportion of older fish (1983 year class). Geostatistics has been employed to describe the spatial structure and to provide an estimate of variance. Data quality control procedures have been performed and are described.

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INTRODUCTION

The spawning stock of Norwegian spring spawning herring has been wintering in the fjords of northern Norway since 1987. The stock has been concentrated, apparently exclusively, in the Ofotfjord-Tysfjord-Vestfjord system. The main concentrations of wintering herring were in the period 1987-1994 found in Ofotfjord and Tysfjord. However, since 1995, with the recruitment of the strong 1991 and 1992 year classes, the main part of the wintering herring biomass has been located in the inner part of Vestfjord. Comprehensive acoustic abundance surveys have been performed since autumn 1992 (Foote 1993, Røttingen et al 1994, Foote and Røttingen 1995, Foote et al 1996). These survey series are an important part of the data input to the models which are applied in the assessment of this stock (ICES 1997)

MIGRATION AND RECRUITMENT BIOLOGY

The adults of the Norwegian spring spawning stock undertake extensive migrations throughout the year. In spring they spawn off the western and north-western coast of Norway. After spawning the herring migrate out into the Norwegian Sea where they feed in the summer season. Here they occupy large areas, and they have a northward migration throughout the feeding season. In autumn the feeding ceases and the herring migrate eastwards to the wintering grounds which have been located in the Vestfjord system in northern Norway. In January the outward migration from the wintering areas to the spawning areas starts. The present migration pattern is shown schematically in Fig. 1. The extent of the distribution in summer during feeding in the Norwegian Sea can be of the order of 250 000 square nautical miles, while the wintering area distribution is restricted to about 200-400 square nautical miles.

In the period 1987 - 1993 the spawning stock of Norwegian spring spawning herring was completely dominated by the 1983 year class, the year classes from 1984 to 1991-1992 being relatively weak. The 1991 and 1992 year classes appeared partly as immatures, in the wintering areas in 1995-96 and formed complex concentrations with the mature herring (Foote et al 1996). While the spawning stock in the beginning of the 1990's was dominated by one year class (large individuals of the 1983 year class), the spawning stock in 1996/1997 was dominated by young herring (many of the recruit spawners) of the 1991 and 1992 year classes.

MATERIALS AND METHODS

The basic materials resemble those used in the mentioned winter surveys conducted over the period December 1992 - January 1996. The methods remain the same. For the sake of completeness, these are described briefly in the following.

Acoustic instruments and platform

The principal acoustic instrument was the SIMRAD EK500 echo sounder (Bodholt et al. 1989) with attached SIMRAD split-beam transducer model ES38B. The operating frequency is 38 kHz.

Acoustic data were reduced by integration in the EK500 and rendered as a time series of values of the volume backscattering strength. By convention these were expressed over the depth range 0-500 m with 1-m resolution and supplemented by 150 values with 0.1-m resolution in a bottom-tracking channel. The resulting 650 values were broadcast on a Local Area Network (LAN). They were received and stored in the Bergen Echo Integrator (BEI) (Foote et al. 1991) together with such other data as position and ship's log. Position data were supplied by a differential Global Positioning System (GPS) unit, the Trimble model NT200D GPS with built-in differential receiver. This is connected to the EK500 by serial line.

The instrument platform for the December 1996 survey was R/V "Johan Hjort". This is a 2000-BRT stern-trawling research vessel. The nominal sailing speed during the measurements reported in this study was 8-10 knots.

Survey design

The survey was done with the intent of putting effort where the fish were. While this is the general aim of abundance surveys, it had practical consequences for the conduct of the reported survey. In particular, the design was adaptive. When the large concentration of herring in Vestfjord was observed at the beginning of the survey, it was decided to increase the sampling density there and to perform only single if comprehensive coverages of Tysfjord and Ofotfjord, barring observation of other significant concentrations.

This plan was realised in most ways. Departures arose from a temporary break in computer operation in Tysfjord and by a strong storm in Vestfjord, prompting additional coverages of central Tysfjord.

The particular designs are described in Table 1. These are also evident in those cases presented in Figs. 2-5.

Acoustic measurements

The measurements were made with the described echo sounder with pulse duration 1 ms and receiver bandwidth 3.8 kHz. The transmission or pinging rate depends on the bottom depth and number of transducers being driven simultaneously, which was four during the survey. The ping rate was nominally 1/s.

During some measurements made under marginal conditions, the retractable keel with 38-kHz transducer was lowered. This resulted in a clear reduction in the reverberation level in the surface zone.

The echo sounder and coupled echo integrator system was calibrated according to the standard ICES procedure (Foote et al. 1987). The 60-mm-diameter copper sphere (Foote 1982) was used.

Postprocessing of acoustic data

Postprocessing was performed in the customary fashion with the Bergen Echo Integrator. Registrations of herring were essentially unambiguous. By encircling these by means of the mouse function of the workstation platform, the precise contribution to the echo integral, the area backscattering coefficient, could be determined. The bottom channel was also interpreted for cases in which the herring were in the vicinity of the bottom.

Following allocation of the echo record to the target species, established quality-control procedures were executed. These consisted of data visualisation, compilation of basic statistics, and comparison of values of the area backscattering coefficient with corresponding values derived from the EK500. The aim of the procedures was to ensure that (1) all applicable data were in fact interpreted, (2) integrator values agreed with expectation from the EK500 echo integrator, (3) database operations did not corrupt the data, and (4) registered positions agreed reasonably well with those drawn on the navigator's chart and with expectations based on the tabulated turning points of transects.

After completing the quality-control tests, compensation was applied for extinction. The standard algorithm (Foote 1990) was used. The ratio of extinction and backscattering cross sections was assumed to be 2.41 (Foote 1994).

Stratification

The general basis of stratification is degree of coverage, uniformity of coverage, fish distribution, biology, and links to external variables. According to the fish distribution pattern presented in Figs. 2-5 and results from the MultiSampler trawl, strata were defined. Some of their characteristics are summarised in Table 2.

Is noted that with only two exceptions, the herring were well mixed throughout the water column and over most of Vestfjord, Tysfjord, and Ofotfjord. Only in Rombaken at the eastern end of Ofotfjord and in Stefjord, a side fjord of central Tysfjord, were significant differences observed, namely a greater proportion of older fish. Hence the biological component of stratification is slight.

Conversion of acoustic numbers to biological measures of fish density

The conversion is achieved through the fundamental equation of echo integration, namely

$$\rho_A = s_A / \sigma_b \, , \qquad (1)$$

where ρ_A is the area fish density expressed as number of fish per square nautical mile, s_A is the cumulative area backscattering cross section per square nautical mile, and σ_b is the backscattering cross section. The last quantity is derived from the standard equation for Norwegian spring-spawning herring at 38 kHz (Foote 1987), namely

$$TS = 10 \log \frac{\sigma_b}{4\pi r_o^2} = 20 \log \ell - 71.9 \, , \qquad (2)$$

where TS is the target strength in decibels, $r_o = 1$ m, and l is the root-mean-square length of the fish.

Fish sampling

To obtain information on fish length necessary for the conversion of acoustic numbers to biological measures of fish density, a new prototype of the MultiSampler (Engås et al. 1996, Foote et al 1996) was used with an Aakra pelagic trawl. The Multisampler replaces the extension section and codend of the pelagic trawl with a multiple-opening-and-closing framework, three attached codends, and a transducer for communication with the vessel, from which command and control signals are sent by acoustic link.

Trials were performed during the early part of the cruise, in advance of the survey proper. However, actual applications of the new gear during the survey constituted a steady trial for all concerned.

Computation of abundance and geostatistical variance

The mean abundance and associated variance were computed for each individual stratum. In computing the estimation variance, the variogram was modelled as the sum of a nugget and spherical function, as earlier documented in the cited series of survey reports. Details are given in Table 2.

Global estimates of abundance and variance were computed for each of the three fjords. The method of combination is based on summing mean abundance estimates and summing variances. To exploit repeated coverages of certain areas, corresponding estimates were compounded as described below in the Discussion. Global estimates of abundance and variance were finally computed for all three fjords according to the same method of combination.

DISCUSSION

Fish length distribution

According to the trawl samples, the herring had a relatively homogenous length and age distribution throughout the main wintering area. Pooling all samples (15 trawl stations) from the main area gave an estimate of the root-mean-square length of the herrring of 29.40 cm with a standard deviation of 2.59 cm.

However, indications of vertical stratification are made in Figs. 6 and 7, and the mean length and age of the herring samples seem to increase with depth. No attempt to use a vertical stratification was attempted when converting the acoustic numbers to biological measures of fish density.

In two minor tributary fjords, Rombaken and Stefjord, concentrations of larger herring were found (mean lengths 33.69 cm and 32.20 cm, Figs. 8 and 9 respectively).

Combining strata

The rationale for combining strata to form global abundance estimates for each fjord and the total fjord system is the following.

Ofotfjord This was surveyed only once during the cruise. Results of trawling support a division into two strata, shown in Fig. 2. Herring in the larger stratum, designated o11, appear to be well mixed, hence with rms-length 29.40 cm and standard deviation 2.59 cm. The herring in Rombaken, stratum o12, contain a greater proportion of older fish, with rms-length 33.69 cm and standard deviation 2.93 cm. The global abundance estimate for Ofotfjord is thus formed by the sum of the two partial estimates, symbolically represented by the following equation:

$$o = o11 + o12.$$

The standard deviation in global abundance estimate is derived from the sum of the corresponding variances for the two strata.

Tysfjord The situation at the mouth of Tysfjord was highly dynamic throughout the cruise period. This may be inferred by inspection of Figs. 3 - 5, as well as from the distribution maps of an *ad hoc* study of the same region performed later in December 1996, after the abundance survey (Huse et al. 1997). The present estimate for central Tysfjord, which includes the entrance region, is thus formed as the mean of the low- and high-concentration cases. The first coverage, designated t11, is assumed to represent the high-concentration case, while the second and third coverages, with stratum designations t21 and t31, represent the low-concentration case. The abundance estimate for central Tysfjord is formed by combining the corresponding abundance estimates according to the following scheme:

$$0.5\ (t11+0.5\ (t21+t31)) = t50.$$

The herring in side fjords to Tysfjord are stratified as shown in Fig. 4, with strata designations t32 - t40 inclusive. In converting acoustic measures of fish density to the biological estimates, expressed as numbers of fish per unit area, reference to trawl data supports the following biological stratification: the herring were well mixed in all areas to the same degree as in o11, with rms-length 29.40 cm, except in Stefjorden, strata t37 and t38, where the rms-length was 32.20 cm and standard deviation 3.16 cm. The global estimate for Tysfjord is composed thus:

$$t = t50+t32+t33+t34+t35+t36+t37+t38+t39+t40.$$

The associated variance estimate is based on the summation of corresponding variance estimates for the respective strata.

Vestfjord A total of five coverages were performed (Fig. 5), with designated temporal strata v11, v21, v31, v41, and v51. The first three coverages were clearly partial, both by design and because of an operational matter, namely the need to put a container ashore at Svolvær, without which trawling could not have been safely performed. The design considerations were those of wanting to cover a rather large area rapidly at the outset, in order to bound the stock, and the conflicting needs of having to extend the survey work to Tysfjord and Ofotfjord and having to capture physical samples for identification and sizing. The capture had to be accomplished, moreover, with prototype trawling gear that was under testing during the same cruise. Results of trawling at different depths and locations in Vestfjord (Fig. 7) indicated a situation of high mixing, like those in central Ofotfjord and central Tysfjord, justifying assumption of an rms-length of 29.40 cm, as in the stratum o11. Because of persistent, unsettled weather, it was also necessary to dodge storms. The evident decline in abundance during the first three coverages was quite dramatic. Following a major storm event from the south-west, acoustic abundance surveying was resumed in Vestfjord with the intent of performing a comprehensive coverage. This was done twice, in face, through the fourth and fifth coverages. The areas of coverage of the five temporal strata were, respectively, 50, 90.2, 48.2, 156, and 156.4 square nautical miles. Because of the admitted incomplete extent of the first three coverages, witness also the larger geostatistical variances, only the two major coverages are used in computing the mean abundance. The corresponding abundance estimate for Vestfjord is symbolically represented thus:

$$v = 0.5(v41+v51).$$

The corresponding variance estimate is formed in similar fashion.

Composite fjord system The global abundance estimate for the fjord system is formed by summing the respective global estimates for Ofotfjord, Tysfjord, and Vestfjord. The corresponding variance estimate is derived from the sum of the respective variance estimates. The result is shown in Table 3 and Fig. 10. The estimated number per year class is given in Table 4.

Herring stock assessment

As indicated in the section on migration biology, the Norwegian spring spawning herring appears in a variety of behavioural patterns during the year, reflecting different physiological states. In spring the herring carry out a complex spawning behaviour. In the beginning of the feeding season, the herring are distributed in large layers at 400 meters depth most of the day, changing to a distribution with small schools feeding on copepods and amphipods later in the feeding season. When the feedings season ends in August -September the herring start to concentrate in schools and migrate eastward to the wintering areas. In the wintering season the herring can appear in dense layers with a vertical extension of several hundred meters. These changes in physiological state and depth may be accomplished by modifications in target strength.

In addition to the present survey, acoustic surveys are conducted on the spawning and feeding area. In the process of converting the acoustic numbers to biological measures of fish density, the standard TS equation is applied to the data from all surveys even if changing behavioural patterns and different average depth of the main concentrations are recorded from survey to survey. Thus for assessment purposes the estimates from all the acoustic surveys are used as input data in the model for tuning the virtual population analysis (ICES 1997).

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Table 2. Summary of measurement and computational results for the cruise with R/V "Johan Hjort" in November-December 1996, arranged by stratum. The stratum area A is divided by the area of a square block of side length 0.2 nautical mile, over which the raw data are averaged, for comparison with the number of samples n_s.

Stratum	Area A(NM^2)	A/0.04	n_s	s_A	CV	se/s_A	A_N	a (NM)	σ_E/s_A	l_{rms} (cm)	Δl_{rms} (cm)	N(10^9)
o 11	89.52	2238	518	3540	3.9	0.172	0.0	1.4	0.270	29.40	2.59	0.4520
o 12	6.16	154	60	14700	0.9	0.122	0.2	1.2	0.145	33.69	2.93	0.0981
t 11	40.24	1006	195	62500	3.9	0.280	1.0	0.0	0.280	29.40	2.59	3.5881
t 21	40.24	1006	185	12100	1.6	0.116	0.4	1.6	0.135	29.40	2.59	0.6950
t 31	40.24	1006	154	10100	2.1	0.166	0.2	1.4	0.208	29.40	2.59	0.5782
t 32	2.04	51	17	40500	0.7	0.166	0.4	0.5	0.171	29.40	2.59	0.1179
t 33	5.72	143	43	4770	3.2	0.482	0.3	0.4	0.539	29.40	2.59	0.0389
t 34	8.20	205	63	658	4.3	0.542	0.5	1.5	0.651	29.40	2.59	0.0077
t 35	4.04	101	57	16900	1.7	0.227	1.0	0.0	0.227	29.40	2.59	0.0971
t 36	3.36	84	43	3320	1.5	0.233	0.4	0.9	0.208	29.40	2.59	0.0159
t 37	3.80	95	29	32400	1.1	0.205	0.5	0.9	0.228	32.20	3.16	0.1465
t 38	1.52	38	18	43000	1.1	0.269	1.0	0.0	0.269	32.20	3.16	0.0777
t 39	3.96	99	34	7480	0.9	0.160	0.0	0.4	0.170	29.40	2.59	0.0422
t 40	1.96	49	19	7160	1.4	0.318	1.0	0.0	0.318	29.40	2.59	0.0200
v 11	50.00	1250	159	359000	1.0	0.082	0.0	2.6	0.078	29.40	2.59	25.6
v 21	90.20	2255	290	125000	1.3	0.077	0.0	5.4	0.056	29.40	2.59	16.0
v 31	48.20	1205	309	166000	0.9	0.050	0.0	3.2	0.049	29.40	2.59	11.4
v 41	156.00	3900	1014	116000	1.8	0.055	0.3	7.8	0.040	29.40	2.59	25.7
v 51	156.00	3910	994	82900	1.6	0.050	0.0	5.6	0.028	29.40	2.59	18.5

Table 1. Survey design types for the strata appearing in Figs. 2-5 among other places, for the cruise with R/V "Johan Hjort" in December 1996. The sailed distance is the net distance along those transects or parts from which data area used in deriving the abundance estimate. The number of statistical blocks of side length 0.2 nautical mile (NM) with acoustic data is denoted by n_s.

	Start time		Stop time		Sailed distance		
Stratum	Date	UTC	Date	UTC	(NM)	n_s	Design type
o 11	1206	1753	1207	0714	97.8	518	Zigzag
o 12	1206	2336	1207	0045	11.2	69	
t11	1207	0936	1207	1508	33.7	195	Roughly equally spaced parallel transects without endpices
t21	1208	0138	1208	0744	31.4	185	Roughly equally spaced parallel transects without endpices
t31	1208	1716	1208	2328	26.9	154	Roughly equally spaced parallel transects without endpices
t32	1208	2343	1209	0129	4.5	17	Ad hoc
t33	1208	0822	1208	1036	17.4	43	Ad hoc
t34	1208	0826	1208	0953	14.3	63	Zigzag
t35	1208	1131	1208	1542	14.2	57	Zigzag
t36	1209	0230	1209	0344	8.8	43	Zigzag
t37	1209	0423	1209	0544	6.8	29	Zigzag
t38	1209	0445	1209	0526	5.1	18	Zigzag
t39	1212	0019	1212	1051	6.4	34	Ad hoc
t40	1212	0044	1212	0125	4.4	19	Zigzag
v11	1204	0847	0847	1254	26.9	159	Parallel
v21	1205	0049	0049	0823	48.7	290	Parallel
v31	1205	1549	1549	2233	52.2	309	Parallel
v41	1209	1143	1143	0942	171.2	1014	Parallel
v51	1210	2246	2246	1923	172.2	994	Parallel

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Stratum	Area $A(NM^2)$	A/0.04	n_s	$\overline{s_A}$	CV	se/s_A	A_N	a (NM)	$\sigma_E/\overline{s_A}$	l_{rms} (cm)	Δl_{rms} (cm)	$N(10^9)$
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Table 3. Summary of results for abundance of Norwegian spring spawning herring as surveyed in Ofotfjord, Tysfjord and Vestfjord in December 1996. The geostatistical variance is expressed through the normalised quantity $\Delta N / N$. The basis of computation of N is described through the constituent strata, which are otherwise described in Figs. 2-5 and Tables 1 and 2.

Fjord	N(10^9)	$\Delta N / N$	Basis of computation of N
Ofotfjord	0.55	0.223	Sum of o11 and o12
Tysfjord	2.66	0.383	Sum of weighted average (0.5 t11 + 0.25 t21 + 0.25 t31) and t32-40
Vestfjord	22.1	0.052	Average of v41 and v51
Combined	25.3	0.061	

Table 4. Acoustic year class abundance (million individuals) of Norwegian spring spawning herring in the wintering area, December 1996.

Year class	Number
1994	1465
1993	3006
1992	13180
1991	5637
1990	994
1989	552
1988	92
1987	0
1986	7
1985	41
1984	15
1983	393
Total	25384

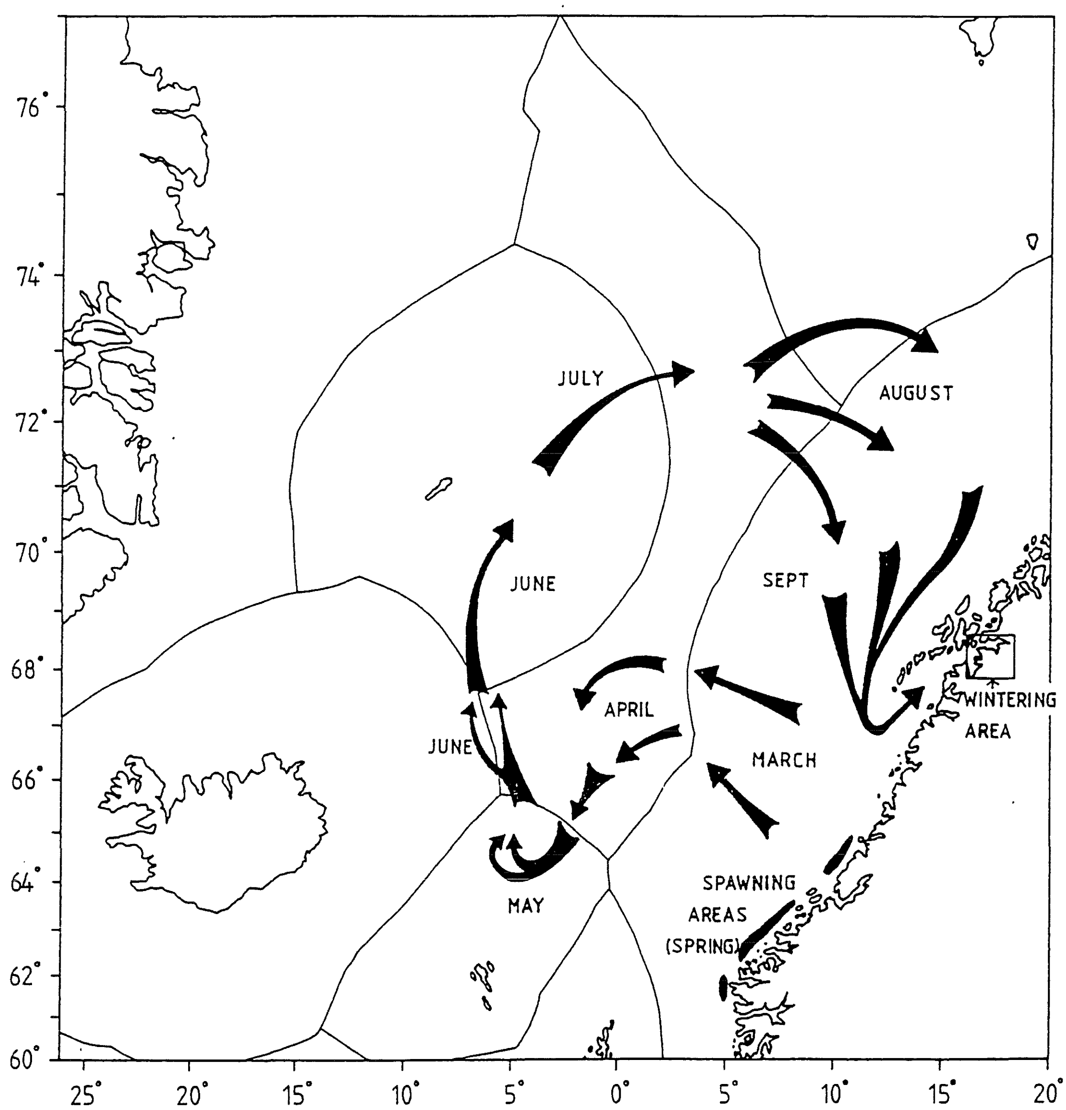

Fig. 1. Schematic presentation of the present migration pattern for adult Norwegian spring spawning herring. The associated exclusive economic zones (EEZ) are shown. Modified from ICES 1996.

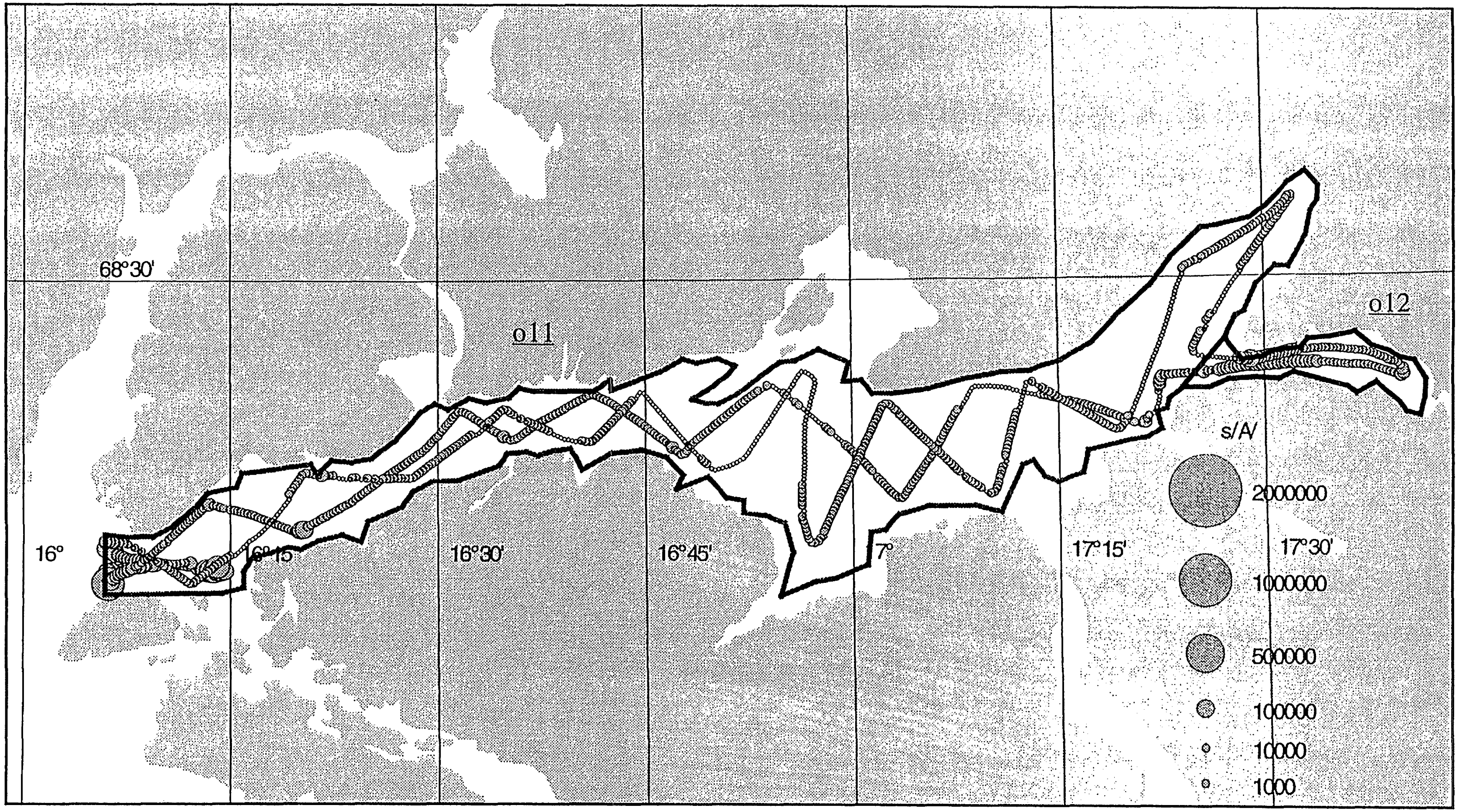

Fig. 2. Distribution of Norwegian spring spawning herring by strata as surveyed in Ofotfjord in December 1996:

- o11: 06/12/96 17:53 - 23:35 and 07/12/96 00:46 - 07:14
- o12: 06/12/96 23:36 - 07/12/96 00:45

The radius of a circle in proportional to the square root of the extinction-corrected s_A-value. The scale shown in the lower right corner pertains to each of Figs. 2-5.

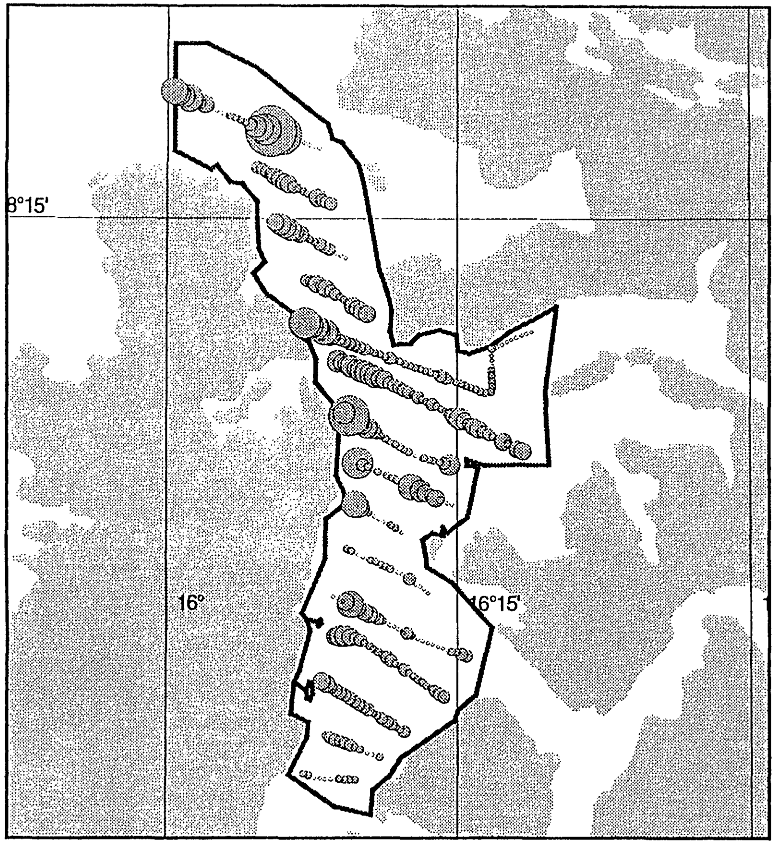

Fig. 3a. Distribution of Norwegian spring spawning herring as surveyed in Tysfjord in December 1996, stratum t11, date 07/12/96, hrs 09:36 - 15:08.

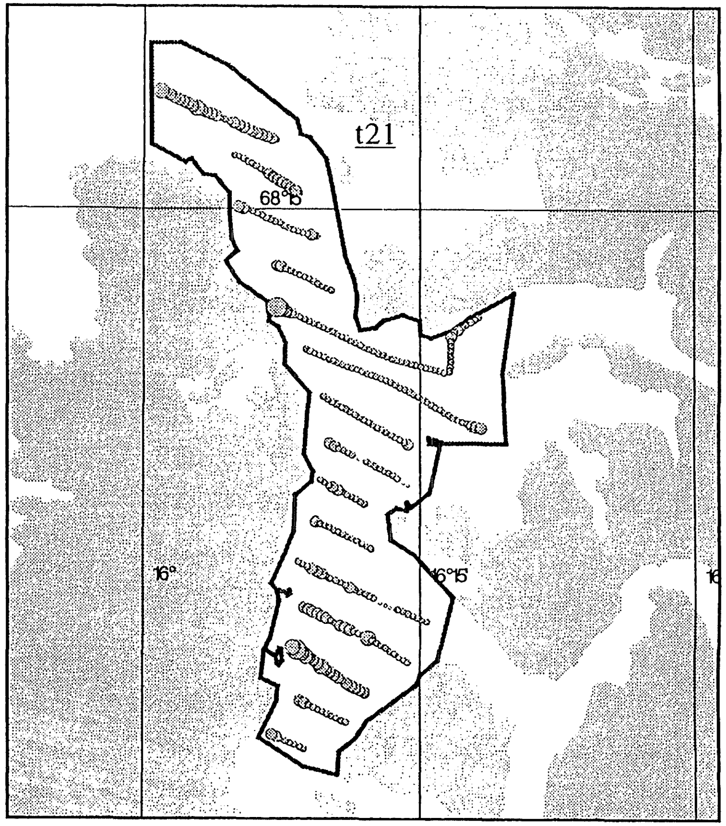

Fig. 3b. Distribution of Norwegian spring spawning herring as surveyed in Tysfjord in December 1996, stratum t21, date 08/12/96, hrs. 01:38 - 07:44.

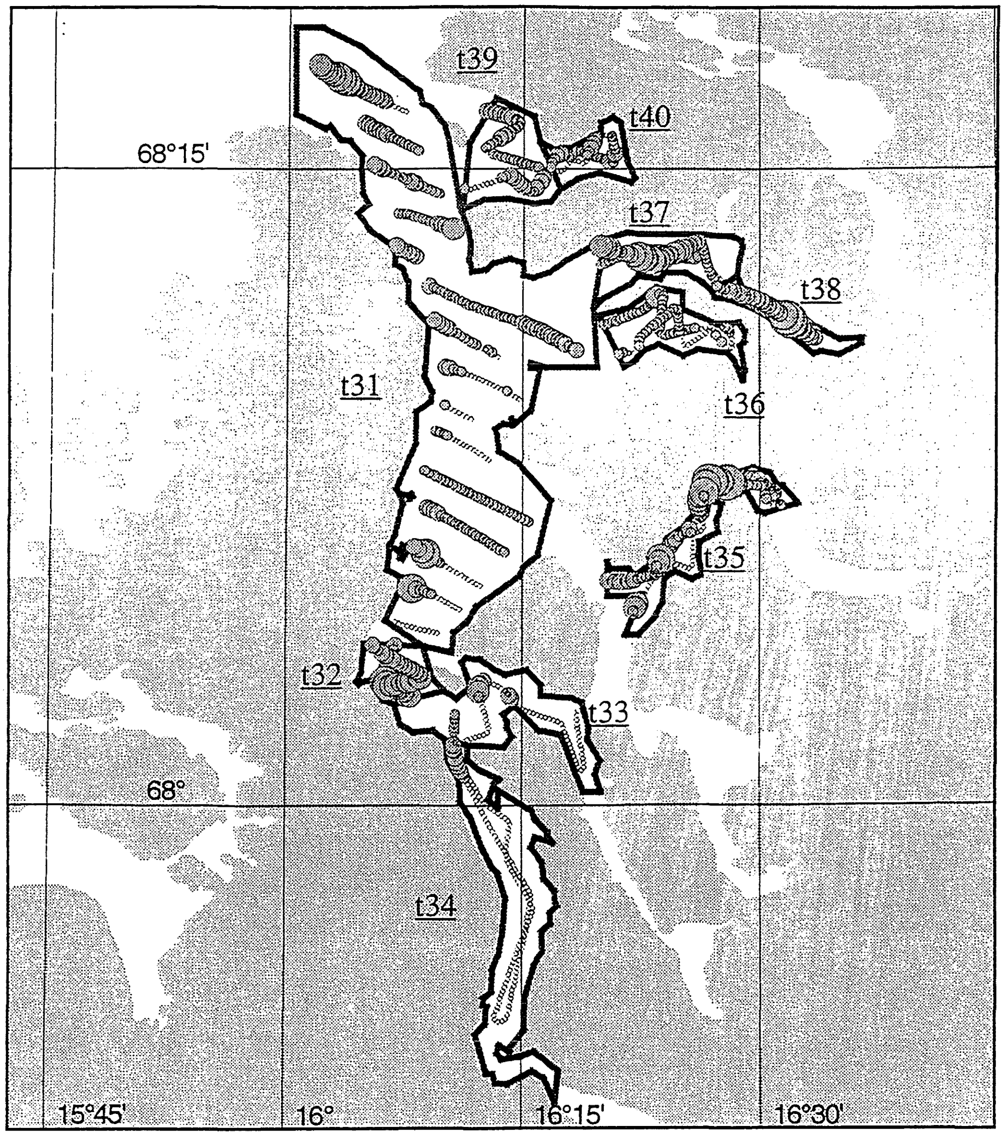

Fig. 4. Distribution of Norwegian spring spawning herring by strata as surveyed in Tysfjord in December 1996:

- t31: date 8/12/96 hrs. 17:16 - 23:28
- t32: date 8/12 20:43 - 9/12/96 01:21
- t33: date 8/12/96 hrs. 08:22 - 08:26 and 09:54 - 10:36
- t34: date 8/12/96 hrs. 08:26 - 09:53
- t35: date 8/12/96 hrs. 11:31 - 15:43
- t36: date 9/12/96 hrs. 02:30 - 03:44
- t37: date 9/12/96 hrs. 04:23 - 04:45 and 05:26 - 05:44
- t38: date 9/12/96 hrs. 04:45 - 05:26
- t39: date 12/12/96 hrs. 00:19 - 00:43 and 01:26 - 01:51
- t40: date 12/12/96 hrs. 00:44 - 01:25

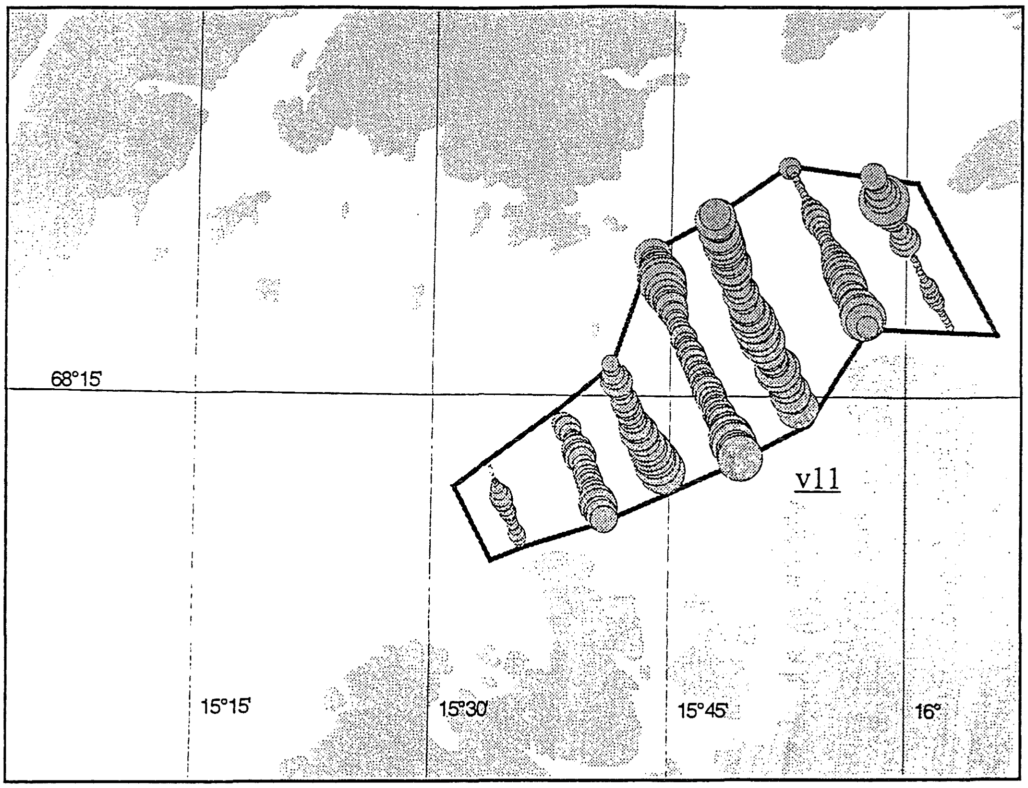

Fig. 5a. Distribution of Norwegian spring spawning herring as surveyed in Vestfjord in December 1996, stratum v11, date 04/12/96, hrs. 08:47 - 12:54.

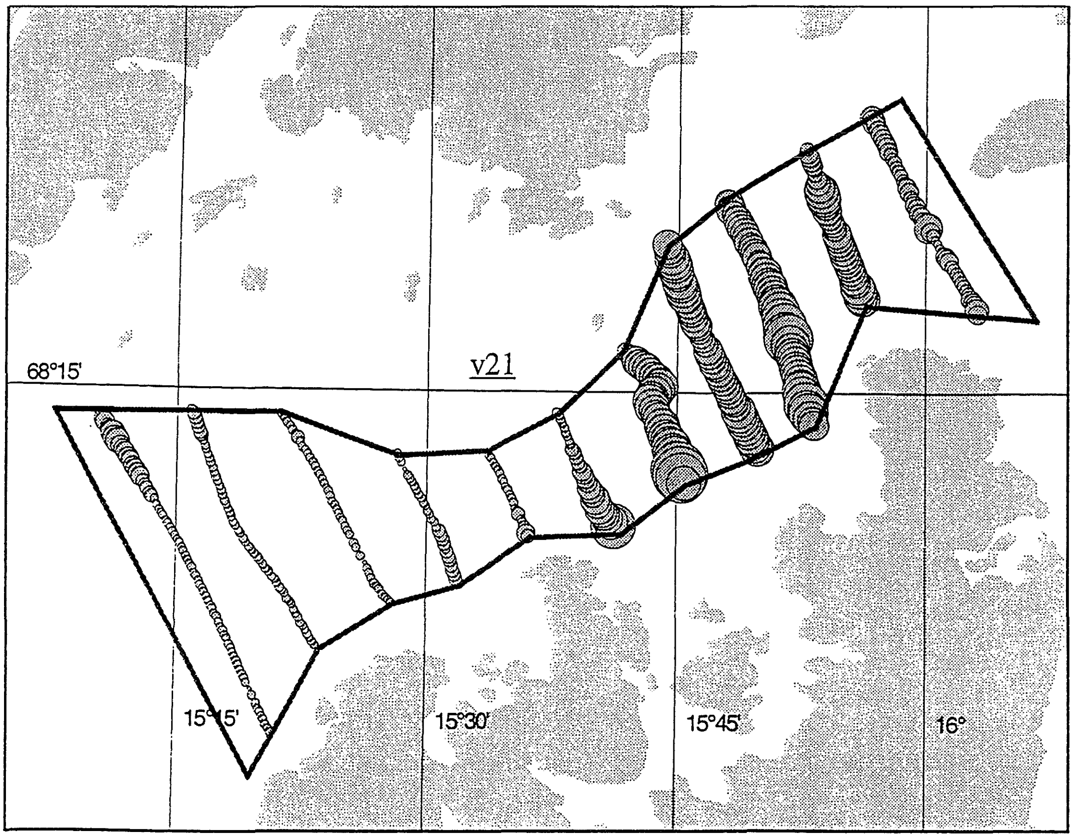

Fig. 5b Distribution of Norwegian spring spawning herring as surveyed in Vestfjord in December 1996, stratum v21, time range 05/12/96, hrs. 00:49 - 08:23.

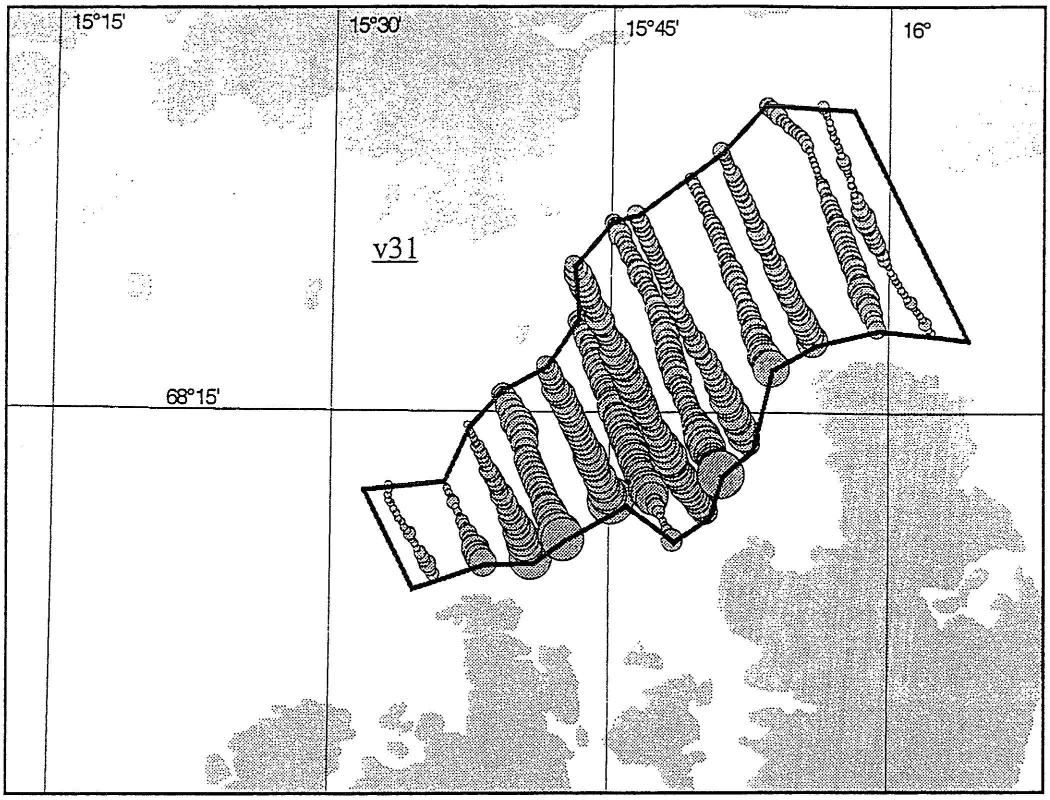

Fig. 5c. Distribution of Norwegian spring spawning herring as surveyed in Vestfjord in December 1996, stratum v31, date 05/12/96, hrs. 15:49 - 23:33.

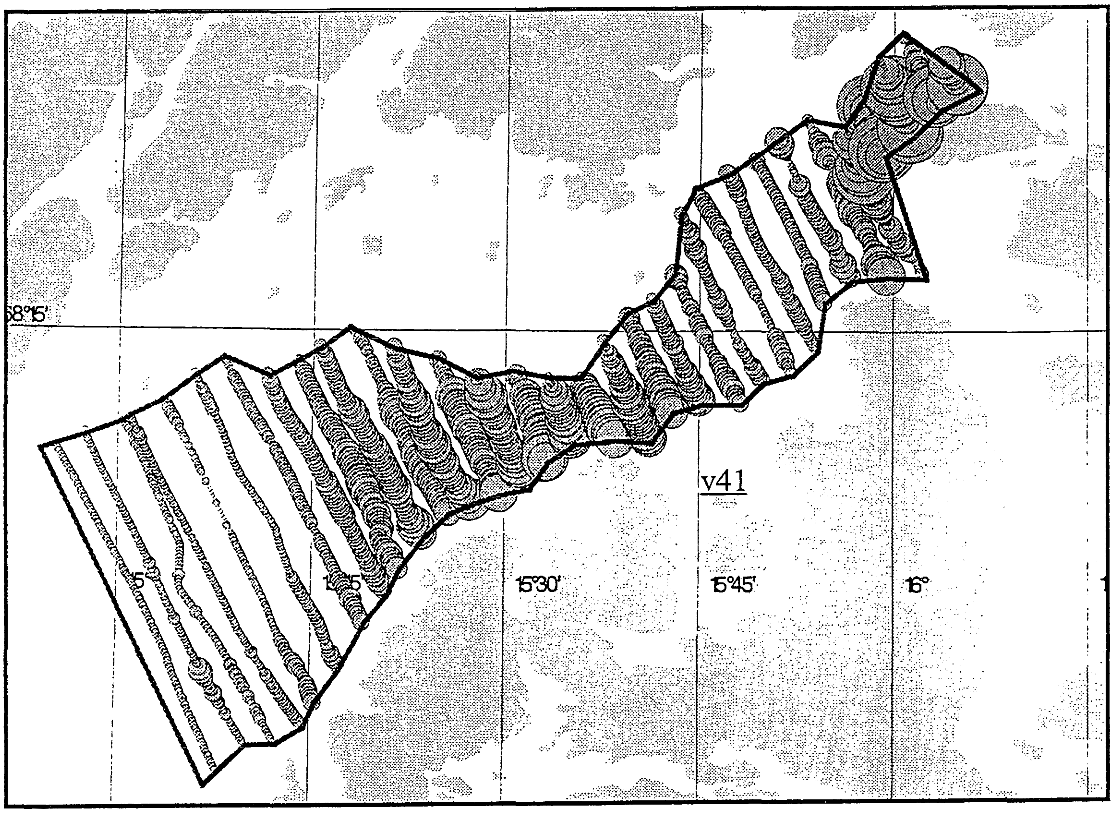

Fig. 5d. Distribution of Norwegian spring spawning herring as surveyed in Vestfjord in December 1996, stratum v41, dates: 09/12/96 11:43 - 10/12/96 09:42.

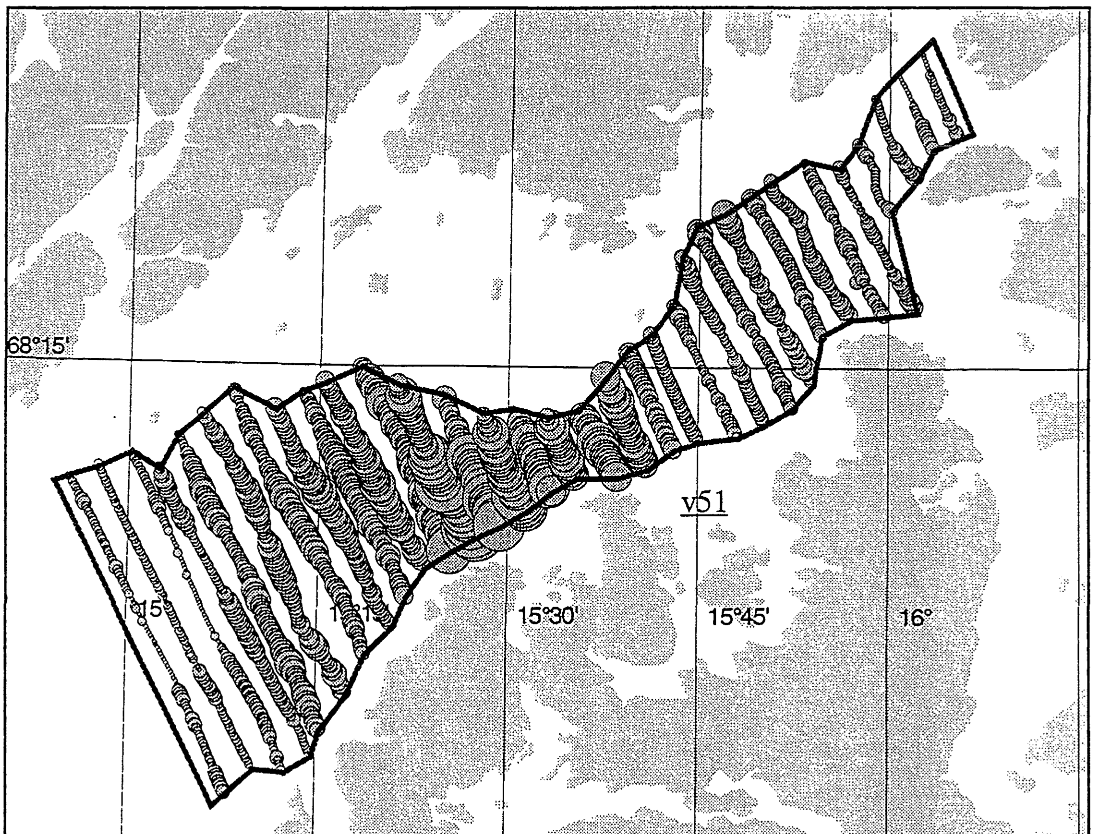

Fig. 5e. Distribution of Norwegian spring spawning herring as surveyed in Vestfjord in December 1996, stratum v51, time range: 10/12/96 22:46 - 11/12/96 19:23.

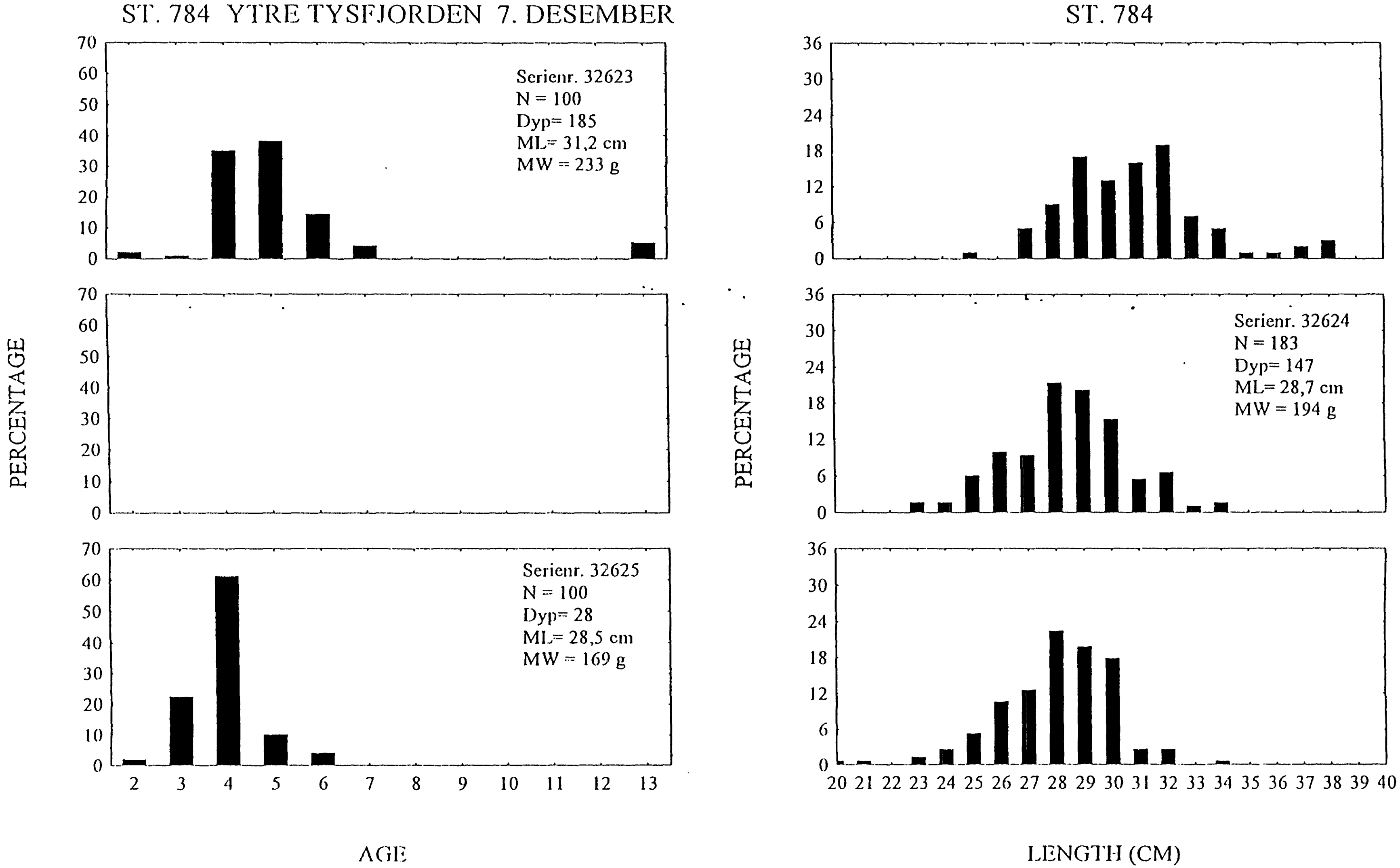

Fig. 6 Norwegian spring spawning herring. Age and length distributions at different depths, 185 m (upper figure), 147 m (middle) and 28 m (lower) in outer part of Tysfjord 07.12.96. Multisampler trawl.

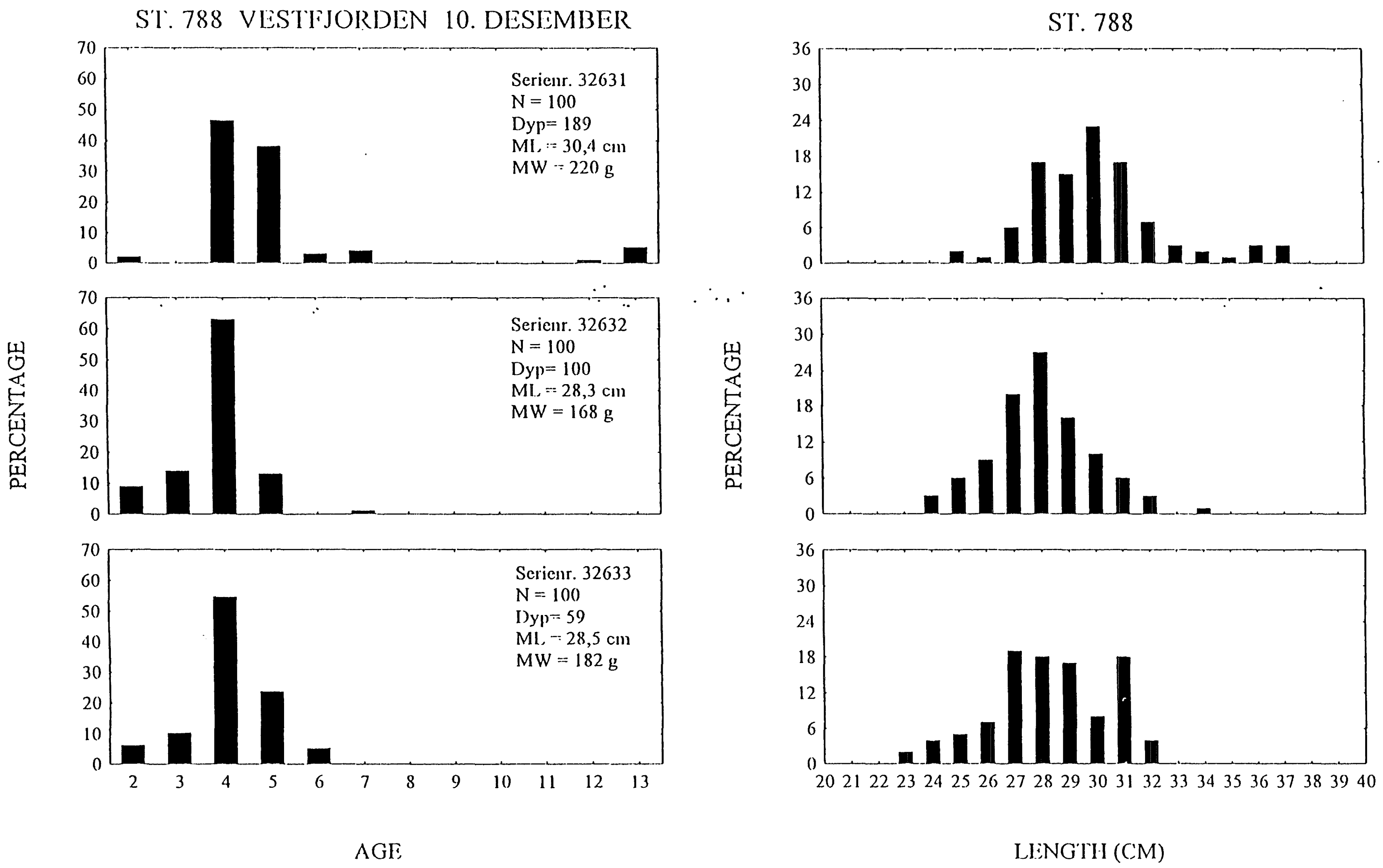

Fig. 7 Norwegian spring spawning herring. Age and length distributions at different depths, 189 m (upper figure), 100 m (middle) and 59 m (lower) in Vestfjord 10.12.96. Multisampler trawl.

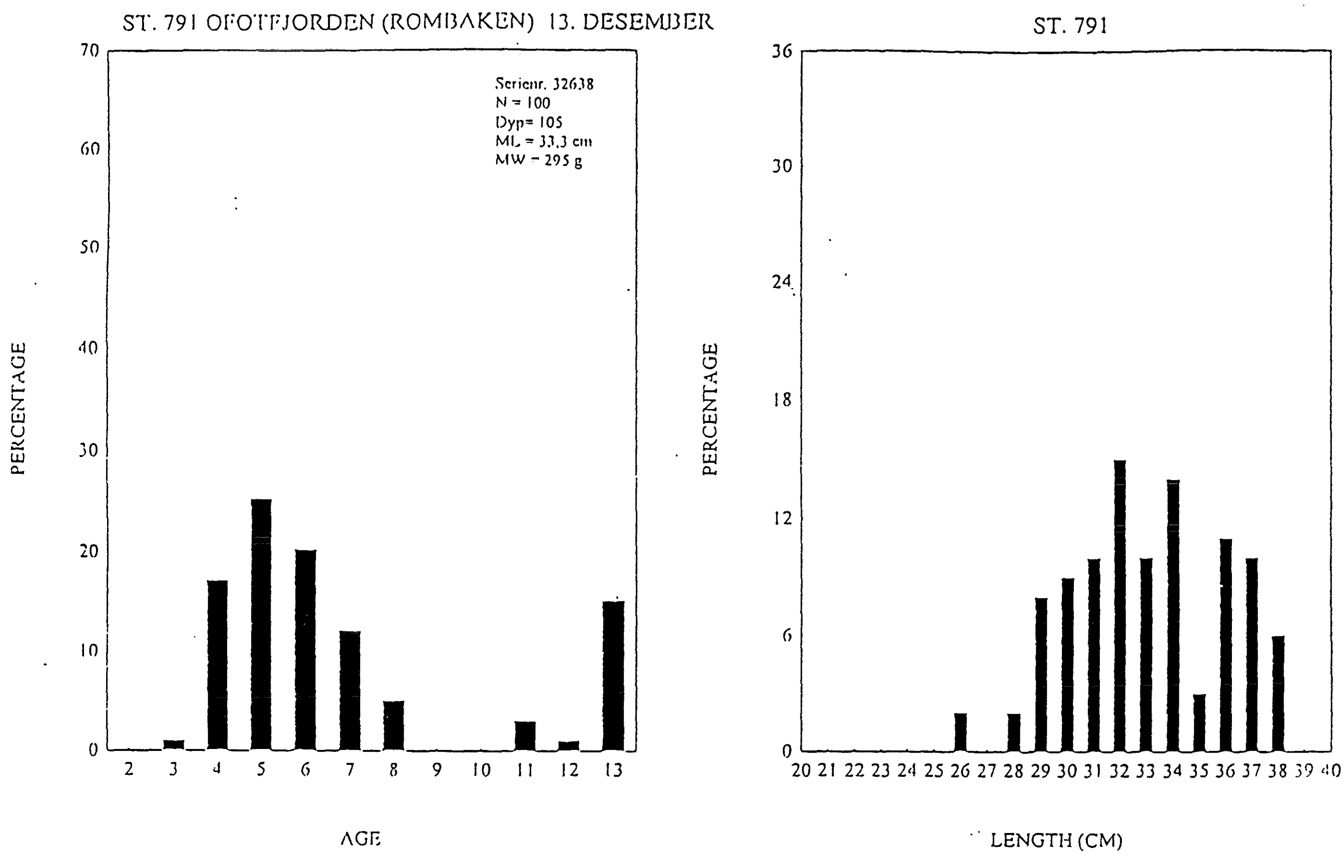

Fig. 8 Norwegian spring spawning herring. Age and length distributions from Rombaken, Ofotfjord (stratum o12), 13.12.96. Depth 105 m.

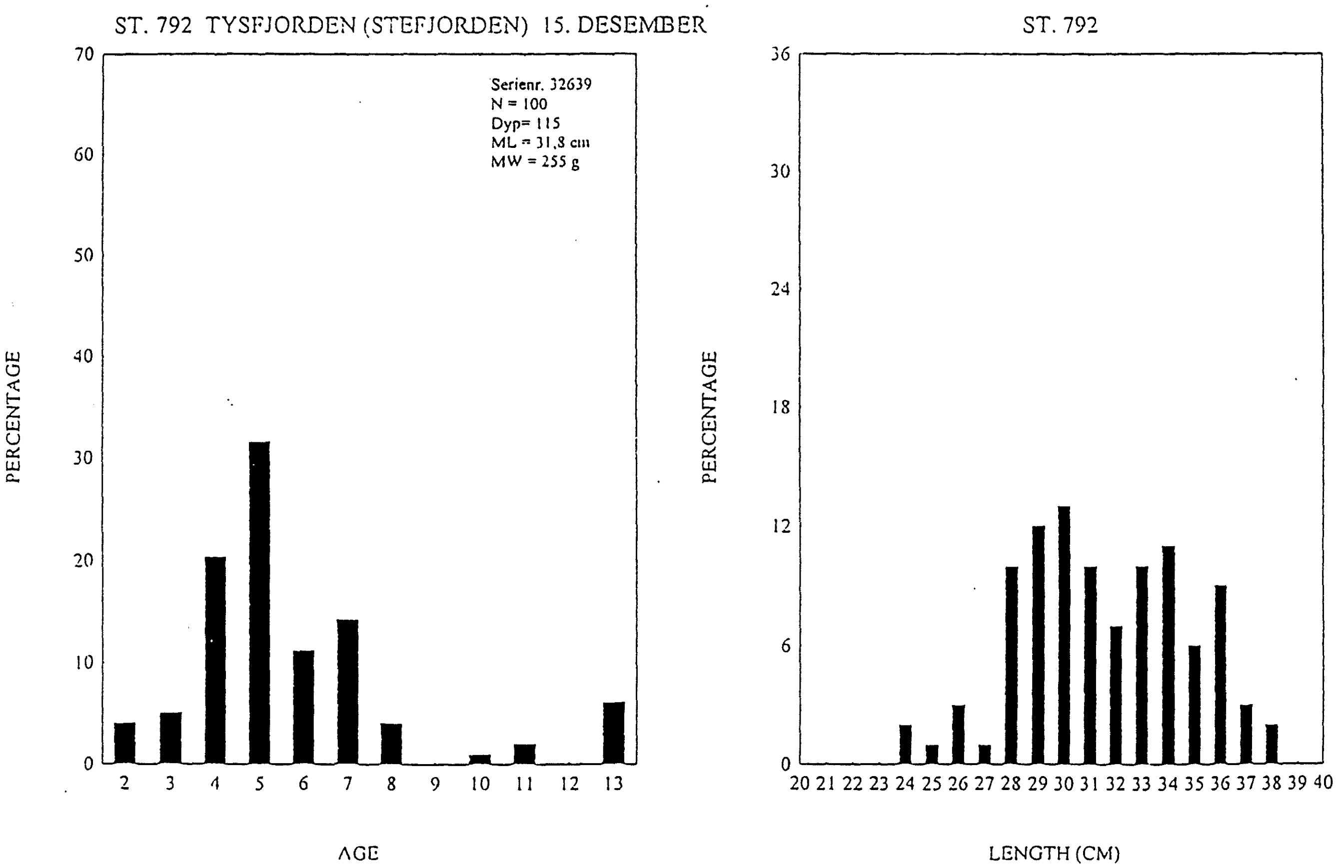

Fig. 9 Norwegian spring spawning herring. Age and length distributions from Stefjorden, Tysfjord (stratum t37, t38), 15.12.96. Depth 115 m.

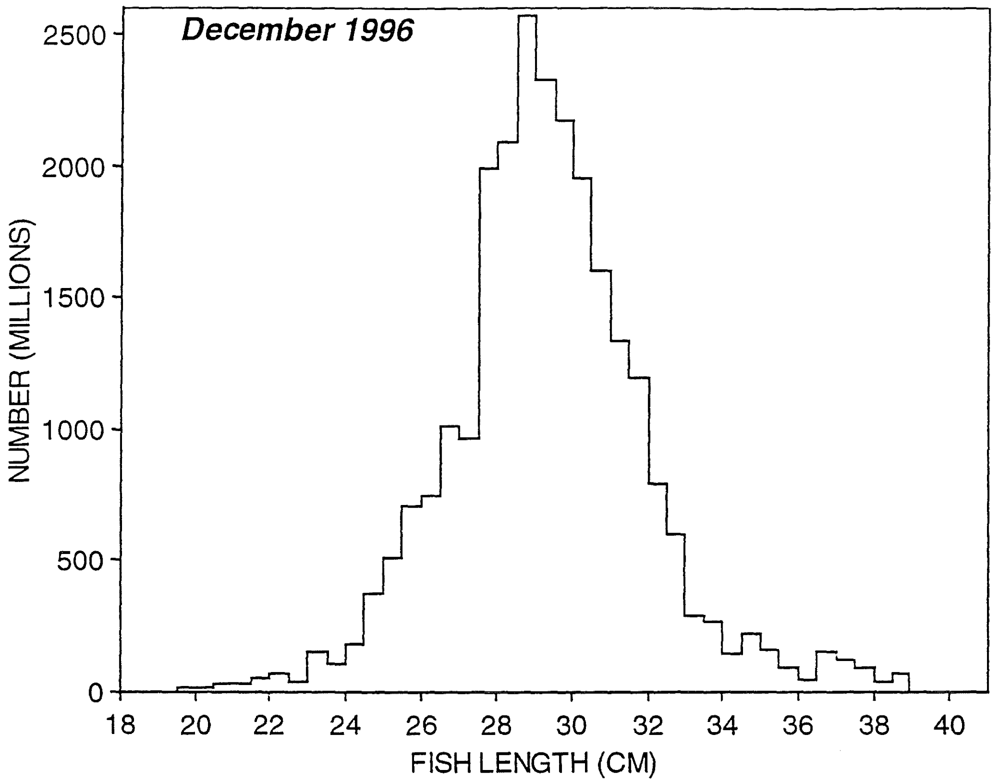

Fig. 10. Composite length frequency distribution of Norwegian spring spawning herring in the Ofotfjord-Tysfjord-Vestfjord system in December 1996.