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Report on surveys of the distribution, abundance and migrations of the Norwegian spring-spawning herring, other pelagic fish and the environment of the Norwegian Sea and adjacent waters in late winter, spring and summer of 1998

by

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Introduction

At high stock levels, the Norwegian spring-spawning herring is a typical straddling and highly migratory stock crossing the borders of several national EEZs (exclusive economic zones) and international waters. After a major stock collapse in the late 1960's the herring migrations were in general confined to Norwegian waters for years, but in the early 1990s, after nearly 25 years of absence, the herring stock reoccupied the Norwegian Sea as its main feeding area. From 1994, an international fishery has taken place during summer in this area. The total catch of this species in the Norwegian Sea and along the Norwegian Coast in 1997 exceeded 1.x million tonnes and is expected to reach about xx tonnes in 1998.

In 1995 and 1996, Norway, Russia, Iceland and the Faroes coordinated their survey effort on this and other pelagic fish stocks in the Norwegian Sea to assess and describe the distribution of the pelagic resources, and their general biology and behaviour in relation to the physical and biological environment (Table x). Based on an ICES recommendation in 1948, similar surveys were conducted under the auspices of ICES from 1950 to the late 70´s. National surveys were continued after this time. At the 1996 Annual Science Conference, the Pelagic Committee recommended that the ICES cooperation should be reintroduced on the planning and conducting of future surveys on herring and the environment in the Norwegian Sea. A planning meeting was held in Reykjavik in August 1997 (Anon, 1997), and a series of 10 surveys to be carried out by Faroese, Icelandic, Norwegian, Russian, and EU-research vessels in spring and summer 1998 were coordinated (Table x). The main objectives of the coordinated surveys were to map the distribution and migration of the herring and other pelagic fish, and to monitor environmental conditions of the Norwegian Sea.

The 1997 coordinated survey results were evaluated during a meeting in Reykjavik in August (Table x). This paper describes the main findings of these surveys with respect to herring distribution and migration, environmental conditions (sea temperature, zooplankton biomass), herring abundance, and discusses the distribution of other pelagic species; blue whiting, lumpsucker, mackerel, horse mackerel and salmon.

Materials and Methods

A total of 10 surveys were conducted to map the distribution and migrations of herring and to monitor environmental conditions of the Norwegian Sea in spring and summer 1998 (Table x). During the surveys, continuous acoustic recordings of fish and plankton were collected using calibrated echo integration systems (38 kHz Simrad EK500 working at a range of 10 - 500 m). The recordings of area back scattering strength (S_A) per nautical mile were averaged over five nautical miles, and the allocation of area backscattering strengths to species was made by comparison of the appearance of the echo recordings to trawl catches. To record schools near the surface, a horizontal guided sonar was operated.

The equipment of the research vessels were calibrated directly before or during the surveys against a standard calibration spheres. Intercalibrations were also done between the R/V "Argos" and R/V " G.O. Sars" in the May cruise.

Fish traces identified on the echosounder were sampled by pelagic trawl (vertical openings of 25 - 40 m). With ordinary rigging the trawls could be used to catch deep fish schools. The trawls could also be rigged to catch fish near the surface by removing the weights, extending the upper bridles and attaching two buoys to each upper wing (Valdemarsen and Misund 1995).

Zooplankton were sampled in vertical hauls from 200-0, 50-0 m by standard WP-2 net with a 180 µm mesh (*Argos, G.O. Sars, Arni Fridriksson* & *Magnus Heinason* (only 50-0 m)) and in oblique hauls with a 1 m^2 MOCNESS gear from 50 - 25 m and 25 - 0 m, also with 180 µm mesh (*G.O. Sars*). Russian zooplankton samples were collected in vertical hauls from 0-50m using a Djady net with a 160 µm mesh (*Atlantida*). Before producing the combined map of zooplankton biomass distribution from the two samplers, the MOCNESS samples from the two depth intervals were initially combined to make one sample for 50-0 m.

Subsamples of up to 100 specimens of herring were taken from the trawl catches. The length, weight, sex, maturity stage and stomach contents were recorded. Scales were taken for age reading. From each cruise, the data on echo integration recordings of herring, length distribution, zooplankton abundance and temperature, were provided in an agreed format as described above.

Acoustic estimation of herring abundance was carried out during the surveys. This was done,

either by visual scrutiny of the echo recordings directly from the echograms or by post-processing using the BEI-system. The allocation of s_A-values to herring was based on the composition of the trawl catches and the appearance of the echo recordings. To estimate the abundance of herring, the allocated s_A-values were averaged for statistical squares measuring 0.5^o of latitude by 1^o of longitude. For each statistical square, the unit area density of herring ($\tilde{n}_A$) in number per square nautical mile (N n.mile^{-2}) was calculated using the standard equations (Foote 1987).

To estimate the total abundance of herring, the unit area abundance for each statistical square was multiplied by the number of square nautical miles in each statistical square and then summed for all the statistical squares within defined sub-areas and for the total area. The biomass was calculated by multiplying abundance in numbers by the average weight of the herring in each statistical square and then summing for all squares within defined subareas and the total area. Furthermore, the average length, weight, area density and biomass of each year class were also estimated for each statistical square, for defined sub-areas and for the total area.*Calibration*

Zooplankton

In May 1998, zooplankton was sampled in vertical net hauls 200-0 m with WP-2 net, 0.25 m^2 opening and 180 µm mesh (R/V "Arni Fridrikson", "Argos" and "G.O. Sars"), in oblique hauls 200-200, 200-50, 50-25 and 25-0 m with 1 m^2 MOCNESS, 180 µm mesh (R/V "G.O. Sars"), and in vertical net hauls 50-0 m with WP-2 net (R/V "Magnus Heinason"). The biomasses in 50-0 m were "converted" to biomasses in 200-0 m using a conversion factor of 1.98 established from simultaneous 50-0 and 200-0 m net hauls on "Arni Fridrikson".

In May 1997, zooplankton was sampled in vertical net hauls 200-0 m with WP-2 net (R/V "G.O. Sars" and "Arni Fridrikson") and in oblique hauls 200-200, 200-50, 50-25 and 25-0 m with MOCNESS (R/V "G.O. Sars"), and in vertical net hauls 50-0 m with WP-2 net (R/V "Magnus Heinason"). The 50-0 m values were converted to 200-0 m values as described above.

In July 1998, zooplankton was sampled in vertical net hauls 200-0 m with WP-2 net and in oblique hauls 200-200, 200-50, 50-25 and 25-0 m with MOCNESS (R/V "G.O. Sars"). Only the WP-2 net samples are shown in this report.

Results

Hydrographic Conditions

The hydrographic situation, as reflected by the temperature distribution in the spring-summer 1998, is shown Figures xx and xx. These are based on the coordinated surveys in May.

The main feature of hydrographic conditions in the survey area is higher temperatures than in the recent cold years. This is reflected in a reduced intensity and extension of the cold waters of the East Icelandic Current to the south and a general warming of the waters of the eastern Norwegian Sea.

The temperature at 50 m depth is shown in Figure x. To the east of Iceland, the southern border of the East Icelandic Current, as defined by the 1° isotherm, was located at about 66°20'N, some 60 nautical miles farther north than in 1997, while the eastern border was at 7°W as in previous years. North of the Faroes, warm Atlantic water (>5°C) also reached further north in the near surface layer and the same is true for the eastern Norwegian Sea. A similar situation was observed at 200 m depth as shown in Figure y.

The observed improvement of the marine climate og the Norwegian Sea and adjacent waters in May 1998 clearly reflects a continued increase in the flow of Atlantic water into these areas which was first observed in summer 1997.

Zooplankton

The distribution of total zooplankton biomass in 200-0 m (g dry weight m^{-2}) is shown in Figure 1 (May 1997) and in Figure 2 (May 1998). In both years the zooplankton biomass was lower in the central and warmer Atlantic regions than in the colder regions in the west, and possibly in the northern and eastern regions, as well.

On average, the zooplankton biomass within the areas covered by the May cruises was 45%

higher in 1998 compared to 1997. The difference in biomass was larger in the eastern regions, i.e. east of 2°W (79% higher), than in the western regions, i.e. west of 2°W (23% higher) (Table 1). Also, during the Russian cruise by R/V "F. Nansen" in June, the measured biomass in the 50-0 m depth interval was higher in 1998 (mean wet weight 1704 mg m^{-3}) than in 1997 (mean 1054 mg m^{-3}), an increase of 61% (Fig. 3).

Table 1. Average zooplankton biomass (g m^{-2}).

Year	1997	1998
Total area	8.4	12.2
Region west of 2°W	9.1	11.2
Region east of 2°W	7.5	13.4

In July 1998 the average zooplankton biomass within survey area was 5.2 g m^{-3}. The highest biomass was found in the central Norwegian Sea (Fig. 4), the region associated with the highest abundance of copepodites stage V of *Calanus finmarchicus*, which probably were the first generation of the year. To the east and to the west of the central area , younger stages of *Calanus finmarchicus* dominated, probably related to a recent production of the first generation of the year in the west and the second generation in the east.

Herring distribution in the Norwegian Sea

April/May

Horizontal distribution

The main survey effort in 1998 was mainly carried out in May when four vessels from the EU, the Faroes, Iceland and Norway covered the Norwegian Sea and one Russian vessel covered the Barents Sea.

During 21/4 – 21/5 the area from 62° 15' N to 71° 15'N, between about 01°30'E and 04°W was

surveyed by *Argos* and *G.O. Sars* (Fig. X). The survey track was selected to cover the designated area with single level of sampling intensity, with both research vessels occupying sequential transects. Herring was observed throughout most of the surveyed area, and the zero line could be drawn in all areas (Fig. x). No herring was observed within a belt of approx. 30 nautical miles width along the Norwegian coast up to about 71° 30´ N. The most southerly observations were at approx. 61° 30'N, while the most westerly observations were at approx. 1° W. There were observed two main concentrations of herring in the areas from about 64° N to 67° N, 0° to approx. E 7°, and 68 to 71° N, 3° W to 0°, 6°E in the Norwegian and EU survey (Fig x). No herring were observed in the Jan Mayen zone at this time of year.

During 9-21 May the area from 63°15'N to 68°N, between about 01°30'E and 07°W was surveyed by *Magnus Heinason* and *Árni Fridriksson*. From north of approximately 64°30N herring were recorded on all transects (Fig. x). The northern and eastern limit of herring distribution was not reached while the western limit was located at 3°-4°W, i.e. 50-60 nautical miles further west than observed by *G. O. Sars* and *Argos* about one week earlier (cf. Figs x and y).

There appeared to be two maxima within the area covered by Magnus Heinason and Árni Fri›riksson, at 66°N and 67°45'N respectively, both between 00°30'E and 03°00'W (Fig. x). Most of the time, the herring were observed as schools of varying density at depths between 100 and 300 m. At times they did, however, form small dense schools in the surface layer, partly above transducer range.

In the third week of May, the Faroese and Icelandic fishing fleets consistently made good catches in the area between 62°30'N and 64°N from about 04°W to 08°W. This area was surveyed by *Árni Fridriksson* during 22-26 May with results as shown in the lowest part of Figure x. It therefore appears most likely that the herring of the concentration, located near 66°N by the *Magnus Heinason* and *Árni Fridriksson* survey a few days earlier, had quickly migrated to the southwest into the Faroese zone and then taken a more westerly course.

By the time when *Árni Fridriksson* left Faroese waters, the had scattered and very few fishable concentrations could be located.

In general the mean length of the herring increased westwards which is in accordance with the observations made earlier years. However, this trend was not as clear this year as last year (Anon., 1997) and the variation in mean lengths was small in the combined Norwegian and EU survey area.

Vertical distribution.

During the surveys in the Norwegian Sea two distinctly different types of echotraces could be identified:

1. A scattering layer at the surface down to 20-30 m (Fig x.).
2. Schools of varying sizes and at varying depths generally between 150-350 m depths

The undulating layer at intermediate depths that was typical in the eastern part of the distribution area in 1997 (Anon., 1997) where not seen in 1998 May survey.

The surface scattering layer was characteristic by small dot on the echograms which gave rather high S_a-values. This was seen throughout the whole distribution of herring.

June

The *Fritiof Nansen* covered the central areas of the Norwegian Sea from 67°30'N to 63°N west of the Norwegian shelf to about 8°W during the period 1/6-5/7, and the *Arni Fridriksson* covered the area from 64°N to 70° and 11° W to 6° W during the period 1/6 to 16/6. (Fig. 1r)

In the westernmost part of the area, the herring were distributed in the relatively warm water above the thermocline, but within the domain of the cold East Icelandic Current (approximately 6-10°W) from 64°30'N to 69°N. East of 10°W the area north of 67°30' N was not covered (Fig.2r).

During The Russian survey in the Norwegian Sea main herring concentration were found in the central part of the Sea – between 68°N - 64° 30' N and 3°W to 9°E. Compared to last year, herring have a more widelely distribution in June (Anon., 1997). Series of small herring schools were registered in under surface layer at water masses with temperature 6,0-9,5 °C.

As compared to the distribution observed in May (Fig. x) the main herring biomass in the south had shifted to the north and northwest.

July

The *Johan Hjort* covered the Norwegian Sea from 63° N up to 73°30'N during the period 30/6-29/7. The cruise had a number of tasks, including mapping the distribution of herring, and compromises were necessary both with regard to the density of cruise tracks and the number of sampling stations

No herring was observed within a belt of approx. 30 nautical miles width along the Norwegian coast up to about 71° 30´ N. The most southerly observations were at approx. 65° 30'N, while the most westerly observations were at approx. 11° W. The highest concentration were found north of 69° N, and particularly north of 71° N. There were also concentrations 68° - 70° and from 11° E to Norwegian Coast and in the area 69-70°N and 9° -11° W. However, east of 10°W the area north of 75°' was not covered.

Recordings were mostly in the upper 50 m. The schools were often close to the surface, above the upper limit for integration. The overall age distribution show that the 1991 and 1992 year classes dominated the recording concentrations and together contributed 75% in numbers.

The "F.Nansen" covered the Norwegian Sea from about 65^0 N to 71^0 N, 5^0 W to 15^0 E during 11^{th} July to 2^{nd} August (Fig. 22).

The main herring concentrations were found in the survey transectc from 69^0 N to 71^0 N (Fig.23). It was possible to conclude that the bulk of the herring had distributed to north from 71^0 N.

August

The *Johan Hjort* covered the Norwegian Sea along the Norwegian Coast from about 61°N to

74°N, 5°W to 15°E (Fig. 13) during the period 1/8-23/8.

Herring were found in the survey transects from XX°N to XX°N (Fig. x). It was possible to conclude that the bulk of the herring had moved north. However, no definite conclusions could be made on the E/W spread or the northward extent of the stock north of this latitude.

Herring distribution in the Barents Sea

May

Fritiof Nansen carried out a survey in the Barents Sea from 24º E to 38º E along the Murman and Norwegian coast during the period 20/5-30/5 to map the distribution and produce an abundance estimate of young herring in this area (Fig.1).

In May the immature herring was distributed in the south-western part Barents Sea to south from 71^0 N (Fig. x). The herring mostly was recorded in schools of law density, in the the upper 50 meter layes of water masses. The same area they recorded closer to surface.

Juveniles from age group 1 and 2 occurred in the narrow coastal zone, eastward, from 30° E to 35°00'E. Maximum densities were noticed outside the Varanger Fjord and near the Kildin Island, where herring were observed as dense schools. In the rest of the area the schools were small and scattered, and often only the trawl catches indicated the presence of herring.

The fishery and herring migrations

The weekly records by statistical square of herring catches taken by the Faroese and Icelandic purse-seine fleet are descriptive of herring migrations west of the zero meridian during May and June. The total catch by the two fleets during these two months amounted to about 220 000 tonnes. Theweeksly distribution of catches is shown in figure xx.

The fishery began in late April with small catches taken during the week 27/08-03/05 in the extreme NE corner of the Faroese zone and in the southernmost part of the international area. During the following week (04/05-10/05) catch rates improved somewhat while the fishing area remained the same.

During 11/05-17/05 the herring began migrating rapidly to the south-west and towards the end of the week the best catches were taken about 100 nautical miles north-east of the Faroes. The migration of this component of the stock to the south-west and west, north of the Faroes, continued during 18/05-24/05. While most of the catch during this week derived from an area some 60-80 nautical miles north-east and north of the Faroes, the southernmost catches were taken at a distance of only 30 nautical miles to the north-east of the islands. Near the end of the week the westernmost herring schools had reached 8°W at 64°N. At this point in time, however, the herring in the Faroese zone suddenly scattered and no more fishable concentrations could be located.

The fishery immediately shifted north to the south-eastern corner of the Jan Mayen zone. During the last week of May (25/05-31/05) very good catches were taken in the Jan Mayen area together with smaller amounts in the international area to the south-east of there.

In the first week of June (01/06-07/06) the fishing area shifted westwards and reached about 30 nautical miles into the Icelandic zone. Most of the catch during this week was taken there with smaller amounts deriving from the Jan Mayen zone.

During the second week of June (08/06-14/06) most of the catch was, on the other hand taken in the Jan Mayen zone. The northernmost catches were obtained only 30-40 nautical miles south-east of the island, but the remainder of the catch was taken farther to the south and west. Smaller catches were also made inside the Icelandic zone.

In the third and fourth weeks of June (15/06-21/6 and 22/06-28/6) all of the catch was taken within the Icelandic zone. Most of these catches were taken in an area some 80-120 nautical miles east and north-east of the Langanes promontory (NE-Iceland). However, it is of historical interest that the westernmost record derives from position 67°15’N, 14°W, i.e. about 60 nautical miles due north of Langanes.

In summary, it is clear that the Icelandic and Faroese fishery during the first weeks of the season followed that part of the stock which migrated south-west and west into the Faroese zone. When no more catches could be made there due to the scattered condition of the herring, the fleet shifted to a more northerly part of the stock, which was then migrating in a north-westerly direction towards Jan Mayen. It seems that part of this component also entered the Icelandic zone, but tended to disperse soon after arriving there. The catches taken within the Icelandic zone, to the east and north-east of Langanes, during the latter half of June most like derive from herring migrations northward migration from Faroese waters.

At the end of June all of the Icelandic vessels had fished their allocated TACs and the fishery ceased. However, a research vessel survey of the area east and north-east of Iceland, west of 6°W and south of 68°N, during the latter half of July, did not locate any herring concentrations within the Icelandic zone. The herring previously occupying these waters must therefore have migrated elsewhere, in all probability to the north-east along but south of the polar front like they have done in recent years.

Other fish species

Blue Whiting

May

Blue Whiting were widely distributed in the Norwegian Sea where they occurred at depths from 100-500 meters. During May the adult stock was situated south of the Faroes, migrating northwards from the spawning grounds (Fig. 1). In 1998 the biomass was significantly lower in the Faroese area than in 1997 indicating a delay in the postspawning migration this year.

North of 62° N young blue whiting with the strong 1996 year class constituting most of the biomass. As opposed to last year much of the strong 1995 year class had matured and was out the area this year (Fig. 2).

This year the distributions blue whiting and herring had a strong degree of overlap in the Norwegian Sea, as opposed to 1997. The western boundary of the blue whiting distribution was at about 3°W in the central Norwegian Sea and 2-3°E in the northern part of the survey area (Fig. 2). The relatively high concentration of blue whiting at approximately 69° N and 12-15° E most probably represents a local northern spawning component since adult individuals were caught in this area.

June

Blue Whiting were widely distributed in the Norwegian Sea with the main concentrations south of 65° N and east of 6° W (Fig. 3). They were observed mainly as scattered layers at depths from 150 m to 300 m. The 1996 year class was dominant in most catches. The total biomass within the surveyed area was estimated at 5.6 million tonnes (48.8 billion specimens).

July

Norwegian Sea: The distribution of blue whiting in July-August was quite comparable with that observed in May and June, except for the higher contribution of older individuals in the central and southern parts of the surveyed area (Fig. 4). The blue whiting were mostly observed at 200-400 m during daytime, and at night it dispersed and in some areas ascended towards the surface.

Iceland: During a survey south and east of Iceland in July 1998, high concentrations were recorded in a narrow region near the shelf edge along the entire south coast as well as southeast of Iceland, south of 64°N (Fig. 5). In the westernmost part of the area, these concentrations consisted mainly of young blue whiting of the 1998 year class while farther east larger fish of the 1996 year class dominated in the samples. This resulted in an industrial fishery off the eastern south coast and in the area southeast of Iceland. Such a fishery also developed in 1989 when the strong 198 year class also spread into the Icelandic area during summer.

The calculated abundance estimate of blue whiting in the Norwegian Sea was 6.6 million tonnes (89.6 billion specimens), with most of the fish belonging to the 1996 year class (Fig. 6). At the

same time, it is estimated that at least 1.5 million tonnes of blue whiting resided along and over the shelf to the south and east of Iceland giving a total of 8.1 million tonnes in the Norwegian Sea and Icelandic waters in July 1988. The biomass estimate this year was about twice of that in 1997, which again was higher than in 1996. This is the highest abundance estimate of blue whiting observed since 1980 (9.1 million tonnes).

Mackerel

During the survey in July mackerel was observed in most of the area covered, from the Faroe/Shetland waters in the south to 62° N (Fig. 7). As in 1997 the highest concentrations were found in the south and central areas. The size distribution increased northwards (Fig. 8).

Horse mackerel

Practically no horse mackerel were caught this year.

Lumpsucker

Lumpsucker was caught during all the surveys carried out in 1998 with the highest abundance observed in the north (Fig. 9). This species is widely distributed in the upper layers of the Norwegian Sea and the areas close to the polar front running north-east from Jan Mayen are believed to be important nursery areas for this species.

Salmon

A total of 68 salmon (64 post-smolts and 4 grilse and adults) were caught in surface trawl hauls (Fig. 10). This is at the same level as in 1995 when 66 salmon were caught during a corresponding survey. In 1996 there were caught 13 salmon and in 1997 only 2 specimen.

Whales

Whales were recorded from the bridge during most of the surveys, but no systematic sampling was done. The species observed during the surveys included killer whale, sperm whale, mink whale, fin whale, humpback whale, dolphins, and other unidentified specimens.

Mesopelagic fishes

Scattered observations of mesopelagic fish were made throughout the surveys.

Acoustic estimates

Acoustic estimates were carried out for the Norwegian spring spawning herring stock in the Norwegian Sea in May (Argos/G.O.Sars, table 4) and in July (Johan Hjort, table 5), and on young herring in the Barents Sea in June (F. Nansen, table 6). An estimate of the blue whiting stock in the Norwegian Sea was carried out in July (Johan Hjort, table 7).

The combined May estimate on the Norwegian spring spawning herring stock is the only estimate which is regarded to cover the entire adult herring stock.

Discussion

Comparison of herring distributions between 1996-1998

May

Complete survey coverage was achieved in all three years. However, the areas occupied by the fish were somewhat different between years. The main difference was that herring had a much

more eastern distribution in 1998 than previous years at the same period. During early May a large part of the stock was still on the migration westward and had not yet passed the 0° longitude, while another part had concentrated further north off the Lofoten Islands. This was probably due to the relationship with the increased water temperature and improved feeding conditions (see below). In comparison to the previous year these two patches did not unite during the summer migration but kept apparently apart from each other. Later in May the southernmost distribution seemed to extend further to the south-west, closer to the Faroes (63^{o}N in 1996, 64^{o}N in 1997, 62^{o}N in 1998), and further into the Icelandic sector (9^{o}W in 1996, 7^{o}W in 1997, 10^{o}W in 1998). In addition, both patches of the stock were more distributed and were less concentrated as previous year, presumably due to the fact that the schools had not yet reached the cold front in early May and were still migrating in water masses of more than 3°C.

The differences between the years in the W and E parts of the area was very marked and can be regarded as significant. This will also see that the stock is not static, but moving during the investigation period. The differences along the northern and southern edges are less conclusive, and should be treated with caution.

June

As in earlier years coverage was only partial in June. In all three years concentrations were observed in Faroese waters (64-66^{o}N, 3-8^{o}W). In 1998 the southernmost herring moved from Faroese area into the Icelandic waters, resulting in large herring catches. This distribution of the stocks into the Icelandic area was much more pronounced than previous years. In 1996, the extension of the distribution into Jan Mayen waters seen in May persisted into June. In 1997 and 1998 no herring were observed in this area by the acoustic surveys, however surface trawl results indicated the presence of substantial numbers of herring in June. There were reasonable quantities of herring in the international waters (66-69^{o}N, 2^{o}E - 4^{o}W) in 1997 and 1998, but no fish were found in this area in 1996.

July/August

By the end of July in all three years the herring had mostly moved into the northern parts of the

Norwegian Sea, with only isolated patches left south of 65°N. In 1996 the southern limit for the main herring distribution was around 66°N, and extended to the west to about 0°. In 1997 the southern limit was between 68 and 69°N. In 1998 the southern limit was back to about 66°N. The western limit was difficult to define but may have been as far as 12° W.
The northern limit was not reach this year as well as previous years, due to low coverage in the northern part. Therefore another survey design should be adopted so the northern limit could be found in future surveys.

Summary of the migration pattern of Norwegian spring-spawning herring

Norwegian spring-spawning herring (NSSH) spawn in January-March along the west coast of Norway from approximately 58°N to 69°N, and the larvae drift north-eastward into the fjords and the Barents Sea (Dragesund *et al.,* 1980; 1997; Hamre, 1990; Røttingen, 1990, Misund *et al.,* 1998). Depending on the growth rate the young herring leave the nurseries at the age of 2 to 5 years and enter the Norwegian Sea. The stock is characterised by large fluctuations in abundance and recruitment (Hjort, 1914; Dragesund *et al.,* 1997) that are often accompanied by pronounced changes in the growth and maturation patterns (Toresson, 1990). The extension of the migration depends largely on the extension of the cold front (2°C isotherm), which is the boundary of the arctic water body. Depending on climatic conditions the cold front typically extends from Spitzbergen along the Mohns Ridge to East Iceland, shifting further to the west in colder periods (e.g. 1965-1969) and extending less far into the North Atlantic in warmer periods (e.g. 1950-1964) (Jakobsson and Østvedt, 1996). The NSSH usually does not pass the cold front. However, on some occasions concentrations can also be found in the arctic water masses (e.g. Jakobsson and Østvedt, 1996; Vilhjálmsson, 1997).

While the adolescent herring enter the North Atlantic from north-east, the older NSSH have come from the Norwegian coast, starting a seaward migration in early March, presumably with the onset of planktonic development and increasing water temperatures. During this migration the fish are presumably guided by an interplay of a few key factors which are essentially the water temperature and the abundance of prey Fenrø et al. (1998). With further warming of the water masses, development of the planktonic prey the adult herring move further north and

eventually mix with the adolescent herring, joining the stock from north-east. Before the period of collapse the stock usually overwintered west of Iceland and / or north of the Lofoten Islands, before coming back to the Norwegian coast for spawning in the early months of the year. While this very generalised picture of the migration pattern of NSSH has not drastically altered since the recovery, a fundamental change in overwintering behaviour has occurred in so far as at least the larger part of the entire adult stock stays in the North Norwegian Fjords during winter (Røttingen 1990, 1992).

Basis for the description of the herring migration path in 1998.

The inferred migration path of the herring in 1998 is presented in two different figures (x-x). These figures represent a synopsis of the data collected during 1998. The basis for each component is discussed below.

In March it is assumed that the herring are still largely in, or near to, their spawning grounds along the Norwegian coast. In April there are few fish left on the Norwegian coast and relatively little within 20 - 30 nautical miles. The main observations in earlier years have been made in the Norwegian waters in the central Norwegian Sea. So it is assumed that the fish move away from the Norwegian coast, probably in a NW or W direction, and then turn SW into international waters. However, there is some evidence from surveys in April 1997 that herring, particularly from the spawning grounds around 60^{o}N, may also move more directly towards the international waters (Anon., 1997).

As the May distribution is so wide spread, it is assumed from previous years that following migration out from the coast the fish then spread out freely throughout the international waters and up into the northern Norwegian Sea (Anon., 1997). However, in 1998 the herring stayed closer to the coast for a protracted period with rather high temperature and good feeding conditions. During the survey period it was obvious that the herring stock was migrating east and showed a more SE distribution later in May than in the beginning of May. After seaward migration in May the schools turn generally southward when reaching the cold front, before it migrate northward.

As in earlier years, the fish are younger to the east and north of this area, but not as clears as in earlier years. It is impossible to determine what migrations are occurring in the north of the area (north of 68^{o}N), however, it seems likely that predominantly young fish are migrating in from the Barents Sea and the Norwegian coast.

In June and and some part of the July survey data is rather weak to properly infer migration paths. However, inn early June the southern part of the stock migrate into the Faroese area, and later to the northwest into the Icelandic zone. In this area an important fishery was taken place in 1998 by the Icelandic and the Faroese (see below). In late June the general migration pattern was north-north east but schools seems to spread out during this migration and now occupy a large area extending from the cold front far east.

In August the fish were almost all found N of 68^{o}N. In previous years the fish have subsequently been caught in September/October close to the Norwegian coast. So it is assumed that the migration in August probably turns to the east towards the coast.

Comparison between migration patterns in 1996-1998

In 1996 two distinct categories of herring migrations were observed (Anon 1996b), with immature herring of the 1991 and 1992 year-classes migrating far south into the Faroes, EU and International zone. This particular migration pattern was not observed in 1997 and 1998, when the now maturing individuals of those two year-classes appeared to have taken up a migration pattern more like the older herring (Fig. x). This indicates that there have not been any good year-classes to recruit to the adult stock during these years.

In recent years, approaching the cold front the schools turn south and migrate along the gradient (Misund et al. 1997). However, in the recent years the schools are also observed to take a southward turn already in April and/or May, not having reached the 2°C isotherm yet (Misund et. al. (1998) for the summer migration in 1996). In May 1996 the schools of adult fish had reached their southern most position at about 66°N, turned and started migrating north end of May. Being guided by the temperature gradient the north-north-east migration lasted until end of July.

However, the schools were not concentrated directly at the cold front but spread out through the entire water body of the Norwegian current during the their northward migration. At about 72°N the schools turned east in August to head more towards the coast of northern Norway.
About the same situation was observed in 1997 by Vilhjálmsson et al. (1997). After the general seaward migration had taken place in April, there was a southward movement of the schools in April and May. While the younger parts of the stock stayed in schools at about 25-100m, the older fish formed schools in 250-400 m and again moved south along the cold front temperature gradient, turning north-north-east early June at about 65°N. Again the schools spread out and inhabited a large area during the northward shift, being bordered to the east by the cold front.

Temperature, zooplankton and herring interactions

In 1998 the zooplankton biomass in the upper 200 m was generally higher than in 1997, and in July this was reflected in higher fat content of the herring. Thus, the feeding conditions for the herring in 1998 seemed to have been similar to the more favourable situation during the years before 1997. In the first half of May 1998 the herring were located in the central Norwegian Sea with two main centers of distribution, between 65 and 66°N and between 69 and 71°N. Therefore the herring were distributed in areas of fairly high zooplankton biomass during this period. However, there still were regions to the west and north of the herring that seemed largely ungrazed, offering high concentrations of zooplankton. In May 1998, the herring in generally experienced surface temperatures above 5°C throughout its distribution area. These are higher temperatures than in 1997 and may have influenced the growth of the herring.

The situation in 1997 was different in that the herring was concentrated further west in a region of low zooplankton biomass just east of higher concentrations of zooplankton farther to the west. This we interpret as herring in search of food, gathering at the cold front of the East-Icelandic Current, in which the elevated zooplankton concentrations probably were not available to the herring due to low temperatures (<2-3 °C).

The zooplankton in the eastern and central Norwegian Sea may have been grazed down already in May in 1997, while in 1998 there still were some zooplankton left in this area. Thus, the herring distribution in 1998 probably was less restricted by temperature and generally showed an

easterly distribution due to the good feeding conditions in the central Norwegian Sea.

The lower zooplankton biomass in 1997 may not have been related to the grazing of the herring alone. The year 1997 was abnormal with regard to the start of the phytoplankton bloom which was almost one month delayed at Weather Station M. Similarly the recruitment of *Calanus finmarchicus* was delayed (Aure *et al.* 1998). Thus, lower zooplankton biomasses in May 1997 may have been due to a more recent reproduction of *C. finmarchicus* and higher concentrations of smaller copepodite stages contributing less to the zooplankton biomass this year than in 1998.

From May to June 1998 there was a movement of the herring in the southern part of its distribution area towards west, and a shift of maximum zooplankton biomass towards the central and eastern Norwegian Sea. Most of the herring were still distributed east of the 6°C surface isotherm. A smaller fraction of the herring stock found south of the East-Icelandic Current between Iceland and the Faeroes in late May, may have joined the northern part of the stock across the East-Icelandic Current as the thermocline developed and the surface temperature arose in June and July.

In July 1998 the herring had left the central and western Norwegian Sea and was found in the northern and eastern parts of the Norwegian Sea. In the Norwegian Sea, zooplankton biomass was low which to some degree must have been related to the past grazing of the herring and other pelagic fishes such as blue whiting and mackerel. However, it was also observed that in many regions *C. finmarchicus* had descended to greater depths (below 200 m) to overwinter.

In May 1998 the herring was distributed in smaller schools, closer to the surface compared to 1997. This is a vertical distribution more typically found during summer. Both the higher temperature in 1998 and the earlier start of biological production this year may have induced such a distribution of the herring in May.

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Tables

Table 1. Organizational frame of the coordinated herring investigations in the Norwegian Sea, 1995-1998.

Year	Participants	Surveys	Planning meeting	Evaluation meeting
1995	Faroe Islands, Iceland Norway, Russia	11	Bergen, (Anon, 1995a)	Reykjavík (Anon, 1995b)
1996	Faroe Islands, Iceland Norway, Russia	13	Tórshavn, (Anon, 1996a)	Reykjavík (Anon, 1996b)

1997	Faroe Islands, Iceland Norway, Russia, EU	11	Bergen (Anon, 1997a)	Reykjavík (Anon, 1997b)
1998	Faroe Islands, Iceland Norway, Russia, EU	11	Reykjavík (Anon, 1997b)	Lysekil (this report)

Table 2. Faroese, EU, Icelandic, Norwegian and Russian surveys of the Norwegian Sea in spring and summer 1998. Detailed survey tracks with fishing, hydrographic and plankton stations are given in this report (FI: Faroes, I: Iceland, N: Norway, R: Russia, D: Djedy net, G: Genzen net, M: MOCNESS net, WP-2: WP-2 net, Herr. smpl: no. of herring samples, st: no of stations).

Vessel	Survey area	Period	Herr. smpl.	Plankton st.	CTD st.
«G.O. Sars»[N]	62° - 72° N, 5° W - 17° E	04.21-05.21	46	123[M + WP-2]	108
«Argos»[EU]	62° - 71° N, 3° W - 17° E	04.30-05.20	10	32[WP-2]	35
«Árni Fridriksson»[I]	62° - 70° N, 8° W - 1° E	05.05-05.29	22	75[WP-2]	77
«Bjarni Sæmundsson»[I]	Icelandic waters	05.26-06.16	0	106 [WP-2]	125
«Árni Fridriksson»[I]	64°- 70° N, 06 ° W-10 ° W	06.19-07.03	1	-	21
«Magnus Heinason»[FI]	59° - 66° N, 9° W - 1° E	05.01-05.19	19	107[WP-2]	106
«F Nansen»[R]	69° - 72° N, 30° – 37° E	05.20-05.30	7[D]	12	24
«F Nansen »[R]	62° – 68° N, 10° W – 10° E	06.01-07.05	14[D]	96	102
«F Nansen »[R]	65° – 72° N, 5° W – 15° E	07.11–08.02	8[D]	70	74
«Johan Hjort»[N]	62° - 74° N, 10° W - 17° E	06.30-07.29	58	119[M + WP-2]	108
«Árni Fridriksson»[I]	South of Iceland & 63° - 67 ° 30' N, 06° -15° W	07.17-07.26	-	-	-

Table 4. Age stratified estimate of the Norwegian spring spawning herring in the Norwegian and the Barents Sea, April-May, 1998. Numbers in millions, weight in thousand tonnes, length in cm, mean weight in grams. No estimate available for ages 11, 12 and 14, which either didn't appear in the samples or were read as other yearclasses.

Norwegian spring spawning herring: Combined EU (Argos) and Norway (G.O. Sars), May, in the Norwegian Sea

Age	1	2	3	4	5	6	7	8	9	10	13	15+	Total
Numbers	24	1404	367	1099	4410	16378	10160	2059	804	183	112	415	37415
Weight	0.8	91.1	40.6	208.6	865.2	3481.1	2363.8	533.6	233.7	57.4	35.3	141.7	8053.0
Mean length (cm)	17.56	21.17	24.79	29.96	30.64	32.04	32.84	34.07	35.42	36.84	37.28	37.73	31.83
Mean weight (g)	33.4	64.9	110.7	189.8	196.2	212.5	232.7	259.2	290.7	313.7	315.5	341.4	215.2

Table 5. Age stratified estimate of the Norwegian spring spawning herring in the Norwegian, R/V"Johan Hjort", July, 1998. Numbers in millions, weight in thousand tonnes, length in cm, mean weight in grams.

Norwegian spring spawning herring: Norway (Johan Hjort), July, in the Norwegian Sea

Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+	Tot
Number	15	0	181	347	699	1805	8895	8527	546	1161	11	282	521	0	62	224	23276
Mean length	33.25	0.00	21.75	23.91	30.51	31.38	32.62	33.54	35.00	35.45	34.75	37.03	37.03	0.00	37.22	37.67	32.99
Weight	6.3	0.0	16.3	41.8	180.5	474.9	2637.1	2765.3	205.6	435.8	4.1	119.3	203.8	0.0	26.9	98.5	7216.2
Mean weight	417.0	0.0	90.3	120.6	258.2	263.1	296.5	324.3	376.6	375.4	370.0	423.0	391.1	0.0	434.0	439.8	310.0
Condition	11.3	0.0	8.6	8.5	9.0	8.5	8.5	8.6	8.8	8.4	8.8	8.4	7.7	0.0	8.4	8.2	8.5

Table 6. Age stratified estimate of the Norwegian spring spawning herring in the Barents Sea, R/V"F. Nansen", June, 1998. Numbers in millions, weight in thousand tonnes, length in cm, mean weight in grams.

Norwegian spring spawning herring : Russia (F Nansen), June, in the Barents Sea

Age	1	2	3	4	5	6	7	8	9	10	13	15+	Total
Numbers	9507	4658	12	10									14187
Weight	62.93	79.68	0.97	1.05									146.46
Mean length (cm)	10.40	14.20	23.13	25.35									11.7
Mean weight (g)	6.6	17.1	79.4	106.3									10.3

Table 7. Age stratified estimate of the Blue Whiting stock in the Norwegian Sea, R/V"Johan Hjort", July, 1998. Numbers in millions, weight in thousand tonnes, length in cm, mean weight in grams.

Blue Whiting: Norway (Johan Hjort), July, in the Norwegian Sea

Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+	Tot
Numbers	0	24244	47815	16282	556	212	100	64	10	255	27	13	0	0	0	0	89578
Mean length	0.00	21.66	23.88	25.42	28.34	30.15	32.85	34.31	33.85	34.38	37.75	37.75	0.00	0.00	0.00	0.00	23.66
Weight	0.0	1284.3	3571.8	1495.9	74.0	31.8	18.3	13.9	2.3	58.9	8.8	3.7	0.0	0.0	0.0	0.0	6563.9
Mean weight	0.0	53.0	74.7	91.9	133.2	150.1	183.3	217.6	233.3	231.1	326.0	288.0	0.0	0.0	0.0	0.0	73.3
Condition	0.0	5.2	5.4	5.5	5.6	5.4	5.2	5.4	6.0	5.5	6.0	5.4	0.0	0.0	0.0	0.0	5.4

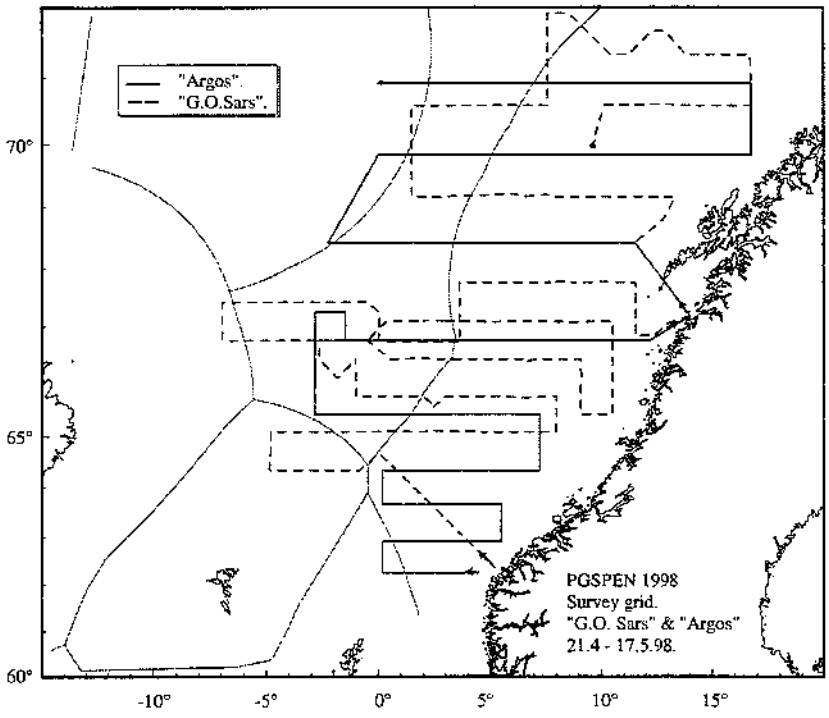


Figure 1. Survey transects of R/V "Argos" and R/V "G.O. Sars", April-May 1998, as included in the acoustic estimate.

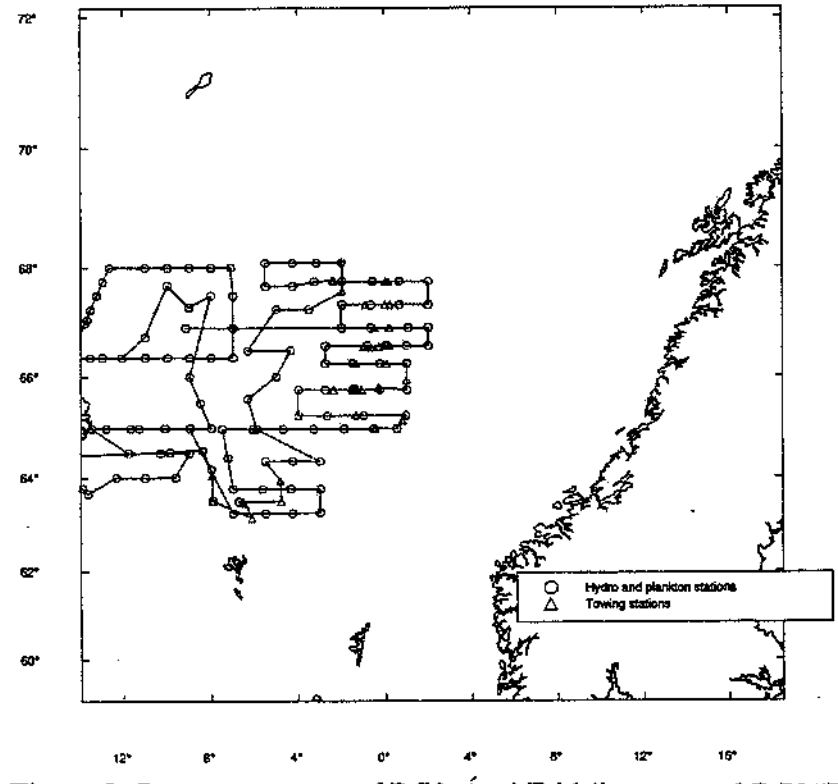


Figure 2. Survey transects of R/V«Árni Fridriksson» and R/V "Bjarni Sæmundsson", May 1998.

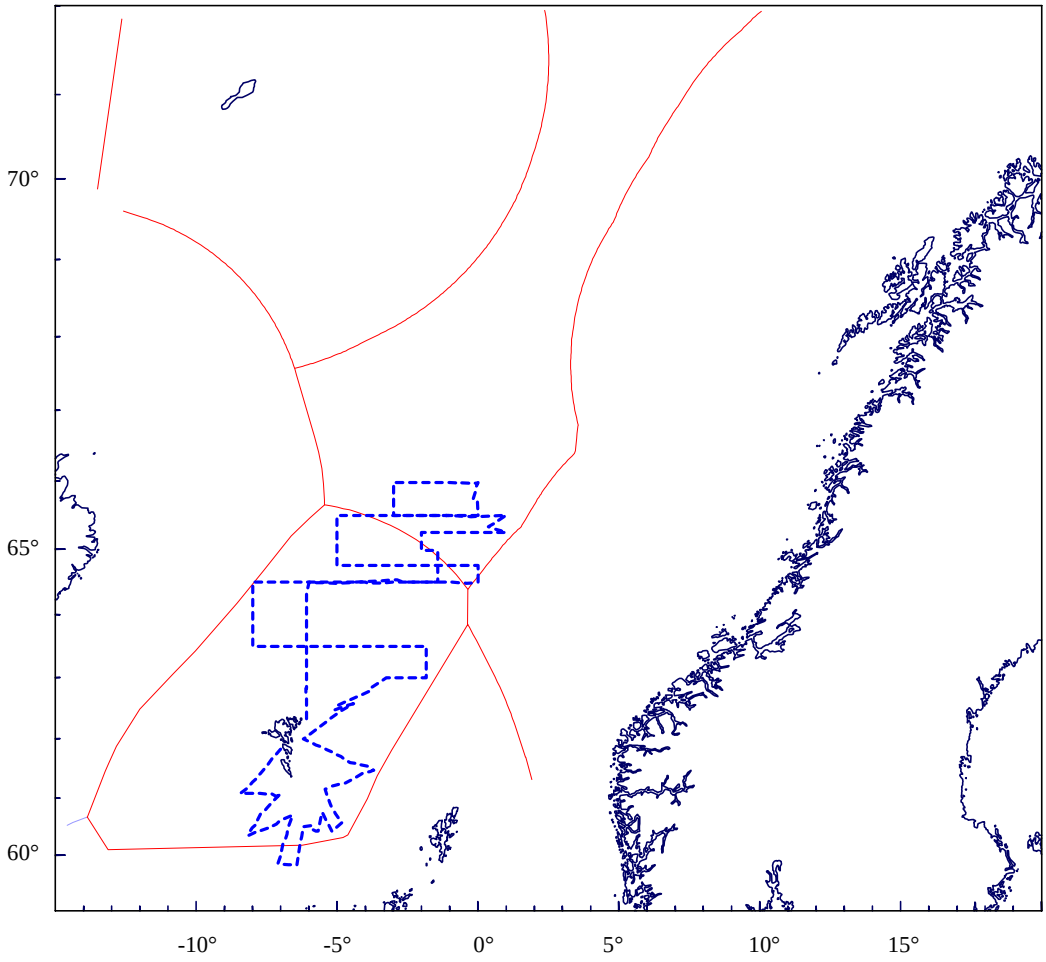


Figure 3. Survey transects of R/V “Magnus Heinasson”, May 1998.

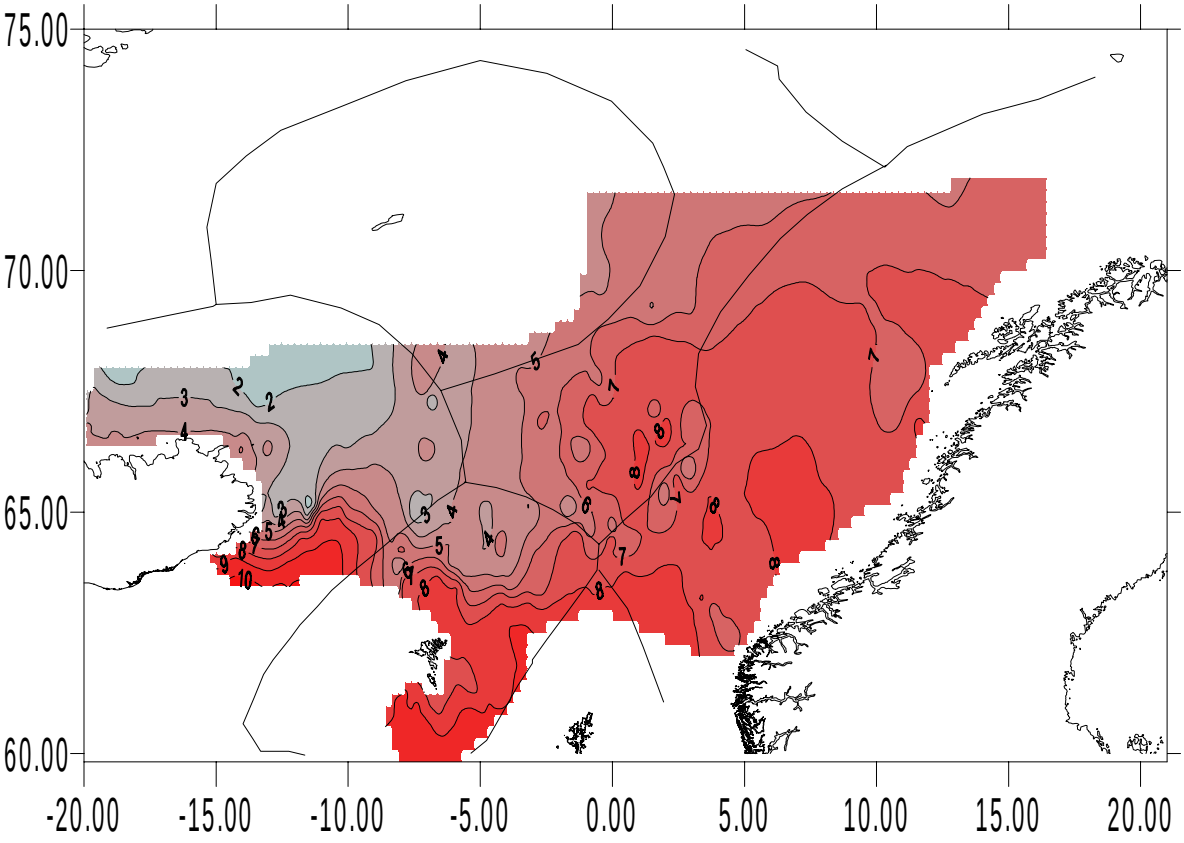


Figure 4. Temperatures in the surface, May 1998.

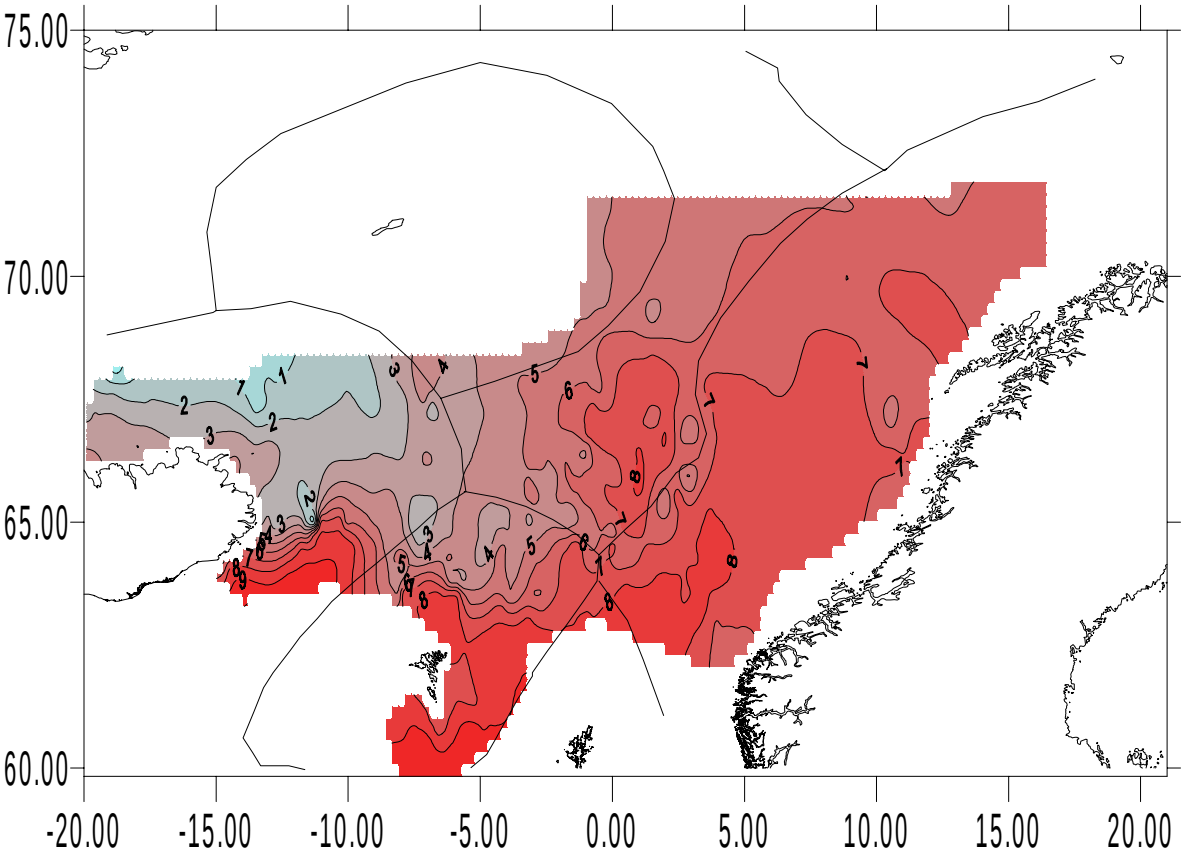


Figure 5. Temperatures in 20 m, May 1998 .

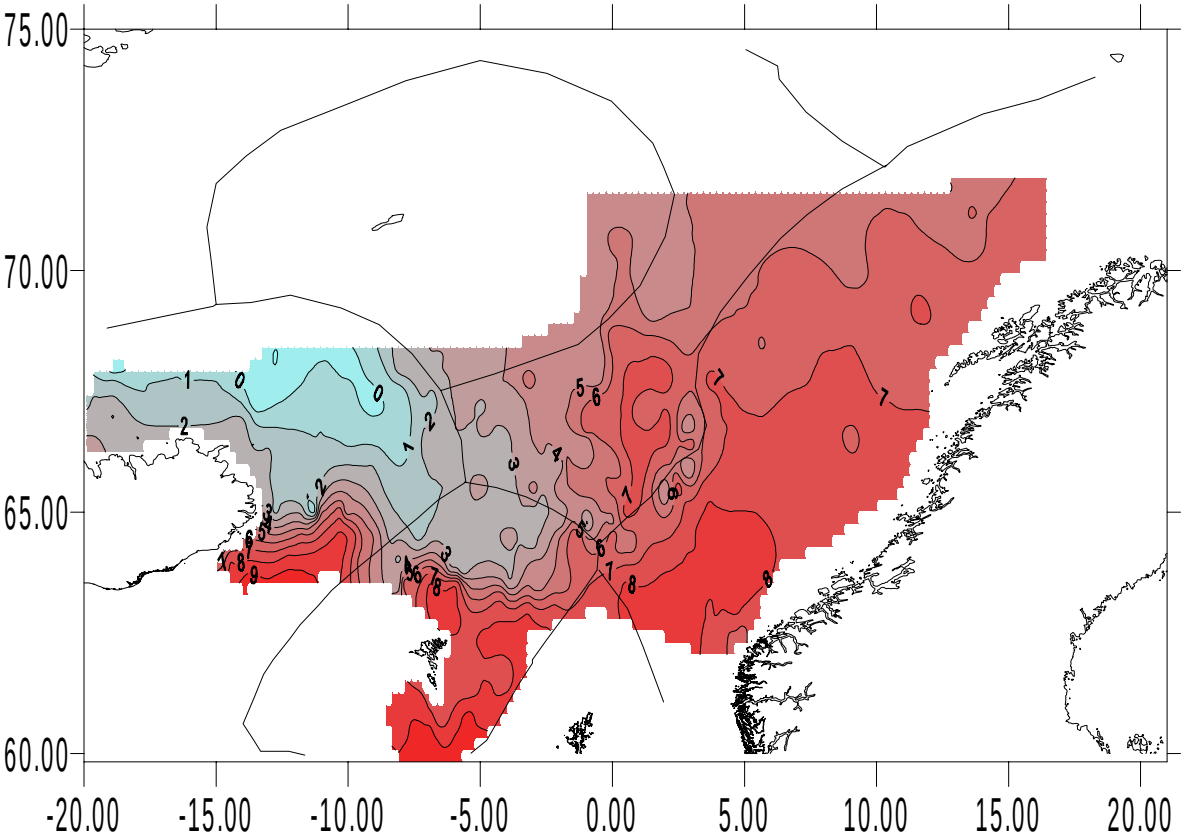


Figure 6. Temperatures in 50 m, May 1998.

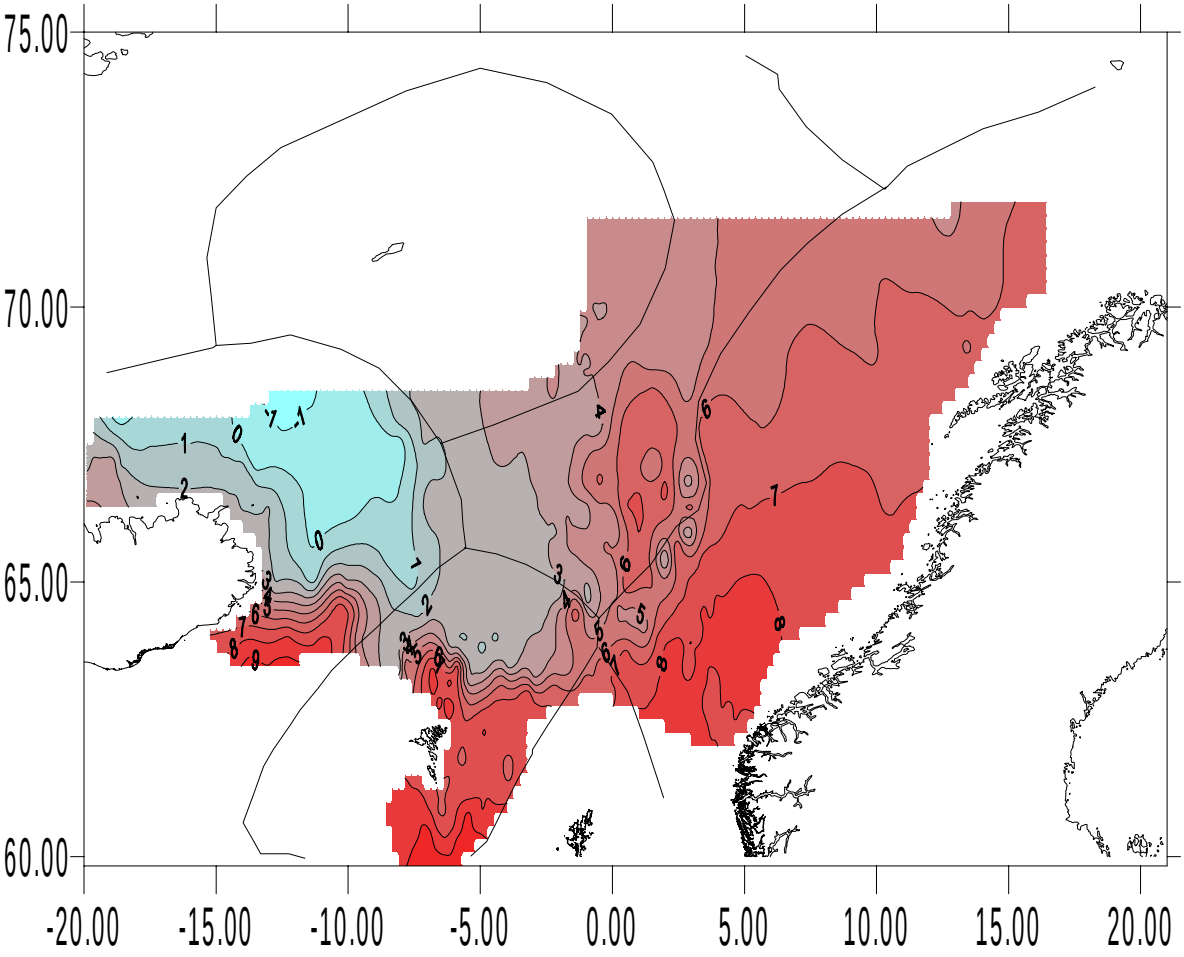


Figure 7. Temperatures in 100 m, May 1998.

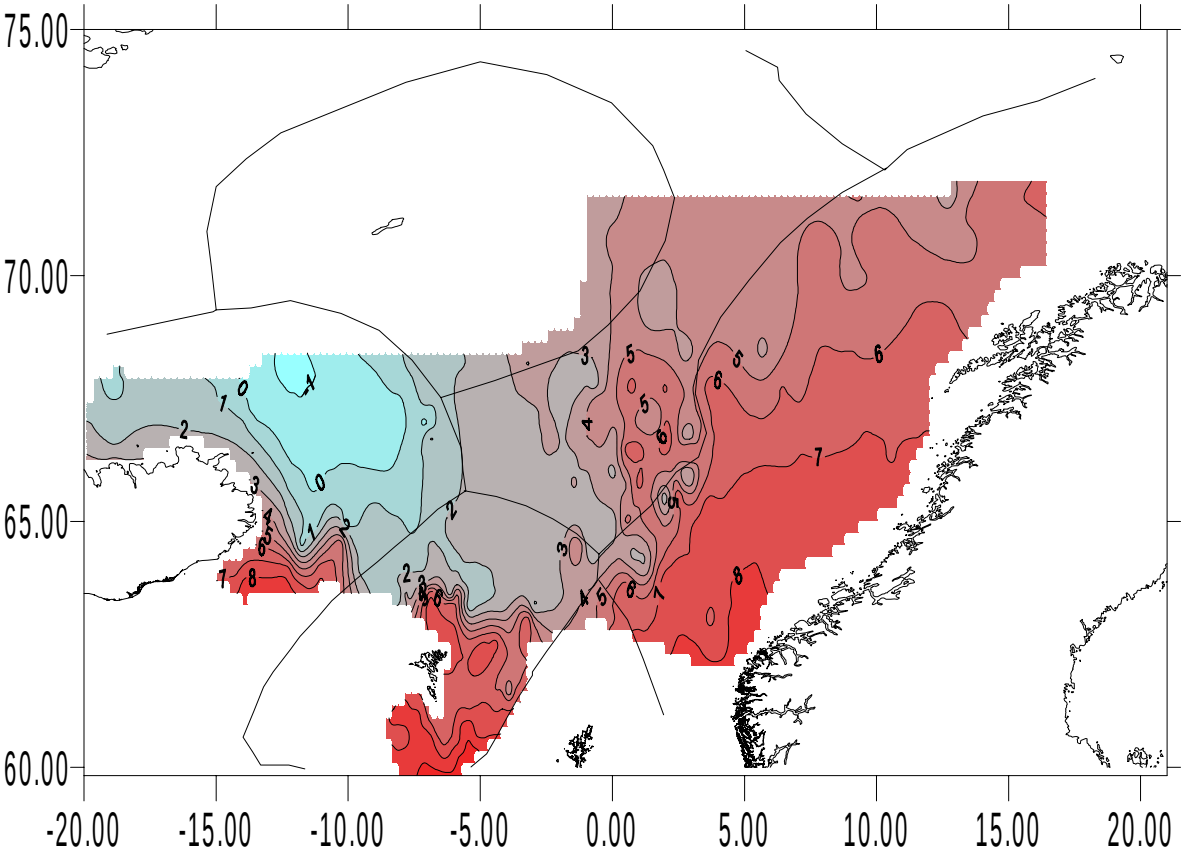


Figure 8. Temperatures in 200 m, May 1998.

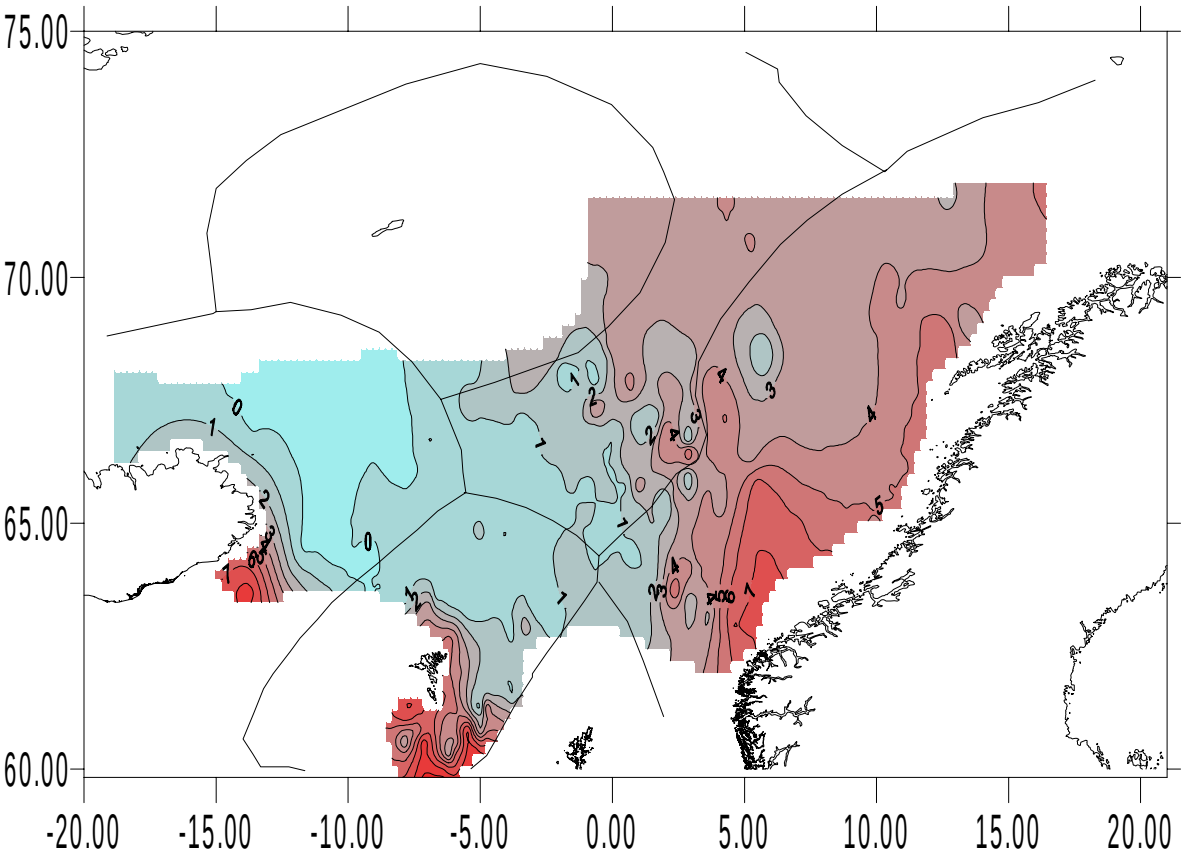


Figure 9. Temperatures in 400m, May 1998.

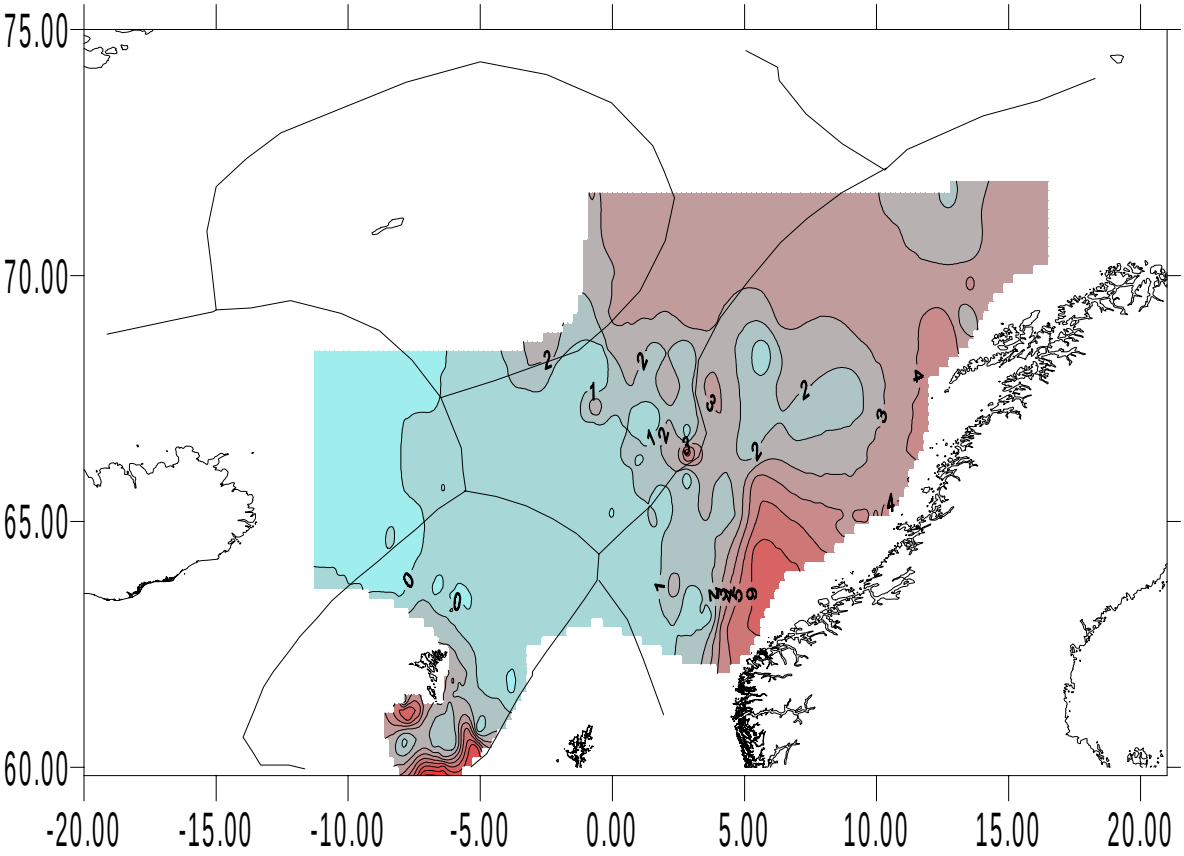


Figure 10. Temperatures in 500 m, May 1998.

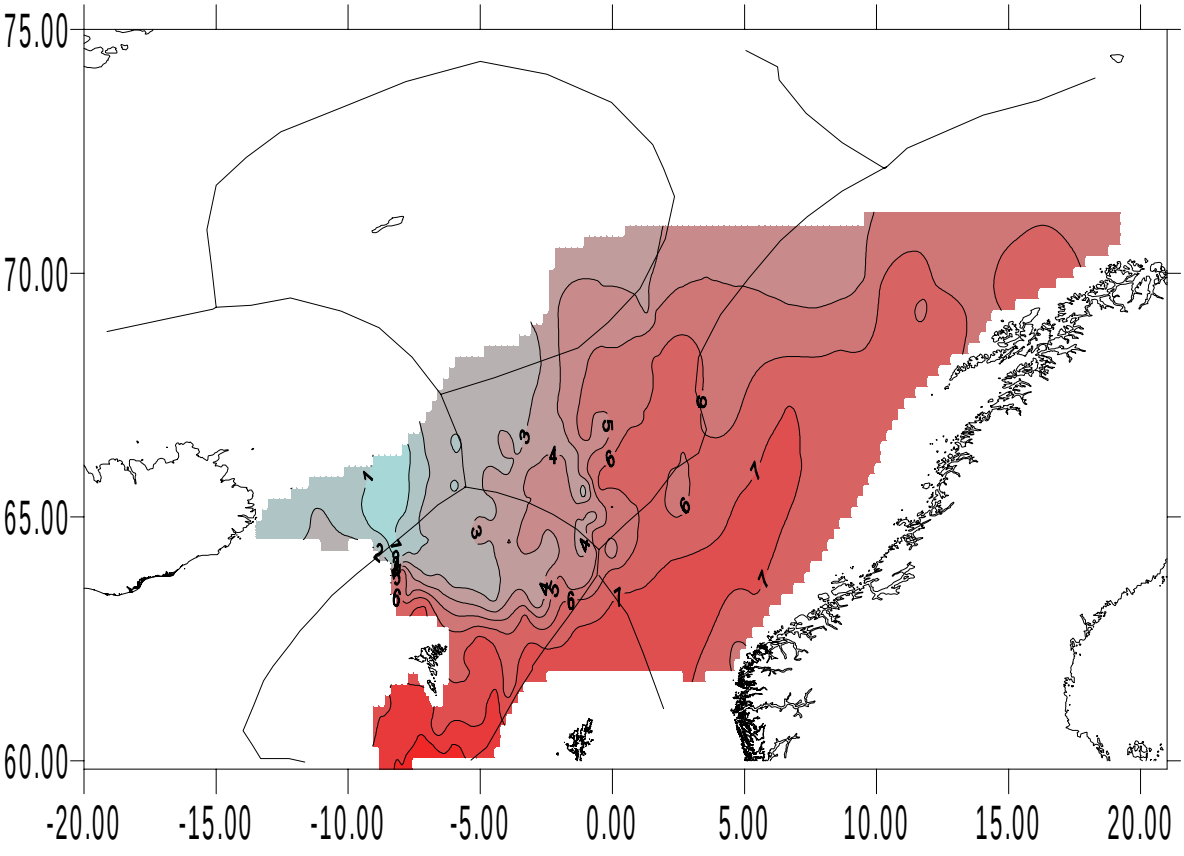


Figure 11. Temperatures in 50 m, May 1997.

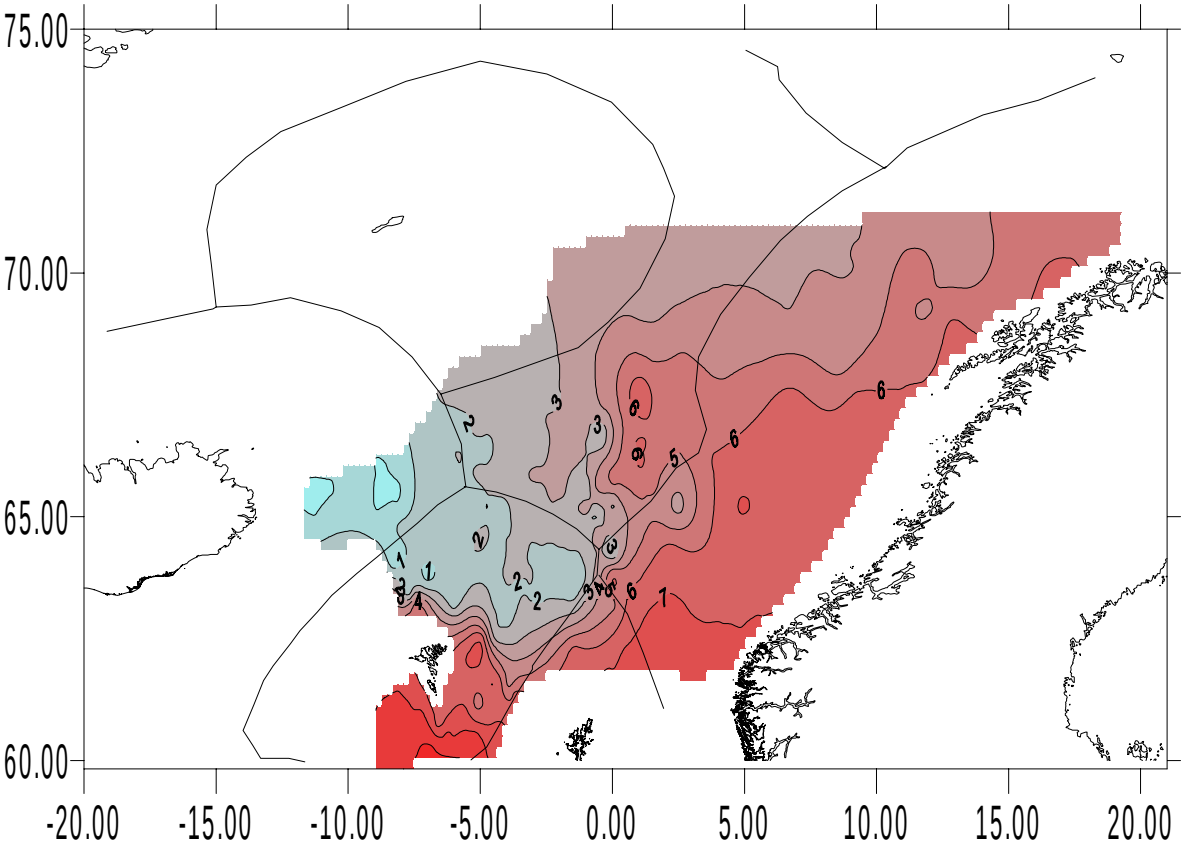


Figure 12. Temperatures in 200 m, May 1997.

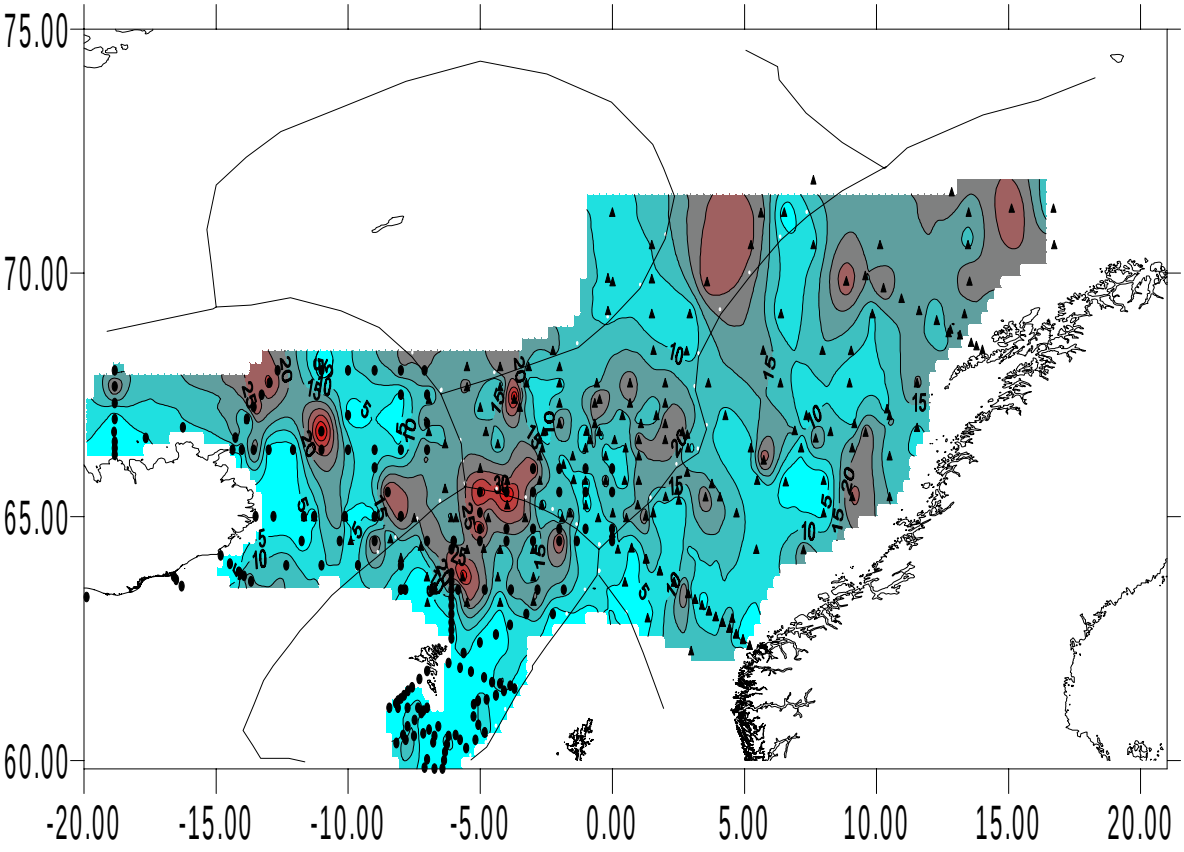


Figure 12b. Zooplankton biomass in mg dry weight per m^2 in upper 200 m, May 1998.

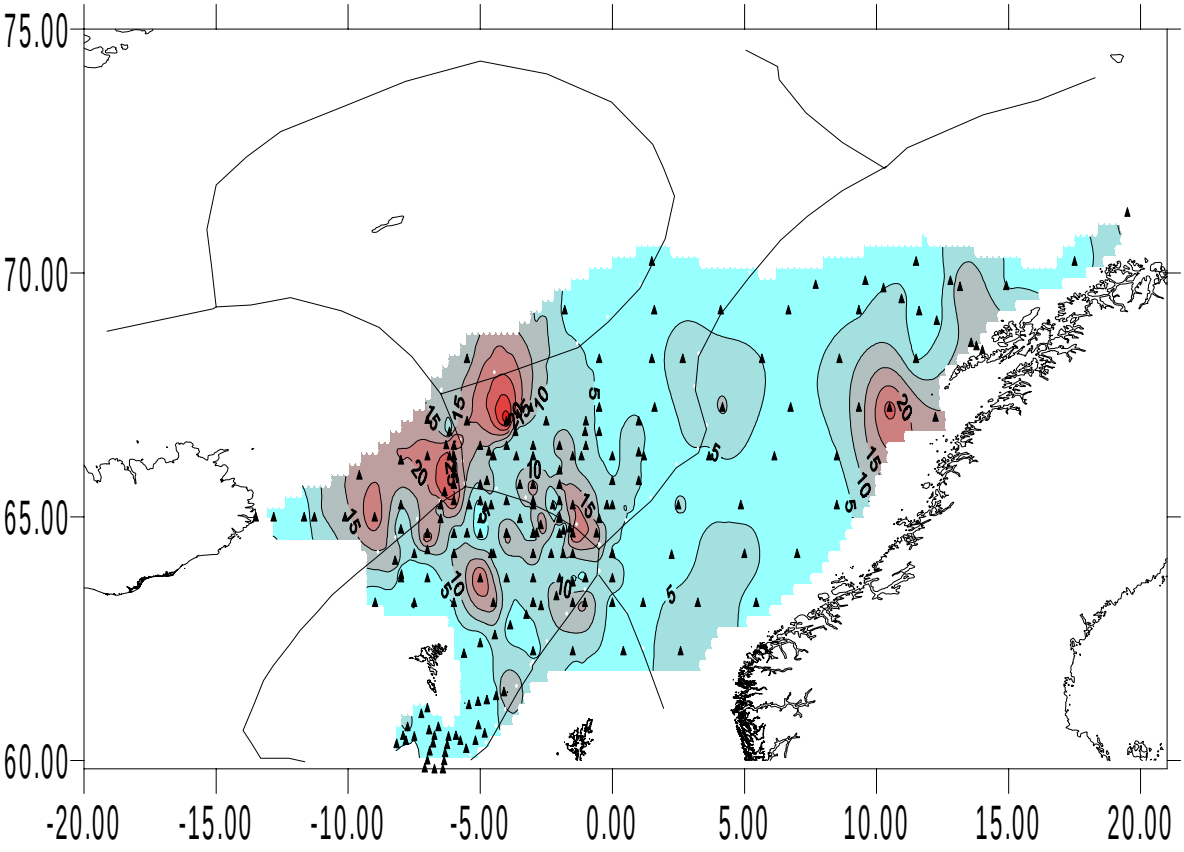


Figure 13. Zooplankton biomass in mg dry weight per m^2 in upper 200 m, May 1997. Sample positions indicated.

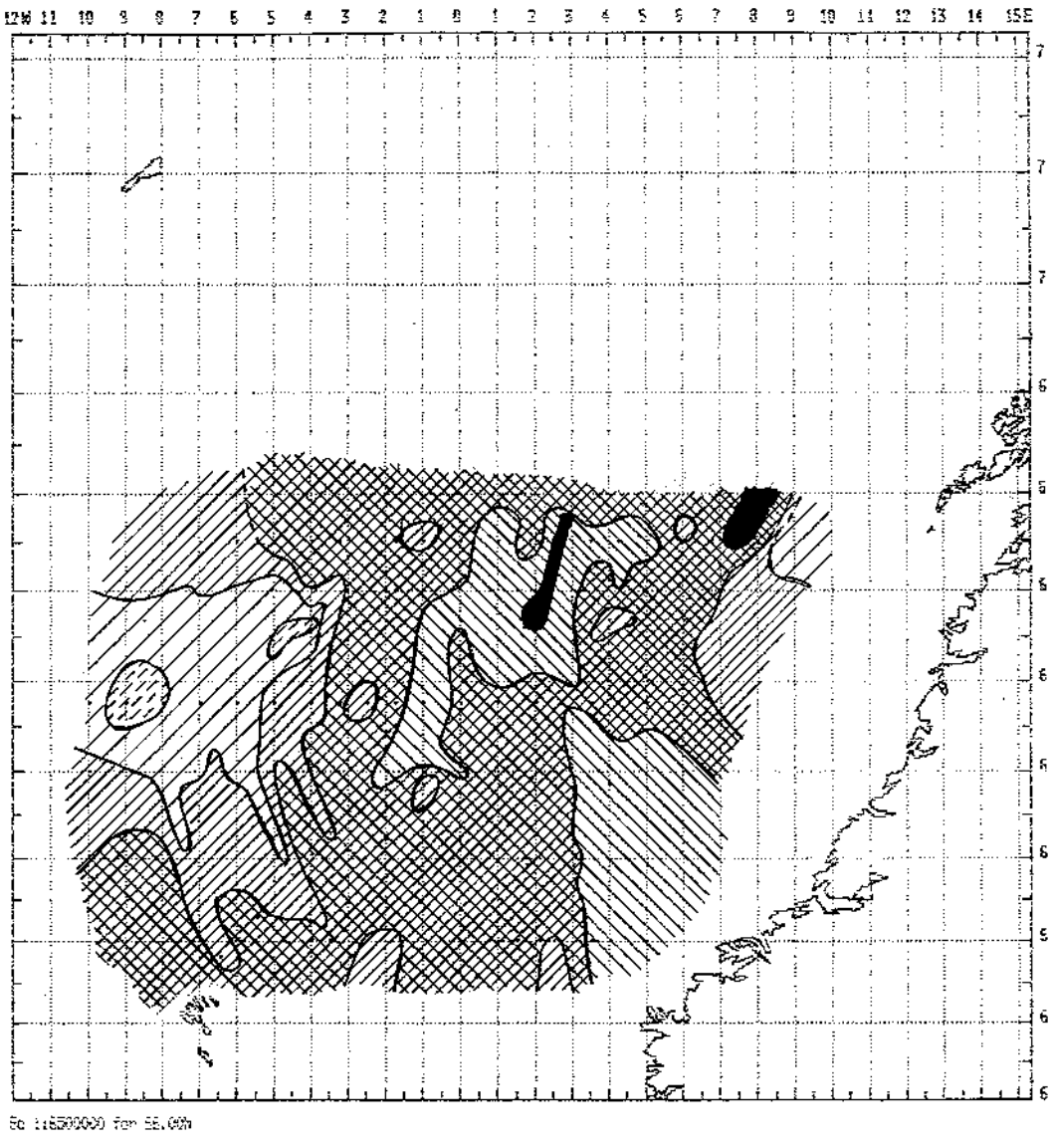


Fig. 14 Plankton biomass distribution 0-50 m layer in the Norwegin sea in june 1998. Jedy net's catches

	0 - 200		1001 - 2500
	201 - 500		2501 - 5000
	501 - 1000		> 5000

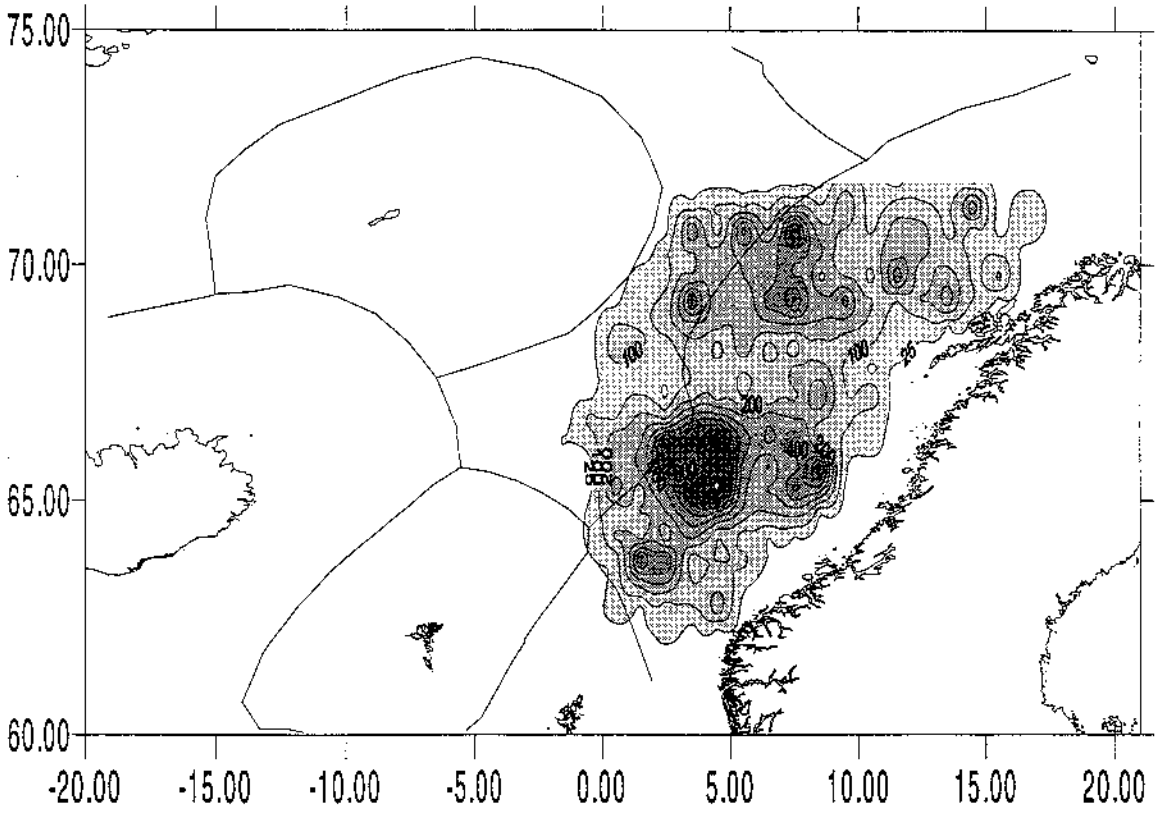


Figure 15. Distribution of Norwegian spring spawning herring during 21/4-17/5, 1998 as measured by R/V Argos and R/V G.O.Sars. Represented by mean Sa value in ICES statistical squares.

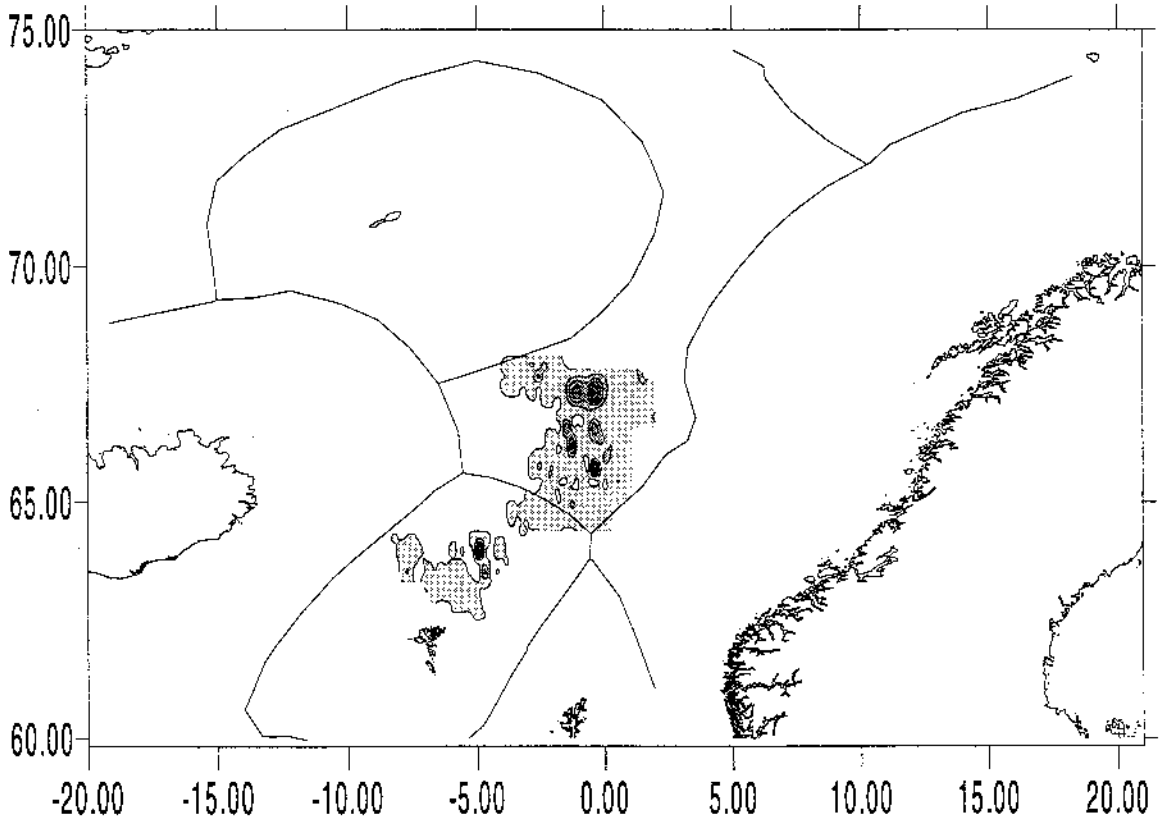


Figure 16. Distribution of Norwegian spring spawning herring during 5/5-29/5, 1998 as measured by R/V Magnus Heinason and R/V Arni Fridriksson. Represented by mean Sa value in 5 nautical miles.

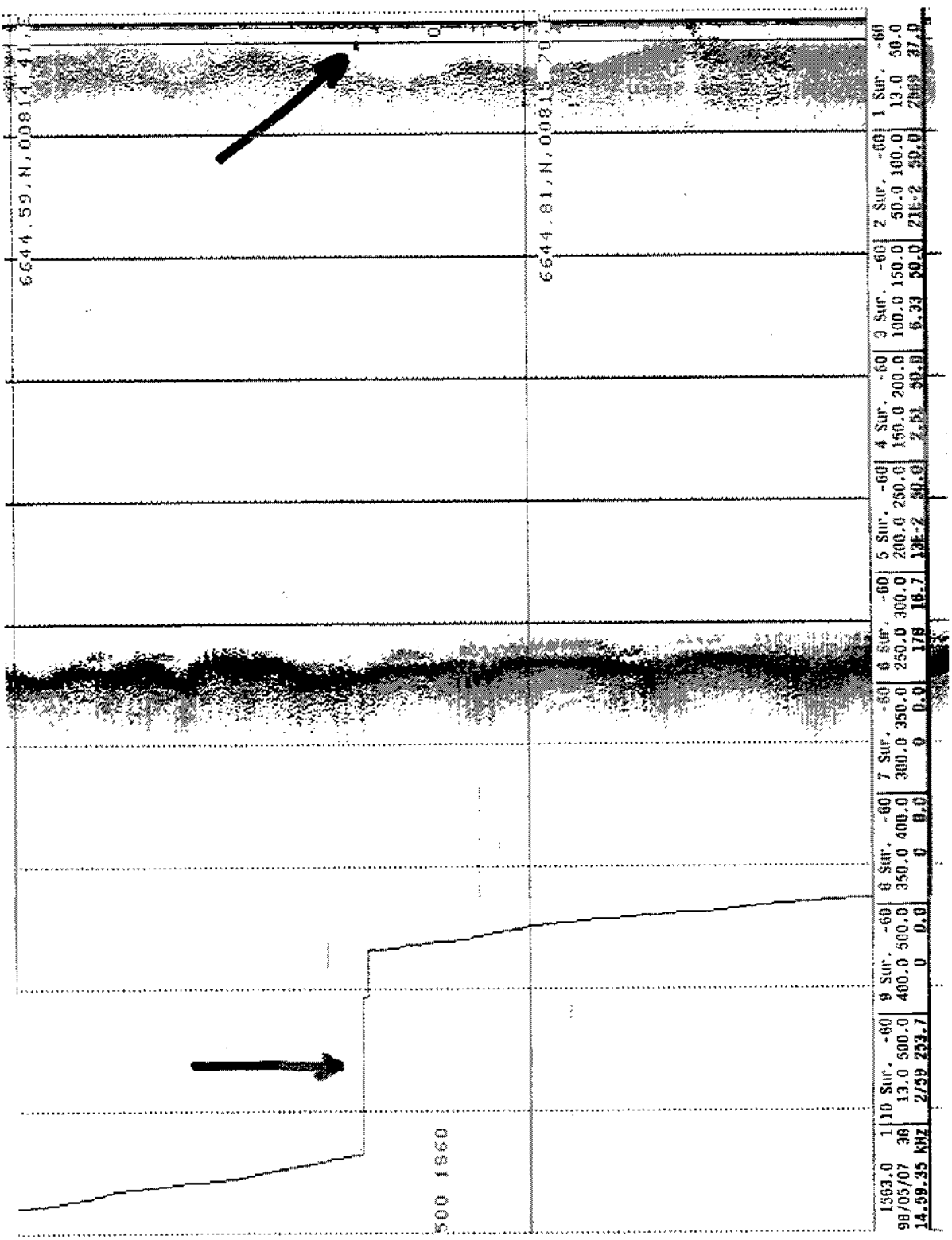


Figure 17. Small schools of herring close to the surface (upper arrow). Typical for the registrations of herring in the Norwegian Sea in May 1998. Echogram from R/V Argos. Lower arrow: Jump in Sa value corresponding to school.

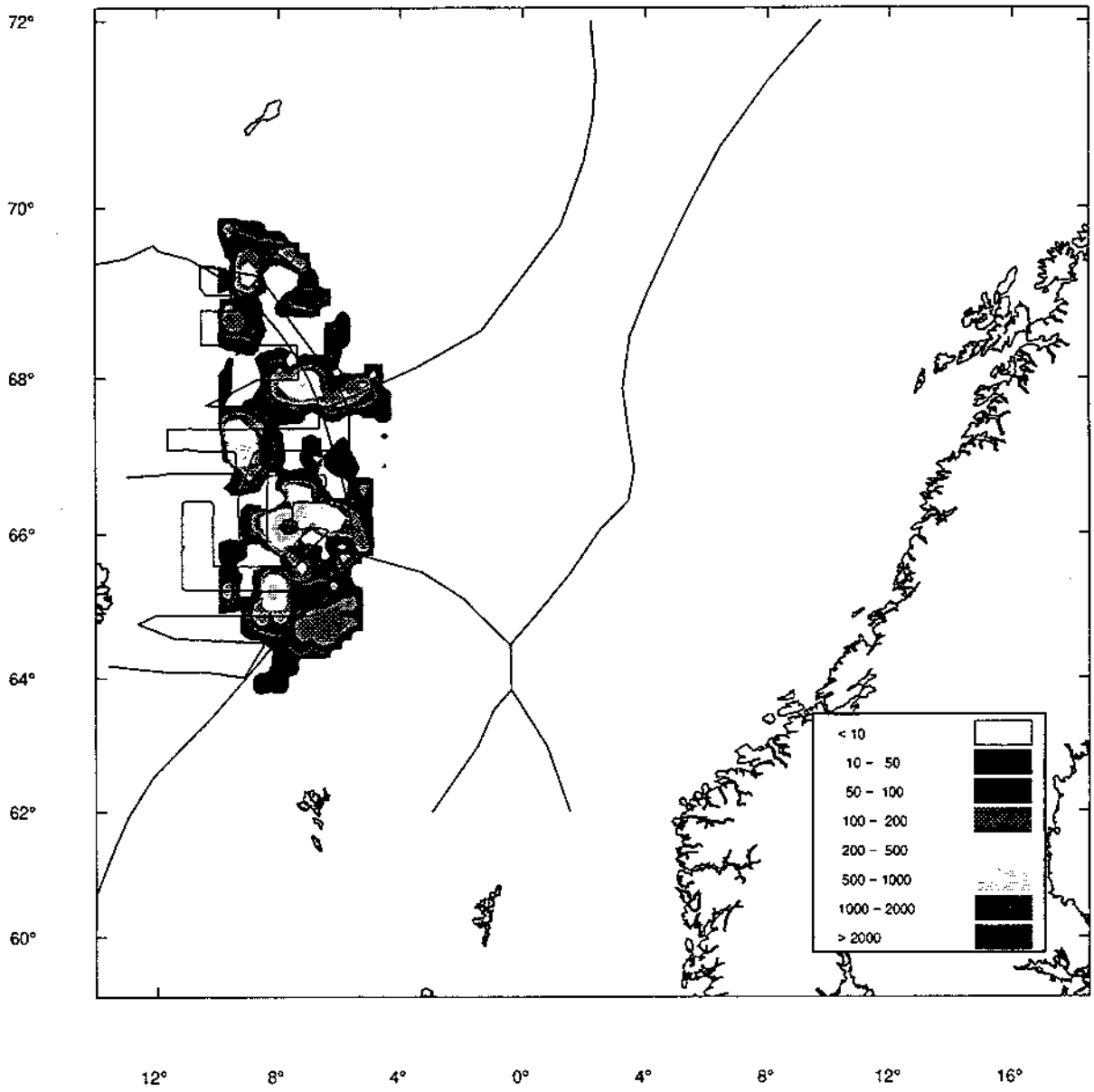


Figure 18. Herring distribution as observed by *Árni Fridriksson* during 19/6-3/7, 1998.

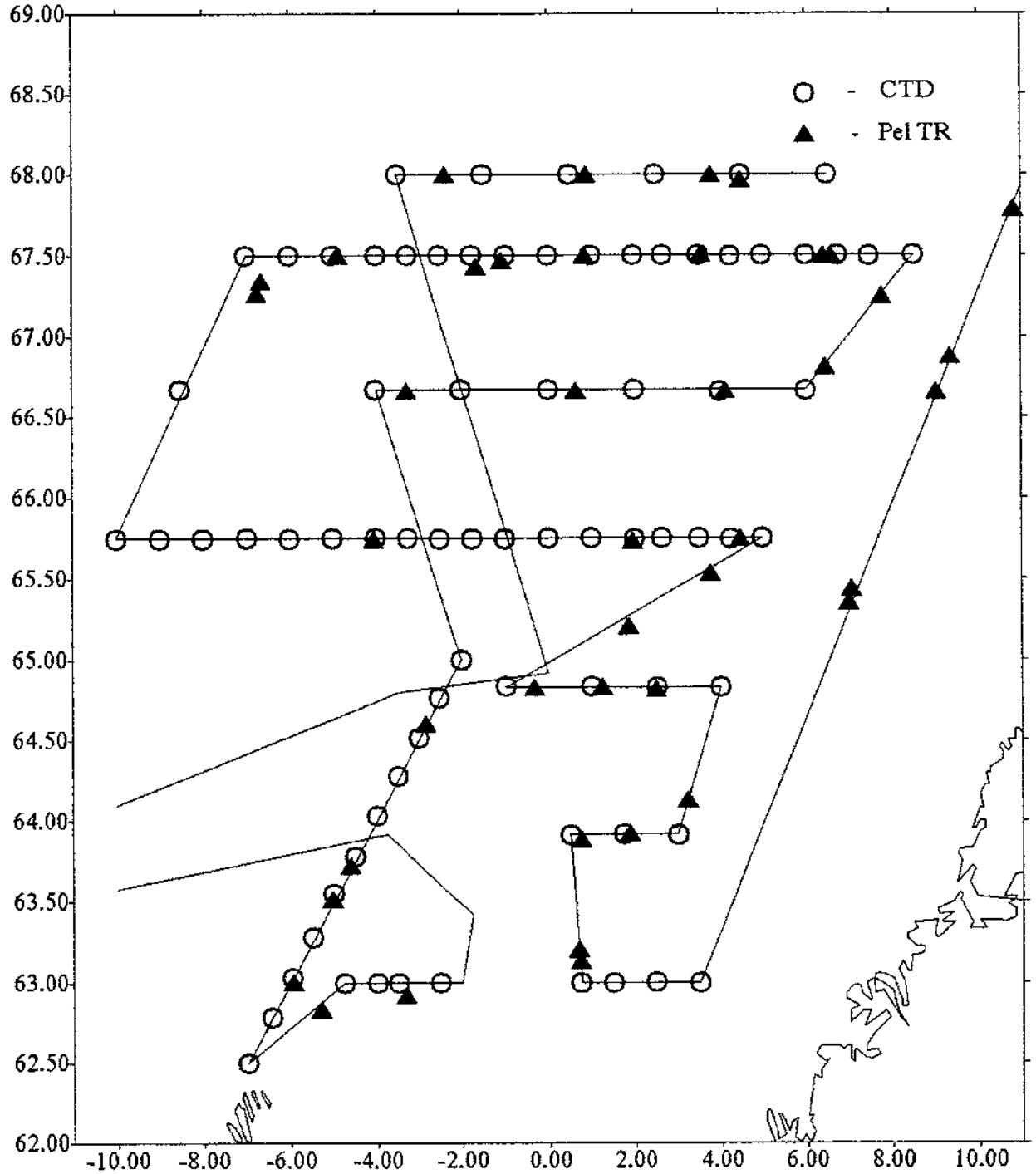
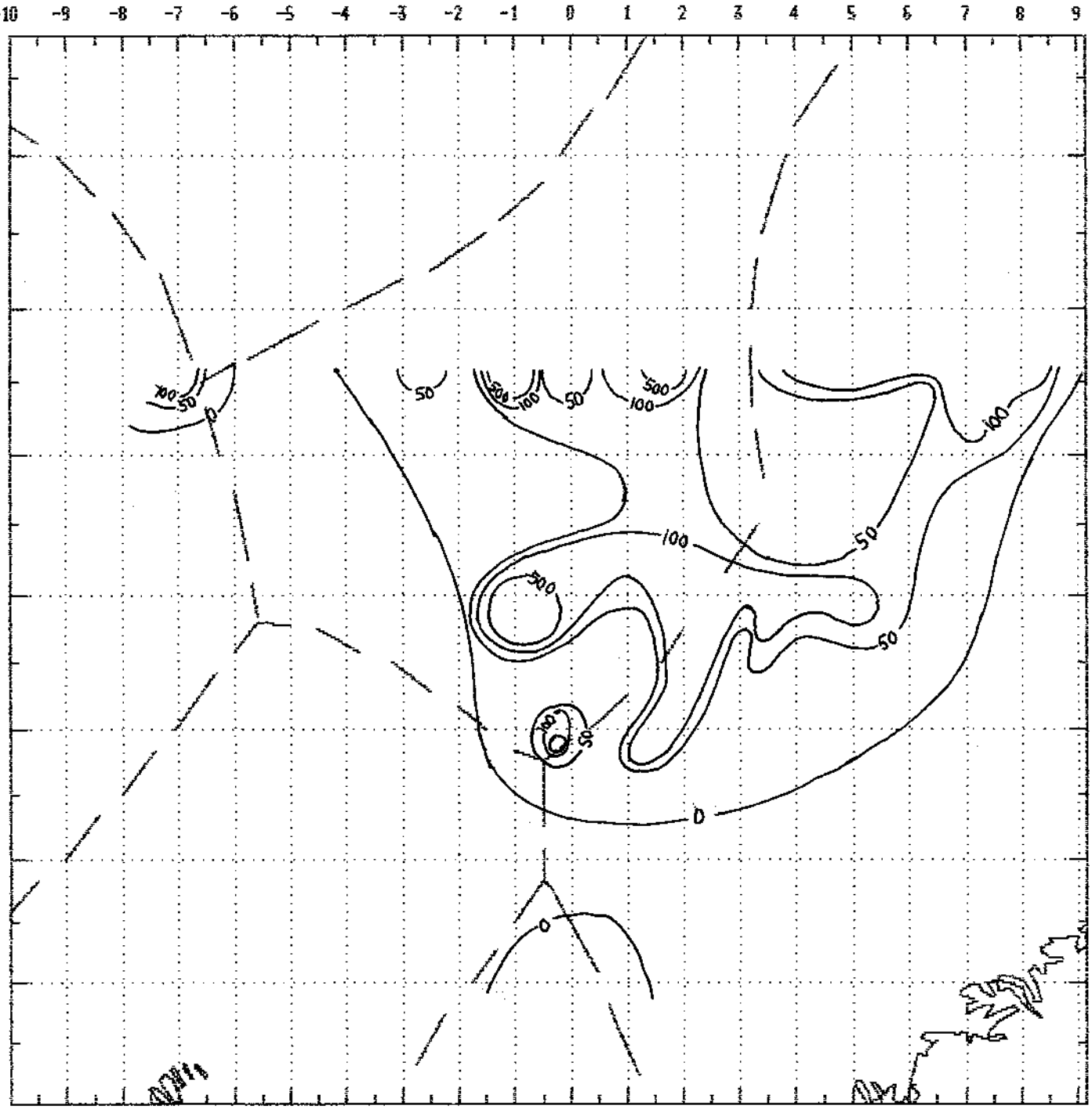


Fig. 19 Survej tracks, position trawl and CTD stations in the Norwegian Sea in June 1998.



Sc 1:5000000 for 65.00N

Fig. 20 Distribution of Herring in the Norwegian Sea in June 1998, Sa refer to integrator values.

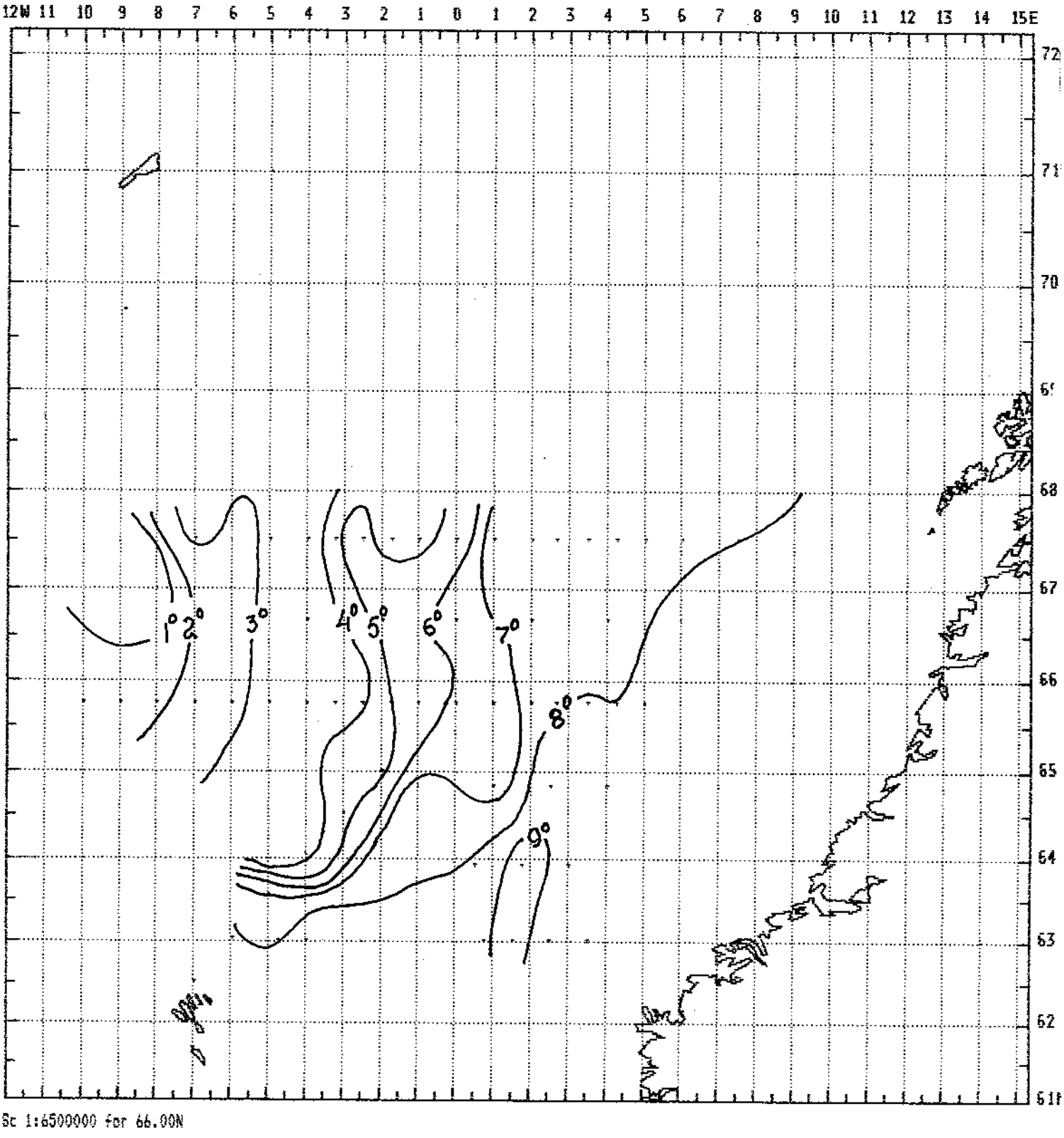


Fig.21, Temperature at 50m in June 1998

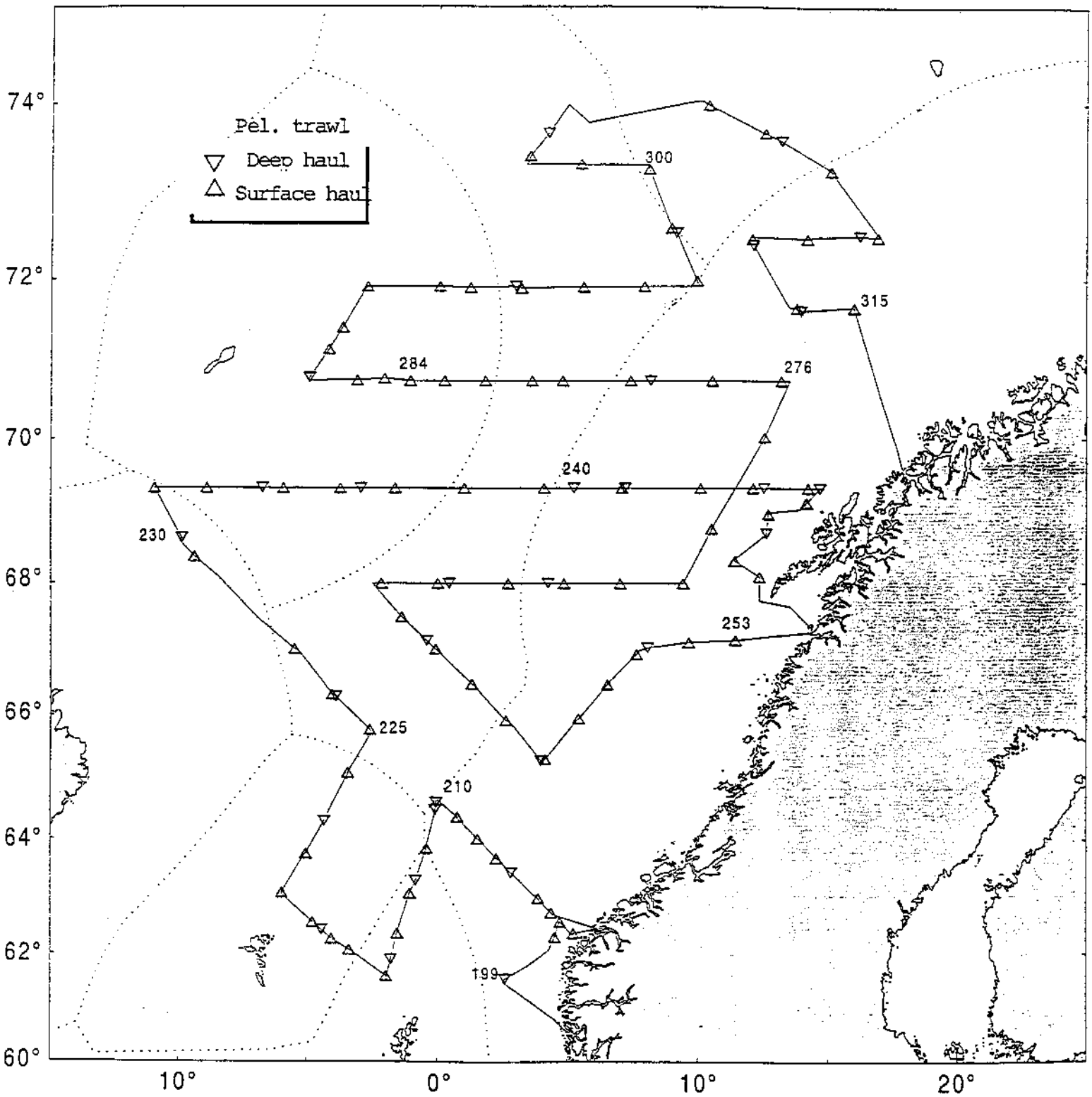


Figure 2. Cruise tracks with fishing stations. "Johan Hjort", 30.6 - 29.7 1998.

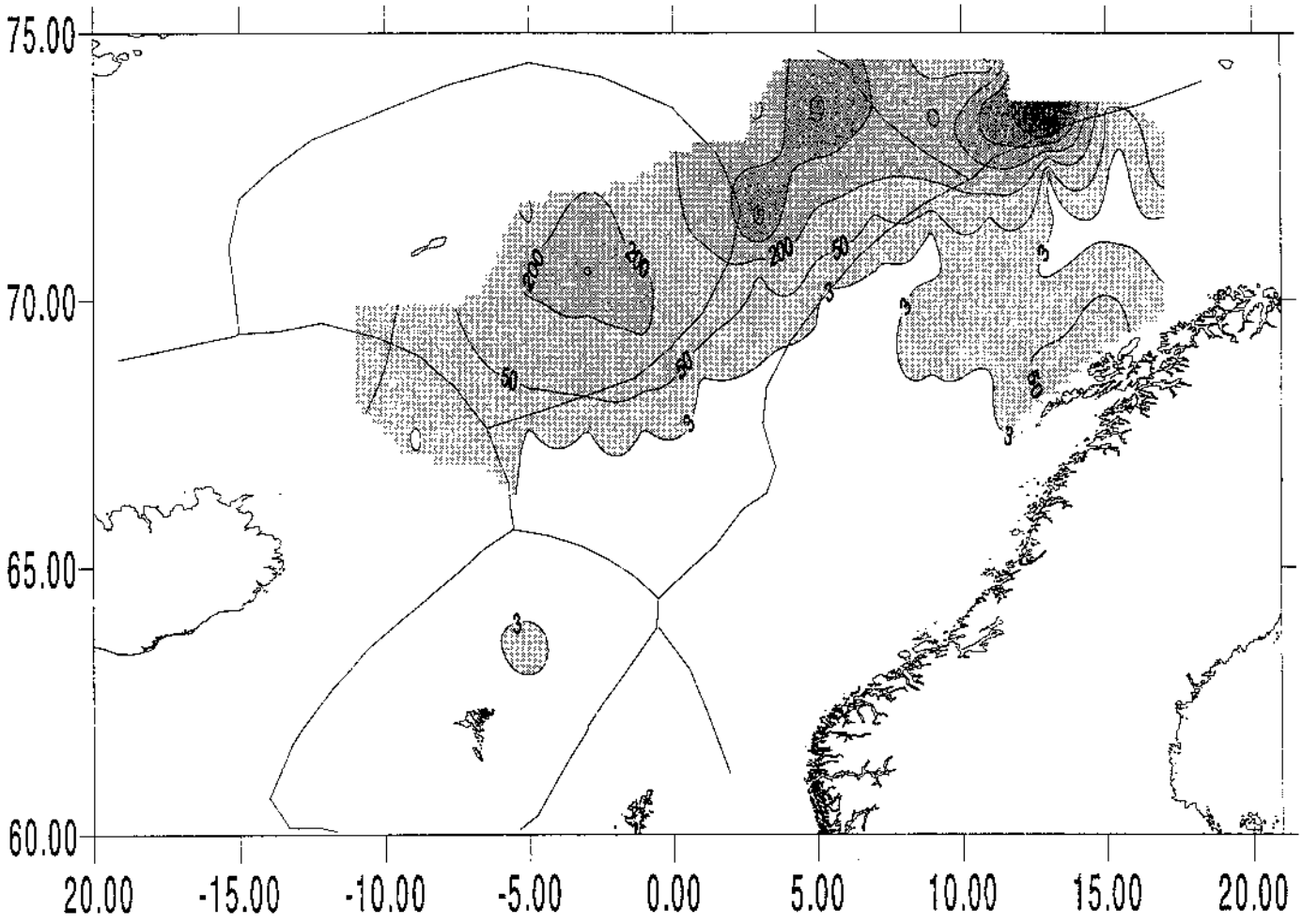


Figure 23. Herring distribution, based on Sa values, as measured by R/V "Johan Hjort" during 30/6-29/7 1998.

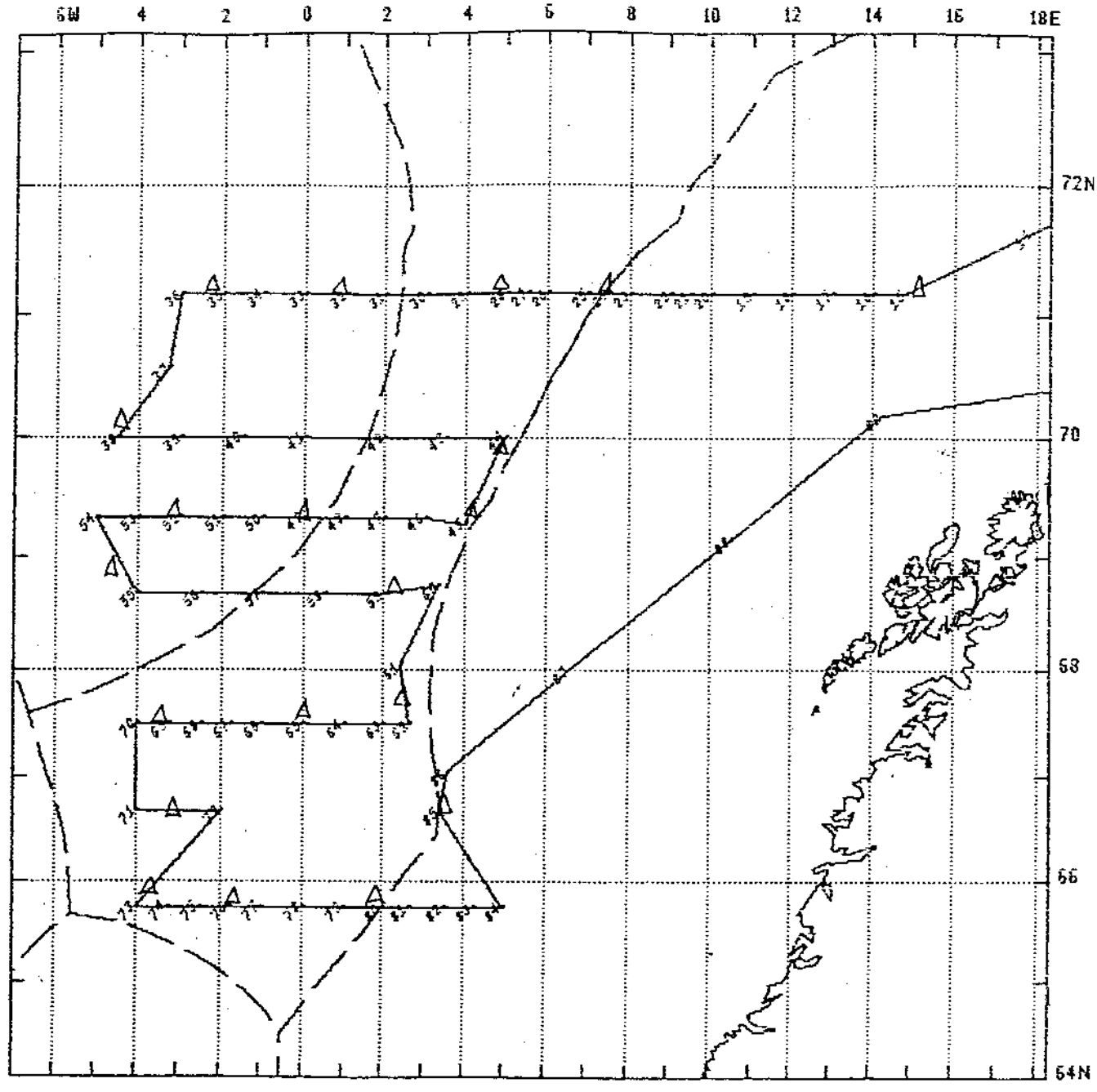


Fig. 24 Survey tracks, position trawl and CTD stations in the Norwegian Sea in July 1998.

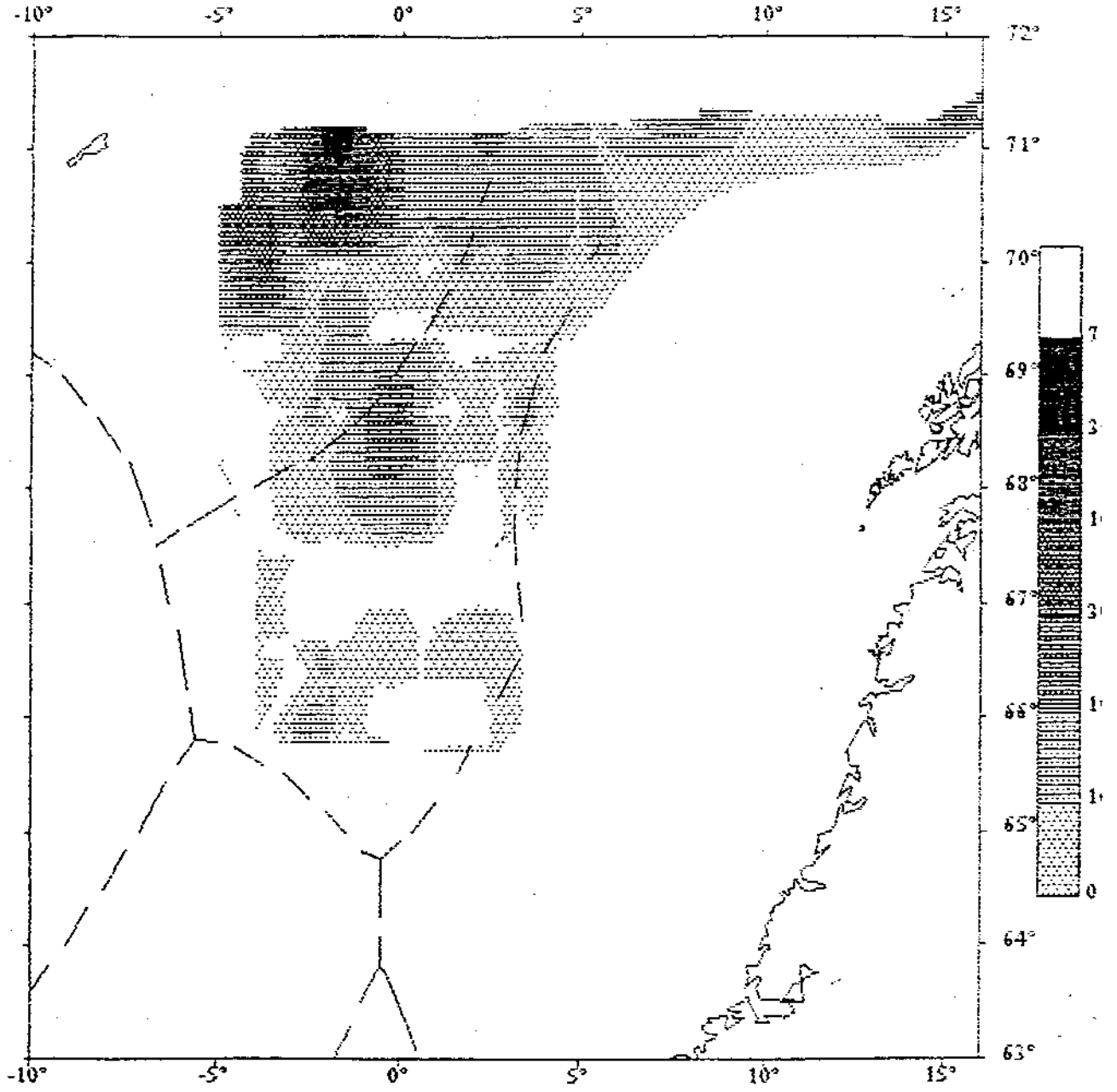


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Fig. Distribution of Herring in the Norwegian Sea in the Norwegian Sea in July 1998, Sa refer to integrator values.

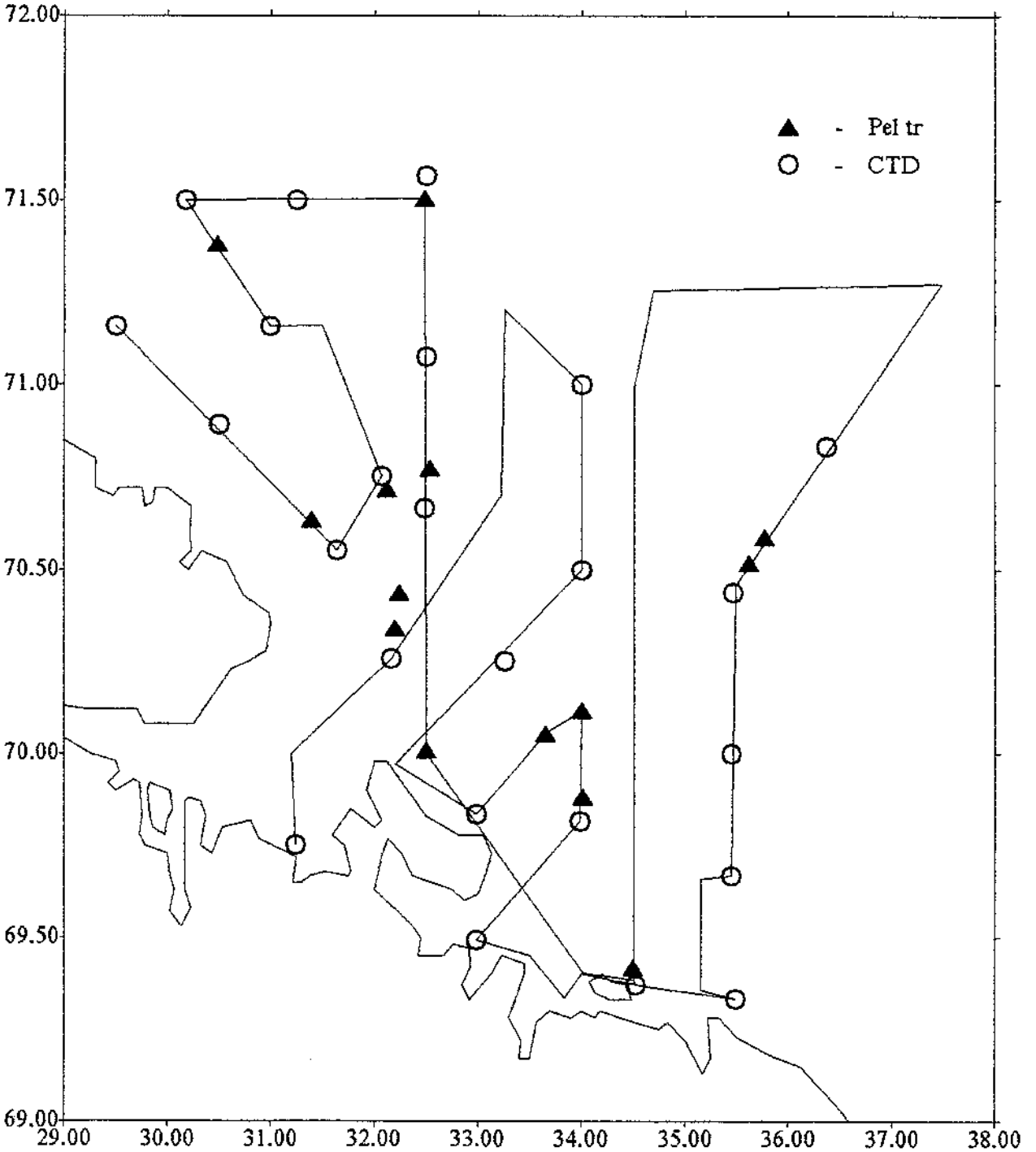

Fig. 26 Cruise track with fishing and CTD stations, R/V "F. Nansen" 20.05.-30.05.1998

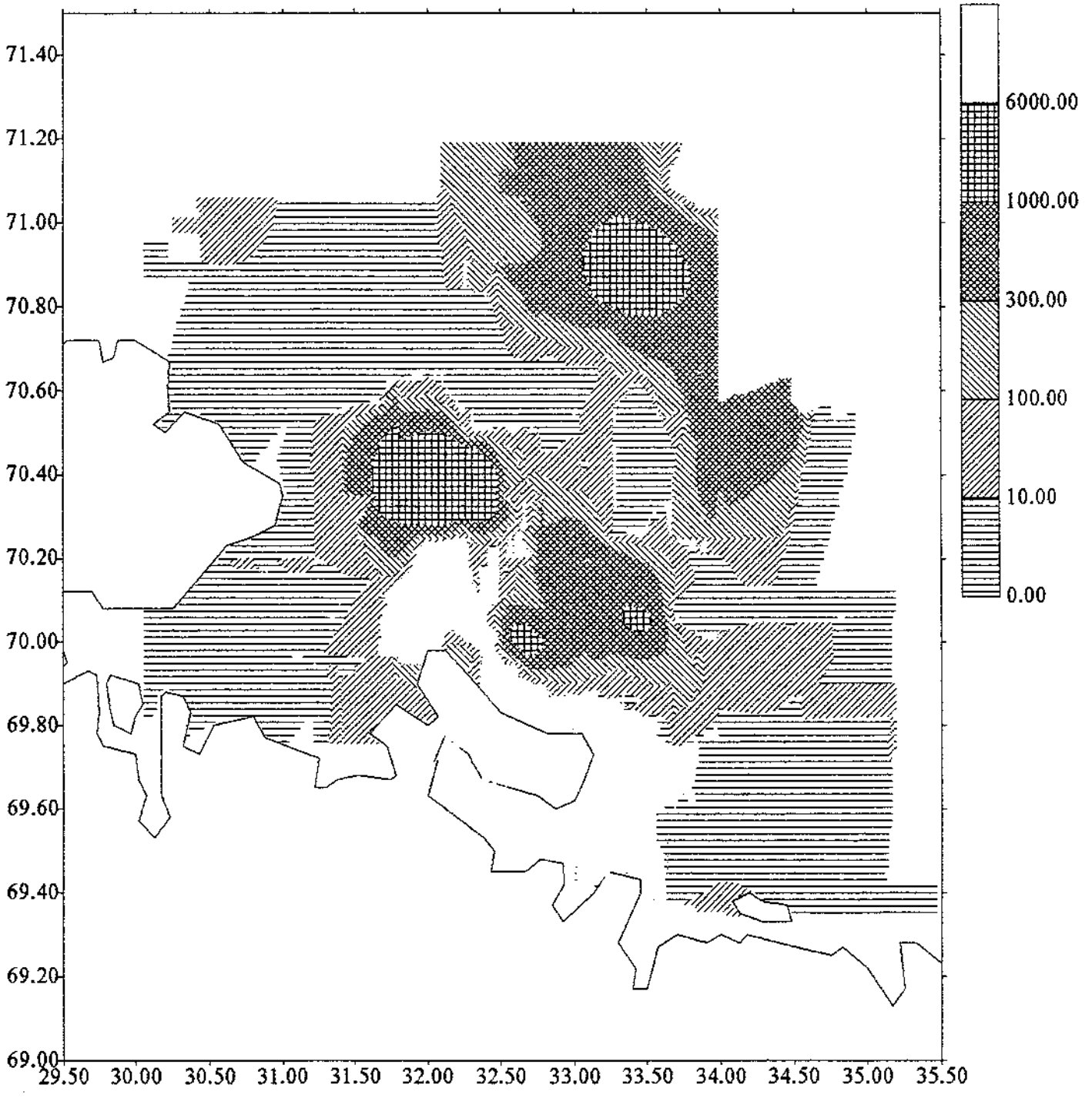

Fig. 27 Distribution of herring in the Barents Sea, map of Sa - values.

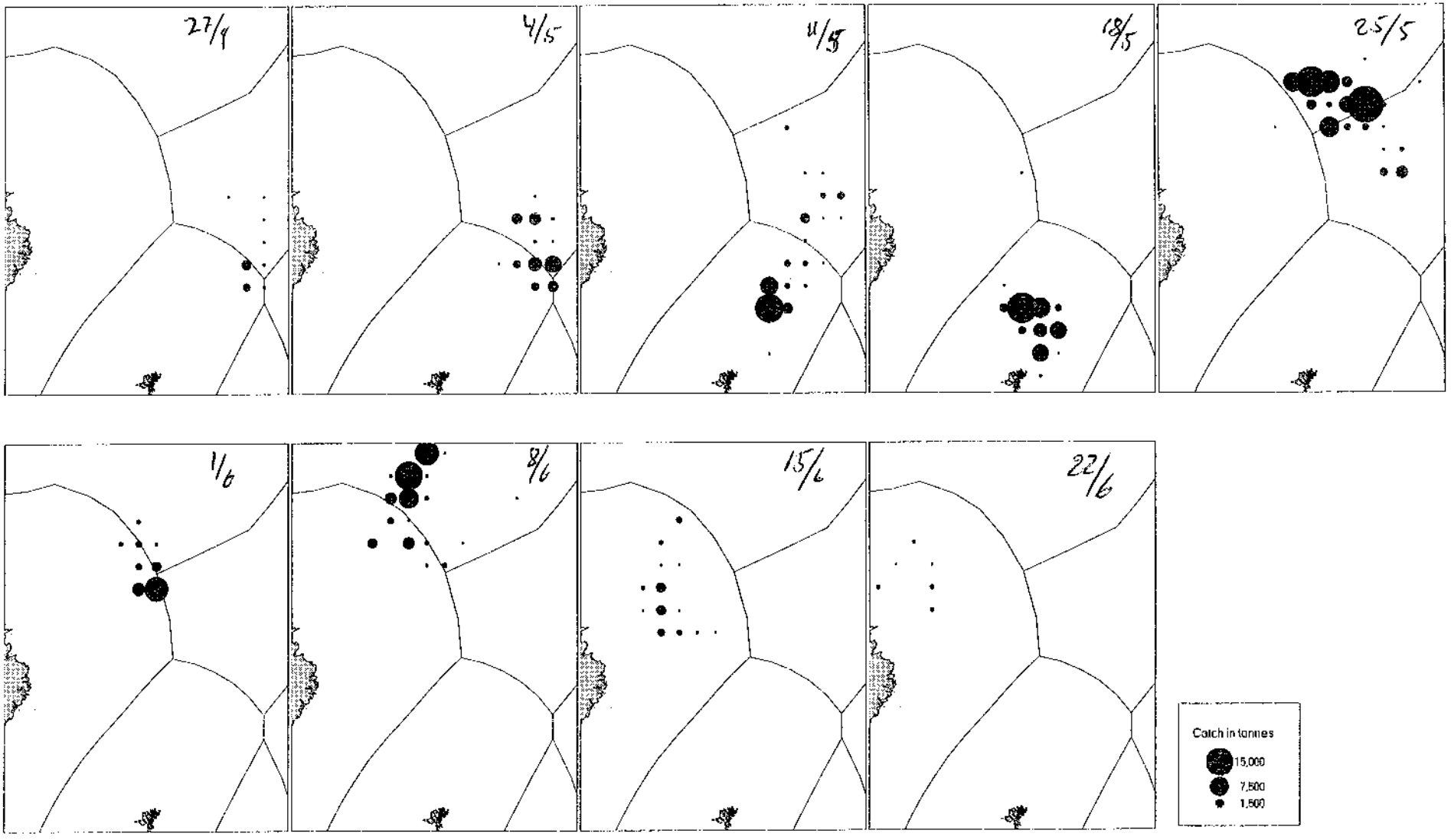

Figure 28 Weekly catches of herring by Icelandic and Faroese vessels during May-June 1998. Each figure corresponds to one week, starting in week no. 18 (27/4-3/5 1998).

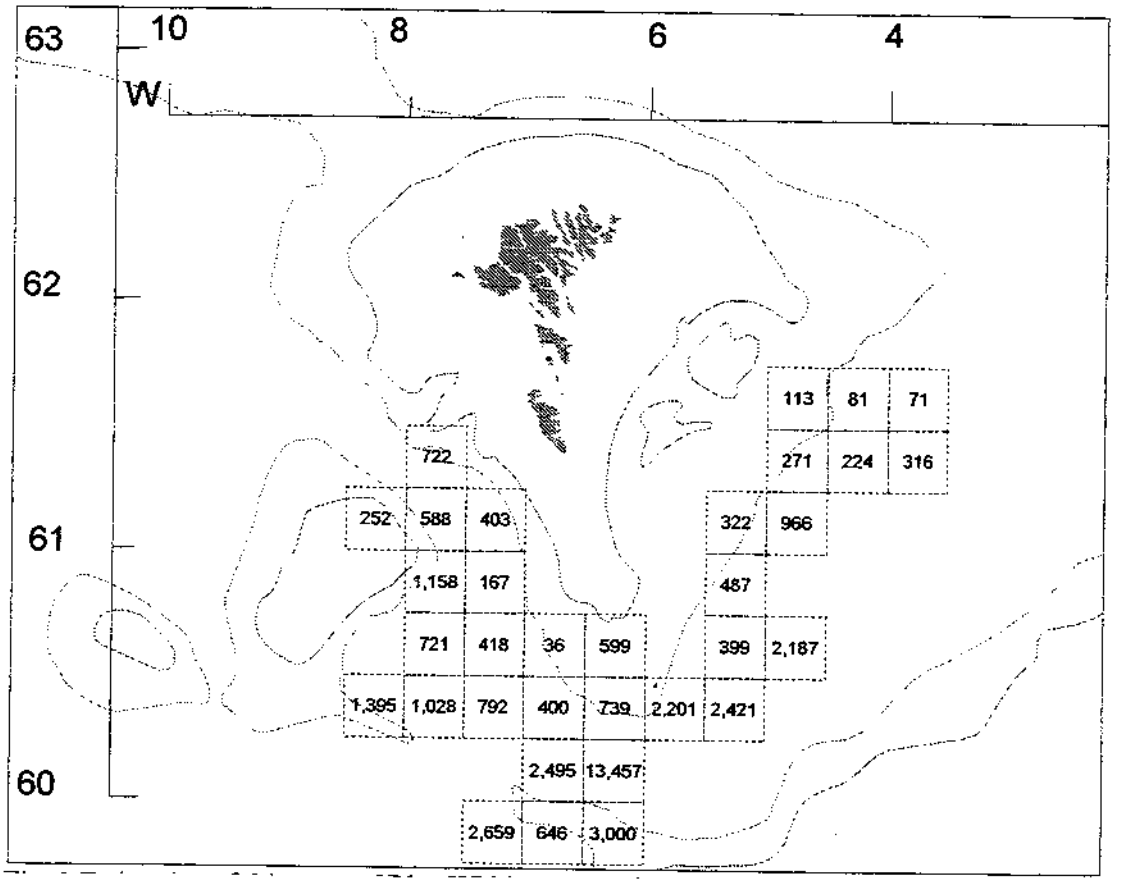

Figure 29. Blue Whiting biomass by square. Measured 2-9/5, 1998, by R/V Magnus Heinason.

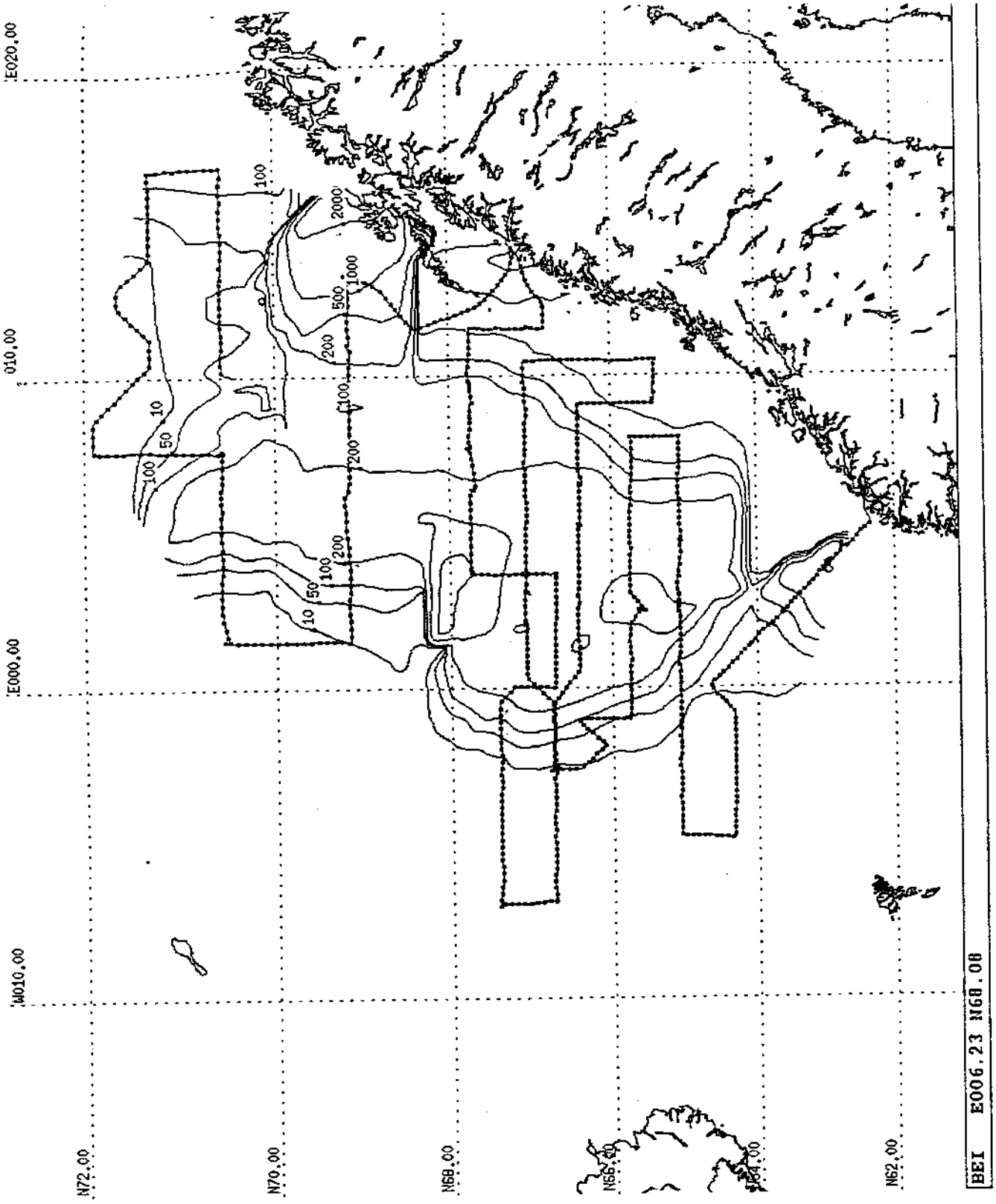

Figure30,Relative distribution of blue whiting represented by isolines of smoothed Sa values. Survey tracks indicated..

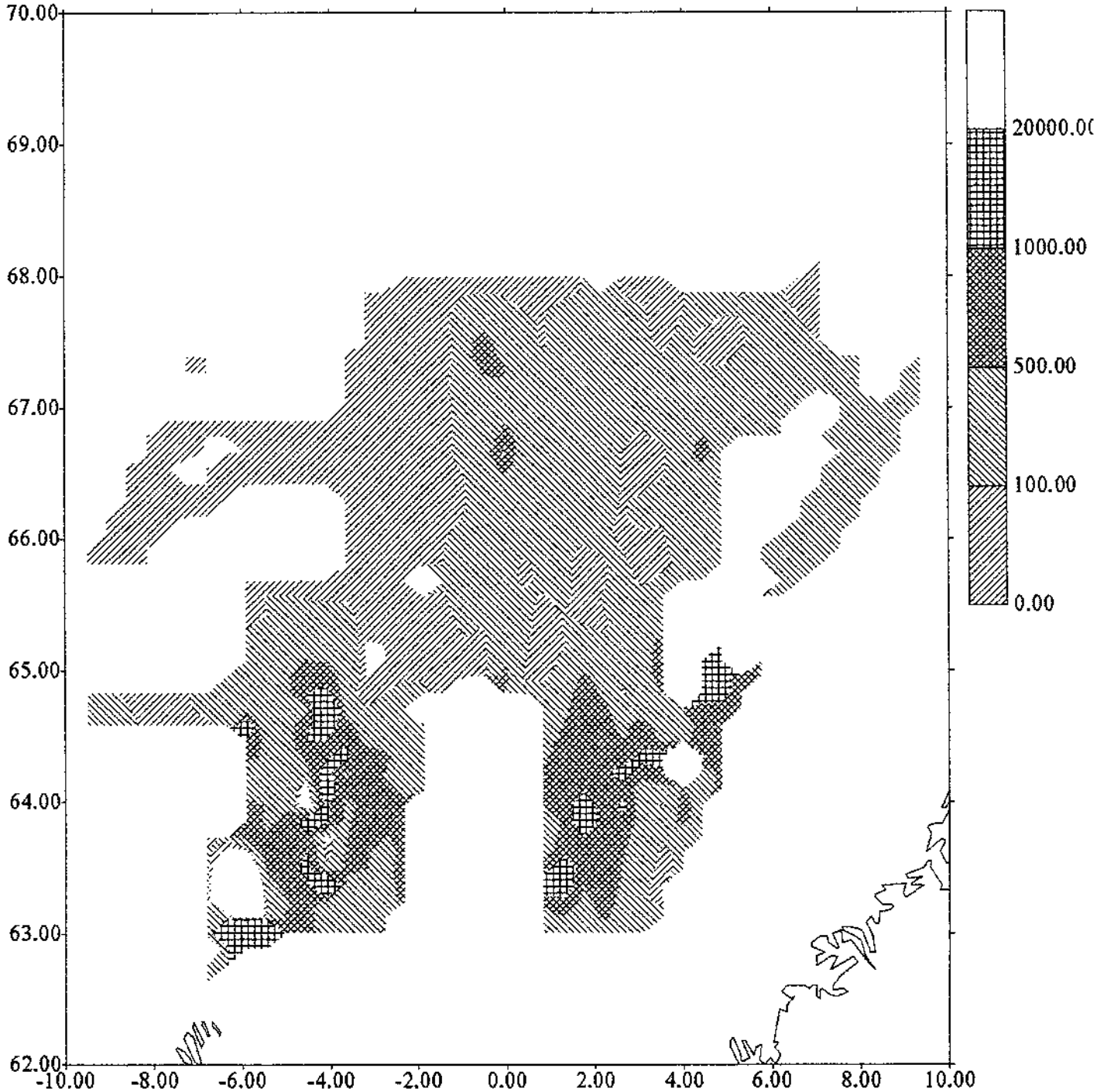

Fig.31 Distribution of Blue Whiting in the Norwegian Sea, map of Sa - values

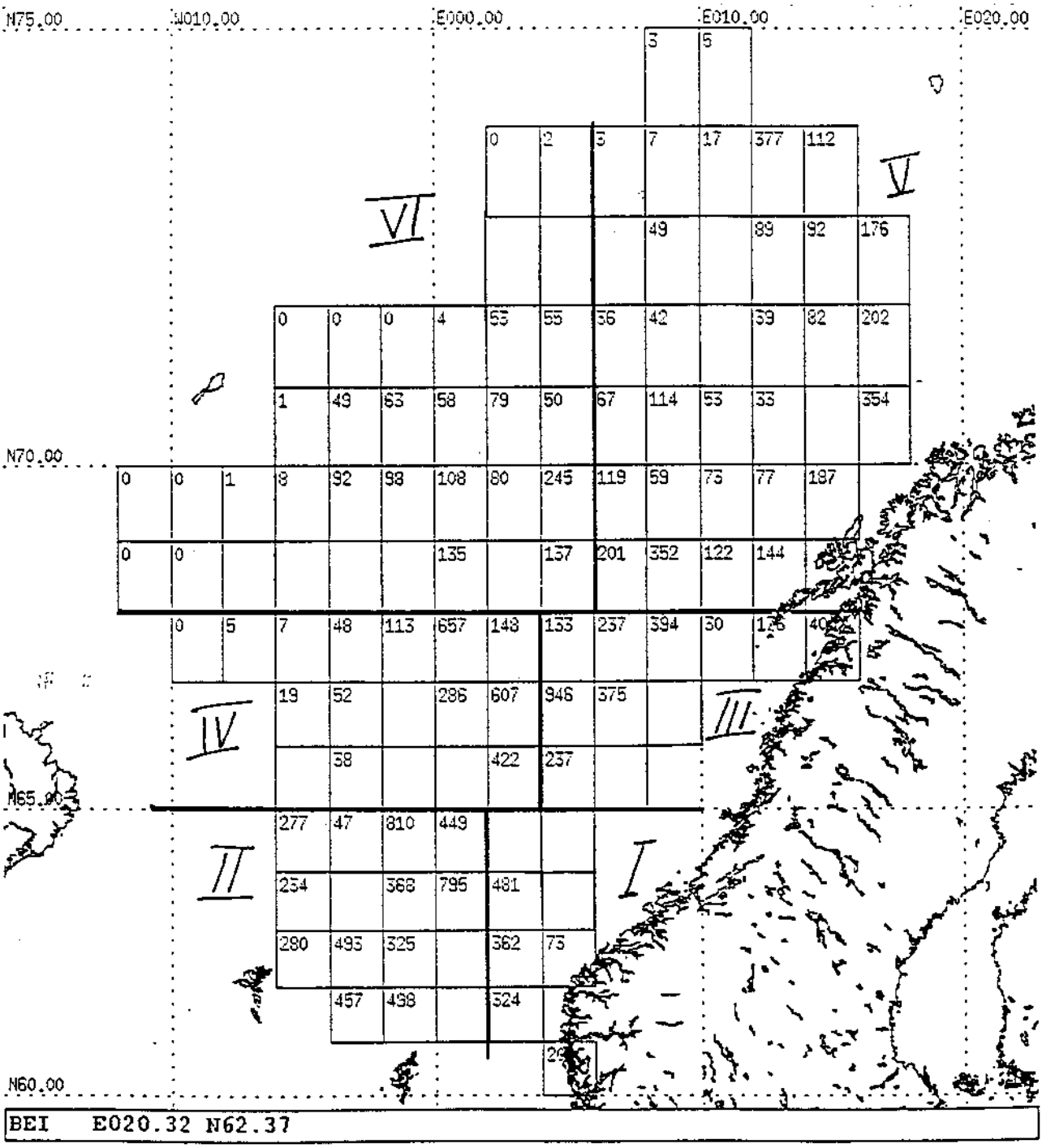

Figure 32. S_A-values for blue whiting, July 1998.

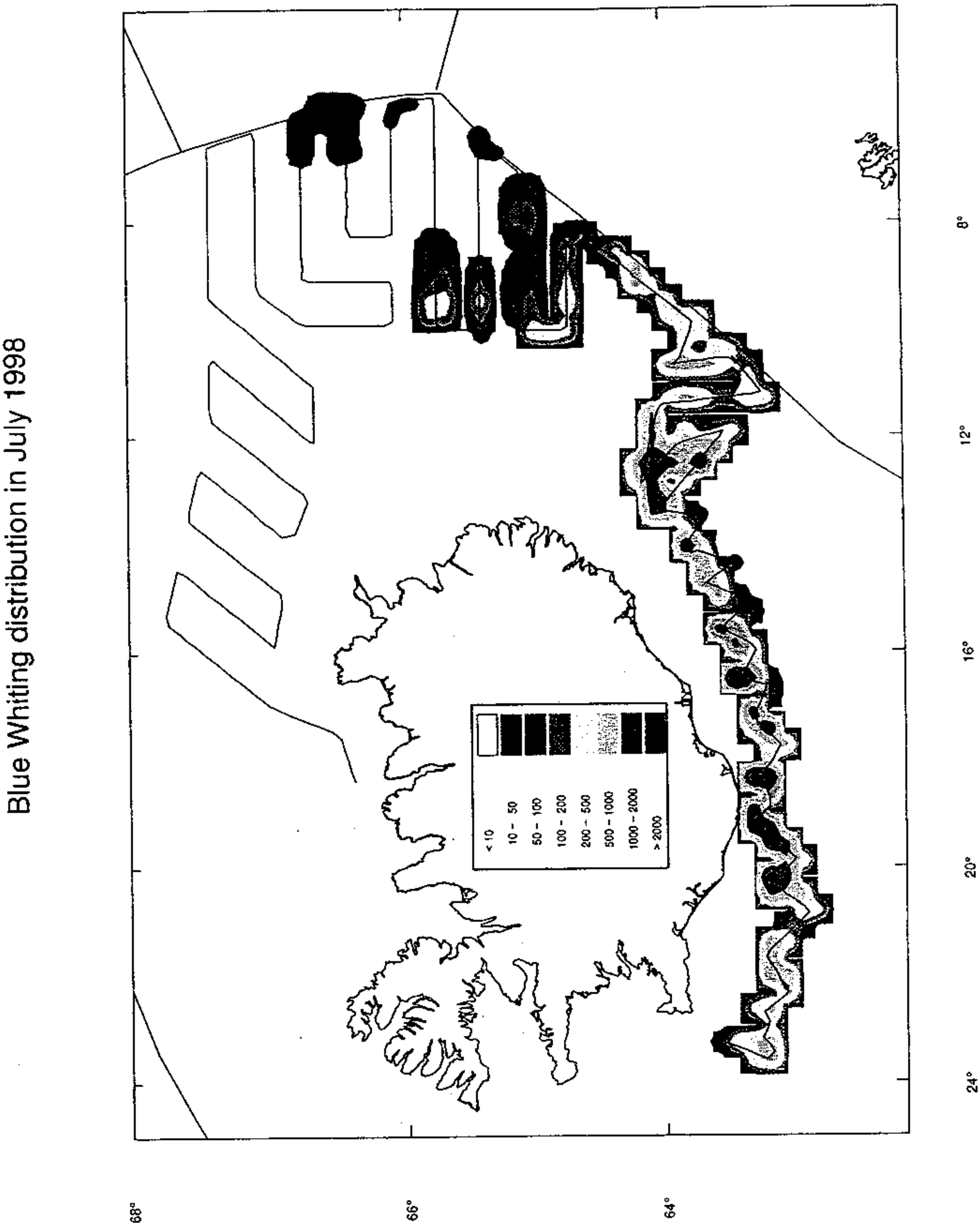

Figure 33. Blue Whiting distribution as observed by *Árni Fridriksson* during 17/7-26/7, 1998.

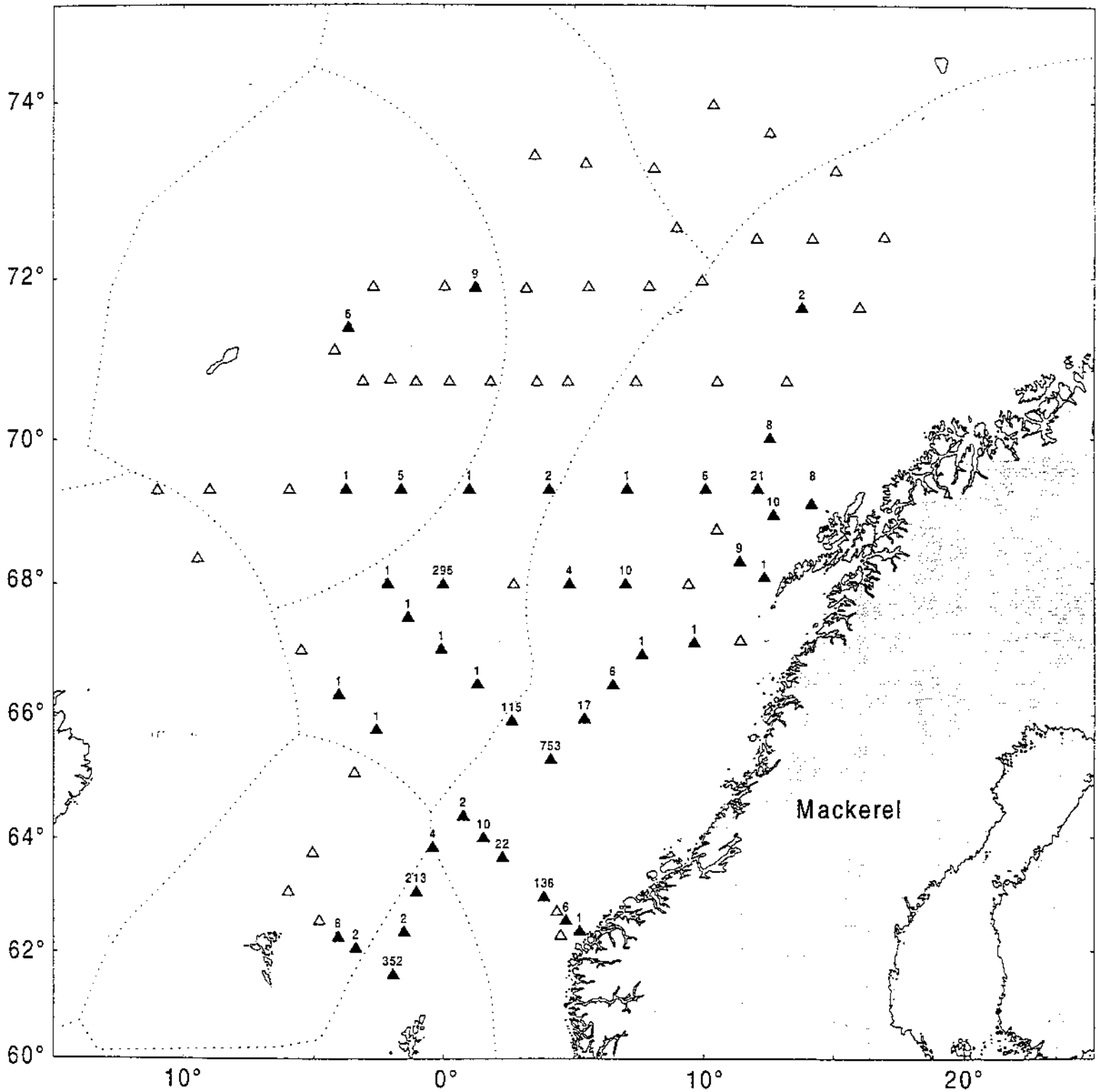

Figure 34 Catch of mackerel in surface hauls, July 1998. Nos. per ½ hour trawling.

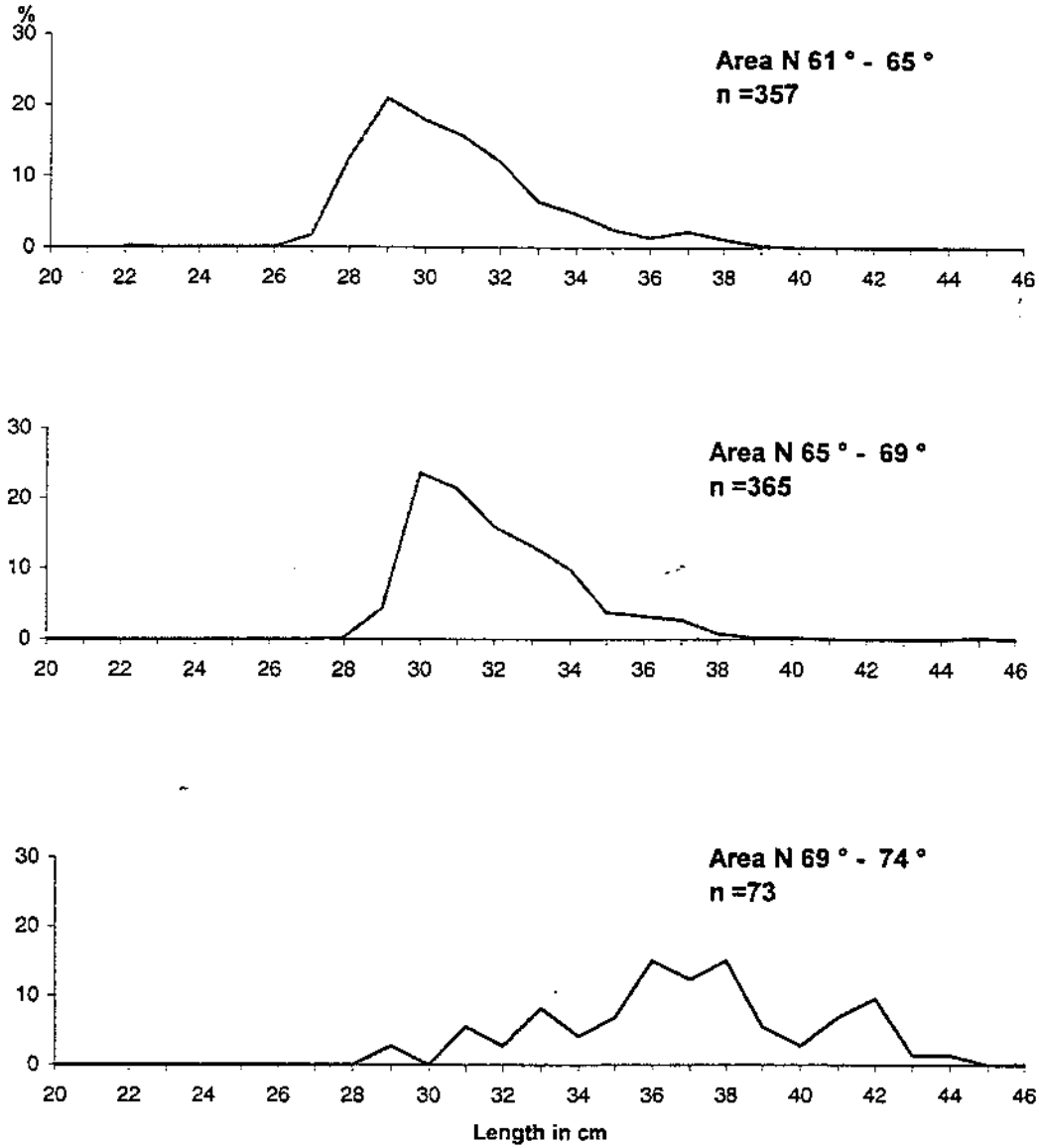

Figure 35. Length distribution of mackerel. Norwegian Sea, July 1998.

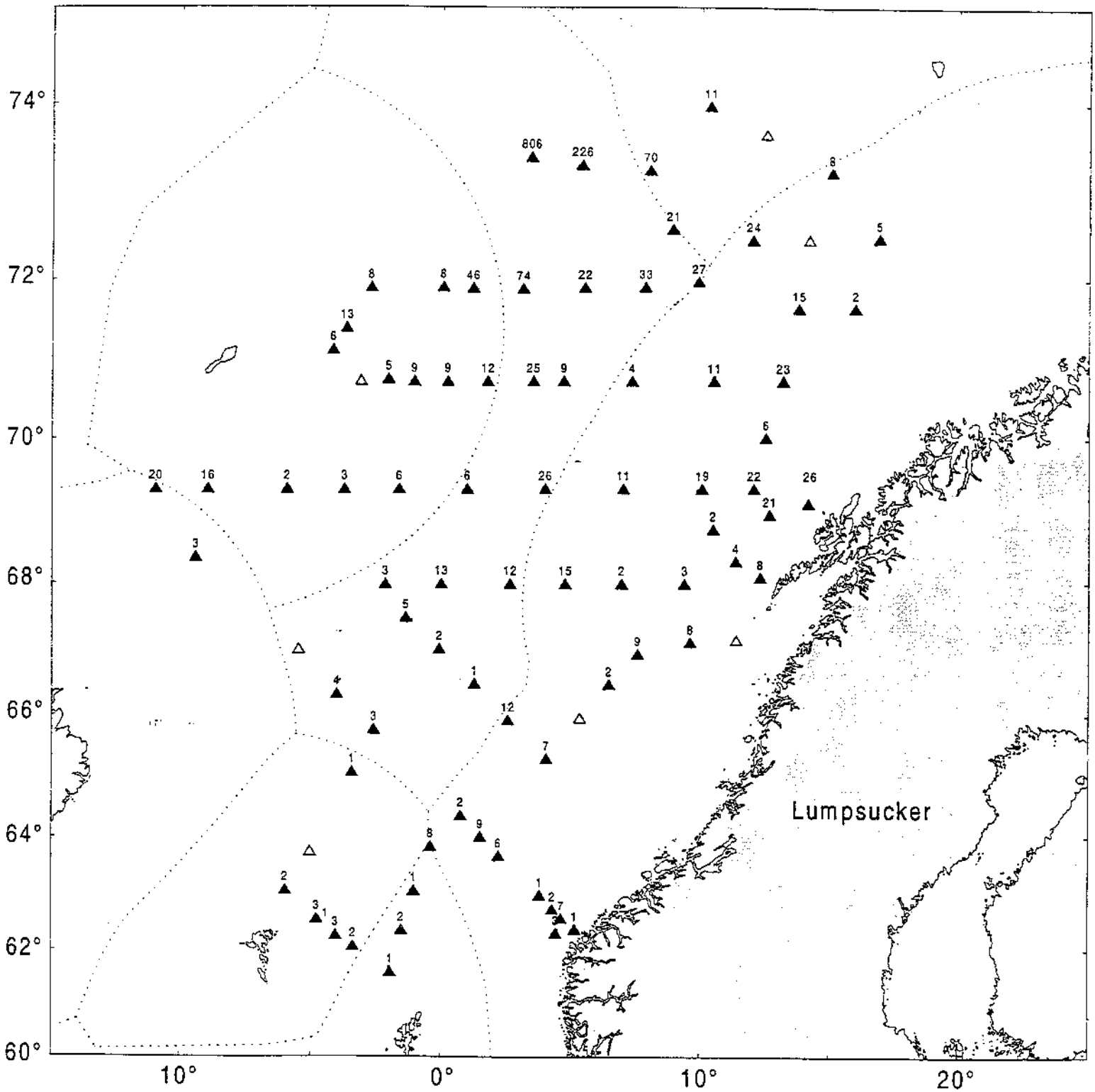

Figure 36. Catch of lumpsucker in surface hauls, July 1998. Nos. per ½ hour trawling.

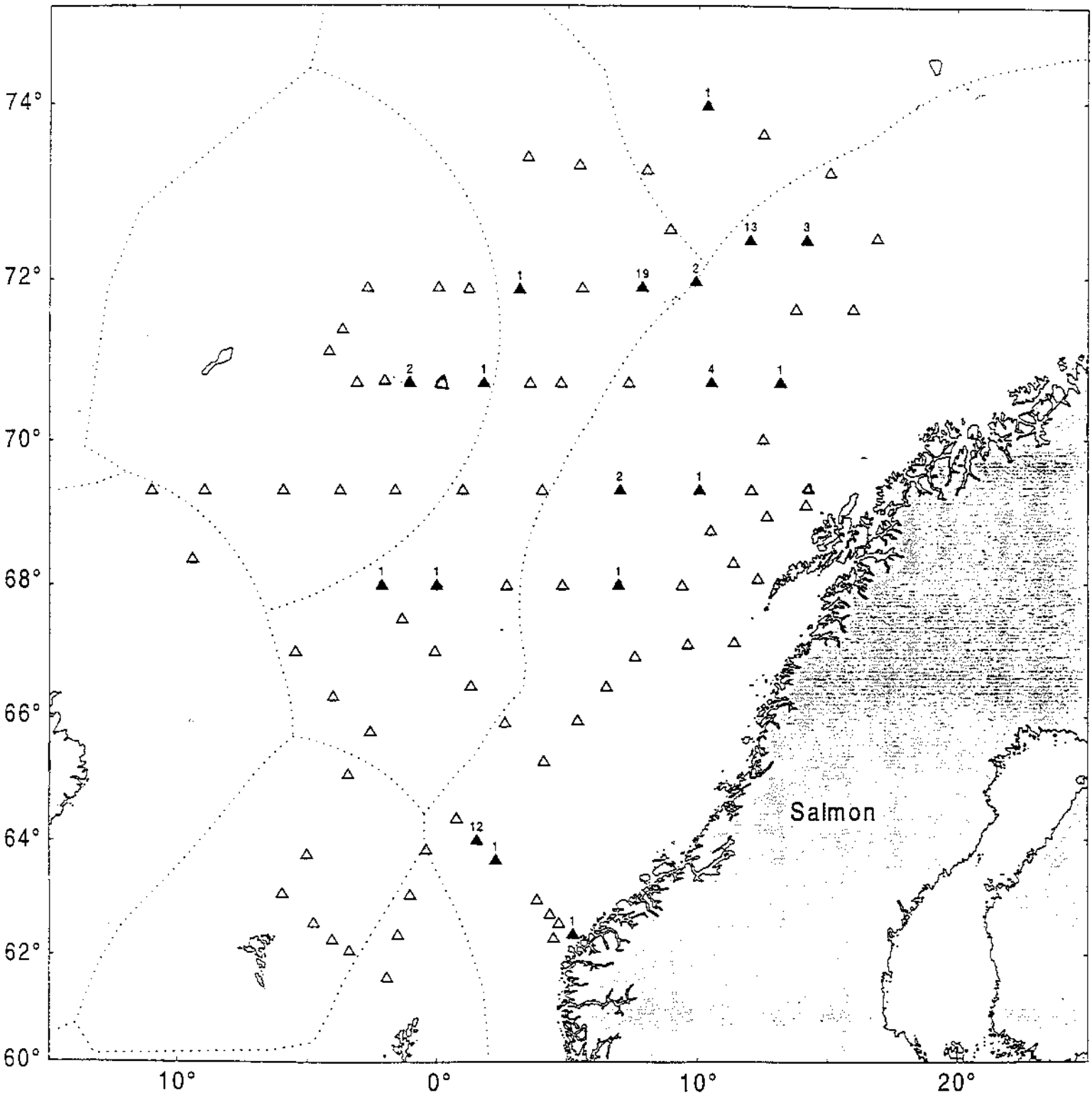

Figure 37 Catch of salmon (smolt) in surface hauls, July 1998. Nos. per ½ hour trawling.

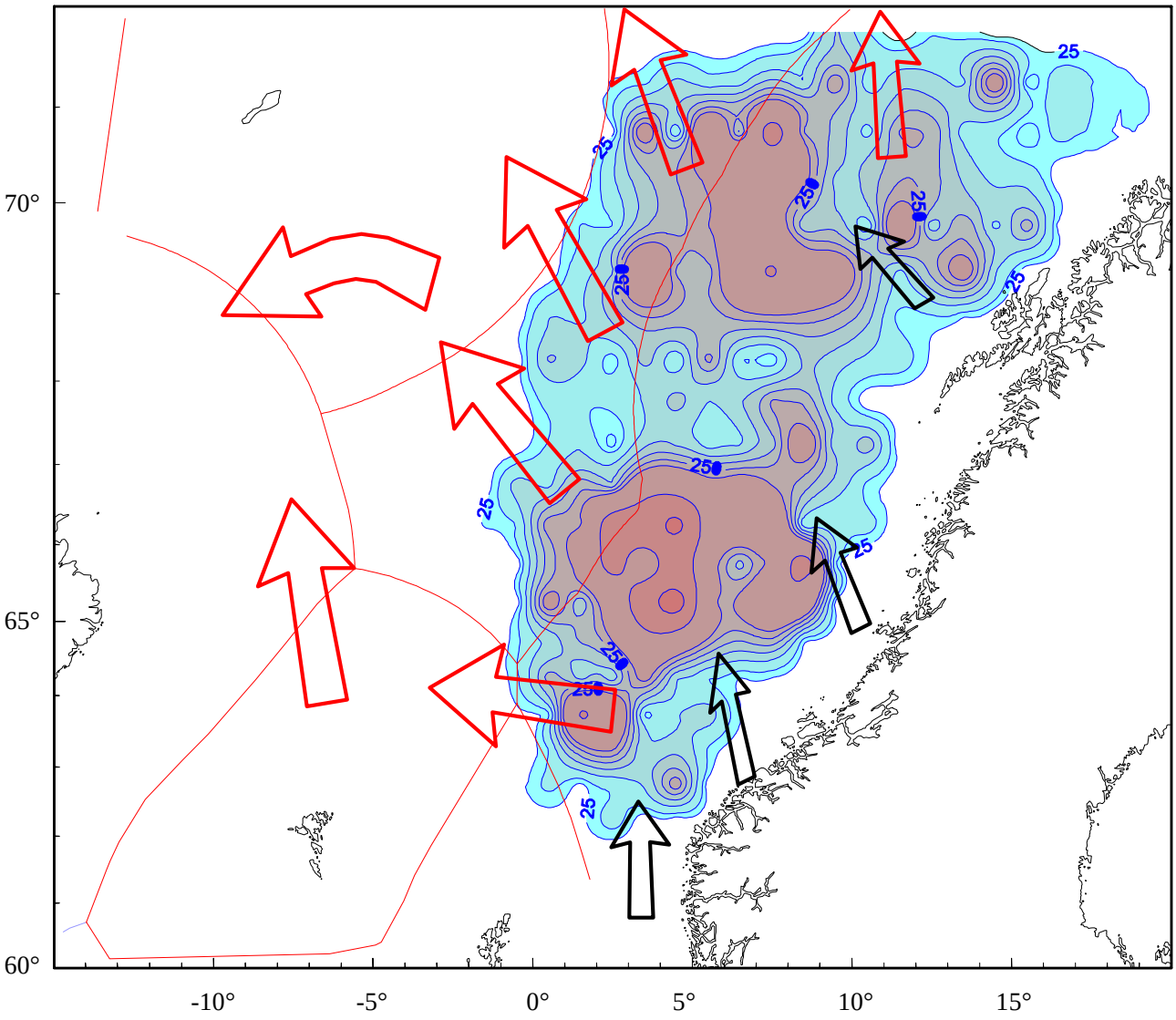

Figure 38. Distribution of Norwegian spring spawning herring as measured by R/V G.O Sars and R/V Argos in April-May 1998. Complete coverage of the adult stock. Small (Black in colours) arrows: anticipated migrations from March to May. Large (Red in colours) arrows: anticipated migrations from May to June. Arrow size not proportional to biomass movement.

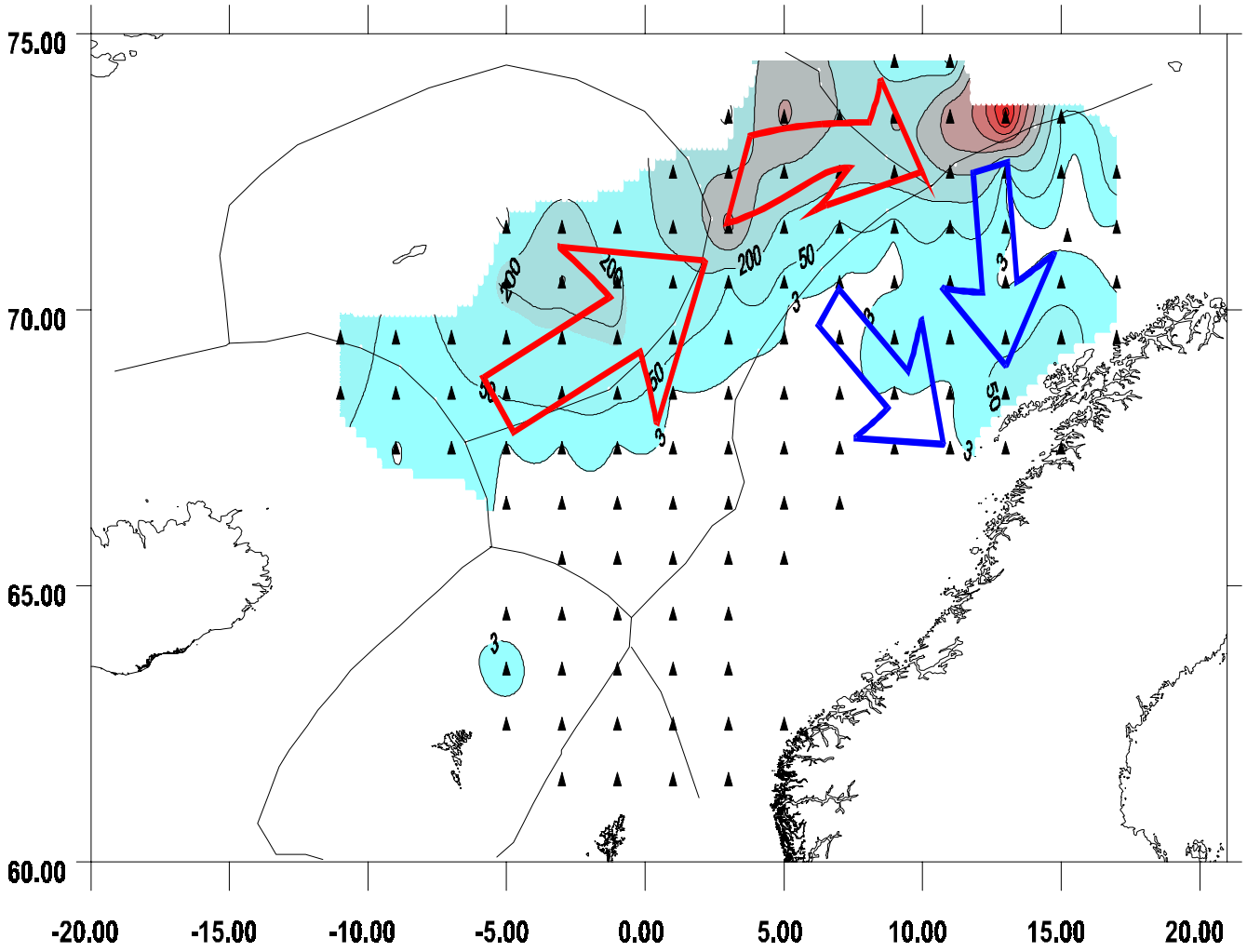

Figure 39. Distribution of Norwegian spring spawning herring as measured by R/V Johan Hjort in July 1998. Not complete coverage. Red arrows (upper, large): anticipated migrations from June to July. Blue arrows (lower, small): expected migrations into wintering area in the Vestfjord in August/September. Arrow size not proportional to biomass movement. Black triangles: Midpoint of squares used for estimating mean Sa value.