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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 1997

by

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Abstract

The distribution and migrations of Norwegian spring spawning herring in the Norwegian Sea in the spring and summer of 1997 were mapped during 11 coordinated surveys carried out by Faroese, Icelandic, Norwegian, Russian and EU research vessels.

After spawning on the banks off the Norwegian coast in February-March, the spent herring migrated out into the Norwegian Sea, and were recorded in international waters in April. In May, the younger part of the spawning stock was distributed in small schools or scattered layers at 25 - 100 m depth over wide areas in the central Norwegian Sea. Older and larger herring formed large schools, generally at 250 - 400 m depth, near the cold front along the eastern border of the Icelandic EEZ (exclusive economic zone). The total abundance of herring in the Norwegian Sea was estimated to be about 45 billion individuals or about 9 million tonnes in May.

Introduction

In the early 1990s, after nearly 25 years of absence, the Norwegian spring-spawning herring 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 1996 exceeded 1.2 million tonnes. The Norwegian spring-spawning herring is now a typical straddling and highly migratory stock. The migration route crosses the borders of several national EEZs (exclusive economic zones) and international waters.

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 1). 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 Bergen in February 1997 (Anon, 1997a), and a series of 11 surveys to be carried out by Faroese, Icelandic, Norwegian, Russian, and EU research vessels in spring and summer 1996 were coordinated (Table 2). 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 1). 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 11 surveys were conducted to map the distribution and migrations of herring and to monitor environmental conditions of the Norwegian Sea in spring and summer 1997 (Table 2). 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.

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 50-0 m by standard WP-2 net with a 180 µm mesh (*Arni Fridriksson & Magnus Heinason*) 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 Djedy 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 (Foote et al. 1991). 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° of latitude by 1° of longitude. For each statistical square, the unit area density of herring ($ñ_A$) in number per square nautical mile (N $n.mile^{-2}$) was calculated using the standard equations, $\rho_A = s_A \cdot 1.23 \cdot 10^6 \cdot L^{-2}$ (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.

Results

Herring distribution in the Norwegian Sea

March

Due to bad weather conditions the coverage of the spawning ground this year was incomplete. Despite this, it was clear that the herring spawned on the same grounds as 1996, but with some extension of the spawning areas to the south. Based on acoustic registrations and the distribution of herring larvae (Anon. 1997b) it was obvious that significant amounts of herring had returned to traditional spawning grounds south of 59° N (Karmøy-Siragrunnen). This change probably reflects the increasing spawning stock biomass in 1997.

The first survey included in the present investigation was carried out on the *Walter Herwig* during the period 21/3-7/4 and covered the areas from 62° to 69° N and from the coast out to approx. 3° E (Fig. 1). The western zero line was not found during this survey, and herring may have been present further west in this period (Fig. 2).

April

The areas from 62° N to 68° N, 4° W to 4° E was mapped by the *G.O. Sars* (Fig. 3) during the period from 6/4 to 19/4. The herring had now moved north-eastwards away from the Norwegian coast and approached the cold East Icelandic Current (Fig. 4). Due to the bad weather conditions experienced, the area covered was smaller than last year and the 0-line could not be drawn in either direction.

During the day herring was observed in schools of varying sizes at depths of 300-400 meters, while during the night the herring ascended to the surface.

May

Horizontal distribution

The main survey effort in 1997 was carried out in May when four vessels from the EU, the Faroes, Iceland and Norway covered the Norwegian Sea from 62° 15' N to 71° 15'N and 9° W to the Norwegian coast. (Fig. 5)

Herring were observed throughout most of the surveyed area, and the zero line could be drawn in all areas except in the NE part where concentrations of adolescent herring stretched into the Barents Sea (Fig. 6). No herring was observed within a belt of approx. 100 nautical miles width along the Norwegian coast up to about 68° N. The most southerly observations were at approx. 62° 30'N, while the most westerly observations were at approx. 7° W. Only small traces of herring were observed in the southeasternmost part of the Jan Mayen zone at this time of year.

The highest concentrations of herring were observed in the areas from about 66° N to 68° N, 4° W to approx. 0°. Local high concentrations were also observed in the areas from 64 to 65° N, 3° W to 0°, and 64° 30'N to 65°30' N, 6°W to 4°W.

In general the mean lengths increased westwards (Fig. 7). The mean length close to the Norwegian coast had increased significantly from last year, reflecting individual growth in the strong 1992 year class.

Vertical distribution.

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

1. Schools of varying sizes and at varying depths generally between 150-450 m depths (Fig. 8)
2. A thin undulating layer mainly in the upper 30-100 m (Fig. 8).
3. A scattering layer at the surface down to 20-30 m (Fig. 9).

The undulating layer at intermediate depths was typical in the eastern part of the distribution area where the herring distribution was more uniform and consisted of younger herring compared to the western and southwestern area. Schools were found more frequently in the western and southwestern part of the distribution area where the abundance was highest. The surface scattering layer, observed in the southwestern area of the distribution area of herring, i.e. Faroese area and in the south-western area of the international zone is only partly recorded during the surveys, as the recordings started at 10 m distance from the transducer for the Icelandic survey and 7.5 m below the transducer for the Faroese vessel, both of which covered this area in May. Therefore any abundance estimates from the southwestern area of the herring distribution are likely to be underestimates. Surface trawl catches revealed this to be herring of 30 cm mean length of mainly the 1991 and 1992 year classes.

June

The *Atlantida* covered the central areas of the Norwegian Sea from 68° N to 63° N and 7° W to 6°E during the period 30/5-13/6, and the *Arni Fridriksson* covered the area from 64°N to 68° 30' and 8° W to 0° during the period 3/6 to 14/6. (Fig. 10)

As compared to the distribution observed in May (Fig. 11) the main herring biomass had shifted to the northeast, resulting in lower concentrations in Faroese and EU EEZs and the southern part of the Norwegian EEZ.

In addition, 6 small catches, consisting of large herring (mean length 33-35.9 cm) were taken in 6 surface hauls in a area between about 6°W and 7°W, from 65°N and 68°N, indicating the presence of very scattered herring in the slowly warming surface layer. No echo recordings of herring were registered in this area.

June-July

The *Johan Hjort* covered the Norwegian Sea from 63° N up to 73°30'N during the period 19/6-16/7. The survey was primarily a plankton survey with large spacing between the transects. Acoustic registrations from the survey were not available to the working group. However, the trawl catches made during the survey give some indications of the distribution of the herring during this period.

Significant catches were made in the Jan Mayen zone and up to 73° 30'N indicating the presence of the herring in the areas close to the subarctic front towards the Mohns Ridge area during late June - early July (Fig. 12). Large catches of herring were also made off the Lofoten/Vesterålen area, from approx. 65°N to 71°N, 6°E to 15°E.

July/August

The *G.O.Sars* 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 20/7-17/8.

Herring were found in the survey transects from 70°N to 74°N (Fig. 14). It was possible to conclude that the bulk of the herring had moved north of 70° N. 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

Atlantida carried out a survey in the Barents Sea from 24° E to 38° E along the Murman and Norwegian coast during the period 13/5 - 29/5 to map the distribution and produce an abundance estimate of young herring in this area. Young herring were observed along the coastline at a distance of 5-30 nautical miles from 20° E to 35° E (Fig. 15).

Juveniles from age group 1 occurred in the narrow coastal zone, eastward, from 33°30' E to 38°00' E, in the 0-20 m layer. Maximum densities were recorded in the Varangerfjord, the outlet from the Kola Bay 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.

Hydrographic conditions

The hydrographic situation, as reflected by the temperature distribution in the spring-summer 1997, is shown Figures 16 and 17. These are based on the coordinated survey in May.

A brief outline of temperature conditions in the survey area, relative to recent years, is as follows:

Once again the cold East Icelandic Current had increased its southward extension towards the Faroes after the warming trend in 1996 as compared to the extremely cold year of 1995. This is reflected both in low temperatures and salinities, recorded within this water mass. Thus, the frontal zone of the East Icelandic Current, with temperatures below 2°C in the upper layers in May-June, reached south to at least 64°N north of the Faroes, as compared to 65°N in 1996. However, as in 1996 the cold front approximately followed longitude 6°W north to 69°N.

In Faroese waters, the temperatures in the upper layers to the north and northeast of the islands were 5-6°C as compared to 7-9°C in 1996.

In the central Norwegian Sea temperatures were about 1°C lower, and in the Barents Sea about 2°C lower than in 1996.

In spite of the lower temperatures, generally observed in the near-surface layers of the Norwegian Sea in spring, a relatively strong seasonal warming of the surface layer occurred during the summer of 1997.

In deeper layers (200-500 m), of the central and eastern parts of the Norwegian Sea, the N-S boundary between the cold and warm regions was located around the zero meridian, with an intrusion of cold water (e.g. <1°C at 200 m, Fig. 17) at about 65°N to 2°E. Off the Faroes, temperatures in the deeper layers were well below those of 1996, but farther east in the Norwegian Sea the temperatures seem to be similar in both years.

In summary, the temperatures of the upper layers in the Norwegian Sea, including the Barents Sea and the waters of the East Icelandic Current, were low in 1997 and in fact up to 2°C lower than in 1996. The same is true for the deeper layers north of the Faroes, but farther east in the Norwegian Sea temperatures seem to be similar to those of 1996 as far as can be judged from the available data.

Zooplankton distribution

Figure 18 shows the distribution of zooplankton at 0-50 m (mg dryweight/m^3) in May 1997, based on data from *G.O. Sars*, *Magnus Heinason* and *Arni Fridriksson*. In general, the highest zooplankton values (>100 mg dry wt/m^3) were observed in the northwestern part of the survey area, in a belt running in a NW-SE direction from roughly 67°N, 4-12°W to approx. 64°N, 2°E-6°W, and southwest of Lofoten west to approx. 8°W. Between these regions, i.e. in the central part of the survey area, the biomass of zooplankton was much lower (<100 mg dry wt/m^3). Low biomass (<100 mg dry wt/m^3) was also observed in the southwestern and southernmost parts of the survey area, and on the nearshore stations east of Iceland.

Calanus finmarchicus was the dominant species throughout most of the survey area. However, in the western and northwestern parts of the region (west of approx. 6°W and north of approx. 65°N) high concentrations of *Calanus hyperboreus* and *M. longa* were observed. This distribution pattern coincides approximately with the distribution of the different water masses in the area.

Figure 20 shows the results of the Russian investigations undertaken during the first half of June. The results are presented as wet weight. However, a conversion of those data to dry weight, using appropriate factors, shows that the range in biomass during the first half of June is similar to that observed during May.

Acoustic abundance estimates May 1997

Norwegian estimate, Norwegian Sea in May 1997

Based on the acoustic registrations, the scrutinized acoustic integrator values (Fig. 1) and the analysed fish samples, an age structured estimate of the herring in the surveyed area was made (Table 1). In squares not covered by the "G.O.Sars", S_A values were interpolated from the nearest squares. A simple algorithm, weighting the four nearest neighbouring squares by 2, while the next second nearest four were given a weight of 1, was applied. It should be stressed that the estimate is based on the data from the Norwegian survey.

Combined estimate, Norwegian Sea in May 1997

The combined estimate of herring in the Norwegian Sea in May 1997 from all participating vessels is presented as a total number and weight of herring (Table 3). Because age-length keys were not available in time for the meeting it was not possible to provide an age structured abundance estimate.

Russian estimate, Barents Sea in May 1997

The total abundance of herring within the area surveyed was estimated at 4,087 million fish, the biomass at 84,700 tonnes, of which 3,396 million fish (81.1%) belonged to age group 1.

In May small (65,000 tonnes) concentrations of the older age groups were found along the coast, at the distance of 5-30 miles from the coastal line (age 4 - 36.0%,age 3 - 28.5%, age 1 - 18.4%, age 2 - 10.7%, age 5 - 6.3%).

Russian estimate, Norwegian Sea June 1997

The survey only covered part of the total distribution of the herring, and the shallow distribution, partly above the transducer depth, caused additional problems. The total estimate was 2.124 million tonnes.

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. 21). North of 62° N young blue whiting of the immature year classes of 1995 and 1996 dominated in the trawl catches.

The distribution of blue whiting was more easterly than that of the herring, and in the areas north of the Faroes from about 63° N to 70° N the western boundary of the blue whiting distribution was at about 2°W. The young blue whiting were distributed outside the coastal shelf, and no blue whiting were observed in areas where the coastal shelf is broad off Norway.

The local high concentration of blue whiting at approx. 70° N and 16° E most probably represents a northern spawning component since mature individuals were caught in this area.

June

Blue Whiting were distributed in the eastern part of the survey area with the main concentrations south of 65° N and east of 1° W (Fig. 22). They were observed mainly as scattered layers at different depth from 150 m to 300 m. The 1995 year-class was dominant in most catches.

July-August

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 part of the surveyed area (Fig. 23). The calculated abundance estimate was 3.89 million tonnes, approximately 85% of which were from the 1995 and 1996 year classes.

Mackerel

During the *G.O Sars* survey in July-August mackerel were observed in the southern parts of the areas covered, approximately from 61°30' N to about 69°30' N. The largest trawl catches were made around 64° N. The mean lengths and ages increased northwards.

Horse mackerel

During the July-August survey by *G.O.Sars* the distribution of horse mackerel corresponded well with the distribution of mackerel, but with the northernmost catches somewhat more to the south than those of mackerel.

Lumpsucker

Lumpsuckers were caught during all the surveys carried out in 1997. This species is widely distributed in the upper layers of the Norwegian Sea, and appears to be the most ubiquitous species in surface trawl catches (1 - 26 specimens per haul).

Salmon

Only 2 specimens of postsmolt salmon were caught by *G.O. Sars* during July and August. One grilse was caught by *Argos* and two by *G.O. Sars* during the May survey.

Discussion

Comparison of herring distributions between 1996 and 1997

April

Survey coverage was only partial in both years, however some conclusions are possible. In both years the surveys mainly covered an area bounded by 63 - 69° N and 5° W - 5° E. In both years, the highest densities were found at 67-68° N, 1° E. In 1997, another density centre was identified at 66°N, 3°W, which was not seen in 1996. However, in 1996 this area was covered by a single N-S transect at 1° W, so it is possible that a similar concentration was missed in this year. In 1996 herring were also seen at 66° N, 6° E but not in 1997. It is possible that in 1996 the migration out from the Norwegian coast occurred farther north (around 66° N) than in 1997 (around 64° N). But due to the low coverage this conclusion should be regarded as tentative.

May

Complete survey coverage was achieved in both years, allowing more definite conclusions to be drawn. Firstly, the areas occupied by the fish are generally fairly similar in both years. The main differences were in the NW, NE and , to a lesser extent, at the southern and western edges. In the NW there was a marked extension of the population into the Jan Mayen sector (68-70° N 0-4° W) in 1996, which was not seen in 1997. This was probably due to the relationship with the water temperature at 200-400m. The main centre of density in both years was around 65° N 3° W. The area occupied by the fish was extended to the NE (70-72° N, 10-18° E) in 1997. This area was largely deserted in 1996, but in 1997 appeared to contain large numbers of young fish, probably migrating out from the Barents Sea, and/or out from the Norwegian coast. In 1996 the distribution seemed to extend farther to the south west than in

1997, closer to the Faroes (63° N in 1996, 64° N in 1997), and farther into the Icelandic sector (9°W in 1996, 7°W in 1997). Again, this may be due to interactions with the water temperature. It is possible that the extent of the distribution also reached slightly farther west between 65 and 68°N in 1996. However, this difference was small, and may be in part be due to the mapping techniques used.

However, in the NW and NE parts of the area the distribution in 1997 was quite different from that of 1996 and the change can be regarded as significant. The differences along the western and southern edges are less conclusive, and should be treated with caution. However, the extension of the distribution into Icelandic waters in 1996 is more definite.

June

As in April, coverage was only partial in June. In both years concentrations were observed in Faroese waters (64-66° N, 3-8° W). In 1996 the extension of the distribution into Jan Mayen waters seen in May persisted into June. In 1997 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. No fish were seen in international waters (66-69° N, 2° E - 4° W) in June 1996. In June 1997, reasonable quantities were found in this area. Based on trawl survey data in the Jan Mayen sector and perceptions of the migration trajectory of this stock it seems likely that there were fish in this area in 1996 also, but that these were not picked up by the surveys.

July/August

By the end of July in both 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° N and 69° N. The western limit was difficult to define but may have been again around 0°.

On 25 July a purse seiner made a catch of 150 tonnes of large herring in position, 67°40' N, 14°30' W. A further search did not reveal other schools in the immediate neighbourhood. However, capelin seiners fishing in an area about 20 nautical miles farther to the northeast a few days later found some individual herring of similar size mixed with their capelin catches.

A short acoustic survey by an Icelandic research vessel in the second week of August, covering the western part of the East Icelandic Current as well as the outer part of the Icelandic shelf from 65° N in the south to 68° N, 16° W in the north and west, did not locate any herring.

Basis for the description of the migration path in 1997

The inferred migration path of the herring in 1997 is presented in Figure 24. This figure represents a synopsis of the data collected during 1997. 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. However, there is some evidence from surveys that some of the population may have already started to migrate out into the deeper waters. By May the surveys show that the population occupies a large area of the Norwegian Sea from 62-72° N. Between these two times the migration track can only be inferred from partial survey data and from sonar recordings of school velocities. In April there are no fish left on the Norwegian coast and relatively little within 50 - 100 nautical miles. The main observations were made in the international waters in the central Norwegian Sea. Sonar tracking has shown that these fish were moving generally SW. 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 that herring, particularly from the spawning grounds around 60° N, may move more directly towards the international waters.

As the May distribution is so wide spread, it is assumed that following migration out from the coast the fish then spread out freely throughout the international waters, the northern sector of the Faroese EEZ and up into the northern Norwegian Sea. Sonar recordings indicate that schools were moving randomly during May. Based on age distributions during the survey, it would appear that the older adult fish move to a western boundary defined by the colder waters at the subarctic front. The fish are progressively younger to the east and north of this area. On the migration map some return migration from international waters is indicated in May. This was mainly made up of young fish. These may actually have migrated west and then back to the east or simply have travelled slower to the west than the older fish. It is impossible to determine what migrations are occurring in the north of the area (north of 68° N), however, it seems likely that predominantly young fish are migrating in from the Barents Sea and the Norwegian coast.

In June and July survey data is too sparse to properly infer migration paths. Sonar recordings indicate a general NE direction of school movement, and surveys indicate that there were still significant concentrations of fish in Faeroese waters as well as scattered herring in the easternmost part of the Icelandic zone. By August the bulk of the fish are found north of 68° N. In combination, these suggest that the May distribution is largely continued into June and that during this month the fish begin to move NE. By July the bulk of the herring will have left the southern end of the May distribution and was beginning to concentrate north of 66-68° N.

In August the fish were almost all found N of 68° 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 and 1997

In 1996 two distinct categories of herring migrations were observed (Anon 1996), with immature herring of the 1991 and 1992 year classes migrating far south into the Faroese, EU and International zones. This particular migration pattern was not observed in 1997, when the now maturing individuals of those two year-classes appeared to have taken up a migration pattern more like the older herring (Fig. 24).

Zooplankton and herring interactions

Comparison of the present findings on the biomass of zooplankton in the 0-50 m layer with those of previous years shows that the biomass of zooplankton recorded during May 1997 (110 mg dry wt./m^3) was much lower than observed during the same time of year in both 1995 and 1996. However, the distribution pattern of the zooplankton biomass during May is somewhat similar during these three years. Thus, the high abundance of zooplankton in the northwestern part of the survey area is a common pattern for the three years. Furthermore, the observed low in the biomass of zooplankton in the southwestern and southernmost parts of the survey area seems to be a common feature for the three years of study. In addition, during both 1996 and 1997 relatively low biomass values were observed in the central parts of the study area.

It is seen that during the first part of their migration westward across the eastern Norwegian Sea, the herring at times feed intensely in deep waters (300-450 m) on the overwintering generation of zooplankton. As the herring enter the central and western Norwegian Sea in May, they appear to search for food at shallower depths. This is reflected in the changes of their vertical distribution which by May has become shallower than in late March and April.

As described above, the zooplankton biomass was comparatively low in the central Norwegian Sea In May 1996. At the time, this was interpreted a 'vacuum cleaner effect' resulting from the previous passage of huge numbers of herring having just traversed the area. This simple explanation does not apply in 1997, since the herring sampled in the area west of the zero meridian had very little food in their stomachs. However, in both cases the developments of herring movements during the period June-August were similar, i.e. the herring migrated northwards across the western Norwegian Sea to feed in the zooplankton-rich areas near and south of the subarctic front in the northern and northeastern Norwegian Sea.

The zooplankton samples have not yet been properly analysed with regard to the species composition and age-stage structure of the dominant zooplankter, *C. finmarchicus*. At this stage it is therefore impossible to evaluate whether the observed interannual variability in zooplankton biomass during the years 1995-1997 is due to differences in the composition and/or seasonal development and migration of the zooplankton. Variations in ocean climate are likely to influence on the distribution patterns and abundance of the zooplankton and it is noted that much of the area traversed by herring in may 1997, including the central Norwegian Sea, was 1-2°C colder that in 1996. Further, one should bear in mind that besides herring there are several other planktivorous species in the area, i.e. mesopelagic fish and, at present, large numbers young of blue whiting, that will affect the biomass and abundance of the herbivorous zooplankton, which in turn is likely to affect the feeding migration pattern of the herring stock.

When interpreting the zooplankton data from the different sources one should bear in mind that the sampling gears and the methods used are not always the same. Therefore the data may not be entirely comparable. However, as discussed in the report for the previous year, this may not be a serious problem. In the future it is, however, desirable that all participating institutes use the same sampling gear. This should be inexpensive and simple to use, e.g. the WP2 net, which is currently in use by two of the participating nations (Iceland and the Faroese Isles).

Herring-temperature relationships

The temperatures of the uppermost 200 m of the waters of the Norwegian Sea and the East Icelandic Current were low in May 1997. Such a situation at that time of year effectively blocks any herring migrations to the area west of the eastern border of the East Icelandic Current at 6-7°W, at least until the surface layers have been considerably warmed by solar radiation.

In spite of somewhat milder oceanic climate in the spring of 1996 as compared to 1997, the East Icelandic Current was fairly strong and the bulk of the herring biomass did nor remain in the western Norwegian Sea for long enough to enable them to extend their feeding area to the west in 1996. The same is true for most of the stock biomass in 1997, and the available information also suggests that it largely followed a similar route to the northern and northeastern feeding grounds as observed in 1996.

However, the months of June and July 1997 were very warm in relative terms, and by early August a very strong thermocline had become established in the domain of the East Icelandic Current with temperatures of about 7°C in the uppermost 50 m water layer. It appears that some of the oldest and largest herring took advantage of this and remained to feed in the warm near-surface layer east of 8°W in the area east of Iceland in June and July. In the area between NE Iceland and Jan Mayen these herring were recorded as far west as 14°30' W at latitude 67°40' N, but appeared to have left by early August.

Future research

The total age-structured estimate of 49 billion individuals, obtained by combining the Norwegian and Russian acoustic data from the May surveys, deviates by less than 5% from the 1997 Northern Pelagic and Blue Whiting Working Group (NPBWG) assessment of the Norwegian spring spawning herring at 54 billion individuals (Anon. 1997b). Such a remarkable similarity between the acoustic estimate and the NPBWWG estimate was also the attained in 1996 (Anon. 1996a).

In May the herring were distributed over large areas in the eastern and northeastern parts of the Norwegian Sea as thin undulating scattering layer at a depth between about 25 and 100 m. Because of low spatial variability and negligible acoustic shadowing, this distribution pattern is favourable for acoustic stock assessments. Furthermore, the recordings just described were within the vertical range for which the applied TS relationship was established (Foote 1987).

The above observations, as well as those of 1996, indicate that the month of May is a favourable time of year for acoustic assessments of the Norwegian spring spawning herring. However, in the western part of the Norwegian Sea the herring tend to be distributed in large schools at 150-300 m depth, resulting in large spatial variability. This is the reason for the dense spacing west of the zero meridian, south of 67°30'N. In the area betwen 0-3°W near 65°N, the herring were also distributed in the near-surface layer, partly above transducer range (i.e. in the acoustic 'dead zone'). Naturally, such a situation results in an underestimate in the area where it occurs.

Both in 1996 and 1997 the Norwegian May estimates were obtained by surveying with a transect spacing of 60 nautical miles. This is usually regarded as too coarse a survey grid for reliable acoustic estimation. However, when combining the S_A-recordings of the other survey vessels with the Norwegian ones only minor changes were observed. While this may be coincidental for the western area, it seems that the even distribution in the eastern Norwegian Sea justifies a spacing of 60 nautical miles in the eastern part of the survey area. However, the echo recordings in that part of the survey area should be analyzed by a geostatistical method in order to determine an appropriate transect spacing there in May.

For future surveys of stock distribution and abundance in May, it is tentatively recommended that they follow an adaptive strategy, starting with coarse coverage (e.g. 60 miles) of the comparatively even distribution in the eastern areas, but a much more closer spacing (e.g. 15 miles) in the western and other areas where clusters or schools are observed.

Furthermore, in order to obtain a picture of stock movements in June-August, future surveys should be coordinated in such a way that the entire stock distribution is covered at least twice during this period.

Acknowledgements

We are grateful to the crews and scientific personnel who participated in the 10 surveys which made this report possible.

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Table 1. Organizational frame of the coordinated herring investigations in the Norwegian Sea, 1995-1997.

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)
1996	Faroe Islands, Iceland Norway, Russia, EU	11	Bergen (Anon, 1997)	Reykjavík (this report)

Table 2. Faroese, EU, Icelandic, Norwegian, Russian surveys of the Norwegian Sea in spring and summer 1996. Detailed survey tracks with fishing, hydrograpic and plankton stations are given in Anon. 1996b (FI: Faroes, I: Iceland, N: Norway, R: Russia, D: Djedy net, G: Genzen net, M: MOCNESS net, WP-2: WP-2 net, Tr. sp.: transect spacing in nautical miles, Herr. smpl: no. of herring samples, CTD: temperature/salinity zonde, st: no of stations).

Vessel	Survey area	Period	Tr.sp. (nm)	Herr. smpl.	Plankton st.	CTD st.
«Walter Herwig III»^{EU}	Norwegian coast	21.03-07.04	60	11	-	29
«G.O. Sars»^{N}	66° - 68° N, 4° W - 5° E	06.04-20.04	30	9	$52^{M + WP2}$	62
«G.O. Sars»^{N}	62° - 70° N, 3° W - 10°E	01.05-01.06	60	55	$68^{M + WP-2}$	84
«Argos»^{EU}	62° - 70° N, 3° W - 10°E	28.04-23.05	60	14	-	25
«Árni Fridriksson»^{I}	62° - 70° N, 10° W - 0°	02.05-27.05	60	18	71^{WP-2}	71
«Magnus Heinason»^{FI}	62° - 70° N, 10° W - 0°	01.05-21.05	60/30	18	123^{WP-2}	123
«Atlantida»^{R}	Kola and Finnmark coast	15.05-31.05	15	12	-	56
«Atlantida»^{R}	63° - 78° N, 7° W - 7° E	01.06-17.06	Variable	16	66	66
«Árni Fridriksson»^{I}	64° - 70°N, 13°W - 3° W	03.06-16.06	30	11	38^{WP-2}	38
«G.O. Sars»^{N}	62° - 72° N, 3° W - 13°E	19.07-17.08	60	8	$116^{M + WP2}$	122
«Johan Hjort»^{N}	62° - 74° N, 8° W - 13°E	19.06-16.07	variable	21	-	-

Table 3. Age stratified herring abundance estimates in the Norwegian Sea during May 1997. Biomass in thousand tonnes, Number in millions, L=Mean total length in cm, W=Mean weight in grammes.

Norway, May,	Age												
Norwegian Sea	3	4	5	6	7	8	9	10	11	12	13	14	Total
Biomass	140	496	3403	2866	626	482	57	23	86	134	19	810	9,141
Number	1169	3599	18867	13546	2473	1771	178	77	288	415	60	2472	44,915
L (cm)	25.3	26.7	30.0	31.8	33.8	34.8	36.2	36.4	36.5	37.2	36.5	37.4	
W (g)	120	138	180	212	253	272	317	302	299	322	311	328	
Combined estimate, May, Norwegian Sea													
Biomas													9,341
Number													45,433
Russia, May, Barents Sea													
Biomas[a)]	47	31	7										85
Number[a)]	3650	311	55										4,087

a) Age group 3 includes age 1-3.

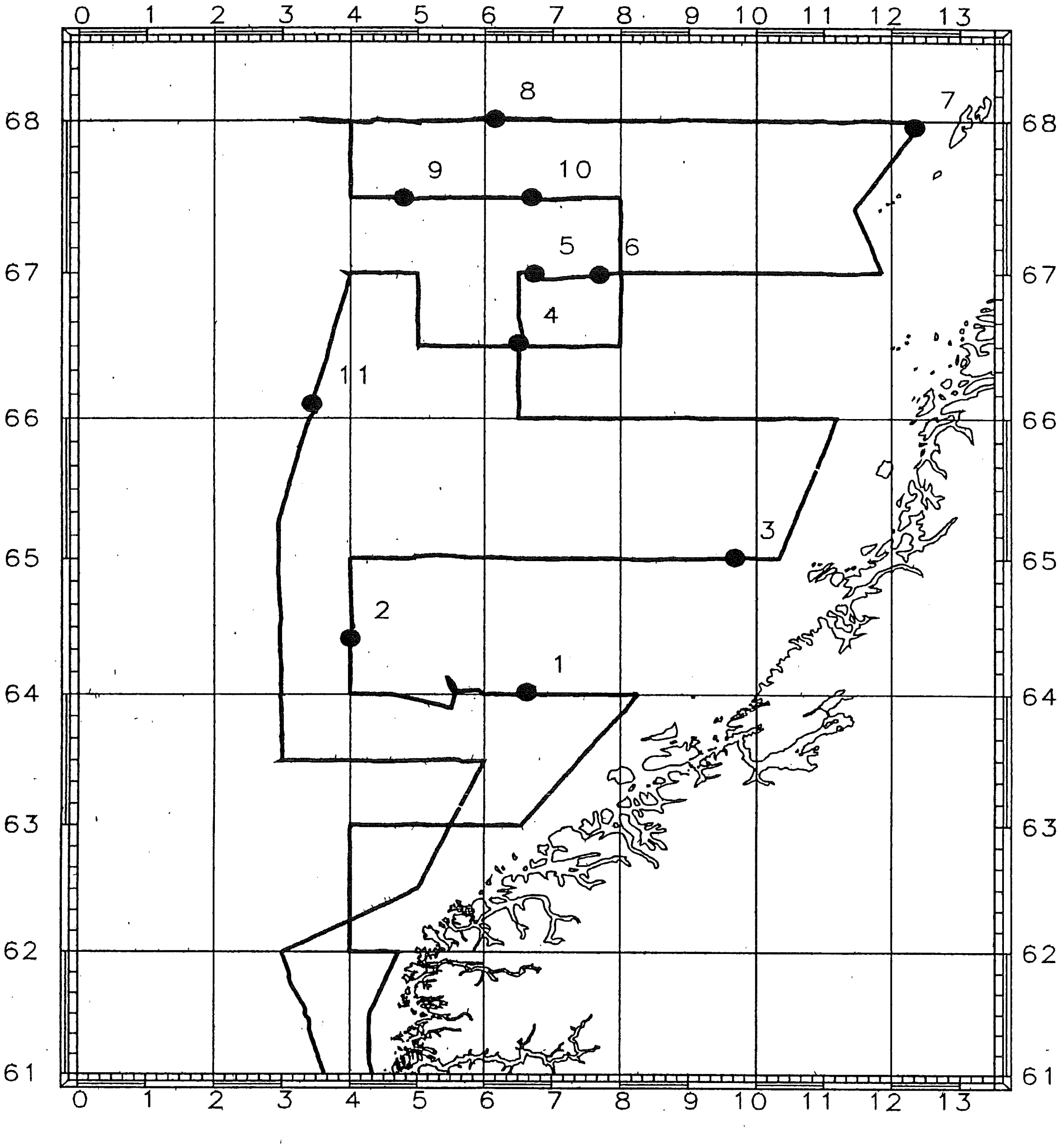


Figure 1. Cruise tracks during the March survey

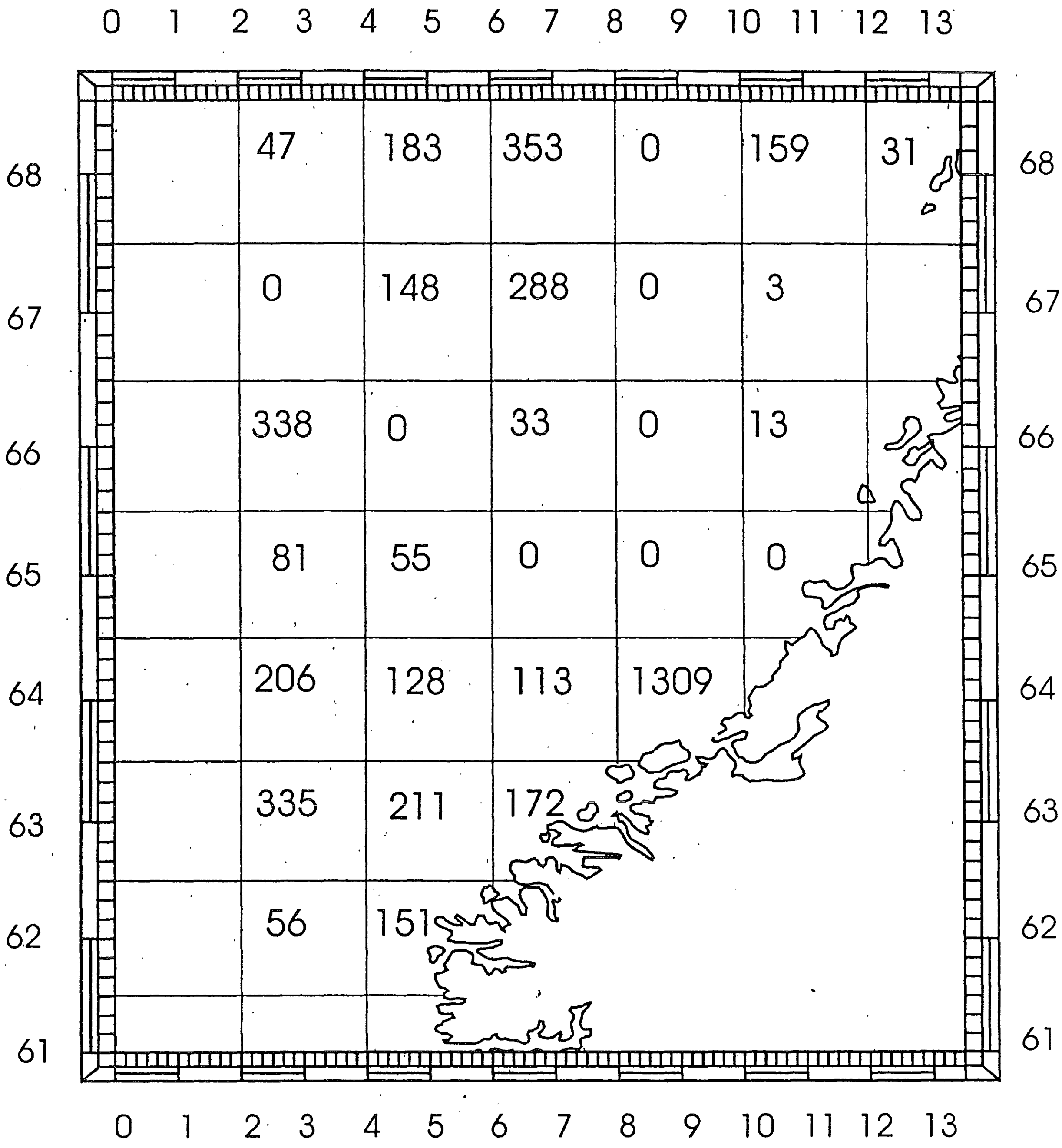
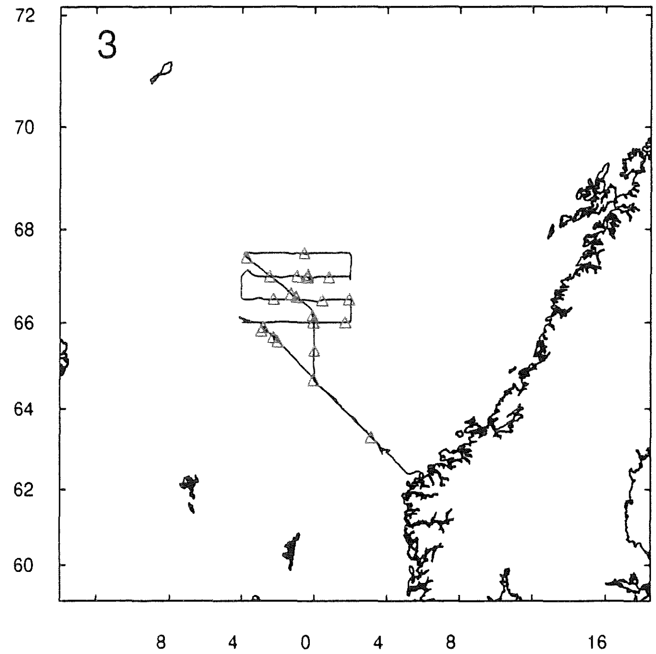
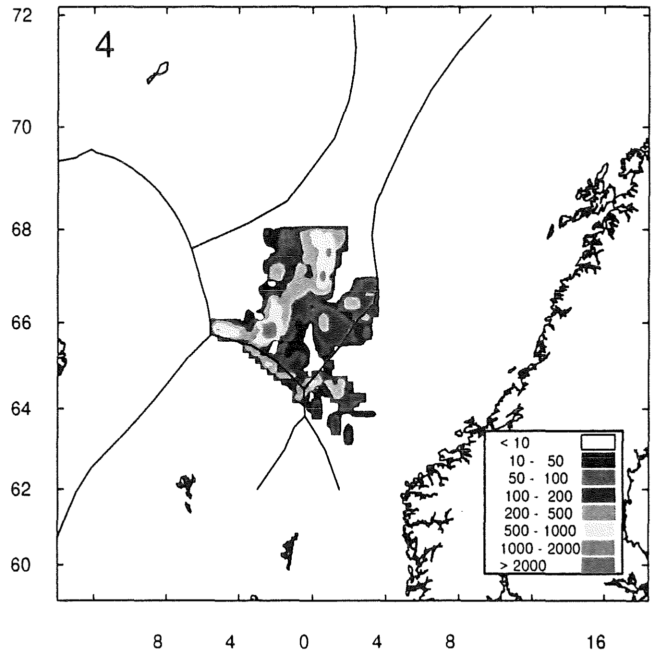
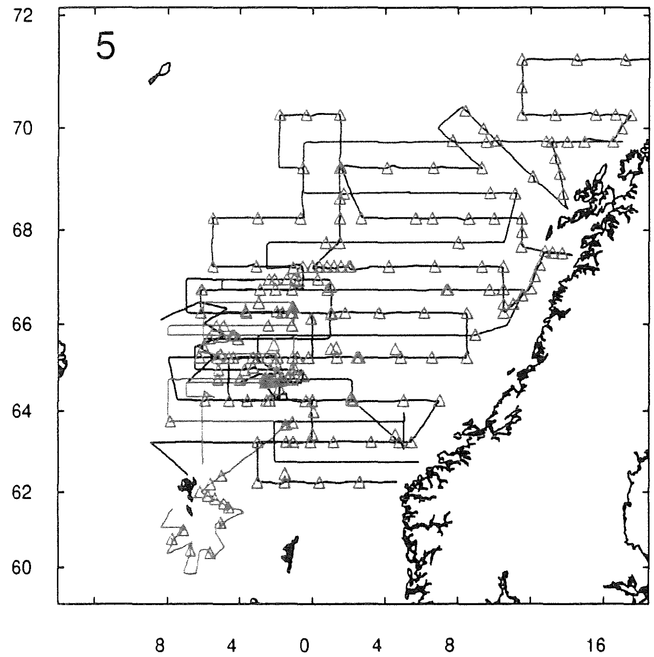
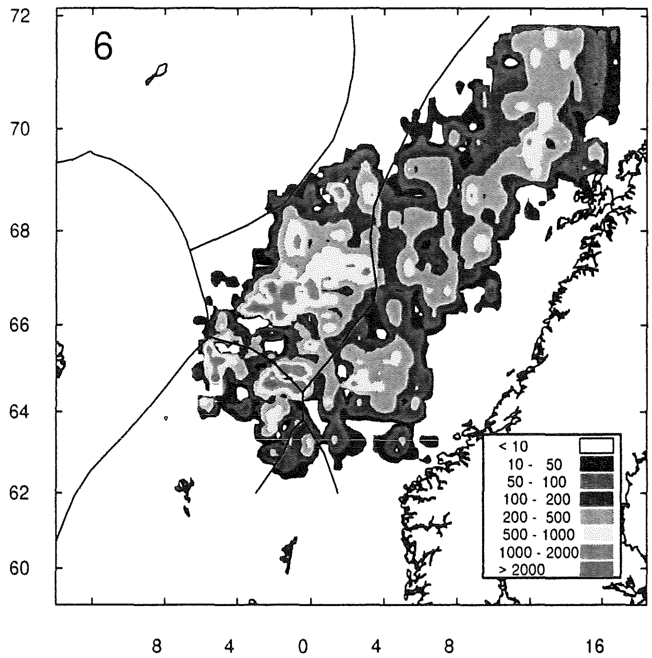


Figure 2. Herring distribution in March.









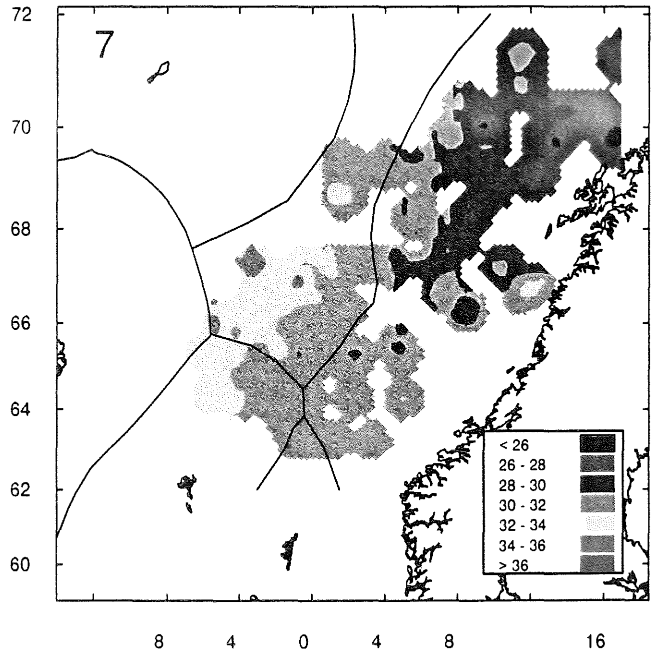


Figure 3. Cruise tracks during the April survey.

Figure 4. Herring distribution in April 1997.

Figure 5. Cruise tracks for the coordinated surveys in May 1997.

Figure 6. Herring distribution in May 1997.

Figure 7. Mean length of herring in May 1997.

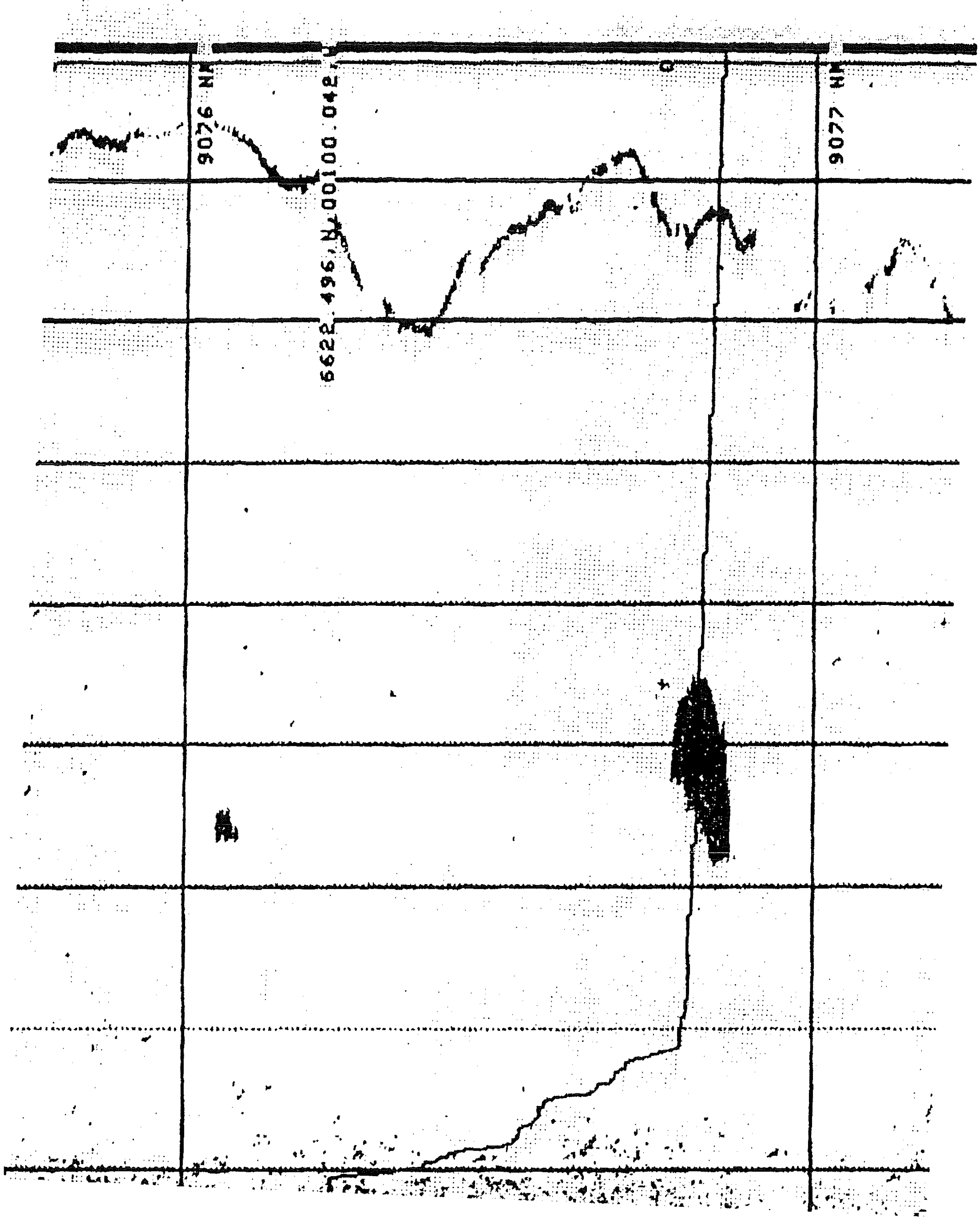


Figure 8. Echogram showing undulating layer and herring school.

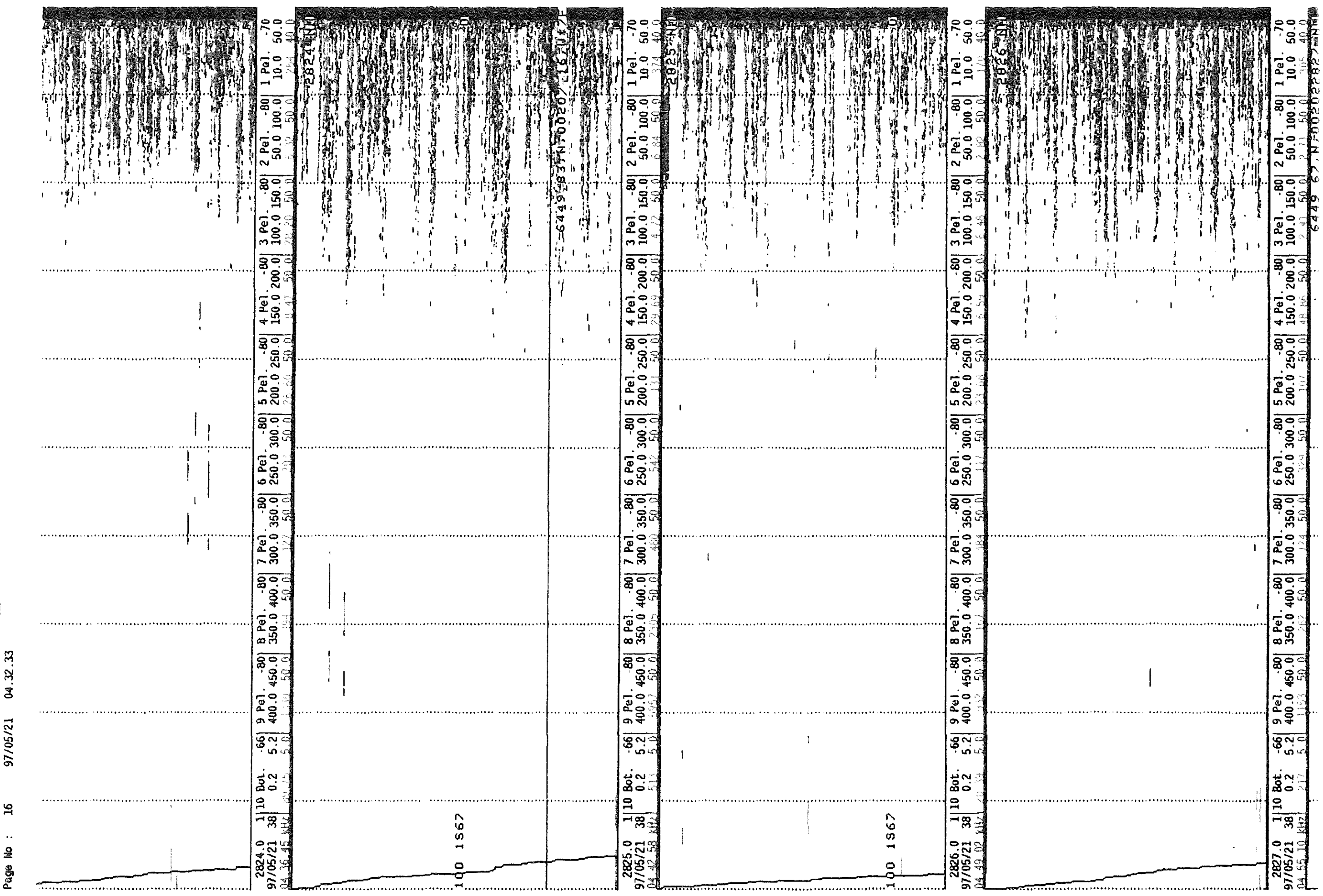


Figure 9. Echogram showing scattering traces of herring near surface (scale 0-100 m)

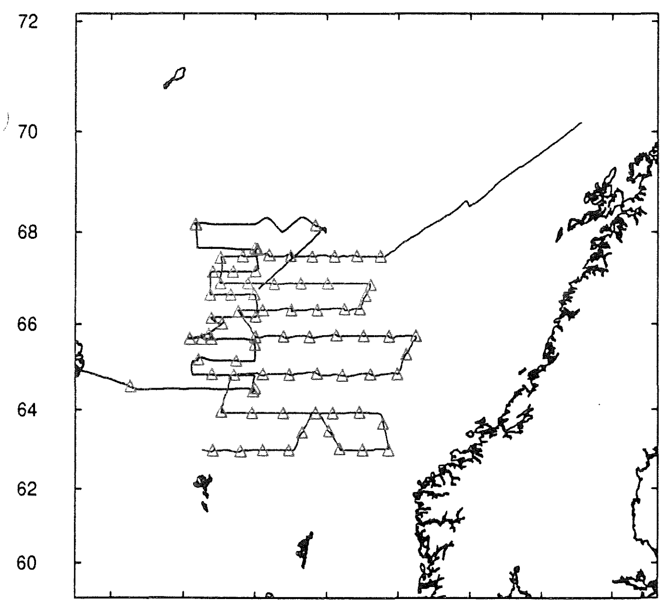


Figure 10. Cruise tracks in June 1997.

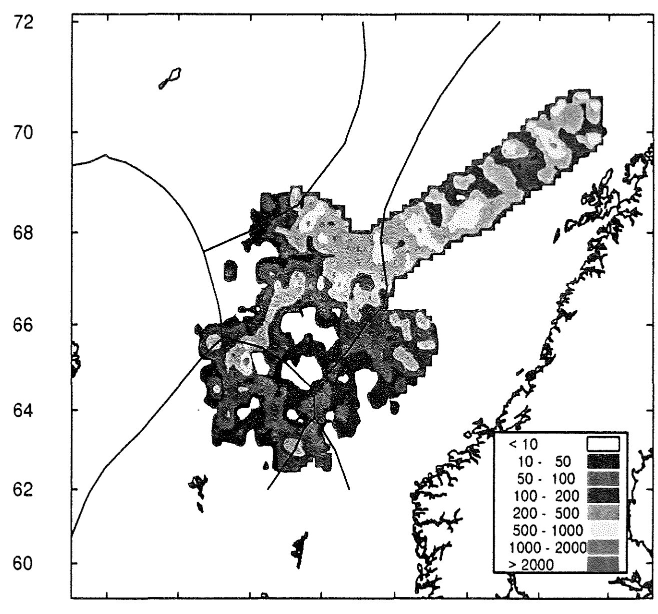


Figure 11. Herring distribution in June 1997.

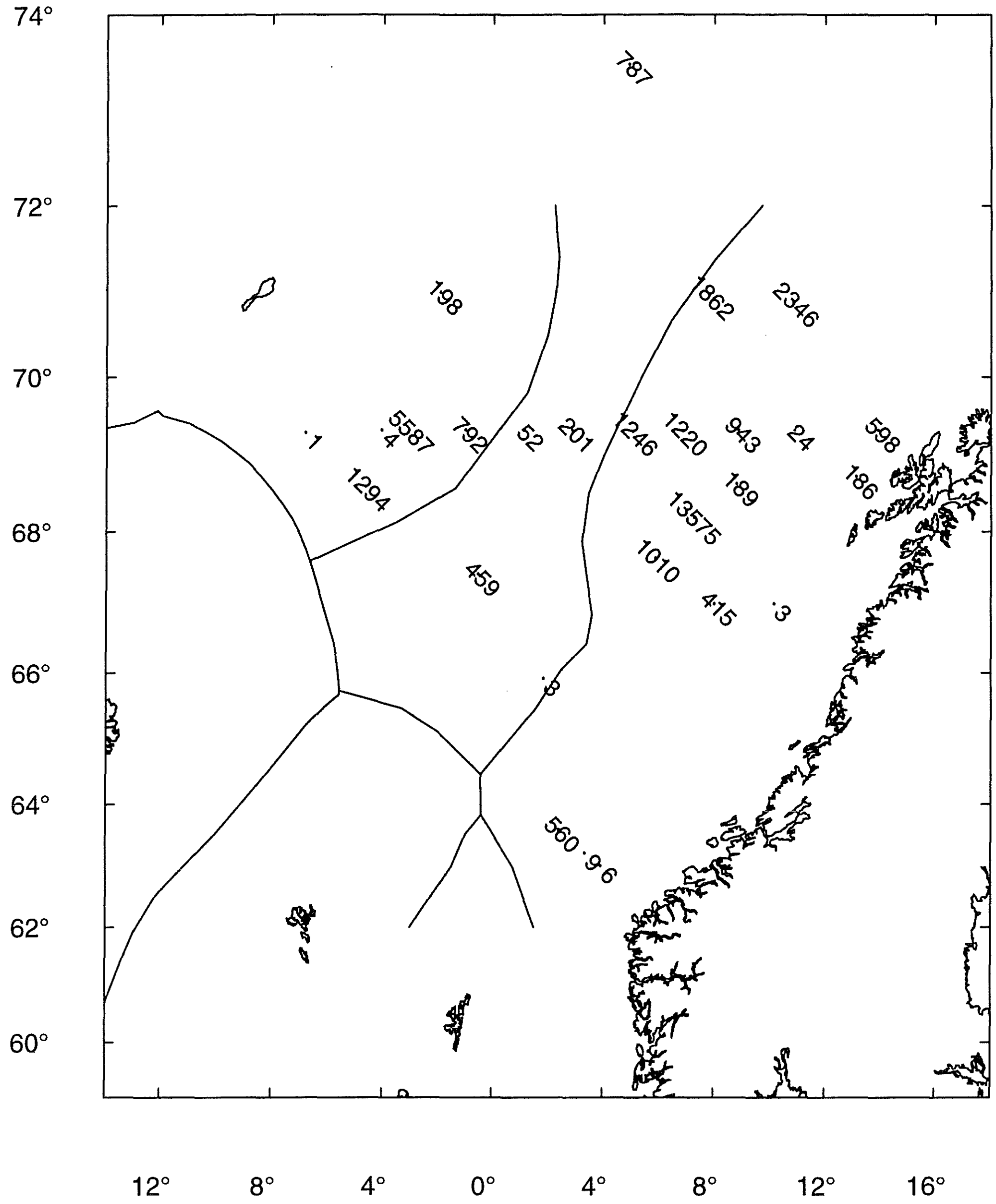


Figure 12. Trawl catches of herring in June/July

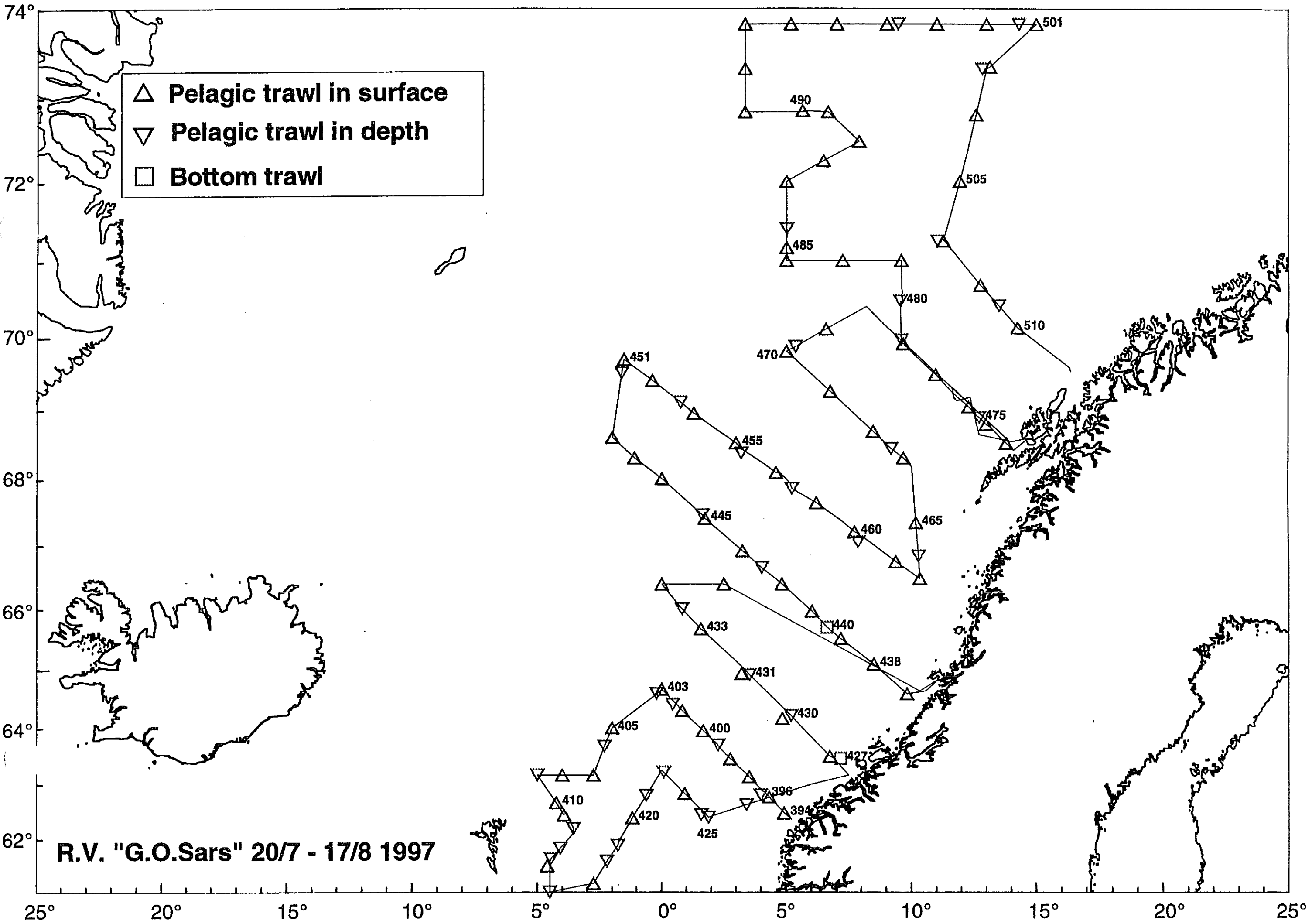


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Figure 13. Cruise tracks in July/August 1997.

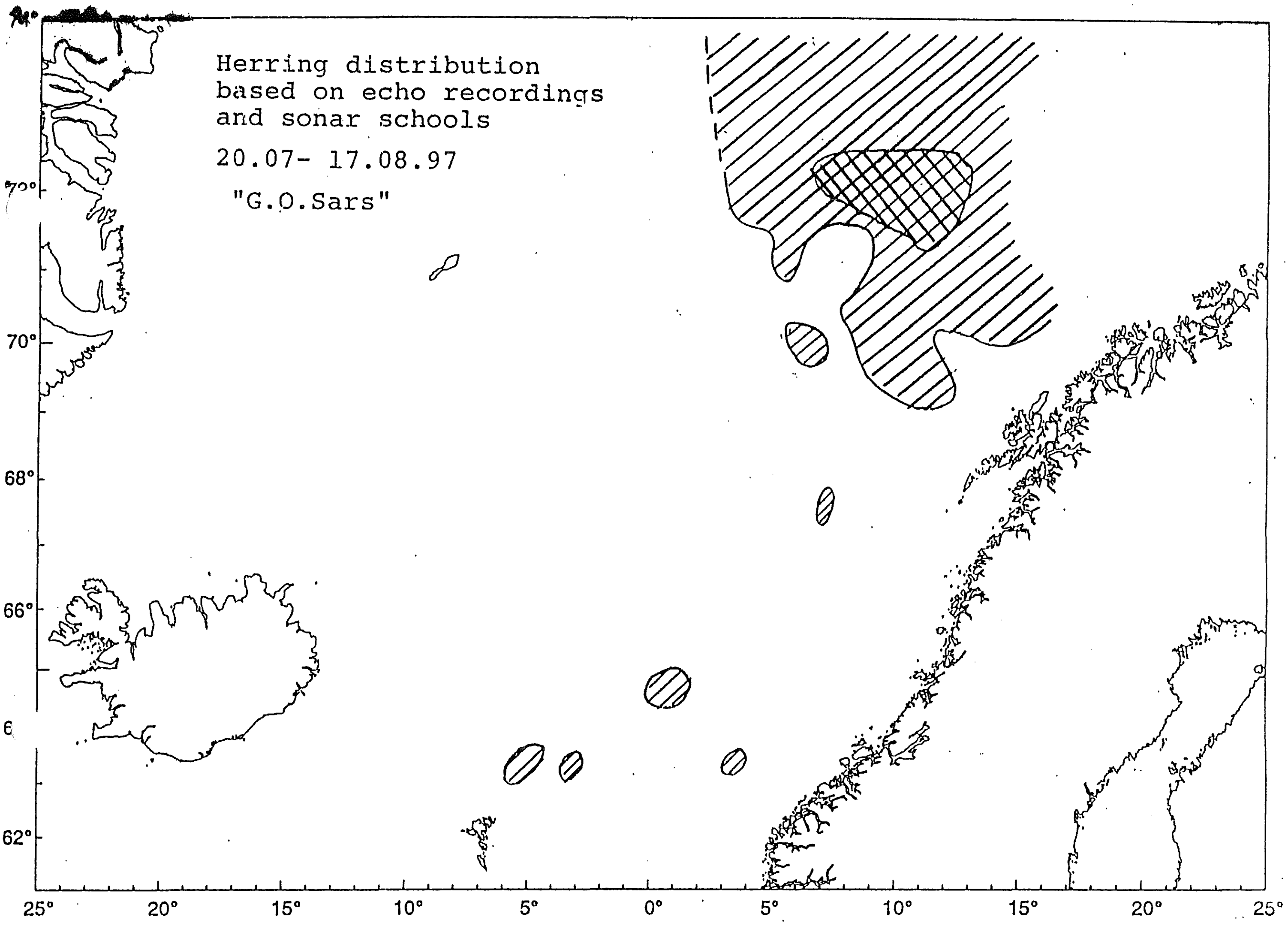


Figure 14. Herring distribution in July/August 1997.

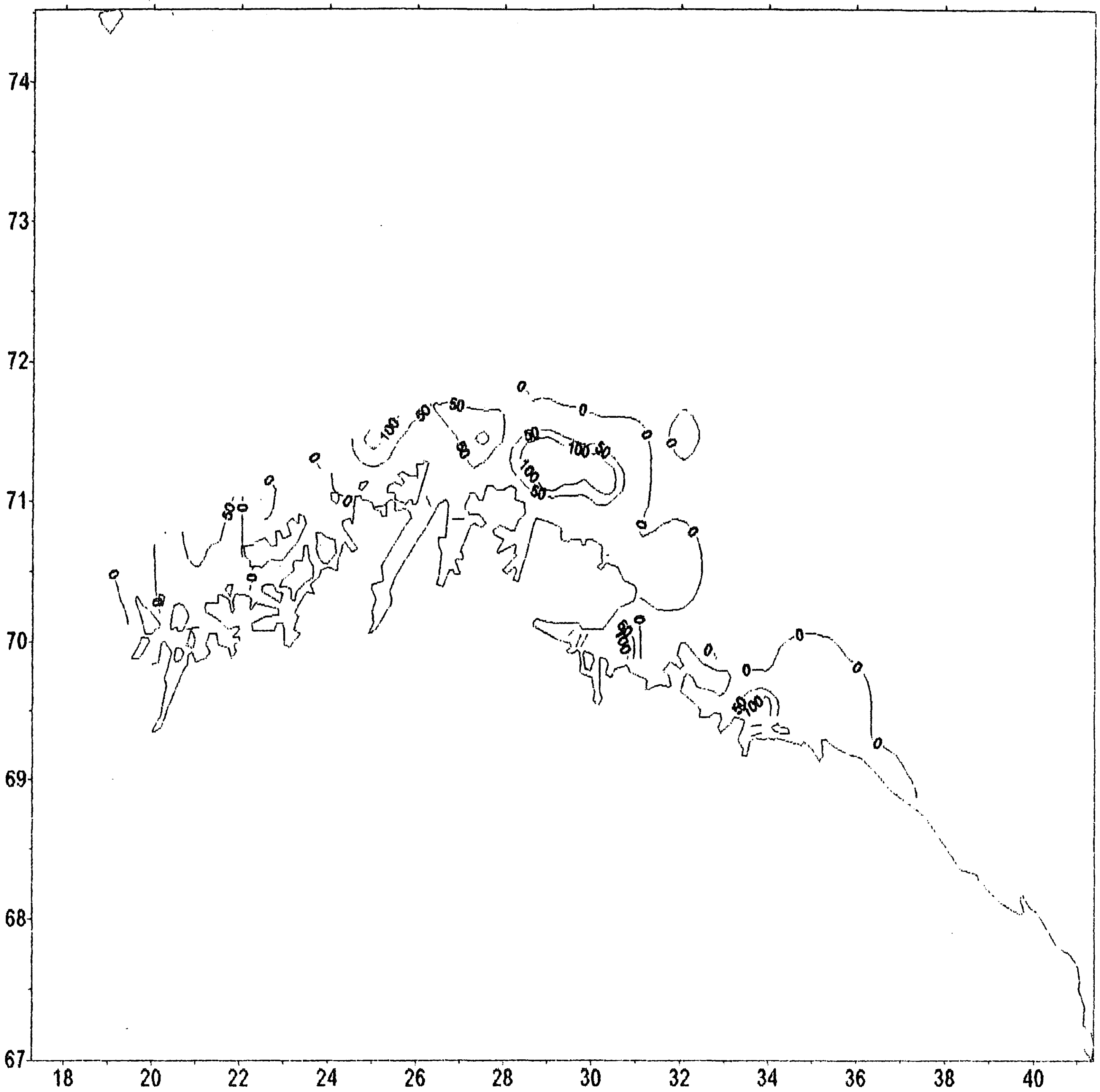
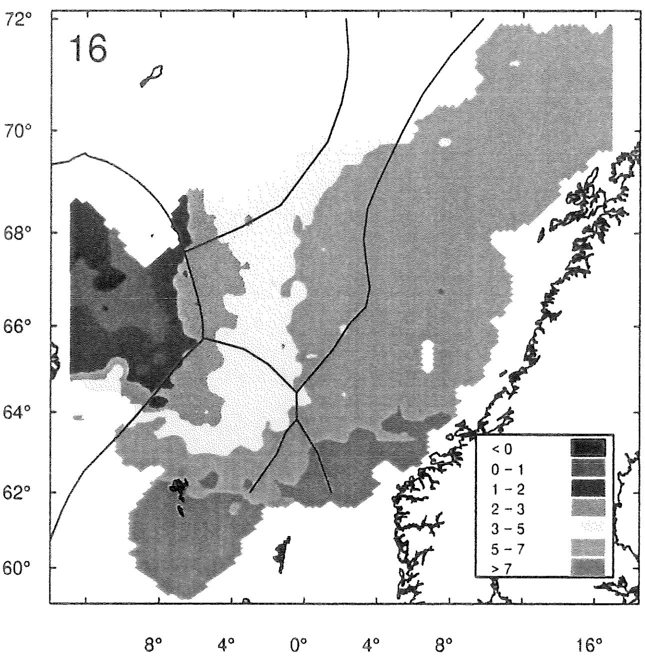
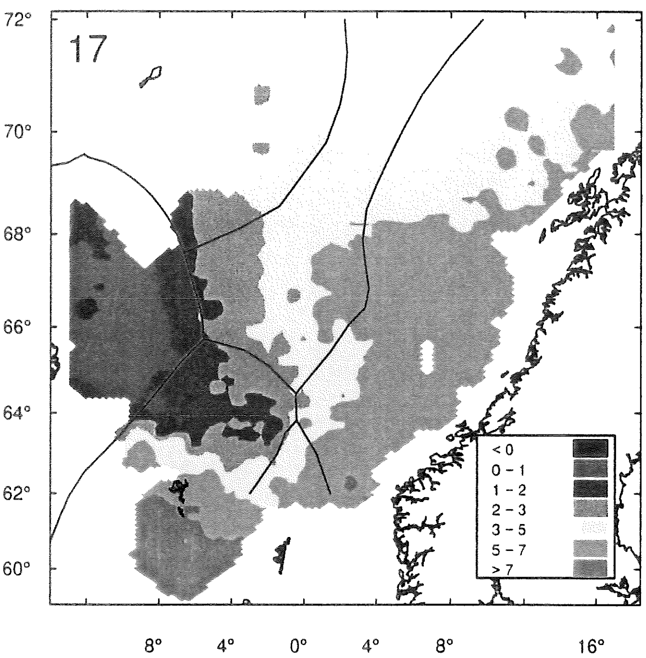
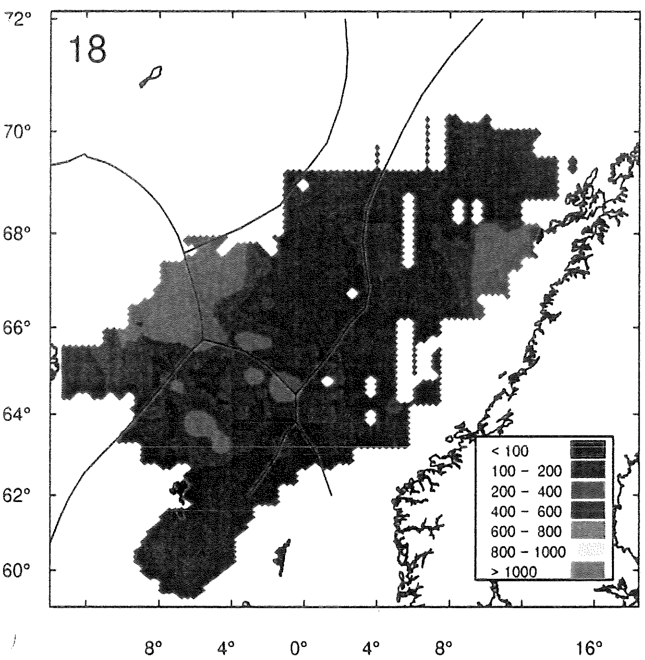
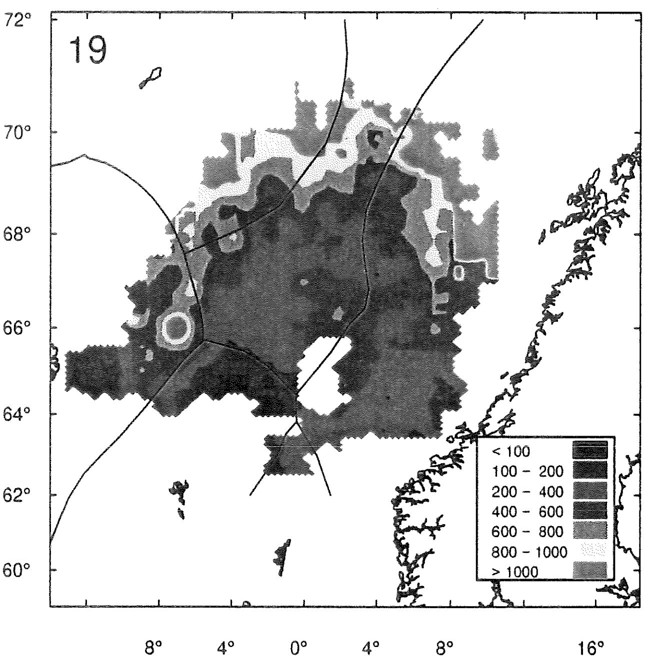


Figure 15. Herring distribution in the Barents Sea in May 1997









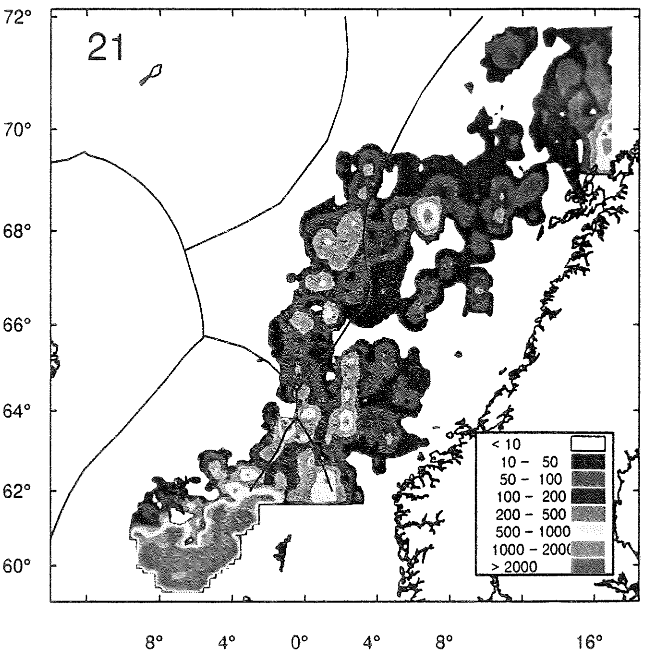


Figure 16. Temperature at 50 m in May 1997.

Figure 17. Temperature at 200 m in May 1997.

Figure 18. Zooplankton distribution in May 1997.

Figure 19. Zooplankton distribution in May 1996.

Figure 21. Blue whiting distribuition in May 1997.

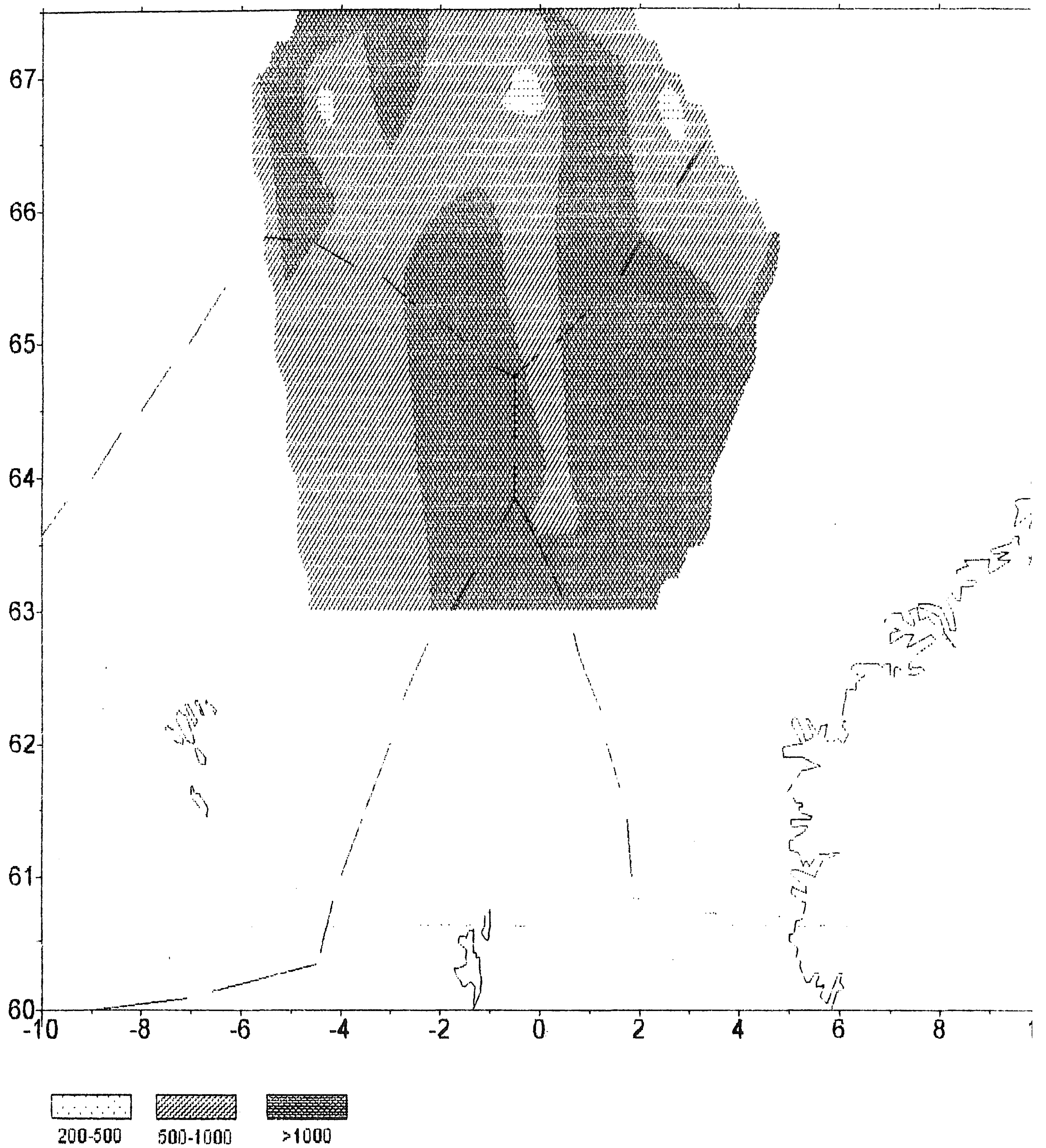


Figure 20. Zooplankton distribution in June 1997.

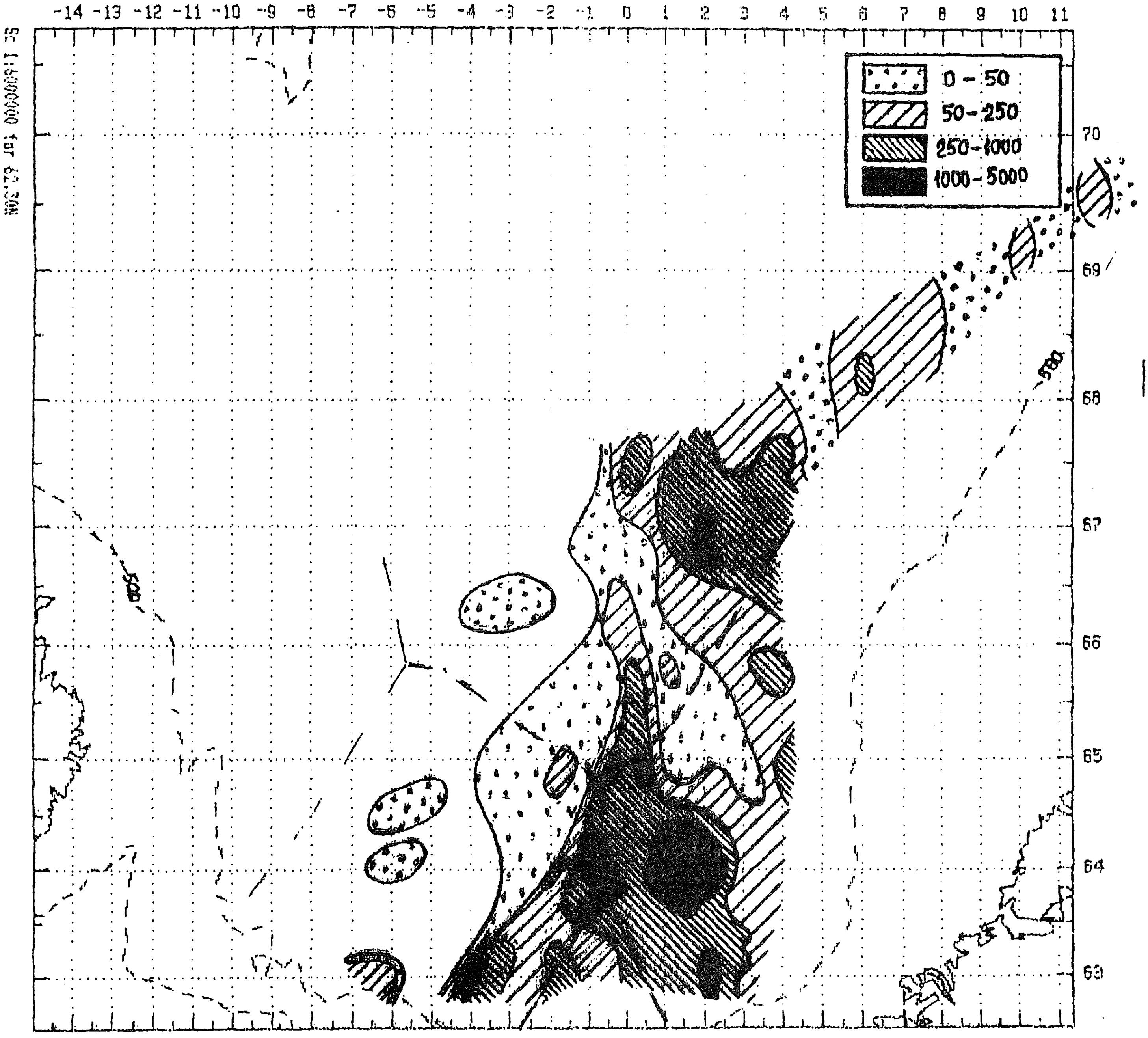


Figure 22. Blue whiting distribution in June 1997.

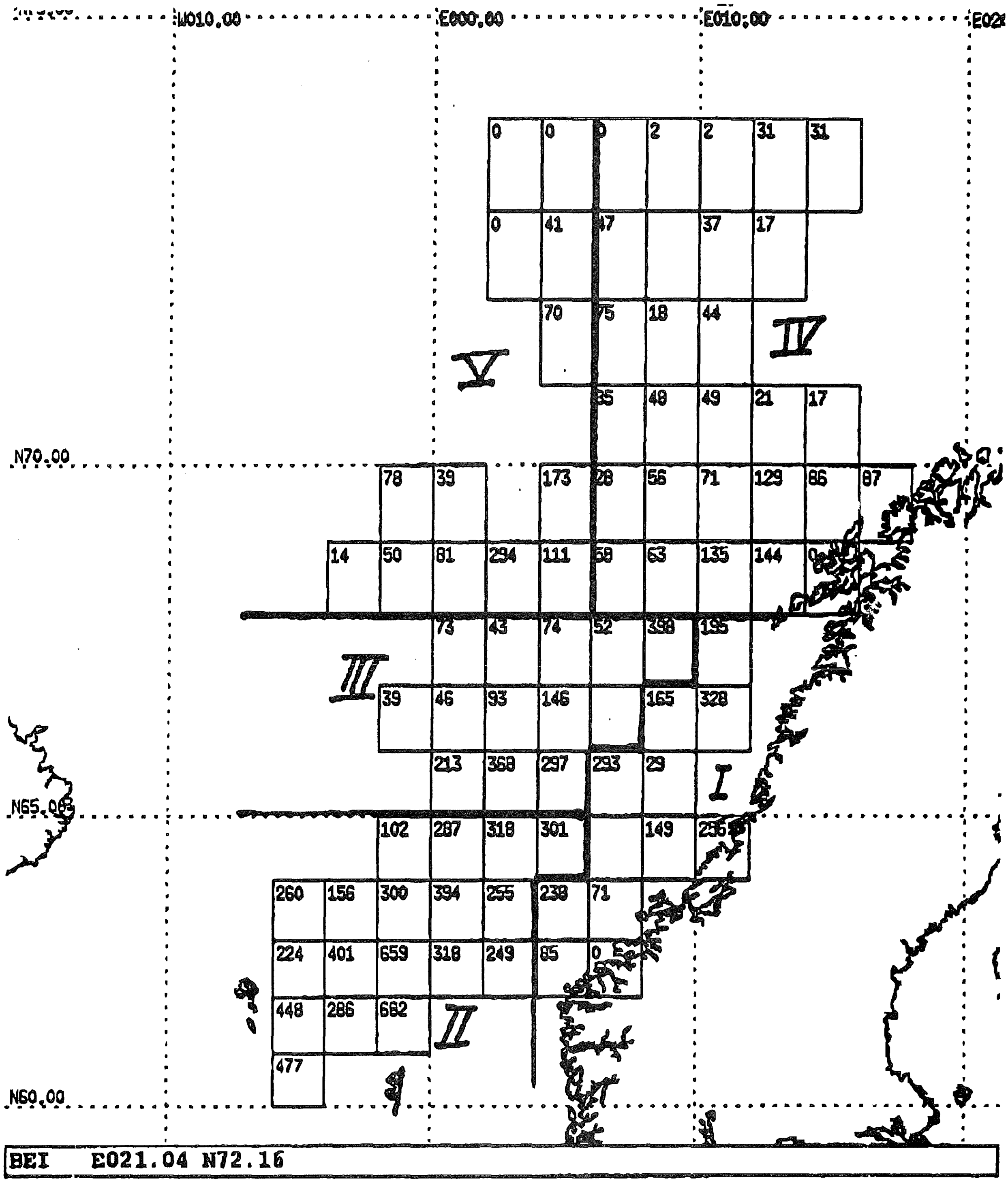


Figure 23. Blue whiting distribution in August 1997.

Figure 24. Migration paths April to August and the distribution in May 1997