DISTRIBUTION, MIGRATION AND ABUNDANCE OF NORWEGIAN SPRING SPAWNING HERRING IN RELATION TO THE TEMPERATURE AND ZOOPLANKTON BIOMASS IN THE NORWEGIAN SEA AS RECORDED BY COORDINATED SURVEYS IN SPRING AND SUMMER 1996

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The distribution and migration of Norwegian spring spawning herring (*Clupea harengus*) in the Norwegian Sea in spring and summer 1996 were mapped during 13 coordinated surveys carried out by Faroese, Icelandic, Norwegian and Russian research vessels.

After spawning at the banks of the Norwegian Coast in February-March, most of the spent herring migrated out in the Norwegian Sea through a corridor between 67°N and 68°N. In May, 4 and 5 year old herring, which form the younger part of the spawning stock, were distributed in small schools or scattered layers at 25-100 m depth over large areas of the central Norwegian Sea. Older and larger herring formed large schools, generally at 250-400 m depth near the cold front along the eastern part of the Icelandic Exclusive Economic Zone (EEZ). The total abundance of herring in the Norwegian Sea was estimated to be about 47 billion individuals or about 8 million tonnes. In June, the older and larger herring had migrated northwards into the Jan Mayen zone, while the younger herring remained in the southern and central Norwegian Sea. In July, the younger herring had migrated back to the area off Vesterålen, northern Norway. In July/August, the larger herring were found in small schools near the surface in the northern Norwegian Sea.

Relationships between the temperature distribution, zooplankton abundance and herring distribution and migration are considered. In May, the lowest zooplankton biomass was observed in the central and southern Norwegian Sea. At that time, there were high zooplankton concentrations in the westernmost part of the Norwegian Sea, within the domain of the East Icelandic Current. The herring did not enter this body of cold water with temperatures of 1-2 °C in the uppermost 300 m, but migrated to the north and north-east in search of food.

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Keywords: Herring; distribution; migration; sea temperature; zooplankton abundance; Norwegian Sea.

INTRODUCTION

From 1986 onwards, the growing stock of Norwegian spring spawning herring (*Clupea harengus* L.) has gradually extended its feeding migration into the Norwegian Sea (Røttingen 1990). Scattered concentrations of adult herring of the 1983 year class have been recorded over large areas as far west as 5°W in summertime. During the annual Icelandic spring survey to monitor environmental conditions in 1994, schools of feeding Norwegian spring spawning herring were recorded as far as 7°W in an area between 63°45'N and 68°N. Following these observations, Norway and Iceland organized an *ad hoc* joint survey to cover the area between 66°N and 68°N, from the zero meridian to 8°W. The survey was carried out 9-14 June 1994, and herring feeding near the surface were recorded in most of the area covered (ANON. 1995a). The discovery of these herring concentrations led to an international herring fishery in these areas in 1994.

Traditionally, the fisheries for Norwegian spring spawning herring have had a great economic importance for the Faroes, Iceland, Norway and Russia (DRAGESUND & al. 1980; JAKOBSSON 1992). In autumn of 1994 it was therefore agreed that these nations should allocate sufficient research effort to monitor the stock of Norwegian spring spawning herring in the Norwegian Sea in 1995. This should be done through coordinated surveys, aimed at recording herring concentrations and their movements in relation to the physical and biological environment. The coordination and evaluation of the surveys were effected by groups with participants from the fisheries research institutes in the Faroes, Iceland, Norway and Russia, (ANON. 1995a, b). Through these coordinated surveys, the feeding migrations of the adult stock of Norwegian spring spawning herring were successively monitored from the spawning areas off western Norway in March, west and south-west across the central Norwegian Sea in April, to the areas north of the Faroes in May. The East Icelandic Current was unusually strong in the spring of 1995, carrying cold, arctic water with an eastern border at about 7°W and reaching south into Faroese waters (ANON. 1995b). The herring did not cross the cold front, but migrated northwards along it in late May and June and arrived off Lofoten at the Norwegian Coast in late August.

To map the distribution and migration of the herring, and to monitor environmental conditions of the Norwegian Sea, a total of 13 coordinated surveys were carried out by Faroese, Icelandic, Norwegian and Russian research vessels in spring and summer 1996 (ANON. 1996a). The echo integration recordings of herring, the measurements of zooplankton abundance, and sea temperature from each cruise were provided in a standard format on EXCEL spreadsheets (ANON. 1996a). This enabled a comprehensive description and evaluation of the environmental conditions and distribution, abundance and migration of herring in the Norwegian Sea on a monthly basis.

The results of the 1996 surveys were evaluated during a meeting of representatives from the participating research institutions in Reykjavik in September 1996. This paper summarizes the main findings of the report from that meeting (ANON. 1996b). A complete description of the environmental conditions (sea temperature, zooplankton abundance) and herring distribution and abundance is, however, limited to May 1996.

MATERIAL AND METHODS

Altogether 13 surveys were conducted to map the distribution and migration of herring and to monitor the environmental conditions in the Norwegian Sea in spring and summer 1996 (Table 1). During the surveys, continuous acoustic recordings of fish and plankton were made by calibrated echo integration units consisting of a 38 kHz Simrad EK500 working at a range of 0-500 m. The recordings of area backscattering strength (s_A) per nautical mile (n.mi.) were averaged over 5 n.mi., and the allocation of area backscattering strengths to species was conducted by scrutinizing the recordings according to trawl catches and the appearance of the recordings. To record schools near surface, a horizontally guided sonar was operated on all research vessels. Onboard R/Vs *G.O. Sars* and *Magnus Heinason*, the sonars were also used to track selected schools for 30-60 minutes. During tracking, the position of the vessel was obtained from the global positioning system (GPS). Onboard R/V *G.O. Sars*, the migration speed

Table 1. Faroese, Icelandic, Norwegian and Russian surveys in the Norwegian Sea in spring and summer 1996. Detailed survey tracks with fishing, hydrographic and plankton stations are given in ANON. 1996b. (FI: Faroe Islands, 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, stn: no of stations).

Vessel	Survey area	Period	Tr.sp.	Herr. smpl.	Plankton stn	CTD stn
Michael Sars[N]	Norwegian coast	17.02-24.03	var	71		113
G.O. Sars[N]	62°N-69°N, 2°W-10°E	21.03-01.04	var	10	33[M + WP-2]	46
G.O. Sars[N]	62°N-69°N, 3°W-10°E	03.04-18.04	var	17	19[M + WP-2]	26
G.O. Sars[N]	62°N-72°N, 8°W-17°E	30.04-28.05	60	47	55[M + WP-2]	97
Árni Fridriksson[I]	64°N-69°N, 13°W-1°E	03.05-29.05	60	35	133[WP-2]	133
Magnus Heinason[FI]	60°N-66°N, 10°W-2°E	03.05-29.05	30			
Fridtjof Nansen[R]	Kola and Finnmark coast	19.05-05.06	12	7		47
Bjarni Sæmundsson[I]	Icelandic coast	21.05-11.06	var	0	118[WP-2]	118
Árni Fridriksson[I]	64°N-70°N, 13°W-3°W	03.06-14.06	var	6	27[WP-2]	27
Fridtjof Nansen[R]	61°N-70°N, 12°W-15°E	12.06-11.07	var	7	108[D + G]	108
Árni Fridriksson[I]	65°N-68°N, 13°W-4°E	08.07-15.07	30	0	28[WP-2]	28
G.O. Sars[N]	62°N-72°N, 3°W-13°E	19.07-15.08	var	33	72[M + WP-2]	81
Johan Hjort[I]	68°N-75°N, 9°W-18°E	20.07-05.08	var		17[WP-2]	68

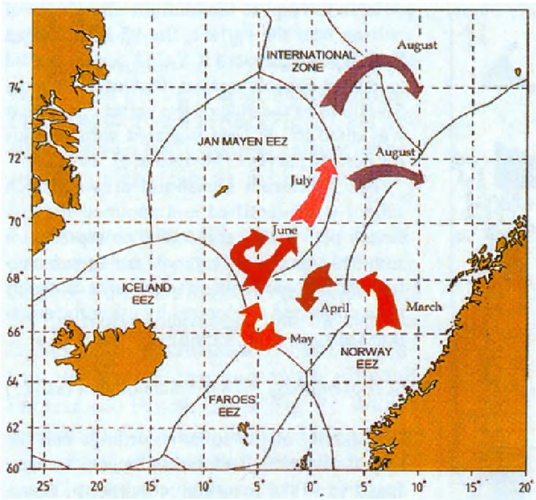

Fig. 1. Migration pattern of the older components of the adult Norwegian spring spawning herring (1983, 1988-1991 year classes) during spring and summer 1996. The colour of the arrows change from red for the March to violet for the August.

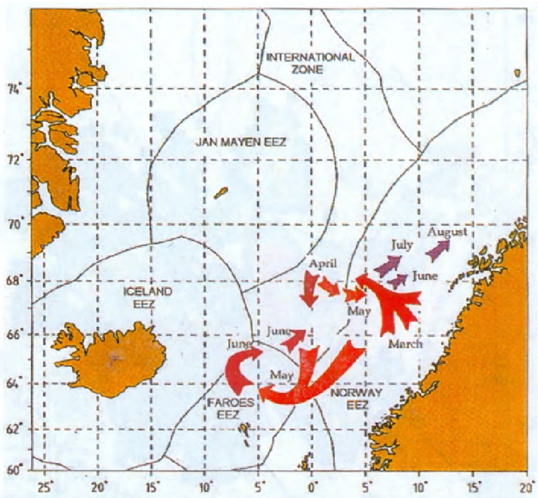

Fig. 2. Migration pattern of the younger components of the adult Norwegian spring spawning herring (1991 - 1992 year classes) during spring and summer 1996. The colour of the arrows change from red for the March to violet for the August.

and direction of the schools were calculated on the basis of computer-based school detection and corresponding GPS positioning by procedures written in SAS software (MISUND & al. 1997). Onboard R/V *Magnus Heinason* the similar calculations were based on the initial and final GPS positions, and initial and final horizontal range and bearing vessel-to-school.

Fish schools producing the acoustic recordings were identified by use of pelagic trawls with vertical openings of 25-40 m. With ordinary rigging the trawls were used to catch deep schools. The trawls were also re-rigged to catch schools near the surface by removing the weights, extending the upper bridles, and attaching two buoys to each upper wing (VALDEMARSEN & MISUND 1995).

Zooplankton data were sampled in with vertical hauls from 50-0 m by standard WP-2 net with 180 µm mesh (R/V *Årni Fridriksson*), and in oblique hauls from 50-25 m and 25-0 m with a 1 m² MOCNESS gear with 180 µm meshes (R/V *G.O. Sars*). The MOCNESS samples from the two depth intervals were combined to one sample from 50-0 m.

Subsamples of 100 specimens of herring were taken from the trawl catches. The length down to nearest 0.5 cm, weight, sex, maturation stage, and stomach content were recorded. Scales from 50 herring were taken for age reading. From each cruise, the echo integration recordings of herring, the length distribution of herring from each trawl sample, the zooplankton abundance at each net tow station, and sea temperature monitored at pre-defined depths, were provided in a standard format on EXCEL spreadsheets.

During the May surveys by R/Vs *Årni Fridriksson*, *Magnus Heinason*, *Fridtjof Nansen* and *G.O. Sars* attempts were made to obtain acoustic abundance estimation of herring abundance. This was done by scrutinizing the echo recordings directly from the echogram or by post-processing by the Bergen Echo Integrator (BEI) system (R/Vs *Årni Fridriksson* and *G.O. Sars*). s_A-values of defined recordings were allocated to herring according to the trawl catches and the appearance of the recordings. To estimate the abundance of herring, the allocated s_A-values were averaged for statistical squares of 1 degree latitude and 2 degrees longitude. For each statistical square, the area density of herring (ρ_A) in number per square nautical mile was calculated by the equation:

$$\rho_A = s_A/\sigma \quad (N\ n.mi.^{-2}) \qquad (1)$$

where the backscattering cross section (σ) is given by:

$$\sigma = 4\pi \cdot 10^{1/10 \cdot TS} \qquad (2)$$

and the target strength (TS) is given by:

$$TS = 20 \log L - 71.9 \quad (\text{FOOTE } 1987) \qquad (3)$$

where L is the length of the herring.

Insertion of equation (3) to (2), and (2) to (1) gives:

$$\rho_A = s_A \cdot 1.23 \cdot 10^6 \cdot L^{-2} \quad (N\ n.mi.^{-2}) \qquad (4)$$

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 square, and then summed for all the statistical squares within defined subareas and for the total area. The biomass was calculated by multiplying the area abundance by the average weight of the herring for each statistical square, and summing for all squares within defined subareas and the total area. The average length, weight, area density and biomass for each year class was also estimated for each statistical square, for defined sub-areas, and for the total area.

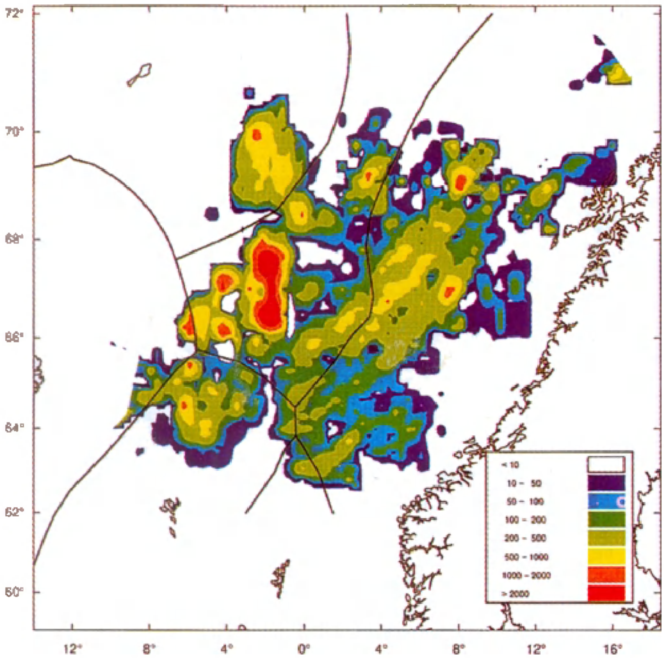

Fig. 3. Distribution of herring in the Norwegian Sea visualized through area backscattering strength (s_A) allocated to herring during the May surveys by R/Vs *G.O. Sars*, *Árni Fridriksson* and *Magnus Heinason*. Numbers in the key are s_A-values in m^2 $n.mi.^{-2}$.

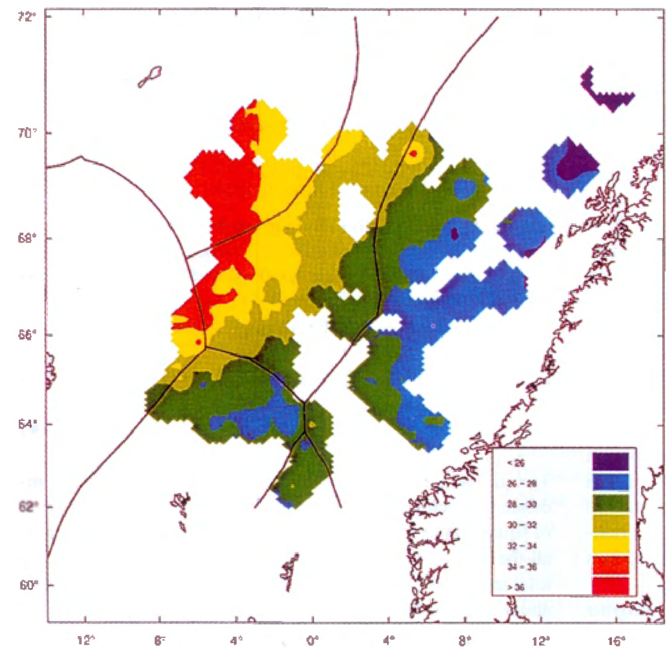

Fig. 4. Mean length (cm) of herring caught on pelagic trawl stations by R/Vs *G.O. Sars*, *Árni Fridriksson* and *Magnus Heinason* during the May surveys. Numbers in the key are length in cm.

In an attempt to measure the abundance of herring near the surface, the 95 kHz Simrad SA950 sonar onboard R/V *G.O. Sars* was used to record schools near-surface at a range of 50-300 m to the side of the vessel. The sonar was tilted to –5°, and operated with settings for herring surveys (MISUND & al. 1996).

The maximum horizontal area for each school was identified and summed for distances of 5 n.mi., and scaled to represent a summed school area estimate per square nautical mile. These summed school area estimates were converted to biomass by using the equation (MISUND & al. 1996b):

School biomass = 18.4 * School area (kg) (5)

The quality of the sonar recordings and the school detections and measurements are very sensitive to the recording conditions. Therefore, only recordings made when the herring occurred exclusively in distinct schools in good weather, with minor rolling and pitching, were accepted. Furthermore, recordings made when the herring were shoaling or occurring in scattered layers near surface were omitted from the sonar analysis.

RESULTS

Distribution and macroscale migration of herring in the Norwegian Sea in spring and summer 1996

After spawning on the coastal banks off the western and northern coast of Norway in the area between 59 and 70°N from about 15 February, the adult herring migrated northwards and westwards. By the end of March, the herring were recorded west of the continental slope in the area north of 66°N (Figs 1 & 2), but the exact western border of the herring distribution was not determined.

In April, the main herring concentrations were located in the central parts of the Norwegian Sea, between 67 and 68°N, and east of 2°W (Figs 1 & 2). The herring were schooling at 300-400 m depth during daytime, and at night the herring ascended to the surface and occurred both in dense schools and in scattered shoals. Since most of the individuals had some contents in their stomachs, the herring were obviously feeding actively. Four and five year old herring (1992 and 1991 year classes) of length 24-31 cm dominated the trawl catches.

The coordinated surveys in May revealed that the herring occupied vast areas of the Norwegian Sea (Fig. 3), but occurred in two fairly distinct categories according to size (Fig. 4) and behaviour:

1. Young herring with a mean length < 30 cm, dominated by the 1991 and 1992 year classes, were distributed over a wide area off the Norwegian coast, into the eastern regions of the international zone of the central Norwegian Sea and south into the Faroese and British EEZs (Fig. 2). Within this part of the distribution area the herring occurred mostly in small schools or scattered in layers at about 25-100 m depth. Off the coast of northern Norway the herring occurred in distinct schools at a depth of about 100-250 m.

2. In the eastern part of the Icelandic EEZ and western part of the international zone in the central Norwegian Sea (Fig. 1), the herring occurred in large schools, mostly at depths between 250 and 400 m but sometimes at shallower depth. However, there were also recordings of large schools from the surface to about 200 m depth in the Jan Mayen EEZ. The herring in this western part of the distribution area were large (mean length > 32 cm) with a contribution of up to 45 % by the 1983 year class in numbers in one catch in the Jan Mayen EEZ. Farther east in this part of the distribution area, the herring were somewhat smaller (> 30 cm), and samples were dominated by the 1991 and 1992 year classes, the contribution of the 1983 year class being about 20 % of the total biomass.

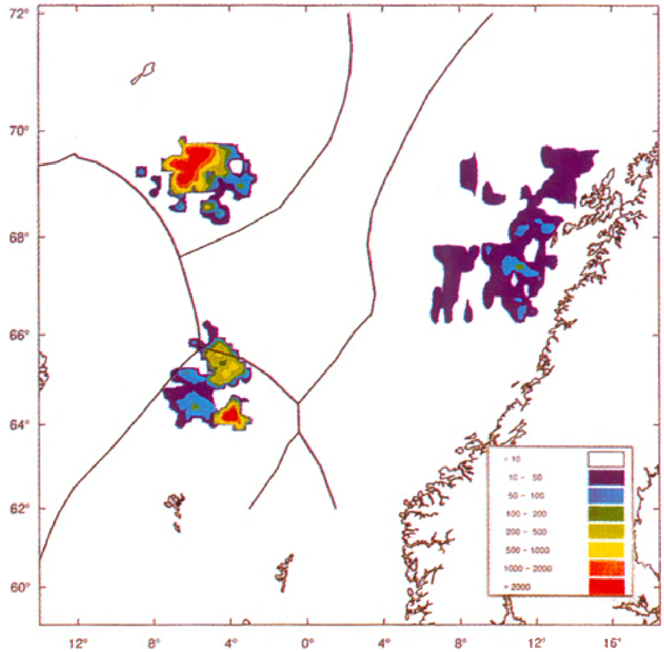

Fig. 5. Distribution of herring in the Norwegian Sea visualized through area backscattering strength (s_A) allocated to herring during the June surveys by R/Vs *Årni Fridriksson* and *Fridtjof Nansen*. Numbers in the key are s_A-values in m² n.mi.⁻².

In June, the herring were recorded in three main areas in the Norwegian Sea (Figs 1, 2 & 5). In a northern area between 69°N and the cold front near 69°30'N there were large concentrations of herring from about 4°W to 7°W (Fig. 5). East of 4°W, there were probably also herring distributed farther to the north. Large herring of the 1983 year class (43 %) together with the 1990 and 1991 year classes (34 %) dominated in this area. In an area off Lofoten, northern Norway (north of 66°N and east of 6°E) there were substantial recordings of younger herring (1991-1992 year classes, Fig. 5). In the area between 64°N and 66°N, 3°W-8°W small, but often quite dense schools were recorded. The highest numbers were located near 64°15'N, between 3°45'W and 5°W (Fig. 5). The herring in this area were mainly of the 1990 (56 %) and the 1989 (34 %) year classes.

In July, herring were recorded in an area between 67°30'N and 69°20'N, from the Norwegian coast and west to 6°E (Fig. 2). The herring occurred as schools of varying densities, consisting of immature herring with a mean length of 24-25 cm, belonging mainly to the 1992 year class (64 %). The northern border of this concentration was not defined. During a survey in the western part of the Norwegian Sea between 65°N and 67°30'N from 6°W to 10°W in the period 8-15 July there were no recordings of herring.

By July-August the younger herring (1991-1993 year classes) had migrated north-eastwards, and the main concentrations were located west of Lofoten, northern Norway (Fig. 2). Younger herring 3-5 years dominate in the trawl samples in this area. North of 70°N, older herring (1983, 1988-1990 year classes) dominated the samples (Fig. 1). However, there were also concentrations of old herring (mainly of the 1983 year class) farther to the west of Bear Island (Fig. 1). The northern boundary of the herring distribution in the area between 0° to 5°E was not reached. The herring appeared either in small schools near the surface, where they could be detected only by sonar, or at a depth of about 20 m where they were recorded by the echo sounder as a thin 'knotted' layer.

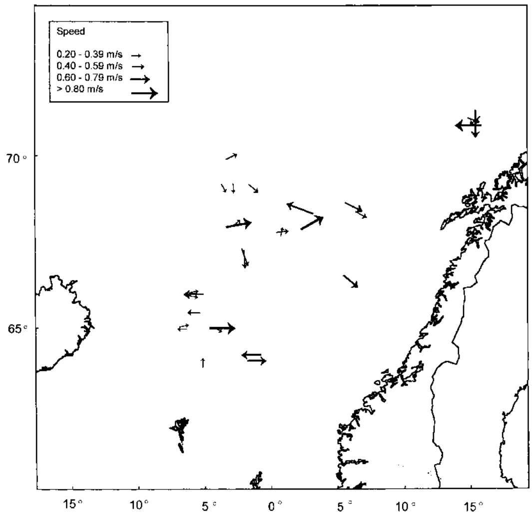

Fig. 6. Migration direction and speed for herring schools tracked by R/Vs *G.O. Sars* and *Magnus Heinason* during the May surveys.

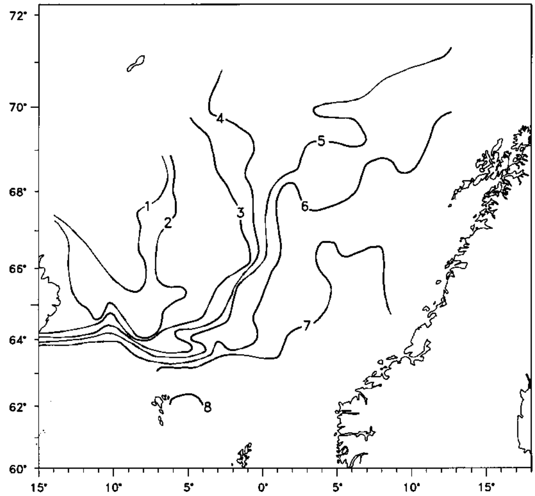

Fig. 7. Temperature distribution at 100 m depth in the Norwegian Sea May/June 1996.

Microscale herring migrations in the Norwegian Sea in May 1996

Twenty-one schools were tracked by R/V *G.O. Sars* for up to 30 minutes each during the May survey. These schools were located in all parts of the survey area, and occurred at depths from about 20 m to about 300 m. The swimming behaviour of the schools varied considerably. The migration direction varied from 47° to 285° and the migration speed from 0.07 m s^{-1} up to 1.28 m s^{-1} (Fig. 6). South of 66°N, there did not seem to be any apparent tendencies in the migration behaviour of the schools. Even schools recorded close to each other could be swimming in opposite directions, one east and the other west. North of 66°N most of the schools were heading in an easterly direction. This may indicate that the eastward-heading schools north of 66°N were migrating back to the Norwegian coast, while the schools south of 66°N were swimming around in various directions searching for prey. Three of the four schools recorded off northern Norway (position 71°N, 15°40'E) were heading in a southerly direction, and one was heading directly west at a speed of 1.28 m s^{-1}. The schools occurred at about 250 m depth and seem to be heading out of the western Barents Sea and into the eastern Norwegian Sea. Five schools were tracked for one hour by R/V *Magnus Heinason* in the Faroese EEZ during the May investigations. Four of the schools were heading north, and one was migrating in a south-westerly direction.

Table 2. Acoustic abundance estimates (in millions) of Norwegian spring spawning herring in the Norwegian Sea and adjacent waters in May 1996.

Survey	Age (years)											Sum
	3	4	5	6	7	8	9	10	11	12	13	
Norway, Norwegian Sea, May	1421	19584	11939	4793	2031	424	14	7	145		3134	43493
Faroes, south of 64°30'N, May	34	1974	1260	123	10				10			3404
Russia, Barents Sea, June	2659	903	45									3607
Total, Norwegian Sea and Barents Sea	4114	22461	13244	4916	2045	424	14	7	155		3134	50504

Relationship between herring distribution and migrations, temperature conditions and zooplankton biomass

When the herring migrated into the Norwegian Sea between 67°-68°N and the zero meridian, they encountered sea temperatures of about 2 °C when at 300 m depth in daytime and about 5 °C near surface at night. In May the older herring (1983, 1988-1991 year classes approached the eastern boundary of the East Icelandic current at about 7°W with temperatures of about 1 °C at 300 m depth and 2 °C at 50-200 m depth (Fig. 7) These herring did not cross the East Icelandic current, but migrated northwards along its eastern boundary in late May and early June. In July and August the older herring were found at temperatures in the range of 9.0-11.0 °C when distributed near surface off northern Norway and south-west of the Bear Island. The younger herring (1991-1992 year classes) which occurred at 25-100 m depth in May over the eastern and southern Norwegian Sea, encountered temperatures of about 4-7 °C. In June-August the sea temperature in the areas occupied by the younger herring ranged from 6-11 °C.

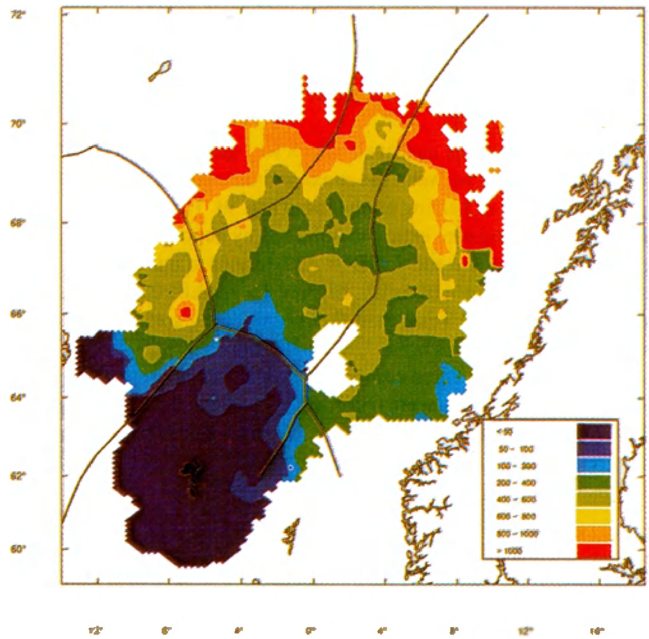

Fig. 8. Zooplankton biomass (mg dry wt/m^3) recorded by MOCNESS and WP-2 net tows during the May surveys by R/Vs *G.O. Sars* and *Árni Fridriksson*. Numbers in the key are mg dry wt/m^3.

By combining the recordings of zooplankton, obtained at stations worked by R/Vs *Árni Fridriksson* and *G.O. Sars* in May, it appears that highest zooplankton abundance (> 1000 mg dry wt/m^3) was located in the western, northern and north-eastern areas of the Norwegian Sea (Fig. 8). The lowest biomass was observed in the central and southern areas, i.e. the areas which the older herring partly migrated across, and in which younger herring were occurring. In June/July, Russian investigations showed a rather similar zooplankton biomass distribution as in May. Then the greatest zooplankton densities were observed in the north-eastern area, 66-68°N, 2-4°E. The younger herring (1991-1992 year classes) were feeding actively in this area.

Acoustic abundance estimates of herring in May 1996

During the May surveys, the herring were quite favourably distributed for conventional echo integration over large areas in the Norwegian Sea, occurring in small schools or scattered layers at about 25-100 m depth. High densities were recorded also in the western areas of the international zone and in the easternmost part of the Icelandic EEZ where the herring occurred in large schools from 250-400 m depth. Totally, about 47 billion individuals of herring of the year classes 1983-1993 were recorded in the Norwegian Sea in May (Table 2). Including the Russian estimate of 3.6 billion 3-5 year old herring along the Kola and Finnmark coast in May, the total abundance estimate of herring in the Norwegian Sea and the Barents Sea amounts to 50.5 billion individuals. The 1991 and 1992 year classes which were recorded to about 13 billion and 22 billion individuals, respectively, made up about 70 % of the total stock by number.

Comparison of echo integration and sonar estimates of herring biomass

The recording conditions during substantial parts of the May cruise by R/V *G.O. Sars* fulfilled the rather strict criteria set for use of sonar recordings, i.e. that the herring should occur in schools close to surface and that the weather conditions should be good with minor rolling and pitching. However, for some parts of the cruise as in the EU and Faroese EEZs, and on the transect from 66°N, 7°W to the Norwegian coast (log 8250-log 9350) these criteria were not met, and the sonar recordings in these areas could therefore not be used to calculate abundance. Similarly, in the western areas of the international zone the schools occurred at great depths, and were not recorded by the shallow tilted sonar during regular surveying. Consequently, only echo integration estimates exist from these areas (e.g. log 9600-9700, 10800-11350).

For the other areas surveyed, there was generally a certain correlation between the sonar and the echo integration estimate of herring abundance (Fig. 9). Totally, the average abundance estimate obtained by echo integration (37 tonnes n.mi.$^{-2}$, SD = 137 tonnes n.mi.$^{-2}$, N = 702) was significantly higher ($p = 0.0001$, Wilcoxon 2-Sample Test) than that obtained by sonar (average = 30.5 tonnes n.mi.$^{-2}$, SD = 92 tonnes n.mi.$^{-2}$, N = 702). However, when comparing only the estimates obtained when herring were recorded by both methods, there was no significant difference between the echo integration and the sonar estimate ($p > 0.05$).

DISCUSSION

The older and larger herring (1983, 1988-1991 year classes) migrated from the spawning grounds off western and north-western Norway in March, northwards along the slope of the continental shelf, and then out in the Norwegian Sea between 67°N and 68°N. In May, these herring were recorded in large schools at 250-400 m depths along the cold front, extending from the eastern part of the Icelandic EEZ and north to the Jan Mayen EEZ (Fig. 1). By June, these herring had migrated northwards along the cold front into the Jan Mayen EEZ, and in July/August the older herring were found in the northern Norwegian Sea up to 75°N as well as south-west of the Bear Island.

In spring and summer 1996, the older part of the adult population (1983, 1988-1990 year classes) has retained a clockwise feeding migration in the Norwegian Sea, similar to that of 1994 and 1995 (Anon. 1995b). However, the migration seems to have extended somewhat further north in 1996 as compared with the two previous years. The western border seems to have been the same in all of these years (Anon. 1995b). Thus, at present the cold water of the East Icelandic Current seems to act as a barrier against further westward expansion of the feeding areas of the Norwegian spring spawning herring.

In the warm period 1950-1964 the herring, on arriving at the cold front, assembled in large schools (Jakobsson & Østvedt 1996). When the sea temperature in the surface layers increased in May and June, the herring migrated westwards in the surface layer above the thermocline, feeding intensely on their way across the cold East Icelandic Current (Jakobsson & Østvedt 1996). Nevertheless, from 1965 and to the stock collapse in the late 1960s (Dragesund & al. 1980), the herring did not cross the East Icelandic Current during the summer feeding migrations in the Norwegian Sea (Jakobsson & Østvedt 1996). In those years the East Icelandic Current was rather strong, and carried cold, arctic water of low salinity (< 34.8 psu) and with a temperature 2-3 °C lower than normal to the areas north and east of Iceland (Dickson & al. 1975; Malmberg & al. 1992). During this period it is probable that the surface water of the East Icelandic Current was not heated enough during spring/early summer for the herring to cross through. The cold water may also have changed the species composition and abundance of the plankton community to such an extent that the herring did not find suitable or sufficient prey when entering the cold waters of the East Icelandic Current. It is probable that the 1996 environmental condition in the waters of the East Icelandic Current resemble that of the 1965 condition, and therefore that the herring did not enter the areas east of Iceland during the summer feeding migration in 1996.

Furthermore, the occurrence of a learning factor may influence the choice of a migration route during the summer feeding migration of the Norwegian spring spawning herring. Possibly, the present year classes of Norwegian spring spawning herring (the 1983, 1988-1992 year classes) will have to learn to enter the fruitful feeding grounds east and north of Iceland. The gradual expansion of the migration route during the summer feeding since 1994 may indicate that a learning factor is operating in the migration determining mechanisms.

During the last years the population of Norwegian spring spawning herring feeding in the Norwegian Sea has increased rapidly to this year's acoustic estimate of about 47 billion individuals or about 8 million tonnes. It is therefore possible that the extended feeding migration of the older herring in 1996 reflects increased feeding pressure on the plankton community in the Norwegian Sea with increasing stock size of herring. Thus, the herring have to search through and feeding over a larger area to accumulate the necessary energy reserves for maturation of the gonads, overwintering, and next years spawning migration and spawning.

After spawning for the first time in 1996, the younger part of the adult population (mainly the 1991 and 1992 year classes) migrated west into the Norwegian Sea (Fig. 2). In late April, this part of the population seems to have split in three components. As early as April, one component seems to have begun a return eastward migration to the coastal banks off Lofoten, northern Norway (Misund & al. 1997), where they seem to have arrived in June (Fig. 2). A second component migrated south-west and into Faroese waters (Fig. 2). The latest recording of this component was in the

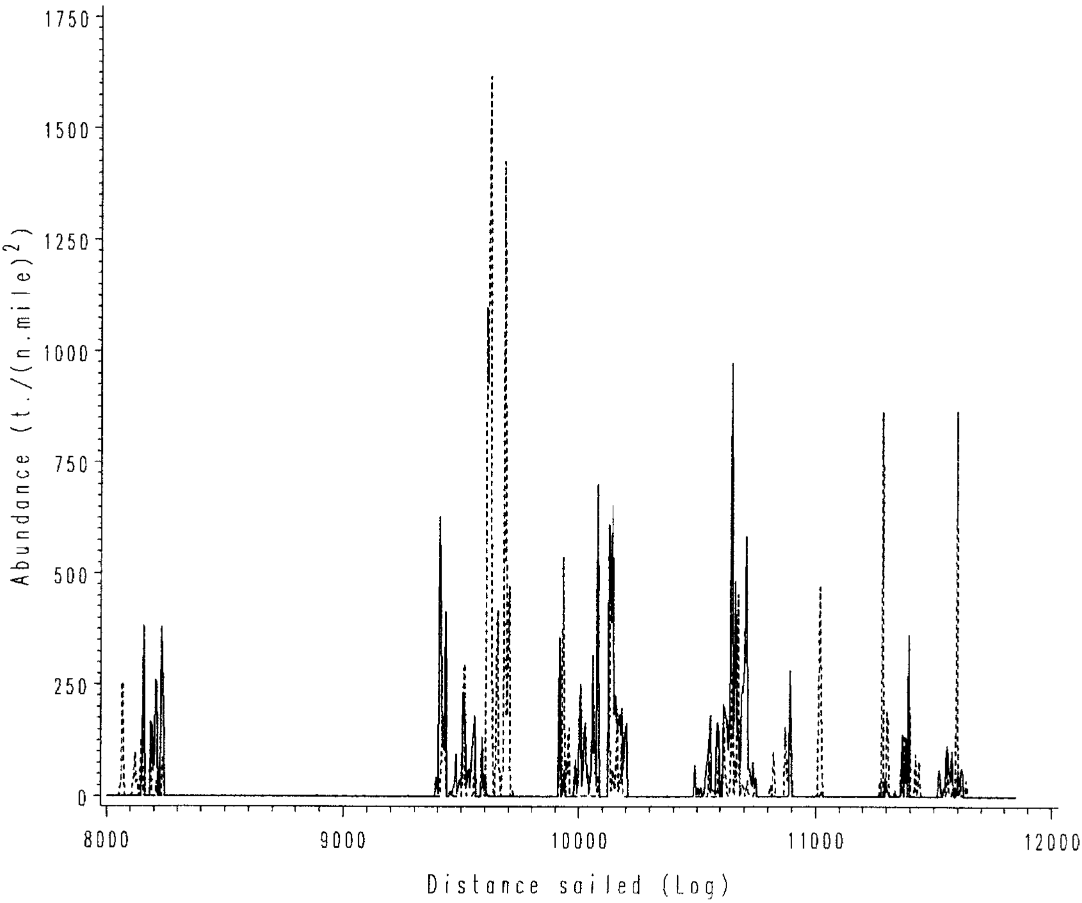

Fig. 9. Abundance of herring in tonnes per square nautical mile (t. n.mi.$^{-2}$) as estimated from the echo integration (broken line) and sonar (full line) recordings.

period 3-14 June, when these herring were located between 64° and 66°N and around 5°W. After this period, the movements of this stock component are uncertain, but it seems to have taken a north-eastern migration to the coastal banks of northern Norway. The third component mixed with the larger and older herring, which were distributed in large schools at 250-400 m depth in the international zone and in the eastern part of the Icelandic EEZ in May. In June, these herring were found in the southern part of the Jan Mayen EEZ, and by July/August they had migrated back to the banks off northern Norway.

Both the younger and older year classes of Norwegian spring spawning herring inhabited the central Norwegian Sea for just about six weeks from about the mid-April until the beginning of June. During that time, the about 47 billion herring present seemed to have exerted a heavy feeding pressure on the plankton communities in the central Norwegian Sea. As evident from the May surveys, the abundance of plankton near surface is substantially lower in the areas in the central Norwegian Sea inhabited by the herring than in the areas west, north and north-east of the Norwegian Sea which at that time had no presence of herring. Because of the possible temperature barrier in the East Icelandic current which may have prevented a further westward migration, the north and north-eastward migrations undertaken in June/July were the only possibilities to encounter areas of higher plankton abundance than in the central Norwegian Sea. The Russian survey in June showed that the plankton community in the central Norwegian Sea did not bloom again after the herring had left. This survey confirmed that the herring encountered higher plankton concentrations when distributed in the northern and north-eastern Norwegian Sea.

The zooplankton biomass distribution for May was obtained by combining data from stations worked by R/Vs *Árni Fridriksson* and *G.O. Sars*. The gears and sampling procedures onboard these vessels were different so that the data obtained may not be entirely comparable. It is to be expected that the MOCNESS sampler hauled obliquely from R/V *G.O. Sars* will catch more of the larger and faster-swimming animals than the WP-2 net hauled vertically from R/V *Árni Fridriksson*. This may partly explain why the very high densities (> 1000 mg dry wt/m^3) were to a large extent confined to the north and north-eastern areas surveyed by R/V *G.O. Sars* in May. However, in this context it is worth pointing out that the large and fast-swimming zooplankton species (e.g. euphausiids) are usually confined to depths > 50 m, and therefore the different nets may have been catching the zooplankton in the near-surface layers to about the same extent.

The total acoustic estimate of about 50 billion herring in the Norwegian Sea and the Barents Sea is remarkably close to the estimate of the ICES Northern Pelagic and Blue whiting Working Group assessment of about 55 billion Norwegian spring spawning herring (Anon. 1996c). The similarities in the age-structured acoustic abundance estimate and the age-structured assessment are especially remarkable. Furthermore, the sonar recordings confirm that quite representative estimates of herring abundance were obtained by the echo integration method over large areas, and distribution in the upper dead zone of the echo sounder or vessel avoidance seem to have been negligible during the May survey by R/V *G.O. Sars*. Finally, there were no systematic migrations during the May surveys which may have biased the acoustic abundance estimate significantly (MacLennan & Simmonds 1992). Thus, it seem possible to obtain a representative abundance estimate of herring when distributed in the Norwegian Sea in May by conventional echo integration. On the other hand, herring recordings by this method in the period June-August in the Norwegian Sea may be significant underestimates because of near surface distribution and avoidance (Misund & al. 1996).

Nevertheless, there are some uncertain factors associated to the acoustic abundance estimate of herring in the Norwegian Sea in May 1996. The areas in the international zone and the Norwegian EEZ were covered with a transect spacing of up to 60 nautical miles which is regarded as far to much for proper mapping of the spatial structure of the distribution of fish stocks (MacLennan & Simmonds 1992). However, the herring were fairly evenly distributed over large areas, both when occurring in scattered layers or small schools at 25-100 m depth in the eastern and southern areas or in large schools at 250-400 m depth in the western areas. When combining the Faroese, Icelandic and Norwegian recordings made by coordinated surveys with 30 nautical mile transects, the combined acoustic estimate for herring in the Norwegian Sea was just 11 % lower than the estimate obtained by the Norwegian survey only. However, for future abundance estimation surveys in the Norwegian Sea, a better coverage with narrower spacing between transects should be attempted to obtain a better mapping of the spatial structure of the herring distributions.

The acoustic abundance estimate was obtained by using a length-dependent target strength relationship recommended for herring surveys (Foote 1987). During the May surveys, the herring were distributed from about 25 m to nearly 400 m depth. For a physostomous species like herring, in which the swimbladder volume seem regulated according to the Boyle-Mariotte law, there are some indications of a depth-dependent target strength (Ona 1990). However, at present a reliable relationship for the depth dependence of the target strength of herring has not been established.

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