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Fifty years of herring migrations in the Norwegian Sea

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The distribution of Norwegian spring-spawning herring is characterized by extensive drift-migration of larvae and fry into the Barents Sea and by substantial feeding and spawning migrations of the adults in the Northeast Atlantic and along the coast of Norway. During the last 50 years, the stock has undergone dramatic changes in numbers and migration. It collapsed in the late 1960s and has taken 30 years to rebuild. The pre- and post-collapse migration patterns are different, and three major migratory regimes can be distinguished during the last 50 years.

Keywords: migration, Norwegian Sea, Norwegian spring-spawning herring, stock size, stock collapse.

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Introduction

Norwegian spring-spawning herring (*Clupea harengus* L.) is a highly migratory stock inhabiting the Norwegian/Icelandic Seas. Its distribution is characterized by extensive drift-migration of larvae and fry into the Barents Sea, and substantial feeding and spawning migrations of the adults in the Norwegian/Icelandic Seas and along the coast of Norway.

During the last 50 years, the Norwegian spring-spawning herring stock has undergone extreme variations in biomass (ICES, 1999). From a stock level estimated at 14 million t in 1950, the stock collapsed in the late 1960s. Slow rebuilding during the 1970s and early 1980s was followed by a significant increase in the late 1980s, after recruitment of the strong 1983 year class, and the mid-1990s after recruitment of the numerous 1991 and 1992 year classes. In 1997, the spawning-stock biomass was again estimated to exceed 10 million t, about 40 years after it had dropped so steeply from that level (ICES, 1999).

The core spawning area is on the Norwegian coast off Møre (62°–63°N), but with important spawning grounds from Lista (58°N) to Vesterålen (69°N), north of the Faroes, and north of the Shetland Isles under appropriate stock size and migratory regimes. At high stock levels, the core feeding area is the Norwegian Sea between Norway, the Faroe Islands, Iceland, Jan Mayen Island, and Bear Island, with feeding north of Iceland when hydrographic conditions permit. At low stock levels, the oceanic distribution is confined to the waters off the Norwegian west coast from about 60°N to 70°N. The wintering areas have been east of Iceland and in fjords in northern Norway, respectively.

The migrations of the herring are closely connected to its stock size and to the hydrographic conditions of the Northeast Atlantic. This paper summarizes the major variability in the herring migrations generated by varying stock size and hydrographic conditions from 1950 to 2000. Most of the high-seas herring research carried out during this period has been coordinated under the auspices of ICES.

The 1950s and 1960s

By 1950, the migrations of Norwegian spring-spawning herring had been studied for almost a century (Boeck, 1871; Sars, 1878; Broch, 1908; Dahl, 1909; Hjort, 1914; Johansen, 1919, 1927; Lea, 1929; Runnstrøm, 1936; Fridriksson, 1944). There was an increasing understanding of the Norwegian and Icelandic Seas as central feeding grounds for the adult herring, and the relation between herring feeding off Icelandic and spawning off the Norwegian coast became steadily clearer. The breakthrough came with tagging experiments by Fridriksson

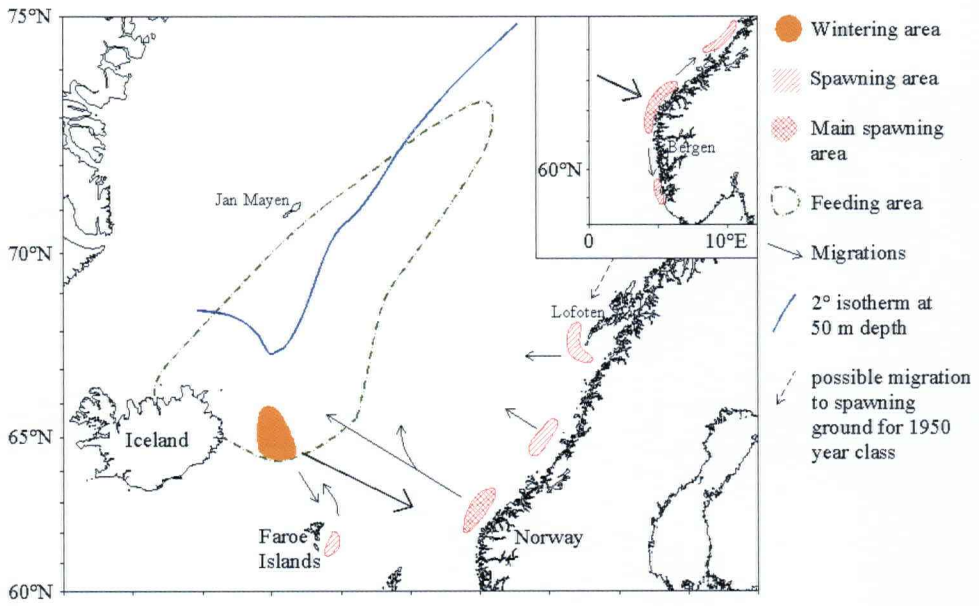

Figure 1. Schematic migration pattern of Norwegian spring-spawning herring, 1950–1962.

and Aasen (1950, 1952), and by extensive acoustic surveys documenting the migrations between Icelandic Sea feeding grounds and Norwegian coast spawning grounds (Devold, 1963). Based on this information, ICES recommended at the 1948 Statutory Meeting that a special investigation of the herring in the Norwegian Sea should start in the summer of 1949. The recommendation was followed up by extensive surveys in the area by Denmark, Iceland, Norway, Scotland, and Sweden. In 1950, the new research vessel "G. O. Sars", equipped with sonar (ASDIC), was available, and sonar was used for the first time to locate herring.

At the 1951 ICES meeting in Amsterdam, three countries—Denmark, Iceland, and Norway—agreed to cooperate on an extended herring investigation programme to cover the Norwegian Sea. From 1957, research vessels from the USSR also joined the programme. These investigations, which were carried out until 1970, originally included only hydrography and herring, but were gradually extended to cover primary production and zooplankton as well.

A review of the joint acoustic investigations during 1950–1970 showed that the stock size, the hydrographic conditions and the migration of the herring in the Norwegian Sea changed greatly (Jakobsson and Østvedt, 1999). In terms of hydrographic conditions, the period can be divided into two unequal parts, the warm years (1950–1964) and the cold years (1965 onwards). In terms of spawning-stock size, the most prominent feature is the more-or-less fatal collapse from more than 10 million t in 1957 to an estimated 1854 t in 1972 (ICES, 1999).

During the warm period (1950–1964), many of the largest herring migrated westwards in the surface layer above the thermocline in June (Figure 1), probably feeding intensely on their way across the cold East Icelandic Current to the areas north of Iceland (Østvedt, 1965; Jakobsson, 1980; Dragesund *et al.*, 1980; Jakobsson and Østvedt, 1999). Younger spawners fed along the polar front from Iceland and northeastwards, past Jan Mayen Island, and towards Bear Island (Figure 1). After the feeding period, the herring gathered in the wintering areas east of Iceland around 10°W (Figure 1). The eastbound spawning migration started in late December/early January, and the herring reached the Norwegian coast by the end of January/February (Devold, 1963). During this period, extensive spawning took place south of Bergen, but gradually, towards the end of the 1950s, the main spawning grounds shifted northwards.

During the cold period in the latter part of the 1960s, the hydrographic conditions off northern Iceland shifted, and in 1965, a large part of the Iceland Sea was covered with ice in the spring (Jakobsson, 1980; Malmberg *et al.*, 1996). This was caused by a strong influx of cold water from the Arctic Ocean. Primary production in the area decreased to a very low level, as did the *Calanus* production (Thórdardóttir, 1977). Reduced food availability and low temperatures were probably the most important reasons for the subsequent major change in the herring's westward feeding migration (Figure 2), al-

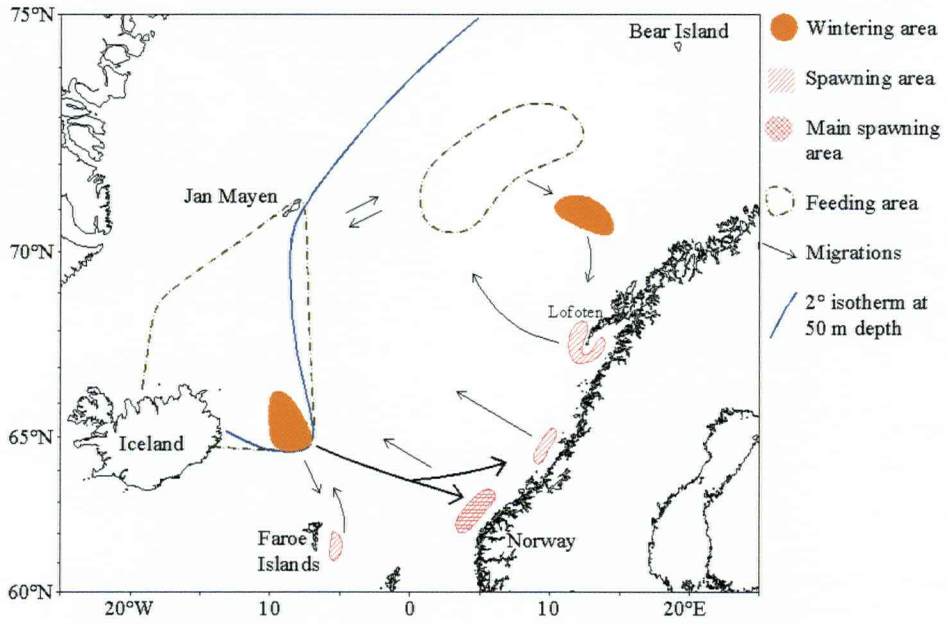

Figure 2. Schematic migration pattern of Norwegian spring-spawning herring, 1965–1966.

though the stock size had also already begun to decline. In subsequent years, feeding herring were observed further and further to the northeast during summer (Figure 3). When the strong 1959 year class matured in 1963–1964, a separate stock component was established in addition to the main component feeding and wintering in the area off East Iceland. This component had its wintering area and feeding grounds in the northeastern parts of the Norwegian Sea (Figure 4), and spawned off Lofoten. This change in the migration pattern occurred at the same time as heavily increased fishing and low recruitment progressively reduced the stock size (ICES, 1999). During 1967–1969, the summer feeding ground fishery had practically ceased owing to the absence of catch by all fleets involved.

The 1970s and 1980s

A comprehensive search for herring on the traditional spawning grounds in 1970–1972 and an extensive larval survey in the same years proved that practically no spawning of herring took place during these years. The spawning stock was practically exterminated. However, reports of shoals of juvenile herring off the Finnmark coast came during the autumn of 1971 and winter of 1972. In late autumn 1972, maturing herring belonging to the 1969 year class were recorded in the Ingøy Deep (71°20'N, 22°40'E), and in the winter of 1973, spawning herring were observed off the Lofoten Islands (Hamre, 1990). This spawning, confirmed by a larval survey the same year, represented the start of the rebuilding phase of Norwegian spring-spawning herring stock. The ban on herring fishing during these years may have saved Norwegian spring-spawning herring from extinction.

During the 1970s, the herring did not leave for the Norwegian Sea summer feeding grounds, but stayed along the Norwegian coast (Hamre, 1990; Figure 5). The northern component fed off Lofoten during the summer and wintered in the fjords inside the Lofoten Islands. In later years, this component spawned along the coast of northern Møre and Trøndelag, fed in coastal waters off Nordland, and wintered in the fjords of Lofoten. The new distribution pattern of the adult stock was confirmed by herring surveys and tagging experiments. The nursery areas of the juveniles are less well known, but small and adolescent herring found on the coast of Nordland, Troms, and Finnmark in subsequent years were obviously the fry of this northern stock component.

A small component of the 1969 year class survived and developed as a separate unit along the Møre coast south of 63°N. It spawned on the southern coast of Møre (62°–63°N), fed in the coastal waters of Møre and Trøndelag, and wintered in the Romsdalfjords (about 63°20'N). The individual growth of the southern stock component was faster than the growth of the northern, the herring spawned at a younger age, and the rate of recruitment in relation to the parent stock was obviously much higher than in the northern stock component.

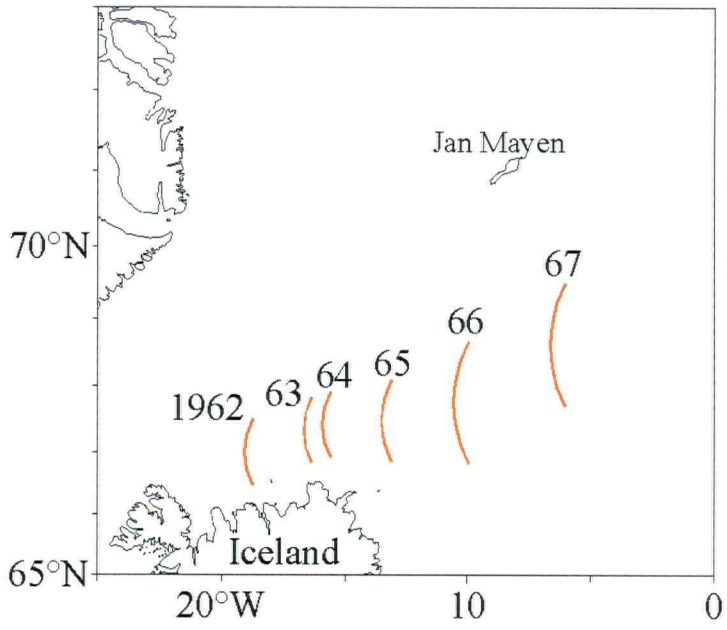

Figure 3. Progressive displacement of the western boundary for the herring feeding migration, 1962–1967.

According to estimates based on tagging data, the southern spawning stock increased from less than 100 000 t in 1977 to more than 200 000 t in 1983, whereas no increase was observed in the northern stock component of about 400 000 t during the same period.

The 1983 year class was the first to give the stock a substantial lift towards its present level. The year class had an oceanic distribution as 0-group (Røttingen, 1990), and an estimated 98.5 % of the juveniles grew up in the Barents Sea (Holst, 1996; Holst and Slotte, 1998). The life history pattern of the juveniles and 0-group indicated that the bulk of the 1983 year class originated from the northern stock component. The 1983 year class emigrated westwards from the Barents Sea in May 1986 and was observed off Lofoten and Vesterålen in the summer and autumn that year (Røttingen, 1990). It wintered in the outer Vestfjord in 1986–1987, fed in a limited area off Lofoten in 1987, and wintered in tributary fjords of the Vestfjord, Ofotfjord, and Tysfjord in 1987–1988. Most of the year class spawned for the first time in 1988 on the traditional grounds of Møre and Trøndelag, and no geographical separation of different stock units was recorded (Røttingen, 1990). Scale readings identified a small component of fast-growing herring, originating from the coastal nurseries, well mixed into the population.

From 1989 onwards, the herring extended their spawning area further to the south and recolonized the grounds between Karmøy and Lindesnes where they had spawned prior to the 1960s. Only a very small fraction of the stock spawned in these areas. After spawning, the herring migrated northwards along the Norwegian west coast and left the coastal waters north of 63°N to feed in the Norwegian Sea. From 1986 onwards, the growing stock of Norwegian spring-spawning herring gradually extended its feeding migration into the central Norwegian Sea. The stock returned to the Norwegian coast in autumn and continued to winter in the Ofotfjord and Tysfjord.

Herring research during the 1970s and 1980s was conducted as national research programmes by Norway and the USSR. The results were reported annually to the ICES Working Group on Atlanto-Scandian Herring, which processed the data for management advice through the Advisory Committee on Fishery Management (ACFM).

The 1990s

During July–August 1991, a herring pairtrawl survey covered large parts of the Norwegian Sea (Holst and Iversen, 1992). Feeding herring were observed in the surface hauls from the Norwegian coast to 5°W and from 66° to 73°N, with the largest concentrations between 69° and 73°N and between 7° and 17°E. The 1983 year class with an estimated spawning biomass at 4.8 million t in 1991 (ICES, 1999) had established a new, but relatively stable oceanic migratory regime. The most pronounced difference as compared with the pre-col-

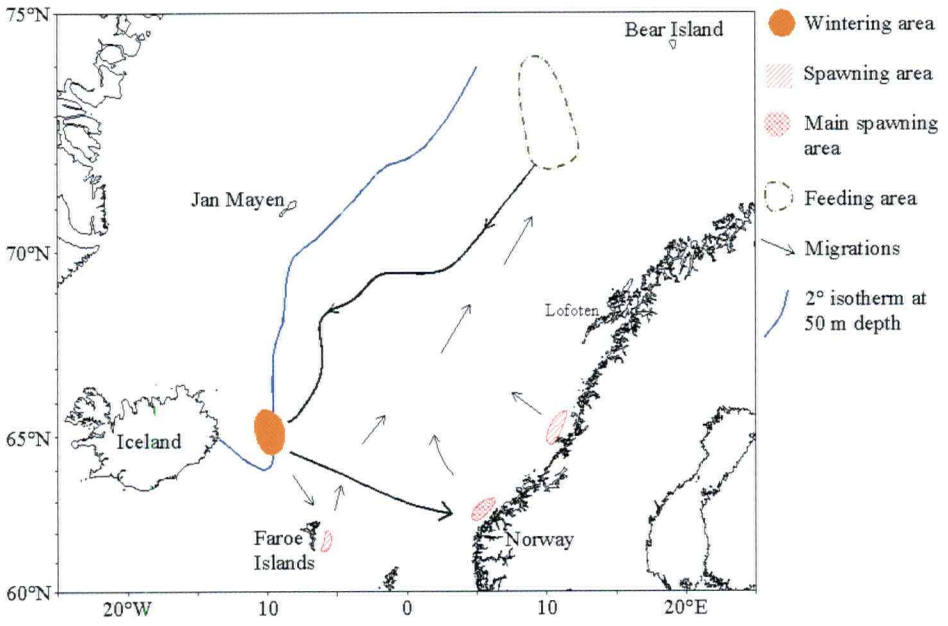

Figure 4. Schematic migration pattern of Norwegian spring-spawning herring, 1967–1969.

lapse period was a shift in wintering areas (Figure 6) from the areas east of Iceland to the Norwegian fjords Ofotfjord and Tysfjord. By 2000, the 1983 year class had been strongly reduced and contributed only marginally to the spawning stock. With the recruitment of the large 1991 and 1992 year classes from 1996 onwards, the wintering area expanded further out into the Vestfjord to about 14°E. The main spawning has been in the Møre area, with significant spawning north towards the Lofoten Archipelago. A small fraction of the stock has spawned south of Stadt (62°N), in particular in the area off Karmøy and south to Lista at 58°N.

In May–June 1994, an international herring fishery developed in the Norwegian Sea. With the renewed interest for the herring, a new need for research arose. During the autumn of 1994, a letter of intent was written by representatives of the marine research institutes of Iceland, Norway, the Faroe Islands, and Russia to initiate a cooperative research effort under the auspices of ICES. Such international efforts had been minimal since the collapse of the herring stock in the late 1960s, and the research efforts had, in general, been carried out only by Norway and Russia in the meantime. From 1995 onwards, international herring surveys have again been organized under the auspices of ICES in the Norwegian Sea. Through an intensive programme of up to 13 acoustic trawl surveys per year during the latter half of the 1990s, the knowledge of the oceanic migrations was more detailed then ever by 2000 (Anon., 1995, 1996; Vilhjálmsson *et al.*, 1997; Misund *et al.*, 1998; Holst *et al.*, 1998, 1999; ICES, 1999, 2000). The surveys have revealed that the older herring migrate from the spawning grounds off western and northwestern Norway in March, northwards along the slope of the continental shelf. A large fraction enters the Norwegian Sea in April through a "corridor" between 67° and 68°N (Misund *et al.*, 1997). The herring schools are then highly aggregated in clusters 0.8–2.5 km apart and extending 0.05–3 km (Mackinson *et al.*, 1999). During the day, the herring "dip into the fridge" when feeding on adult *Calanus*, which are abundant in cold water (about 1°C) at depths up to 400 m (Misund *et al.*, 1997; Mackinson *et al.*, 1999).

In May, the herring are spread over a large area stretching almost from the Norwegian coast and west to about 0–3°W (Misund *et al.*, 1998; Holst *et al.*, 1999; ICES, 2000). A characteristic of the western part of the migration has been large schools at 250–400 m of depth along the cold front extending from the eastern part of the Icelandic EEZ and north to the Jan Mayen EEZ (Vilhjálmsson *et al.*, 1997; Holst *et al.*, 1998, 1999).

By June, the herring have 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. The herring entered the Faroese EEZ in 1995–1998, but in 1999 turned north of these waters, most probably because of lowered temperature caused by a strong East Icelandic Current (Holst *et al.*, 1999). Only sporadic records of herring have been made in the Icelandic EEZ during the latter half of the

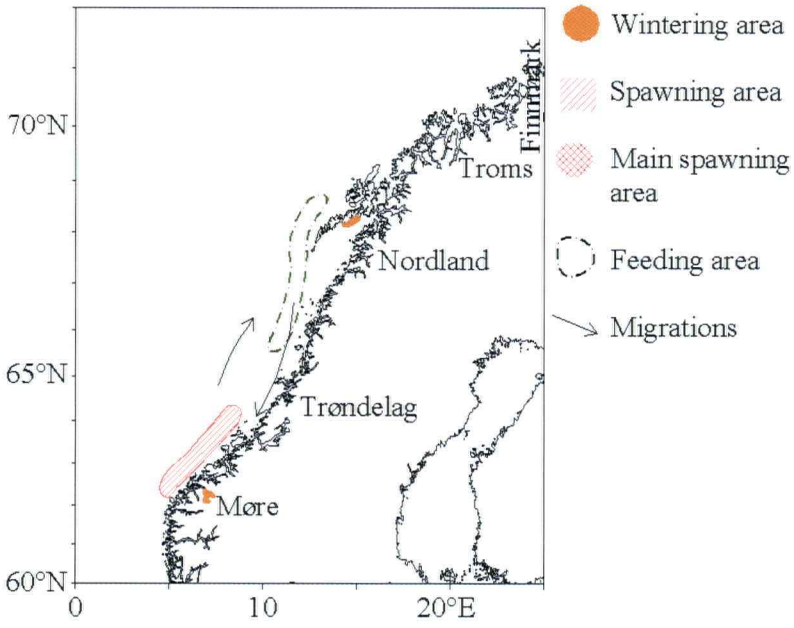

Figure 5. Schematic migration pattern of Norwegian spring-spawning herring, 1972–1986.

1990s. From the central and northern parts of the Norwegian Sea, the stock contracts by a southeasterly migration in August–September towards Vesterålen/ Lofoten (Figure 7), where it arrives by late August–September. The herring then enter the Vestfjord southeast of the Lofoten Archipelago, and by late autumn, some of the herring are also observed in the Ofotfjord and Tysfjord.

Discussion

The stock collapse in the late 1960s was closely related to an extreme increase in the rate of exploitation of all age groups. Although changes in the ocean climate may partly be responsible for the change in migration pattern of the herring after the collapse, it is reasonable to conclude that the shift in wintering area was mainly human induced. It was, therefore, expected that when the stock was rebuilt to the 1950s stock level, the herring would retain their previous migration pattern, including the wintering area off the east coast of Iceland. This has not happened, and the most important question that occupies scientists at present is why. It has been argued that the abandonment of the feeding grounds north of Iceland was an inevitable consequence of the major shift in the flow of the East Icelandic Current and that the area north of Iceland has had low production in the 1960s and after the rebuilding of the stock. This hypothesis indicates that if the area north of Iceland again becomes highly productive and favourable for feeding, the herring may change to their old migration pattern and retain their previous wintering area. Our basic hypothesis is that the herring migration is density-dependent. The core areas of the stock will be visited both during high and low stock levels, while more marginal areas will only be visited during large or extremely large stock levels. If the feeding grounds north of Iceland represent such a marginal feeding ground, it may not be visited again unless the stock rebuilds to a level of maybe 15 or 20 million t.

Another hypothesis is concerned with the effects of learning. When the 1969 year class spawned in 1973, there were no adults available to guide them to the rich feeding areas north of Iceland and to the wintering area in the western Norwegian Sea. The latter hypothesis has no answer to the questions of how, when, and if the herring will return to their previous migration pattern. Nobody knows and only time may show.

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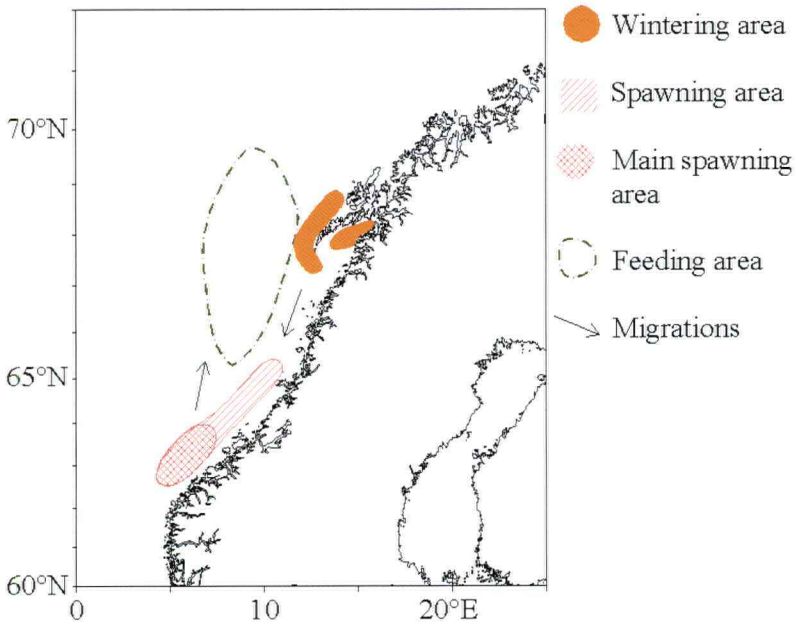

Figure 6. Migration pattern of Norwegian spring-spawning herring, 1986–1988.

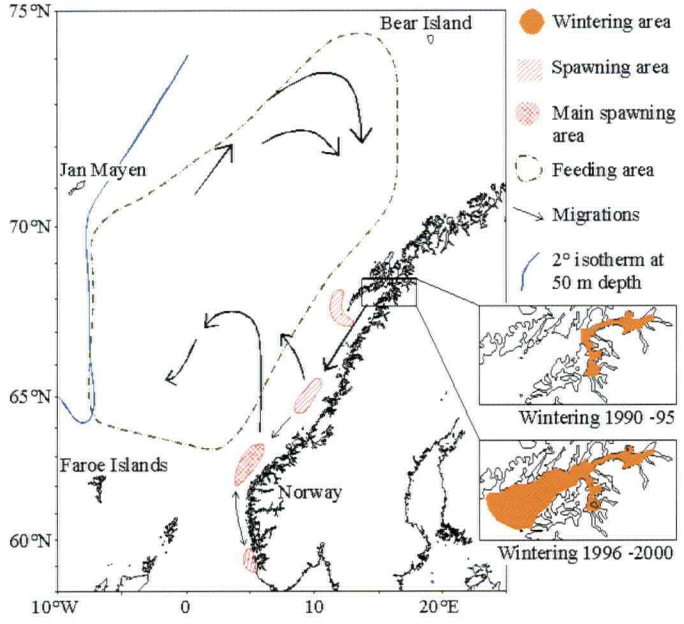

Figure 7. Migration pattern of Norwegian spring-spawning herring during the 1990s.

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