VARIATION IN MIGRATION AND ABUNDANCE OF NORWEGIAN SPRING SPAWNING HERRING (*CLUPEA HARENGUS* L.)

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The Norwegian spring spawning herring has undergone great fluctuations in abundance and changes in migration. In the middle of this century the stock was in a productive phase, after which a serious depletion took place and the stock collapsed by the end of the 1960s. The primary factor for the collapse was high fishing pressure. A gradual, but small increase in the adult stock took place between 1974 and 1986. In this period the adult herring did not leave the coast after spawning to feed in the Norwegian Sea, as in previous years, but remained near shore to feed and later migrated into the fjords for wintering.

The only numerous year class between 1970 and 1987 was that of 1983. When this year class became mature a significant increase in the spawning stock took place. At the same time a change in the migration pattern was recorded. From 1989 spawning extended southwards along the Norwegian coast, and during the 1990s the Norwegian Sea was increasingly reutilized for feeding. However, wintering still took place in the fjords. Two strong year classes, those of 1991 and 1992, started to recruit to the spawning stock in 1994 and 1995. The subsequent three year classes are weak and a decline in the spawning stock size is expected after 1997-98. Without agreement on total allowable catches (TACs), which limit fishing mortality to a low level, the spawning stock may again decrease below the minimum biological acceptable limit, and the potential largest fish resource in the North Atlantic may again be depleted.

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KEYWORDS: Juveniles and adults; exploitation; feeding; growth; spawning; wintering.

INTRODUCTION

The Norwegian spring spawning herring (*Clupea harengus* L.) belong to the group of Atlanto-Scandian herring. This name was introduced by JOHANSEN (1919) to describe the herring found along the Norwegian coast, in the Norwegian Sea, in areas off Iceland, off the Faroes and on the north-eastern edge of the North Sea. Today Atlanto-Scandian herring is used as a common name for the Norwegian spring spawning herring, Icelandic spring and Icelandic summer spawners (Fig. 1).

The Norwegian spring spawning herring is potentially the largest of these stocks. In a virgin state the total stock biomass may have reached a level of 15 million tonnes, and constituted the largest single fish stock unit in the North Atlantic. It is one of the world's most important clupeid stocks. However, great fluctuations in abundance have taken place. The stock was in a productive phase in the middle of this century up to the end of the 1950s (DEVOLD 1963; DRAGESUND & JAKOBSSON 1963; MARTI & FEDOROV 1963; ØSTVEDT 1963), when a serious depletion started. A dramatic increase in the exploitation rate took place and the stock collapsed by the end of the 1960s (DRAGESUND & al. 1980; JAKOBSSON 1980). The distribution and migratory pattern of the herring changed when the stock size declined, and the traditional feeding and wintering grounds in the Norwegian Sea were left after the collapse. During the first part of the recovery period, from 1970 to 1986, the adult herring remained in coastal waters to feed and wintered in fjords of northern Norway. From the late 1980s, when a further increase in stock size was recorded, feeding in the Norwegian Sea again took place (RØTTINGEN 1992).

As a plankton feeder the herring plays an important role in converting the abundant standing stocks of zooplankton in the Norwegian Sea into food directly available for human consumption. However, the plankton production is highly dependent on the dynamic and circulation processes of the water masses as well as on the environmental conditions in the area of distribution and adjacent waters (JAKOBSSON 1963a; 1980; PAVSHTIKS & TIMOKHINA 1972; AKSNES & BLINDHEIM 1996). Figure 2 indicates the monthly development from March to September of zooplankton concentrations in the surface layers from the Norwegian coastal area into

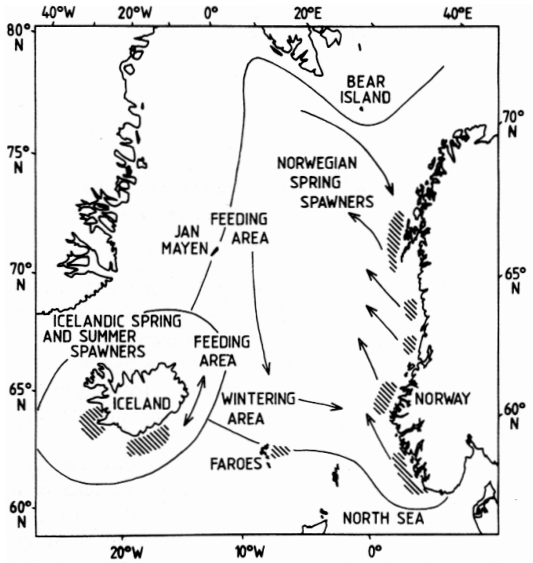

Figure 1. Distribution of stocks within the Atlanto-Scandian herring group. Spawning areas are hatched (after Dragesund & al. 1980).

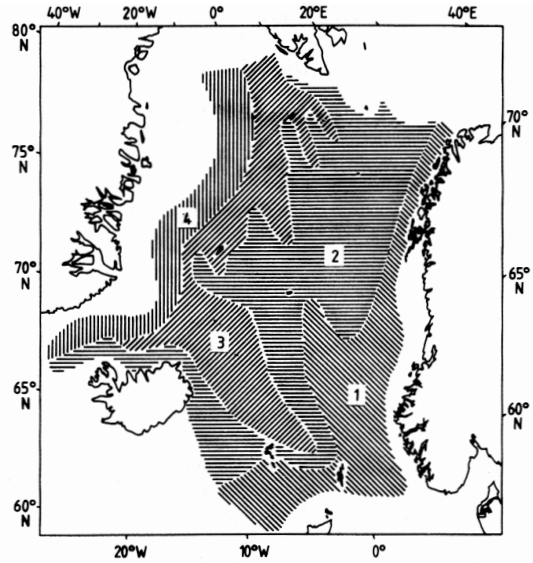

Figure 2. Monthly development of the 'spring' increase of zooplankton in the Norwegian Sea and adjacent waters (modified from Pavshtiks & Timokhina 1972). 1. March-April. 2. May-June. 3. July-August. 4. September.

the Norwegian Sea. The 'spring' increase in zooplankton gradually extends north-westwards into Atlantic water in spring and early summer, and later into mixed and Arctic waters. It is expected that the availability of these plankton resources will determine the distribution and migration pattern of the herring during the feeding season, and they will also play an important role for the production potential of the stock.

In the present paper we will summarise the variation in migration and abundance of the Norwegian spring spawning herring during the period 1950-1995 and comment on the exploitation and management of the stock during the same period.

THE PERIOD BEFORE THE COLLAPSE, 1950-1969

Distribution and migration

The main migration pattern of the adult herring during the period 1950-1962 is illustrated in Figure 3. In this period the adult herring migrated after spawning towards the feeding area in the Norwegian Sea and fed heavily on zooplankton (mainly copepods). The limit of the summer feeding migration extended from the Jan Mayen area in the north to the western borders of the East Icelandic Current in the south (Fridriksson & Aasen 1950; Devold 1963; Jakobsson 1968). The feeding area contracted during autumn when the herring were found along the southern border of the East Icelandic Current. The ripening herring wintered in this area. In January the prespawning concentrations moved towards the Norwegian coast, usually reaching the coast in the area off Stad (at about 62° N) in January-February (Devold 1963) and distributed themselves along the coast for spawning in March at depths from 50 to 150 m. During the early 1950s, when the standing stock was at a high level, the herring spawned at several places along the Norwegian coast from Lindesnes to Lofoten, with the most important spawning areas at the Møre coast and at the southwestern grounds south of Bergen (Devold 1963). This brief description of the distribution and migration of the adult stock was the usual one during the 1950s. It is likely that a similar migratory pattern also existed prior to this period, e.g. during the 1930s and 1940s, when the stock probably also was in a productive phase. However, in the late 1950s the spawning gradually shifted northwards and from 1960 onwards the spawning south of Stad was negligible (Dragesund 1970a). In general, the area of spawning shrunk in proportion to the stock size, which in 1960 had decreased to a level of almost half its size in 1950 (Anon. 1970; 1977).

Figure 4 shows a schematic illustration of the general distribution of the early stages of herring, with special reference to the abundant 1959 year class. Soon after hatching (mainly in April) the larvae rise into the upper water layers (50-0m) and are transported northwards in coastal waters (S < 35). An extensive north-

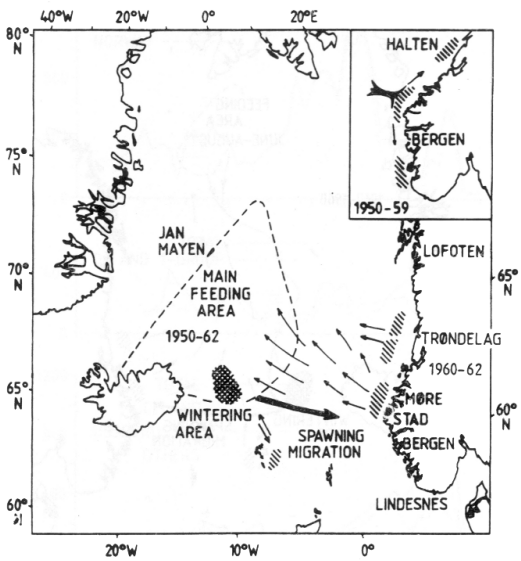

Figure 3. Migration routes of Norwegian spring spawning herring, 1950-1962. (modified from ANON. 1970).

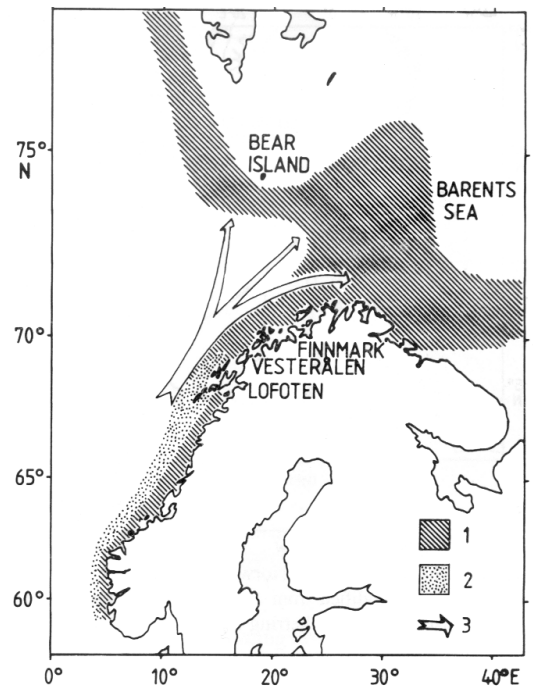

Figure 4. Distribution of young herring. 1. Nursery area. 2. Larval distribution. 3. Direction of post-larval drift to the offshore nursery area (DRAGESUND & al. 1980).

ward drift of most larvae takes place from spawning grounds along the coast. In summer and early autumn 0-group herring are generally recorded as sound scatterers in the top layers of water along the Norwegian coast and in the Barents Sea. In all years concentrations of 0-group herring are observed along the coast in early autumn, particularly at the entrances to the fjords (DRAGESUND 1970b). Later in the autumn the herring penetrate farther into the fjords. The offshore distribution is more variable and is closely related to the 0-group abundance and the surface current and wind pattern along the coast during the drift migration phase (DRAGESUND 1970a; DRAGESUND & NAKKEN 1973; KRYSOV & al. 1995; JOHANNESSEN & al. 1995a).

The 0-group herring remain in these areas during the following 2 to 3 years before a gradual emigration from the nursery areas (the fjords and the central parts of the Barents Sea) takes place depending on the feeding conditions for the juvenile herring. Before the collapse of the stock the maturing herring usually joined the adults at an age of 4-5 years during the feeding period in the Norwegian Sea (DRAGESUND & al. 1980).

Also during the period 1963-66 the main feeding took place in the Iceland-Jan Mayen area. However, in 1963 a separate stock component was established in addition to the main one (Fig. 5). This herring had spawned for the first time at Lofoten in 1963 and migrated after spawning to the region south-west of Bear Island for feeding. At the end of the feeding season some of this herring moved to the wintering area off East Iceland, and recruited to the main component of the adult stock. However, most of the herring which had spawned at Lofoten together with some herring coming from the main feeding area at Jan Mayen migrated after feeding to a wintering area located between Bear Island and the Norwegian coast, and migrated thereafter to Lofoten for spawning. The main part of the maturing herring, which recruited to the Lofoten component, were also wintering in this area. (BENKO & al. 1966; DEVOLD 1968; JAKOBSSON 1968).

In the autumn of 1966 this separate stock component migrated all the way from the Bear Island feeding grounds to the wintering area off East Iceland and mixed with the main component of the stock that traditionally wintered in that area. In 1967-1968 the two components came together (Fig. 6) and the feeding took place in an area west of Bear Island, whereas the wintering was located off East Iceland (DEVOLD 1968; JAKOBSSON 1968). The spawning was concentrated at the coast off mid Norway (DRAGESUND & al. 1980).

The significant changes in the distribution and migratory pattern which took place in the 1960s, first a splitting of the stock into two components and later a rejoining of the two with the adoption of a migration pattern combined from the two earlier patterns, are dif-

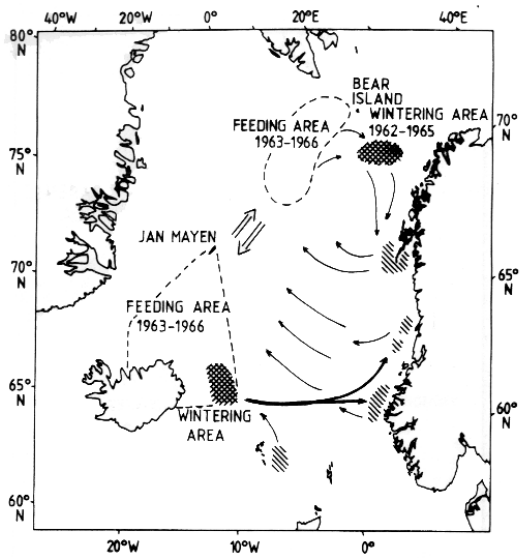

Figure 5. Migration routes of Norwegian spring spawning herring, 1963-66. (modified from ANON. 1970). Double arrows indicate a splitting of the herring in two separate areas.

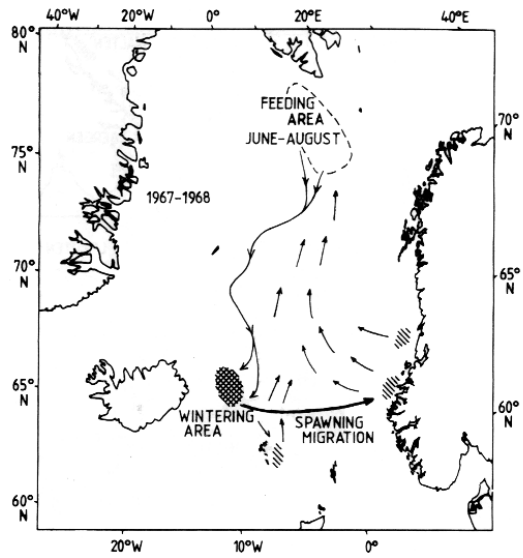

Figure 6. Migration routes of Norwegian spring spawning herring in 1967-1968, with a rejoining of the two components adopting a migration pattern combined from the two earlier ones.

ficult to explain. They occurred during the same period as a dramatic increase in fishing effort took place and could be due to a combination of high exploitation rate (DRAGESUND & al. 1980) and changes in the environmental conditions (MALMBERG 1969; JAKOBSSON 1980).

Exploitation and abundance

Traditionally the main fishery on adult herring has been the winter herring fishery along the Norwegian west coast prior to and during the spawning season (ØSTVEDT 1958, 1963, DEVOLD 1963; DRAGESUND & al. 1980; SLOTTE & JOHANNESSEN in press). This fishery has almost entirely been carried out by Norway (Fig. 7). In addition to the fishery on adults, a fishery on young and adolescent herring has taken place at the Norwegian coast and in the fjords, mainly in northern Norway. This fishery has been based on 'small herring' (*småsild*), i.e. mainly 0- and 1-group fish, and on 'fat herring' (*feitsild*), i.e. 1- to 4-group fish (DRAGESUND 1970b). An analysis of the total catch of young and adolescent herring landed during the period 1930-1970 shows that considerable fluctuations have occurred (Fig. 7). It should be noted that a significant increase in the catch of 'fat-herring' was recorded in the 1960s.

Another important fishery for adult herring, the summer and autumn herring fishery, took place on the feeding grounds in the Norwegian Sea (FRIDRIKSSON 1944; 1963; MARTI 1959; MARTI & FEDOROV 1963; JAKOBSSON 1963a,b). This fishery (Fig. 7) was located for a long period off northern and north-eastern Iceland and the stock was principally exploited by Icelandic and Norwegian vessels, mainly purse seiners, until about 1950 when an extensive drift net fishery was started by Russia. In the late 1950s new technical advances considerably improved the purse-seining system in this fishery. Development of acoustic instruments also made the searching technique for pelagic schools considerably more efficient. The new fishing technique made it possible to extend the fishery far offshore into the Norwegian Sea and the fishing season lasted until October-November with fishing mortality increasing considerably. The adult stock was depleted from a level of 10 mill. tonnes in 1950 to almost zero in 1968-1970. During this period fishing mortality increased from about 0.1 to about 1.0-1.5 (DRAGESUND & al. 1980) (Fig. 8).

The rise in fishing mortalities on the adult stock was mainly a result of higher fishing effort in the summer and autumn fishery combined with decreasing stock size. ULLTANG (1976) showed that in a purse seine fishery a constant fishing effort may generate a constant catch instead of a constant fishing mortality as is usually assumed. ULLTANG (1980) has further shown that under such circumstances, increasing fishing effort and decreasing recruitment may lead to an exponential increase in the fishing mortality.

Although at least two very strong year classes (1950 and 1959) recruited to the adult stock during the period 1955-1965, the spawning stock showed a dramatic de-

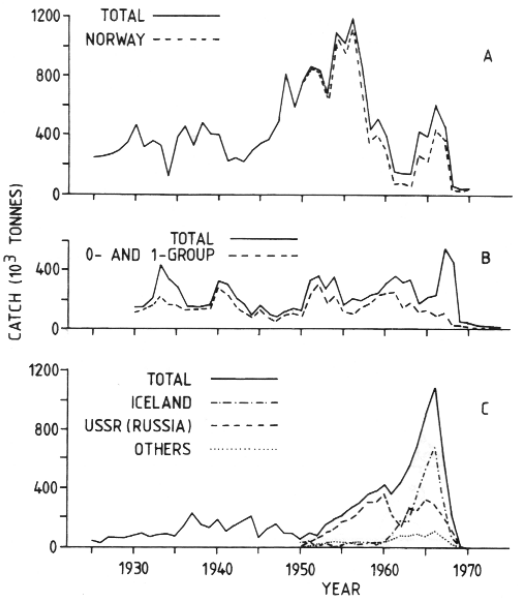

Figure 7. Landings of Norwegian spring spawning herring (Dragesund & al. 1980). A. The catch of adults during the winter herring fishery in 1925-1970. B. The catch of young and adolescent herring in 1930-1974. C. The catch of adults during the summer and autumn herring fishery in 1925-1970.

cline (Dragesund & al. 1980). The failure in recruitment was partly due to a series of weak or moderate year classes (Fig. 9), but the main reason for the very weak recruitment to the adult stock in 1950-1970 was the Norwegian young and adolescent herring fishery in coastal and later also offshore waters (Dragesund & al. 1980). An increase in fishing mortality with decreasing year class strength was observed in the young herring fishery. These estimates reflect the fact that in this fishery as well the catchability coefficient increased with decreasing abundance. All investigations carried out on

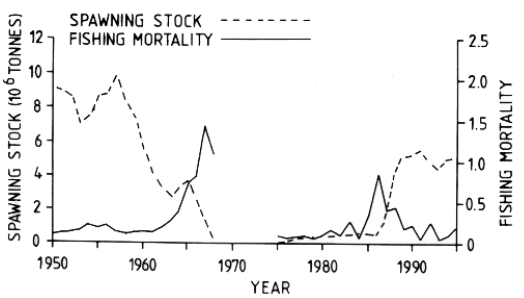

Figure 8. Spawning stock size and fishing mortality of 7-year old and older herring in 1950-1968 (Dragesund & al. 1980) and 1975-1995 (after Anon. 1996).

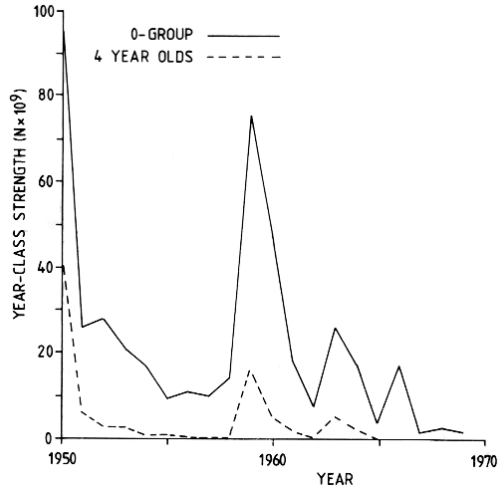

Figure 9. Year class strength in number as 0-group and 4 year old herring, 1950-1969 (Dragesund & al. 1980).

Norwegian spring spawning herring clearly showed that the fishing pressure, especially on young and adolescent herring, but also on adult herring in the years 1965-1968, was the primary factor in the collapse of this herring stock (Dragesund 1970b; Dragesund & al. 1980).

THE RECOVERY PERIOD, 1970-1995

The state of the stock from 1970 to 1986

The summer and autumn fishery for adult herring terminated in 1969, and no herring were recorded at the usual feeding areas in the Norwegian Sea during the following years. The winter herring fishery on the spawning grounds continued on the depleted stock also in 1970 and 1971. A total ban on this fishery was introduced in 1972 (Dragesund & al. 1980). Practically no adult herring were recorded on the usual spawning grounds in 1972. The very low number of newly hatched larvae in 1970-1972 (Fig. 10) and later the very low abundances of the 1970-72 year classes as adults, demonstrated that the spawning stock collapsed by the end of the 1960s.

The development in the stock since 1970 has been closely monitored by use of tagging experiments, research vessel surveys and information from surveys and commercial fishery directed towards other species. High fishing activity for other species by commercial vessels and extensive year-round surveys by research vessels, applying acoustic recording equipment, would detect herring if present in large quantities in any area during the 1970s.

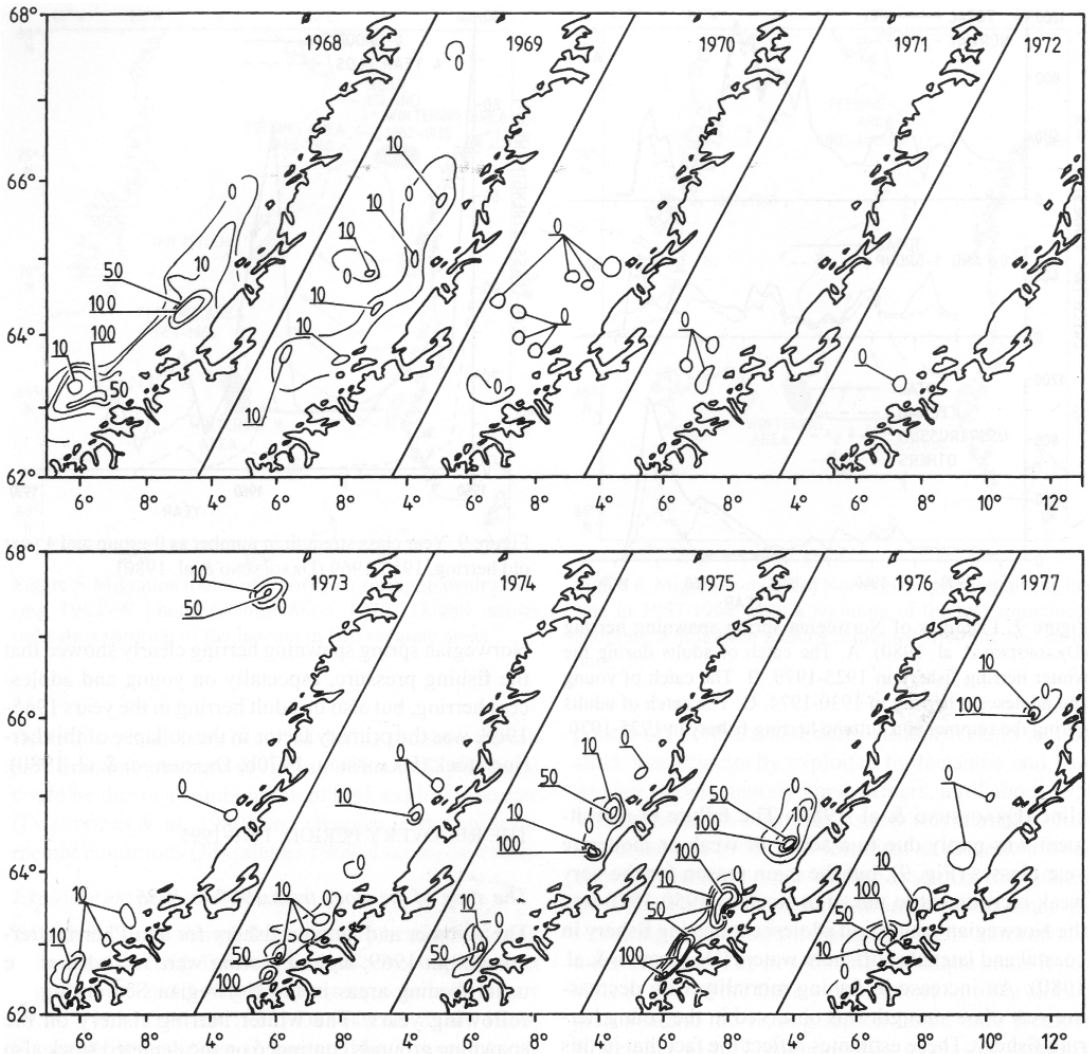

Figure 10. Distribution of herring larvae, 1968-1977. Equal levels of larval abundance are indicated by isolines. The figures represent number of larvae below 1 m^2 surface (Dragesund & al. 1980).

The abundance of immature herring was also very low after the collapse, but still some fishery on young herring was carried out. Small concentrations of herring, mainly belonging to the 1969 year class were observed off the coast of northern Norway (Finnmark) in 1971. This last remnant of the stock probably survived as juveniles somewhere in the Barents Sea or in the north-eastern part of the Norwegian Sea (Dragesund & al. 1980).

First time spawners of the 1969 year class were observed at the spawning grounds off Lofoten and Vesterålen in the winter of 1973. Also farther south at the Møre coast herring from the same year class spawned for the first time in 1973 (Fig. 10). Thus two small components of immature herring (mainly from the 1969 year class) survived the heavy exploitation in the 1960s, one in the Barents Sea and the other one at the west coast of Norway, the northern component being by far the largest (Dragesund & al. 1980). The northern component left the spawning grounds at Lofoten and continued to spawn in 1974-77 on the traditional spawning grounds along the coast of mid Norway (Fig. 10).

After spawning the adult herring did not leave the coast to feed in the Norwegian Sea as in previous years, but remained in near shore waters to feed. The adult herring migrated northwards along the coast after spawning and most frequently had their feeding grounds

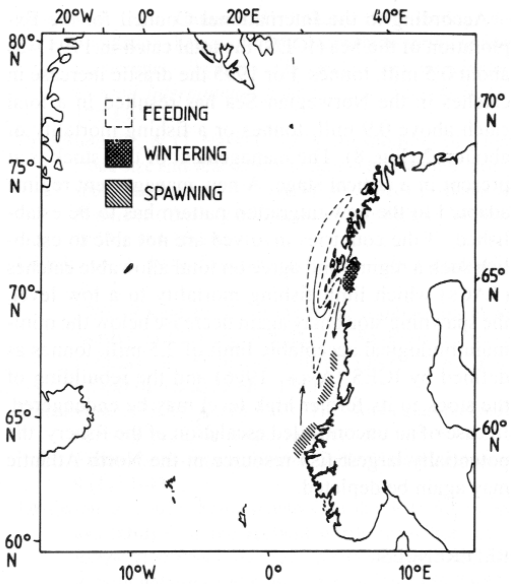

Figure 11. Distribution and migration of adult herring during feeding, wintering and spawning in 1974-1986 (modified from Dragesund & al. 1980; Røttingen 1990).

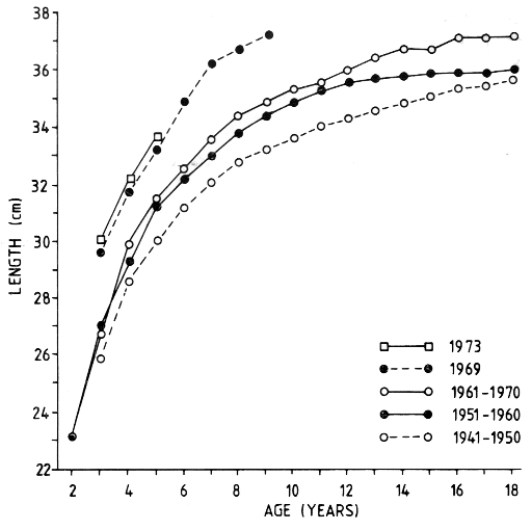

Figure 12. Growth curves of Norwegian spring spawning herring in earlier periods compared with those of the 1969 and 1973 year classes (after Dragesund & al. 1980).

in the Lofoten and Vesterålen area during the summer. In late autumn, after the feeding period was over, the herring migrated into the fjords for wintering. Here they were found in dense concentrations until an emigration took place in January-February and the herring moved to the spawning grounds located along the coast of Trøndelag and Møre (Fig. 11). From 1974 to 1986 this was the general migration pattern for the adult stock.

No marked increase in the spawning stock size was observed in 1973-76. However, in 1977 an increase in the spawning stock size was recorded when the 1973 year class started to recruit to the spawning stock (Fig.8). A gradual, but small increase in the adult stock took place during the following 10 years up to 1986 (Anon. 1996).

The migration pattern of the young herring during the early stages (the first 2-3 years) was similar to the period before the collapse. The maturing herring recruited to the adult stock mainly during the feeding and wintering period along the coast as they gradually reached the prespawning stage at an age of 3-4 years. A significant change in the growth pattern was observed during the period with low stock abundance. Figure 12 shows growth curves for earlier periods compared with those of the 1969 and 1973 year classes. The growth pattern changed from being slower for the abundant 1950 year class to be more rapid for the less numerous 1969 and 1973 year classes.

Abundance and migration: development from 1987 to 1995

The first really numerous year class observed during the recovery period from 1970 to 1990 was that of 1983 (Røttingen 1990). When this year class became mature a significant increase in the spawning stock occurred (Fig. 8). During the 0-group survey in 1983 the abundance of this year class was considerably higher than earlier recordings in the 1970s and 1980s. As the 1983 year class gradually started to mature in 1986, the spawning stock size increased from a level of 1.2 mill. tonnes in 1987 to about 4.0 mill. tonnes in 1988 (Anon. 1996). At the same time a change in the migration could be seen. Although the same spawning grounds were used as in the previous 10-15 years a more southward extension of the spawning could be observed. Already in 1989 some spawning took place at the traditional spawning grounds south of Bergen (Karmøy) and also the spawning at the Møre coast moved slightly southwards (Johannessen & al. 1995b).

After spawning the feeding migration gradually extended somewhat farther out from the coast (Røttingen 1990) and during the 1990s also the more central part of the Norwegian Sea was used as feeding areas (Røttingen 1992; Misund & al. 1997). However, after feeding the herring still continued to move eastward towards the Norwegian coast (off Vesterålen and Lofoten) and penetrated farther inshore, mainly into the Ofoten fjord and Tysfjord to winter. In January a gradual emigration took place from the wintering areas and the

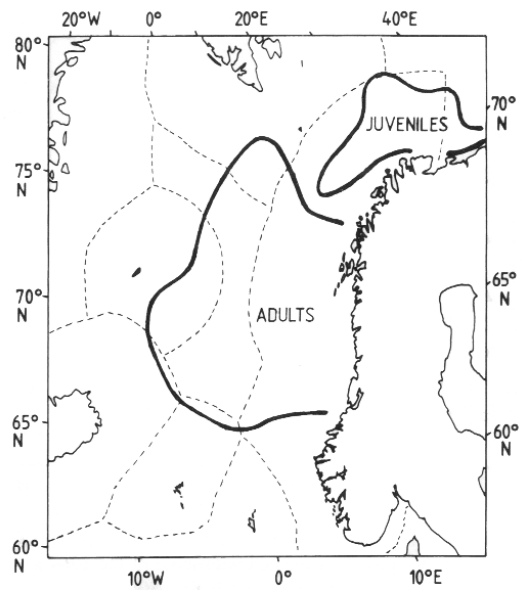

Figure 13. Distribution of juvenile and adult herring in the Norwegian Sea and Barents Sea during early summer and autumn of 1995 in relation to national EEZs and international waters (modified after ANON. 1996).

herring started a southward migration towards the spawning grounds off mid Norway. Also some spawning was observed in 1989-95 at spawning grounds south of Bergen (JOHANNESSEN & al. 1995b; Aril Slotte & Arne Johannessen pers. commn). The spawning stock size during the early 1990s varied between 4.5 and 5.5 mill. tonnes (ANON. 1996).

In 1991 and especially in 1992, the abundances of 0-group herring again were found to be very high in the Barents Sea**.** Accordingly, the strong year classes of 1991 and 1992 recruited to the spawning stock from 1995/96 onwards resulting in a considerable increase in the spawning stock size to a level of at least 7 mill. tonnes in 1997 (ANON. 1996). However, as the subsequent three year classes are weak (ANON. 1996) a reduction in the spawning stock size probably will start after 1998.

CONCLUDING REMARKS

The increase in stock size and availability of herring resulted in a considerably higher total catch in 1995 than expected. As the stock again migrated far into the Norwegian Sea and reached the former feeding grounds in the Icelandic and Faroese economic zones as well as the international area in the central Norwegian Sea (Fig. 13) a large international herring fleet started to fish on the stock throughout the summer-autumn feeding season.

According to the International Council for the Exploration of the Sea (ICES) the total catch in 1994 was about 0.5 mill. tonnes. For 1995 the drastic increase in catches in the Norwegian Sea has resulted in a total catch above 0.9 mill. tonnes or a fishing mortality of about 0.2 (Fig. 8). The management of this stock is at present in a critical stage. A new management regime adapted to the new migration pattern has to be established. If the countries involved are not able to establish such a regime and agree on total allowable catches (TACs) which limit fishing mortality to a low level, the spawning stock may again decrease below the minimum biological acceptable limit of 2.5 mill. tonnes as defined by ICES (ANON. 1996) and the rebuilding of the stock to its former high level may be endangered. In case of an uncontrolled escalation of the fishery, the potentially largest fish resource in the North Atlantic may again be depleted.

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