Herring

Section I: Life history.

LIFE HISTORY AND EXPLOITATION OF THE NORWEGIAN SPRING SPAWNING HERRING

by

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ABSTRACT

This paper is a review of the history and exploitation of the Norwegian spring spawning herring stock. In a virgin state the biomass of this stock may have ranged from 15 to 20 million tonnes and it was the most important fish resource in the Northeast Atlantic. The adult stock utilized the rich plankton production along the Polar Front in the Norwegian Sea but spawned during winter on the Norwegian west coast. These spawners formed the basis for the largest fishery in Europe for centuries. The young and adolescent herring are distributed in Norwegian coastal waters and in the Barents Sea where they constitute the most important prey species for many stocks of predators, both of fish, birds and mammals.

Due to technical advances the exploitation of the herring increased tremendously in the 1960's and the adult stock was fished out completely in 1970. Some small components of juvenile herring did however survive, and spawned on the traditional spawning grounds in 1973. After spawning the herring did not migrate to the traditional feeding area in the Norwegian Sea, but remained in Norwegian coastal waters throughout the year. In later years the stock has recovered slowly, but the old traditional migration pattern of herring between the Polar Front area and the Norwegian coast has not yet been retained. It is concluded that the break down of the life cycles of the herring is the prime reason for the recent crisis which has developed in the Barents Sea stocks and fisheries.

INTRODUCTION

The present paper reviews the history of the fishery and research on the Norwegian spring spawning herring and the regulation measures introduced to conserve the stock in recent years. In conclusion emphasis is laid on the importance of the stock for the balance in the predation/prey relationship in the ecosystem of the Norwegian Sea and Barents Sea.

STOCK IDENTITY

The term "Atlanto-Scandian herring" was introduced by Johansen (1919) and is used as a common name for three stocks: Norwegian spring spawners, Icelandic spring spawners, and Icelandic summer spawners. The Norwegian spring spawners are the largest of these stocks, with spawning grounds situated mainly along the Norwegian coast.

STOCK STRUCTURE

Whether the Norwegian spring-spawning herring constitute a single homogeneous stock has been the subject of conflicting scientific views. Broch (1908) found that the vertebral counts of the spawners were not the same throughout the total distribution range. Lea (1929) observed that the scales of young herring from northern and southern Norway differed in the pattern of their winter rings, reflecting differences in their growth rates during adolescence. In the light of such differences, Schnackenbeck (1931) concluded that the Norwegian spawning population was divisible into at least two "races", and Ottestad (1934) splitted the stock into a northern and a southern component with spawning grounds to the north and south of Møre respectively. Runnstrøm (1937,1941), on the other hand, claimed that such a strict separation was not consistent with the available evidences.

Østvedt (1958) found that there was an increasing intermixing of the two types with age, and that the proportions of the two types varied considerably between year classes. He concluded that herring of the two growth types could not be members of different "races". The results of the tagging experiments carried out on the Norwegian spawning grounds and in the oceanic feeding areas (Dragesund and Jakobsson, 1963) also show that the spawners change their grounds from year to year along the Norwegian coast. In light of all the available evidences it is therefore reasonable to assume that the Norwegian spring spawners are members of a single stock and that the two distinctive growth types are herring which originate from different nursery areas.

DISTRIBUTION AND MIGRATION

1. Adult herring

Knowledge of the distribution and migration of the adult herring is obtained from several sources, such as racial analysis (Fridriksson, 1963), tagging experiments (Fridriksson and Aasen, 1952; Jakobsson, 1963) and acoustic surveys (Devold, 1963; Anon., 1964; and Jakobsson, 1971). For many years these surveys were carried out jointly by Denmark, Iceland, Norway and the USSR.

2. Herring periods

For centuries this herring has been the basis for one of the largest fisheries in Norway, and for more than 100 years the subject of scientific investigations. In 1857 the Norwegian Government gave Dr.Axel Boeck (1871) the task of investigating the so-called "spring herring". Boeck brought together many historical facts about the Norwegian spring herring fishery and he found that the fishery had periods of high abundance alternating with periods of extreme scarcity. According to Boeck, the symptoms of a Norwegian herring period approaching its end are that the herring arrive later each year at the Norwegian coast, which had been the situation in the 1870's. Boeck found similar periodicity in the herring fishery of Bohuslän in Sweden and suggested that this fishery could originate from the Norwegian spring spawning herring stock. Boeck's view that the spring herring could leave the usual spawning grounds created great fear among the fishermen, and the Norwegian Government asked G.O. Sars to investigate this problem.

After three years of investigation G.O.Sars succeeded in drawing a fairly correct picture of the life history of the Norwegian herring. He believed that the "spring herring" lived in the surface layers of the open sea between Scotland, Norway and Iceland, feeding on copepods, and attaining maturity when being about 6 years old. The spawning area was located off the Norwegian coast between Stavanger and Kristiansund, from which the larvae were spread northwards by the currents. In the years 1868-1874 great quantities of so-called "large herring" were caught off northern Norway in the autumn. Originally he regarded the "large herring" as a special tribe with unknown spawning grounds but later he found that the connection between the "spring herring" and "large herring" fisheries was closer than he earlier believed. With respect to alternating herring periods, G.O. Sars views were differed from those of Boeck. Sars had found juvenile herring further off the coast than was usual and considered it likely that the herring would soon return to the old spawning grounds. He questioned whether herring periods really did exist in the Norwegian herring fisheries and thought it unlikely that there should be any connection between the "spring herring" and the herring responsible for the great herring fisheries in Bohuslän.

Jensen (1881) and Buck (1888) continued the herring studies in the following years and described the herring on the west coast as "new herring" consisting of a mixture of immature and mature herring which in size became similar to the spring herring. The herring spawned on the usual spawning grounds but was far less abundant as before 1870.

The mature herring found in shallow areas off northern Norway in 1868-1874 were investigated by Boeck and Sars and were described as herring of the same size as the "spring herring", but in much better condition. The ovaries showed that they were not ready to spawn. In December, the "large herring" disappeared from northern Norway but their spawning ground was never observed.

During the winter of 1877, great schools of herring were discovered penetrating the Bohuslän skerries, and for 20 winters in succession, a great herring fishery was carried out there. The herring had been absent since 1808, but similar fishing periods in this area are traced back in history for about 1000 years, and it looks as if the Bohuslän and Norwegian "spring herring" fishing periods occured alternately. At the time of the Bohuslan fishery, herring fisheries also grew up on the Norwegian side of the border to Sweden (Ljungman, 1882; O. Pettersson, 1922; Devold 1963).

During the winter of 1895-96 Norwegian fishermen caught great quantities of large herring in the Skagerak for the last time. It was also the last winter in which great herring fisheries occurred inside the skerries in Bohuslän. The following winter herring concentrations along the coast of western Norway were of the same magnitude as in the good fishing winters before 1870 (Buvik, 1895-99).

In the autumn of 1896 onwards, great schools of herring were discovered off Møre. They were called "large herring", and an extensive herring fishery began on them. These herring schools disappeared before Christmas, but in January new schools arrived and moved southwards along the coast and were later caught from Haugesund southwards to Lindesnes. These schools were called "spring herring". In the beginning of this century the herring fisheries had two seasons, one based on the "large herring", the other on the "spring herring". The large herring arrived each year later in the coastal waters and after 1921 no herring arrived in the Møre region before the 1st of January. In the 1930's the herring spawned in early February, whereas the spawning in the 1950's took place in early March. Simultaneously the distribution area decreased and the center of spawning moved northwards. The spawning grounds south of Bergen were abandoned in the late 1950's, and in later years the spawning has been concentrated on the coast from Møre to Lofoten (Devold, 1963).

The simultaneous changes in the spawning time and in the displacement of the spawning grounds northwards gave rise to a renewed discussion of alternating herring periods between the rich Bohuslän fishery and the winter herring fishery on the Norwegian west coast. In a series of articles and publications in the 1950's Finn Devold supported the theory of alternating herring periods and predicted that the displacement of the spawning grounds and the delay in the spawning time indicated the end of the herring fishery on the Norwegian west coast (Devold 1950,1955,1959,1960,1963,1964). Devold also developed an hypothesis which explained the processes which governed the relation between the spawning behaviour and the migration. His basic assumption was that it takes a little more than one year between successive spawnings. The herring will then arrive at the Norwegian coast later each year and also leave the coast later. When post spawners are leaving late, they have to pass the area on the Norwegian continental shelf after the copepods have entered surface layers, in April. The herring will therefore start feeding here and will move northwards off the Norwegian coast.

In the autumn, the herring used to migrate to the cold arctic water in the East Icelandic Current for wintering. Being off northern Norway they will be far from the arctic water of the East Icelandic Current. Cold water will, however, be available near the Norwegian coast, where the winter cooling of the coastal waters will have started, and these waters will therefore be invaded for wintering. Since the temperature of the coastal water of northern Norway is higher than that of the East Icelandic Current, the gonads of these herring will develop faster and spawning will take place earlier than in the preceding season. After spawning these herring will leave the Norwegian coast early, and return for feeding along the Polar Front earlier than usual. The next autumn their spawning migration will therefore start early., and the migrating schools will have to pass through water masses of a higher temperature than usual. The Norwegian coastal waters off Møre, where the herring usually arrive, have a surface temperature above 10^{0}C in the autumn. The herring will avoid this warm water and move toward the Baltic water of a temperature of six to seven degrees. The herring may then pass through the Norwegian Channel into the Skagerak, and spawn off the Norwegian south coast, and off Bohuslän. After spawning the herring invade the coastal areas of Bohuslän, and the south-east coast of Norway where they spend the "resting time" in cold water. The delay in spawning time by years will however increase the chances that the herring meet cold Baltic water in the Skagerak on the spawning migration. If the Baltic water is too cold, the herring will find warmer spawning grounds further west. If the herring have to leave a spawning ground and find a new one, they will return to this new ground for the succeeding spawnings. In this way the herring are driven out of the Skagerak, and later also have to avoid the southern spawning grounds in western Norway. In this way rich herring periods of the Bohuslän and of the Norwegian west coast may alternate and the hypothesis also explaine the intermediate occurrence of the "large herring" wintering in the north Norwegian fjords.

Devolds hypothesis was strongly opposed by Swedish scientists (Andersson 1950, 1956, Høglund 1959,1960,1977). Based on size and age composition analysis of the Bohuslän herring, they claimed that this stock had no connections with the Norwegian spring spawning herring, but was related to tribes which were ususally fished in the North Sea, Skagerak and Kattegat.

The Norwegian west coast herring fishery collapsed in the 1960's due to depletion of the stock by the fishery. The feeding migration to the Polar Front area was interrupted in the early 1970's, and in the subsequent years the postspawners have been feeding off the Norwegian coast and have wintered in the Norwegian fjords as presupposed by Devold's hypothesis. The maturing of the herring has, however, not developed as predicted. The herring have matured in February-March as they did in the 1960's and have spawned on the traditional spawning grounds from Møre to Lofoten. In 1989 a small component also spawned on the southern grounds for the first time since 1959, and this spawning took place rather late in the spawning season (first half of March).

3. Migration pattern

The migration of the adult herring stock is recorded in detail since the early 1950's. After spawning most of the spent herring moved northwestwards into the Norwegian Sea where they fed on zooplankton. The larger fish reached the Polar Front in June and July and some crossed into the cold water. The limit of the summer feeding migration extended from the Spitsbergen-Jan Mayen area in the north to the western borders of the East Icelandic Current in the south. The larger fish moved further to the northwest than the smaller fish (Marty, 1959; Marty and Wilson, 1960).

During the autumn the herring was found in the southwestern part of the Norwegian Sea along the borders of the East Icelandic Current. The ripening herring wintered in an area off East Iceland. In December and January prespawning concentrations moved towards the Norwegian coast. Devold (1951,1959,1963) described in detail the spawning migration towards the coast in the 50's. He found that the herring gather in cold-water pockets before penetrating the warm Atlantic Current into the colder Norwegian coastal water. The herring usually arrive at the

Norwegian coast off Møre and spread farther south and north to spawn.

This description of the distribution and migratory pattern of the adult stock refers to a state when the stock was at a relatively high level. Between 1950 and 1962 the stock declined. The spawning was gradually displaced northwards, and after 1959 spawning south of Bergen was negligible (Devold,1963; Dragesund, 1970). In 1950-1962 the main summer feeding grounds varied somewhat but remained in the Iceland-Jan Mayen area, but in 1963-1966 a stock component fed and wintered in an area south of Bjørnøya (Fig.1). The densest summer concentrations were usually found near the borders of the East Icelandic Current. In the autumn the herring assembled on the wintering grounds situated near the southern and southwestern borders of the East Icelandic Current.

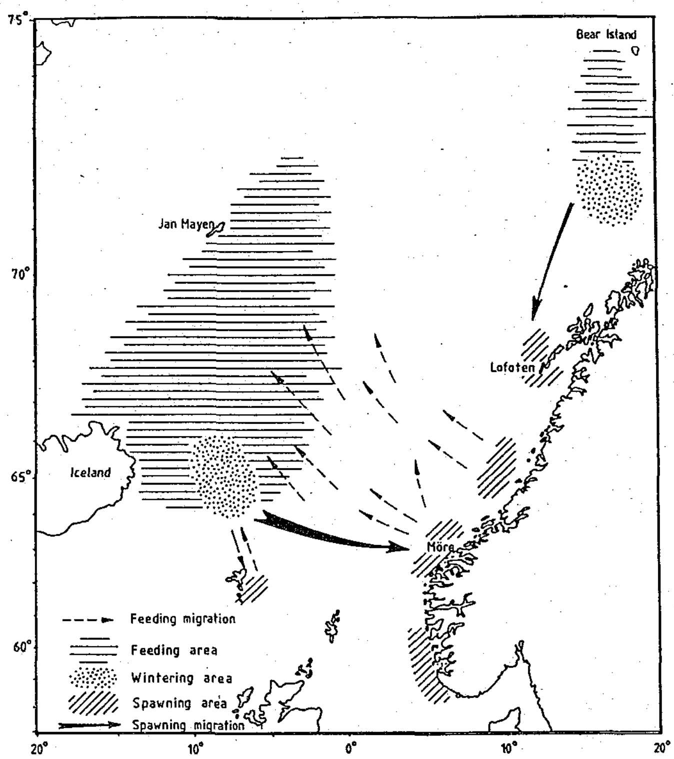


Fig. 1 Migration of Norwegian spring spawning herring prior to 1970.

4. Migration pattern after 1970

The summer and autumn fishery for adult herring terminated in 1969, and since then no herring have been recorded in the Polar Front area of the Norwegian Sea. The winter herring fishery on the spawning grounds decreased sharply after 1967 but continued on the depleted stock until 1971. The stock of immature herring was almost depleted in 1969, and immature fish recorded in the early 1970's belonged mainly to the 1969 year class.

The use of herring for reduction purposes was prohibited in Norway from January 1971. This regulation probably prevented the complete extinction of the 1969 year class. Purse seiners fishing for capelin reported concentrations of young herring off the coast of Finnmark during the winter of 1971, and several catches of fat herring were released that year because of the ban on the industrial fishery. This last remnant of the stock probably survived as juveniles somewhere in the Barents Sea or in the northeastern part of the Norwegian Sea.

In 1972, five purse seiners were chartered to survey the spawning grounds. Practically no spawning herring were recorded (Dragesund, Bjerke, and Sangolt, 1972). The absence of spawning herring and herring larvae in 1972 and the very low abundance of the 1970-1972 year classes in the spawning stock demonstrates that the adult stock of Norwegian spring-spawning herring collapsed in the early 1970's.

In November 1972 shoals of maturing herring were recorded off western Finnmark (in the Ingøy Deep), and in January 1973 a Norwegian purse seiner located herring shoals some 50 nm northwest of Ingøy. Most of these herring belonged to the 1969 year class, and were obviously on their way to the coast to spawn. Maturing herring of the 1969 year class were found, later in 1973, off Vesterålen and Lofoten. These herring probably spawned in the Lofoten area in March, because herring larvae were found there in April. The traditional spawning grounds off Møre and Trøndelag were surveyed throughout the spawning season in 1973. No concentration of spawning herring was found, but gill-net catches of herring with running gonads indicated that some spawning took place. This was later confirmed by the larval survey that year. The spawning stock off Møre was also dominated by the 1969 year class (Dragesund, Bjerke, and Sangolt, 1973).

Two components of immature herring survived the heavy exploitation in the 1960's, one in the Barents Sea and the other on the west coast of Norway. Both components spawned for the first time in 1973, one off the Møre coast, the other off Lofoten. According to recordings of maturing herring in 1973, the northern component was by far the larger. After spawning, the herring did not leave the coast as in previous years, but migrated into inshore waters to feed during summer and autumn. No spawning was observed off Lofoten in the winter of 1974. The northern component migrated southward, and since 1974 spawning has taken place on the traditional spawning grounds off Møre and Trøndelag (Dragesund et.al 1980).

The traditional migration pattern of the herring was thus interrupted in the early 70's and has not yet been retained. The two stock components have developed as separate units, with different spawning grounds, feeding areas and wintering localities (Figure 3).

The southern component has spawned on the southern coast off Møre and some years also further south. As already mentioned, shoals of spawning herring were in 1989 recorded on the southern spawning grounds in the beginning of March. These grounds have been abandoned by the herring since the late 1950's. The southern component has fed during summer and autumn off the coast of Møre and Trøndelag, and wintered in the fjords of northern Møre. The southern component has usually left the wintering area in late January and arrived at the spawning ground in the early February. Growth rate, recruitment and age structure of the herring indicate that this stock component has developed as a separate unit. This is also supported by the recovery of tagged herring. The southern component of spring spawners has to some extent been mixed with autumn spawners and herring from local stocks which spawn in the fjords.

The northern component has spawned in the area from northern Møre (Buagrunnen) to Lofoten. This herring has spawned some weeks later than the herring of the southern component. The northern component has also fed on the Norwegian shelf during summer and autumn, but more offshore and farther north. The shoals have moved northwards during the summer and have usually been found off Lofoten in the early autumn. In September they have migrated into the Vestfjorden area and wintered in the fjords of Lofoten and Vesterålen. The herring have returned to the same fjords every year but when the abundant Barents Sea component of the 1983 year class migrated to the coastal area for wintering in the autumn 1986, the wintering area was expanded to include several new fjords in the same region.

In the years 1988 and 89 most of the 1983 year class wintered in the inner part of Vestfjorden. When the 1983 year class recruited to the spawning stock the separation of the herring in two different stock units disappeared. Tag returns from the winter fishery in 1989 do, however, indicate that the Barents Sea component of the 1983 year class has invaded all spawning grounds on Møre, whereas the herring from the Møre-Trøndelag area are displaced to spawning grounds farther to the south (Fig. 3B).

5. Distribution of young and adolescent herring

Until the beginning of the 1960's little was known about the distribution and migration of the early stages of Norwegian spring spawners. Devold (1950) showed that 0-group herring of the rich 1950 year class were distributed far offshore in the northeastern part of the Norwegian Sea, and he suggested that only part of the total 0-group population entered the Norwegian fjords. From later investigations it can be stated that the distribution of the young and adolescent herring is widespread, ranging from the fjords of northern

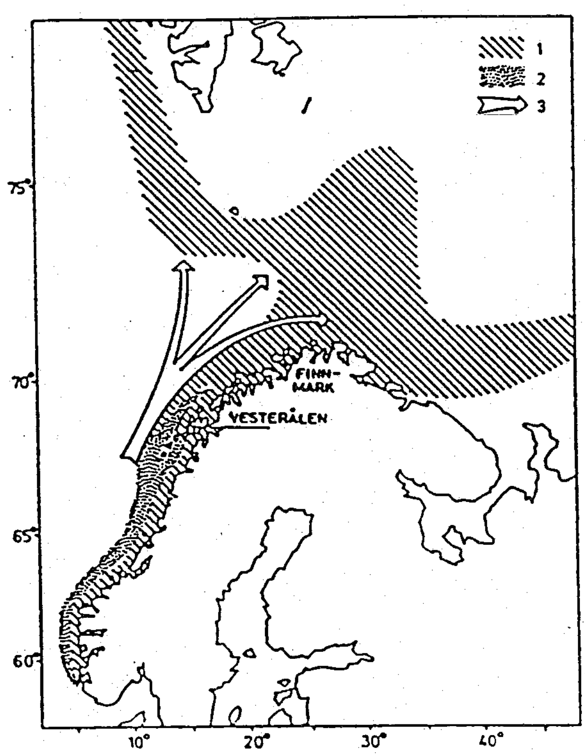
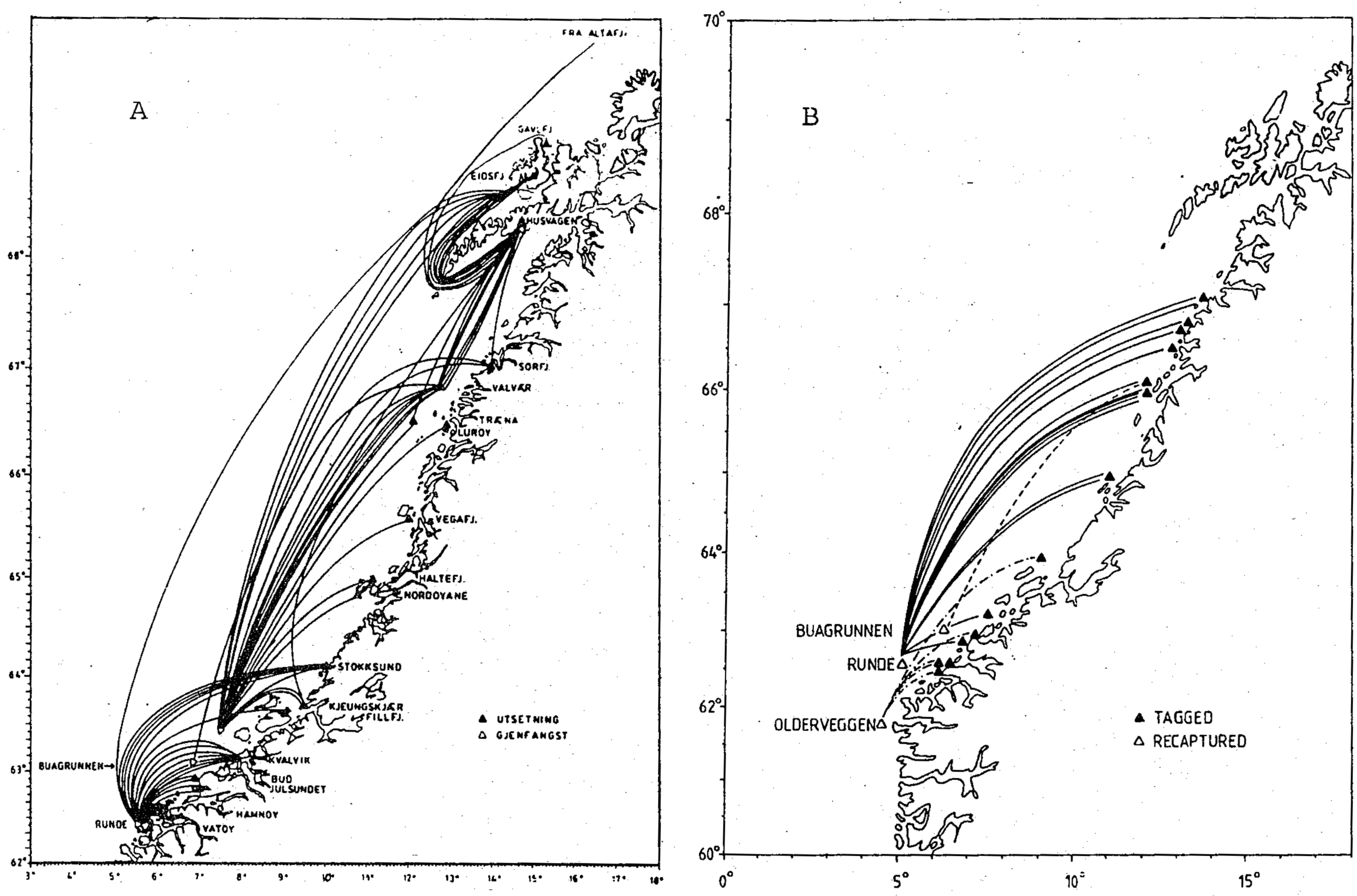


Fig. 2. Distribution of young herring. (1) nursery area, (2) larval distribution, (3) direction of post-larval drift to the offshore nursery area.



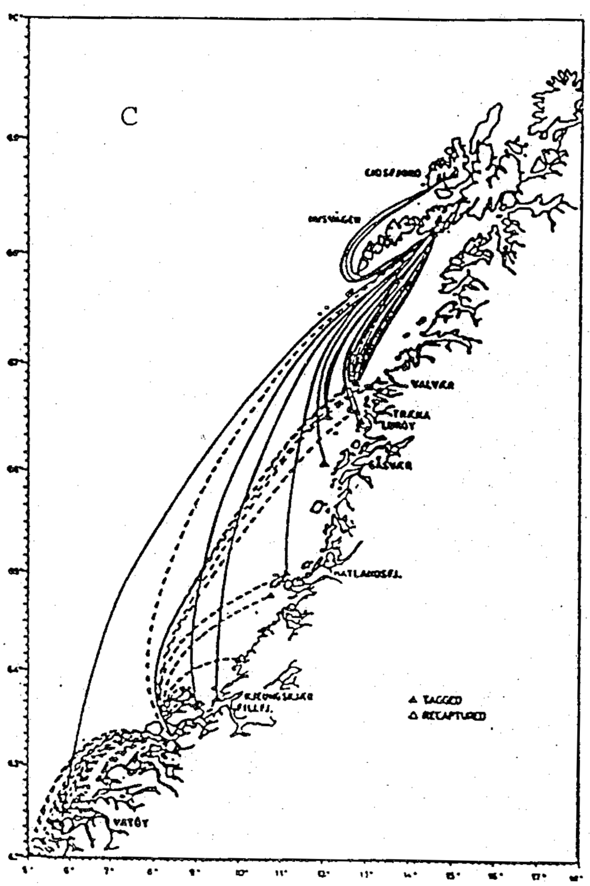


Fig. 3. Distribution of tag returns. A= returns from the winter fishery in 1979, B=returns from the winter fishery in 1989, C= returns from catches taken in the northern and southern wintering areas of the herring during late autumn.

Norway to the open ocean of the Norwegian Sea and the Barents Sea (Dragesund and Hognestad, 1960; Devold, 1968; Jakobsson, 1968; Dragesund, 1970). When recruitment conditions are favourable, most of the juvenile herring are found in the Barents Sea (Røttingen, 1987).

Figure 2 shows a schematic illustration of the general distribution of the early stages. Soon after hatching, the larvae rise into the upper water layers and are transported northwards from the spawning grounds. During the northward drift, part of the larvae accumulates at the entrance to the fjords along the Norwegian coast. In late summer and early autumn 0-group herring are generally recorded in the top water layers along the Norwegian coast and in the Barents Sea (Dragesund, 1970; Anon., 1970). The offshore distribution is, however, more variable and is closely related to year class strength, and hence the inflow of Atlantic water to this region (see section 5).

In late autumn a major part of the 0-group in offshore waters is concentrated along the fronts between the cold arctic water and the warmer water masses off the Spitsbergen-Bear Island and in the central and southeastern parts of the Barents Sea. The herring remain in this area during the following winter and spring. During spring and early summer, the I-group herring distributed in the northern and northeastern part of the Barents Sea move southwards. At the same time, herring of the same age, which have wintered in the fjords of northern Norway, migrate from the coast and mix with the open-sea concentrations. During the following winter the 2-group herring are found in almost the same area, although the distribution is more restricted to coastal banks and to the central and southern part of the Barents Sea.

During summer and autumn part of the 2-group herring, the fastest growing fish, move westward into the Norwegian Sea. However, most of the fish remain in the Barents Sea and in the area off Finnmark for another year before they start the westward migration into the Norwegian Sea to join the adult stock. The slowest growing fish start their emigration from the Barents Sea during the 4-group stage. The adolescent herring moving into the Norwegian Sea usually have an oceanic stage before they mature. Some individuals mature after one year, others after two or three years (Dragesund et.al 1980).

This distribution and migration pattern of young and adolescent herring in the Barents Sea is in accordance with the observations of the movement of the 1983 year class (Røttingen, 1989). The coastal component of the 1983 year class from the fjords in Finnmark mixed with the Barents Sea component in 1984 and the mixed stock left the Barents Sea during the spring and the summer 1986. Most of these herring had a one year oceanic stage before they matured and spawned for the first time in 1988. In 1963-66 the 4-years old immature herring wintered in the Bear Island wintering area, but most of the 1983 year class wintered as immature in Vestfjorden as 4 year olds.

RECRUITMENT AND AGE COMPOSITION

The age structure of the adult herring stock has been known since the beginning of this century (Hjort, 1926). In a virgin state, the life span of herring is about 20-25 years. The maturation of a year class takes place about some five years, which means that the adult stock may consist of as much as 15-20 year classes. The recruitment is more-over variable and these factors govern the age structure of the stock and the stability of stock abundance. The age composition of herring from 1908 onwards compared with general information on stock abundance indicate that the stock recovered gradually at the end of the previous century. An extraordinary strong year class was recruited in 1904 which may have rebuilt the spawning stock to a level of 5 to 10 million tonnes in the second decade of this century (Marty and Fedorov, 1963). Three rich year classes occured between 1900-1930, the year classes 1904, 1918 and 1923. The 1930's constituted a period of good recruitment and only the year classes 1931 and 1936 were poor. In the 1940's there were three rich year classes, those of 1943, 1944 and 1947 and another very abundant year class occurred in 1950. According to Marty and Fedorov the periodicity of occurrence of abundant year classes ranged from one to 14 years, whereas a seven years interval had been typical from 1923 to 1950. The autors also showed that the occurrence of abundant year classes coinsided with increasing inflow of warm water to the Barents Sea, which affects the mean Kola Meridian temperature. In a recent paper Sætersdal and Loeng (1984) have shown that a similar correlation does exist between the temperature of the Kola Meridian and recruitment success for Northeast Arctic cod.

Since 1950 abundant herring year classes have occurred in 1959 and 1960 coinsiding with a warm climate in the Barents Sea. In the early 70's, another warm period occured, but at that time the spawning stock of herring was depleted. In relation to spawning stock the herring year class 1973 was known extra-ordinary strong. The late 1970's was a cold period in the Barents Sea. The climatic conditions improved in the early 80's and strong year classes were recruited in the years 1983-85. The herring year classes 1984-85 were however depleted by increased predation from a very strong 1983 year class of cod. Recruitment after 1985 has been poor.

Plots of VPA-estimates of recruitment versus spawning stock biomass are shown in Figure 10 for the years 1950 onwards.The VPA figures are derived from the catch in number by year classes adjusted by a constant natural mortality by age groups. Variations in the mortality due to predation or other forms of stock interactions have not been accounted for. Judging from the stock interrelationship observed in recent years it is assumed that these recruitment figures are grossly underestimated, particularly the recruitment in warm periods when the cod have had favourable recruitment conditions. The stock-recruitment plot demonstrates a linear releationship between stock biomass and recruitment when recruitment conditions are favourable. When using catch-related recruitment figures, this applies to the first year class which is recruited in a good recruitment period. The year classes of the subsequent years may however also have been abundant as 0-group herring, but may have been reduced at a young age by predation from abundant year classes of cod.

EXPLOITATION

The main fishery on adult herring has been the winter herring fishery during the spawning season. In the period 1925-1960 the winter herring catches were shared about equally by purse seiners and drifters. Earlier in this century the land seine was also extensively used. Originally the purse-seine fishery was carried out by vessels equipped with a purse seine operated from two dories. The ring-net technique with power block replaced the two-dory system in the early 1960's, and most of the herring has been caught by this technique in later years.

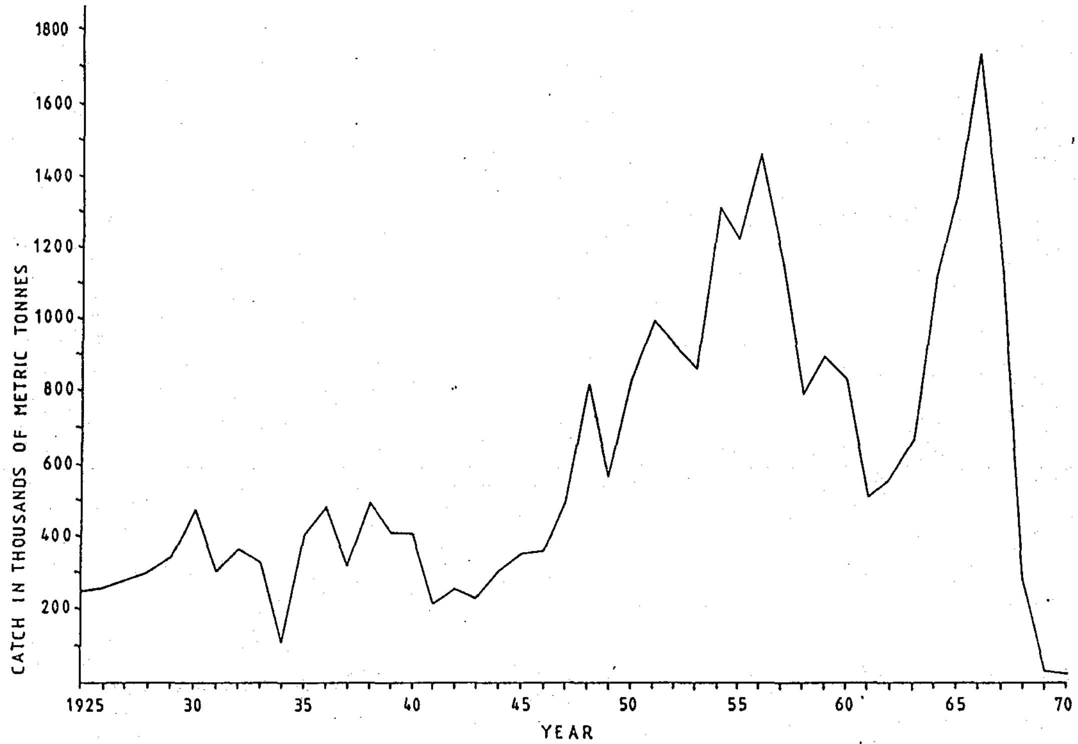


Fig. 4. Total catch of adult herring 1925-1970.

The annual catches from the adult herring fishery over the period 1925-1970 are shown in Figure 4. Details of the herring catches 1950-1988 are given in Table 1. Although the catches fluctuated considerably, they did not show any major trend up to 1947. Thereafter the catches rose steadily to about one million tonnes in 1954-1956, when the rich 1950 year class started to recruit to the spawning stock. The catches then fell steadily, up to 1963, to a level near that of the poorest year of the prewar period. There was a recovery in 1964 when the rich year classes of 1959 and 1960 entered the stock. From 1965 onwards a rapid decrease in the stock size took place, and the winter-herring fishery collapsed in 1970.

The summer and autumn fishery on adults, took place on the feeding grounds along the Polar Front in the Norwegian Sea. This fishery was located for a long period off northern and northeastern Iceland (Jakobsson, 1963). The fishing season normally lasted from June to early September, and up to 1950 the stock was mainly exploited by Icelandic and Norwegian vessels.

In the early 1960's new technical advances improved the technique in the Icelandic fishery, as they did in the Norwegian herring fishery, and the fishery extended seawards. During the 1960's the fishery took place far offshore in the Norwegian Sea, and the fishing season lasted until October-November. In 1966 when the record catch of adult herring was taken, Iceland caught 40% whereas Norway and USSR caught about 30% of the total catch each (Table 2).

The Soviet driftnet fishery on feeding herring in the Norwegian Sea started in 1950. Initially, the fishery was purely a summer one, exploiting the grounds between Spitsbergen, Jan Mayen, and Iceland. In

1952 an autumn and winter fishery started along the migratory routes of the prespawning concentrations towards the spawning grounds off the Norwegian coast.

The change in the migratory pattern of the adult stock during the 1960's strongly influenced the location of the summer and autumn fishery. Off Iceland it became negligible and most of the summer and autumn fishery in the 1960's took place off the shelf south and west of Bear Island-Spitsbergen. From the 1970's onwards most of the herring has been caught in Norwegian coastal waters within a range of some 20 n.m. off the coast.

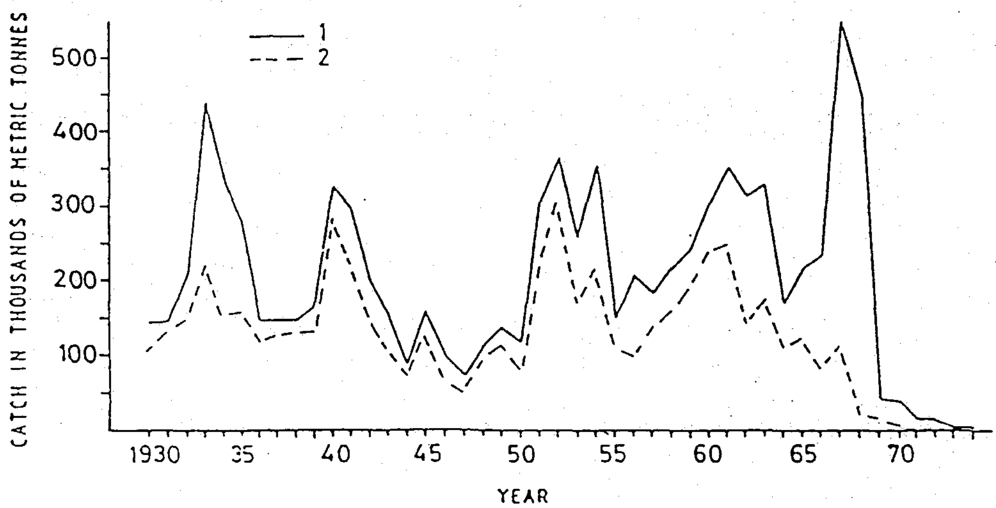


Fig. 5. The catch of young and adolescent herring. (1) the total catch, (2) the catch of small herring.

In addition to the fishery on adults, the young and adolescent herring were fished at the Norwegian coast and in the fjords (Figure 5). Almost all the catches were taken with purse seine, and from 1964 onwards the ring-net technique was used and the efficiency increased. The most important small-herring fishery occurred in the fjords from late autumn to early spring.

STOCK ASSESSMENT

The abundance of the Norwegian spring spawning herring stock has been assessed by various methods. Marty and Fedorov (1963) assessed the stock abundance and year class strength for the period 1904-1960 on the basis of catch by year classes in succesive years after a method developed by Denzhavin (1922). Dragesund and Jakobsson (1963) estimated stock size and total mortality rate for the period 1953-1960 on the basis of tag returns from internal tagging experiments and Østvedt (1963) estimated total mortality from catch and effort data in the driftnet fishery for the period 1950-1960. The ICES Working Group on Atlanto-Scandian herring (hereafter termed the Working Group), has in two reports (Anon. 1970, 1977) assessed the state of the stock for the period 1953-1959, using data from various sources. A conventional VPA for the years 1950-1971 is published by Dragesund and Ulltang (1978) and the results of a somewhat adjusted version of this are shown in Figure 7 (Dragesund et.al 1980). The ICES Working Group results are included for comparison. In the period 1975 onwards, the stock has been assessed by VPA, tagging and acoustic methods.

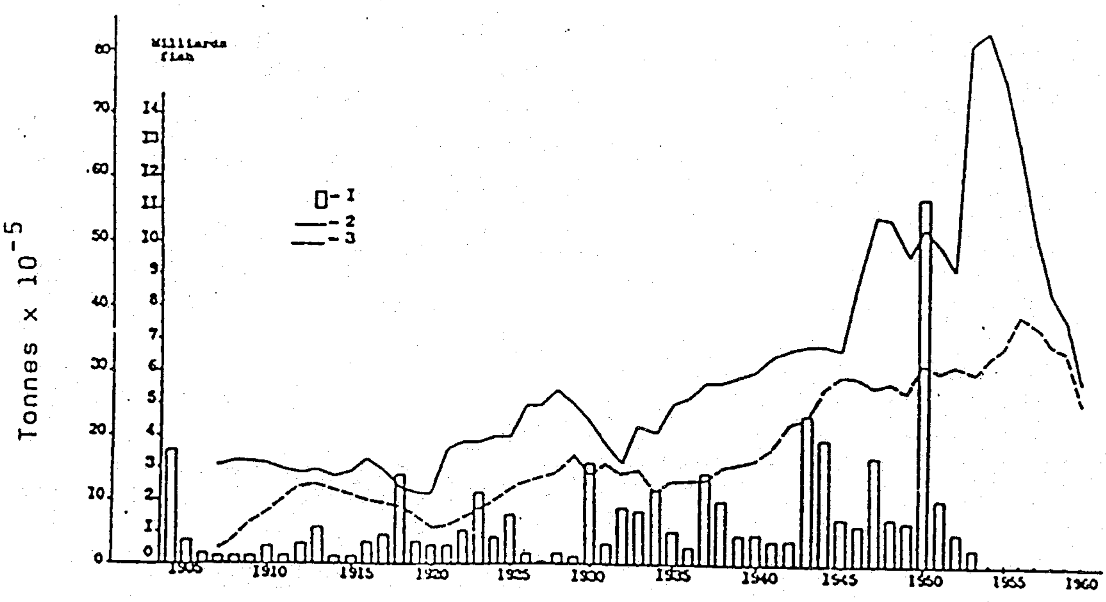


Fig. 6. (I) Abundance indices of some year classes of Norwegian spring spawning herring in billions of fish, stock values of herring from three year olds and older, (2) mature herring, (3) by years in million metric centners (Marty and Fedorov 1963).

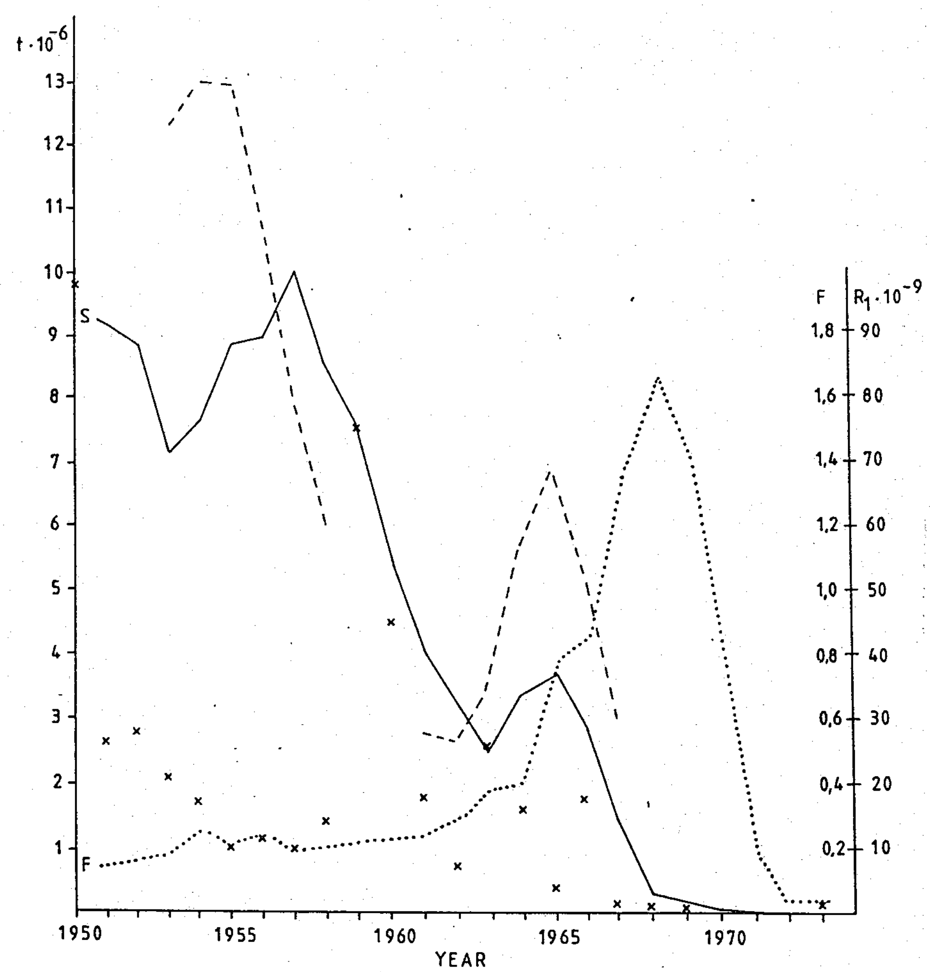


Fig. 7. Estimated spawning stock (S), fishing mortality (F) and recruitment (X) of herring 1950-1973 as 1 year old. The broken line shows stock estimates given by the Working Group.

The stock abundance estimates of herring older than 3 years for the period 1904 to 1960 are shown in Figure 6 (Marty and Fedorov, 1963). The natural mortality has not been accounted for in these estimates. According to this method, the accumulated catches ranged between 1.5 and 2.0 mill. tonnes prior to 1925. Assuming that the fishing mortality at that time was lower than the natural mortality, Marty and Fedorow found that the standing stock biomass must have been five to six times greater than the accumulated catch figures or in an order of magnitude of 10 mill. tonnes. For the 1950's the Dezhavin's method gave a stock estimate of 7 to 8 mill. tonnes. Assuming that the fishing mortality in the 1950's was 5 times higher than the natural mortality the author concluded that the stock may have remained on a steady state level of an order of magnitude of 10 mill. tonnes throughout the whole period under study.

According to the VPA (Figure 7), the spawning stock size was at a level of about 9 million tonnes in 1950 and decreased to about 7 million tonnes in 1953. From 1954 to 1957 the strong 1950 year class gradually recruited to the spawning stock, resulting in an increase in stock size to about 10 million tonnes in 1957. The stock then decreased to about 2.5 million tonnes in 1963 mainly as a result of poor recruitment. From 1963 to 1965 the spawning stock size increased again, reaching about 3.7 million tonnes in 1965. From 1966 onwards there was a rapid decrease in spawning stock size owing to an almost complete lack of recruitment to the adult stock and rapidly increasing fishing mortalities. The rise in F during the years 1963-1966 was caused by increasing fishing effort, but the further large increase in F in 1967 onwards was probably mainly the effect of decreasing stock size caused by both the increase in fishing mortality in previous years and the failure in recruitment (Ulltang 1976).

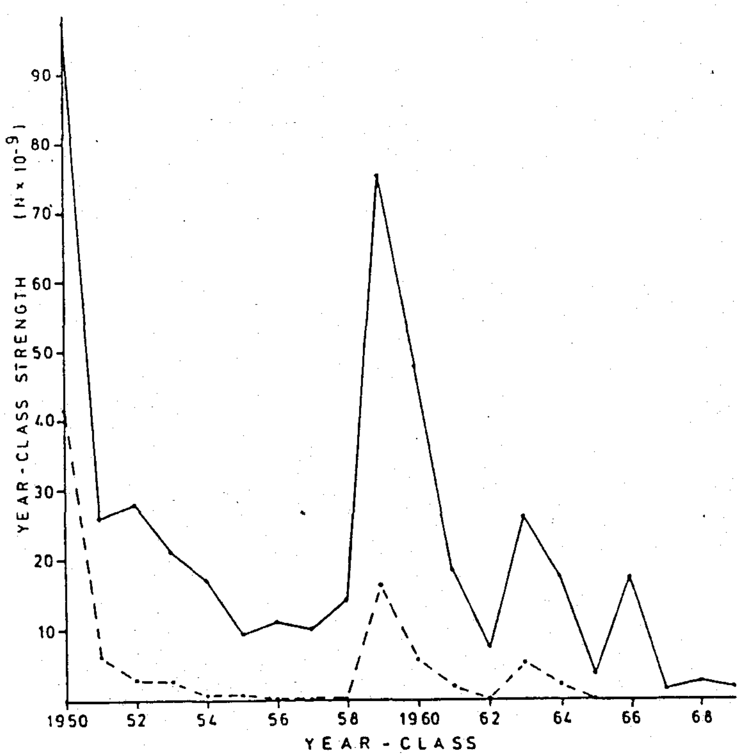


Fig. 8. Year-class strength in number as 0-group and 4 year olds (broken line), 1950-1969 (Dragesund et al. 1980).

Comparing the present estimates of stock size and rate of exploitation of adults from VPA with earlier Working Group estimates, it can be concluded that the Working Group assessed the situation more or less correctly until the rapid increase in fishing effort started in the early 1960's, i.e. before the introduction of the ring-net technique. Thereafter the Working Group badly overestimated the stock size.

The exploitation rate of young herring was also high during the period 1950-1969. In Figure 8 are given the VPA estimates of year class strength as 0 and 4 years old in the period. The Figure shows that year classes in the 1950's which have traditionally been described as weak, were all of what could be called normal strength $10 \cdot 10^9$ to $30 \cdot 10^9$ fish at the 0-group stage. However, year class of strengths less than $20 \cdot 10^9$ as 0-group survived the fishery only in small quantities to reach the age of 4 years. The 1965 year class was the first one in the period studied which really should be classified as weak at the 0-group stage (Dragesund and Ulltang, 1978).

The VPA clearly shows that the fishing pressure, on young and adolescent herring in general and on adult herring in the years 1965-1968, was the primary factor in the collapse of this herring stock. As mentioned previously some few herring of the 1969 year class survived as juveniles in the early 1970's in the Barents Sea and some very few survived on the Møre coast. These stock components have in later years been assessed by an acoustic method and by tagging as adults. An echo abundance survey of 0-group herring in the Norwegian fjords were initiated in 1975 and extended to cover the distribution area of 0-group herring in the Barents Sea since 1983. The survey are carried out in November-December and the technique used is the same as that applied for capelin (Nakken and Dommasnes 1975). The results appear from the text table below:

Year	Coastal comp.	Barents Sea
1975	1.0	
1976	3.8	
1977	0.4	
1978	1.2	
1979	3.4	
1980	0.2	
1981	0.2	
1982	2.9	
1983	13.7	35.7
1984	1.4	6.2
1985	1.0	41.5
1986	0.4	0
1987	0.3	0
1988	2.5	9.8

These recruitment figures are not comparable to the back calculated recruitment number of 1-group herring (R_1) derived from the VPA. In the stock prognosis the acoustic 0-group estimates have been used as indices of recruitment at age 3 by scaling the number down by a calculated conversion factor of 0.51 (Anon. 1986).

Compared to the period before the stock collapse in the late 1960's the recruitment in later years has been extremely low except for the years 1983-85. The stock has been grossly recruitment overexploited, but in the years 1975-82 the rate of recruitment has also been low. This was probably due to unfavourable recruitment condition, linked to low water temperatures in the Barents Sea (Marty and Fedorov 1963, Hamre 1988).

Assessment by tagging

In the period 1975-1986 the state of the adult stock has been assessed by tuning the VPA against stock estimates obtained from tagging (Anon. 1980,1986). The tagging project as well as the model used for the processing of the data have been described in working documents and reports of the Working Group (Anon. 1984,1986).

The tagging project using internal steel tags was initiated in 1975 and since then herring have been tagged and released annually on various localities along the west coast in April-May. Prior to 1982 the herring were caught by purse seine, towed to the shore and kept in keepnets before tagging. Since 1982 the herring have been brailed from the seine to the RSV-tanks onboard the seiner and tagged and released from the tanks. The tagged herring are released in batches and under various conditions and the mortality due to the tagging is expected to be variable.

The tagged herring are recovered by screening herring catches using a special constructed internal tag detector. The efficiency of the detector is tested by mixing tagged herring with the catch before screening (Gytre and Jakupsstovu, 1977).

The recoveries used for stock assessment are all obtained from winter catches of spawners and prespawners. The commercial herring winter fishery was prohibited until 1984, but experimental fishing for tag recovery was allowed during the winters 1977-83. The commercial winter fishery was opened in 1984 and in later years both commercial and experimental catches have been screened for tags. The herring stock has developed in two separate units, and the data on releases and corresponding recoveries are prosessed by the two stock components separately. The tagging is done during the feeding season, and in areas where shoals from both components are distributed. It has therefore been difficult to allocate the releases on components when released. The tagged herring are released in batches of 2 000 - 10 000 individuals, and the allocation of the batches on components is made on the basis of the recoveries, i.e., the position and the age-composition of the catches from which the bulk of the recoveries are retained. The boundary between the spawning grounds of the two components runs at about 63^0N.

By this grouping of data the consistency of the abundance estimates by years is improved, but the results indicate that no random mixing of the tagged fish in the two stock units is a major source of error in the estimates. The releases and recoveries by components and years are given in Table 3. At the bottom of the table is given the corresponding number of herring effectively screened for tags.

Mortality estimates

The most simple model for explicit estimates of survival rate from two successive releases is the Ricker's model (Ricker 1975):

$$S_1 = \frac{r_{12} \cdot M_2}{r_{22} \cdot M_1} \qquad (1)$$

where S_1 = survival rate during year 1
M_1 = number marked at the start of the first year
M_2 = number marked at the start of the second year
R_{11} = recaptures of first-year marked in the first year
R_{12} = recaptures of first-year marked in the second year
R_{22} = recaptures of second year marked in the second year

If sampling is done over a series of years, the recaptures can be summarized over the whole period. A review of models for explicite maximum-likelihood estimates of animal abundance by tagging is published by Seber (1982). These methods presuppose that the tagging mortality is negligible or at least does not vary with releases. This underlying assumption is not fulfilled in the present experiment, and a regression model has therefore been applied.

The regression model estimates the total instantaneous mortality rate Z for equal time periods when Z is assumed to be constant. Two types of models are available. It can be shown that if the returns from one release over a long time serie are grouped in equal time intervals, the logarithm to the number of returns from each of the time intervals plotted against time, will yield a straight line with slope equal to the instantaneous mortality rate (Gulland 1973). It is noted that the mortality estimate from this model is independent of the number released and consequently also of the mortality due to the tagging.

In an analogous way it can be proved that if Z is constant the logarithm to the fraction number released/number recovered from successive releases in the same catch plotted against time in liberty will yield
a straight line with slope equal to the instantaneous mortality Z. If the survivals of the last release are denoted $s_0 \cdot m_0$ the stock size N_0 according to a Petersen estimate is:

$$N_0 = \frac{s_0 \cdot m_0 \cdot C_0}{r_0} \qquad (2)$$

where s_0 is the coefficient of survival after tagging and r_0 is the number of recoveries in the catch C_0.

An estimate of N_0 may also be expressed by the recoveries from the previous years' releases as follows:

$$N_0 = \frac{s_1 \cdot m_1 \cdot e^{-Z} \cdot C_0}{r_1} = \frac{s_2 \cdot m_2 \cdot e^{-2Z} \cdot C_0}{r_2}$$

provided that the mortality Z is constant.

In general terms this can be written:

$$N_0 = \frac{s_t \cdot m_t \cdot e^{-Zt} \cdot C_0}{r_t}$$

where r_t denotes the recoveries from m_t released t years prior to time when the sample c_0 was drawn. Reorganizing this equation and taking the natural logarithm we have:

$$\ln\left[\frac{s_t \cdot m_t}{r_t}\right] = Z \cdot t + \ln\left[\frac{N_0}{C_0}\right] \quad (3)$$

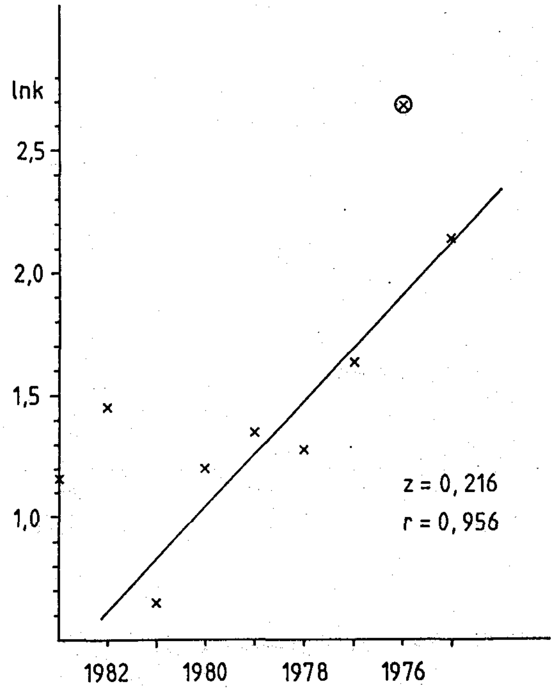
Here the plots will fall along a straight line if s is a random variable and thus can be regarded as a part of the co-variance of the regression line. This assumption is reasonable, at least for each of the periods when the tagged fish have been handled in an equal way (1975-1981;1982 onwards). The tagging mortality is assumed to be high and the variance in s is considered to constitute the main part of the co-variance of the regression line. A point located far above the line indicates a low survival rate of that experiment (failure of recoveries), a point below the line a corresponding high value of s. If all other sources of model variance were negligible the model provides a method to estimate the relative tagging survival s_r.

In the text table below the relevant model parameters are calculated for the northern component using the recoveries 1984-87 of the releases 1975-83 (Table 3). According to reports of the Working Group there has been no substantial change in the fishing mortality during this period, whereas the fishing mortality of the older age groups may have increased significantly after 1983 (Anon., 1986, 1988).

Release	m_t	r	lnK	t	f(t)	s_r
1975	20991	25	2.13	8	2.09	0.96
1976	15947	11	2.67	7	1.87	0.45
1977	24989	50	1.61	6	1.65	1.04
1978	19998	56	1.27	5	1.44	1.19
1979	8797	23	1.34	4	1.22	0.89
1980	15988	48	1.20	3	1.01	0.83
1981	9977	52	0.65	2	0.79	1.15
1982	14884	35	1.45	1	0.57	0.42
1983	17925	56	1.16	0	0.36	0.45

m_t is the number released in year t, r is the corresponding number of tags retained from the screened winter catches in 1984 to 1987. f(t) is the function value of lnK calculated from the regression line and s_r is a calculated index of relative tagging survival.

The plots of lnK (where $K = m/r \cdot 10^{-2}$) versus time in liberty t are shown in the Figure below:



Plot showing lnK versus time in liberty

As pointed out by the Working Group the returns from the 1982 and 1983 releases indicate a substantial increase in the tagging mortality after 1981 (Anon. 1986). The Working Group has therefore not used tag returns from releases after 1981 in the assessment of the stock.

The returns from the 1976 releases do also indicate an extraordinary high tagging mortality although no likely reason for this is known. The 1976 sample has therefore been considered as an exception from the assumed random variation in the tagging mortality and has been omitted in calculation of the regression line. The other points for the period 1975-1981 fit well to a straight line with slope Z= 0.216 and an intercept of the lnK axis of 0.358. The correlation coefficient of the points is 0.956.

If we assume no substantial change in Z from 1981 to 1983, the most simple way to calculate the stock number in 1983 is to use equation (3):

$$f(0) + \ln 10^2 = \ln \frac{N_0}{C_0}$$

where f(o) is the intercept of the regression line with the lnK-axis and C_0 is the sum of screened catches 1984-87 (Table 3):

$$0.358 + 4.605 = \ln \frac{N_{83}}{C_{84-87}}$$

$$N_{83} = 1541 \cdot 10^6$$

This stock estimate refers to the year classes 1981 and older and has not been adjusted for tagging mortality. The estimate is in accordance with the stock estimate given by the Working Group in 1986 (Anon. 1987).

As mentioned previously the model provides a method to estimate a relative tagging survival coefficient (s_r) assuming that the variance in the tagging mortality is the main source of the co-variance of the line. This index is derived from the formula:

$$\ln(s_r)_t = f(t) - \ln K_t \qquad (4)$$

where f(t) is the function value of $\ln K_t$ of the releases in year t. The calculated s_r-values by releases are given in the text table above. The 1982 and 1983 releases indicate an increased tagging mortality by the new handling method of the tagged herring in an order of magnitude of 50%.

In the text table below are given the survival estimates s_t by year obtained when the explicit model of Richer (equation 1) is applied to the recoveries in Table 3. s_t' are the corresponding estimates obtained when the releases m_t are adjusted by the corresponding relative survival s_r calculated from equation 4.

Survival	1975	1976	1977	1978	1979	1980	1981
s_t	1.57	0.45	0.68	1.07	0.86	0.54	2.24
s_t'	0.74	1.03	0.78	0.80	0.80	0.75	0.82

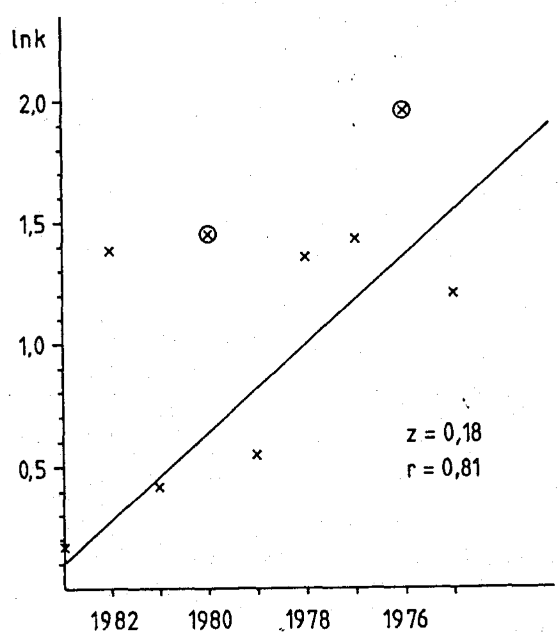
The two sets of survival estimates demonstrate the necessity of applying a regression model in processing of tag recovery data when tagging mortality is variable. It should be noted that the 1976-estimate is expected to be biased upwards due to a low number of tags retained.

The releases in 1983 to 1985 provide data to estimate yearly survival rate by the use of equation (1). The model yields survival estimates of 0.93 and 1.11 for the years 1983 and 1984 respectively. It is likely that these estimates reflect trends in the tagging mortality rather than trends in the survival rate of the population. The Working Group has therefore not used these data in recent stock estimates, but tuned the VPA against acoustic estimates of the spawning stock (Anon. 1988).

Similar data for mortality estimates of the southern stock component are given in the text table below. The recoveries refer to the winter catches 1984-87, the details appear from Table 3.

Release	m_t	r	lnK	t
1975	5000	15	1.20	8
1976	7998	11	1.987	7
1977	16044	38	1.44	6
1978	11998	31	1.35	5
1979	5995	35	0.54	4
1980	19994	47	1.45	3
1981	24967	163	0.43	2
1982	12380	31	1.39	1
1983	15891	134	0.17	0

K is set equal to $m/r \cdot 10^{-2}$, and the plot of lnK against time in liberty (t) is shown in the figure below:



Plot showing lnK against time in liberty

The consistency of this plot is rather poor and is assumed to reflect variable tagging mortality and the occurrence of mixed stocks in the southern area. It is known that autumn spawners probably from the North Sea and herring from local stocks which spawn in the Norwegian fjords are mixed with the herring of the southern component when the fish are tagged. In some cases this has been quantified and adjusted for in the calculation. Based on recoveries from the northern spawning area it has moreover been calculated that some 30% of the releases allocated to the southern stock originated from the northern stock component (Anon. 1987). The basic supposition of random mixing of the tagged fish in the area where the stock is sampled for tags is therefore not fulfilled. This is probably the main reason for the poor symmetry in the variance of the plots. The Working Group has, however, used the recoveries of the releases in 1975-81 for assessment work, omitting the releases in 1976 and 1980 in the calculation of the regression line (Anon.,1986). The remaining plots yield a straight line with slope z= 0.18 and an intercept of the lnK axis of 0.1. Using equation (3) and a screened catch of $18.680 \cdot 10^6$ (Table 3), N_{83} is calculated to some $2000 \cdot 10^6$. Herring of the northern stock component account for 30% of this number (Anon.,1987) and the 1983 stock estimate of the southern component is therefore in an order of magnitude of $1400 \cdot 10^6$, before the estimate is adjusted for tagging mortality. This is likely to be an overestimate of the Atlanto-Scandian herring because a part of the tagged herring may also originate from autumn spawners and from local stocks, which spawn in other areas.

It may be noted that the plot of the 1983 releases is located close to the intercept of the regression line. This indicates that the tagging mortality in 1983 equals the average tagging mortality of the previously used tagging method. This is in conflict with the previous findings, but the relatively high return rate of the 1983 releases may on the other hand be explained by a low contribution of tagged herring from other stocks in that particular year. The confidence of this observation is therefore considered to be rather poor. The consistency of results obtained by using the releases after 1981 in equation 1 is also poor and these data have not been used for assessment purposes.

The Working Group has adopted an average tagging mortality of 30% (Dragesund and Jacobsen, 1963). Recent tests of tagging mortality carried out in an indoor basin gave results of tagging mortality ranging from about 10% to 25% (Hamre and Toresen, 1989). These estimates are, however, not accounting for the mortality caused by the catching of the tagged fish. The sum of the two stock component estimates in number, adjusted by 30% tagging mortality and converted to weight, yields a spawning stock biomass in 1983 of some 600 000 t. The further development of these year classes in subsequent years is assessed by tuning the VPA against the stock estimates obtained from tagging prior to 1984. For the year classes younger than the 1981 year class the state of stock is measured by the acoustic method. The total stock biomass for the years 1977-1989, and by components for the years 1977 to 1984 are shown in Figure 9. The Figure shows that whereas the northern component has remained in an approximately steady state during this period, the spawning stock of the southern component has increased from below 100 000 tonnes in 1977 to about 250 000 tonnes in 1983. When the strong 1983 year class recruited to the spawning stock the occurrence of the stock in two separate components disappeared.

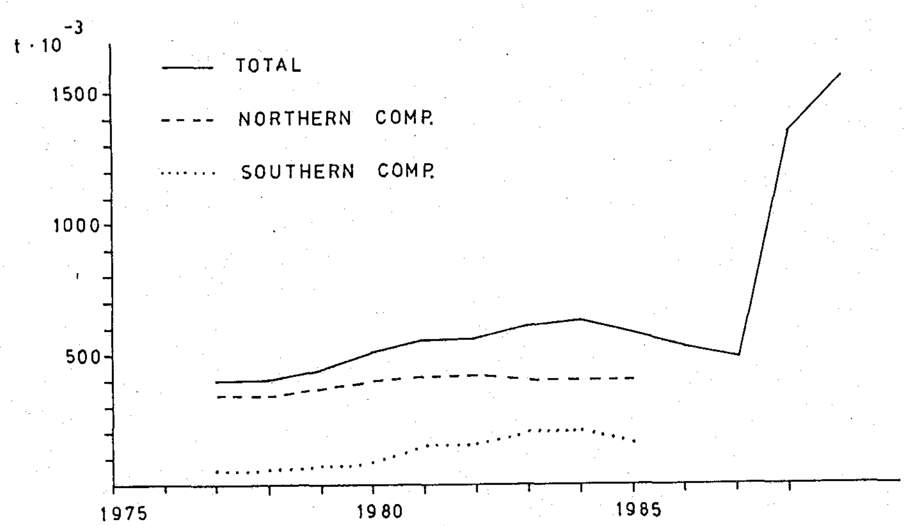


Fig. 9. Estimate of spawning stock by components 1977-1988.

The 1983 year class has increased the spawning stock biomass to about 1.5 mill.tonnes in 1989, but the prospects for further stock development is not promising. The year classes younger than the 1983 year class are all weak, and the spawning stock is expected to decline in the 1990's.At present about 95% of the spawning stock belongs to the 1983 year class.

FISHERY MANAGEMENT

After the drastic decline in catches in the late 1960's, the Working Group considered the state of the stock and found that there had been almost no recruitment to the adult stock since 1966, owing to the heavy exploitation of the 1963-1964 year classes in the fishery of juveniles. The Working Group concluded that in view of the critical state of the stock it would be advisable to keep the exploitation rate of small and fat herring at a much lower level than in previous years (Anon., 1972). A minimum landing size of 20 cm was set on the Norwegian herring fishery north of 62^{0}N in the spring 1970, and the use of herring for reduction was prohibited from 1 January 1971. A total ban of the Norwegian winter fishery was introduced in 1972. The minimum landing size of 20cm was replaced by catch quotas on small and fat herring in 1973 and 1974, limiting the catches to 6800 t and 6300 tonnes respectively. From 1975 to 1983 the Norwegian herring fishery has been regulated by catch quotas and by a minimum landing size of 25 cm. The commercial fishery on the spawning grounds was closed in 1972 but was reopened in 1984. The ICES's recommended catches (1000 t) and the national quotas set for the years 1984-89 are shown in the text table below. For the years 1975 to 1983 ICES's recommended a total ban on the fishery.

YEAR	1984	1985	1986	1987	1988	1989
Recom. catch	38	50	150	150	150	100
Agreed catch	38	60	126	115	120	90

ICES considers the Norwegian spring spawning herring as a recruitment overexploited stock, and the recommended catch should not be regarded as a catch quota, but as a maximum level the catch should not exceed. 2.5 million tonnes is set as the preferred minimum level of spawning stock.

STOCK INTERRELATIONSHIP

The Norwegian spring spawning herring is the largest catchable fish resource in the Northeast Atlantic and constitutes as a plankton feeder the most important link in the food chain above fish level in the ecosystem of the Norwegian Sea and the Barents Sea. This stock is of particular importance for the marine life on the Norwegian shelf and in the Barents Sea due to the migration pattern of the adults and to the distribution and migration of the juveniles. Prior to the 1960's the spawning migration of the herring constituted a huge displacement of biomass from distant areas of the Norwegian Sea to the Norwegian west coast. This migration was followed by hords of marine predators which made the Norwegian west coast one of the most profitable fishing areas in the world. When the stock collapsed in the late 1960's this huge input of biomass terminated and the immidiate effect was a drastic decline in the yield from the Norwegian west coast fisheries. The lack of income from the coastal fisheries had a marked impact on the activities and social life of the coastal communities in the area south of Lofoten.

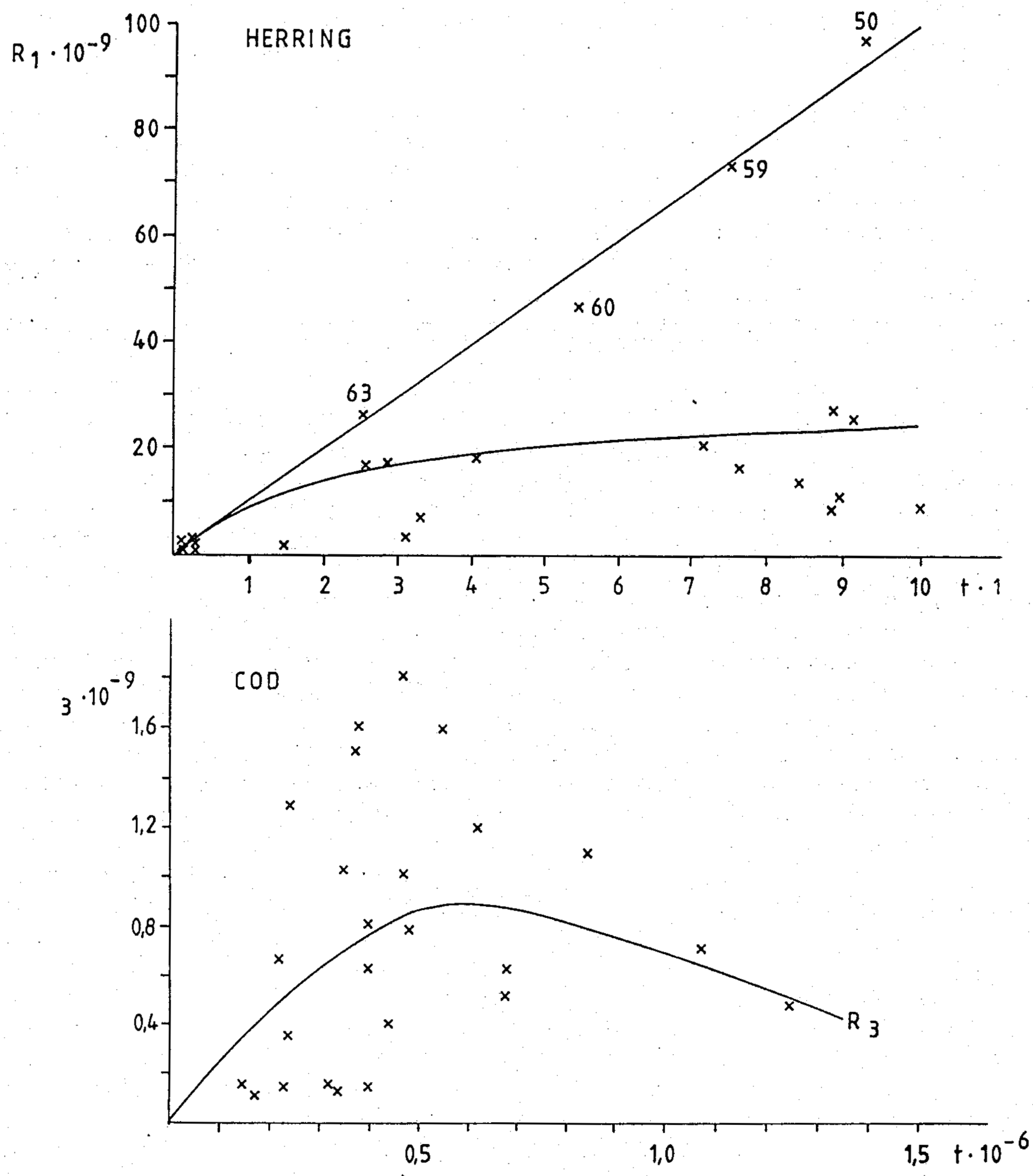


Fig.10. Stock/recruitment relationships for herring and cod. spawning stock in million tonnes, recruitment billion individuals.

A new crisis has struck the Norwegian coastal fisheries in recent years and this has developed in the stocks and fisheries of Northern Norway and in the Barents Sea. The crisis is obviously linked to an unbalanced state of the predator/prey relationship in the Barents Sea which became exposed in 1986 onwards when starved cod, sea-birds and seals appeared in Norwegian coastal waters. The prime reason for the lack of prey species in the region is most probably related to the overexploitation of the herring (Hamre 1988). Herring and cod are the key species in the predator/prey relationships in the Barents Sea. This because they are the largest stocks in the region and their success of recruitment is governed by common environmental factors, i.e. the inflow of warm Atlantic water to the area (Sætersdal and Loeng, 1984). Both stocks were reduced in the early 1980's, but only the herring stock was grossly recruitment overexploited. This constituted a latent unbalanced state of the ecosystem released by a shift from a cold to a warm climate in the early 1980's. Extraordinary strong year classes of herring and cod were recruited in 1983 to 1985, but the spawning stock of herring was not rebuilt to a sufficient level to take full advantage of the improved climatic condition. The recruited year classes of herring were not sufficiently large to meet the food demand of the cod. In the years 1983 to 86 the rapid growing stock of young cod together with other predators grazed down the plankton feeders and other available food items in the area (Mehl, 1988). The high predation pressure resulted in a collapse of the Barents Sea capelin stock in 1986, and due to lack of food the abundance of cod declined substantially in the subsequent years (Anon.,1986 b, 1988 b).

The recent development in stocks and fisheries in the Barents Sea demonstrates the importance of the herring for the ecobalance in the region. The dynamics behind the development are understood from the differences in the stock/recruitment functions of the two species (Figure 10). For herring there seems to be a linear relationship between spawning stock biomass and recruitment in periods of favourable recruitment conditions. The food supply for abundant cod year classes in form of juvenile herring is thus proportional to the state of the adult herring stock. The stock/recruitment relationship for cod shows, however, that cod recruits strong year classes on relative low stock levels. This means that in a state of reduced stock sizes for both the stocks for instance after a long period of low temperature in the Barents Sea, as in the 1980's, the balance in the predator/prey relationship may change dramatically in the shift from a cold to a warm climate. This recruitment mechanism explains the paradox that a crisis in stocks and fisheries may develop when recruitment conditions of the main species are improved.

CONCLUDING REMARKS

The stock structure of the Norwegian spring spawning herring is not yet properly known. The stock components which have developed as separate units in recent years, show similar characters of being members of different races as the stock components described by Schnackenbeck and Ottestad in the 1930's. These components may, however, not be selfsustained, but may consist of groups of individuals which inhabit different areas throughout their life span according to the location of their nursery area as juveniles. This form of stock separation is difficult to identify and distinguish from separation in races. Knowledge of the homogeneity of the stock is crucial for the interpretation of the stock estimates obtained from tagging and for a proper management of the stock as well. Studies of stock structure should therefore be given high priority in future herring research.

The distribution pattern and migration of the herring changed during the period when the stock size declined. This resulted in speculations regarding the prime reason for the disappearance of the herring, whether the collapse of the stock was caused by overfishing only, or whether the stock depletion was also due to natural causes. The collapse seemed to occur as a combined effect of increased effort in the adult fishery and the continuation of the high exploitation rate on the immature stock. It has been shown that a regulation in one of these two fisheries would have had a significant effect on maintaining a spawning stock size at a reasonable level up to 1970. It is therefore concluded that the collapse of the stock in the 1970's was mainly due to overexploitation.

With respect to Devold's hypothesis of alternating herring periods which predicted that the Norwegian spring spawning herring was on the point of leaving the Norwegian west coast in the 1960's, for later to occur at Bohuslän, the question is whether the herring would have disappeared from the west coast irrespective of the increased exploitation. The depletion of the stock by the fishery will from this point of view be a logical explanation to the absence of a subsequent Bohuslän fishery in the 1970's. The knowledge obtained in recent years do, however, not support the crucial point in the dynamics of the migration theory developed by Devold, namely that higher temperature in the wintering area should accelerate the maturing of the herring and thus affect the spawning time accordingly. Since 1974 the maturing herring in northern Norway have wintered in relatively high water temperatures as presupposed by the migration theory, but the time of spawning has not been affected as predicted. In general, some similarities in the state of the stock in the 1970's compared to that in the 1870's are, however, observed. The occurence of the large herring in northern Norway in the previous century indicates that the traditional migration pattern was broken as in recent years, but lasted for only 6 years. The occurence of the mixed herring on Møre and Trøndelag and the two fishing seasons which developed at the end of the century, may moreover be taken as evidence for a stock recovery process of two stock components similar to the recovery of the stock observed in recent years. At the end of the previous century the spawning took, however, place in the early winter, and after spawning the herring obviously left the coast. The prolonged stay of the herring in the Norwegian coastal waters in recent years may therefore be related to the late spawning time.

The herring stock was fished out in 1970, and without protection the immature stock would probably also have been depleted in 1971. This history shows that the efficiency of the fishing techniques directed at schooling fish has reached a level at which the survival of stocks is endangered. It is thus thought provoking to note that the most important fish resource in the Northeast Atlantic may have survived exploitation only on account of regulations introduced at the very last moment. The stock is now increasing, but is still below the critical level of 2.5 mill. tonnes where recruitment is assumed to be affected. The stock consists mainly of one year class, the year class 1983. The younger age groups are all poor and the spawning stock is expected to decline in the 1990's. The future development of the stock will to a large extent depend on the survival conditions of the herring fry in coming years, but the recovery of the stock is still dependent on effective protection.

As the main plankton feeder in this region the herring must have played a decisive role for all top carnivores . The herring fishery has not been replaced by any fishery on other plankton-feeding species which may have utilized the production which previously maintained the herring stock. The consequence of the collapse of the herring stock is therefore that the production, in one of the richest areas in the Northeast Atlantic, became unavailable to top carnivores, including man. The depletion of the herring may have changed the balanse in the ecosystem of the region fundamentally and is probably the prime reason to the severe crisis which has developed in the Barents Sea's stocks and fisheries in recent years. The depletion of the Norwegian spring spawning herring resulting in a break down of the life cycle of one of the largest fish stocks in the world, is likely to be the most destructive encroachment to a marine ecosystem ever done by a commercial fishery.

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Table 1. Catches (in thousand tonnes) of Norwegian spring-spawning herring during the period 1950-1988

Winter Year	herring	Summer and autumn herring	Total adult herring	Small and fat herring	Grand total
1950	771.3	54.8	826.1	106.9	933.0
1951	889.3	104.9	994.2	284.2	1278.4
1952	829.4	89.8	919.2	335.6	1254.8
1953	678.6	171.3	849.9	240.7	1090.6
1954	1119.1	187.3	1306.4	338.1	1644.5
1955	1004.4	213.1	1217.5	142.3	1359.8
1956	1192.8	267.8	1460.6	198.8	1659.4
1957	856.5	291.8	1148.3	171.2	1319.5
1958	429.1	355.9	785.0	201.6	986.6
1959	510.2	372.9	883.1	228.0	1111.1
1960	401.0	420.1	821.1	280.7	1101.8
1961	146.3	351.6	497.9	332.2	830.1
1962	133.5	417.7	551.2	297.4	848.6
1963	132.8	538.0	670.8	313.7	984.5
1964	420.2	697.7	1117.9	163.9	1281.8
1965	391.2	934.6	1325.8	221.9	1547.7
1966	631.8	1091.7	1723.5	231.5	1955.0
1967	458.8	672.7	1131.5	545.7	1677.2
1968	44.8	228.3	273.1	439.1	712.2
1969	20.5	3.6	24.1	43.7	67.8
1970	20.9	-	20.9	41.4	62.3
1971	6.9	-	6.9	14.2	21.1
1972	-	9.9	9.9	13.2	23.1
1973	0.1	6.6	6.7	0.3	7.0
1974	0.9	6.1	7.0	0.6	7.6
1975	0.1	3.4	3.5	0.3	3.8
1976	-	0.2	0.2	0.2	0.4
1977	0.4	11.8	12.2	0.5	12.7
1978	0.5	9.2	9.7	0.2	9.9
1979	0.7	1.9	2.6	0.3	2.9
1980	0.9	7.6	8.5	0.1	8.6
1981	0.8	7.8	8.6	0.1	8.7
1982	1.0	10.4	11.4	0.2	11.6
1983	3.9	13.3	17.2	0.9	18.1
1984	18.7	29.5	48.2	0.3	48.5
1985	29.4	37.2	66.6	4.5	71.1
1986	71.1	55.5	126.6	0.2	126.8
1987	62.9	49.8	112.7	0.2	112.9
1988*	71.0	52.0	103.0		

* Preliminary

Table 2. Total catch.

Catch (in thousand of tons) of adult and pre-recruit Norwegian spring-spawning herring 1950-1968.

Year	Iceland	Norway	USSR	Faroes	Germany	Total
1950	30.7	781.4	14.0	-	-	826.1
1951	48.9	902.3	43.0	-	-	994.2
1952	9.2	840.1	70.0	-	-	919.3
1953	31.5	692.2	110.0	17.0	-	850.7
1954	15.2	1103.6	160.0	27.6	-	1306.4
1955	18.1	979.3	207.0	13.1	-	1217.5
1956	41.2	1160.7	235.0	23.7	-	1460.6
1957	18.2	813.1	300.0	17.0	-	1148.3
1958	22.6	356.7	388.0	17.7	-	785.0
1959	34.5	426.9	408.0	13.7	-	883.1
1960	26.7	318.4	465.0	11.0	-	821.1
1961	85.0	111.0	285.0	16.9	-	497.9
1962	176.2	156.2	209.0	9.8	-	551.2
1963	177.5	130.4	330.0	12.9	-	650.8
1964	367.4	366.4	365.8	19.3	-	1118.3
1965	540.0	259.5	489.2	31.5	5.6	1325.8
1966	691.4	497.9	447.4	60.2	26.1	1723.0
1967	359.3	423.7	303.3	34.9	9.7	1130.9
1968	75.2	55.7	124.3	-	1.8	257.0

Table 3. Tag releases (m) and recoveries by components 1975-87 including yearclasses 1981 and older.
C= catch (in number) effectively screened

Northern component

Releases		Recaptures													
Year	m	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	SUM
1975	20991	0	0	7	12	7	8	1	0	0	4	3	18	0	60
1976	15947		0	2	5	2	7	2	0	0	2	4	5	0	29
1977	24989			0	12	10	17	4	0	2	11	5	34	0	95
1978	19998				0	18	15	7	0	2	15	8	27	6	98
1979	8797					0	7	1	0	2	6	5	11	1	33
1980	15988						0	4	0	3	17	4	25	2	55
1981	9977							0	2	5	11	10	29	2	59
1982	14884								0	3	15	3	15	2	38
1983	17925									0	13	8	34	1	56
1984	13957										0	3	30	3	36
1985	18717											0	39	1	40
SUM		0	0	9	29	37	54	19	2	17	94	53	267	18	
C . 10-3				939	705	710	1537	900	103	484	2479	1763	6182	350	

Southern component

Releases		Recaptures													
Year	m	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	SUM
1975	5000	0	0	4	5	2	1	8	2	3	4	2	7	2	40
1976	7998		0	0	0	3	0	2	2	2	4	7	0	0	20
1977	16044			0	7	15	8	9	12	2	15	10	12	1	91
1978	11998				0	7	8	7	8	2	10	8	13	0	63
1979	5995					0	7	14	9	1	9	10	16	0	66
1980	19994						0	10	23	3	19	10	18	0	83
1981	24967							0	33	13	56	40	66	1	209
1982	12380								0	7	9	8	14	0	38
1983	15891									0	50	36	45	3	134
1984	12221										0	39	70	5	114
1985	12167											0	55	4	59
SUM		0	0	4	12	27	24	50	89	33	176	170	316	16	
C . 10-3					150	241	587	1209	1406	1279	4992	5340	7837	512	