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BIOLOGY AND POPULATION DYNAMICS OF THE NORWEGIAN SPRING-SPAWNING HERRING

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IDENTITY

The name "Atlanto-Scandian herring" was introduced by Johansen (1919) to describe most of the herring found along the Norwegian coast, in the Norwegian Sea, off Iceland, off the Faroes, and on the northeastern edge of the North Sea. Today the term is frequently used as a common name for three stocks: Norwegian spring spawners, Icelandic spring spawners, and Icelandic summer spawners (Fig. 1). The Norwegian spring spawners are the largest of these stocks, with spawning grounds situated mainly along the Norwegian coast. The Icelandic spring and summer spawners have their spawning grounds at various localities off the Icelandic south and southwest coast. It is known from studies of biological characters and from tagging experiments (Fridriksson and Aasen, 1952; Jakobsson, 1963a) that the spring spawners from the Norwegian and Icelandic grounds are not geographically isolated during the non-spawning phase. Although the fish mix on the feeding grounds they are considered to constitute three self-contained stock units.

Detailed investigations have shown that apart from differences in spawning time the Icelandic summer spawners also differ consistently from the spring spawners in a number of morphological and physiological characters (Johansen, 1926; Fridriksson, 1944, 1958; Liamin, 1959; Einarsson, 1951). Less strongly marked differences are observed between the characters of the Norwegian and Icelandic spring spawners. However, many research workers have shown consistent differences between them, such as those found by Fridriksson (1944, 1958) in the growth pattern and scale structure. More direct evidence that they are separable into two distinct stocks has been obtained from tagging experiments (Fridriksson and Aasen, 1950, 1952; Fridriksson, 1955; Jakobsson, 1963a, 1965; Anon., 1964). In these experiments, herring tagged on both the Norwegian and Icelandic spawning grounds were subsequently recaptured on the feeding grounds, whereas only a few records of fish tagged on the southwest Icelandic spawning grounds were subsequently recaptured off the Norwegian west coast and vice versa. In addition, studies of the age compositions of the catches from the Norwegian and Icelandic spawning grounds (Jakobsson, 1965; Østvedt, 1965) show homogeneity of population structure within areas, but heterogeneity between them, especially as regards the occurrence of rich and poor year classes. It seems likely therefore that the interchange of spawners between these two areas is small and that the Ice-

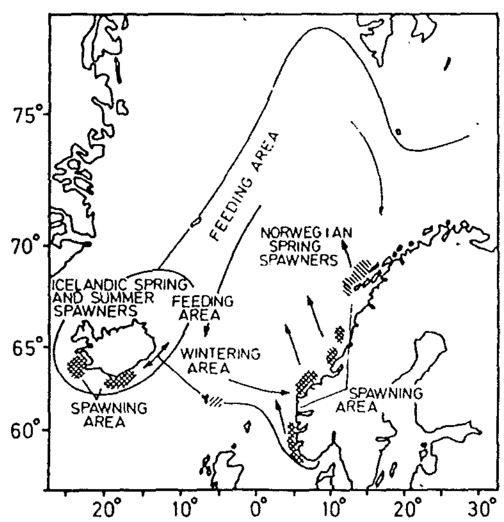


Figure 1. Distribution of stocks within the Atlanto-Scandian herring group.

landic spring spawners form a stock unit distinct from the Norwegian spawners.

Whether the Norwegian spring-spawning herring constitute a single homogeneous stock has been the subject of much investigation and conflicting scientific views. Broch (1908) and Johansen (1919) found that the vertebral counts of the spawners were not the same throughout the total spawning range. Lea (1929) observed that the scales of young herring from northern and southern Norway differed in the nature and 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) split it into northern and southern components with spawning grounds to the north and south of Møre respectively. Runnstrøm (1933, 1936, 1937, 1941), on the other hand, claimed that such a strict separation was not consistent with the available evidence. In a later analysis of the characters of adult spawners with the northern and southern growth types, Østvedt (1958) observed that there was an increasing intermixing of the two types with age and that both were found together over the whole spawning range. He also found that the proportions of the two types varied considerably between year classes and concluded that herring of the two growth types are not 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 evidence, therefore, it has been concluded that the Norwegian spring spawners are members of a single stock and that the two distinctive growth types originate from the northern or southern nursery areas respectively.

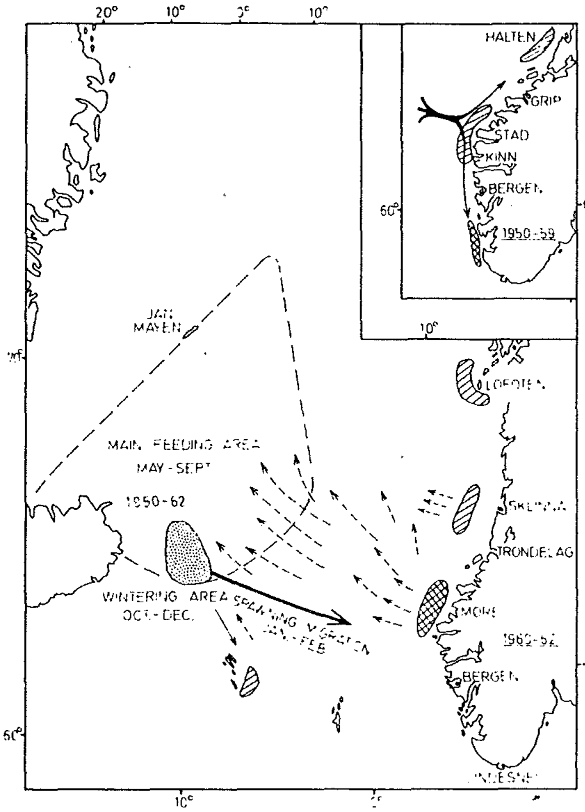


Figure 2. Migration routes of Norwegian spring-spawning herring, 1950–1962 (modified from Anon., 1970).

DISTRIBUTION AND MIGRATION

ADULT HERRING

Knowledge of the distribution and movements of the adult herring is obtained from several sources, such as racial analysis of herring caught in the Icelandic summer fishery (Fridriksson, 1963), Icelandic and Norwegian tagging experiments (Fridriksson and Aasen, 1952), data derived from the catch statistics of the high seas drift-net and purse-seine fishery (Marti, 1956; Jakobsson, 1963b) 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.

The larger fish are the first to spawn and the first to leave the spawning grounds. Recoveries of herring tagged on the spawning grounds at the Norwegian coast have been made in the Skagerrak, the North Sea, and at Iceland in the year of tagging. Most of the spent herring move northwestward into the Norwegian Sea where they feed heavily on zooplankton (Fig. 1). The larger fish reach the Polar Front in June and July and some cross into the cold water. The limit of the summer feeding migration extends from the Spitsbergen–Jan Mayen area in the north to the western borders of the East Icelandic Current in the south. The length composition of herring caught during summer in the different areas shows that the larger fish move farther to the northwest than the smaller fish (Marti, 1959; Marti and Wilson, 1960).

The feeding area contracts during the autumn when the herring are found in the southwestern part of the Norwegian Sea along the borders of the East Icelandic Current. The ripening herring winter in an area off East Iceland. In December and January prespawning concentrations move towards the Norwegian coast. Devold (1951, 1959, 1963) has described in detail the spawning migration towards the coast. He found that the herring gather in cold-water

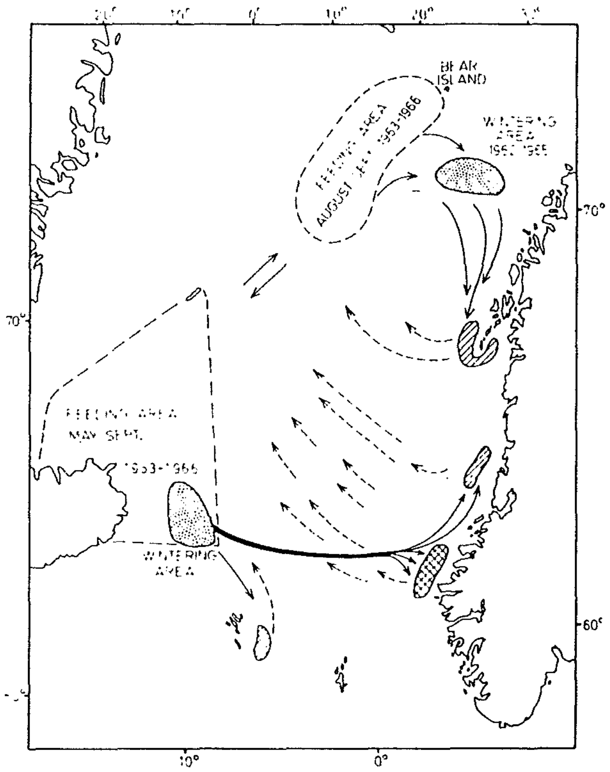


Figure 3. Migration routes of Norwegian spring-spawning herring, 1963–1966 (modified from Anon., 1970).

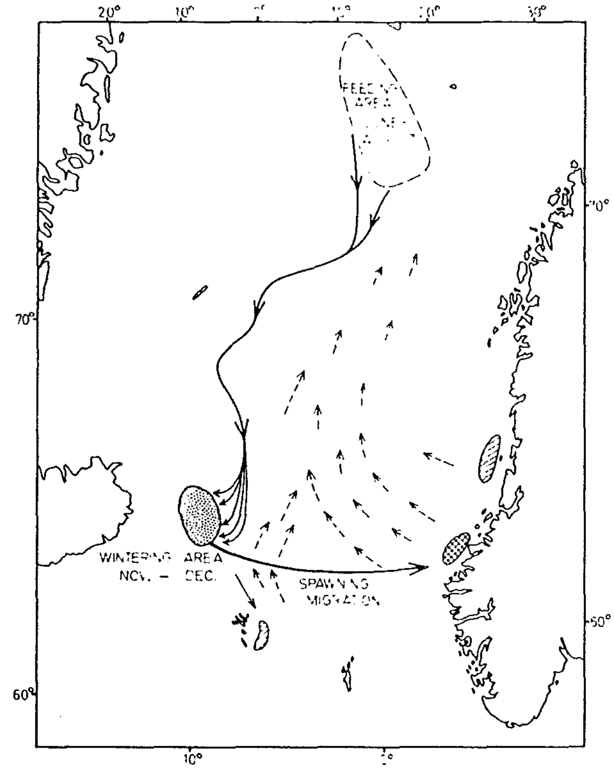


Figure 4. Migration routes of Norwegian spring-spawning herring, 1967–1968 (modified from Anon., 1970).

pockets before penetrating the warm Atlantic Current into the colder Norwegian coastal water. The full herring usually arrive at the Norwegian coast off Stad and spread farther south and north to spawn.

This brief description of the distribution and migratory pattern of the adult stock is the usual one when the stock size is at a relatively high level. However, during the period 1950–1969 changes in the migratory pattern took place (Figs. 2, 3, and 4). Between 1950 and 1962 the spawning grounds of the stock gradually moved northwards (Fig. 2), and after 1959 spawning south of Bergen was negligible (Devold, 1963; Dragesund, 1970). During the period 1960–1966 spawning was concentrated off Møre–Trøndelag and Lofoten (Figs. 2 and 3). Later in the 1960s the area decreased even further (Fig. 4). In general, the area of spawning has shrunk in proportion to the stock size.

In 1950–1962 the main summer feeding grounds varied somewhat but remained in the Iceland–Jan Mayen area (Fig. 2). The densest summer concentrations were usually found near the borders of the East Icelandic Current. In the autumn the herring assembled on the usual wintering grounds situated off East Iceland near the southern and southwestern borders of the East Icelandic Current.

During the period 1963–1966 a separate stock component (Devold, 1968; Jakobsson, 1968) was found in addition to the main one. This had feeding grounds in the region southwest of Bear Island (Fig. 3). At the end of the feeding period some of the herring which had spawned for the first time at Lofoten moved to the wintering grounds to the east of Iceland and recruited to the main component of the adult stock. However, most of the prespawning herring which spawned for the first time at Lofoten migrated after the feeding period to the wintering grounds located south of Bear Island. The main part of the maturing herring recruiting to the Lofoten component were also wintering in this area (Benko, Seliverstov, and Zilanov, 1966; Devold, 1968).

In the autumn of 1966 this separate stock component migrated all the way from the Bear Island feeding grounds to the wintering grounds off East Iceland and mixed with the main component of the stock that traditionally wintered in that area. In 1967–1968 (Fig. 4) the stock migrated as a single unit to the main spawning grounds off Møre–Trøndelag (with no

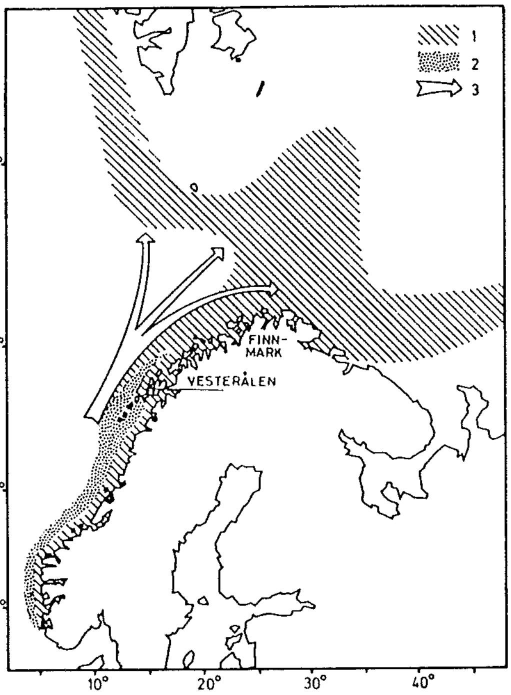


Figure 5. Distribution of young herring. (1) nursery area, (2) larval distribution, (3) direction of post-larval drift to the offshore nursery area.

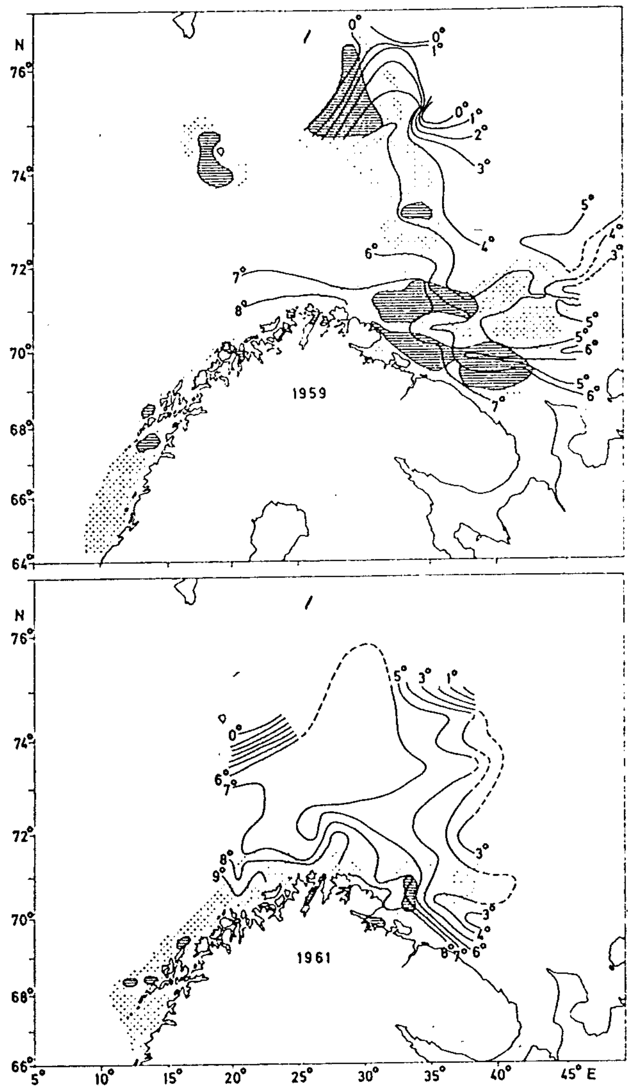


Figure 6. Distribution of 0-group herring in relation to temperature (°C) at 50 m depth in autumn of 1959 and 1961.

spawning at Lofoten). After spawning, the stock moved to the summer feeding grounds in the Spitsbergen–Bear Island area. During late autumn the herring again concentrated in the traditional wintering area off East Iceland.

YOUNG AND ADOLESCENT HERRING

Until the beginning of the 1960s little was known about the distribution and migration of the early stages of Norwegian spring spawners. Lea (1929) was of the opinion that most of the 0-group herring entered the fjords of western and northern Norway and were distributed in coastal waters, but at that time no attempt had been made to search for 0-group herring in the open sea. 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. This view was not shared by Marti (1956), who held that most of the 0-group herring were to be found along the coast and in the fjords of Norway. From later investigations (Dragesund and Hognestad, 1960; Devold, 1968; Jakobsson, 1968; Dragesund, 1970) it can be stated that the distribution of the young and adolescent herring is widespread, ranging from the fjords of northern Norway to the open ocean of the Norwegian Sea and the Barents Sea, and varies with the different year classes.

Figure 5 shows a schematic illustration of the general distribution of the early stages, with special reference to the 1959 year class. Soon after hatching, the major part of the larvae rise into the upper water layers (50–0 m). They are transported northwards from the spawning grounds mainly in coastal waters, that is water with salinity less than 35 ‰. An extensive northward drift of larvae takes place from all the spawning grounds along the coast. During the northward drift part of the larval population accumulates

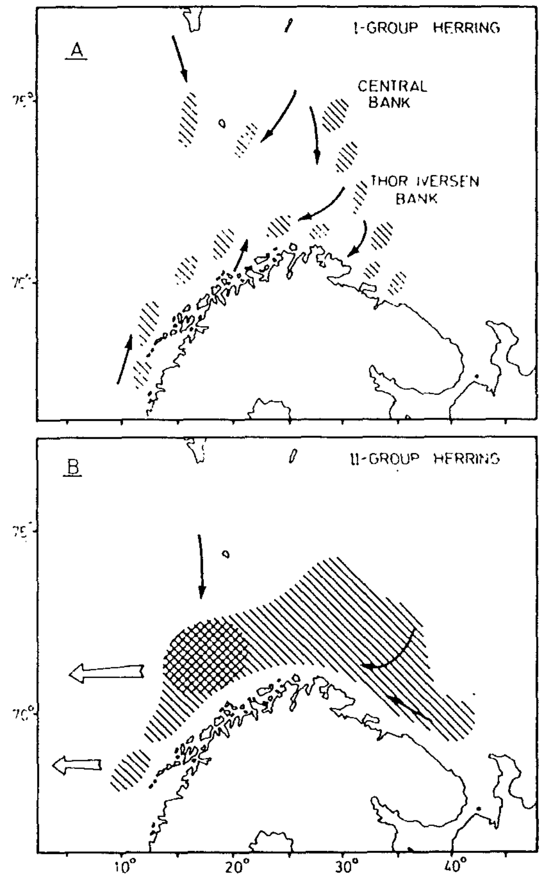


Figure 7. Distribution of young and adolescent herring during summer. (A) as 1-group, and (B) as 2-group. The arrows denote the migration routes during the summer.

at the entrance to the fjords along the Norwegian coast. In late 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. Comprehensive investigations of the distribution and abundance of young and adolescent herring in coastal and offshore waters of northern Norway have been carried out since 1959 (Dragesund, 1970; Anon., 1970). In all years concentrations of 0-group herring have been observed along the coast, particularly at the entrances to the fjords. The offshore distribution is more variable and is closely related to year-class strength of the 0-group.

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 which cover the area west of Spitsbergen–Bear Island and the central and southeastern parts of the Barents Sea (Fig. 6). The herring remain in this area during the following winter and spring and generally live in colder water than 0-group accumulating along the coast, especially west and south of North Cape. The 0-group herring located at the entrances to the fjords during early autumn subsequently migrate farther into the fjords later in the autumn. These herring then remain in the fjords throughout the following winter. A gradual emigration takes place in April–May.

A schematic illustration of the distribution and movement of adolescent herring located off northern Norway and in the Barents Sea is given in Figure 7. During spring and early summer, the 1-group herring distributed in the northern and northeastern part of the Barents Sea move southwards along the front between the cold and warmer water in the area from the Central Bank towards the Thor Iversen Bank. 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 (Fig. 7A). 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 (Fig. 7B). 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.

STOCK CHARACTERISTICS

SPAWNING STOCK

The age at first spawning is dependent on the growth rate. For the fastest growing fish the mean age at first maturity is four years, while for the slow growing fish the mean age varies somewhat between different year classes but normally occurs at 6–7 years of age. In the stock as a whole, the range of variation in age at first maturity varies from 3 to 9 years.

During the period from 1950 to 1962 the spawning stock had only one component which migrated towards the coast of Møre from the usual wintering area east of Iceland. The age composition in the spawning stock during this period is given in Table 1. It shows the great variability of year-class strength in the stock with the relatively strong year classes of 1943, 1944, and 1947, and the very strong one of

Table 1. Percentage age composition of Norwegian spring-spawning herring during the Norwegian winter fishery, 1950–1962

Age	Year 1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962
2	0·1	–	0·1	0·1	0·1	–	–	0·2	–	–	–	–	–
3	8·3	0·2	1·3	4·0	1·3	1·5	0·6	0·4	0·5	0·4	–	–	0·1
4	5·5	11·6	2·0	1·9	25·2	6·3	5·0	7·4	1·0	1·3	0·3	0·4	–
5	5·5	5·2	19·9	4·1	3·3	46·9	5·9	4·3	6·1	1·4	1·6	0·9	0·5
6	16·3	4·8	4·5	14·4	5·4	2·7	50·6	5·6	4·7	7·5	1·2	3·3	0·9
7	18·7	15·2	6·7	3·2	11·0	4·3	2·3	56·5	6·6	5·1	6·5	2·9	2·5
8	2·3	17·7	12·4	4·2	2·8	5·8	3·9	1·8	50·5	7·8	3·5	7·7	1·5
9	2·5	2·0	12·2	12·0	4·2	1·7	4·6	2·6	2·6	47·3	5·0	4·8	8·0
10	3·1	2·2	2·4	14·4	9·2	4·0	2·2	2·4	3·5	2·2	58·1	6·5	4·0
11	2·4	2·6	2·5	2·0	9·5	5·5	3·5	1·6	3·4	3·3	1·6	59·0	6·6
12	5·4	2·7	3·1	2·8	1·7	3·3	4·1	2·2	2·3	4·5	3·8	4·4	63·5
13	10·4	6·7	3·0	2·9	1·9	1·0	1·9	2·7	2·2	1·9	4·1	3·0	2·1
14	1·6	9·1	5·0	3·0	2·5	1·4	0·9	1·5	1·8	2·3	1·5	2·3	3·6
15	2·7	1·5	7·0	6·6	2·2	1·8	1·2	0·5	1·1	2·2	1·0	1·5	3·4
16	4·8	3·0	1·6	7·0	3·4	1·9	1·4	0·6	0·6	0·9	1·3	1·4	0·7
17	1·1	4·0	2·2	2·2	4·3	2·2	1·7	0·8	0·7	0·5	0·9	0·9	1·0
18	0·5	0·4	3·4	2·9	1·7	1·3	1·6	1·0	0·7	0·7	0·5	0·3	1·0
19	–	0·2	0·8	2·9	1·4	1·5	0·6	0·7	0·5	0·4	0·3	0·4	0·3
20	0·1	–	0·1	0·7	1·0	0·7	0·6	0·3	0·3	0·3	0·5	0·1	–
21	–	0·1	–	0·1	0·1	0·2	0·3	0·2	0·2	0·2	0·3	0·1	0·2
22	–	–	–	–	0·1	0·1	0·1	–	–	0·1	0·1	0·1	–
23	–	–	–	–	–	–	–	–	–	0·1	0·1	–	0·1
?	8·6	10·8	9·8	8·6	7·8	5·9	7·0	6·6	10·6	10·0	7·8	–	–
n	3 973	3 841	3 336	2 796	4 839	4 174	4 998	2 779	972	1 116	1 155	452	398

1950. In 1954–1956 the age structure of the stock changed as recruit spawners from the 1950 year class entered the stock. This year class dominated the spawning stock until 1963–1964, when the age structure again changed (Table 2). From 1964 onwards, the 1959 year class dominated the spawning stock off Møre–Trøndelag, but herring of the 1960 and 1961 year classes gradually also appeared on the spawning grounds. In 1965, these three year classes made up 80–85% of the spawning herring off Møre–Trøndelag. The spawning stock at Lofoten consisted almost entirely of the 1959–1961 year classes.

Spawning usually occurs at certain places along the entire coast from Lindesnes to Lofoten. In the 1930s the most important spawning region was located off the southwest coast of Norway between Lindesnes and Bergen. Regular spawning also took place farther north on the shelf between Kinn and Grip (Fig. 2). Spawning was usually recorded off Halten and Sklinna, whereas spawning at Lofoten–Vesterålen was more sporadic.

During the period from 1930 to 1959 the spawning time changed markedly in the southernmost spawning region (Fig. 8). In the early 1930s the main spawning took place in early February, whereas in the late 1930s it occurred in the second half of February. During the 1950–1959 period the spawning in this region occurred during the first half of March. In the area off Møre, from Stad to Grip, no marked change could be found, although in the early 1960s the spawning took place slightly later than in previous years. At Lofoten the spawning is somewhat later than farther south. During the three decades from 1930 to 1960 the main spawning time thus changed simultaneously with a progressively northward displacement of the main spawning centre.

GROWTH AND RECRUITMENT PATTERN

In comparison with most other herring groups in the Northeast Atlantic, Norwegian spring spawners are characterized by a low initial growth during the first two years of life. However, this growth rate is maintained to a greater age, in conformity with the delay in sexual maturity, resulting in a greater mean size at age five and all subsequent ages. It should also be noted that the initial growth is extremely variable, depending on the area in which the fish spend their adolescent phase.

The 0-group herring located along the coast from Vesterålen to Varangerfjord have fairly uniform lengths. This is to be expected since larvae hatched on the spawning grounds off Møre–Trøndelag are transported northwards in the same water masses and live under rather similar environmental conditions during their first five or six months. However, larvae

Table 2. Percentage age composition of Norwegian herring caught with purse seine during spawning seasons in 1963–1968

Year	Area	Total no.	Year class 1963	1962	1961	1960	1959	1958	1957	1956	1955	1954	1953	1952	1951	1950	<1950	Mean age
1963	Stad-Halten	923	–	–	–	–	4·0	0·3	0·4	0·7	1·8	1·7	8·7	3·6	8·3	61·1	9·4	12·2
	Halten-Sklinna......	314	–	–	–	–	13·1	0·3	–	–	–	0·3	7·3	3·2	7·3	62·5	6·0	11·6
	Lofoten-Vesterålen ..	433	–	–	–	9·5	89·8	0·7	–	–	–	–	–	–	–	–	–	3·9
1964	Stad-Halten	1 198	–	–	–	4·0	51·5	0·4	0·2	0·7	1·3	0·5	4·2	2·2	3·2	28·0	3·8	8·7
	Lofoten-Vesterålen ..	1 089	–	–	0·6	10·1	88·4	0·3	–	–	–	–	0·1	–	–	0·5	–	4·9
1965	Stad-Halten	1 141	–	–	3·2	10·7	62·7	0·1	0·2	–	0·4	0·9	2·0	1·4	2·2	14·4	1·8	7·8
	Halten-Sklinna......	96	–	–	18·8	26·0	55·2	–	–	–	–	–	–	–	–	–	–	5·4
	Lofoten-Vesterålen ..	719	–	–	5·8	19·6	74·1	0·1	–	–	–	–	0·3	–	–	–	0·1	5·7
1966	Stad-Halten	2 963	–	0·1	10·3	27·7	53·4	0·2	0·2	0·1	0·2	0·3	0·7	0·7	0·4	5·2	0·5	7·2
	Halten-Sklinna......	471	–	–	3·6	25·1	60·8	–	–	0·2	–	–	0·6	0·6	0·2	8·5	0·4	7·6
	Lofoten-Vesterålen ..	749	–	0·3	8·0	39·1	51·6	0·3	–	–	–	–	–	0·1	0·3	0·3	–	6·5
1967	Stad-Halten	2 135	0·5	0·4	13·4	32·1	48·8	0·1	0·1	0·1	0·2	0·3	0·7	0·3	0·3	2·6	0·1	7·3
	Halten-Sklinna......	99	1·0	–	10·1	41·4	46·5	1·0	–	–	–	–	–	–	–	–	–	7·4
1968	Stad-Halten	1 352	0·7	1·7	13·8	34·2	46·9	0·2	–	0·1	0·2	0·2	0·7	0·3	–	1·0	–	8·5
	Halten-Sklinna......	243	0·8	1·2	9·9	34·6	51·5	–	–	–	–	–	0·4	–	–	1·2	0·4	8·6

which accumulate at the entrances to the fjords between Møre and Lofoten and later enter the fjords in this area, live in warmer water and grow faster than those transported farther north.

Herring located off Finnmark and in the Barents Sea during the adolescent phase have a markedly slower growth than those found off the coast between Møre and Lofoten. The westward migration of adolescent herring from the Barents Sea into the Norwegian Sea to join the adult stock is, therefore, considerably delayed compared with those herring of the same year class located farther south. Accordingly, immature herring older than three years are scarce south of Lofoten, whereas off Finnmark, herring in the adolescent stage are common up to four years of age. Thus, herring that spend the nursery period in the northern nursery area have a longer phase of migration to the spawning grounds than those distributed farther south. The growth rate may therefore influence the migration pattern and duration of the adolescent phase. Growth, on the other hand, is determined by the distribution during the 0-group stage, and the 0-group distribution consequently plays an important role in the recruitment mechanism.

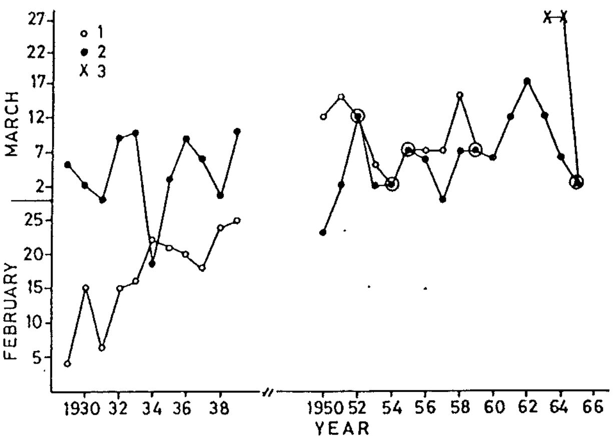


Figure 8. Time of main spawning during the periods 1929–1939 and 1950–1965. (1) south of Bergen, (2) off Møre, (3) at Lofoten.

EXPLOITATION

WINTER HERRING FISHERY

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. 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, but during the last three decades this fishing gear has been of little importance.

The purse-seine fishery, like the drift-net fishery, is carried out in the open sea and at the entrances to the fjords. Originally it was carried out by vessels of 80–120 feet, equipped with a purse seine operated from two dories. The purse seine was shot around the shoal from the dories, necessitating a large crew and thus restricting fishing in the open sea to periods with good weather.

In the late 1950s the stock size was reduced drastically, and the Norwegian fishermen, losing their main resource, ran into a serious economic crisis. Consequently, the number of fishing vessels in operation

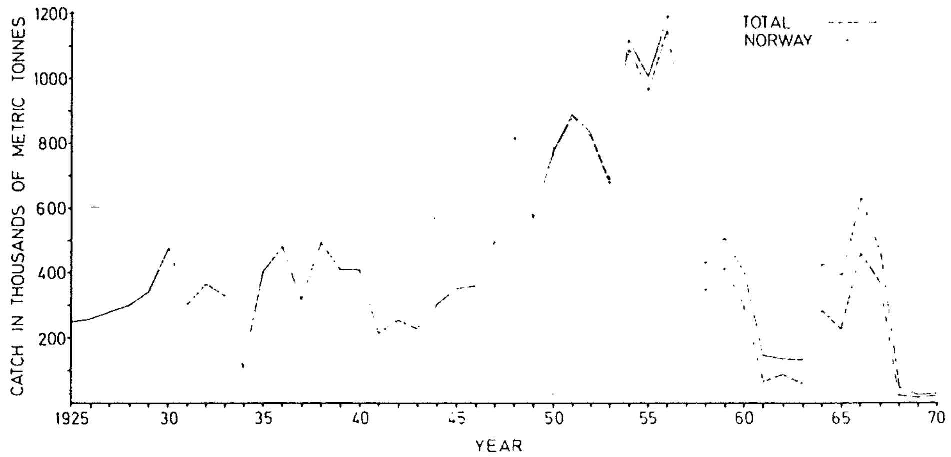


Figure 9. The catch of winter herring in 1925–1970.

fell considerably and the situation forced the fishermen to increase their efficiency and reduce the cost of fishing. This was achieved when the ring-net technique with power block replaced the two-dory system in the early 1960s. By 1968 all the two-dory purse seiners in the Norwegian fleet had been replaced by ring-net seiners.

The annual catches from the winter herring fishery over the period 1925–1970 are given in Figure 9. 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 in 1968–1971 the catches in the winter-herring fisheries were negligible compared with those in earlier years.

SUMMER AND AUTUMN HERRING FISHERY

Another important fishery, the summer and autumn herring fishery, takes 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 and mainly exploited the adult stock (Jakobsson, 1963). The fishing season off north and east Iceland normally lasted from June to early September, and up to 1950 the stock was principally exploited by Icelandic and Norwegian vessels.

In the late 1950s new technical advances considerably improved the purse-seining system in this fishery, as they did in the Norwegian winter herring fishery. The new technique made it possible to use larger and deeper nets, and the fishery extended seawards. During the 1950s and throughout the 1960s the fishery took place far offshore in the Norwegian Sea, and the fishing season lasted until October–November.

The Soviet fishery on feeding herring in the Norwegian Sea started in 1950. This has been a drift-net fishery. 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 Soviet drift-net fishing technique also improved during the 1950s. Thus in 1952 very few of the vessels taking part in the fishery were equipped with echo sounders and at that time about 38% of the shots were unproductive. With an increasing number of echo sounders in succeeding years, the percentage of unproductive shots decreased to 15% (Parrish and Saville, 1967).

The drastic change in the migratory pattern of the adult stock during the 1960s strongly influenced the location of the summer and autumn fishery. Off Iceland it became negligible and most of the summer fishery took place off the shelf west of Bear Island–Spitsbergen. In 1925–1936 the catches of the summer and autumn fishery off Iceland were fairly constant at 60000–70000 t (Fig. 10). There was a marked rise in the yield over the period 1936–1944. From 1945 to 1955 the Icelandic and Norwegian catches were at a relatively low level, whereas the Soviet catches gradually increased from 1950 onwards. In 1962–1966 there was a sharp increase in the total yield of this fishery, mainly owing to the Icelandic catches.

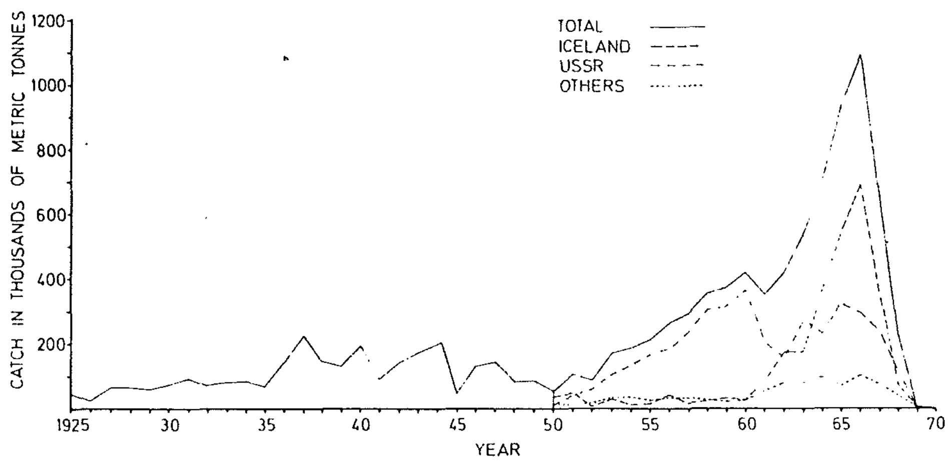


Figure 10. The catch of summer and autumn herring in 1925–1970.

YOUNG HERRING FISHERY

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 herring (Dragesund, 1970). An analysis of the total catch of small and fat herring landed during the period 1930–1970 (Fig. 11) shows that considerable fluctuations have occurred. Almost all the catches were taken with purse seine. From 1964 onwards in the young-herring fishery 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. The fishery started with the immigration of 0-group herring to the fjords and continued throughout the wintering period. A peak in the early spring coincided with the migration of 1-group herring from the fjords. Usually the adolescent herring found along the Norwegian coast are recorded outside the entrances to the fjords. The main fat-herring fishery, therefore, especially in the 1960s, took place offshore and most intensively off eastern Finnmark and off Vesterålen/Lofoten. In these areas the fishery started in early summer and reached a peak in the summer or early autumn. Farther south along the coast (off Møre and Trøndelag) most of the fat herring were landed in spring and early summer. A shift northwards of the spawning grounds could be the reason why a higher percentage of the total catches of both small and fat herring during the period 1950–1970 were taken in the northernmost region, Finnmark.

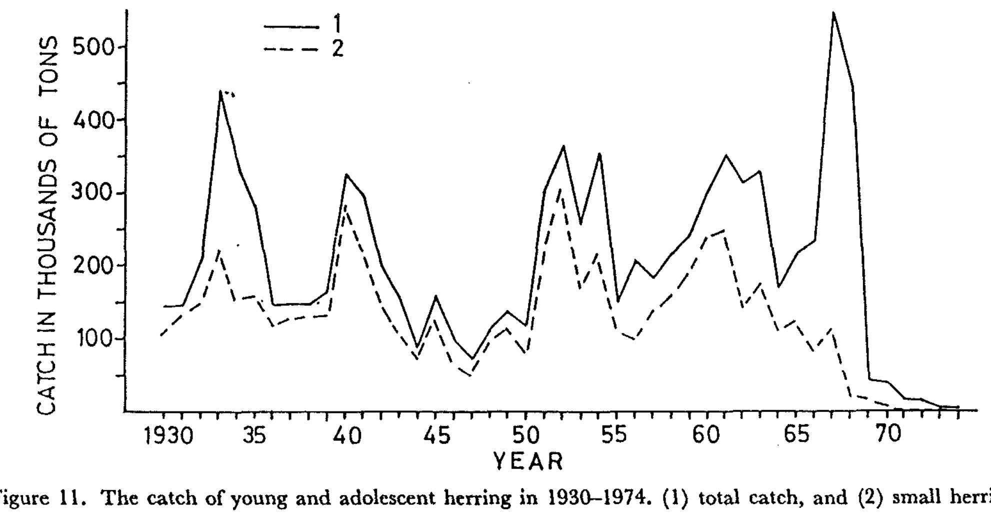


Figure 11. The catch of young and adolescent herring in 1930–1974. (1) total catch, and (2) small herring.

STOCK ASSESSMENT AND MANAGEMENT

PREVIOUS ASSESSMENT

In 1965 an ICES assessment report (Anon., 1965) dealing with the state of the stocks of Atlanto-Scandian herring and their exploitation up to the year 1963, was presented to the North-East Atlantic Fisheries Commission. The report concluded that "the exploitation of the adult Norwegian spring spawners is probably still at a level where any reduction of effort exerted on the adult stock would tend to reduce the total catch" and that "the magnitude of the reduction of recruitment due to the "små-sild" fishery is not yet known". Estimates from tag returns (Dragesund and Jakobsson, 1963) showed a decrease in spawning-stock size from 14 million t in 1956 to 5 million t in 1959–1960, caused by a sequence of poor year classes recruiting to the stock. Mortality estimates from the Norwegian drift-net fishery (Østvedt, 1963) gave a mean instantaneous total mortality coefficient of 0·2 of the adult stock for the period 1950–1955 and 0·22 for the period 1955–1960. A mean Z of 0·51 was calculated from tag returns by Dragesund and Jakobsson (1963) covering the years 1953–1959.

An ICES working group met again in 1969 to consider the state of the stocks of Atlanto-Scandian herring (Anon., 1970). Based on tagging data, combined acoustic surveys and underwater photography experiments, and catch and effort data, the working group concluded that after a further decline in spawning stock from 1959 to 1962, the stock size increased again to about 7 million t in 1964–1965, owing to the rich 1959 year class. From 1966 onwards a rapid decrease again took place, reaching an estimated level of 2 million t in 1968. The fishing mortality for 1965–1967 was estimated to be at a level of 0·4–0·5, reflecting an increase in total effort. The working group also concluded that the stock was subject to an increasing exploitation at the fat-herring stage, and advised restriction of the fisheries on young herring, especially the fat herring. Concerning the adult stock, "a further increase in the fishing rate should probably be avoided and even some reduction of fishing be considered". After the drastic decline in catches in 1969 and 1970, the working group met again in 1971 (Anon., 1972), stating 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 fat-herring fishery and of the weak 1965–1968 year classes in the small-herring fisheries. The working group concluded that "in view of the present critical state of the stock it would be advisable, in order to maximize recruitment and safeguard the continued existence of the Norwegian spring spawning stock, to keep the exploitation rate of small and fat herring at a much lower level than in recent years".

No effective management action was taken before 1 January 1971, when use of herring for reduction was prohibited in Norway. A total ban on the Norwegian winter fishery was introduced in 1972, and catch quotas on small and fat herring were introduced in 1973 and 1974, limiting the catches to 6800 t and 6300 t respectively.

ESTIMATES OF STOCK SIZE AND MORTALITIES FROM VPA

From catch in number by age groups in the various fisheries, based partially on data given in previous working group reports and partially on the records of the Institute of Marine Research in Bergen, Dragesund and Ulltang (1978) estimated fishing mortalities and stock sizes of the Norwegian spring-spawning herring back to 1950.

Adult stock

Table 3 shows the estimated spawning stock size in number and weight and the fishing mortality on herring 4, 5, 6, and 7 years old and older for the years 1950–1971, assuming a fishing mortality of 0·3 on the year classes which were fully recruited to the spawning stock in 1971 (corresponding to a spawning

Table 3. Spawning stock size in number ($N \times 10^{-9}$) and weight (million tonnes) and fishing mortality, 1950–1971. Figures in brackets are uncertain because VPA information is from catches for only a few years.

Year	Spawning stock size		Fishing mortality			
	Number	Weight	4 years	5 years	6 years	7 years and older
1950	36·9	9·4	0·054	0·047	0·091	0·095
1951	30·3	9·1	0·050	0·062	0·051	0·12
1952	28·8	8·8	0·014	0·098	0·061	0·12
1953	23·5	7·1	0·016	0·028	0·074	0·14
1954	27·0	7·6	0·038	0·059	0·082	0·22
1955	34·1	8·8	0·051	0·067	0·058	0·17
1956	32·3	8·9	0·10	0·072	0·11	0·21
1957	35·8	10·0	0·17	0·079	0·066	0·13
1958	28·7	8·5	0·040	0·065	0·057	0·097
1959	23·3	7·5	0·074	0·072	0·110	0·13
1960	17·0	5·5	0·16	0·10	0·087	0·15
1961	12·7	4·1	0·088	0·048	0·068	0·11
1962	9·7	3·3	0·054	0·042	0·106	0·163
1963	7·9	2·5	0·057	0·041	0·030	0·29
1964	13·2	3·4	0·081	0·18	0·14	0·40
1965	15·0	3·7	0·17	0·15	0·29	0·75
1966	11·4	2·8	0·39	0·51	0·58	0·83
1967	4·8	1·4	1·1	0·80	1·2	1·5
1968	1·0	0·28	4·5	4·4	1·4	1·1
1969	(0·31)	(0·09)	(0·28)	(0·71)	(0·39)	(0·42)
1970	(0·18)	(0·06)	(1·31)	(0·34)	(0·60)	(0·63)
1971	(0·09)	(0·03)	(0·10)	(0·24)	(0·33)	0·3[a]

[a] Assumed value.

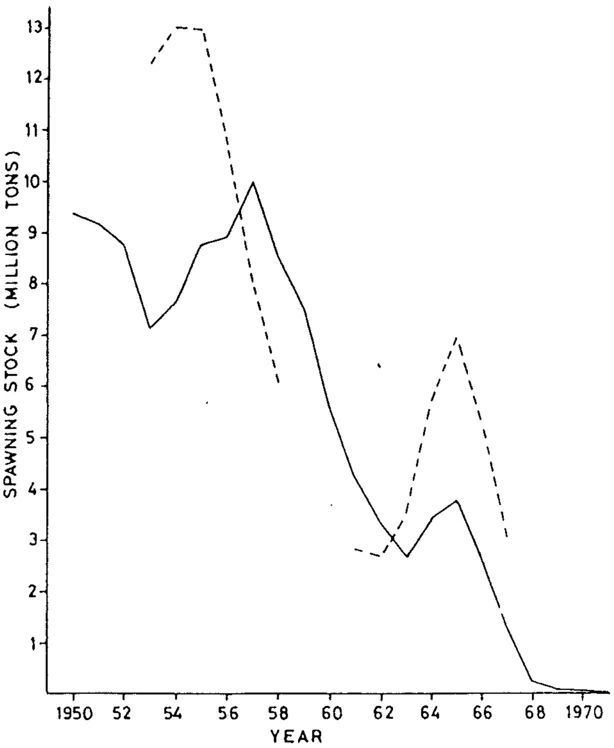


Figure 12. Spawning stock size in weight for the years 1950–1971. The broken line shows stock size estimates given by the Working Group on Atlanto-Scandian Herring (Anon., 1970, 1977).

stock size of about 30000 t). The spawning stock size in weight is plotted in Figure 12, together with corresponding estimates given by the Working Group on Atlanto-Scandian Herring.

Some small adjustments have been made in the VPA presented by Dragesund and Ulltang (1978). Corrections have been made in the catch in number by age in the adult fisheries in 1962. More extensive data on age composition and mean weights in the winter fishery were used when calculating the spawning stock for the period 1960–1970. This had a significant effect only on the estimates for 1963–1965. The estimate of the spawning stock size in 1963 increased because of a change in the mean weights used, and the estimates for 1964 and 1965 decreased because of changes in the estimated proportion of the 1959–1961 year classes in the spawning stock in these years. The calculated spawning stocks for 1964–1965 depend critically on the assumed size of the Lofoten component in which recruit spawners predominated. For 1964 it has been assumed that the 1959 year class contributed the same proportion to the Lofoten spawning as off Møre, which means that 56% of the year class recruited to the spawning stock. For 1965 it has been assumed that all of the 1959 year class spawned, which implies that the Lofoten component of the year class was about a third of the one at Møre. The contribution of other year classes spawning at Lofoten was estimated from the assumptions made about the 1959 year class and the age compositions from the Lofoten spawning grounds.

The spawning stock size was at a level of about 9 million t in 1950 and decreased to about 7 million t 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 t in 1957. The stock then decreased again as a result of poor recruitment to about 2·5 million t in 1963. From 1963 to 1965 the spawning stock size increased again, reaching about 3·7 million t 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 (Fig. 13).

The rise in fishing mortalities was probably a result of higher fishing effort in the summer and autumn fishery combined with an increasing catchability coefficient with decreasing stock size. Ulltang (1976) demonstrated that during the 1950s the catchability coefficient q in the Norwegian purse-seine winter herring fishery was related to stock size N by the equation

$$q = kN^{-b} \quad (1)$$

with $b \approx 1$. If N is the mean stock size during the year, the catch C is given by

$$C = FN = qfN = kN^{-b}fN = kfN^{1-b}$$

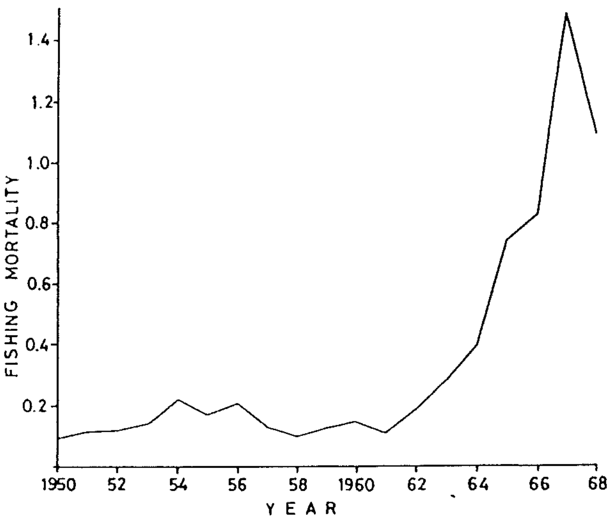


Figure 13. Fishing mortality on 7-year-old and older herring, 1950–1968.

Table 4. Fishing mortality of young herring by year class and age, 1950–1969

Age	Year class 1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
0	0·058	0·07	0·75	0·35	1·12	0·92	0·73	0·80	1·38	0·30	0·35	0·45	0·79	0·22	0·26	1·17	0·28	0·45	1·31	0·36
1	0·11	0·64	0·66	0·91	1·06	1·18	1·45	1·59	1·27	0·37	0·92	0·58	1·62	0·18	0·44	1·38	2·63	1·13	2·24	0·65
2	0·023	0·07	0·21	0·14	0·67	0·34	1·52	0·78	0·91	0·12	0·12	0·62	0·69	0·28	0·34	0·47	0·93	1·58	1·06	0·19
3	0·016	0·04	0·03	0·04	0·04	0·04	0·10	0·73	0·15	0·10	0·12	0·06	0·65	0·31	0·50	3·26	1·98	0·23	0·11	0·10
Total	0·21	0·82	1·65	1·43	2·89	2·48	3·80	3·90	3·71	0·89	1·51	1·71	3·75	0·98	1·53	6·28	5·82	3·39	4·72	1·90

Table 5. Stock size in number ($N \times 10^{-6}$) of young herring by year class and age and survival (S) from 0-group to 4 years old, 1950–1969

Age	Year class 1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
0	97 375	26 081	27 910	20 973	16 878	9 188	11 098	9 725	13 723	74 965
1	78 267	20 718	11 254	12 642	4 680	3 114	4 558	3 723	2 937	47 442
2	59 690	9 289	4 969	4 330	1 377	816	906	644	702	27 965
3	49 721	7 380	3 448	3 220	600	494	169	252	241	21 175
4	41 687	6 043	2 852	2 637	490	405	130	103	176	16 297
S	0·428	0·232	0·102	0·126	0·029	0·044	0·012	0·011	0·013	0·217

Age	Year class 1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
0	47 478	18 327	7 242	26 264	17 305	3 560	17 334	1 267	2 599	1 999
1	28 631	9 927	2 807	17 957	11 426	942	11 194	687	599	1 194
2	9 751	4 754	475	12 792	6 297	201	682	190	55	532
3	7 337	2 175	203	8 281	3 832	107	230	33	16	375
4	5 552	1 747	91	5 185	1 987	4	27	22	12	289
S	0·117	0·095	0·013	0·197	0·115	0·001	0·002	0·017	0·005	0·145

where F is fishing mortality and f is fishing effort. It is seen that if $b = 1$, the relationship (1) implies that a constant fishing effort will generate a constant catch ($C = kf$) instead of a constant fishing mortality as is usually assumed. Ulltang (1980) further shows that under such circumstances, increasing fishing effort and decreasing recruitment may lead to an exponential increase in the fishing mortality. The increasing fishing mortality during the period 1963–1967 demonstrated in Figure 13 is really a typical example of this. The rise in F during the years 1963–1966 was caused by increasing fishing effort, and the further large increase in 1967 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.

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 mortality started. Thereafter the working group badly overestimated the stock size and underestimated the exploitation rate.

Immature stock

Table 4 shows the fishing mortality on age groups 0–3 for the year classes 1950–1969, and Table 5 shows the year-class size in numbers at age. The year-class size of 0-group and 4-year-old herring is plotted in Figure 14. Some slight changes have been made in the VPA for the 1967–1969 year classes compared with material in Dragesund and Ulltang (1978); as more data from the 1970s have been utilized.

The exploitation rate on young herring was high during the whole period 1950–1969. There is a clear correlation between year-class size and survival during the first years of life (Fig. 14, Table 5), with the survival rate decreasing with decreasing year-class strength. Year classes in the 1950s, which have traditionally been described as weak, were all of what could be called normal strength 10×10^9 to 30×10^9 fish at the 0-group stage. However, year classes of strengths less than 20×10^9 as 0-group survived the

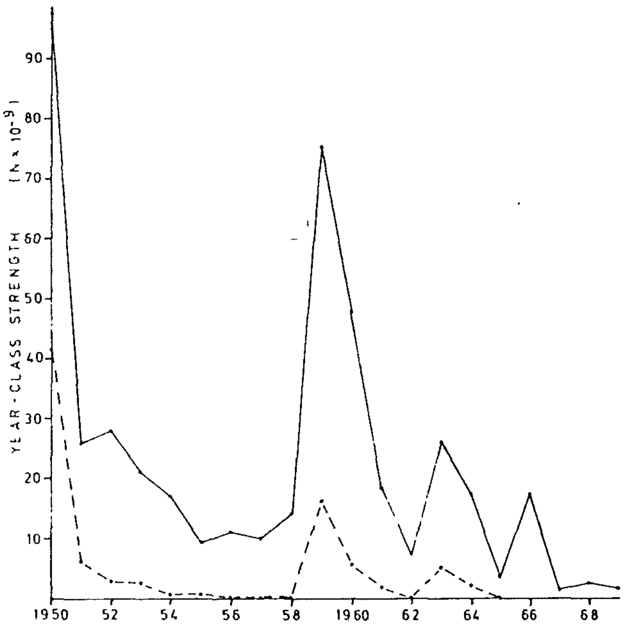


Figure 14. Year-class strength in number as 0-group and 4 year olds (broken line), 1950–1969.

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. The Atlanto-Scandian Herring Working Group (Anon., 1972) classified all year classes after 1964 as weak. From Figure 14 and Table 5 it is seen, however, that the 1966 year class was of reasonable strength as 0-group, but was nearly fished out during the 0- and 1-group stages.

The 1961 year class was the last to recruit the spawning stock in any quantity. Some herring of the 1963 and 1964 year classes survived to an age of 4 years. These year classes were, however, practically fished out in the fat-herring fishery off Finnmark in 1966–1968. The 1967–1969 year classes had an 0-group strength of only 10% of the 1963, 1964, and 1966 year classes, and the 1969 year class is the only one of these which has been observed in any quantities in the spawning stock in recent years.

The increasing fishing mortality with decreasing year-class strength observed for the young herring fisheries partially reflects the fact that in these fisheries as well the catchability coefficient has increased with decreasing abundance. However, it also reflects the fact that strong year classes had a more offshore distribution and that a part of those year classes was outside the traditional fishing areas (Dragesund and Nakken, 1973). The VPA clearly shows that the fishing pressure, especially on young and adolescent

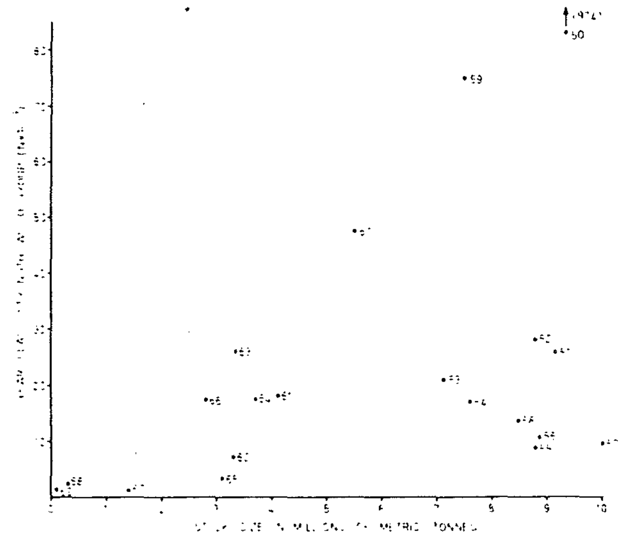


Figure 15. Recruitment as 0-group plotted against spawning stock size for the period 1950–1970.

herring but also on adult herring in the years 1965–1968, was the primary factor in the collapse of this herring stock.

Stock and recruitment

In Figure 15 the estimated recruitment as 0-group strength is plotted against spawning stock size for the years 1950–1970. This plot indicates that there is a critical spawning stock size of about 2·5 million t. In the years when the spawning stock size has been below this level (1967 and later) a significant drop in recruitment has been observed.

SIMULATION STUDIES OF ALTERNATIVE EXPLOITATION STRATEGIES DURING THE 1960s

Starting with a VPA estimate of the stock size in number at age in 1960 and the recruitment as 0-group in later years as input, a series of simulation runs have been made for the period 1960–1970. In this way the probable effect on the stock size and the catch of exploitation strategies other than that actually employed on the stock during this period could be analysed.

In order to get the catch and the stock in weight for various exploitation strategies, mean weights at age of both the catch and the stock on 1 January were estimated for each year. These estimates were based on:

1. Weight at age given by Dragesund (1970) for small and fat herring,
2. Weight at age of adult herring in the Norwegian winter herring fishery for each year,

3. Icelandic data on mean weight at age during the summer and autumn fishery (Jakobsson, personal communication).

The estimated annual mean weights in the catch were finally adjusted (separately for young and adult herring) in order to equate with the observed total catches.

The simulation runs may conveniently be classified in two groups. In the first, the effect of some minimum regulations were studied in order to see whether they could have had a significant effect on the final spawning stock in 1970, which might have avoided the almost complete collapse of the stock ("saving" strategies). In these runs the simulated exploitation pattern is still irrational. In the second group some more optimal strategies were studied, although no complete optimization has been aimed at.

"Saving" strategies

In this group the following runs were made:

Run 1: This was simply a check run with the estimated fishing mortalities at age from VPA as input values. If the programme and input parameters (stock size in 1960, recruitment in later years, mean weight at age, fishing mortality at age, and percentage of mature of the younger year classes) were "correct", the calculated catches in 1960–1970 should be equal to the observed ones. The calculated spawning stock should also be equal to that estimated from VPA.

Run 2: This run simulated the likely effects of closing the small-herring fishery from 1960 onwards by putting $F_0 = F_1 = 0$ for all years in the period 1960–1970. Fishing mortalities on the older age groups were put equal to the VPA values.

Run 3: This run simulated the likely effects of restrictions on the adult fisheries from 1963 onwards when the increase in F values generated by these fisheries started. F_7+ was put equal to 0·2 for the years 1963–1970. F values on 4-, 5-, and 6-year-old herring were put equal to 0·2 in the cases where the VPA value was higher, and equal to the VPA value in the cases where this was lower than 0·2, with one exception. The F values on the 1963 and 1964 year classes in 1967 and 1968 were put equal to the high VPA values, as these were generated in the fat-herring fishery. F values on age groups younger than 4 years were put equal to the VPA values.

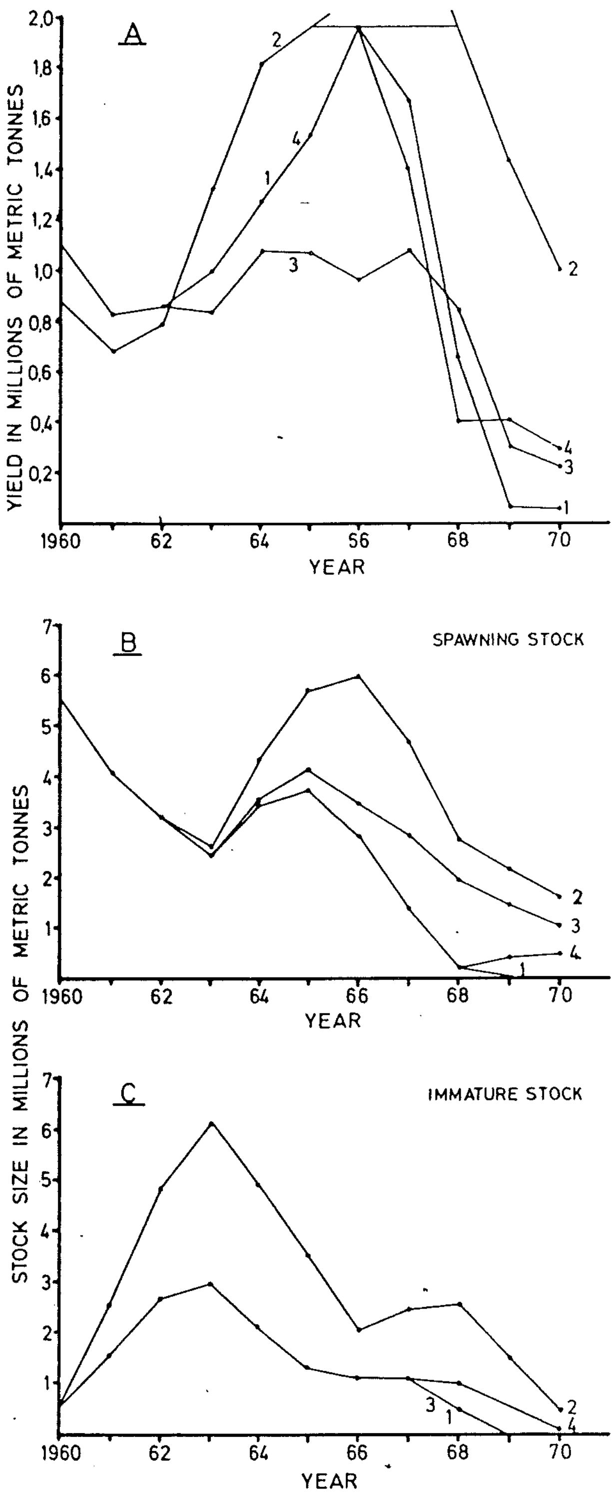


Figure 16. (A) Total catches, (B) spawning stock size, (C) immature stock size from simulation runs 1–4. For further explanation, see text.

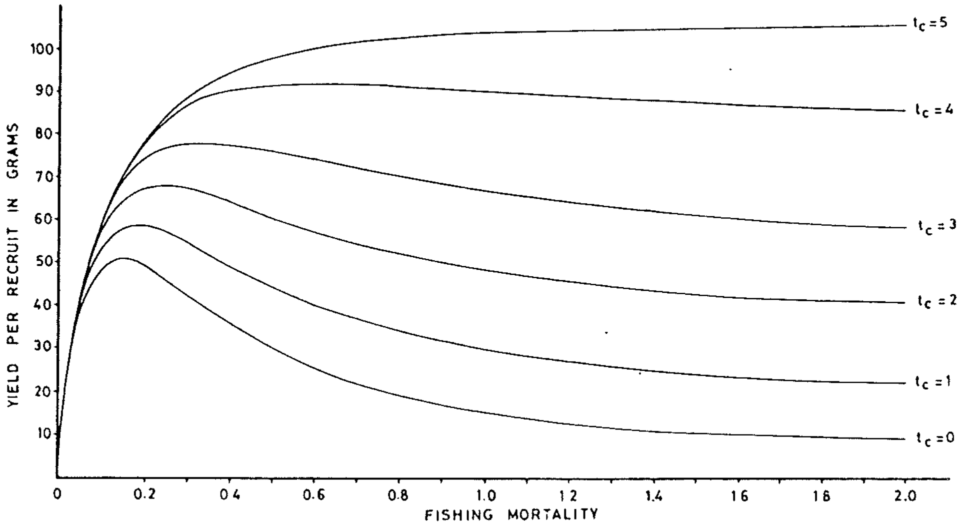


Figure 17. Yield per recruit for various values of age at first capture (t_c).

Run 4: In this run $F = 0{\cdot}2$ was chosen for the 1963 and 1964 year classes in 1967 and 1968. All other F values were put equal to the VPA values. This run thus simulated the effect of a severe restriction on the heavy fat-herring fishery on these two year classes in 1967 and 1968, letting all other fisheries go on unregulated.

For all runs, a constraint was put on the total catch, which was not allowed to exceed 1·955 million t, i.e. the largest total catch ever recorded (1966), and it was thought unrealistic that the fleet would be able to catch and land significantly higher quantities. In cases where the input fishing mortalities gave higher catches, the F values were reduced proportionally on all age groups until the catch was down to this highest level permitted. In Figure 16 total catch, spawning stock size, and immature stock size are plotted for the four runs.

It should be stressed that it is impossible to state the exact results of other exploitation strategies, because a different size of the juvenile and/or adult stock could have led to changes in various population parameters such as growth and natural mortality. According to run 2, a total prohibition of the fishery for 0- and 1-group herring would have resulted in slightly smaller total catches (Fig. 16A) than those actually taken (run 1) for the years 1960–1962. Then a rapid increase would have taken place, and the catch would have reached the maximum level of 1·955 million t in 1965 and stayed at that level for four years. In 1969 and 1970 the simulated catches decreased again (about 1 million t in 1970). The most interesting feature of this strategy is, however, its effect on the spawning stock (Fig. 16B). The simulated spawning stock size would have reached a peak level of 6 million t in 1966, and by 1970 it would still have been at a level of about 1·6 million t, against the VPA value of only 60000 t.

Figure 16C shows that the juvenile stock would have been at a peak level of about 6 million t in 1963 if no small herring had been caught. This is only slightly above the highest level ever recorded in the period covered by the VPA (5·5–5·6 million t in 1953–1954). It seems likely therefore, that a prohibition of fishing on 0- and 1-group herring from 1960 onwards would have resulted in much higher total catches from 1963 onwards and a much higher spawning stock from 1965 onwards. Even with the low strength of the 1967–1969 year classes a spawning stock size in 1970 of 1·6 million t would probably have been sufficient to avoid the complete collapse of the stock if further management action were then taken. It should also be taken into account that the year classes of 1967–1969 would probably have been stronger than observed, if the spawning stock in these years had not been reduced to a low level.

The effects of the strategy simulated in run 3 are much smaller. The catches in 1963–1967 would have been smaller than the actual ones, but the sharp decline in catches after 1967 would have been less pronounced, and the complete collapse by 1970 would have been avoided. However, with a spawning stock of about 1 million t in 1970, the future of the stock would have been more dependent on very effective management action thereafter than would have been the case if strategy 2 (run 2) had been followed, because the juvenile population would have been much smaller. Strategy 4 (run 4) would also have led to a significantly better situation in 1970 than the actual one, although the spawning stock would have been reduced to 0·5 million t. This is, however, probably more than twice the 1978 level, and the possibilities for a rapid rebuilding of the stock would have been significantly improved. The complete collapse of the stock might thus have been avoided by regulating only the fat-herring fishery in 1967 and 1968, although the stock would still have been in a heavily depleted state by 1970.

Optimum strategies

Two sets of runs simulating more optimum strategies were carried out. In the first set, constant fishing mortalities, F_{max} or $F_{0.1}$, were assumed for the whole period. In the second set, fishing strategies assuming constant catch were studied. Yield per recruit curves for $t_c = 0, 1, 2, 3, 4$, and 5 years (t_c = age at first capture) are shown in Figure 17. F_{max} and $F_{0.1}$ values together with yield per recruit for the various values of t_c are shown in Table 6. The yield per recruit curves are based on mean weight at age in the catch for the period 1960–1970, and a natural mortality of 0·16. The following runs were made for constant fishing mortalities:

Run 5: $t_c = 0$
$F_{max} = 0.15$ and $F_{0.1} = 0.10$.

Run 6: $t_c = 2$
$F_{max} = 0.24$ and $F_{0.1} = 0.14$.

Run 7: $t_c = 5$
$F_{0.1} = 0.25$.

Here $t_c = 2$ would be an approximation to a situation where the so-called small-herring fishery was prohibited, while $t_c = 5$ would mean that only a fishery on the adult stock was allowed, closing both the small- and fat-herring fisheries. The results are shown in Figure 18 (total catches), Figure 19 (spawning stock size), and Figure 20 (immature stock size).

Table 6. F_{max}, $F_{0.1}$, and corresponding values of yield per recruit (Y/R) for various values of age at first capture (t_c)

t_c	F_{max}	Y/R (kg)	$F_{0.1}$	Y/R (kg)
0	0·15	0·051	0·10	0·049
1	0·18	0·059	0·12	0·056
2	0·24	0·069	0·14	0·063
3	0·34	0·078	0·17	0·072
4	0·61	0·092	0·21	0·080
5	∞	0·112	0·25	0·085

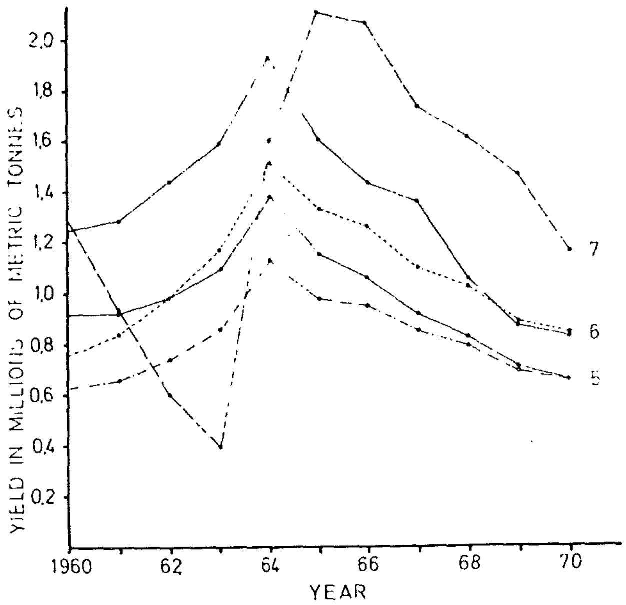
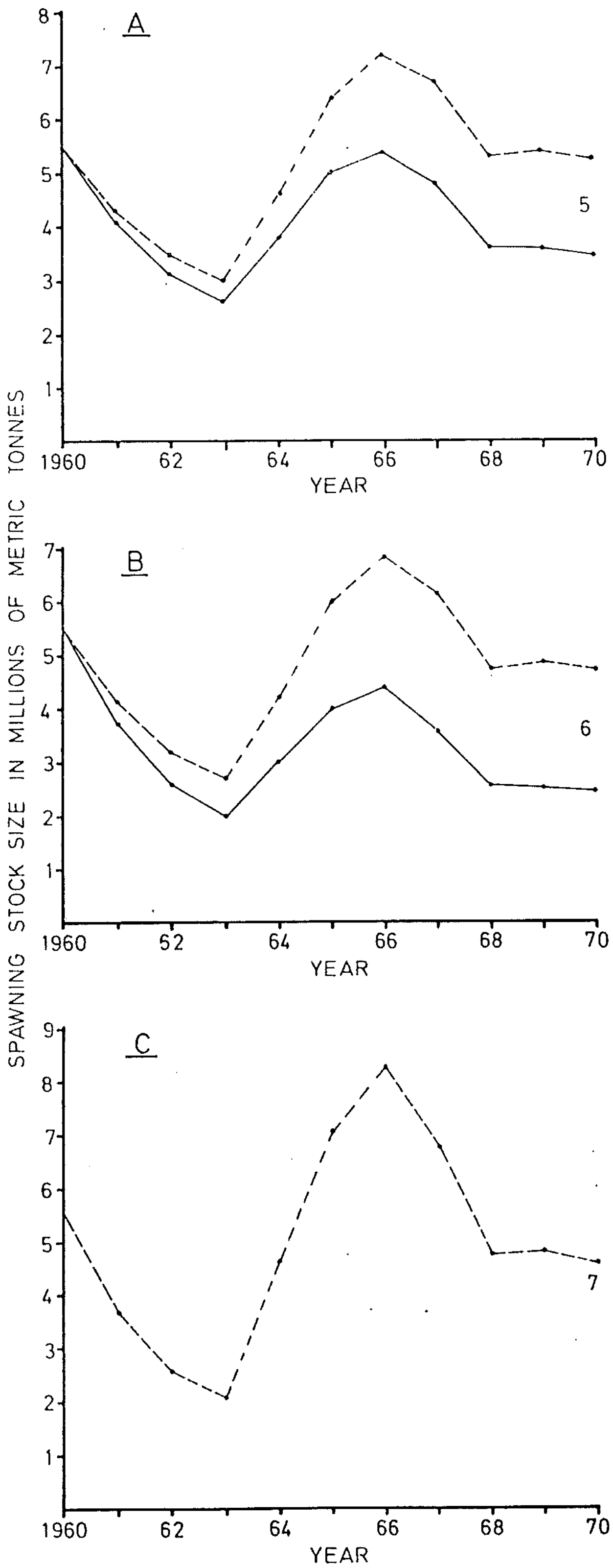


Figure 18. Total catches from simulation runs 5–7. Solid line: $F = F_{max}$. Broken line: $F = F_{0.1}$. For further explanation, see text.

The text table shows the mean total catch in 1960–1970 and the spawning stock size in 1970 for the various alternatives. Only run 5 gave lower mean catches for the period than the actual ones, and for $F = F_{max}$ the difference was minimal. For all alternatives the collapse at the end of the 1960s was avoided and the simulated catches did not fluctuate to the same extent as the actual ones.

		Mean catch 1960–1970 (million t)	Spawning stock size 1970 (million t)
Actual catch		1·006	0·06
Run 5	F_{max}	0·966	3·45
	$F_{0.1}$	0·811	5·31
Run 6	F_{max}	1·313	2·44
	$F_{0.1}$	1·066	4·73
Run 7	$F_{0.1}$	1·363	4·65

Run 7 gave a sharp decrease in catches from 1960 to 1963, and thereafter a sharp increase in 1964 and 1965. The sharp decrease at the beginning of the period is a result of poor recruitment to the adult stock until the full effect of the high t_c, combined with strong year classes, resulted in very high catches from 1964 onwards. It should also be noted that the difference in yield between F_{max} and $F_{0.1}$ for runs 5 and 6



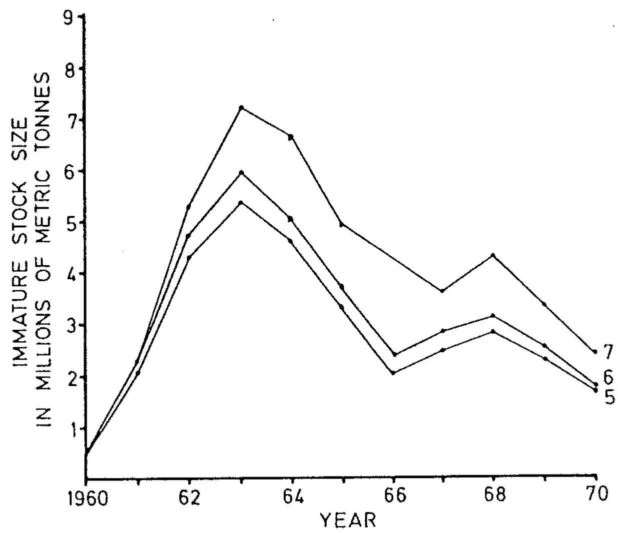


Figure 20. Immature stock size from simulation runs 5–7. $F = F_{0 \cdot 1}$.

gradually decreased during the period, as would be expected. Run 6 with F_{max} gave a spawning stock size in 1970 around the critical level of 2·5 million t, while all other alternatives gave a spawning stock well above this level. As would be expected from the yield per recruit curves, the catches increased with increasing t_c during the second half of the period.

In the second set of runs, a constant catch during the period was maximized under the constraint that the spawning stock in 1970 should be 2·5 million t. Because the stock size fluctuates with recruitment, such a maximum catch could generate very high fishing mortalities in one particular year or indeed completely denude the stock. Therefore, a constraint was also put on the fishing mortality, not allowing it to exceed 1·0.

With $t_c = 0$ (run 8), a constant catch of 1·08 million t could have been taken each year, and with $t_c = 2$ (run 9), 1·36 million t. With $t_c = 5$ (run 10), a catch of 2·12 million t could have been taken each year except for the years 1962, 1963, and 1970, when a catch of only 0·735, 0·291, and 1·905 million t respectively could have been taken with an F value of 1·0. The spawning stock size, the immature stock size, and the fishing mortalities are shown in Figures 21, 22, and 23.

A better strategy than that simulated by run 10 would probably have been to decrease the catch significantly in 1960–1961 and increase it somewhat above the calculated low level in 1962–1963. This

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Figure 19. Spawning stock size from (A) simulation run 5, (B) simulation run 6, (C) simulation run 7. Solid line: $F = F_{max}$. Broken line: $F = F_{0 \cdot 1}$.

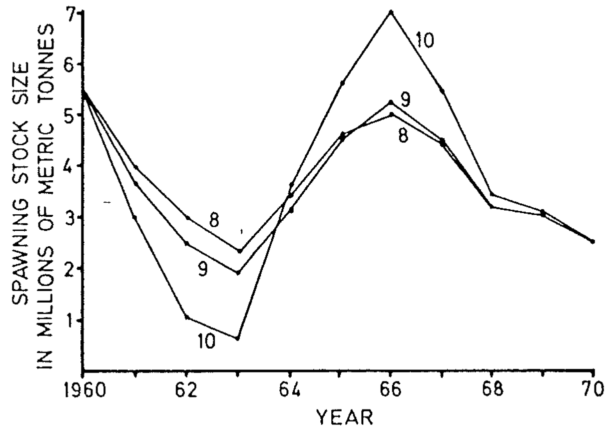

Figure 21. Spawning stock size from simulation runs 8–10. For further explanation, see text.

could have given more stable catches at the beginning of the period and a higher spawning stock size in 1962–1963, when the calculated spawning stock size (Fig. 21) is far below the critical level of 2·5 million t.

As discussed earlier, runs where the spawning stock at the end of the period is around 2·5 million t or higher, probably underestimate the immature stock size and the eventual catches of immature herring during 1967–1970, as the recruitment failure might have been avoided with a higher spawning stock. On the other hand, runs which give a very high immature stock size for some years may overestimate stock size and catches during parts of the period, as growth and/or natural mortality and/or maturity at age could possibly be density-dependent.

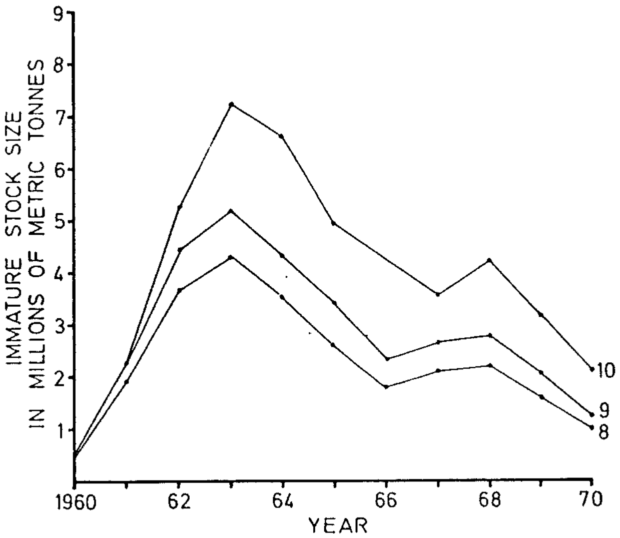

Figure 22. Immature stock size from simulation runs 8–10.

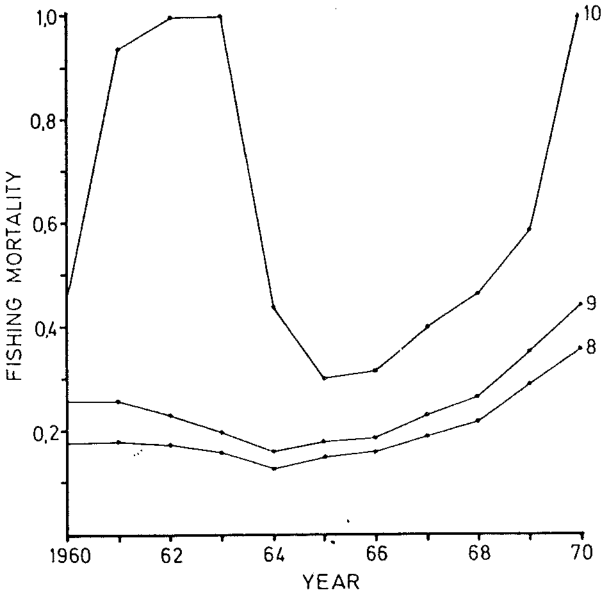

Figure 23. Fishing mortality from simulation runs 8–10.

It may be argued that the natural mortality on 0- and 1-group herring is probably higher than 0·16, and that the present analysis, therefore, overestimates the effect of the small-herring fishery. It is, however, unlikely that this could significantly alter the conclusions. A higher natural mortality would give somewhat lower VPA estimates of the fishing mortality on 0- and 1-group herring, and the estimated increase in yield and size of the adult stock resulting from a stop in the small-herring fishery would also decrease slightly.

The effect would be largest for the year classes which have been most heavily exploited as small herring, and these are generally the weakest ones. A higher natural mortality on 0- and 1-group herring would mainly affect the calculations carried out on the 1960–1969 year classes in the simulation runs. Of these the 1960–1966 year classes are the most important ones for the yield during the period and for the spawning stock by 1970. The mean fishing mortalities estimated from VPA for these year classes are 0·50 and 1·11 for the 0- and 1-group herring respectively. For a year class with these fishing mortalities when $M = 0{\cdot}16$ is assumed, the VPA would have given fishing mortalities of 0·36 and 0·98 on the 0- and 1-group herring if a natural mortality as high as 0·5 were assumed. When $M = 0{\cdot}16$, the year classes would have been five times stronger as 2 year olds than observed in case there were no small-herring fishery, while for $M = 0{\cdot}5$, it would have been 3·8 times stronger. These values indicate that the runs simulating an exploitation strategy with no small-

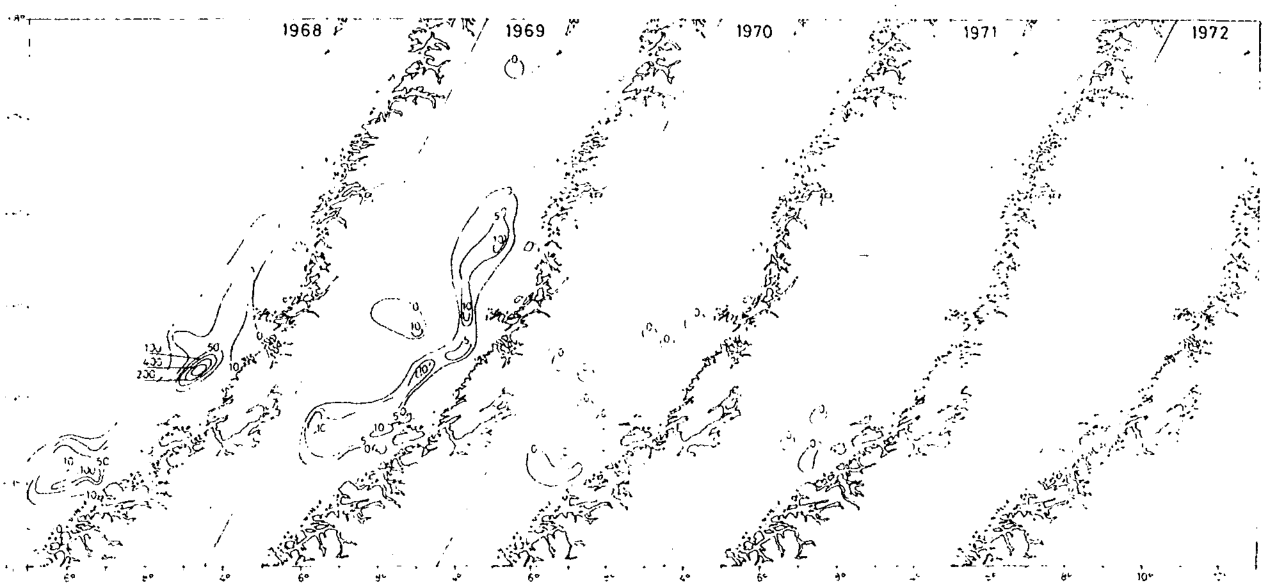

Figure 24. Distribution of herring larvae, 1968–1972. Equal levels of larval abundance are indicated by isolines. The figures represent number of larvae below 1 m² surface.

herring fishery would overestimate stock size and yield from age 2 onwards of the 1960–1966 year classes by approximately 30 per cent, if M really were as high as 0·5 instead of 0·16 on 0- and 1-group herring. Even a 30 per cent reduction of the calculated spawning stock in 1970 would not alter the conclusions in this section: the collapse of the stock around 1970 could have been avoided by restrictions on the herring fisheries, as demonstrated by the various simulated fishing strategies.

STATE OF THE STOCK IN THE 1970s

THE FISHERIES

The summer and autumn fishery for adult herring terminated in 1969, and since then no herring have been recorded in the usual feeding area in the Norwegian Sea. The winter herring fishery on the spawning grounds decreased sharply from 1967 to 1968, but owing to increased prices for herring, the fishery continued on the depleted stock until 1971. A total ban on the Norwegian winter herring fishery was introduced in 1972. The stock of immature herring was almost depleted in 1969, when the catch declined by some 90 per cent compared with 1968. Immature fish recorded after 1969 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. The research programme monitoring the state of the stock includes: (a) echo surveys on the spawning and feeding grounds, (b) larval surveys, (c) echo abundance surveys of 0-group herring in coastal areas, and (d) tagging experiments.

Echo surveys on spawning and feeding grounds

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 (Fig. 24) and later and the very low abundance of the 1970–1972 year classes in the spawning stock both demonstrate that the adult stock of Norwegian spring-spawning herring collapsed in the early 1970s.

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 for spawning. Maturing herring of the 1969 year class were found, later in 1973, off Vesterålen and Lofoten. These herring probably spawned in these areas in March,

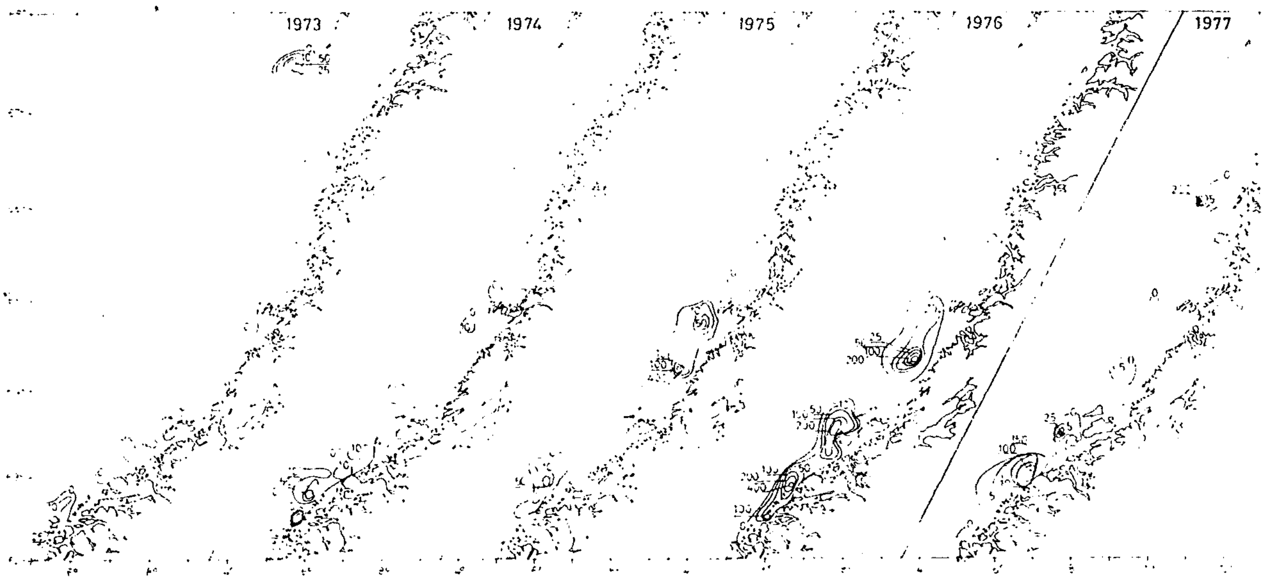

Figure 25. *Distribution of herring larvae, 1973–1977.* Equal levels of larval abundance are indicated by isolines. The figures represent number of larvae below 1 m² surface.

because herring larvae were found there in April (Fig. 25). 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 (Fig. 25). 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 1960s, 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 seems to have migrated southward, and since 1974 spawning has taken place on the traditional spawning grounds off Møre and Trøndelag (Fig. 25). During the feeding period, the adult herring migrated northwards and were most frequently found in the Lofoten 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, often in the surface layer and close to the shore.

No significant increase in the spawning stock size could be registered during the period 1973–1976, although a fraction of the 1973 year class were already mature as 3 year olds in 1976 (Table 7). A considerable increase in the abundance of spawning herring, however, was registered in the winter of 1977, particularly off Trøndelag and the northern coast of Møre. In March 1977, concentrations of spent herring were recorded on the Træna Bank, about 130 nm from the coast. No herring were recorded during a survey in June 1977 of the traditional feeding grounds in the Norwegian Sea. In 1978, no similar increase in stock strength on the spawning grounds could be registered.

Larval surveys

Larval surveys have been carried out for several years. The larvae were collected with a Clarke-Bumpus plankton sampler until 1972. Since then a modified Gulf III plankton sampler has been used. There has been about the same survey effort each year. Figures 24 and 25 show the density distribution of herring larvae for the years 1968–1972 and 1973–1977 respectively. The density distribution of the larvae is in reasonably good agreement with the echo recordings of herring on the spawning grounds. The decreasing abundance of spawners and the collapse of the stock in the period 1968–1972 are clearly demonstrated in Figure 24. The renewal of the spawning stock in 1973 by the appearance of one component spawning off Møre and another off Lofoten is seen in

Table 7. Spawning stock in number and weight

Year	$N\times10^{-6}$ Age 3	4	5	6	7	8	9	Spawning stock ($t\times10^{-3}$)	% increase from 1973
1973	18	289	9	14	6	3	5	93	–
1974	6	21	237	3	2	1	1	71	−23·6
1975	44	4	6	194	1	1	1	81	−12·9
1976	237	57	1	3	159	1	–	124	33·3
1977	173	413	23	–	–	130	–	200	115·1

Table 8. Abundance ($N\times10^{-6}$) of 0-group herring in 1974–1976

Year	Area: More Trøndelag	Nordland	Troms, Finnmark	Total
1974....	50	249	31	330
1975....	1 933	692	55	2 680
1976....	440	2 610	750	3 800
1977....	63	305	37	405

Figure 25. The two spawning components still seemed to be separated in 1975, and the density-distribution charts indicate that the northern component, this year spawning off Trøndelag, was by far the larger. In 1976, the density of larvae increased considerably, owing to the recruitment of the 1973 year class to the spawning stock (Table 7). The increased stock strength recorded in 1977 is, however, not reflected in the measure of larval production in that year. This is probably the result of late sampling in relation to the time of hatching.

It should also be noted that autumn-spawning herring have been reported off Møre in recent years. The occurrence of autumn spawners was confirmed by a few larval catches in November 1976. This may indicate a relation to the herring stocks in the North Sea.

0-group surveys

The immature herring of the 1973 year class were mainly found in the fjords of Troms and Finnmark, whereas later year classes have all been distributed farther south. The 1973 year class was also recorded during the international 0-group survey in the Barents Sea. This was the first year since 1969 that 0-group herring were recorded in the Barents Sea. The 1974 and 1975 year classes were absent in the Barents Sea 0-group surveys, whereas the year classes of 1976 and 1977 did occur. In 1974, echo abundance surveys of 0-group herring in the Norwegian fjords were initiated. The surveys are carried out in November–December and the technique used is the same as that applied in the echo abundance surveys of capelin in the Barents Sea (Nakken and Dommasnes, 1975).

The abundance estimates of 0-group herring by area are shown in Table 8. The abundance of the 1974 year class is probably underestimated owing to poor area coverage that year. It is noted that the bulk of the 1975 year class was found on the Møre–Trøndelag coast, particularly in the Trondheimsfjord. The larval distribution (Fig. 25) in that year indicates that these 0-group herring were recruited from the southern stock component. The herring of the 1975 year class, which were recorded in the Trondheimsfjord in 1976 and 1977, have a reduced growth rate compared with the 1975 year class from other parts of the distribution area. In 1976, most of the 0-group herring were found on the coast of Helgeland, the 0-group abundance on the Møre–Trøndelag coast being rather low. A marked drop in the 0-group abundance in all areas occurred in 1977, indicating unfavourable conditions for survival of the herring larvae that year.

Tagging experiments

A tagging project was initiated in 1975. The time of tagging was April–May, and altogether 104870 herring were internally tagged and released at various localities along the Norwegian coast in 1975–1977. The tagged herring were released from purse-seine catches using the same technique as applied in previous herring-tagging experiments. The tagged fish were measured and allocated to age groups by age-length keys. Details of the releases are given in Table 9.

During the winter of 1977/1978 the Institute of Marine Research, Bergen, was allowed to fish for 5000 hl herring each year in order to sample the spawning stock for tagged fish. The herring were fished by purse seine and pelagic trawl and the catches screened for tags by a new device retaining internally tagged fish (Gytre and Jakupsstovu, 1977). Details of the catches and corresponding recoveries are given in Table 10. Localities of release and recapture are shown in Figures 26 and 27.

Stock structure and migration

The catches from Møre and Trøndelag are from the spawning grounds and consist mainly of spawners. The herring from the fjords of Lofoten were caught in early February and may be regarded as wintering prespawners. The data on release and recapture confirm the migration pattern observed in the seasonal distribution of herring along the coast. The tag returns from the experimental fishing provide evidence for the separation of the herring stock into two components, one spawning on the southern coast of

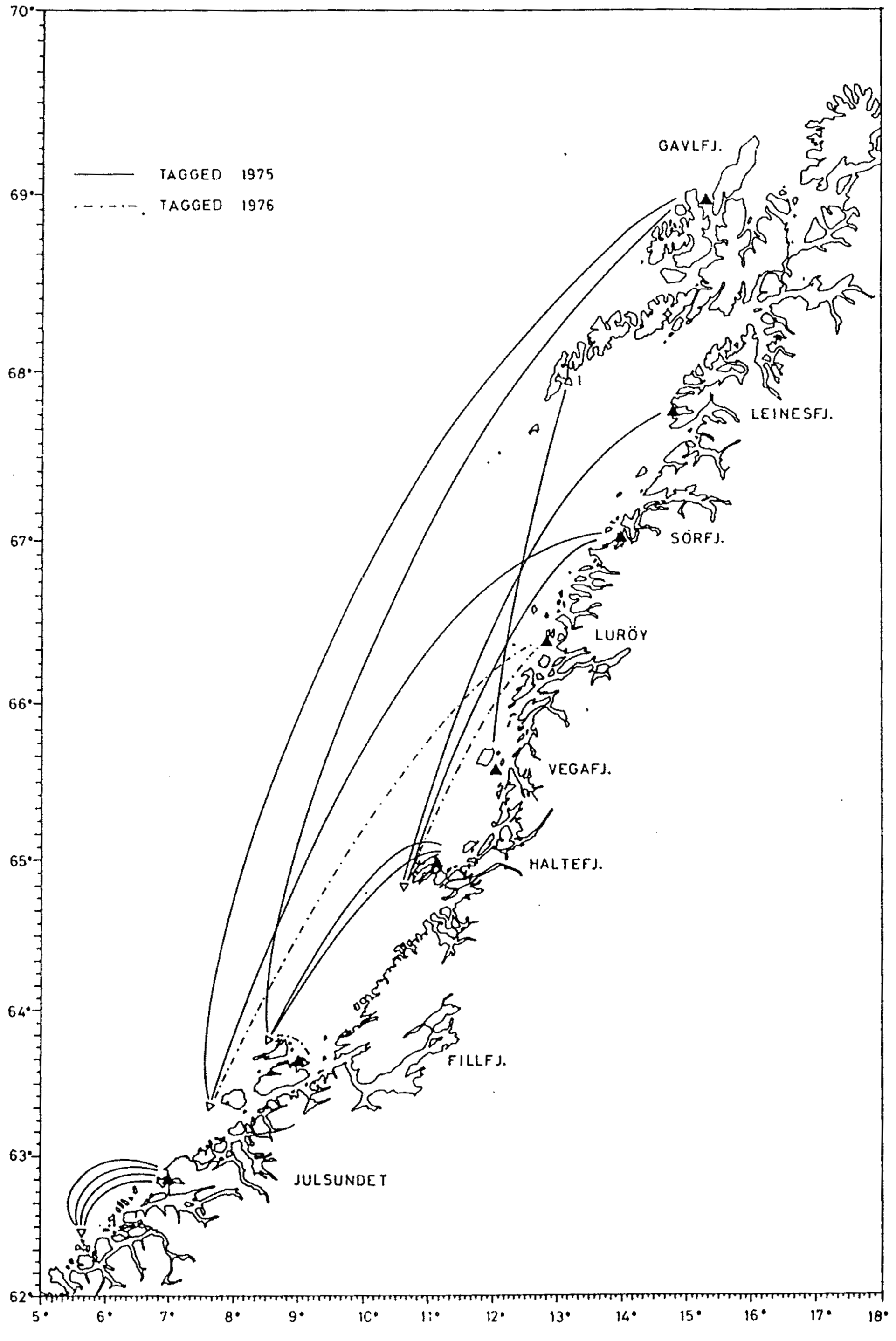

Figure 26. Distribution of tag returns from experimental fishing in 1977. Filled symbols indicate the tagging localities and the open symbols the area of recapture.

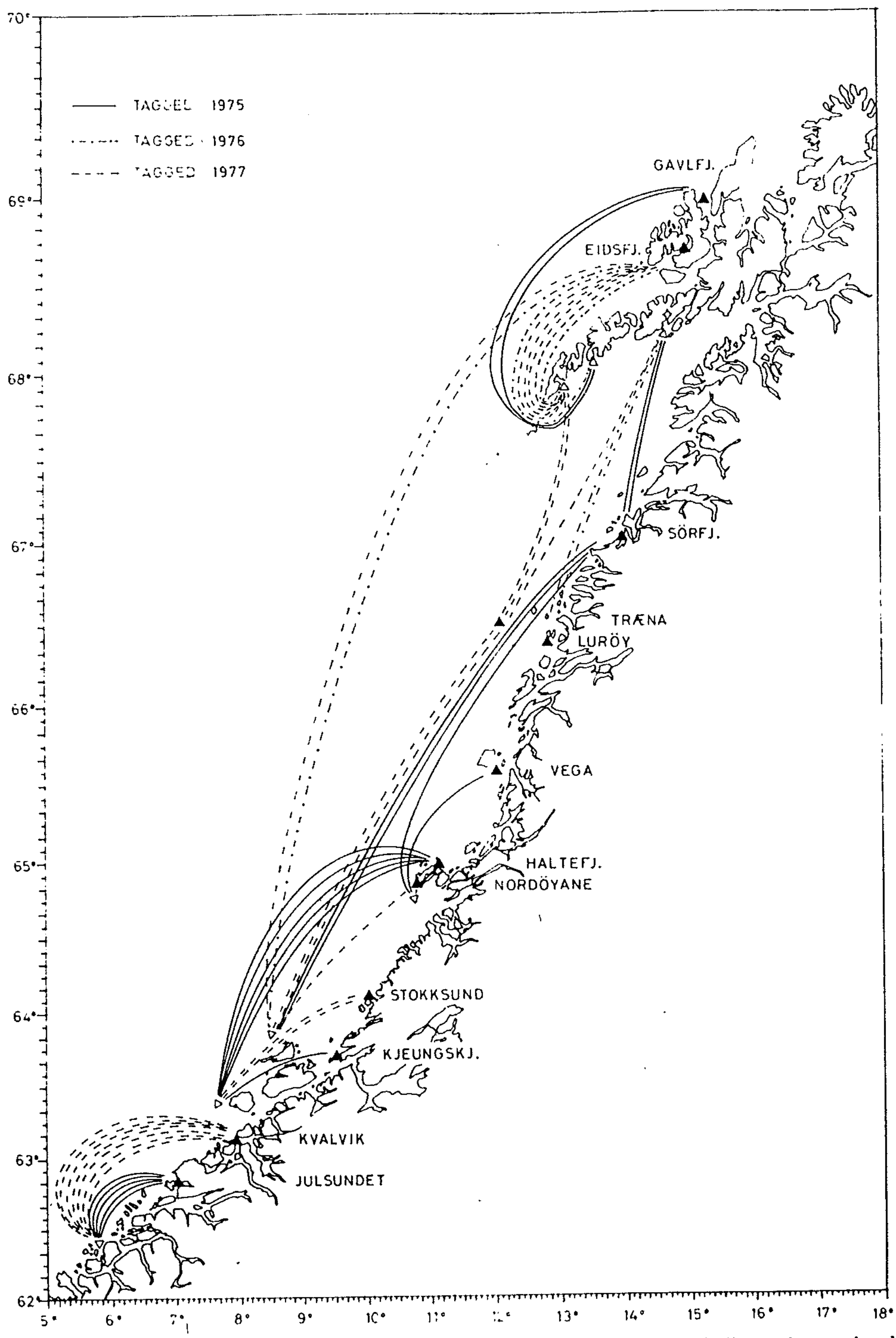

Figure 27. Distribution of tag returns from experimental fishing in 1978. Filled symbols indicate the tagging localities and the open symbols the area of recapture.

Table 9. Releases of tagged herring in 1975–1977

Year of release	Locality	Approximate position		Number of herring tagged, Year class 1972 +	1973	1974	1975
1975	Julsundet	62°51′ N	06°58′ E	150	4 850	–	–
	Kjeungskjæret	63°43′ N	09°31′ E	151	1 713	3 124	–
	Haltefjord	64°57′ N	11°06′ E	420	5 576	–	–
	Vegafjord	65°30′ N	11°58′ E	90	988	–	–
	Sørfjord	66°58′ N	13°55′ E	4 931	50	1 925	–
	Leinesfjord	67°47′ N	14°58′ E	40	1 959	–	–
	Gavlfjord	68°53′ N	15°19′ E	–	4 000	–	–
	Jøkelfjord	70°04′ N	21°56′ E	–	3 999	–	–
	Altafjord	70°02′ N	22°59′ E	–	3 985	–	–
1976	Bud	62°54′ N	06°55′ E	1 032	2 133	33	–
	Fillfjord	63°35′ N	90°01′ E	–	459	4 338	–
	Lurøy	66°27′ N	12°55′ E	–	1 000	4 999	–
	Eidsfjord	68°43′ N	15°07′ E	–	9 744	203	–
	Nordreisa			–	2 950	–	–
1977	Rundø	62°22′ N	05°48′ E	67	845	2 751	385
	Kvalvika	63°06′ N	07°54′ E	261	2 612	2 507	617
	Stokksund	64°05′ N	10°02′ E	22	385	528	5 063
	Nordøyane	64°50′ N	10°36′ E	1 302	5 815	2 707	172
	Træna	66°30′ N	12°06′ E	599	2 735	662	–
	Eidsfjord	68°44′ N	15°04′ E	51	4 511	4 949	486

Table 10. Total catch (C_N) in number ($N \times 10^{-3}$) by area and year class, and corresponding recoveries (R) from releases in 1975–1977. (N) = northern stock component, (S) = southern stock component

Year of recapture	Area	Year class 1975	1974	1973	1972	1969	ΣC_N	R_{75}	R_{76}	R_{77}
1977	Lofoten (N)	–	16	34	–	5	55	1	–	–
	Nordøyane (N)	–	45	195	13	61	314	3	1	–
	Sula (N)	–	78	296	28	140	542	3	1	–
	Grip (N)	–	193	236	–	33	462	2	1	–
	Ulsteinfjord (S)	–	12	57	4	6	78	4	–	–
	Grasøyane (S)	–	5	25	2	3	35	1	–	–
1978	Lofoten (N)	–	103	280	14	67	464	4	4	7
	Nordøyane (N)	–	122	82	–	9	213	2	–	1
	Sula (N)	–	86	169	3	39	297	3	1	4
	Grip (N)	–	65	82	18	49	214	4	–	1
	Ulsteinfjord (S)	13	97	68	2	–	180	5	–	7
	Total	13	822	1 524	84	412	2 854	32	8	20

Møre, the other between Buagrunnen (northern part of Møre) and Lofoten. It should be noted that most of the recaptured fish belonged to the 1973 year class; that is the stock separation observed in the spawning stock in 1973 also occurred among the progeny. As shown in Table 11, the l_1-distribution is also significantly different in the two groups. The relative stock strength, estimated on the basis of tag returns, is 1:15 for the southern and northern components respectively (Table 13).

Apart from the recoveries obtained from the experimental fishing, tag returns have also been reported from other fisheries. Thus tags have been recovered in plants which have reduced herring and offal of herring fished in the North Sea. Eight of these recoveries are from plants in Denmark and twelve from Norwegian plants. All the tagged herring caught in the North Sea originate from taggings of the southern stock component. Besides providing further evidence of the division of the stock into two components, these data also indicate that the southern stock component has a relation to the autumn-spawning herring stocks in the North Sea. The occurrence of autumn-spawning herring off Møre also supports this. However, it should be noted that recoveries of herring tagged on the spawning grounds and during the

Table 11. l_1 (cm) for the 1973 and 1974 year classes from the northern and southern stock components. Age of sampling is 3 years. Sample size in parenthesis.

Stock component	Year class 1973	1974
Northern	11·3 (271)	15·1 (97)
Southern	14·2 (23)	16·2 (14)

adolescent phase at Lofoten in the 1950s have been made frequently both in the Skagerrak and the North Sea (Fridriksson and Aasen, 1952; Aasen, 1954).

Stock size estimates

Although the recoveries so far obtained are few, the tagging data provide some evidence of the size of the stock. In Table 12 the number of recoveries and corresponding catch effectively screened for tags are shown. The data refer to the 1973 and older year classes, grouped by release of tagged fish belonging to the northern and southern spawning components respectively. The 1975 releases had been in the herring population approximately 2 and 3 years by the winters of 1977 and 1978 respectively, and a random mixing of the tagged fish could be expected. It is, however, observed that the rate of recovery increased considerably in 1978 compared with 1977, with respect to the releases north of Møre. The reason for this is probably that the tagging operation affects the condition of the tagged fish for a long period after release, and this may delay the maturing of the tagged herring (Anon., 1977). The effect of the marking is demonstrated in Figures 28 and 29.

Assuming the tagged fish of the 1973 and older year classes to be fully recruited to the spawning stock in the winter of 1978, the 13 tags recovered from the 18055 fish tagged and released between Gavlfjord and Haltefjord in 1975 provide a basis for a single census estimate of the northern stock component ($\mathcal{N}_1$):

$$\mathcal{N}_1 = (s \times 18055 \times 810 \times 10^3)/13 = s \times 1125 \times 10^6$$

where s denotes the coefficient of survival of the tagged fish. The 95% confidence limit of this estimate is about $\pm 50\%$.

The rate of recovery of the 5000 herring tagged in Julsundet in 1975 did not differ significantly in the two samples of the southern spawning component. Adding the samples, the stock estimate of the southern component ($\mathcal{N}_2$) is:

$$\mathcal{N}_2 = (s \times 5000 \times (67+70) \times 10^3)/(4+5) = s \times 76 \times 10^6$$

The confidence limit of this estimate is about $\pm$ 60%.

The estimates refer to the time of release, i.e. the spring of 1975. According to Dragesund and Jakobsson (1963), the initial death rate $(1-s)$ of internally tagged herring may be of the order of 30%. Assuming s equal to 0·70, the maximum likelihood estimates of $\mathcal{N}$ including the 1973 year class and older fish are:

$$\mathcal{N}_1 = 788 \times 10^6 \qquad \mathcal{N}_2 = 53 \times 10^6$$

The estimates refer to the state of the stock in the spring of 1975 including both mature and immature herring.

SPAWNING STOCK IN 1973–1978

The Atlanto-Scandian Herring Working Group considered the results of the Norwegian tagging experiments obtained in 1977, and concluded that although the results were too tentative to be used for stock abundance calculations, the data indicated an abundance level of the spawning stock in 1977 of the

Table 12. Catch screened for tags, number of recoveries, and recoveries per 10^6 individuals for different releases. Data refer to the 1973 and older year classes. (N) = northern stock component, (S) = southern stock component

Release Year	Release Number	Release locality	Time of recovery	Number ($\times 10^{-3}$) screened for tags	Number of recoveries	Recoveries per 10^6 individuals
1975	18 055	Gavlfjord-Haltefjord (N)	Winter 77	1 041	9	9
			Winter 78	810	13	16
			Winter 77	67	4	60
1975	5 000	Julsundet (S)	Autumn 77	25	4	160
			Winter 78	70	5	71
1976	11 248	Lurøy-Fillfjord (N)	Winter 77	1 041	3	3
			Winter 78	810	5	6
1977	13 446	Stokksund-Eidsfjord (N)	Autumn 77	309	2	7
			Winter 78	810	13	16
1977	2 612	Kvalvika (S)	Winter 78	70	4	57

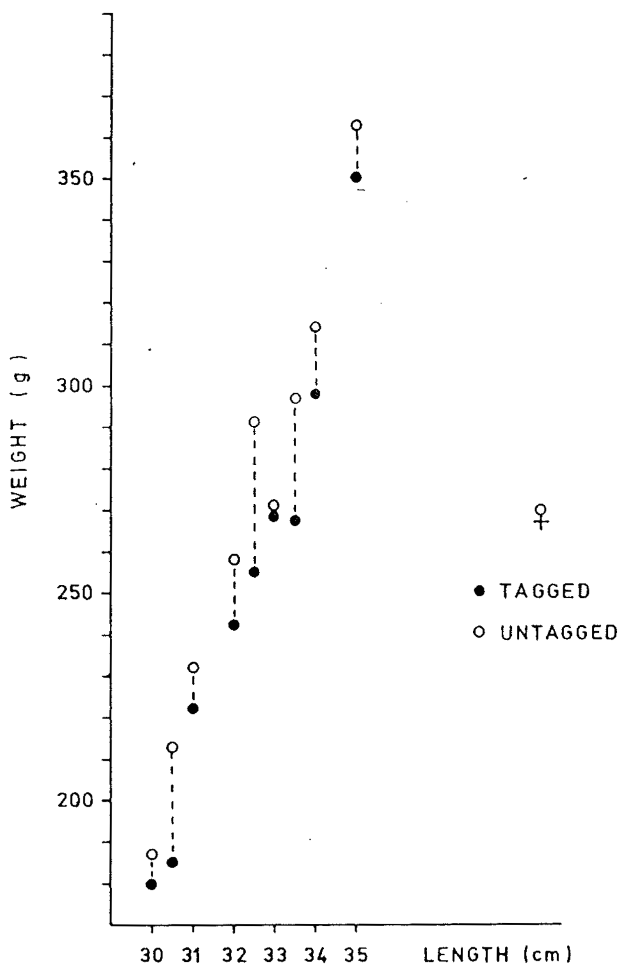

Figure 28. Weight comparison between tagged and untagged female herring of the same length. Average values for maturity stages 4–7.

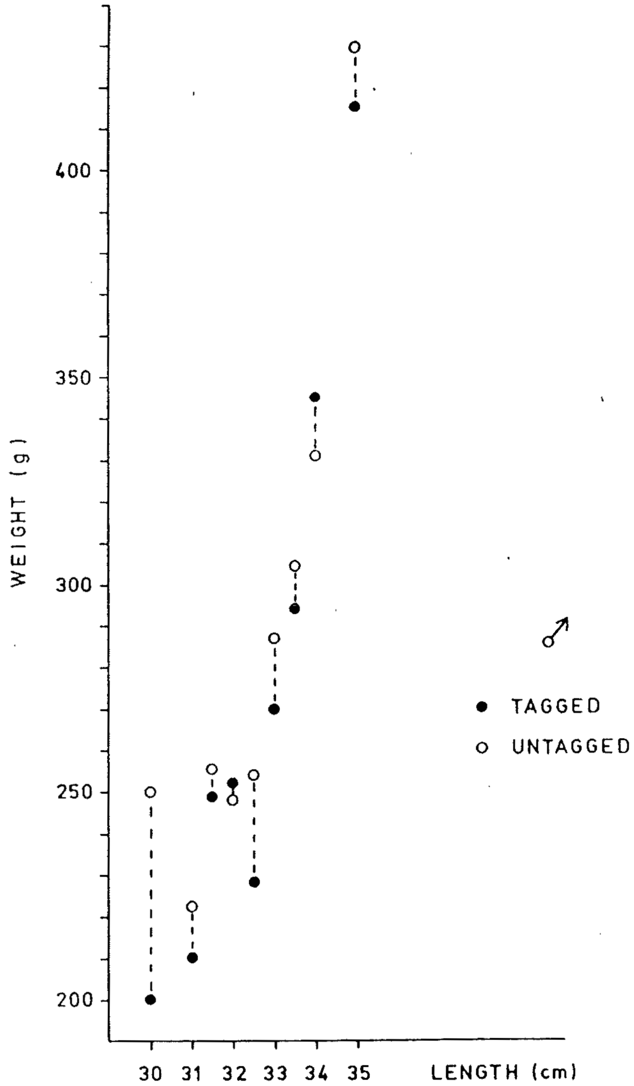

Figure 29. Weight comparison between tagged and untagged male herring of the same length. Average values for maturity stages 4–7.

order of 200000 t. Using the age composition and weight at age data of the spawning stock, the spawning stock in number at age in 1977 was estimated. The spawning stock in number at age for 1973–1976 was then estimated from back calculations of the 1969 year class and the age composition of the spawning stock in the various years, using a total annual mortality Z of 0·2. Spawning stock in weight was calculated from the estimated stock in number using age and weight at age data. The resulting spawning stock sizes are shown in Table 7 (Anon., 1977).

The working group considered the abundance of the 1973 and older year classes in 1977 to be 566×10^6 individuals. Using $Z = 0{\cdot}2$, the estimate of $N_1 + N_2$ in 1977 based on the 1978 recoveries is:

$$(788 + 53) \times \exp(-0{\cdot}4) \times 10^6 = 563 \times 10^6 \text{ individuals.}$$

This estimate thus confirms the appraisal made by the working group on the state of the stock in 1977.

The total instantaneous mortality rate of 0·2 suggested by the working group is slightly higher than the natural mortality of 0·16 used in previous assessments (Anon., 1975). The difference may compensate for the catch, which in recent years has been very low owing to the regulations (3100 t in 1975 and 0 in 1976). The unreported catch used for home consumption is, however, assumed to be of a certain magnitude.

Table 13 shows the estimated stock strength for the northern and southern stock components in 1977 and

Table 13. Abundance estimates ($N \times 10^{-6}$) by year class for the northern (N) and southern (S) components in 1977 and 1978

Year		Year class				Σ
		1975	1974	1973	<1973	
1977	(N)	–	167	386	142	695
	(S)	–	7	30	6	43
	Total ...	–	174	416	148	738
1978	(N)	–	185	301	111	597
	(S)	6	39	25	3	73
	Total ...	6	224	326	114	670
1978 prognosis ...		934	295	352	130	1 711

1978. In 1977, a catch quota of 12 000 t was allowed. This may have increased the total mortality rate to about 0·25. The stock in 1978 has therefore been calculated using a Z of 0·25 in 1977. The row at the bottom of Table 13 shows the working group prognosis of the spawning stock for 1978, assuming no catch in 1977. The working group estimated the recruitment from the acoustic 0-group estimate (Table 8) using an annual mortality of 0·16. Recruitment to the spawning stock was set at 50% for 3-year-old herring and 100% for older herring.

The failure of the recruitment of the 1975 year class to the spawning stock in 1978 is probably due to a slower growth rate and a correspondingly later maturity than observed for the 1973 and 1974 year classes. The entry of the 1975 year class into the spawning stock will thus be delayed for one or two years, and the estimates of the recruitment of the 1975 year class to the spawning stock will have to be reduced accordingly, owing to natural mortality in that period.

The estimate for the 1974 year class in 1978 is also lower than was expected by the working group. This is due to the fact that they underestimated the proportion of this year class, which matured and spawned in 1977 as 3-year-old herring. The higher proportion is in accordance with the extraordinarily high growth rate observed in this year class, particularly in the first year of growth (Table 11).

The low level of subsequent recruitment has thus resulted in no further increase in the spawning stock size in 1978, although the recruiting year class of 1975 is considered to be stronger than the previous ones. It should, however, be borne in mind that maturing of a year class at 3 years old is not normal. The age composition observed in the spawning stock in 1978 may therefore indicate a return to normal growth and sexual development. Figure 30 shows growth curves for earlier periods compared with the growth of the 1969 and 1973 year classes.

CONCLUDING REMARKS

In a virgin state, the total stock biomass of the Norwegian spring-spawning herring may have ranged between 15 and 20 million t. As a plankton feeder the herring must have played a very important role for all top carnivores in the area. The effects of the disappearance of the herring on other marine stocks are, however, difficult to assess. It has not so far been observed that the herring fishery has 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 therefore is that the production, in one of the richest areas in the Northeast Atlantic, became unavailable to top carnivores, including man.

The distribution pattern and migration of the herring changed during the period when the stock size declined. This resulted in speculation 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 simulation runs indicate that the collapse of the stock could have been avoided if the herring fishery had been managed by fishery regulations in the 1960s. 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 is 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.

The fishery on 0- and 1-group herring constitutes the most irrational fishing strategy when the fishing mortality approaches F_{max}. In the 1960s a minimum landing size, protecting 0- and 1-group fish, was the only regulatory measure needed to prevent the depletion of the stock. With the same recruitment as observed in the 1960s this regulation could have conserved a spawning stock in 1970 at a level of 1·6 million t. If such a regulation had also been combined with a catch quota regulation aiming at F_{max} or $F_{0.1}$ on older fish, it is estimated that the spawning stock by 1970 could have remained at a level of 2·4 to 4·7 million t. It is therefore concluded that the collapse of the stock in the 1970s was mainly due to overexploitation.

The adult herring stock was fished out in 1970, and without protection the immature stock would probably also have been 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. Although it cannot be stated with certainty that the Norwegian spring-spawning herring were on the point of being extinguished in

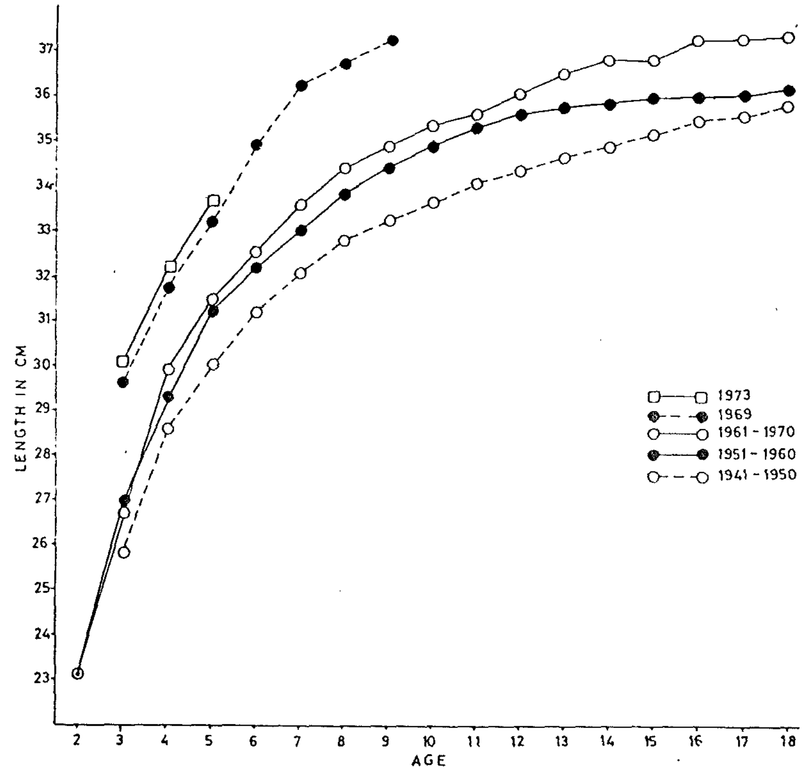

Figure 30. Growth curves for earlier periods compared with growth curves for the 1969 and 1973 year classes.

the 1970s, it is suggestive 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 1973 and 1974 year classes have produced a spawning stock biomass which is larger than that of the parent stock. The stock is thus increasing, and the severe crisis this stock was brought into in the early 1970s is regarded as being over. However, the stock is still in a depleted state and its future is completely dependent on effective protection. Judging from the abundance estimates of the 1975 and 1976 year classes as 0-group fish, the rebuilding of the herring stock can be rapid if it is properly managed in the years to come.

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