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Exploitation and management of Norwegian spring-spawning herring in the 20th century

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The Norwegian spring-spawning herring is a herring stock with large natural stock size fluctuations. Through the 20th century, the stock reached high abundance levels in the 1930s and 1940s and decreasing levels in the 1950s and 1960s with a stock collapse in the late 1960s and early 1970s. In this paper, the history, in terms of exploitation and management of this stock, is described, and the role of ICES in the years when the stock collapsed is emphasized. Through the years when the stock decreased severely and the exploitation reached the highest levels, it was not generally understood by the scientific community that the stock level really was that poor, and there was also uncertainty about the reason for the decreasing trend of the stock at that time. Therefore, regulatory measures were not decided until it was too late, and the stock collapsed. The rebuilding of the stock has been successful following strict advice from ICES and also annual agreements of TACs in international waters.

Keywords: herring history, herring management, long-term exploitation history.

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Introduction

Historically, the Scandinavian herring fisheries have been characterized by severe fluctuations causing series of alternating wealth and poverty in the coastal communities (Jakobsson, 2002). Late in the 19th century, the herring "disappeared" and Norwegian herring investigations started, first by Axel Boeck (1871) and thereafter continued by Georg Ossian Sars (Devold, 1963). The crises led scientists to ask relevant questions about stock-size fluctuations and why these happened (Hjort, 1914). As a result, formal fishery investigations were initiated in the early years of the 20th century led by Johan Hjort. The International Council for the Exploration of the Sea (ICES) was established in 1902, and from then on the need for increased knowledge in this field became an international pursuit.

A systematic sampling programme on cod and herring was begun by the start of the 20th century and initiated the extensive fishery investigations in Norway. These stocks were considered to be the most important to the Norwegian fishing industry. The resulting long-term data series on these stocks has now made it possible to reconstruct the stock-size fluctuations of Norwegian spring-spawning herring from 1907 through 1998 (Figure 1; Toresen and Østvedt, 2000).

The main question dealt with in this paper is how fishery, fishery science, and management have reacted to the large stock-size fluctuations of the Norwegian spring-spawning herring (Toresen and Østvedt, 2000) through the 20th century.

The period 1900–1950

The fisheries

Main fleets

The fishery for Norwegian spring-spawning herring throughout the period 1900–1950 can be divided into the following groups according to the size and localization of the fishery (Anon., 1911, 1924, 1933, 1942, 1974, 1982):

A) Fishery for adult mature herring on the spawning grounds in winter and early spring. This is the so-called winter herring fishery, harvesting "the large herring" before the herring spawn and "the spring herring", which is the fishery for spawning herring and spent herring leaving the spawning grounds.

B) Fishery for adult herring during summer on the feeding grounds off Iceland and in the Norwegian Sea.

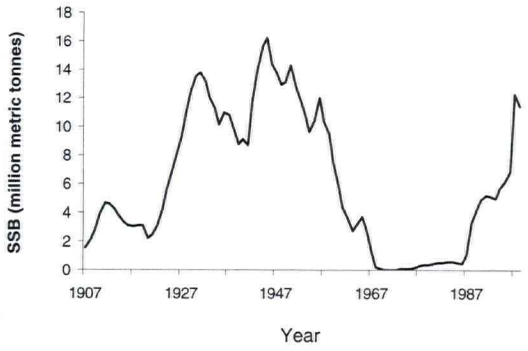

Figure 1. Fluctuations in spawning stock biomass (SSB) of Norwegian spring-spawning herring, 1907–1998 (Toresen and Østvedt, 2000).

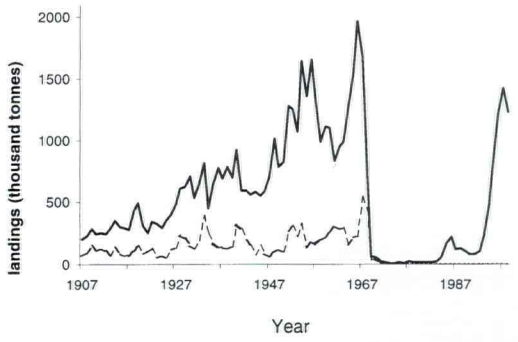

Figure 2. Landings of Norwegian spring-spawning herring, 1907–1998. Solid line = total landings, broken line = landings of small herring.

C) Fishery for juvenile (fat) herring in the nursery areas at the coast and in the fjords, mainly in northern Norway.
D) Fishery for small (0- and 1-group) herring in the fjords along the Norwegian coast.

Fishery A took place annually whenever (as far back as history books can tell) there were herring spawning along the coast. Fishery B started as a beach-seine fishery in the 1860s, but ceased temporarily in the late 19th century. Early in the 20th century, the fishery developed as a driftnet and purse-seine fishery and was subsequently carried out on a regular basis (Thordarson, 1930; Vollan, 1971). Fishery C took place on a regular basis mostly in late summer and autumn. Fishery D was carried out on a regular basis mostly in late summer and autumn, especially after about 1910 when the first reduction plants were built in northern Norway.

Fishing technique

The exploitation of the Atlanto-Scandian herring stocks is reflected by the long-term development of the gear through the period. By the turn of the 20th century, the herring fisheries were dominated by small vessels operating in coastal and inshore waters. The major fishing gears in use were shore seines and nets (standing nets and driftnets) (von Brant, 1984; Vollan, 1971). The use of driftnets developed from the start of the 20th century, reflecting the need to search for herring in more offshore waters. The purse-seine fishery also developed from the early years of the century, but for many years the fishery was dependent on fair weather conditions because of the use of dories and the hauling of the seines by manpower (Vollan, 1971). In the 1930s and 1940s, the proportion of the total herring landings taken by nets and purse-seines was about 50:50.

Landings and fishing mortality

The landings of Norwegian spring-spawning herring throughout the period 1907–1998 are given in Figure 2 and Table 1 (Toresen and Østvedt, 2000). By the end of the 19th century, total landings were about 200 000 t, but soon increased to about 250 000–300 000 t. The total quantity increased somewhat during the first 25 years of the 20th century to about 400 000 t by 1926. During the following five years, total landings increased to about 700 000 t. This level was maintained until the late 1940s. Throughout the first 50 years of the century, the fishing mortality rate (F) was less than 0.15. Landings increased, but so did the spawning-stock biomass. The total landings of small and fat herring (fisheries C and D) were annually at 100 000–200 000 t from the beginning of the 20th century until about 1930, after which they increased to about 200 000 t. During the 1940s, landings decreased to about 100 000 t.

The stock

By the end of the 19th century, the stock was in a rebuilding phase (Toresen and Østvedt, 2000) and increased in abundance until it was above 12 million t by 1930. Several rich year classes through the 1930s made the stock increase even more to above 15 million t in the mid-1940s. By 1950, the stock was estimated to be 14 million t.

The scientific studies and management

In 1902, ICES was established, and it was emphasized from the very start that a primary objective of this organization was to promote and improve fisheries through international agreements on the basis of international scientific cooperation (ICES, 1903). As Chair of Committee A (the Migration Committee) in ICES, Johan Hjort held the view that vital statistics (demographic data) should be used in the assessment of fish stocks, and he suggested in a lecture at the 1907 ICES annual meeting that fishery biologists might find it useful to

think in such terms (Hjort, 1908). This implied the introduction of ageing of fish and the division of fish stocks into age groups and year classes. In Bergen, Hjort and his colleagues Hjalmar Broch, Knut Dahl, and Einar Lea developed the age-reading method by the use of herring scales (Broch, 1908). Dahl (1907) and Lea (1910) continued the studies of herring scales for many years. However, in contrast to the attitude of fishery scientists in England, Scotland, and the Netherlands, who held the view that the changes in the fishery were caused by overfishing, Hjort and his colleagues, in the early years of the 20th century, believed that the large fluctuations in the fish stocks were caused by large-scale migrations. Shortly thereafter, Hjort changed his opinion and advocated the view that the variation was caused by variations in year-class strength recruiting to the fisheries (Hjort, 1914).

In 1924, Lea (1924) published a note on the exploitation of small herring. Fishermen harvesting the somewhat older "fat herring" were complaining and asked if the small herring fishery influenced the yield of fat herring the following years. Lea concluded that it was unlikely that the yield in the fat herring fishery would increase if the small herring fishery were regulated.

In 1929, ICES organized a special meeting on "Fluctuations in the abundance of the various year classes of food fishes" (ICES, 1930). In relation to herring research, one contribution was quite innovative and demonstrated one of the most important future uses of age determination: Lea's "Mortality in the tribe of Norwegian herring" (Lea, 1930).

The intended role of ICES in providing advice on the regulation of international fisheries did not, however, come about until the early 1930s, when advice was submitted dealing with the protection of undersized fish in the trawl fisheries in the North Sea. The effects of fishing on the stocks were not perceived as urgent problems in the Norwegian fisheries in the 1920s and 1930s, with the exception of whales.

However, important contributions to the understanding of the biology and migration of the adult Norwegian spring-spawning herring were completed by the late 1940s and early 1950s. Árni Fridriksson, in 1935, arrived at the conclusion that the herring caught during the summer off the north coast of Iceland were at least partly identical to the Norwegian winter herring. He found it desirable to carry out tagging experiments in order to prove or disprove the theory of long-distance migration of the herring (Fridriksson, 1944). A joint project between Icelandic and Norwegian fishery scientists was organized, and during the period 1948–1950, a total of 42 054 herring were tagged (Fridriksson and Aasen, 1950). The experiments proved that, at the time, the Norwegian spring spawners migrated to Iceland during the summer and returned to the Norwegian coast to spawn during the winter. However, the migration routes between these two areas were not known, and at the 1948 ICES Statutory Meeting, it was recommended that the countries interested in the exploitation of this stock should adhere to a common plan of investigations to be coordinated by the Chair of the Northwest Area Committee. In adhering to this recommendation, Denmark, Iceland, Norway, Scotland, and Sweden carried out research in the area from 1949 until 1970 (Jakobsson and Østvedt, 1999). The recommendation from 1948 can be considered as the first ICES initiative for joint international herring surveys. At the 1951 ICES meeting in Amsterdam, three countries, Denmark, Iceland, and Norway, agreed to cooperate in an extended herring research programme to cover the whole area of the Norwegian and Iceland Seas. Beginning in 1957 the USSR also participated in this programme (Jakobsson and Østvedt, 1999).

The period 1950–1975

The fishery

Main fleets

The fishery was carried out according to the same groups as during the 1900–1950 period. However, by the late 1960s, the summer and autumn fishery at Iceland and in the Norwegian Sea (fishery B) ended because there were no herring there. By 1973, the small and fat herring fisheries had also stopped. The main fishery (fishery A) at the spawning grounds gradually decreased and ceased in 1973. The total landings were lowest in 1973 with only 7000 t.

Fishing technique

During the 1950s, fishing techniques – the way of searching and fishing – developed markedly, and when fishermen discovered that large catches of herring could be handled more easily and quickly, the use of the "new" techniques accelerated (Vollan, 1971; Jakobsson, 1959, 1964; Bakken and Dragesund, 1971). In the late 1950s and early 1960s, herring fishing vessels began to make use of sonar (Forbes and Nakken, 1972), power blocks were used to haul large seines directly from the fishing vessel, and seines were made of nylon, which made them lighter (von Brandt, 1984). In addition, fishing vessels started to use pumps to transfer the catch from the seines to the vessels. This increased the ability of fishermen to handle much larger catches than before.

Landings and fishing mortality

Landings (totals and small herring) in number and weight are shown in Figures 3 and 4. During the 1950s, the fisheries expanded and landings increased to about 1.3 million t. In 1956, about 1.6 million t were landed. During 1965–1967, annual landings were more than 1.5 million t, with nearly 2 million t landed in 1966. The

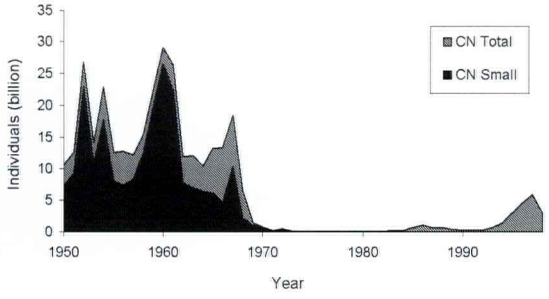

Figure 3. Landings in numbers (CN) of total and small Norwegian spring-spawning herring, 1950–1998.

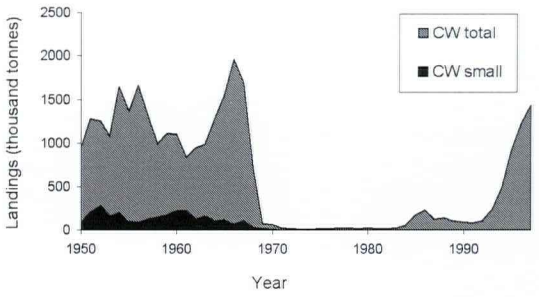

Figure 4. Landings in weight (CW) of total and small Norwegian spring-spawning herring, 1950–1998.

mean fishing mortality (ages 5–12) increased sharply from 0.2 in 1964 to 1.7 in 1968 (Toresen and Østvedt, 2000), reflecting the very high exploitation of adult herring in these years.

Landings of small and fat herring increased to about 300 000 t during the 1950s. This high level of exploitation continued during the 1960s and reached a record high of 546 000 t in 1967. Also in 1968, the landings of juveniles (fat herring) were high, about 440 000 t, but thereafter dropped to less than 50 000 t.

The stock

Between 1950 and 1975, the stock collapsed. During this entire period, stock abundance decreased (Toresen and Østvedt, 2000). There were two main reasons for the decline. The environment, which is known to influence the recruitment of the stock, developed negatively and recruitment failed (Toresen and Østvedt, 2000). At the same time, the exploitation rate increased owing to the development of new fishing techniques. Stock biomass decreased from 14 million t in 1950 to 6 million t in 1960 and further to only 50 000 t in 1970. The stock was assessed as being nearly extinct during the early years of the 1970s.

Scientific studies and management

At the beginning of this period, herring scientists in Norway assumed the role of guides for Norwegian fishermen. The new Norwegian research vessel "G. O. Sars" was equipped with the most modern acoustic equipment, and the large concentrations of herring were "followed" from the open ocean to the spawning grounds off the west coast of Norway. Over the radio on board "G. O. Sars", the leading Norwegian herring scientist, Finn Devold, guided the herring fishermen to the densest aggregations of fish.

The serious declines in some of the most important European herring fisheries during the 1950s, especially those off the Norwegian west coast and in the North Sea, caused fisheries scientists to pay attention to the possible importance of man-made factors as major determinants. Consequently, ICES, acting on a recommendation from its Herring Committee (1960), held a Herring Symposium in 1961 to bring forward all available knowledge on the subject. During the Symposium, three papers addressed the decline in the Norwegian spring-spawning stock. One paper (Østvedt, 1963) dealt with catch per unit of effort in the Norwegian winter fishery. Based on the results derived from these effort data, Østvedt concluded that the declining catches of winter herring resulted mainly from depletion of the spawning stock due to low recruitment and not because of higher fishing mortality rates caused by increased effort. In their paper, Marty and Federov (1963) agreed on the issue of low recruitment, but disagreed on the effect of juvenile fishing and concluded that the first thing to do when attempting to rationalize the utilization of the Atlanto-Scandian stock was to consider the problem of ending the mass harvest of young fish. This statement was heavily debated at the Symposium and strongly opposed by the Norwegian scientists. The third paper on the state of the Atlanto-Scandian herring (Dragesund and Jakobsson, 1963) was based on herring tag returns since 1948 and was a joint project of Norway and Iceland. Their estimate of the stock in 1952 of about 20 million t of adult herring was high, probably because it was based on the very early tagging experiments when tagging mortality may have been much higher than in later years after more experience had been gained in handling the herring. Comparing these stock estimates from 1953 to 1959 with the results of the most recent virtual population analysis (VPA) (ICES, 1999), it is clear that the results from the tagging experiments reflect the decline in the stock during 1953–1959 (Table 2). The tagging results overestimated the stock size dur-

Table 1. Landings (thousands of t) of Norwegian spring-spawning herring, 1907–1998.

Year	Total landing	Fat herring	Small herring	Adult Iceland	Adult Norway
1907	207.6	50.1	20.9	19.3	117.3
1908	233.4	61.6	34.3	21.9	233.4
1909	288.5	114.0	40.0	18.8	115.6
1910	250.0	89.4	29.6	15.3	115.7
1911	253.5	61.2	70.1	6.2	116.0
1912	245.2	44.6	74.0	10.7	116.0
1913	290.7	27.8	50.3	18.7	193.9
1914	356.0	37.6	101.4	23.0	193.9
1915	306.1	41.8	44.8	25.6	193.9
1916	296.9	28.4	48.4	26.1	194.0
1917	276.2	31.2	41.1	10.0	193.9
1918	433.5	52.5	64.6	8.2	308.2
1919	498.1	47.4	110.8	19.1	320.8
1920	316.5	38.8	49.1	16.7	211.9
1921	258.5	35.4	71.1	17.0	135.0
1922	349.9	78.7	49.7	37.7	183.7
1923	330.5	26.3	34.0	9.2	261.0
1924	295.0	14.8	55.6	8.3	216.3
1925	355.5	17.0	42.4	16.4	279.7
1926	403.8	16.7	103.8	28.6	254.7
1927	489.9	25.3	110.9	71.9	281.8
1928	611.9	124.8	117.3	69.3	300.6
1929	624.6	84.1	133.8	63.2	343.5
1930	704.5	41.8	111.6	76.2	475.0
1931	538.2	12.9	117.5	100.2	307.7
1932	652.6	41.3	155.1	91.4	364.8
1933	818.2	178.5	219.0	90.8	329.9
1934	451.7	112.9	132.6	95.2	111.0
1935	649.4	36.5	138.4	73.8	400.8
1936	775.2	31.0	112.9	150.0	481.4
1937	695.9	18.5	123.9	237.0	316.4
1938	783.6	9.4	121.2	156.8	496.3
1939	703.4	25.8	122.8	148.7	406.2
1940	923.1	44.3	277.6	204.2	397.0
1941	594.0	71.5	217.0	95.2	210.3
1942	592.7	51.8	145.5	145.0	250.4
1943	556.6	47.8	106.4	177.0	225.4
1944	587.8	13.3	69.4	216.4	288.7
1945	554.4	29.3	124.3	60.0	340.8
1946	586.2	28.2	64.6	150.1	343.2
1947	710.4	20.3	47.1	195.8	447.2
1948	1012.6	17.9	87.8	86.1	820.7
1949	783.0	21.8	101.1	94.6	565.5
1950	826.1	29.7	72.9	54.8	668.7
1951	1277.8	75.0	208.6	104.9	889.3
1952	1254.8	33.2	302.4	89.8	829.4

1953	1074.4	79.8	160.9	155.1	678.6
1954	1644.5	130.0	208.1	187.3	1119.1
1955	1359.8	39.7	103.1	213.1	1003.9
1956	1659.4	103.7	95.1	267.8	1192.8
1957	1318.5	40.6	129.6	291.8	856.5
1958	986.3	55.2	146.1	355.9	429.1
1959	1111.1	48.1	179.9	372.9	510.2
1960	1101.8	48.7	232.0	420.1	401.0
1961	830.1	88.5	243.7	351.6	146.3
1962	948.6	161.2	136.2	517.7	133.5
1963	984.5	140.9	172.8	538.0	132.8
1964	1281.8	57.2	106.7	697.7	420.2
1965	1547.7	105.1	117.0	934.6	391.0
1966	1972.1	170.0	78.5	1091.7	631.9
1967	1677.2	438.7	107.0	672.7	458.8
1968	712.2	412.8	26.3	227.8	45.3
1969	67.8	29.3	14.4	–	24.1
1970	61.2	3.9	36.4	–	20.9
1971	21.1	–	14.2	–	–
1972	13.2	–	13.2	–	–
1973	7.0	–	6.8	–	–
1974	7.6	–	6.3	–	–
1975	13.7	–	–	–	–
1976	10.4	–	–	–	–
1977	22.7	–	–	–	–
1978	19.8	–	–	–	–
1979	12.9	–	–	–	–
1980	18.6	–	–	–	–
1981	13.7	–	–	–	–
1982	16.7	–	–	–	–
1983	23.1	–	–	–	–
1984	53.5	–	–	–	–
1985	169.9	–	–	–	–
1986	225.3	–	–	–	–
1987	127.3	–	–	–	–
1988	135.3	–	–	–	–
1989	103.8	–	–	–	–
1990	86.4	–	–	–	–
1991	84.7	–	–	–	–
1992	104.4	–	–	–	–
1993	232.5	–	–	–	–
1994	479.2	–	–	–	–
1995	905.5	–	–	–	–
1996	1220.3	–	–	–	–
1997	1426.5	–	–	–	–
1998	1426.1	–	–	–	–

Table 2. Stock estimates (thousands of t) of Norwegian spring-spawning herring (adult stock). From Dragesund and Jakobsson (1963), ICES (1965a, 1969, 1999), and Toresen and Østvedt (2000).

Year	1961	1965	1969	5 and older - 1999	SSB - 1999
1953	12 462	12 462	12 500	12 000	10 613
1954	12 183	12 183	12 100	9 700	9 445
1955	13 857	13 857	13 900	14 700	10 223
1956	11 997	11 997	12 000	13 500	11 740
1957	9 393	9 393	9 400	10 900	10 129
1958	6 603	6 603	6 300	9 800	9 280
1959	5 022	5 022	5 000	7 600	7 350
1960	–	–	–	6 000	5 817
1961	–	–	3 100	4 300	4 230
1962	–	2 504	2 500	3 600	3 465
1963		2 847	2 800	2 600	2 635
1964		3 256	4 150	5 200	2 795
1965		6 800	7 250	4 600	3 067
1966			6 600	2 800	2 595
1967			4 000	1 400	1 145
1968			2 000	600	219

ing the three first years, but in 1956, the estimates were equal, while the tagging results gave somewhat lower stock size estimates and a sharper decline during 1957–1959. However, the results of the tagging experiments do not necessarily reflect the exact abundance of the spawning stock, as calculated from the VPA. The results of the tagging may have just represented the available stock of herring in the so-called adult fisheries at the north coast of Iceland and at the west coast of Norway during the winter season. Comparison of the abundance of 5-year-old and older herring estimated from VPA with that calculated from the tagging experiments shows an even closer agreement than comparison with the spawning stock. Thus, already in 1961, the decline in the stock during the 1950s was clearly illustrated in the paper presented by Dragesund and Jakobsson (1963).

In accordance with recommendations made at the Herring Symposium in 1961 and endorsed at the 1961 and 1962 ICES annual meetings, it was decided to establish an assessment working group for Atlanto-Scandian herring. The first meeting of this working group was held in 1963, and it is of interest to note that, in the terms of reference, it was stated that the working group was established in view of the recent serious decline in the fisheries based on the Norwegian spring spawners, but not because of the serious decline in the stock.

Although the early ICES working groups dealing with the assessment of Atlanto-Scandian herring (ICES, 1963, 1964, 1965a) were preoccupied with biology, estimates of stock size and how the stock decreased in abundance throughout the 1950s were presented. However, such estimates were not available for the years 1960–1963 owing to the fact that the catches during the Norwegian winter fishery were almost all utilized for human consumption. Given the very low catches, practically no herring were processed in the fishmeal factories where the tags used for the abundance estimates were recovered. At these meetings, estimates of abundance were also presented for 1958, 1961, and 1962 based on underwater photography and acoustic methods. Comparison of the results of the tagging as well as the acoustic data with those of the VPA up to and including 1964 shows that the estimates presented by the early working groups on stock abundance were very close to those obtained by the most recent VPA results for 5-year-old and older herring. Similarly, the working groups presented fishing mortalities for the 1950s and the early 1960s (ICES, 1964) which were almost identical to those obtained from the recent VPA for 1953– 1958, but for 1959–1963, there is a discrepancy between the two series. The mean of the working group estimates for those years was 0.21, while the VPA mean (Toresen and Østvedt, 2000) for the same period was 0.13 (Table 3). Thus, it is clear that the early ICES Atlanto-Scandian Working Group that met in 1963–1965 estimated the stock and the rate of exploitation realistically, although the fishing mortality appears to have been temporarily overestimated.

The severe reduction in stock abundance observed during the late 1950s and the early 1960s was correctly assessed as being attributable to a series of weak year classes (1951–1958) recruiting to the adult stock. Whether this was, at least partly, due to the juvenile fishery was heavily debated at the time, although not

Table 3. Fishing mortality estimates for Norwegian spring-spawning herring, 1953–1963, determined by 1964 and 1999 ICES working groups (ICES, 1964, 1999).

Year	1964 WG	1999 WG
	F adult and pre-recruits	VPA estimates
1953	0.06	0.06
1954	0.12	0.11
1955	0.09	0.09
1956	0.13	0.12
1957	0.13	0.10
1958	0.10	0.10
1959	0.17	0.13
1960	0.27	0.14
1961	0.21	0.09
1962	0.21	0.11
1963	0.20	0.17

properly reflected in the Working Group reports. Therefore, in the 1964 Working Group report it was concluded that:

> while the recent fishery and stock decline could definitely be attributed to a sustained failure in recruitment, it was not possible from current evidence to determine the part played by the fishery for 'small' and 'fat' herring as a governing factor in it. However, the Soviet representatives expressed the view that this fishery has influenced the level of recruitment in recent years.

In the report of an *ad hoc* Assessment Group on Herring and Herring Fisheries in the North-Eastern Atlantic (ICES, 1965b), scientists concluded that the primary cause of failure of year classes at the time to provide good recruitment was natural. It was probably on the basis of this report that the ICES Liaison Committee concluded that (ICES, 1966):

> The exploitation of the adult Norwegian spring spawners is probably still at a level where no benefit for total landings can be expected by any regulatory measure. The decrease in catch from 1957 to 1963 was caused by the sequence of poor year-classes from 1951 to 1958. The primary cause of the failure of any of these year-classes to provide good recruitment has been natural.

The strong 1959 and the average 1960 year classes recruited to the adult winter and summer fisheries in the middle of the 1960s. As a result, the catches of the fishing fleet equipped with sonar and power block escalated and reached a peak of 1.7 million t in 1966. Similarly, when the average 1963 and 1964 year classes recruited to the juvenile fishery in the middle and late 1960s, the catches increased to more than half a million t in 1967.

The Atlanto-Scandian Herring Working Group did not meet during this boom period of fishing as the regular annual working group meeting system was not yet established in ICES. However, the Working Group was re-established and met in April 1969. In the intervening period since its previous meeting in 1965, new stock estimates from tagging had become available.

In 1964, the Norwegian winter fishery increased from 61 000 t to 286 000 t owing to the recruitment of the 1959 year class. In addition, considerable amounts of adult herring were caught in the Norwegian Sea and at Iceland during 1964–1967. The mean landing figures of the three major harvesting countries, Iceland, Norway, and the USSR, in the Norwegian Sea in 1964–1967 were 490 000 t, 386 000 t, and 401 000 t, respectively. As a result, a considerable proportion of these catches was reduced to meal and oil, and sufficient numbers of herring tags were returned to make it possible to estimate the stock size after a four-year period without information on stock abundance from the tagging programme. From these data, it was estimated that the adult stock was about 5 million t in 1964. A comparison with the most recent VPA results shows that the spawning stock in 1964 was estimated to be only 3.2 million t, while the adult stock of 5-year-old and older fish was estimated to 5.2 million t, which corresponded very well with the results based on the tagging data.

However, during the period 1965–1967, the estimates from the tagging data deviated rapidly from those of the VPA. Therefore, in 1965, the adult population from the VPA estimate was 3.1 million t, while the tagging estimate was 7.7 million t. In 1966, the VPA estimate was 2.6 million t and that based on the tagging data was 6.6 million t. In 1967, the VPA estimate was only 1.1 million t, while the tagging estimate was 4.0 million t. An acoustic estimate of 2.0 million t was available for 1968, while the VPA estimate was 0.2 million t of adult herring. Based on the available estimates, the Working Group determined that the average fishing mortality had increased from 0.21 in 1961–1965 to 0.43 in 1966– 1967, compared with the VPA estimates of 0.18 and 1.1, respectively.

The obvious question is why the results of the tagging experiments as well as the acoustic estimates agreed so well with the VPA results during 1953–1964 and disagreed so drastically in the subsequent two or three years. One must bear in mind that the estimates derived from VPA for these last years were entirely dependent on the conclusion that there was virtually no spawning stock present on the spawning grounds in the winter of 1972 and that it was assumed that natural mortality had been constant during the whole period. This assumption may have been wrong, and it is likely that the stock also experienced an increase in natural mortality during the 1960s. This may be the reason for the discrepancy between the tagging experiment results and the VPA estimates in the mid-1960s.

The effect of the juvenile fishery was debated again at the 1969 meeting of the Working Group. Despite the fact that the rate of exploitation in the fat-herring fisheries increased substantially in 1967–1968 and that this fishery would have a serious impact on the subsequent recruitment to the adult stock, it proved impossible to

reach agreement on a proposal to ban the juvenile fishery. Consequently, the Liaison Committee concluded in 1970:

> ...the Committee considers it would increase the stock and the long-term fishery prospects to reduce the fishing mortality rate on the immature herring and to avoid a further increase in the fishing rate on the adult stock of Norwegian spring-spawning herring.

It should be noted that, by 1970, the adult stock was almost completely fished out by Norway, the USSR, and Iceland, while the recruiting 1963 and 1964 year classes were fished by the Norwegian purse-seiners at the coast. The adult summer and autumn fishery ceased completely, and Norway was the only country still fishing for Atlanto-Scandian herring (young herring) at the coast (Anon., 1995).

Management through international pressure on regulations, and the "first" North-East Atlantic Fisheries Commission (NEAFC)

The North-East Atlantic Fisheries Convention was ratified on 23 January 1959. Soon after, the competence of NEAFC to discuss and advance recommendations was expanded. The possibility to "take measures to limit the total allowable catch or exploitation capacity... to preserve fish stocks" proved a very important point in the agreements.

Through the 1960s, it became clearer and clearer that the Norwegian spring-spawning herring stock was in danger.

The records of agreement from the meetings in NEAFC (1964a–1968b) illustrate that NEAFC could do little but watch the worrying situation develop. However, at the 7th NEAFC meeting in London (May 1969), it was decided to set up a working group of administrators and scientists from interested countries to discuss necessary and suitable measures for regulating the fishery of herring in the Northeast Atlantic (NEAFC, 1969). At the 8th meeting in London (May 1970), a report from a Scientific Study Group for Atlanto-Scandian Herring, which met in Moscow in 1970, was presented. The Group recommended a minimum size regulation of 25 cm and the establishment of a quota system, with exceptions for certain countries to fish immature fish for canning and bait (NEAFC, 1970). This proposal was rejected by the Norwegian delegation, which advocated a minimum size of 20 cm, a limit offering no protection for the so-called fat herring (mainly 2- and 3-year-olds). The response to the Norwegian attitude was recorded in the following way in the report from the meeting:

> Other delegations drew attention to the serious – even catastrophic – situation of this stock. Catches had fallen from over 1 000 000 metric tonnes up to 1966 to a very low figure in 1969. This had been caused by lack of recruitment from the year classes after 1961, and the decline had been accelerated by over exploitation. The continuing exploitation of juveniles made the outlook for the stock extremely poor.

The USSR delegation informed the Commission that they had banned the fishery of Atlanto-Scandian herring in the Norwegian Sea and off Greenland. In the Barents Sea, they had restricted the fishery by a mesh-size regulation and banned the purse-seine fishery. Iceland reported that it had introduced a closed season from January to September, a minimum size regulation of 25 cm, and a quota system.

In Norway, a minimum size regulation of 20 cm was established the same year, and the Norwegians proposed to divide the stock into three exploitation components: small herring (<20 cm), fat herring (20–28 cm), and adult herring (>28 cm).

It was generally understood that NEAFC, at the time, did not have the necessary legal authority to enforce the needed regulatory measures. Thus, herring under 25 cm landed by Norwegian fishermen were taken mainly within national fishery limits, and their regulation was, therefore, not within the power of the Commission.

Subsequently, in 1971, Iceland, the USSR, and Norway agreed to regulate the fishery. The agreement limited the fishery of the adult stock to the quantity each country had landed in 1969. The fisheries for fat herring and small herring were limited to 70% of the amount each country had landed in 1969. It should be noted that Iceland and the USSR had ceased fishing for Atlanto-Scandian herring as of 1969. The agreement, therefore, only aimed at limiting the Norwegian fishery as far as possible.

In February 1972, the three parties agreed to ban fishing for adult herring. However, Norway held the view that a small fishery for fat herring could continue for socio-economic reasons, and the fisheries for fat and small herring would be limited to 45% of the quantity each country had landed in 1969 (Anon., 1971–1972).

In December 1972, the three parties extended the 1972 agreement to 1973. The fisheries for fat and small herring were limited to 26% of the quantity each country had landed in 1969. At that time, Norwegian scientists had confirmed that no herring were recorded on the traditional spawning grounds during the winter season of 1972.

At the 11th annual meeting of NEAFC in London (May 1973), it was decided to ban the fishery for Atlanto-Scandian herring. The three-party agreement was replaced in 1974 by a Commission agreement on the fishery. An exception from the ban was a possibility to take a small amount for human consumption and bait – corresponding to 20% of the amount each country had fished of fat and small herring in 1969. However, the exception was not restricted to fat and small herring only (NEAFC, 1974).

At the 12th meeting in Bonn (June 1974), and at the 13th meeting in London (May 1975), it was agreed to continue the ban, with small exception quotas for the fat and small herring fishery (NEAFC, 1975, 1976).

At the 14th meeting in Lisbon (July 1976), Atlanto-Scandian herring were not discussed. Norway wanted to cancel the convention. A new convention was agreed

upon and signed in London in 1980. The new Commission's authority was restricted to areas outside 200 nautical miles from the shore (international waters) (NEAFC, 1978).

The period 1975–2000

The fishery

Main fleets

There are currently two main fisheries for herring: (a) a fishery exploiting mainly the mature adult herring during winter and spring by purse-seiners only, and (b) a fishery exploiting the same part of the population as fishery (a), but conducted in the Norwegian Sea while the herring are distributed in the summer feeding areas.

During 1975–1983, only small amounts of herring were landed by driftnet and small purse-seiners. The herring were used for human consumption and bait.

In 1984–2000, the fishery expanded, and large purse-seiners were allowed to exploit the stock. The fishery takes place all year, with a concentration of fishing at the spawning ground and in the feeding area (Norwegian Sea) during summer. The driftnet fishery ended in the late 1970s.

Fishing techniques

During the rebuilding phase, herring fisheries were held at the lowest possible level and then allowed to develop slowly; purse-seiners were currently the most important component of the overall herring fleet. Some trawlers from European countries and Russia harvested the stock in the Norwegian Sea during the summer. The driftnet fishery came to a complete stop.

Landings and fishing mortality

During the late 1970s, the amount landed was very low. Landings increased somewhat from 1985 on, and the mean fishing mortality rate (ages 5–12) increased to 0.8 in 1983, 0.4 in 1985, and 1.0 in 1986. Landings subsequently decreased to less than 100 000 t in 1990 and 1991, while spawning-stock biomass increased and fishing mortality decreased to low levels again by 1991. Throughout the 1990s, landings increased, going from 480 000 t in 1994 to more than 1.2 million t in 1996–1998. Since 1991, fishing mortality has been low, and less than 0.15 (ICES, 2000).

Landings of small and fat herring were insignificant after 1974. However, despite decreased catches after 1968, fishing mortality on the juvenile component remained high until 1973 (Toresen and Østvedt, 2000). The exploitation of young herring has been prohibited since 1977 owing to a minimum size regulation of 25 cm, which has been strictly enforced.

The stock

The period 1975–2000 must be characterized as the rebuilding phase. During 1975–1982, the stock failed to produce good recruitment because of very low spawning-stock abundance. In 1983, a very rich year class survived, and when this year class matured to spawn in the late 1980s, the stock was assessed above the critical low level of 2.5 million t. In 1991 and 1992, recruitment was successful, and during the 1990s, the stock increased to about 10 million t. In recent years, stock abundance has decreased owing to poor recruitment during the period 1994–1999 (Toresen and Østvedt, 2000; ICES, 2000).

Management during 1975–2000 and the role of the new NEAFC

Beginning in 1976, coastal states suddenly acquired greater influence over their "own" resources. The implementation of the 200-mile exclusive economic zones (EEZs) confirmed their ownership of resources and made the implementation of regulatory measures much easier. The size of the international areas containing large fishery resources decreased drastically. The role of NEAFC, therefore, changed, and the need for multilateral agreements suddenly became more important.

Norwegian spring-spawning herring were distributed within the Norwegian EEZ from 1970 on (Anon., 1995). The stock was at low levels of abundance (ICES, 1999) and distributed only in inshore waters along the Norwegian coast (Dragesund *et al.*, 1997). The management of the stock was regarded by Norwegian authorities, therefore, as a national matter. The goal of this management was to rebuild the spawning stock as soon as possible to a level above the Minimum Biological Acceptable Level (MBAL) of 2.5 million t. The fishery was, therefore, strictly regulated with a minimum landing size regulation of 25 cm (from 1977 on) and the lowest possible catch of adult herring through the years 1976–1980. Throughout the late 1970s and early 1980s, there was a "struggle" between the scientists at the Institute of Marine Research in Bergen (as advisers), on the one hand, and the fishing industry, on the other, concerning how much herring could be harvested. In 1979, the Institute produced an abundance estimate of the spawning stock, based on tagging experiment data. This estimate showed that the stock was still at a very low level of abundance, and served as a basis for the continuation of the strict regulations (ICES, 1979; Hamre, 1990). ICES, therefore, continued to advise a zero catch (begun in the 1970s) until 1984. After 1980, the fishery was expanded somewhat. Following intense pressure from the Norwegian fishing industry, the authorities agreed on small annual quotas, limited to a maximum yield corresponding to a fishing mortality rate of 0.05. In 1984, the purse-seiners were allocated a small quota

on the spawning grounds, which was a turning point. From 1987, the USSR was allocated quotas of about 10% of the total set by Norway, but allocated to the USSR in the Joint Norwegian–USSR Fisheries Commission. By the early 1990s, the spawning stock was increasing (ICES, 1999) and starting to migrate into the Norwegian Sea during the summer. Accordingly, the stock again became a "hot" issue in the new NEAFC. The organization had, in their annual meetings, always discussed the herring stock, but when it again appeared in international waters and more nations expressed an interest in it, NEAFC suddenly had to play a more active role. In 1995, an international scientific working group with participation from Iceland, Russia, the Faroe Islands, and Norway was established to assess the zonal attachment of Norwegian spring-spawning herring. A report from the group (Anon., 1995) was finished in 1995. On the basis of the results from the Working Group, NEAFC agreed in 1996 to set a TAC (total allowable catch) for the stock and to allocate this TAC among what was defined as five coastal states: Iceland, Faroe Islands, Russia, Norway, and the European Union. For 1997, NEAFC decided on an additional catch limit in international waters in the Norwegian Sea. The five coastal states that had made the agreement on the TAC, as well as Poland, were given the right to fish this extra quota. In 1999, these states agreed on a long-term management regime for Norwegian spring-spawning herring, with an implementation of the precautionary approach concept.

Discussion

Recently, it was shown that the Norwegian spring-spawning herring stock has had large, long-term fluctuations in size, which can be related to fluctuations in environmental factors (Toresen and Østvedt, 2000). The environmental factors affect recruitment either directly or indirectly by an influence on the prey or the predators of the herring larvae. The annual fishing mortality estimates by age group show that the fishery probably had minimal influence on the fluctuations in stock size prior to 1950. The spawning stock was in an increasing phase through the first 40 years of the century, and recruitment was good (Toresen and Østvedt, 2000). In 1945, the stock reached a high of 16 million t. From then on, however, the stock began to decrease in abundance, but still remained at or above 10 million t until 1958. The stock continued to decrease and, at the same time, a large increase in efficiency took place in the fishing operations through the introduction of the power block on the purse-seiners and better searching tools (i.e., sonar). The purse-seine fishery was then extended to the entire Norwegian Sea and could be conducted in rougher weather conditions. Consequently, the herring became available all year round. The profound change in searching techniques and fishing methods during these years made the fishing vessels so efficient that few scientists could evaluate the effect. This accelerated the decline of the stock. As shown in Table 2, the stock decline from 1953 to 1963 was already accurately estimated in 1961 (Dragesund and Jakobsson, 1963) and in 1964 by the Atlanto-Scandian Herring Working Group. When the Group was reconvened in 1969, it used the same methods as those used in its previous meeting in 1964 to estimate stock abundance for 1964–1968. The estimate for 1964 was identical to the most recent VPA estimate, while those for 1965–1968 were much higher than the VPA estimate. This difference has never been satisfactorily explained. The rate of decline shown by the last four Working Group stock estimates for 1965–1968 is comparable to that of the VPA results, although the absolute abundance estimates differ. Based on the reliability of the tagging and acoustic estimates from 1953–1964 as well as the contemporary survey results, it is concluded that one should also consider them reliable in 1965–1968. It has been pointed out (Jakobsson, 1980a, 1980b; Dragesund *et al.*, 1997) that the drastic changes in the distribution and migration pattern, which took place during 1964–1969 through the recruitment of the rich 1959 year class, began with the splitting of the stock into two components. This was followed by a collapse of the forage stocks in the traditional Iceland–Jan Mayen area, increased flow of cold Polar Water (Malmberg, 1969), and a rejoining of the two components of the stock following the adoption of a new migration pattern (2000–2500 nm/year). All of this occurred at the same time that the exploitation rate was rapidly increasing for all age groups in the stock. It is suggested here that the combined effect of all of these negative factors may have imposed additional stress on the stock, resulting in increased natural mortality and thus accelerating the complete collapse in 1968–1970.

The fishing mortality rate (F) on the adult stock (ages 5–14) during the period 1950–1961 had remained low at about 0.1 despite the increased efficiency of parts of the fishing fleet. However, through the years 1960–1965, the mean F (ages 5–14) was 0.20, based on the 1999 ICES VPA, while the 1969 Working Group estimate for the same period was 0.22. Thereafter, it escalated to very high levels (>1.0 in 1967 and 1968), based on the 1999 VPA, while, at the time, the fishing mortality was not assessed as being that high. The large increase in F through the years 1966–1968 was due to heavy fishing on the adult stock in Norwegian, Icelandic, and international waters.

Fishing mortality on the juveniles, and hence the effect of that fishery on recruitment, was extensively debated during the 1960s, while the stock was declining, and in the early 1970s, when the stock was already depleted. The detrimental effect of the large-scale juvenile fishery in the 1950s and its disastrous effect in the 1960s, when all recruitment to the adult stock was prevented, has, however, been generally accepted in retrospective analyses. As a result of the disagreement

amongst the scientists (Norwegians versus Soviets and Icelanders), strong advice on the juvenile fishery was delayed until 1970 when scientists from the three countries agreed to propose the 25-cm minimum landing size for herring. Even at that late date, the proposal was rejected by Norway, and this fishery continued until 1973, however, with restrictions.

Looking at this history retrospectively, could the collapse of the stock have been avoided? In the early 1960s, the herring scientists knew the stock was in a severe declining trend. However, there was no consensus in the scientific community as to the reason for this declining trend. Leading (Norwegian) scientists still claimed that the herring were not available because they were probably distributed in other areas, while others argued that the exploitation was too intense. At the time, the methods now used for stock analyses had not been developed. Even though tagging experiments had been carried out, scientists were uncertain of the total stock abundance because of uncertainties in the tagging mortality. At the time, doubts were expressed about the abundance estimation methods that were difficult to disprove. Traditionally, demersal stocks were overfished, while pelagic fish such as herring were considered inexhaustible. The severe decline in abundance of the herring stock in the late 1960s may also have been intensified by increased natural mortality. In the VPAs, the natural mortality (M) of adult herring is assumed constant at 0.15. As an example, a standing stock of whales in the Norwegian Sea through these years preying on the herring would have a much greater and more severe impact on the reduced herring stock (in the late 1960s) than earlier (higher M), and this would thus accelerate the decline in abundance. The Atlanto-Scandian Herring Working Group at the time (ICES, 1969) did not consider such ecological factors. This may (at least partly) explain why the scientists did not fully realize that the stock had actually collapsed until it was too late.

In the period 1975–1988, the stock was in a rebuilding phase, whereas in the mid-1970s, it was generally understood that the stock was nearly depleted. It was decided to aim at rebuilding the spawning stock to a level of 2.5 million t as soon as possible. This is the level which historically has been the biomass below which there is a reduced chance for good recruitment. The remaining part of the stock was, by then, distributed all year along the coast of Norway. The 10-year period from 1975 to 1985 was one of difficulties for Norwegian scientists and managers. The fishing industry in Norway had not quite understood the fact that the stock was depleted, and pressed hard, every year, to obtain quotas of herring to fish. The fishing industry found it difficult to accept the ICES advice of zero fishing and argued for the reopening of a fishery of a certain level. The leading Norwegian herring scientist at the time, Johannes Hamre, was of another view, and argued strongly for protection of the stock. The assessments in the ICES Working Group were also under development and time-series of abundance estimates were established. As a "compromise", it was agreed to restrict the fishing mortality rate to below 0.05 until the rebuilding aim for the spawning stock had been reached. The systematic surveying of pelagic fish, by means of acoustics, had only found scarce amounts of herring either on the spawning grounds or in the fjords along the west coast of Norway where they overwintered. The scientists were, therefore, convinced that the herring stock really was depleted. To confirm the status of the stock, the Institute of Marine Research in Bergen started tagging experiments in 1975. The first results from these investigations were presented to the Working Group on Atlanto-Scandian Herring in 1977 (ICES, 1978), and showed that the spawning stock was only at about 200 000 t. This result helped the managers in Norway to maintain the strict regulations that had been introduced earlier, i.e., the lowest catch possible and a minimum landing size of 25 cm.

In 1983, a very rich year class was produced representing the new area and the start of a new herring period. The stock soon increased to higher levels and produced new rich year classes in 1991 and 1992. However, as the stock increased in abundance, it also resumed the migrations to international waters for feeding. This called for international agreements between the coastal states of Norway, Iceland, Russia, and the Faroe Islands. The agreement was followed by the European Union, which also claimed fishing rights on the stock, and final agreement was reached in December 1996. The five parties meet annually to negotiate a TAC and their respective shares. They have agreed on a long-term management plan for the stock, the main elements of which include 1) not to exceed a fishing mortality rate of 0.125, 2) the acceptance of the precautionary limit of 5 million t of spawning-stock biomass (SSB), and 3) the acceptance of the limit reference point of 2.5 million t of SSB. Norway and Iceland wanted a catch limit of 1 million t, a position for which it was impossible to get approval. If the SSB should be assessed below 5 million t (precautionary SSB limit), the parties also agree to take further actions to prevent the stock from decreasing towards the lower limit 2.5 million t.

Summary

Norwegian spring-spawning herring underwent large stock-size fluctuations throughout the 20th century. These fluctuations were mainly natural, and it has been shown that the production in the stock varies significantly under the influence of environmental conditions (Toresen and Østvedt, 2000). At the end of the 19th century, stock size was low, as was the fishery. As the stock increased in abundance, the fishery also developed. The stock started to decrease in the 1940s, but the fisheries expanded even more, and there was a significant change

in the exploitation level during the 1960s. This happened at the same time that natural conditions were unfavourable for recruitment as well as for the feeding migrations of the adult stock. As a consequence of this expansion and a complete lack of recruitment due to natural and man-made causes, the stock collapsed. Even though ICES working groups had assessed the stock correctly, the state of knowledge on fishery assessment in the 1960s was insufficient to give firm advice and to limit the crisis. In the rebuilding phase throughout the 1970s, minimum size regulations were enforced to prevent the exploitation of small herring, and strict regulations on TACs were agreed. The countries which currently exploit this stock have agreed on a long-term management strategy with limitations of the exploitation level. However, the long-term natural stock-size fluctuations throughout the 20th century indicate that this stock probably will challenge scientists and managers again in the future.

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