https://doi.org/10.17895/ices.pub.19271168

ICES mar. Sci. Symp., 198: 17–30. 1994

Historic changes in cod stocks and cod fisheries: Northeast Arctic cod

Victor Øiestad

Øiestad, V. 1994. Historic changes in cod stocks and cod fisheries: Northeast Arctic cod. – ICES mar. Sci. Symp., 198: 17–30.

Observations made in Norwegian waters in this century have been used to interpret the fragmentary fishery and climate data from the period 1500 to 1900. During the Little Ice Age, lasting from about 1550 to 1850, the Northeast Arctic cod stock went through large fluctuations in stock size, as reflected in catch per unit of effort and in overall catch. Behind these fluctuations may have been faltering recruitment in periods with very cold climate and lack of herring or capelin in the Barents Sea, two main prey organisms, as both these species also experienced stock fluctuations. The potential detrimental influence of young herring on the capelin stock in the Barents Sea is also considered. The quantity of drift ice around Iceland is considered as an indicator of both the general climate influencing cod recruitment and of the productivity in the main summer-feeding area for Norwegian spring-spawning herring, northeast of Iceland. The deterioration of this area's productivity has coincided repeatedly with sudden collapses in the herring stock. In all cases, except after the fast decline in the 1960s, a recovery of the Bohuslän herring fishery followed these collapses. The fished quantities of cod and herring has increased almost 10-fold for every century during the Little Ice Age, from 5000 t of herring in the 1640s to 1.2 million tonnes in the 1950s; and from 10 000 t of cod in 1590 to 1.2 million tonnes in 1960s. These catch values may indicate an underexploitation of the cod and herring stock at least until the turn of the twentieth century.

Victor Øiestad: Norwegian College of Fishery Science, University of Tromsø, N-9037 Tromsø, Norway.

Introduction

The Northeast Arctic (NA) cod stock has been through a severe decline followed by a recent and sharp build-up (ICES, 1993). It is tempting to blame fishing for this type of decline and the restrictive actions of the regulation authorities for the recovery. This is only part of the picture, however, as a heavy blow also came from the ecosystem itself, and not for the first time (Jakobsen, 1992; Nakken, 1994). The recovery, on the other hand, is basically brought about by a number of strong year classes in a situation with significantly improved feeding conditions (ICES, 1992, 1993).

The NA cod stock is not the only one experiencing drastic changes. The Baltic cod stock went through an abrupt build-up from the late 1970s due probably to a shift in the hydrographic conditions promoting egg and larval survival. The decline from the mid-1980s has brought that cod stock back to a level more in line with that experienced throughout this century (Otterlind, 1984; Bagge and Thurow, 1994).

Even more peculiar was the increase of the West Greenland cod stock starting in about 1920 and culminating in about 1965 with a fished quantity of more than 400 000 t yearly during peak catches (Jensen, 1939; Buch and Hansen, 1988). A shift in the Northeast Atlantic current system, influencing the Irminger Current dominating that area, frequently raised the water temperature enough to dramatically improve the survival rate of cod eggs and larvae. A return to the previous current pattern in about 1960 sharply reduced recruitment and the foundation for the fishery eroded rapidly, similar to the situation experienced by the Norse settlements in medieval times (Grove, 1988).

The NA cod stock has been through a number of declines and recoveries in addition to the most recent one (Otterstad, 1960). One decline often commented on occurred at the turn of the century, when ICES was in its formative years and little was yet known about the reason behind fluctuations in fish stocks (Pettersson, 1905; Helland-Hansen and Nansen, 1909). An abortive recovery after that crisis was followed by an even deeper

decline; catches in Lofoten hit the lowest recorded values, i.e. since 1864 (Rollefsen, 1954). A lasting recovery started about 1925 and continued for more than 20 years until the stock reached a level of around 5 million tonnes about 1950 (Lee, 1949; Sætersdal and Hylen, 1964; ICES, 1993).

Detailed landing statistics concerning NA cod, including liver and roe, go back to 1864. There are fairly good records back to 1815, the year following the Norwegian breakaway from 400 years of Danish rule, but information before then is far more obscure and fragmented (Solhaug, 1976). Nevertheless, this paper deals mainly with that early period, back to about 1500.

Intensive fishery and oceanographic research during the last 100 years in Norwegian waters has elucidated inter- and intraspecific relationships, and underscored the influence of short- and long-term variations in ocean currents and water temperature on processes starting with the broodstock and leading on to the next generation. This knowledge will be used to throw light on old records. The main working hypotheses applied will be these:

- Strong year classes of cod are produced when above-normal water temperatures occur around Lofoten and the southwestern parts of the Barents Sea.
- Large populations of young Norwegian spring-spawning (NSS) herring, distributed in the Barents Sea on a regular basis, are a prerequisite for a strong build-up of the NA cod population.
- Strong year classes of young herring distributed in the Barents Sea may for a while severely reduce the recruitment of the capelin population in that region, and might cause one or more years with almost no spawning capelin along the Norwegian coast.
- Expansion of Arctic water with reduced salinity may severely reduce productivity within the summer-feeding areas for NSS herring northeast of Iceland for years, and this might contribute to and even cause severe declines in this herring stock.

The Norwegian cod fishery from 1500 to 1900

The main fish product exported from Norway for hundreds of years was dried cod[1] or stockfish, and the principal region for the production of stockfish was northern Norway. The main season for the spawning NA cod or *skrei* fishery off Nordland and Troms counties was during springtime, and for the young cod fishery in Finnmark in early summer, when the young cod followed the migration of spawning capelin. A minor and variable skrei fishery also took place off the Møre coast (62°N) at the same time as the one off Lofoten (Fig. 1). Cod prepared with salt ("klippfish") had a later introduction as an export article from Norway than in the competing Newfoundland cod fishery, which introduced salted and dried cod to Europe as early as about 1520 (Cushing, 1988).

Quantitative information about the cod fishery is available from about 1300 (Helle, 1967; Nedkvitne, 1978). In the aftermath of the Great Plague (Black death), dried cod was highly priced. During the fifteenth century there was a church-building boom in the main cod fishery districts in Norway, indicating solid income from the fishery to the Church as tithes (Kårstad, 1981). At the end of that century, debt in the region of Nordland began to increase simultaneously with the falling prices of dried cod (Nedkvitne, 1988). The special taxation introduced by the Danish king in 1522 taxed the fishery districts in North Norway at a rate two to three times higher than farmers in mid-Norway (Trøndelag), supporting the view that incomes from the cod fishery were still good (Dybdahl, 1971; Holmsen, 1975; Lunden, 1976; Kårstad, 1981; Nedkvitne, 1988). However, the exchange rate continued to erode in favour of grain, the main product the fishermen had to buy (Fig. 5c; Lindbekk, 1974a; Lunden, 1976; Nedkvitne, 1988).

In 1536, Norway changed from being Catholic to Lutheran. However, the church continued to receive income from tithes for the coming centuries. Information from the tithe paid as dried cod is one of the basic data available[2] about the quantity of cod caught (Nedkvitne, 1988). The other source of information is export data from Bergen and some other main fish-export ports (Dyrvik *et al.*, 1979; Fossen, 1979; Ertresvaag, 1982), including export quantities of other fish types. Although data are incomplete with respect to quantities and destinations, they give a general picture of the trade and the quantities landed and exported to Hanseatic cities on the continent and cities outside the Hansa monopoly in a number of European countries.

General overview of the cod fishery from 1570 to 1900

The production of stockfish during the sixteenth century has been calculated at about 120 000 våger (1 våg = 18.5 kg) per year, or about 10 000 t roundfish (based on data from 1567 and 1577; Dyrvik *et al.*, 1979). By the end of the century, exports doubled and continued to increase, with large annual variations, to 350 000 våger about 1650 or between 25 000 and 30 000 t of roundfish (Fig. 2a and Fig. 3). A lengthy decline followed, reaching less than 5000 t in the 1680s. The decline in the cod stock had started about 1660 in the southern cod district, off Møre (Dyrvik *et al.*, 1979). During the 1680s and 1690s almost every year was a failure in the fishery along most of the coast, as also in Icelandic and Faeroe waters (Lamb, 1979; Nedkvitne, 1988). The capelin cod-fishery off the

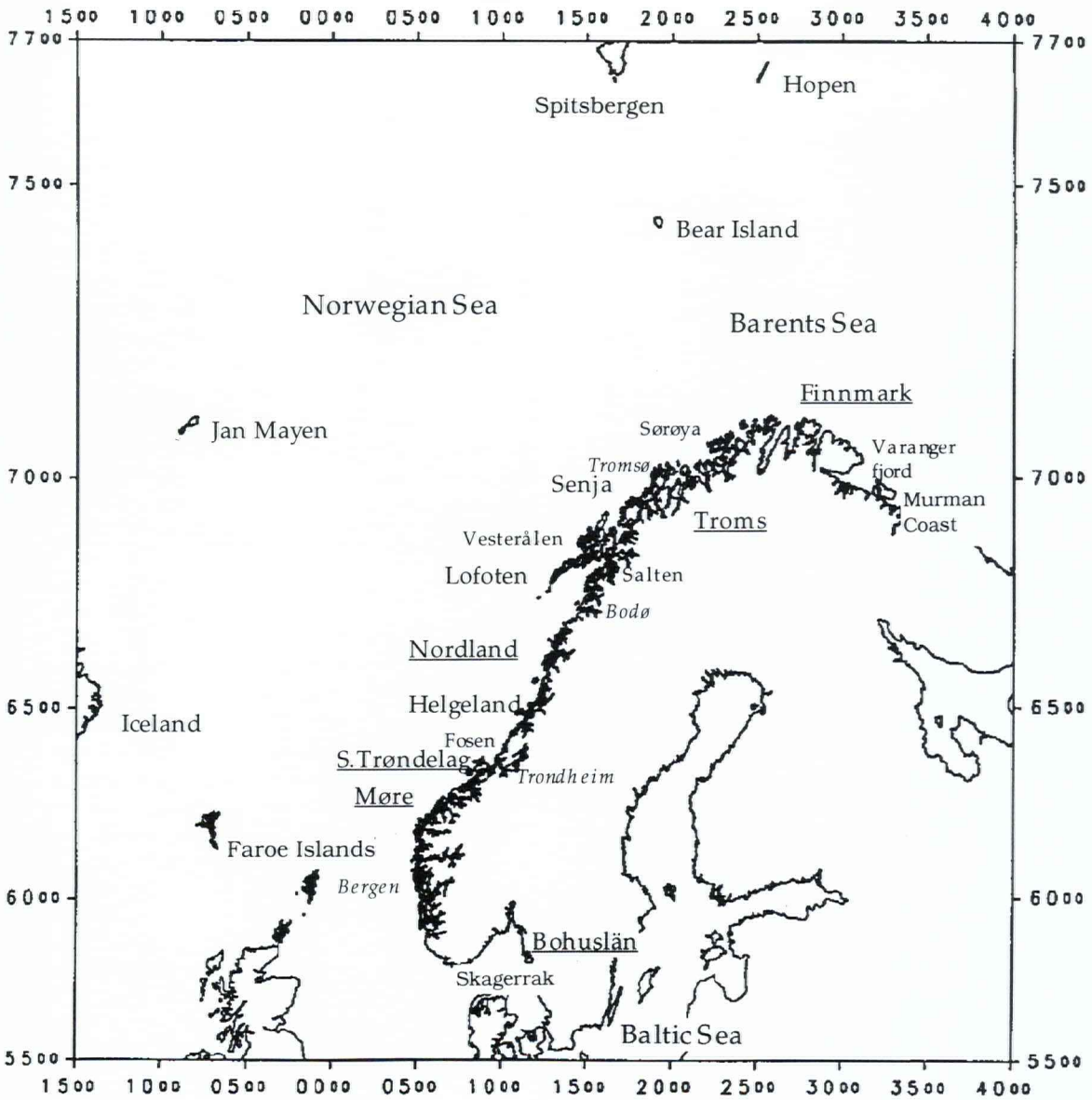

Figure 1. Geographical names used. Names of counties are underlined while cities are in italic.

coast of Finnmark, however, was reasonably good in the 1690s (Fossen, 1979; Nedkvitne, 1988).

The new century started off poorly, but a minor recovery in the cod fishery from 1713 was followed by a more significant recovery from the mid-1720s. During the crop failure of the 1740s, the fishery was good and improved even more in the 1750s (Fossen, 1979).

In about 1750, the export attained in 1650 was again reached, or even exceeded. Salted cod in barrels and, gradually from the mid-1700s, klippfish increased in importance as trading articles. After a new decline in about 1775 came a strong recovery, with an export in 1800 of more than 700 000 våger (i.e. about 60 000 t) roundfish. Of this, klippfish contributed an equivalent of about 14 000 t roundfish. The decline in export during the Napoleonic Wars (1807 to 1814) was partly caused by failure of the fishery in the Lofoten. This failure also hit the Møre skrei fishery from 1790 to about 1820, bringing to a stop a fishery that had been outstandingly good for some decades (Friele, 1877; Dyrvik *et al.*, 1979).

The high export level from 1800 was surpassed in 1825, but by about 1830 the cod fishery stabilized at about 75 000 t roundfish, remaining at this level for 15 years. A new period of expansion started about 1845,

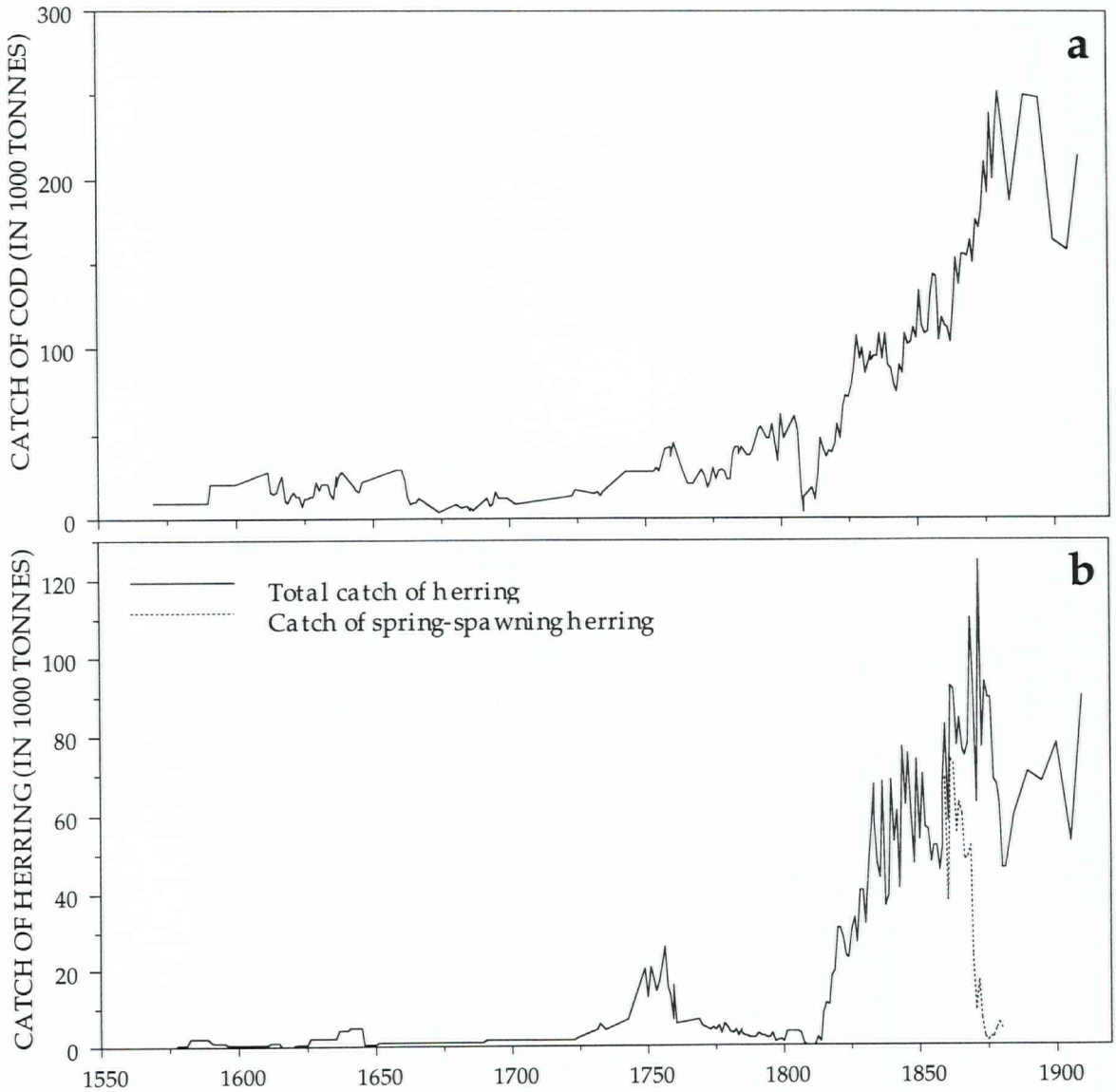

Figure 2. Landings in tonnes of NA cod (a) and herring (b); all types, but with catches of spring-spawning herring indicated for 1860 to 1880, hatched curve) along the west coast of Norway. From 1815 the values are the total for Norway; before that time the data are largely based on export records from Bergen, the main port of exportation. The cod data for 1610 to 1695 are based on tithe records from the Lofoten district adjusted to the level of export from Bergen in 1655. The cod records also include coastal cod catches and catches from the capelin-cod fishery (Dyrvik *et al.*, 1979; Fossen, 1979; Ertresvaag, 1982; Nedkvitne, 1988).

and catches reached a maximum of about 200 000 t roundfish during the 1890s (Fig. 2a). A new decline occurred at the turn of the century (Helland-Hansen and Nansen, 1909).

Stock size and availability

For centuries the skrei fishery was carried out by angling. The first change in the Lofoten region came with gillnets and long-line, from the 1790s (Dyrvik *et al.*, 1979). The dominance of angling makes it easier to compare the catch per unit of effort (c.p.u.e.) during most of the Little Ice Age.

A drawback with angling is that it does not operate well below 100–150 m. When a strong expansion of cold Baltic water dominates the Norwegian coastal current, the migrating and spawning skrei might be forced to stay deeper, becoming less available to angler fishery. A similar effect has been observed on spring-spawning herring (Soleim, 1940).

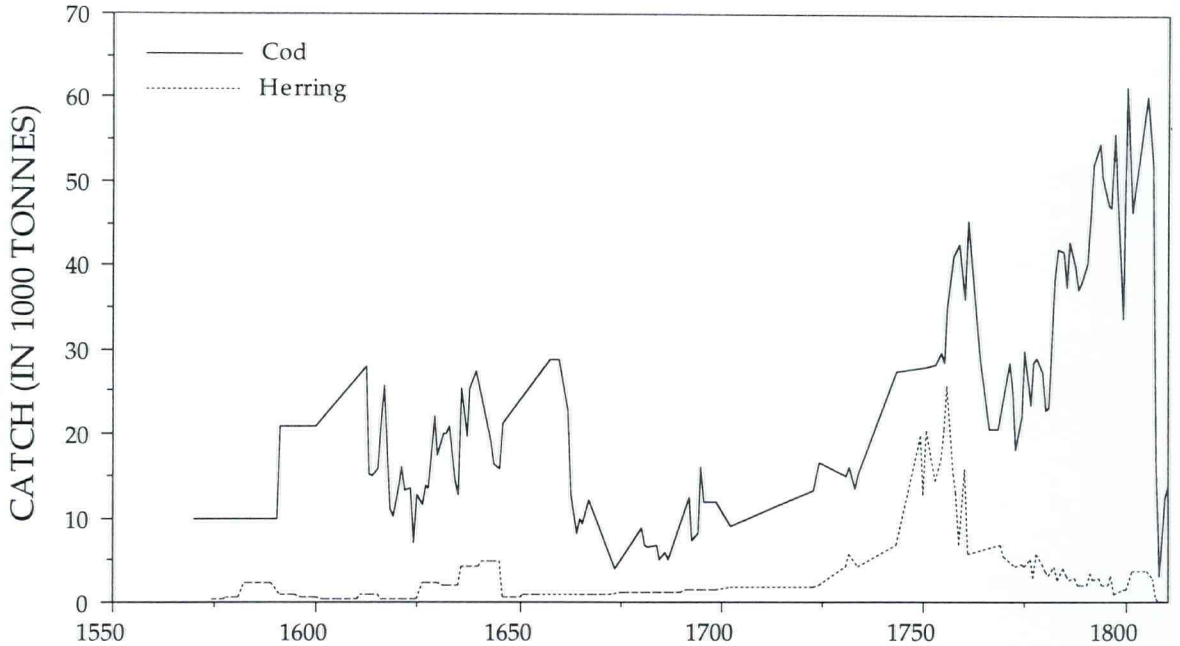

Figure 3. Landings in tonnes of NA cod (upper) and herring (lower; all types) along the west coast of Norway. The data are largely based on export records from Bergen, the main port of exportation. The cod data for 1610 to 1695 are based on tithe records from the Lofoten district adjusted to the level of export from Bergen in 1655. The cod records also include coastal cod catches and catches from the capelin-cod fishery (Dyrvik *et al.*, 1979; Fossen, 1979; Ertresvaag, 1982; Nedkvitne, 1988).

What was the size of the NA cod stock during the Little Ice Age? Did the fishery reflect its size? About 1590, a good fishery season could yield 1300 cod per fisherman, but the normal catch would be 600 to 700 cod, or about 30–40 våger, per fisherman (Dyrvik *et al.*, 1979; Nedkvitne, 1988). Similar mean values (500–1200 cod) were typical for the Lofoten region for centuries until 1925 (Rollefsen, 1954). Improved equipment and better fishing boats did not dramatically improve c.p.u.e. during this long period.[3]

Some of the annual variation was caused by weather conditions during the fishery season and also by the cod being mainly west or east of the Lofoten islands (Nedkvitne, 1988). However, these conditions would not bring about long-lasting trends in the catches; rather, they represented noise within periods of normal, above normal, or below normal catches.

Catches as low as 2–10 våger (40–200 kg) per fisherman after two to three months' effort, and with similar results for about 20 years throughout the Lofoten region, as reported during the 1680s and 1690s, might reflect a cod stock at an alarmingly low level (Nedkvitne, 1988).

The motivation for participation in the skrei fishery was very strong, as most fishermen needed the income to survive. Nevertheless, during prolonged periods of crisis in the fishery, participation would decline if alternative work existed or if the credit system was unwilling to risk further credit[4] (Lindbekk, 1974b; Nedkvitne, 1988). This might have been the case in the 1690s. Variations in the market might also have influenced the quantities caught.

The c.p.u.e. had a range of 1:7 within the timespan from 1864 to 1925, and this might indicate the range in abundance of skrei within that period (Rollefsen, 1954). C.p.u.e. information from the 1600s indicates a somewhat wider range during that century, perhaps about 1:10. The reported range of the tithes in the county of Nordland had values of 1:7 (Lofoten), 1:5 (Steigen), and 1:9 (Bodø), (Fig. 4). These values are within the same range as the abundance variation of NA cod after 1950, which has been about 1:7 (ICES, 1993). In the same timespan the spawning stock has had a range of 1:8, with a maximum of about 1.2 million tonnes in 1959 and a minimum of 150 000 t in 1988 (Nilssen *et al.*, 1994).

The variation in level of tithes at the Faroe Islands was 1:7 from 1584 to 1652 (a total of 39 annual tithe values preserved), if the mean values of the five smallest and largest tithes reported are compared (Zachariassen, 1959). Highest values were reported from 1613 to 1624, with very low values about 1630.

In conclusion, there is reason to believe that the main pattern of variation in catches reflected the true variations in the cod abundance.

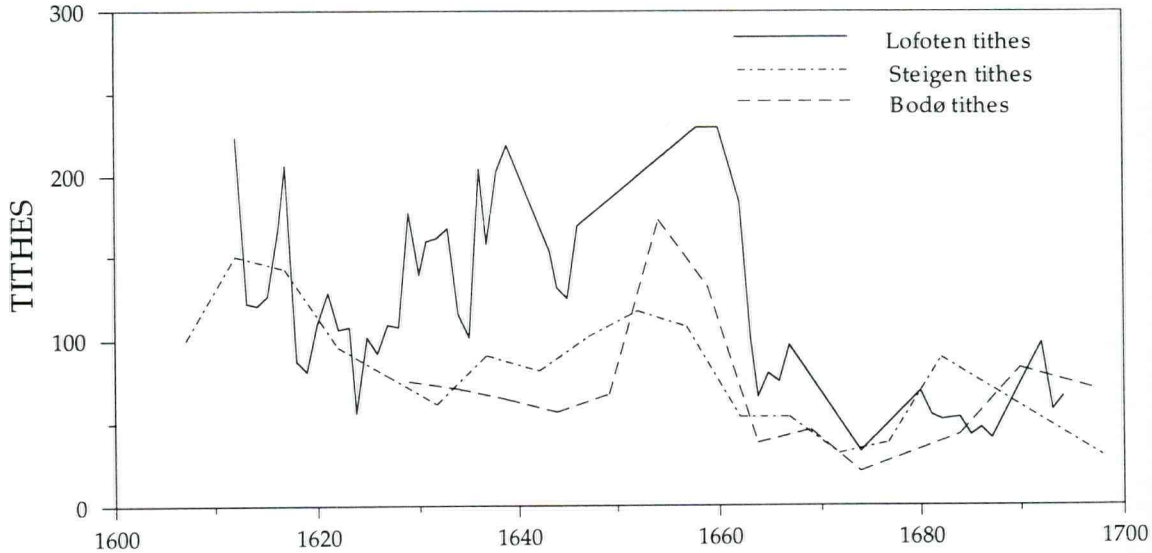

Figure 4. Relative tithe values from three locations in northern Norway to illustrate the common tendency in the fishery of low catches after the 1660s. The records from Lofoten have been divided by five (Aarsæther, 1981; Nedkvitne, 1988).

It is more difficult, however, to say anything about the *absolute* stock size around which these variations took place throughout these 300 years. The modest increase in c.p.u.e. from 1864 to 1925 might indicate that no significant increase in overall stock size took place in that timespan (Rollefsen, 1954). Furthermore, the similarity in c.p.u.e. between short periods during the 1600s, with typically high catch and c.p.u.e. values, and the late 1800s might suggest that the general level of the cod stock could have been similar for some hundred years. The huge increase in landings during the 1800s and 1900s thus being mainly a result of sharply increased fishing effort.

The pattern of participation in the fishery and demographic data

After the Great Plague, the increase in the Norwegian population was greatest in coastal areas with easy access to fishery resources (Aarsæther, 1980), while many former agricultural districts went into lasting decline. The reason for this preference could have been the high price paid for dried cod. Gradually, the price dropped; the turning-point came in about 1570, when the fish:grain price relationship became just as unfavourable as it was before the Great Plague, when 90 kg dry cod was needed to buy grain for one person's yearly need (Fig. 5c; Nedkvitne, 1988). At the same time, the population growth increased faster inland in agricultural districts, fishing villages in particular becoming depopulated (Fig. 5a; Lindbekk, 1974b; Aarsæther, 1980).

In many parts of northern Norway the population declined during the seventeenth century, partly due to periods of failed fishery, but also to repeated crop failure (Fig. 5a, c; Aarsæther, 1980). The combination of fishing and agriculture was the foundation for settlement along most of the Norwegian coast until recently (Lunden, 1976; Nedkvitne, 1988). In the northern district for skrei fishery, Senja, a new decline swept the area as people migrated inland or south (Fig. 5a; Lindbekk, 1974b). The severe living conditions are also reflected in the taxes in the seventeenth century, which declined in northern Norway relative to the rest of the country (Fig. 5b). The taxation per capita declined from 200% to 50% of the taxation level of farmers in Trøndelag from 1574 to 1647 (Lunden, 1976; Fladby, 1978).

Severe periods of famine, as in the 1690s and 1740s, might have led to the abnormal socio-economic reactions described by Petter Dass (1989)[5] (Fig. 5c; Olafsen, 1914). The long-lasting crisis in the cod fishery in the 1680s and 1690s resulted in a deterioration of the infrastructure supporting the fishery.

Recruitment in a colder ocean

The Little Ice Age was in general a lengthy period of low temperature, but also with more severe storms and more precipitation (Lamb, 1979). Its duration is still disputed, but 1550 to 1850 is a generally agreed estimate (Grove, 1988). The temperature record deduced for Iceland during the last 1000 years clearly emphasizes the Little Ice Age (Fig. 6b; Bergthórsson, 1969; Bryson, 1974). Glaciers advanced in the Alps, on Iceland, and in Norway (Grove, 1988). The cold conditions lasted to the

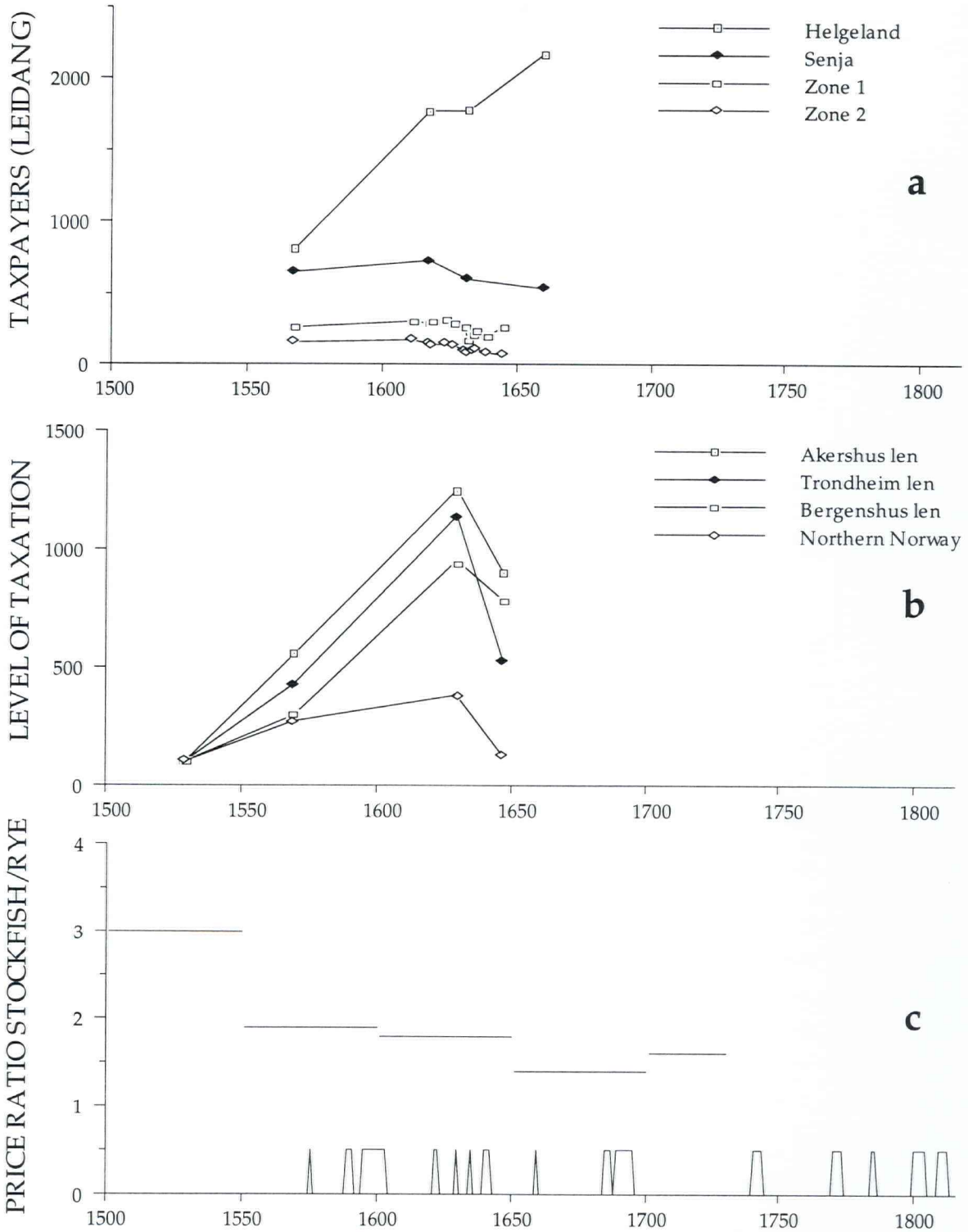

Figure 5. Comparison between a fishery district (Senja) and an agricultural district (Helgeland) to illustrate the changes in settlement preference during the 1600s. Within the Senja region there was a similar pattern recorded as that shown for zone 1 dominated by agriculture and zone 2 dominated by fishery (a; Kårstad, 1981); the shift in taxation level (set to 100 in 1530) in northern Norway during the 1500s and until the mid-1600s compared with the three regions in southern Norway; the depression in northern Norway is obvious (b; Lunden, 1976; Fladby, 1978); years with famine in Norway (c, indicated by peaks along the axis; Olafsen, 1914) and the relative mean price level between stockfish and rye (1 kg to 1 kg) during five time intervals (c, horizontal lines; Nedkvitne, 1988).

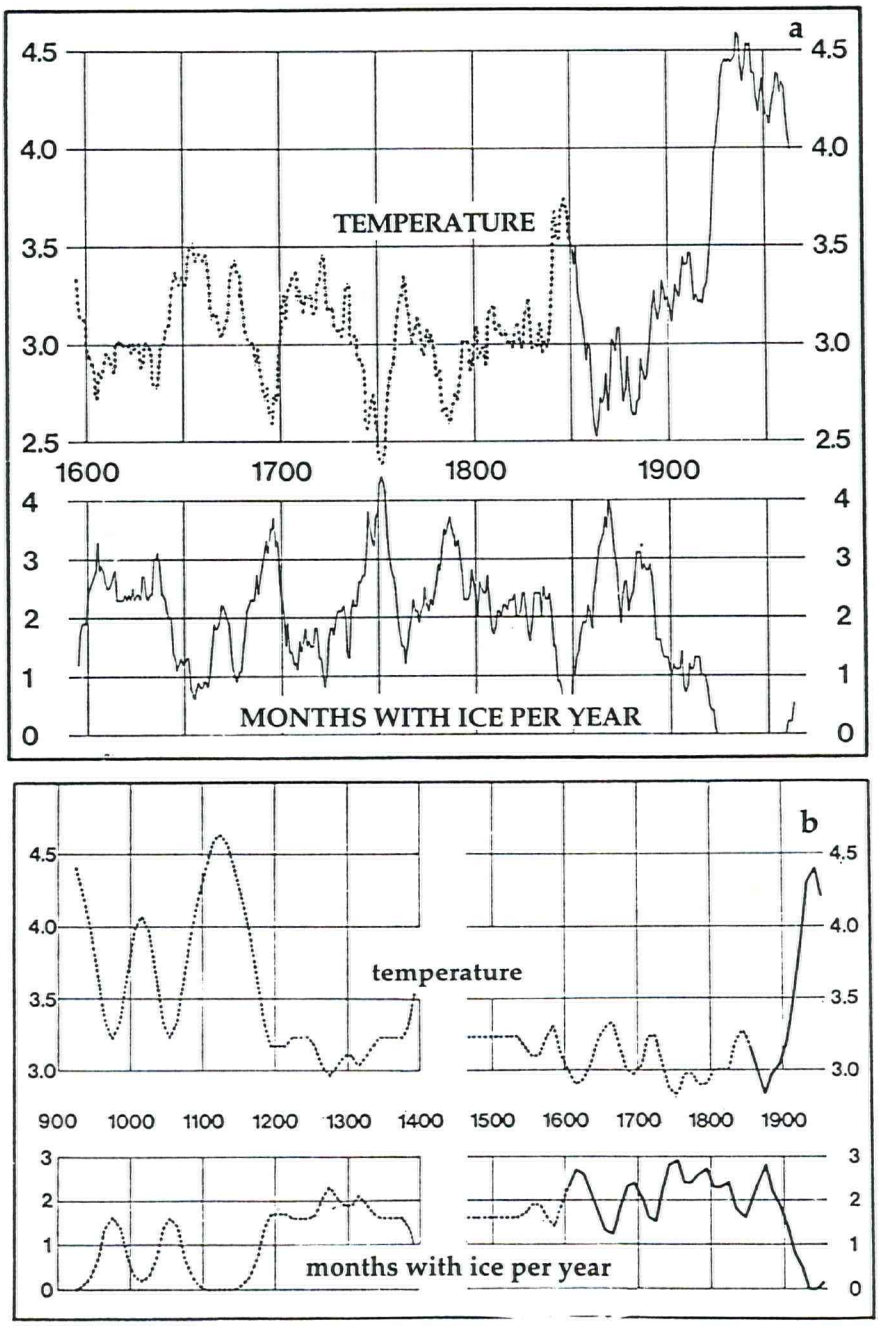

Figure 6. Decadal running means of temperature (top: a) and of ice incidence in months per year (bottom: a) from 1600 to 1950 and running 30-year means of temperature (top: b) and of ice incidence in months per year (bottom: b) from 900 to 1950. Estimated values are presented as dotted curves (Bergthórsson, 1969).

end of the nineteenth century, although episodes of warm summers and winters occurred (Lamb, 1979). The worst period was probably from 1675 to 1704, culminating in 1695, when the drift ice around Iceland reached the Faroes. During this period the sea temperature might have been 4–5°C below the normal for Faroe waters (Lamb, 1979).

There was almost no drift ice off the coast of Iceland from 1920 to 1965 (Fig. 6a; Bergthórsson, 1969; Grove, 1988). This period generally has temperatures above the

mean for 1900–1990 at the Kola section in the Barents Sea (Loeng, 1989). In the period there was a number of strong and medium-strong year classes of cod and herring, often with concurrently strong year classes for the two species (Sætersdal and Loeng, 1987). There seems to be a connection between climate in the Barents Sea and the Icelandic Sea due to the influence from the atmospheric pressure over the Arctic and the wind pattern dictated by the position of the anticyclonic centre (Hill and Jones, 1990; Jónsson, 1994).

In this century, strong year classes of NA cod have been produced only in years with above normal sea temperature in Lofoten and the Western Barents Sea (Ellertsen *et al.*, 1989; Ottersen *et al.*, 1994). Most of the Little Ice Age probably had temperatures below the normal for this century, thus probably resulting in predominantly weak or average strength year classes. Almost total failure might also have occurred, and might have caused the sharp stock decline in the 1680s. However, during the 1690s the capelin cod fishery in Finnmark was good, possibly indicative of a steady recruitment at that time. The relative importance of coastal cod increased during this period, and partly compensated for the decline in the skrei fishery, particularly off the Møre coast, through a coastal bank fishery for cod (Nedkvitne, 1988).

Based on the detailed information on ice around Iceland, there seems to have been a mild period from 1640 to 1670 (Fig. 6a) during which there was one of the best cod fisheries during the Little Ice Age. There was also a mild period from 1720 to 1740 and another from 1840 to 1865 (Grove, 1988) and in both these periods, too, cod recovered markedly. During the lasting mild period from 1920 to 1965, the fishery for NA cod increased from 150 000 t to 1.2 million tonnes (Bergstad *et al.*, 1987). Thus, cod recruitment may have improved during all these mild periods.[6]

The Norwegian herring fishery since 1520

The first fishery reported on spring-spawning herring started about 1520 (Nedkvitne, 1988) and came to an abrupt end in 1564. For about 100 years there was no spring-spawning herring fishery until the next started in 1656 and lasted for a few decades, contributing only very modest catches (Figs. 2b and 3).

A new recovery started in 1698 in the Bergen region, heralding the beginning of a significant fishery for spring-spawning herring in addition to a fat-herring fishery (Boeck, 1871). The best period was from 1749 to 1760 (Figs. 2b and 3). The fishery then declined sharply: from 1784 no spring-spawning herring were caught. Recovery started in 1808 when the spring-spawning herring suddenly showed up off the Norwegian coast and disappeared from Bohuslän (Fig. 7; Boeck, 1871). It culminated in 1872 with 130 000 t, but the contribution from spring-spawning herring that year was only 20 000 t; 1872 was the last year with more than 10 000 t of that herring type for 30 years (Solhaug, 1976).

The NSS herring fishery in Norway has been characterized by "herring periods". The herring fishery in Bohuslän normally evolves about the time the fishery terminates in Norway, and the former arose, according to Devold (1959), as a result of immigrants from the vanishing Norwegian population (Fig. 7; Ljungman, 1882; Pettersson, 1922).

The collapse of the herring population during the 1960s coincided with a severe decline in the production of phytoplankton and zooplankton in the traditional summer-feeding area for herring in the polar front northeast of Iceland, a decline caused by an expansion of polar water covering this area (Malmberg, 1988). A similar situation was observed in the same area at about the same time as the herring vanished in 1873; the

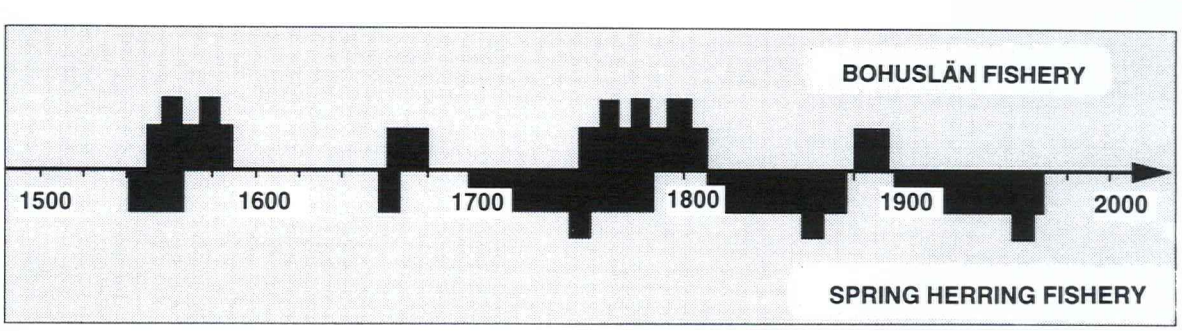

Figure 7. Herring periods off the coat of Bohuslän (above line) and the Norwegian coast; only periods with occurrence of Norwegian spring-spawning herring have been indicated. Culminations are indicated by peaks (Boeck, 1871; Ljungman, 1882; Pettersson, 1922).

Norwegian expedition northeast of Iceland in 1876 with RV "Vøringen" reported greenish water with no zooplankton, although Sars knew from numerous whaling reports that in these waters the ocean normally changed colour owing to the huge quantity of *Calanus finmarchicus* (Sars, 1879a). In general, the period from 1855 to 1902 was characterized by large quantities of drift ice (Fig. 6a; Lamb, 1979; Grove, 1988).

Although historic records from this summer-feeding area are fragmentary, there is strong reason to believe that this area was unsuitable for sustaining the feeding pressure from a large herring population during the very cold period from 1680 to 1710; during the 1780s with severe outbursts of polar water until 1820, and, from the early 1960s, when outbursts of polar water caused unfavourable conditions for production of food for the herring (Lamb, 1979; Malmberg, 1988). The situation back in the 1560s is more obscure, but in 1577 the Atlantic current had already shifted southward, initiating the Little Ice Age (Lamb, 1979).

The capelin cod fishery since the seventeenth century

The cod fishery along the coast of Finnmark has long traditions. It is known, for example, that the taxes paid by the fishermen in Finnmark in 1522 were twice those paid by farmers in Trøndelag (Dybdahl, 1971). In the late 1620s and lasting almost 20 years, this fishery went into crisis (ICES, 1890).

During the eighteenth century new collapses in the young-cod fishery took place, with the longest period said to have lasted for 15 years (ICES, 1890).

The next identifiable decline in the capelin–cod fishery is from about 1830, lasting for almost 15 years (ICES, 1890). The situation was similar off the Murman coast (Sars, 1879b).[7] Recovery started about 1840, but there was no significant fishery until after 1845; it then paralleled an improved fishery in Lofoten lasting until 1895 (Fig. 2a; Rollefsen, 1954; Solhaug, 1976).

Linking indices

The recent recovery of the NA cod stock has firmly demonstrated the tremendous ability of this species to expand in number and accelerate in growth when conditions are favourable. Similar shifts have been repeated over and over again, although none has been recorded in such detail as the one unfolding just now. The driving forces seem to be mainly three: a sharp decrease in fishing mortality since 1988 (Garrod and Schumacher, 1994); above-normal sea temperature since 1989, which may result in strong year classes (Sætersdal and Loeng, 1987; ICES, 1993); and an easy access to young herring as a surplus food supply. At present, about 4 million tonnes of young herring are distributed throughout the Barents Sea. These three factors may outweigh other forces, which then contribute only as minor adjustments.[8]

Higher temperatures are normally accompanied by a stronger flux of Atlantic water into the Barents Sea, leading to an expansion of the area occupied by cod (Jensen, 1939; Lee, 1949; Loeng, 1989; Øiestad, 1990). The higher inflow may also increase the supply of advected food resources, such as *C. finmarchicus* and krill species, especially *Meganyctiphanes norvegica*, and ensure a wider distribution of other food items such as shrimps (*Pandalus borealis*) and, most importantly, young-of-the-year herring (Ponomarenko, 1973; Berenboim and Lysy, 1987).

The cod–herring food web

In what way has the herring contributed as food for NA cod during the Little Ice Age?[9] The spring-herring fishery begun in 1697 reflects the increased availability of all types of herring as food for cod. This availability might have contributed to the recovery of the cod population, which must have been dramatically low during the 1680s and 1690s, when the c.p.u.e. dropped to 10–20% of the value for the best period of the seventeenth century. A strong recovery of the herring stock from the mid-1730s coincided with a strong build-up of the cod population.

In many respects, the fish resource situation in the 1700s had many parallels with this century, with an initial recovery of cod about 1710, stagnation until 1720, followed by a strengthened recovery during the 1720s and 1730s; a particularly good cod fishery in the 1750s and 1760s; decline during the 1770s and poor results in the 1780s. In parallel, the herring population was strong and increasing during the 1750s and 1760s, followed by a decline and final termination of spring-spawning activity along the Norwegian coast in 1784, although this had been negligible since the mid-1750s. During the 1790s there was a new and strong recovery of the cod fishery in the Lofoten region.

At the end of the eighteenth century, the Norwegian fishery in general was restricted to springtime and to the Lofoten region, as the cod fishing took place only in northern Norway with the herring fishery being insignificant everywhere.

The strong recovery of cod after 1845 was paralleled by a very stable capelin–cod fishery off the coast of Finnmark, indicating minor disturbance of the capelin stock by young herring in the Barents Sea. However, earlier, a report exists about herring in the Barents Sea in the 1830s, although no commercial herring fishery took place in northern Norway in that century before

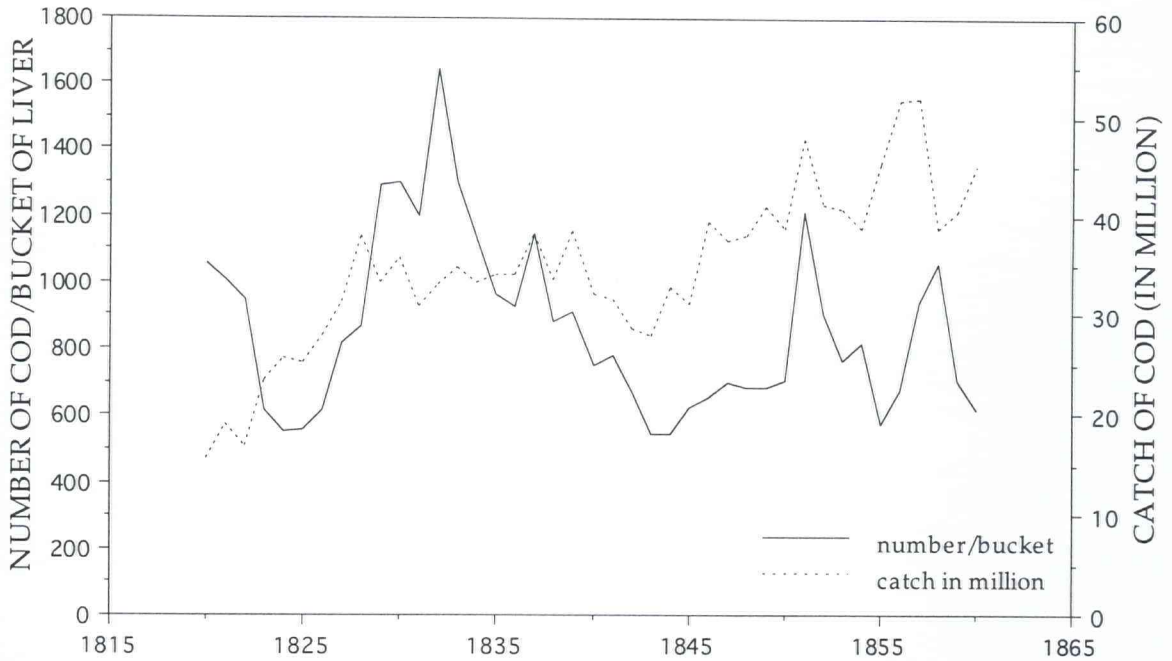

Figure 8. Liver index of the NA cod from 1820 to 1860 expressed as number of cod needed to fill one bucket. The number of cod caught in millions is indicated by a hatched line (Solhaug, 1976).

1850 (ICES, 1890). The strong recovery of the spring-spawning herring in the late 1820s, leading to a record fishery of herring in the 1830s, might have caused a collapse in the capelin population for more than ten years. The extremely small quantity of cod liver per cod from 1828 to 1842 indicates a prolonged food shortage in the Barents Sea (Fig. 8). The situation might have been similar to that observed in the Barents Sea from 1983 on: a single strong year class of young herring might have preyed heavily on the originally large population of capelin larvae in 1984 and 1985 drifting eastward through the area of distribution of young herring. Repeated lack of recruitment resulted in a collapse of the capelin population[10] (Hamre, 1991; Fossum, 1992). The 1983 year class of herring left the Barents Sea during early summer 1986, before it had contributed significantly as food for the cod (Røttingen, 1990a). The Barents Sea was left without any pelagic fish as food for the very numerous cod population (Nakken, 1994). Spawning cod "without roe and liver" was reported in the Lofoten in 1987 just as it was in 1832.[11] In the late 1820s and 1830s, a parallel to the 1983 situation might have occurred twice or even more often, causing the long-lasting decline in the stock of capelin, contributing to the low cod liver index, lasting from 1828 to 1842, and further contributing to a 20-year stagnation in cod catches (Figs. 2a, 7). A repetition of the 1983 situation is observed in 1993, but with a number of year classes of young herring staying in the Barents Sea, serving as food for a numerous and fast-growing cod population (ICES, 1993; Nilssen *et al.*, 1994).

The pulsing of the NA cod stock may be a delayed reflex of the pulsing in the herring population (Figs. 2a, b). This seems to be less clear during 1875 to 1890, a period with no known herring spawning in Norwegian waters, but with a very strong fat-herring fishery along the Norwegian coast. These immature herring most likely originated from spawning somewhere in the North Sea (Runnstrøm, 1935). The collapse of the Bohuslän herring fishery from 1896 was assumed to be the result of a change in current system in the North Sea (Pettersson, 1905, 1922). This change might have reduced the quantity of new recruits of herring being advected to Norwegian coastal waters, as the decline in the cod population was very sharp from 1895 to 1900: the number of spawning cod caught in the Lofoten district in 1900 was less than 25% of the number caught in 1895 (Helland-Hansen and Nansen, 1909).

The herring period initiated by the exceptionally strong 1904 herring year class may have contributed to a first modest recovery of the cod population. As no new strong year classes of herring occurred in the wake of the 1904 year class, the enhancement effect from that year class faded out about 1910, when all fat-herring had been recruited to the spawning stock, a stock with unknown summer-feeding areas and wintering locations, but with

a potential distribution out of range of the NA cod stock. Strong year classes of herring in the late 1910s provided a firm foundation for the observed recovery of the cod population after a new catastrophically low catch in 1920.

The impact on the NA cod stock from temperature and from availability of herring as food needs to be further elaborated. The interpretation given here may have given too much attention to the effect of herring on the NA cod stock, as capelin has been the dominating prey organism for decades (Nilssen *et al.*, 1994). Further examination with more data might highlight the modulating effects on both recruitment and growth from large-scale fluctuations in the two pelagic fish stocks and temperature.

The enormous increases in catches of herring, with typical values of 2000 t in the seventeenth century and 1 million tonnes in the twentieth century, might partly be due to lesser predation pressure from marine mammals. The parallel increase in the cod catches, from 10 000 t in 1590 to 1.2 million tonnes in 1965, might thus indirectly have been caused partly by the decline in carnivorous marine mammals. This trophic network needs further examination (Bax *et al.*, 1989).

Concluding remarks

Available information from the Little Ice Age has been scrutinized in relation to the four working hypotheses put forward in the Introduction. Severe declines of the NA cod stock took place in periods with particularly hostile climate (1) or when the food supply was deteriorating (2); declines in the capelin–cod fishery have occurred, but not necessarily in conjunction with strong recruitment of herring (3); there is strong support for the necessity of the summer-feeding area northeast of Iceland maintaining a strong NSS herring (4).

Most old records are only indicative in their support of the four hypotheses and not conclusive. Future work within this field should profit from the participation of a number of disciplines. This is not a new idea.

The collapse of the spring-spawning herring fishery in 1872 and the parallel recovery of the Bohuslän herring fishery gave rise to much speculation and led to international oceanographic studies in the Skagerrak–Kattegat. It also fostered a genuine interest in old records as a potential source of understanding this peculiar shift in herring fishery (Boeck, 1871; Ljungman, 1882). The Swedish fishery biologist Ljungman (1882) recommended close cooperation between historians and biologists, with historians going through old records under the supervision of biologists. Sars (1879a) suggested the same, but did not expect as much from historic studies as from new field studies.

Significant information on climate and fisheries may still be available from old books such as logbooks of British and Netherlands whaling vessels crossing the Northeast Atlantic from about 1620 to the end of the nineteenth century (Lamb, 1979). Records from Russian sources might soon be available from the same period. The close cooperation between historians and biologists suggested by Ljungman (1882) and Lamb (1979) might be more fruitful today than ever.

Notes

1. Dried cod had a weight of 24% of its round weight and a calorific content of 333 cal g^{-1} compared with 222 cal g^{-1} for salted herring, which had a higher water content (Nedkvitne, 1988).
2. The tithe was calculated when the fish were taken down from the drying rack; for that reason its value accurately reflects the total catch for each main centre of fishing. The method of calculation was stable for the fifteenth and sixteenth centuries, after which this source of information is almost lost because of changes in the taxation system (Nedkvitne, 1988).
3. Detailed information on c.p.u.e. is only available after 1864.
4. Most fishermen were dependent on a specific fishmonger who sold him the needed equipment and other supply on credit in advance of the fishing season. The fishermen were forced by law to sell their catches to the same fishmonger (Nedkvitne, 1988).
5. "The Sea withholds its wealth, before for a year, but now for ten; tumbledown sheds shivered in the cold rain; strong wind brought down the empty cod-drying racks; no vessels, no boats, no sails, no masts; as was the land all desolated", a poem from about 1695 describing the situation at the main fishing harbour, Vågan, in the Lofoten region (first published in 1739; translated for this report by Øiestad).
6. During the warm period in the 1930s, eggs and larvae of cod and haddock were registered on the Bear Island Bank, indicating that some spawning had taken place that far north (Iversen, 1933).
7. Sars got this information from Nordvie, who got it from a Russian publication by Danilewsky on the Murman fishery.
8. Helland-Hansen and Nansen (1909) postulated better recruitment in years with *below*-normal temperature, but they had a short time series from 1899 to 1906 and based their postulate on the quantities of roe and liver: lesser quantities in years with higher temperature.
9. The Norwegian scientist G. O. Sars (1879a) commented on the cod–herring food web in his report to the government, saying: "If the Norwegian Sea did not have the enormous quantities of herring, it would probably not be able to support the huge stock of cod embodying these waters. The richness of carnivorous fish species is dependent upon the abundance of the oceanic herring."
10. Strong year classes of herring might have caused repeated declines in the capelin population following the 1937, 1950, and 1959 year classes (Olsen, 1968). Better described is the decline of the capelin stock following the 1983 outburst of herring and the recent decline of the capelin stock following the 1991, 1992, and 1993 year classes of herring (Røttingen, 1990a, 1990b; Fossum, 1992). Perhaps we will ex-

perience a long-lasting decline of the capelin stock, like the one observed from 1826 to 1840, unless considerably spawning takes place east of the main young herring distribution in the southeast Barents Sea (Olsen, 1968; Hamre, 1991).

11. Also the quantity of roe was exceptionally low in 1832 (Solhaug, 1976). A similar situation was also observed in 1903 when the index for both liver and roe dropped dramatically from a high level in 1900 (Helland-Hansen and Nansen, 1909).

References

Aarsæther, R. 1980. Værmenn, fiskere, bønder og fiskerbønder. Nord-norsk bosettingsutvikling fra høymiddelalderen til begynnelsen av det 17. århundre (The dynamics of settlement in Norway from the Middle Ages to the early 17th Century) (in Norwegian). Heimen, 18: 406–426.

Aarsæther, R. 1981. Bosettingsutvikling i Salten fjerding fra høymiddelalderen til ca. 1660 (Pattern of inhabitation in Salten county from late Middle Age to 1660) (in Norwegian). *In* Seinmiddelalder i norske bygder, pp. 394–432. Ed. by N. Bjørgo, R. Fladby, K. Helle and J. Sandnes. Universitets forlaget, Oslo. 489 pp.

Bagge, O., and Thurow, F. 1994. The Baltic cod stock: fluctuations and possible causes. ICES mar. Sci. Symp., 198: 254–268.

Bax, N. J., Mehl, S., Godø, O. R., and Sunnanå, K. 1989. Transparent multispeciesanalysis. An exploration of fisheries and survey data off the Norwegian coast and Barents Sea. ICES CM 1989, MSM/Poster 18.

Berenboim, B. I., and Lysy, A. Y. 1987. Effects of oceanographic factors on populational structure of shrimp (*Pandalus borealis* Krøyer) in the Barents Sea and Spitzbergen area. *In* The effect of oceanographic conditions on distribution and population dynamics of commercial fish stocks in the Barents Sea, pp. 243–250. Ed. by H. Loeng. Institute of Marine Research, Bergen. 250 pp.

Bergstad, O. A., Jørgensen, T., and Dragesund, O. 1987. Life history and ecology of the gadoid resources of the Barents Sea. Fish. Res., 5: 119–161.

Bergthórsson, P. 1969. An estimate of drift ice and temperature in Iceland in 1000 years. Jøkull, 19: 94–101.

Boeck, A. 1871. The norske Vaarsildfiske. Silden og sildefiskerierne (The Norwegian spring-spawning herring fishery. The herring and the herring fishery) (in Norwegian). Det Kgl. Departement for det Indre, Christiania. 136 pp.

Bryson, R. A. 1974. A perspective on climatic change. Science, 184: 753–760.

Buch, E., and Hansen, H. H. 1988. Climate and cod fishery at West Greenland. *In* Long-term changes in marine fish populations, pp. 345–364. Ed. by T. Wyatt and M. G. Larrañeta. Instituto de Investigaciones marinas de Vigo, Vigo, Spain. 554 pp.

Cushing, D. H. 1988. The Northwest Atlantic cod fishery. *In* Long-term changes in marine fish populations, pp. 83–94. Ed. by T. Wyatt and M. G. Larrañeta. Instituto de Investigaciones marinas de Vigo, Vigo, Spain. 554 pp.

Dass, P. 1989. Nordlands Trompet. Stenersen forlag, Oslo. 143 pp.

Devold, F. 1959. Otto Petterssons teori om de skandinaviske sildeperioder sett i sammenheng med de senere års undersøkelser over den atlanto-skandiske sild (Otto Petterssons theory on herring periods in Scandinavia related to recent investigations on the Atlanto-Scandian herring stock) (in Norwegian). Naturen, 160: 83–92.

Dybdahl, A. 1971. Tiendpenningskatten 1521/22 som kilde for vurdering av bosetning og folketall i Nord-Norge (The 1521/22 taxation as a source of information about pattern of inhabitation and population size in Northern Norway) (in Norwegian). Heimen, 15: 299–311.

Dyrvik, S., Fossen, A. B., Grønlie, T., Hovland, E., Nordvik, H., and Tveite, S. 1979. Norsk økonomisk historie 1500–1970. Vol. 1. Universitets forlaget, Oslo. 271 pp.

Ellertsen, B., Fossum, P., Solemdal, P., and Sundby, S. 1989. Relation between temperature and survival of eggs and first-feeding larvae of Northeast Arctic cod (*Gadus morhua* L.). Rapp. P.-v. Réun. Cons. int. Explor. Mer, 191: 209–219.

Ertresvaag, E. 1982. Bergen bys historie. Et bysamfunn i utvikling 1800–1920 (The Bergen city history. The development of the city 1800–1920) (in Norwegian) vol. 3. Universitets forlaget, Oslo. 713 pp.

Fladby, R. 1978. Hvordan Nord-Norge ble styrt. Nordnorsk administrasjonshistorie fra 1530-åra til 1660. Universitets forlaget, Oslo. 120 pp.

Fossen, A. B. 1979. Bergens bys historie. Borgerskapets by 1536–1800 (The Bergen city history. The city of the bourgeoisie) (in Norwegian) vol. 2. Universitets forlaget, Oslo. 935 pp.

Fossum, P. 1992. The recovery of the Barents Sea capelin (*Mallotus villosus*) from a larval point of view. ICES J. mar. Sci., 49: 237–243.

Friele, M. 1877. An account of the fisheries of Norway. Rep. US Commn. Fish., V: 707–739.

Garrod, D. J., and Schumacher, D. 1994. North Atlantic cod: the broad canvas. ICES mar Sci. Symp., 198: 59–76.

Grove, J.M. 1988. The Little Ice Age. Methuen, London. 498 pp.

Hamre, J. 1991. Interrelation between environmental changes and fluctuating fish populations in the Barents Sea. *In* Long-term changes in marine fish populations, pp. 259–270. Ed. by T. Wyatt and M. G. Larrañeta. Instituto de Investigaciones marinas de Vigo, Vigo, Spain. 554 pp.

Helland-Hansen, B., and Nansen, F. 1909. The Norwegian Sea. Its physical oceanography based upon the Norwegian researches 1900–1904. FiskDir. Skr. Ser. HavUnders., 2(2): 390 pp.

Helle, K. 1967. Trade and shipping between Norway and England in the reign of Håkon Håkonsson (1217–63). Sjøfartshist. Årb., 7–34.

Hill, B. T., and Jones, S. J. 1990. The Newfoundland ice extent and the solar cycle from 1860 to 1988. J. geophys. Res., 95: 5385–5394.

Holmsen, A. 1975. Bonde-økonomi og fisker-økonomi i Norge i slutten av middelalderen (The economy of farmers and fishermen at the end of the Middle Age) (in Norwegian). Heimen, 16: 545–556.

ICES, 1890. Indstilling fra den af den kongelige norske Regjerings Departement for det Indre under 30te Januar 1890 nedsatte Komite til Undersøgelse betræffende Spørsmaalet om nye Lovbestemmelser angaaende Hvalfangsten i Finmarkens og Tromsø Amter (A report to the government from the committee suggesting a new law for the whaling in Finmark and Troms) (in Norwegian). Fabricius, Christiania. 109 pp.

ICES, 1992. Preliminary report of the International 0-Group Fish Survey in the Barents Sea and Adjacent Waters in August–September 1992. ICES CM 1992/G: 82.

ICES, 1993. Ressursoversikt for 1993 (Fish resources in Norwegian waters in 1993) (in Norwegian). Fisken Havet, Særnummer, 1. 66 pp.

Iversen, T. 1933. Some observations on fry in trawl catches in the Barents Sea. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer, 85(3): 3–6.

Jakobsen, T. 1992. Biological reference points for the North-East Arctic cod and haddock. ICES J. mar. Sci., 49: 155–166.

Jensen, A. S. 1939. Concerning a change of climate. Kgl. Dansk. Vid. Selsk. Biol. Meddr, 14: 1–74.

Jónsson, S. 1994. Cyclonic gyres in the North Atlantic. ICES mar. Sci. Symp., 198: 287–291.

Kårstad, E. 1981. XII. Ødegårder og oppgangstid i Trondenes. Bosetningen i bygdene opp mot Malangen i seinmiddelalderen (Desolated farms and prosperity in Trondenes. Inhabitation in the area surrounding the Malangen fjord during late Middle Age) (in Norwegian). *In* Seinmiddelalder i norske bygder, pp. 433–476. Ed. by N. Bjørgo, R. Fladby, K. Helle and J. Sandnes. Universitets forlaget, Oslo. 489 pp.

Lamb, H. H. 1979. Climatic variation and changes in the wind and ocean circulation: the Little Ice Age in the Northeast Atlantic. Q. Res., 11: 1–20.

Lee, A. J. 1949. The forecasting of climatic fluctuations and its importance to the Arctic fishery. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer, 125: 40–41.

Lindbekk, K. 1974a. Norsk tørrfiskhandel i det 16. og 17. århundre. Del 1 (The Norwegian stockfish trade in the 16th and 17th centuries, part 1) (in Norwegian). Heimen, 16: 379–390.

Lindbekk, K. 1974b. Norsk tørrfiskhandel i det 16. og 17. århundre. Del 2 (The Norwegian stockfish trade in the 16th and 17th centuries, part 2) (in Norwegian). Heimen, 16: 425–441.

Ljungman, A. V. 1882. Contribution towards solving the question of the secular periodicity of the great herring fisheries. Rep. US Commn. Fish., 1880, VII: 497–503.

Loeng, H. 1989. The influence of temperature on some fish population parameters in the Barents Sea. J. Northw. Atl. Fish. Sci., 9: 103–113.

Lunden, K. 1976. Fisket og norsk økonomi på 1500- og 1600-tallet (The fishery and Norwegian economy during the 1500s and 1600s) (in Norwegian). Heimen, 17: 129–158.

Malmberg, S. A. 1988. Ecological impact of hydrographic conditions in Icelandic waters. *In* Long-term changes in marine fish populations, pp. 95–123. Ed. by T. Wyatt and M. G. Larrañeta. Instituto de Investigaciones marinas de Vigo, Vigo, Spain. 554 pp.

Nakken, O. 1994. Causes of trends and fluctuations in the Arcto-Norwegian cod stock. ICES mar. Sci. Symp., 198: 212–228.

Nedkvitne, A. 1978. Stapelreguleringer, handelsveier og varekvanta i bergenshandelen i seinmiddelalderen (Trade routes for the stockfish from Bergen in the late Middle Ages) (in Norwegian, English summary). Hist. tidsskr., 57: 53–91.

Nedkvitne, A. 1988. "Mens Bønderne seilte og Jægterne for". Nordnorsk og vestnorsk kystøkonomi 1500–1730" (North Norwegian and West Norwegian coastal economy from 1500–1730) (in Norwegian). Universitets forlaget, Oslo. 753 pp.

Nilssen, E. M., Pedersen, T., Hopkins, C. C. E., Thyholdt, K., and Pope, J. G. 1994. Recruitment variability and growth of Northeast Arctic cod: influence of physical environment, demography, and predator-prey energetic. ICES mar. Sci. Symp., 198: 449–470.

Øiestad, V. 1990. Konsekvenser av klimaendringer for fiskeri- og havbruksnæringen. Bidrag til den interdepartementale klima-utredningen (A climatic change – consequences for fisheries and aqua-culture) (in Norwegian, English Summary). Fisken Havet, 2: 96 pp.

Olafsen, O. 1914. Misvæxt, uaar og hungersnød i Norge (Crop failure and famine in Norway) (in Norwegian). Tidsskr. for det norske landbrug: 69–81.

Olsen, S. 1968. Some results of the Norwegian capelin investigation 1960–1965. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer, 158: 18–23.

Otterlind, G. 1984. On fluctuations of the Baltic cod stock. ICES CM 1984/J: 14.

Ottersen, G., Loeng, H., and Raknes, A. 1994. Influence of temperature variability on recruitment of cod in the Barents Sea. ICES mar. Sci. Symp., 198: 471–481.

Otterstad, P. 1960. Forecasting the annual yield in sea fisheries. Nature, Lond., 185: 183.

Pettersson, O. 1905. On the probable occurrence in the Atlantic Current of variations periodical, and otherwise, and their bearing on meteorological and biological phenomena. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer, 3 (A): 1–26.

Pettersson, O. 1922. Om det Bohuslänska Sillfiskets periodicitet (On the periodicity of the Bohuslän herring fishery) (in Swedish). Svenska Hydrogr. Biol. Komm. Skr., VII: 9–23.

Ponomarenko, I. Y. 1973. The effects of food and temperature conditions on the survival of young bottom-dwelling cod in the Barents Sea. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer, 164: 201–207.

Rollefsen, G. 1954. Observations on the cod and the cod fisheries of Lofoten. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer, 135: 40–47.

Runnstrøm, S. 1935. The relationship between the spring-spawning herring population of the northern North Sea and the norwegian west coast. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer, 94(3): 3–6.

Røttingen, I. 1990a. The 1983 year class of Norwegian spring spawning herring as juveniles and recruit spawners. *In* Biology of fisheries of the Norwegian spring spawning herring and blue whiting in the Northeast Atlantic, pp. 165–203. Ed. by T. Monstad. Proceedings of the Soviet–Norwegian Symposium, Bergen, 12–16 June 1989. Institute of Marine Research, Bergen. 358 pp.

Røttingen, I. 1990b. A review of variability in the distribution and abundance of Norwegian spring spawning herring and Barents Sea capelin. Pol. Res., 8: 33–42.

Sars, G. O. 1879a. Indberetning til Departementet for det Indre om de af ham i Aarene 1864–1878 anstillede Undersøgelser angaaende Saltvanns-fiskerierne (Report on the investigations on the seawater fisheries from 1864–1878) (in Norwegian). Bergh & Ellefsens Bogtrykkeri, Kristiania. 221 pp.

Sars, G. O. 1879b. Indberetning til Departementet for det Indre om de af ham i Vaaren 1879 anstillede praktisk-vitenskapelige Undersøgelser over Loddefisket ved Finmarken (Investigation on the capelin–cod fishery in Finmark, 1879) (in Norwegian). Bergh & Ellefsens Bogtrykkeri, Kristiania. 32 pp.

Soleim, P. 1940. Storsildas og vårsildas gytefelt (The spawning locations of the large and spring herring) (in Norwegian, English summary). FiskDir. Skr. Ser. HavUnders., 6(4): 56–68.

Solhaug, T. 1976. De norske fiskeriers historie 1815–1880 (The Norwegian fishery history 1815–1880) (in Norwegian). Universitets forlaget, Oslo. 770 pp.

Sætersdal, G., and Hylen, A. 1964. The decline of the skrei fisheries. FiskDir. Skr. Ser. HavUnders., 13: 56–69.

Sætersdal, G., and Loeng, H. 1987. Ecological adaptation of reproduction in Northeast Arctic cod. Fish. Res., 5: 253–270.

Zachariassen, L. 1959. Føroyar sum rættarsamfelag 1535–1655. Annl. Soc. Scient. Færoensis, 1 (IV). Føroya Fródskaparfelag, Tórshavn. 423 pp.