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Sea Ice, Climate, and Icelandic Fisheries in the Eighteenth and Nineteenth Centuries

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ABSTRACT. The expansion and subsequent decline in catches in many fisheries of the world during the 20th century suggest that the history of fisheries needs our urgent attention. Analysis of environmental effects on fisheries in the past (when overfishing was not an issue) may cast light on current concerns about declining fish stocks. Primary documentary evidence from Iceland was used for preliminary investigations into correlations between sea-ice extent, sea temperatures, ocean currents, and cod fishing, and hence between severe weather and the decline of Icelandic fisheries in the past. The sources suggest that fishing was generally successful in Iceland during the medieval period and well into the 16th century. However, in the 17th through the 19th centuries, the fisheries failed on numerous occasions, sometimes for several years. The causes of these failures were complex. Climate likely played a part, and this was certainly the perception of contemporary writers; however, socioeconomic factors were also involved.

Key words: Arctic sea ice, climate/sea interactions, cod fisheries, fisheries history, Iceland

RÉSUMÉ. L'expansion, et le déclin qui suivit, touchant les prises de nombreuses pêcheries dans le monde au cours du XX^{e} siècle suggèrent que nous devons nous pencher sans tarder sur l'historique de la pêche. Une analyse des répercussions environnementales sur les pêcheries dans le passé (quand la surpêche ne constituait pas un problème) peut jeter de la lumière sur les enjeux actuels concernant l'épuisement des stocks de poissons. Des preuves documentaires primaires provenant d'Islande ont servi aux recherches préliminaires portant sur les corrélations entre l'étendue de la glace marine, les températures de la mer, les courants océaniques et la pêche de la morue – donc entre le mauvais temps et le déclin des pêcheries islandaises dans le passé. Les sources suggèrent que la pêche était généralement fructueuse en Islande durant la période médiévale et les premières décennies du XVI^{e} siècle. Toutefois, du XVII^{e} à la fin du XIX^{e} siècle, les pêcheries connurent bien des échecs, parfois sur plusieurs années. Les causes en étaient complexes. Si le climat jouait vraisemblablement un rôle – ce que perçurent bien les écrivains de l'époque –, des facteurs socio-économiques entraient aussi en jeu.

Mots clés: glace marine arctique, interactions climat/mer, pêcheries de morue, historique des pêcheries, Islande

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INTRODUCTION

> The inhabitants procure...various other species of fish; but particularly the cod-fish, which assemble and keep near those masses of ice that sink deep in the water. (Ólafsson and Pálsson, 1975)

Sea fishing has always been an extremely important part of the Icelandic economy, although it did not become a major industry until the 20th century. The correlation between sea temperature, ocean currents, and fish stocks that has been observed in the 20th century (see e.g., Vilhjálmsson, 1997) suggests that it may be possible to draw conclusions on similar relationships in the past. It is therefore of interest to investigate the extent to which variations in catches of Icelandic fisheries have been driven by climatic or socioeconomic changes, or both.

The context of this research on climate and fisheries is ongoing work on proxy climate records in the North Atlantic region, which involves comparing marine sediment cores from the Iceland and Greenland shelves, ice-core records from the Greenland ice sheet, and documentary historical sea-ice and climate records from Iceland (see e.g., Barlow et al., 1997a; Ogilvie et al., 2000; Jennings et al., in press). The human dimensions of climate impacts have also been considered (Ogilvie, 1984a, 1997, in press; Buckland et al., 1996; Barlow et al., 1997b; Ogilvie and McGovern, 2000). Our present focus is on the analysis of documentary sources, particularly to elucidate contemporary perceptions of the interconnections between climate and fisheries. Preliminary investigations concerned the role of climatic and environmental changes (especially variations in sea ice) and socioeconomic factors in the history of Icelandic fisheries.

Fish, and particularly cod (*Gadus morhua*), are known to be highly dependent on oceanographic parameters such as temperature (Jónsson, 1969; Malmberg and Blindheim, 1993; Schopka and Marteinsdóttir, 1994; Vilhjálmsson,

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1997; Gunnarsson et al., 1998). Thus records of variations in the Icelandic fisheries may yield a further climate proxy for the North Atlantic region and increase our understanding of the climate/ocean system.

The fish caught by Icelanders in the past included haddock, halibut, lumpfish, and sharks. Herring was also caught, but only on a very small scale before the last two decades of the 19th century. The most important catch, both for home consumption and for export, was cod. This fish therefore features in the discussion.

SOURCES AND METHODS

A wide variety of documentary sources relating to the climatic as well as the general history of Iceland have been collected and analyzed (Ogilvie, 1982, 1991, 1992, 1996, 1997; Jónsdóttir, 1995; Ogilvie and Jónsdóttir, 1996; Jónsdóttir and Ogilvie, 1997). These include official governmental records, annals, early newspapers, geographical descriptions, weather diaries, and early sea-ice charts. Certain of these records also contain information on Icelandic fisheries from medieval times to the late 19th century. In addition, we have several detailed contemporary treatises on fish and fisheries written by both Icelanders and foreign observers: an example is the treatise by Jón Ólafsson, *Ichtyographia Islandica* (1737). In the middle of the 18th century, Eggert Ólafsson and Bjarni Pálsson travelled through Iceland on behalf of the Danish Scientific Society to investigate many aspects of life in Iceland. Their resulting book contains some particularly interesting comments on fisheries (Ólafsson, 1772; Ólafsson and Pálsson, 1975). Other accounts are found in several general descriptions of Iceland (e.g., Horrebow, 1758; Olavius, 1780; Mohr, 1786; Pálsson, 1945; Faber, 1829; Gröndal, 1874).

The history of fisheries in Iceland has already been extensively researched, in particular by Kristjánsson (1971, 1980–86) and Jónsson (1988, 1994a, b). Our contribution is to analyze information on the Icelandic cod fisheries gleaned from the documentary historical sources listed above in the context of changes in climate, specifically sea-ice and ocean changes. Particular emphasis is given to unpublished government reports in the form of letters written from all districts of Iceland by the *sýslumenn* or district sheriffs (These *Bréf til Stiftamtmanns*, "Letters to the Governor," are located in the National Archives in Reykjavik. They are identified in the text below as *B.S.* followed by the relevant district: for example, *B.S. Múlasýsla* means "Letter from the Múla district"). Some of these sources were written in Icelandic, others in Danish, the official government language of the day. (Quotations given below have been translated into English by Ogilvie.) As these reports have rarely been used by other researchers, they add important new information to the pool of knowledge regarding developments in the Icelandic fisheries. The documents themselves are described in more detail in Ogilvie (1992). Another interesting source from the latter part of the 19th century, quoted extensively here, is a two-part report on the trade and fisheries of Iceland made by Consul Crowe for the British government (Crowe, 1867, 1872). This source does not appear to have been used by other researchers.

All the documentary sources used in this assessment were analyzed carefully to ensure their reliability (see, e.g., Bell and Ogilvie, 1978). The data were then evaluated and quantified. First, we performed a coarse "content analysis" (see, e.g., Moodie and Catchpole, 1976) of the data and categorized both the climate information and fisheries data. Table 1 summarizes fishing catches during the period 1680–1780, using data from the government reports. For this analysis, Iceland was divided into four regions: north, south, west, and east. Blank spaces indicate that no data were found for that particular year or region. There are fewer data for the east than for other regions, probably because this part of Iceland was more sparsely populated than the others and therefore has fewer historical sources. The available information was grouped into categories of "good," "average," or "poor" catches, quantified as 1, 0, and –1, respectively (as in Ogilvie, 1997). A decadal fishing index for the south of Iceland was then calculated by adding the annual values. Although cold conditions and poor fishing coincide for some decades (for example, the 1690s and the 1750s), in as many or more decades the relationship is in the opposite direction. The overall correlation between fishing success and winter/spring temperature indices for south Iceland is poor. This fact does not, of course, negate the link between fishing and *sea* temperature, but serves primarily to illustrate the complexity of the issue.

Figure 1 shows a sea-ice index for the period 1600–1850. In constructing this index, the coastal areas of Iceland were divided into four regions: north, northwest, east and south. Sea ice drifting to the coasts of Iceland occurs most commonly off the northwestern, northern and eastern coasts. It occurs only very rarely off the south coasts. Also, because of the prevailing ocean currents, sea ice virtually never reaches the southwest coast. This index was derived by evaluating data from all the regions of Iceland that reported the presence of ice in any given season in a certain year. Thus it takes into account both the geographical extent and the duration of the ice. The data were then smoothed using a 15-year, low-pass filter to highlight the lower frequency variations. (For further details on this ice index, see, e.g. Ogilvie, 1992, 1996; Ogilvie and Jónsson, in press.)

THE MARINE ENVIRONMENT AROUND ICELAND

The waters around Iceland are dominated by two major, distinct, and contrasting ocean currents (see Fig. 2). The Irminger Current brings warm, saline Atlantic Water along western Iceland. Opposing this, across Denmark Strait (to

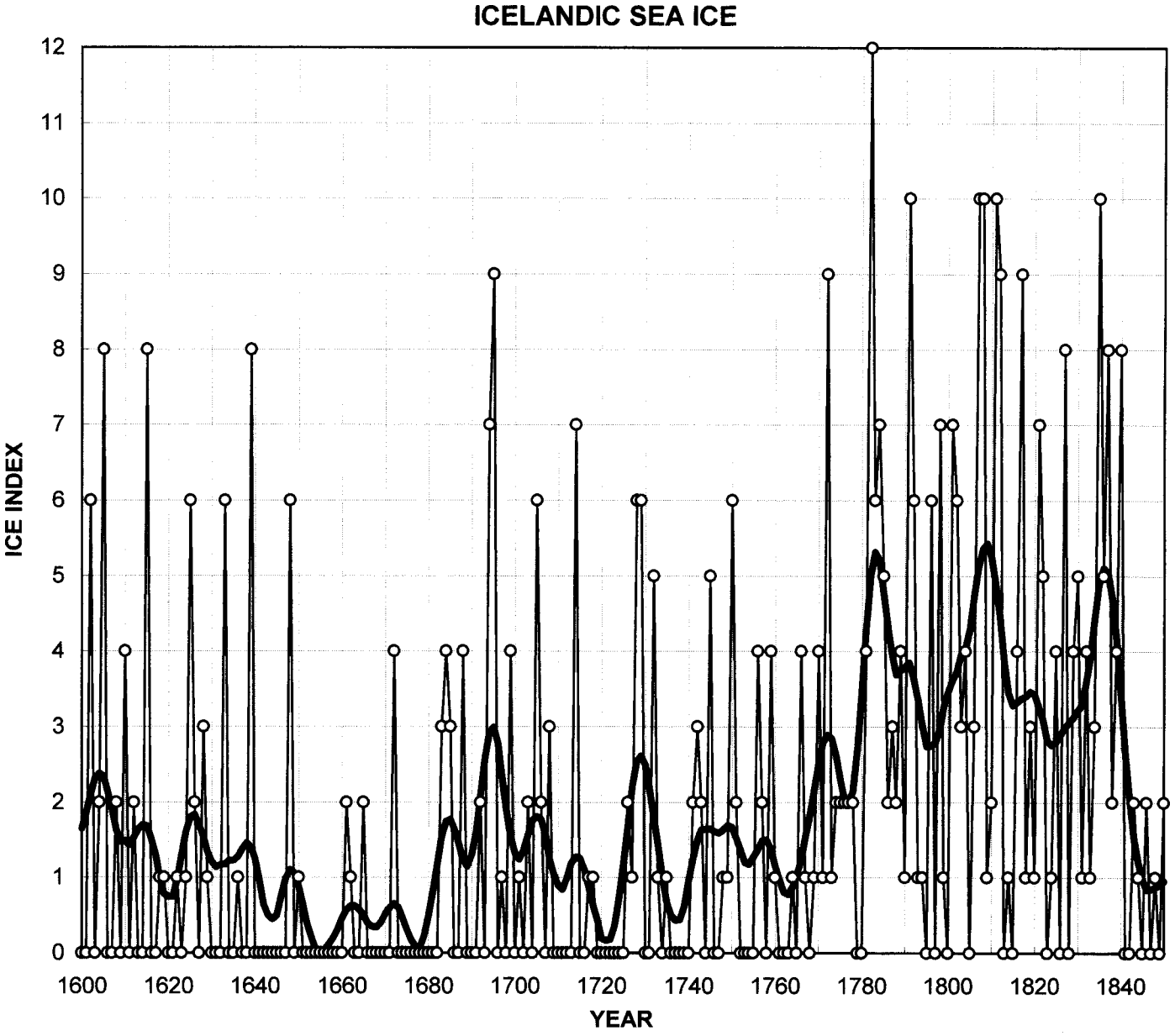

FIG. 1. A sea-ice index for Iceland showing variations in the incidence of ice off the coasts during A.D. 1600–1850. The data have also been smoothed to highlight the lower frequency variations using a 15-year low pass filter. The documentary data used to construct this index are described in Ogilvie (1992).

the northwest of Iceland), cold, relatively fresh, polar water from the Arctic Ocean is carried southward in the East Greenland Current. A sharp oceanographic front marks the boundary between the two water masses (Stefánsson, 1969; Malmberg, 1985). For many decades, Icelandic researchers have maintained hydrographic stations, which provide a detailed record of changes in water temperature and salinity (Malmberg and Magnússon, 1982). The record shows a significant correlation between the air temperatures over land and the sea surface temperatures (SSTs) off Iceland (Eythórsson and Sigtryggsson, 1971). Therefore the *proxy* climate records from offshore and on land can be expected to show similar fluctuations.

The fertility in the waters around Iceland arises from winter convection, bringing nutrients to the near-surface waters, followed by stratification of the ocean column and blooming of zooplankton in spring. Figure 2 also shows the spawning grounds for cod, located to the southwest and south of Iceland, as well as the drift of juvenile cod and the migration of sexually mature cod.

The seasonal boundary of the Arctic drift ice, carried southward by the East Greenland current, also lies close to Iceland. Figure 3 shows the position of the ice edge in relation to the coast of Iceland in both a "normal" severe ice year and a "normal" mild ice year (Eythórsson and Sigtryggsson, 1971). The ice most commonly reaches Iceland in the late winter or early summer and most usually affects the northern and northwestern coasts. The drift ice reaches Iceland via a complex mix of oceanic and atmospheric circulation and local winds and currents. Icelandic

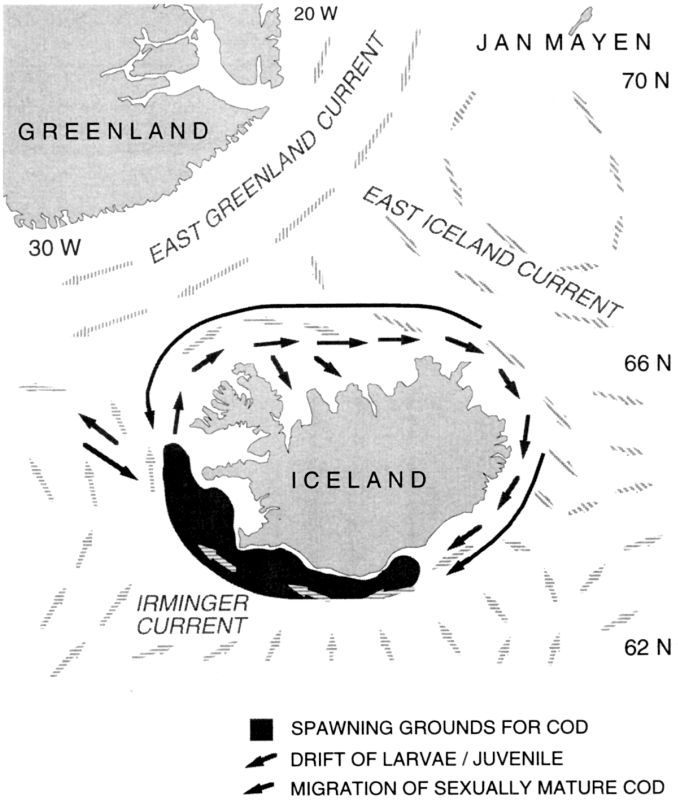

FIG. 2. Ocean currents in Icelandic waters. Also shown are typical spawning areas for cod as well as drift of larvae (short arrows closer to land) and migration of sexually mature cod (long arrow).

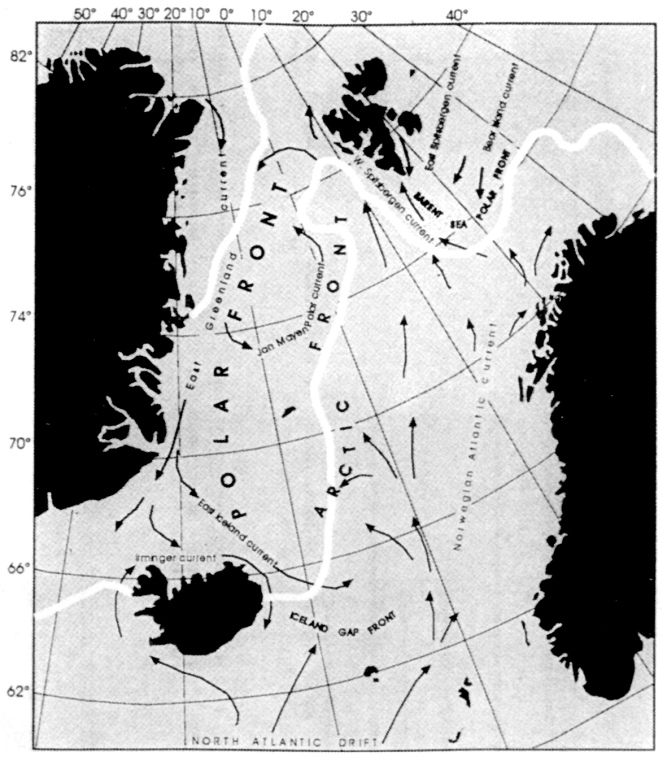

FIG. 3. The position of the sea ice edge in relation to the coast of Iceland in both a "normal" severe ice year (the more southerly white line) and a "normal" mild ice year (the more northerly white line located close to the coast of Greenland). (Modified after Hurdle, 1986).

ice extremes are associated with interannual variability either in the high-pressure region over Greenland or in deep storms passing farther east over the East Greenland Sea. Both of these circulation features further the advection of ice towards Iceland from its usual location in the East Greenland Sea along the Greenland coast.

THE PAST CLIMATE AND SEA-ICE RECORD FROM ICELAND

A brief outline of Iceland's climate and sea-ice history is appropriate here. The data used in the following section derive from Ogilvie (1991, 1992). For more information, see also Ogilvie (1984b, 1996), Ogilvie and Jónsdóttir (1996), and Jónsdóttir and Ogilvie (1997).

Iceland was first settled in the late ninth century. Since there are no contemporary documents for the first few centuries of settlement, evidence for a relatively mild climate at that time (comparable to the warmest parts of the 20th century) relies largely on circumstantial evidence and other data sets (Ogilvie et al., 2000). The climate of the succeeding centuries shows considerable variability. Relatively cold periods are suggested during ca. 1180 to 1210, and again during the 1280s and 1290s. The 14th century was markedly variable. There is some evidence for a mild climate between 1430 and 1560; however, for much of this period documentary sources are lacking. For the latter part of the 16th century, sources suggest a comparatively harsh climate. A cooling trend may be seen around the beginning and end of the 17th century. However, these periods are separated by a mild period from ca. 1640 to 1670. The early decades of the 18th century were mild in contrast to the very cold 1690s, 1730s, 1740s, and 1750s. The 1760s and 1770s show a return to a milder regime, but the 1780s are likely to have been the coldest decade of the century, with the harsh conditions compounded by volcanic activity. The 1810s, 1830s, and 1880s were also comparatively cold. Overall, the 20th century has had milder temperatures than the preceding three centuries.

The sea-ice data for the period before ca. A.D. 1600 are sparse and do not warrant a statistical analysis; but for the subsequent period, sufficient data are available to construct indices. Figure 1 shows the variations in sea-ice incidence off the coasts of Iceland from A.D. 1600 to 1850. During the early and late decades of the 17th century, much sea ice was present, but from ca. 1640 to ca. 1680, there appears to have been little sea ice off Iceland. During the period 1600–1850, the decades with most ice present were the 1780s, the 1810s, and the 1830s. From 1840 to 1855, there was virtually no ice off the Icelandic coasts. The presence of sea ice off the coasts of Iceland during some or all of a winter, spring, summer, or autumn season during 1680–1780 is also shown in Table 1.

Ice incidence after 1850 (not shown in Fig. 1) is briefly summarized here. Frequent ice reappeared around 1855–60; however, the incidence does not seem to have been as heavy as in the earlier part of the century. Further clusters of sea-ice years occurred from ca. 1864 to 1872. The 1880s contained several very severe sea-ice years, and some sea-ice years also occurred in the 1890s, but far less often than in the 1880s. From 1900 onwards, sea-ice incidence fell off dramatically. Clearly, both the sea ice that reaches Iceland's coasts and the temperature on land are highly variable. Further information on sea-ice reconstructions for the period after 1850 may be found in Jónsdóttir (1995) and Ogilvie and Jónsson (in press).

FISHING IN THE ICELANDIC ECONOMY

Although fishing did not become a major industry in Iceland until the late 19th century and was rarely carried out as an occupation totally separated from farming, it has always been an extremely important part of the Icelandic economy. From early settlement times in the late 9th century, fish formed a major part of the Icelanders' diet, and from the 14th century onwards, fish was the most important export item. From 1602 to 1854, the Danes held a trading monopoly in Iceland and controlled the stockfish (dried cod) trade. After that time, Denmark remained Iceland's main trading partner for many decades. From Denmark, much of the best-quality fish was exported further to Bilbao and Barcelona, "where the Iceland dried cod is much esteemed...The inferior qualities are shipped to England and Denmark" (Crowe, 1867:37).

Iceland's fishing grounds are shown in Figure 4. Before the 20th century, the most important fishing grounds were in the south, particularly off the Vestmannaeyjar (Westman Islands) and in the west, off Snæfellsnes and the Reykjanes peninsula, and in the Faxaflói area. In 1867, Consul Crowe, reporting to England on the trade and fisheries of Iceland (1867:29), noted:

> It appears that the large cod remain during the winter near the island, and in February and March approach the south coast to spawn; the fishermen, in Faxe Bay [Faxaflói, in the west], affirm that the direction of the fish is from the south and west.

Crowe (1867:29) also commented:

> A glance at the map of Iceland seems to indicate that the long, flat coast stretching from Vestmanns Islands [Vestmannaeyjar] to Vesterhorn, is specially adapted for a spawning ground, and at

TABLE 1. A summary of contemporary perceptions of fishing catches in Iceland, A.D. 1680 to 1780. The presence of sea ice during winter (W), spring (SP), summer (SM), and autumn (A) is also indicated.

Year	Sea Ice	Fisheries			
		North	South	West	East
1680			Good		
1681			Small catch		
1682				Very good	
1683	SP, SM	Much herring	Poor	Variable	
1684	W, SP	Good	Very good	Very good	
1685	W, SP, SM		Below average		
1686			Average	Good	
1687			Poor	Adequate	
1688	SP, SM			Little fish	
1689		Not much fish			
1690		Reasonable	Poor	Variable	Poor
1691			Poor	Reasonable	Poor
1692	W, SP	Good	Poor	Average/Poor	Poor
1693		Quite good	Poor	Fair	Poor
1694	SP, SM	Good after ice	Variable/Poor	Quite good	Poor
1695	SP, SM	Lack	Variable	Average	Poor
1696		Poor	Good	Poor	
1697	W	Poor		Poor	
1698			Average	Reasonable	
1699	SP	Poor	Mainly poor	Very poor	
1700		Very poor		Very poor	
1701	SM, A	Lack	Lack	Lack	Better in east
1702		Lack	Variable	Small catches	
1703	SP	Mainly poor	Variable		Good
1704		Good	Quite good	Quite good	Good
1705	SP, SM	Variable	Lack	Reasonable	Good
1706	SP	Variable	Variable	Good	Quite good
1707			Good	Variable	Good
1708	W, SP, SM	Quite good	Not very good	Small catches	
1709		Reasonable		Good	Not very good
1710		Reasonable	Reasonable	Reasonable	
1711		Good		Variable	
1712		Good		Average/Good	
1713		Very good	Good	Good	
1714	SP, SM		Catches small	Poor	
1715		Not very good	Average/Poor	Not very good	
1716		Good	Poor	Good	Good
1717	A	Poor	Poor	Poor	Good
1718	SP	Poor		Poor	
1719			Poor	Reasonable	Poor
1720		Good	Poor	Average	
1721		Poor	Poor		Poor
1722		Variable	Quite good	Average	Good/Average
1723		Good			
1724		Good	Poor	Reasonable	Poor
1725		Good	Good	Good	
1726	SP	Good		Reasonable	
1727	W	Good	Good	Quite good	
1728	SP, SM	Variable		Fairly good	Good
1729	W, SP, SM	Late but good	Good	Average	Very poor
1730		Lack	Good	Quite good	Variable
1731		Failed	Quite good	Variable	Poor
1732	SP, SM	Poor	Very poor	Great lack	Poor
1733	SM	Quite good	Average/Poor	Variable/Poor	Very poor
1734		Poor	Failed	Poor	Variable
1735	SP	Very poor	Below average	Great lack	
1736		Quite good	Average	Average/Good	Poor
1737		Poor	Poor		None winter
1738		Very poor	Average	Variable	Very poor
1739		Variable	Very poor	Mainly poor	
1740		Reasonable		Good	Very poor
1741	SP		Average	Variable	Very poor
1742	W, SP, SM	Quite good		Quite good	Poor
1743	SP, SM	Reasonable		Average	Very poor
1744		Rather poor	Very poor	Variable	
1745	W, SP, SM	Lack	Good before ice	Mainly poor	
1746		Average/Poor	Average	Very poor	

TABLE 1. *continued*: A summary of contemporary perceptions of fishing catches in Iceland, A.D. 1680 to 1780. The presence of sea ice during winter (W), spring (SP), summer (SM), and autumn (A) is also indicated.

Year	Sea Ice	Fisheries			
		North	South	West	East
1747		Great lack	Small catches	Great lack	
1748	SP	Poor	Average/Good	Average/Poor	
1749	W	Variable	Average/Poor	Variable	
1750	W, SP, SM, A	Poor	Quite good	Variable	Good
1751	W, SP	Very poor	Mainly poor	Very poor	Very poor
1752		Very poor	Very poor	Mainly poor	
1753		Mainly poor	Very poor	Average	
1754		Variable	Terrible	Very poor	
1755		Very little	Average/Poor	Poor	
1756	SP, SM	No fish	Very poor	Variable	
1757	SP, SM	Poor	Variable	Mainly poor	Quite good
1758		Mainly poor	Average	Poor	
1759	SP, SM	Poor		Reasonable	
1760	SP	Reasonable	Variable	Average	
1761		Very good	Poor	Poor	
1762		Good	Rain spoiled	Variable	
1763		Mainly good	Very good	Variable	
1764	SP	Spring good		Variable	
1765		Spring good	Very good	Average	
1766	W, SP, SM	Variable	Variable		
1767	SP	Variable	Not very good	Good	
1768		Good	Variable	Good	
1769	W	Reasonable	Very poor		
1770	SP, SM	Good	Good	Good	
1771	SP	Reasonable	Good		
1772	W, SP, SM	Good		Not very good	
1773	SP	Reasonable		Variable	
1774	W, SP	Good	Mainly poor	Mainly good	Lack
1775	SM	Quite good	Mainly poor	Variable	Very poor
1776	SP	Good	Variable	Variable	Lack
1777	SP	Quite good	Variable	Quite good	
1778	SP	Good	Variable	Poor/Average	Very poor
1779		Reasonable	Poor	Poor	Very poor
1780		Variable	Variable	Variable	Lack

> the Snefjeldsjökull, the earliest and best fishings commence in February or March, and it is not until towards the end of June, or beginning of July, that the fishings begin further round to the north. Cod is found in great numbers in Faxe Bay as late as May, and in Breiða Bay [Breiðafjörður] in June, and somewhat later along the coast to the northwest.

Throughout the 18th and 19th centuries, the fishing seasons varied from one place to another, determined primarily by when the largest runs of fish occurred in a given place and whether local weather conditions allowed small boats to go to sea. The choice of fishing grounds and the appointed seasons for fishing reflect the movements of the cod during the year (Kristjánsson, 1982), but activities in the seasonal round on land also had to be taken into account.

Around the Vestmannaeyjar (Westman Islands) and Eyrarbakki, the main fishing season was from 28 January to 12 May, after which the fish generally left this area. Around the Reykjanes peninsula, the season lasted from 2 February to 12 May. In Breiðafjord there were two seasons: the autumn season, from 29 September to 23 December, and the spring season, from 10 April to 12 May. In the western fjords there was just one season, from 10 April to 30 June, but in many places there fish could also be caught in the autumn and winter (Aðils, 1926–27:514–515). Also, according to Crowe (1867:30):

> The winter and spring fishings give the large fat cod which is sold at the factories and trading ports, and afterwards prepared for export, while the summer fishings only produce the small cod, cole-fish, haddock, and halibut, which are salted and smoked for home consumption.

In the north and east, the best time for fishing was in the spring/summer and autumn. The spring season lasted from April until around the middle of July, and the autumn season, in theory, from around the end of haymaking until November or even Christmas (Kristjánsson, 1982). However, in practice, autumn fishing frequently conflicted with the harvesting of the hay crop, and the fishing was interrupted during the haymaking season every year. This, coupled with the fairly short season, meant that fishing was of less importance in the north and east. A letter written in 1721 by Sheriff Hallgrímur Thorlacius in the Múla district (in the east) illustrates the problem:

> The fishing on the coast has been quite good since July, but because of our grass and hay, which we have to harvest from the beginning of August, the ordinary people have not had much benefit from it. (*B.S. Múlasýsla*)

FISH AND CLIMATE

Current research makes the importance of climate in biological responses amongst fish quite clear. However, during the 20th century, the effects of overfishing may have masked environmental impacts on fish (see e.g., McGoodwin, 1990; Hutchings and Myers, 1995; Vilhjálmsson and Jakobsson, 1998; Aagaard et al., 1999; Hamilton and Haedrich, 1999). The link between various aspects of atmospheric and oceanographic conditions and the life cycles and distribution of different species of fish is extremely complex (Woodhead and Woodhead, 1959; Beverton and Lee, 1965; Cushing, 1976; Dunbar, 1976; Stefánsson, 1994; Thór, 1994; Vilhjálmsson, 1997). Nevertheless, certain facts concerning fish and climate are well established. In particular, it appears that sea temperature is the most important ocean climate parameter influencing growth in fish stocks, since it influences all life stages (Sundby, 1998). The cod, for example, is a cold-water fish: temperatures of 4°

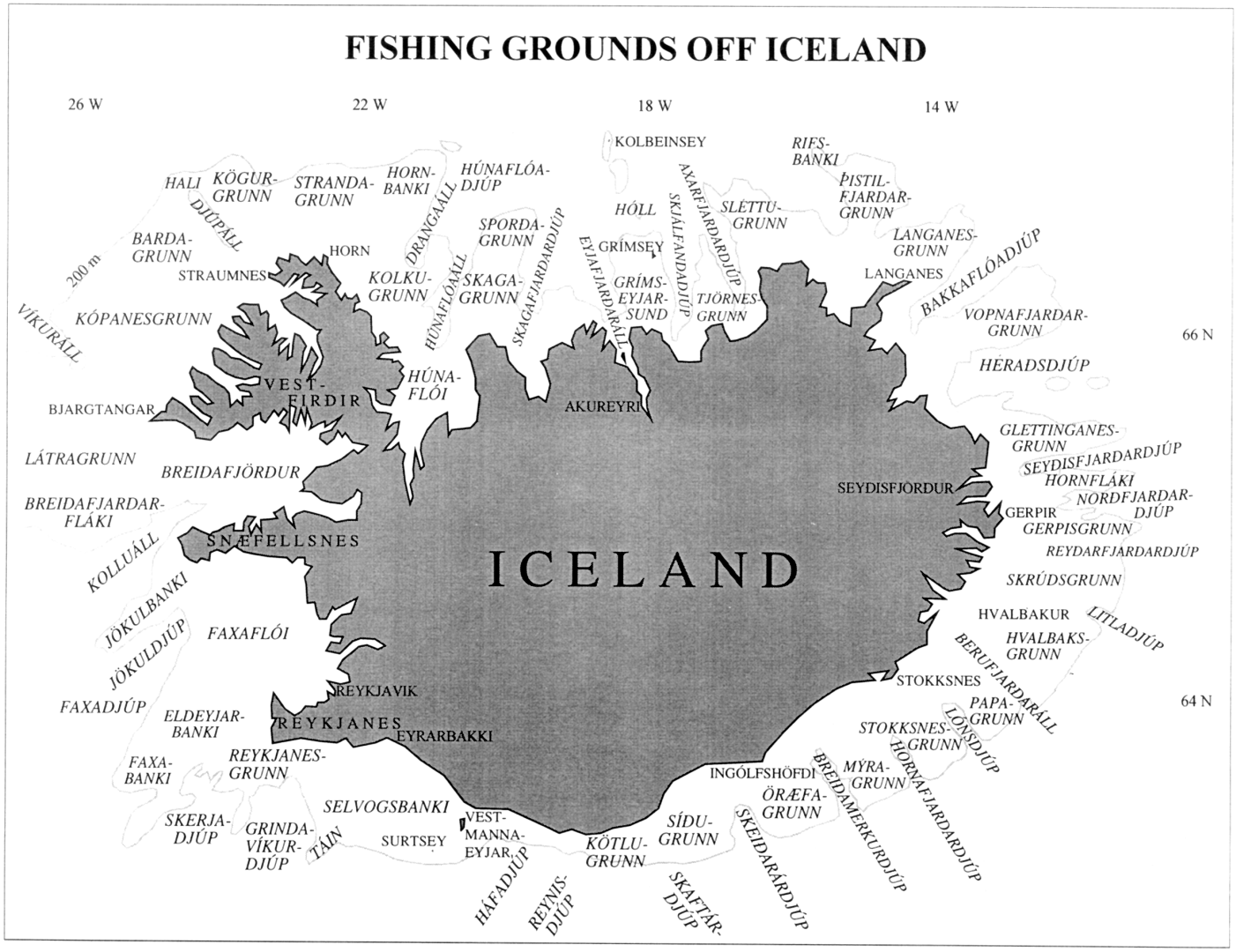

FIG. 4. Fishing grounds off Iceland.

to 7°C are optimal for its reproduction and early survival (Jónsson, 1969). This feature of the cod's physiology is reflected in temporal variations in the distribution of the species. Its strict climatic limits make the cod likely to be a useful climate indicator. Other important ocean climate parameters are turbulence and light conditions (Sundby, 1998).

A marked warming occurred in the Iceland and Greenland areas in the 1920s and 1930s (Jones et al., 1999), and many changes in fish distributions were observed during this period. A striking example was the mass spawning of cod off northern and eastern Iceland in addition to the usual spawning off the southern and western coasts (see Fig. 2 for "average" conditions) and the drift of cod larvae west to Greenland (Sæmundsson, 1934). Climatic deterioration in this area of the North Atlantic in the late 1960s, manifested by increasing drift ice, low air temperature, and a marked drop in ocean temperature and salinity, had wide-ranging repercussions on the ecology of the waters (Thórdardóttir, 1977). This climatic cooling also greatly reduced the size of the zooplankton community. The change here was so great that it has been described as a change in marine species composition from boreal to arctic (Jakobsson, 1978; Ástthórsson et al., 1983). During this time, however, an unfortunate combination of improved modern fishing technology and an unusually high fish population led to overfishing.

The dramatic improvement in climatic conditions in Icelandic waters that took place in the first half of the 20th century led to radical changes in the quantity, distribution, and reproduction of the fish fauna (Vilhjálmsson, 1997). These changes also had a very strong socioeconomic impact in Iceland, in that revenue from the fishing industry greatly increased prosperity. Recent research suggests that subsequent changes have been more complex, involving an interplay between environmental and exploitation factors (O'Brien et al., 2000).

CLIMATE IMPACT STUDIES IN ICELAND

Research into the socioeconomic impacts of climate and climate change in Iceland may be said to have begun in the 18th century, with works such as Finnsson (1796).

For a discussion of this and other relevant works, see Ogilvie (1982) and Ogilvie and Jónsson (in press). Some modern researchers have also asserted the considerable importance of climatic and environmental effects in the shaping of Icelandic history (see, e.g., Thórarinsson, 1956; Andrésson, 1964; Bergthórsson, 1966; Friðriksson, 1969; Ogilvie, 1982, 1984b, 2000), but others have suggested that climate has had a minimal effect and stressed the importance of socioeconomic factors alone (see, e.g., Gunnarson, 1980, 1983, 1987). The debate on whether environmental or socioeconomic factors are most important is not entered into here. However, although climate determinism arguments are too simplistic, climatic and environmental elements cannot be ignored when considering the history of a marginal area for settlement such as Iceland.

Climate impact on fisheries in the past has also begun to be explored. It has been suggested, for example, that the failure of the Færoese cod fishery during the 17th and 18th centuries was due to a reduction in sea-surface temperatures (Lamb, 1979). This issue has also been discussed by Jónsson (1994b), and Ogilvie (1982, 1997).

Little doubt surrounds the specific effects of sea ice on the Icelandic populace in the past. Three main negative impacts may be mentioned. First, the presence of ice had the effect of lowering temperatures on land (Friðriksson, 1969). This, in turn had a detrimental effect on the all-important grass crop, which provided fodder for the livestock (Ogilvie, 1984a). Second, with an extensive ice cover around Iceland's coasts, trading vessels carrying vital supplies were unable to land. Third, and of particular relevance here, the sea ice prevented access to fishing grounds. Occasionally, the sea ice also brought benefits with it, in the form of driftwood and marine mammals such as seals and whales. Further research will help resolve the question of whether the presence of a certain amount of sea ice (but not enough to completely block the coasts) brought, for example, certain nutrients in its wake, and therefore had a positive impact on fisheries.

CONTEMPORARY PERCEPTIONS REGARDING FISHERIES' CATCHES

Historical sources suggest that fishing was generally successful in Iceland from early settlement times to the 16th century, and there are few records of fisheries failing. However, our analyses suggest that in the 17th and 18th centuries, the fisheries failed on numerous occasions, sometimes for several years (see also Aðils, 1926–27; Jónsson, 1969; Kristjánsson, 1971; Ogilvie, 1982, 1997). Table 1 summarizes contemporary perceptions of fishing catches for the period 1680–1780. Jónsson (1994b) has made a similar analysis, using different data. These independent analyses show some disagreement, and a closer comparison of the two data sets is required.

Catches during the 18th century, in particular, appear to have declined. The many years when fishing was described as "poor" or "lacking" in Table 1 illustrate this clearly. For example, in the mid-17th century in the south of Iceland, one man would have been expected to catch, on average, about 500 cod during the winter fishing season; but after the mid-18th century, 300 cod were regarded as the maximum catch (Aðils, 1926–27:515). The number of fish exported also fell in the 18th century. Most contemporary writers seem to have noticed this decline and remarked upon it. Certainly the poor catches are reflected in the reports of Icelandic officials. A typical example is the account for 1722 from the Sheriff of Þingeyjar district in the northeast, who wrote: "The fishing is very poor in the north, and decreases every year" (*B. S. Þingeyjarsýslu*). Similar reports came from other regions. The account below for 1747 is from Barðastrand district in the northwest:

> In the west, the fishing was poor; there were average to small catches of lumpfish, but everywhere the cod catch was the worst that people could remember for many years, both during the autumn fishing last year and this spring. In most places most boats did not catch more than about ten fish, and in many places, less. (*B.S. Barðastrandarsýsla*)

Clearly, poor fishing was often associated with the presence of sea ice in the minds of many contemporaries. Thus, for example, the Sheriff of Skagafjörður in the north noted in 1729 that fishing "occurred late because of the sea ice..." and again in 1733, "The fish seem not to have come as close to the land as usual. This is believed to be because of the drift ice..." (*B. S. Skagafjarðarsýsla*).

POSSIBLE EXPLANATIONS FOR VARIATIONS IN FISHERIES' CATCHES

Data analyzed here show that fishing was generally poor, for example, from about 1680 to 1760 (except during the 1720s). Of the several possible explanations for this, some are socioeconomic. When fish disappeared from some fishing grounds, for whatever reason, people who had lived in these areas and were dependent on fishing had to leave their homes and try to find a living elsewhere. When and if the fish returned, the population able to go out fishing was depleted.

The great smallpox epidemic of 1707–08, which wiped out one-third of Iceland's population, had a significant negative impact on fisheries. Farmers living in the coastal regions had great difficulty finding enough people to man their boats (Aðils, 1926–27:516–517). This fact may be illustrated by the following example:

> Instead of the usual fourteen or fifteen boats from Ólafsvík only two could be manned this year because of the lack of labour. Many people who lived by the coast have left and the people who live further inland do not want to risk setting out to fish because of the recent failure of the fishing. (*B. S. Húnavatnssýsla*, 1732)

The lack of labour meant that smaller boats had to be built. In the 17th century, boats with 10 or 12 oars were most usual, but boats for six or fewer men came into use before the middle of the 18th century. This change, apart from anything else, would mean smaller total catches.

Other factors should also be considered. In particular, during the 17th and 18th centuries, the Icelanders had only fairly small, open rowing boats (decked vessels did not come into use until the mid-19th century) and were therefore restricted in the distance they could travel, as well as in the time they could spend at sea. Crowe makes some interesting comments. Although he points out the technological inferiority of the Icelanders' boats and equipment, he also observes that in many places (for example, Vogur in Faxaflói and Bolungarvík in Ísafjörður), the fishing is best done close to shore, where small boats are better than ships, and that small boats are "generally more suitable for casting out and attending to deep-sea lines." He adds:

> Owing likewise to the eminently inhospitable character of much of the coast, larger vessels would be exposed to serious dangers for want of harbours of refuge, whereas small flat-bottomed craft can run in everywhere, and with ease and safety be drawn up on land at night. (Crowe, 1872:640)

However, Crowe (1867:30) also attests that the Icelanders did "often put many miles out to sea." The general seaworthiness of the Icelanders' fishing boats may also be relevant when considering fishing catches. Crowe (1872:640–641) thought the sails they used seemed unsuitable: too large, and liable to make the boat capsize in a squall. In addition, the rudders were too loose and "in critical moments, often useless." Crowe also suggests that the Icelanders did not maintain their boats as well as they might:

> The Icelander is an excellent mariner, his powers of endurance, courage, and ability to keep the sea in all weathers is above praise, but his recklessness as to the soundness of the craft he trusts his life to is equally remarkable.

The numerous shipwrecks, and consequent loss of life, documented in the sources support Crowe's remarks.

However, it is unlikely that factors such as the state of the boats could, on their own, account for a decline in catches during the 18th century, and additional explanations must be sought. One suggestion is that the Dutch, who persistently fished in Icelandic waters during that century, caused depletion of the stocks (see, e.g. Guðnason, 1957:220). Certainly there are numerous complaints to this effect from contemporary Icelanders, but it seems unlikely that Dutch catches would have made any significant difference to the overall availability of fish. Foreign vessels had frequently fished in Icelandic waters since the 15th century, but there is no evidence to suggest that the stocks were in any way affected by this exploitation. Compared with modern catches, pre-20th century catches must have been very small.

Another possible explanation of poor fishing catches in Iceland in the past is a real decline in fishing stocks related to climate, more specifically to sea temperatures and ocean currents. It is possible that during a cold period, as in the 18th century, the range of the cod could have withdrawn southward. During that century, the Arctic sea ice frequently reached the coasts of Iceland. The presence of the ice would certainly have had a negative impact on fishing, both because its effect in lowering temperatures could have been detrimental to the fish stocks and because its presence off the coast prevented people from going out to fish.

CONCLUSIONS

Modern analyses (see e.g., Vilhjálmsson, 1997) have clearly demonstrated a link between environmental variations in the atmosphere and marine life in the oceans. The preliminary investigations on interactions between climate and fisheries conducted here and elsewhere (e.g., Jónsson, 1994b) indicate that such a link also existed in the past. As yet, however, the evidence is not clearly defined. There is no doubt that catches off the coasts of Iceland in the 17th to 19th centuries varied greatly and did indeed decline to very low levels at certain times. The years between about 1680 and 1760, for example, seem to have been mainly poor for fishing. Socioeconomic factors were partly the cause of this. However, the severe climatic conditions during these years must also have had more direct effects. Cold ocean temperatures would almost certainly have reduced fish stocks. Furthermore, the presence of sea ice could prevent people from going fishing and thus reduce the catches. The position of the ice edge could also change the nutrient status of the water, bringing productivity changes that would affect fish populations. (Ólafsson and Pálsson's statement that the fish stayed near to the sea-ice edge, quoted at the start of this paper, suggests that this could be the case.) Thus, the influences of climate involve a complex interplay between socioeconomic factors and direct climatic effects on fish populations that may act in either positive or negative directions. Further research is required to unravel this tangled skein.

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