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The use of historical catch data to trace the influence of climate on fish populations: examples from the White and Barents Sea fisheries in the 17th and 18th centuries

Dmitry L. Lajus, Julia A. Lajus, Zoya V. Dmitrieva, Alexei V. Kraikovski, and Daniel A. Alexandrov

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We analysed catch records of Atlantic salmon (*Salmo salar*), cod (*Gadus morhua*), and halibut (*Hippoglossus hippoglossus* and *Reinhardtius hippoglossoides*) from the 17th and 18th centuries from several locations of the Barents and White Seas areas. Historical records, found in Russian archives, allow analysis of long-term series of catches, and sometimes of the average weight of the fish. In total, we obtained data on catches of salmon for 51 years (for the period from 1615 to 1772) and of cod and halibut for 33 years (for the period from 1710 to 1793). These data are comparable with respect to fishing effort within the series. The data on Atlantic salmon are also comparable with statistical data for the period 1875–1915. We found notable fluctuations in catches and sometimes in the average weight of salmon. There was also fluctuation in catches of cod and halibut. Both observational comparison of catch series and temperature data and formal statistical analysis showed that catches tended to decrease during relatively colder periods.

Keywords: Atlantic salmon, Barents Sea, climate change, cod, fisheries, halibut, history, White Sea.

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D. L. Lajus: St. Petersburg State University, Department of Ichthyology and Hydrobiology, 16 Linia V.O., 29, 199178 St. Petersburg, Russian Federation. J. A. Lajus, A. V. Kraikovski, and D. A. Alexandrov: Centre for Environmental and Technological History, European University at St. Petersburg, Gagarinskaya Str. 3, 191187, St. Petersburg, Russian Federation. Z. V. Dmitrieva: St. Petersburg Institute for History, Russian Academy of Sciences, Petrozavodskaia Str. 7, St. Petersburg, 197110, Russian Federation. Correspondence to D. L. Lajus: tel: +7 812 3213279; fax: +7 812 3280852; e-mail: dlajus@yahoo.com.

Introduction

Historical records of fisheries can be used in analysing population dynamics of commercial species and assessing the environmental effects on them. A number of encouraging examples of the use of historical documents for the analysis of the long-term population dynamics of fish species and ecosystem changes have recently been produced (Øiestad, 1994; Holm *et al.*, 2001; Jackson *et al.*, 2001; MacKenzie *et al.*, 2002). Despite the difficulties of interpreting results and often uncertain fishing effort, historical methods may provide additional important information to the data available from statistics published by fisheries. In some cases historical analyses may provide long-term data series, whereas fisheries statistics usually start in the Northeast Atlantic only in the second half of the 19th century. During this period and especially during the last half of the 20th century, many commercial species were seriously affected by overfishing. Superimposing the effects of overfishing and environmental factors makes it very difficult to evaluate their individual contribution.

Existing studies on the dynamics of fish populations, based on historical data in the North Atlantic (e.g. Summers, 1995; Holm *et al.*, 2001), only cover a part of the distributional range of many commercially important species. Species respond to environmental change as a whole, and populations near the extremes of their distributional range in most cases are more vulnerable to environmental change than those from the central parts. The Barents and the White Seas area is located on the border of the distributional range for a number of important, commercial boreal fish species including cod, halibut, herring, and Atlantic salmon. Therefore studies in this area may provide valuable information about population dynamics of these species.

There is evidence that temperature is the main causal factor influencing changes in the abundance of populations of boreal species. For Atlantic salmon (*Salmo salar* L.), the negative effects of low temperature can be critical in different life stages, particularly in the first months after migration of smolts from the river to the sea (Friedland, 1998; Friedland *et al.*, 2003) and during their freshwater stage when young fish are affected in the winter by different factors which can cause stress and mortality (see Cunjak *et al.*, 1998, for review). Although populations of Atlantic salmon are genetically isolated due to homing, the dynamics of populations from different parts of the distributional range are coherent. This coherence is related to the proximity of spawning areas of different populations to the locale where the oceanic phase of the Atlantic salmon life cycle takes place. Populations from different Russian rivers spend the oceanic part of their life cycle in the same areas, mostly in the waters adjacent to West Greenland and the Faroe Islands (Hansen and Quinn, 1998). Since mortality in the sea can be high, sometimes exceeding 95% (Hansen and Quinn, 1998), and survival in the sea is generally more variable than in freshwater (Chadwick, 1987), mortality levels of different populations are ultimately attributable to the same factors. This results in synchronous dynamics of populations. There is evidence that sea surface temperature is the most important factor influencing fluctuations of populations (Friedland *et al.*, 1998). At the same time, temperature conditions of the freshwater period, especially during the winter season, also have to be taken into account because winters in the Russian north are long and severe.

For cod (*Gadus morhua* L.) there are a number of studies that report a positive correlation between the strength of year classes of the Arcto-Norwegian (also known as Northeast Arctic) population and sea temperatures. Strong year classes of cod occur more frequently in warm periods than in cold ones. An important factor in causing such a relationship is feeding conditions and, in turn, abundance of *Calanus finmarchicus* spawning, which affects the survival and abundance of cod larvae for up to 5–6 months. Availability of other prey, notably capelin, is also a very important factor in determining the growth and survival of later stage cod (Nakken, 1994; Ottersen *et al.*, 1994; Smirnov and Smirnova, 2000).

In the waters surrounding Kildin Island, there are two species of halibut, Atlantic halibut (*Hippoglossus hippoglossus* L.), and blue halibut [*Reinhardtius hippoglossoides* (Walbaum)]. Historical sources do not allow us to identify which of these species fishers caught. However, some documents (RGADA Fond 1201. Op. 1. D. 4060. L. 23) allow evaluation of the average weight of fish. For instance, during two trips in 1761, the average weights were 19.7 and 21.0 kg (seven and 15 fish were weighed, respectively). In total, the average weight of halibut was approximately 11.0 kg. These values indicate that they were Atlantic halibut, because blue halibut do not reach such weights in this region (Milinsky, 1944a, b). Therefore it is most likely that Kildin fishers in the 18th century fished for both species but primarily for Atlantic halibut. Both species of halibut are boreal, and the Murman coast is situated on the border of their distributional range. As with other boreal species, their abundance is positively related to temperature.

In this study, we discuss catch data of salmon, cod, and halibut from the 17th and 18th centuries recently found in the Russian archives, and examine the influence of long-term temperature changes on the abundance of these species.

Case 1. Atlantic salmon from the White and Barents Sea Basin, 17th and 18th centuries

Records on the Atlantic salmon fisheries were found in archival documents of state central governmental departments and of large monasteries (Ju. A. Lajus *et al.*, 2001; Kraikovski *et al.*, 2003; D. L. Lajus *et al.* in press). We combined data on all spawning migrants entering rivers in different seasons. In most cases, it is not possible to determine exactly how many salmon existed 400 years ago because, for most existing catch data, the exploitation rates are unknown or fishing effort is inaccurate (Shearer, 1992; Parrish *et al.*, 1998). For our analysis, we only looked at data which are comparable with fishing effort within the series, and for Atlantic salmon with statistical data for the late 19th and beginning of the 20th centuries. Considerable difficulties arise from the quite complicated system of fisheries ownership. Fisheries in particular locations were usually shared between several owners, and it was necessary to know exactly the share of catches reported in the documents of particular owners in order to calculate the whole catch for the area. Also, it was important to consider carefully the changes in administrative units over time, because catches normally were reported for some particular administrative unit. For this purpose, we used a special handbook (Administrativno-territorial'noe…, 1997).

The main features of the organization of the salmon fisheries were more or less similar up until the middle of the 20th century. The main gear used was weirs, which were very traditional in their construction and places where the fish were caught. Usually the weir crossed the whole river and therefore was targeted to catch all fish entering the river. The quality of weirs was maintained by fishers (D. L. Lajus *et al.*, in press). Operating weirs in the same locations over centuries did not result in the disappearance of salmon populations. Salmon were able to pass weirs through accidental holes or when rains increased the water level in the river. In autumn weirs were sometimes destroyed by floating ice prior to the end of the salmon migration. The fish that escaped from weirs were able to maintain the population because, most probably, the main limitation for population reproduction was the availability of spawning grounds and areas suitable for the growing of juveniles. Other types of gear used for salmon fishing in the Russian north were drift and fixed nets.

The present study is based on the historical catch data for Atlantic salmon from four locations in the basin of the White and Barents Seas: the Onega and the Vyg Rivers, the Varzuga district, and the Western Murmansk area (Figure 1). Quantitative data on catches collected in Russian archives were reported in earlier papers (Ju. A. Lajus *et al.*, 2001, D. L. Lajus *et al.* in press. The primary data are available at http://www.hull.ac.uk/history/MHSC/hmap12ds09.htm.). Since the time-series obtained for each location is short (27, 12, 13, and 5 years for Onega, Vyg, Varzuga, and Western Murmansk, respectively), we pooled these four data sets into one using the following technique. The original catch data from the 17th and 18th centuries were divided by the average catch for the period 1875−1915, which was calculated from official statistics provided by the Arkhangelsk Statistical Committee (Otchet…, 1877−1908; Obzor…, 1905−1915) for the respective areas. Thus, we obtained figures reflecting the ratio of catches in the 17th and 18th centuries to catches for the period 1875−1915 for the four locations. Then we pooled the four sets into a single data set and obtained a time-series containing data for 51 years spanning the period 1615−1772. If for a particular year there were data for one location, it was used in further calculations. If for the same year we have data in two or more data sets, we used the average between them.

This approach implies that each location was roughly representative of the average, i.e. that there was a high correlation between them. The magnitude of the correlation between the locations cannot be checked using data from the 17th and 18th centuries because only a few years overlapped, but we did study the correlation for the later period, 1875−1915, when more data were available and fishing techniques remained similar. For that period, catches among the six districts in the European North of Russia indeed showed positive correlation: r ranged between 0.183 and 0.802, being statistically significant ($p < 0.05$) in almost all cases (Ju. A. Lajus *et al.*, 2001).

The catches show considerable year-to-year fluctuations (Figure 2). To study whether these fluctuations were random in time, we analysed autocorrelations with lags equal to 1 and 2 years. For lag = 1, $r = +0.301$, $n = 29$, and $p > 0.05$, and for lag = 2, $r = +0.510$, $n = 24$, and $p < 0.01$. This analysis shows that year-to-year variation in catches was not random.

We studied the relationship between Atlantic salmon catches and climate changes in the Russian north, where salmon spend the freshwater phase of their life cycle, and in

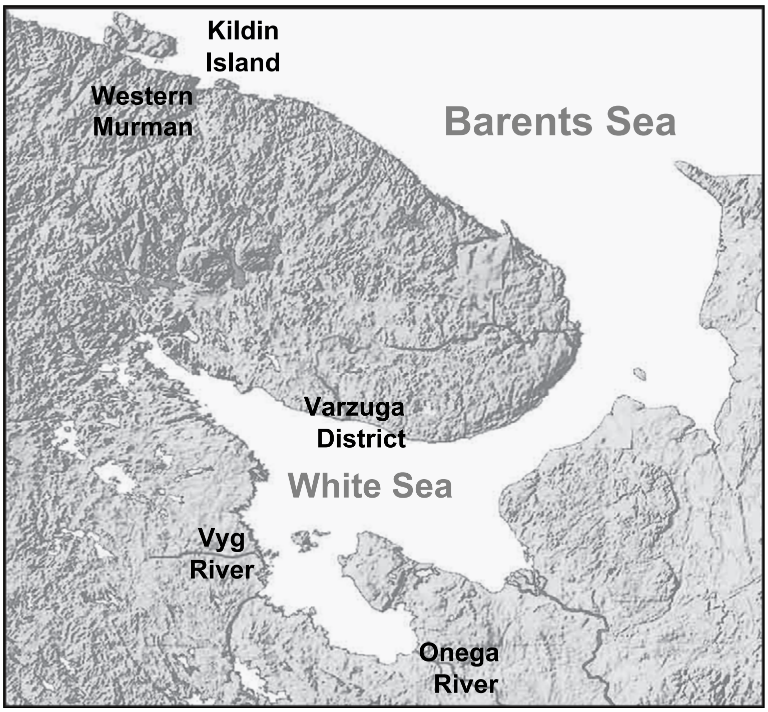

Figure 1. Locations of case studies. The Onega and Vyg rivers, Varzuga district, and Western Murman are locations where we obtained data on Atlantic salmon and Kildin Island is the location of the fishing station of the Solovetsky Monastery for cod and halibut fisheries.

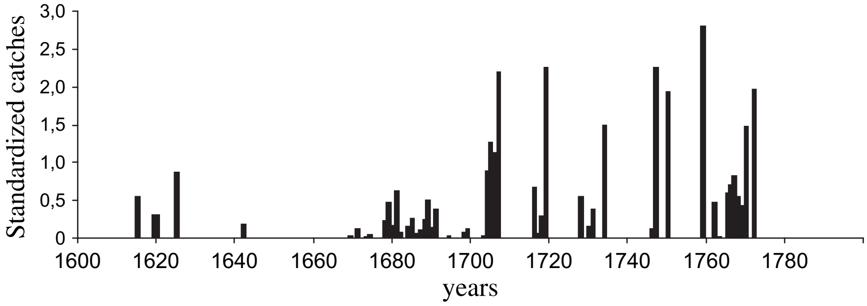

Figure 2. Catches of Atlantic salmon in the Russian north, 17th and 18th centuries: pooled data based on four case studies (see text for more details).

the Northern Atlantic where they spend the oceanic phase. There are time-series available for the Northern Atlantic allowing direct comparison of catch sizes with temperature. In northern Russia, the data are more difficult to quantify.

The period 1500–1850 in Europe is known as the "Little Ice Age" (Lamb, 1982; Fagan, 2002). In Russia, historians also recorded low temperatures at that time. According to Dulov's (1983) data for the European north of Russia, cold winters were mentioned seven times during the period 1551–1600, and mild ones five times. During the following 50 years (1601–1650), cold winters were mentioned 12 times and mild ones only twice. Between 1651 and 1700, the winters were characterized as unusually cold on 19 occasions, whereas mild winters were mentioned three times. An analysis of the data extracted from old Russian chronicles also leads to the conclusion that the cold period in the second half of the 17th century occurred in the Russian north as well (Borisenkov and Pasetsky, 1988). For the 18th century, the low-temperature periods were noted for 1738–1744 and 1755–1764 and at the very end of the century, on the basis of the timing of ice melt and freeze up of the Severnaya Dvina River (Brückner, 1890).

Comparing these climate data with catches shows a relationship: periods of low catches coincided with periods of low temperatures. In particular, not only were there considerably fewer catches in the Onega River during 1685–1691 than in the 19th and 20th centuries, but they were about half the size of the catches in 1614–1625 (Ju. A. Lajus *et al.*, 2001). In the Varzuga district, a decrease in catch was observed during 1625–1650. Unfortunately we have no data for the later period of the 17th century. In the 18th century there was a pronounced decrease of catches around the 1760s, especially in the Varzuga district. For instance, in 1763 catches were less than 1000 units, whereas in previous years they were normally about ten times as much (D. L. Lajus *et al.*, in press). Our results also agree with an eye-witness account. A. Fomin wrote at the end of the 18th century: "In the first half of the century in the Arkhangelsk region, the catches of salmon were quite large… That time it was imported overseas. Since that time catches have decreased until the salmon completely disappeared. In 1774 it appeared again… After that the catch grew…". (Fomin, 1805, p. 338).

In our formal statistical analysis, we compared our data with the known time-series on temperature and catches of other fish. The following time-series were used: (i) 10-year running mean of temperatures for the northeastern Atlantic (Iceland), which reflect temperatures in the warm season (Bergthórsson, 1969, cited in Figure 6 of Øiestad, 1994), (ii) 10-year means of temperature based on analysis of oxygen isotope from Camp Century on the Greenland ice sheet (Johnsen *et al.*, 1972), (iii) 10-year means of global temperature for the northern hemisphere based on proxy data from 17 sites worldwide (proxy types include tree rings, ice cores, corals, and historical documents (Jones *et al.*, 1998). Correlation for the period 1615–1793 (which includes all our data) was negative between the time-series from Iceland and Greenland ($r = -0.499$, $p < 0.101$), positive between global temperature and Greenlandic temperature ($r = +0.410$, $p < 0.001$), and almost absent between Icelandic and global temperature time-series ($r = 0.065$, $p > 0.05$). Also, we studied the relationship of our data to historical records on the catches of cod and herring along the Norwegian coast (Øiestad, 1994).

When analysing the relationship between two time-series of data, we used standard Pearson product-moment correlations. In our case, we have short positively autocorrelated time-series, so the data points were not statistically independent. This needs to be accounted for when estimating standard significance levels (Ottersen *et al.*, 2002). To deal with this, we estimated the effective number of independent observations (N_e), adjusted for order 1 and 2 autocorrelations, using the formula of Quenouille (1952):

$$N_e = N/(1 + 2r_{a1}r_{b1} + 2r_{a2}r_{b2}),$$

where N is the number of data points common to the two series, r_{a1} and r_{b1} are the lag-one autocorrelations, and r_{a2} and r_{b2} are the lag-two autocorrelations for the time-series a and b.

Catches of Atlantic salmon showed a positive significant correlation with global temperature ($r = +0.556$, $p < 0.05$), but almost no relationship with other temperature time-series ($r = +0.193$, $p > 0.05$ and $r = +0.006$, $p > 0.05$ for Greenlandic and Icelandic series, respectively). Correlation of salmon catches with cod and herring landings along the Norwegian coast was positive and relatively high ($r = +0.462$, $p < 0.05$; $r = +0.413$, $p > 0.05$, respectively). As population sizes of cod and herring in their northern distribution range are positively correlated with temperature (see analysis below), these results probably reflect the effect of temperature on populations of Atlantic salmon, i.e. a decrease of temperature leads to a decline in the Atlantic salmon populations.

It is interesting that there is archaeological evidence to show that in the 17th century there was a major change in the distribution range of Atlantic salmon in North America (Carlson, 1988, 1996). There was a mass appearance of salmon remains in New England (the southwestern limit of its distribution), perhaps associated with cooling, which made conditions more amenable to salmon in New England and conversely less amenable in the Russian north.

In addition to catch sizes, historical records provide some data on the weight of fish that sometimes reveal unexpected results. In particular, average weight of salmon in the Varzuga district in the 20th century ranged between approximately 2.5 and 3.0 kg (Kazakov *et al.*, 1992). Similar weights are reported in historical documents from the 17th and 18th centuries (D. L. Lajus *et al.*, in press). At the same time, we found a remarkable increase in the average weight of salmon in the Varzuga district in 1763 that occurred synchronously in several locations in this area. The average weight of salmon in the Varzuga district in 1763 was 6.3 kg, and in one location, the Indera River, the average weight of 33 fish was 11.5 kg. This is very close to the maximum weight of Atlantic salmon for this area today. The weights of three large fish caught in the area were 13.0, 11.8, and 10.9 kg (Kazakov *et al.*, 1992). Although we have no individual weights of salmon for 1763, undoubtedly the weight of several of the fish that year must have exceeded these values.

Both stable average weights for periods covering several centuries and its drastic increase in one particular year are of interest. The similarity between weights of salmon in the 17th and the 18th centuries and in the 20th century indicates no or weak selective fishing mortality during the last few centuries and probably no major changes in available food. The drastic increase in average weight in 1763 is probably due to unusual environmental conditions. Remarkably, that increase of weight coincides with a decrease in catches. Likely, these two observations are interrelated and caused by some common factor.

One possible explanation is that salmon spent a longer time in the sea during that period. Since salmon grow mostly in the sea, an increase in the duration of their sea life should considerably increase their weight as a result of longer feeding. This is especially important for salmon from the Varzuga area, which usually spend only 1 or 2 years in the sea (Kazakov *et al.*, 1992). Increases in the duration of sea life could simultaneously cause a decrease in the number of fish caught because of a decrease in anadromous migrants, which results from an increased occurrence of mortality in the sea. One needs also to keep in mind that a decrease in the number of salmon caught resulted from a decrease in the proportion of small fish caught, because fishing gear in this area was the most suitable for catching smaller fish.

One possible reason for such notable changes in salmon weight and number is the extreme temperature (probably in the sea), but by what particular mechanism remains unclear. Another explanation deals with extreme wintering conditions in the rivers. Brückner (1890) recorded the late ice melting in the Severnaia Dvina River during the period 1755−1764. This may cause low survival of parr during wintering, which is one of the most critical periods for salmon (Cunjak *et al.*, 1998). Few parr may result in comparatively little competition for food and hence fast growth, and on the other hand, in a low number of spawners entering rivers. Because these two suggestions do not contradict each other, each may partially explain the phenomenon.

Case 2. Cod and halibut near Kildin Island, the 18th century

We have found two types of catch records for the Kildin fisheries: (i) daily catches and (ii) information on the total amount of fish products: salted and dried cod, salted halibut, cod oil, etc.

Daily records were kept by the cloistral agent who supervised the fisheries of the Kildin station. He recorded the date, the name of the helmsman of the boat, and the weight of the different kinds of fish (mostly cod and halibut) caught. One such book included the number of fish and provided estimates of the average weight of the fish. Also, one of the documents from 1756 (RGADA Fond 1201. Op. 2. D. 703. L. 84 − 84 ob) permits us to assess the coefficient of transformation from salted to raw fish because information on both was provided. This coefficient appeared equal to be 1.200 for cod and 1.230 for halibut. Salted and raw fish, where data on both were available, were highly correlated ($r = +0.963$, $p < 0.001$, $n = 7$ for cod; and $r = +0.975$, $p < 0.001$, $n = 7$ for halibut). We have assumed that this indicates that the raw fish was mostly used for salting. When data on both raw and salted fish were available, we used the average of them.

Data on the catches for the Kildin Island fisheries are presented in Table 1 and Figure 3. Catches of cod and halibut show a slight positive correlation with each other, although it was not significant ($r = +0.124$, $p > 0.05$). We suppose that joint dynamics of catches of the two species result from the superimposition of two processes. First, the positive relationship between them is due to dependence on a common factor (variation of climate or fishing effort), and

Table 1. Data on cod and halibut fisheries of Solovetsky Monastery at Kildin Island, 18th century, (RGADA Fond 1201).

Year	No. of boats	Salted cod, kg	Raw cod (adjusted from salted) kg	Cod, direct data, kg	Combined catches of cod (based on direct data and salted fish), kg	Cod, catch per boat, kg	Salted halibut, kg	Raw halibut (adjusted from salted), kg	Halibut, direct data, kg	Combined catches of halibut (based on direct data and salted fish), kg	Halibut, catch per boat, kg	Cod and halibut, summarized catches, kg	Sum of combined cod and halibut catches, kg	Sum of catches of cod and halibut, kg	Cod and halibut per boat, kg	Source (RGADA Fond 1201)
1710	4			16 757	16 757	4 189			8 124	8 124	2 031		24 881	24 881	6 220	Op. 1. D. 807. L. 1 ob - 5.
1711	4			11 679	11 679	2 920			14 087	14 087	3 522		25 766	25 766	6 441	Op. 1. D. 825. L. 1 - 2.
1717		5 667	6 812		6 812	1 362	1 884	2 321		2 321	464		9 133	9 133	1 827	Op. 1. D. 875. L. 1, 2.
1719												25 766		25 766	5 153	Op. 5. D. 1530. L. 261.
1725												29 458		29 458	5 892	Op. 5. D. 1530. L. 261.
1740												47 961		47 961	9 592	Op. 5. D. 1530. L. 261.
1741												40 491		40 491	8 098	Op. 5. D. 1530. L. 261.
1742												42 211		42 211	8 442	Op. 5. D. 1530. L. 261.
1743												67 731		67 731	13 546	Op. 5. D. 1530. L. 261.
1744												51 188		51 188	10 238	Op. 5. D. 1530. L. 261.
1745	5	21 188	25 467		25 467	5 093	17 142	21 119		21 119	4 224		46 586	46 586	9 317	Op. 5. D. 1530. L. 298.
1746												62 604		62 604	12 521	Op. 5. D. 1530. L. 261.
1747												40 573		40 573	8 115	Op. 5. D. 1530. L. 261.
1748												39 492		39 492	7 898	Op. 5. D. 1530. L. 261.
1749												50 254		50 254	10 051	Op. 5. D. 1530. L. 261.
1750												58 591		58 591	11 718	Op. 5. D. 1530. L. 261.
1751												67 158		67 158	13 432	Op. 5. D. 1530. L. 261.
1754	5	47 830	57 491		57 491	11 498	15 037	18 525		18 525	3 705		76 017	76 017	15 203	D. 3008. L. 5.
1755	5	40 164	48 277		48 277	9 655	25 258	31 118		31 118	6 224		79 395	79 395	15 879	D. 3144. L. 14, 36.
1761	6	25 487	30 636	33 022	31 829	5 305	35 430	43 650	51 859	47 754	7 959		79 583	79 583	13 264	D. 4060. L. 23.
1762	6	30 205	36 306		36 306	6 051	12 940	15 942		15 942	2 657		52 248	52 248	8 708	D. 4475. L. 6 ob, D. 4280. L. 6.
1763		17 555	21 101	20 803	20 952	4 190	32 400	39 916	41 966	40 941	8 188		61 893	61 893	12 379	D. 4824. L. 3., D. 4475. L. 3 ob
1764		11 171	13 428	6 077	9 752	1 950	18 509	22 804	15 086	18 945	3 789		28 697	28 697	5 739	Op. 5. D. 4655. L. 9 ob
1765		9 054	10 883		10 883	2 177	7 744	9 540		9 540	1 908		20 423	20 423	4 085	D. 4824. L. 3.
1766		9 951	11 961		11 961	2 392	13 182	16 240		16 240	3 248		28 201	28 201	5 640	D. 4824. L. 3.
1767		7 404	8 899		8 899	1 780	15 070	18 566		18 566	3 713		27 465	27 465	5 493	D. 4824. L. 1 ob - 2.
1784	5	24 750	29 750	28 190	28 970	5 794	3 391	4 177	4 308	4 243	849		33 212	33 212	6 642	D. 5291. L. 720
1785	5	4 283	5 149	4 921	5 035	1 007	23 800	29 322	30 057	29 690	5 938		34 724	34 724	6 945	D. 5281. L. 17 ob - 18.
1786				33 645	33 645	6 729			20 844	20 844	4 169		54 488	54 488	10 898	D. 5281. L. 17 ob - 18.
1787				7 854	7 854	1 571			16 724	16 724	3 345		24 578	24 578	4 916	D. 5281. L. 17 ob - 18.
1789		11 122	13 369	15 332	14 350	2 870	16 284	20 062	21 425	20 743	4 149		35 093	35 093	7 019	D. 5433. L. 294.
1791				10 254	10 254	2 051			8 471	8 471	1 694		18 725	18 725	3 745	D. 5433. L. 294.
1793	5	29 124	35 007	36 822	35 914	7 183	1 343	1 655	1 605	1 630	326		37 544	37 544	7 509	Op. 2. D. 1965. L. 3.

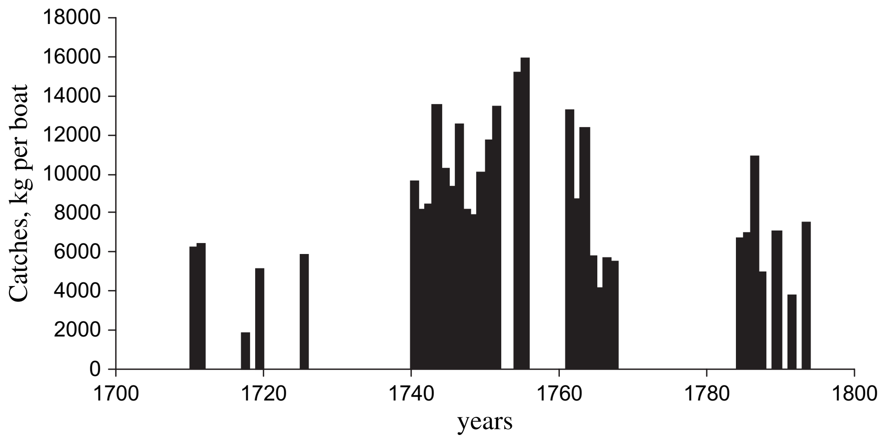

Figure 3. Catches of cod and halibut fisheries of the Solovetsky Monastery on Kildin Island, 18th century.

second, the negative relationship is in part due to alternative fishing strategies for these two species. Cod were fished offshore or inshore using longline or hook and line, whereas halibut were fished mostly offshore using longline. Since halibut provided more valuable products (Hellie, 1999), offshore longline fisheries were probably chosen over inshore hook and line fisheries when weather conditions were good enough for offshore fishing. In bad weather only inshore fishing was possible, so no halibut were registered in these catches. We tried to check this suggestion statistically by examining the relationship between residuals from the 2-year moving averages (without data for the missing years) of catches of both species. Indeed, we found a negative correlation between the residuals ($r = -0.258$, $p > 0.05$), i.e. the more halibut, the less cod caught in a particular year. This potentially confounds the higher positive correlation which can result from variation in weather conditions or fishing effort. Overall positive correlation between cod and halibut catch shows that the effect of dependence from the common factor slightly exceeds the effect of choosing between alternative fishing strategies.

For 10 of 33 years, the number of boats involved in the fisheries at Kildin Island was recorded (Table 1), reflecting fishing effort. The number of boats ranged from four to six and was five in most cases. We divided the total catch by the number of boats for years where it was known and thus obtained estimates of the catch per unit effort, cpue, which reflects population trend better than the total catch. When no data on the number of boats involved in fisheries were available, we divided the total catch by the average number of boats, i.e. five. Given that the correlation between total catch and catch per boat for those years where both data were available is very high ($r = +0.968$, $p < 0.01$), the total catch divided by five also characterizes the cpue well.

Catches per boat showed a positive autocorrelation. For a 1-year lag, $r = +0.456$, $p < 0.05$, and for a 2-year lag, $r = +0.369$, $p > 0.05$. This proves the presence of some long-term (longer than 1 or 2 years) fluctuations in catches. Catches were rather low at the beginning of the 18th century, increased in the 1740s, and then decreased at the end of the 1740s. In the late 1750s we observe maximum catches for the century and, from the 1760s up to the end of the century, catches decreased. It seems that this pattern shows some similarities with the dynamics of salmon populations, although detailed comparison is difficult because of gaps in both data sets.

As we did for Atlantic salmon, we investigated the relationship of cod and halibut catches to available data from literature on temperatures and catches of commercial fish in the region. Since it is known that environmental conditions affect the recruitment of marine fish, we also introduced 5- and 10-year lags when analysing relationships. The analysis showed a negative correlation of cod and halibut catches with temperature in Iceland ($r = -0.466$, $p > 0.05$), and a positive correlation with global temperature ($r = +0.310$, $p > 0.05$) and almost no correlation with temperature in Greenland ($r = +0.045$, $p > 0.05$). Interestingly, the use of a 30-year moving average instead of a 10-year one, as is sometimes recommended (Klyashtorin, 2001), resulted in a significant positive correlation with global temperature ($r = 0.642$, $p < 0.05$) and did not effect other relationships. The introduction of 5- and 10-year lags did not significantly change the results. There is, however, a positive correlation of our time-series with landings of cod ($r = +0.205$, $p \geq 0.05$) and herring ($r = +0.653$, $p < 0.05$), reported by Øiestad (1994).

In general, our data on cod and halibut show similarities with data reported by Øiestad (1994) for Norwegian cod and herring. Data by Øiestad were based on the taxation and landing of cod and herring in Norway, and thus do not take into account fishing effort. Our data refer to a very restricted area, namely Kildin Island, and cover only 33 years of the 18th century, but account for fishing effort. As both sets are completely independent of each other, their positive correlation shows their dependence on a common factor, which is most likely climate.

All marine species involved in the analysis − cod, herring, and halibut − are boreal species and are expected to show similar response to environmental changes. In particular, the populations are expected to increase in warm periods and decrease in cold ones. However, correlation with temperature shows different patterns for different temperature curves. Catches show a negative relationship with temperatures in Iceland, close to statistical significance ($r = -0.466$, $p > 0.05$). This finding contradicts the conclusion of Øiestad (1994) about the positive correlation of cod and herring catches with temperature in Iceland. Øiestad based his conclusion on visual analysis of catch and temperature curves. However, our re-analysis of Øiestad's time-series using a coefficient of correlation showed a significant negative correlation of catches of both cod and herring to temperature in Iceland ($r = -0.639$, $p < 0.01$, and $r = -0.590$, $p < 0.01$, for cod and herring, respectively, for the period 1710−1793). Analysis of the correlations for a longer period, 1600−1800, also gave significant negative correlations ($r = -0.334$, $p < 0.05$, and $r = -0.439$, $p < 0.01$ for cod and herring, respectively). Similar to our data, Øiestad's data showed a positive and significant relationship with the global temperature curve for the period 1710−1793 ($r = +0.605$, $p < 0.01$, and $r = +0.444$, $p < 0.05$ for cod and herring, respectively). The correlation to temperature in Greenland had different patterns for cod ($r = +0.842$, $p < 0.001$) and herring ($r = +0.082$, $p > 0.05$).

Therefore, our data on cod and halibut fisheries at Kildin Island demonstrate a tendency towards a positive relationship between catches and temperature. Potentially, such a relationship can be caused by several factors, such as the dependence of population size on environmental conditions, changes in fish migration pathways as a response to changes in currents, which are also related to environmental changes, or alteration in fishing effort. All of these factors must be taken into account when considering the results of our case study of the Kildin fisheries. Although the number of boats participating in fisheries was rather stable over the entire period of the study, it is difficult to account for the effect of weather conditions, which are important for small fishing boats. Under colder and harsher weather conditions, the fisheries are less productive. Migrations of cod and halibut are known to be highly dependent on currents: in warm years fish migrate eastwards and thus can become less available to fisheries. Population size is known to change in response to environmental conditions, and probably interacts with other factors resulting in the observed relationships.

The relationships, however, are heterogeneous with respect to different temperature time-series. The heterogeneity of these relationships deals with discordance among different temperature curves. Time-series of global temperature in the northern hemisphere, based on numerous locations and several proxies, shows that the patterns are most similar to those for the modern period when climate and population size relationships were studied in great detail. It must be stressed that the expected positive relationship has been found using both our original time-series and the published time-series for cod and herring in Øiestad (1994).

Conclusion

Historical data on fisheries were collected for non-scientific reasons. They are usually fragmentary and estimate fishing effort poorly. At the same time, historical data may provide long time-series and give an opportunity to study fish populations in times when no human impact like overfishing, habit degradation, or chemical pollution took place. The growing interest in the use of historical data in analysing the effect of environmental changes on fish populations shows that, in many cases, the advantages of historical approaches prevail over the disadvantages.

In our study, we analysed the dynamics of populations of Atlantic salmon, cod, and halibut 250−400 years ago in the White and Barents Seas area, and their response to climate changes. These historical data demonstrate a tendency towards a positive relationship between catches and temperature. This possibly reveals a dependence of population size on temperature, which is expected, based on present data on cod and halibut biology. At the same time, one also must take into account possible changes in migration routes and fishing effort. These factors are much less significant in the case of Atlantic salmon, as they were caught mostly in rivers. In this case, the more straightforward interpretation of our results on the effect of temperature on population size is more justified.

Thus, we believe that our study casts light on the long-term population dynamics of the species, and its value will increase when more historical data become available. If additional data for the same periods and locations are found, they would allow verification of our data. Additionally, data from other periods and other locations would be important. Given that the fluctuations of populations of Atlantic cod in different parts of its distributional range have opposing responses to climate changes, i.e. warm periods are favourable for northern populations but stressful for southern (Garrod and Schumacher, 1994; Smirnov and Smirnova, 2000), data from different periods would allow us to assemble a more complete picture. It will take significant time and effort from both historians and biologists to obtain that more complete picture.

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