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Geographical Distribution of Fish Catches and Temperature Variations in the Northeast Atlantic Since 1945

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Abstract

Warming of the northeast Atlantic is expected to affect the location and productivity of fish stocks. It is examined whether variations in catches of cod, herring, mackerel, anchovy and sardines in the ICES statistical areas are related to variations in ocean temperature. Temperatures at certain locations along the Norwegian coast are taken as proxies for temperatures in the Norwegian Sea and the North Sea. It is found that the catches of cod in the North Sea are inversely correlated with temperature and that recruitment and catches of cod in the Norwegian Sea and the Barents Sea are positively related to temperature. There is also some indication of a positive correlation between temperature and the catches of mackerel in the North Sea and the Norwegian Sea, and between temperature and the catches of sardines in the North Sea.

1. INTRODUCTION

The global warming that is widely expected to occur over this century will not be confined to the atmosphere; the oceans would also get warmer. Such changes are likely to affect fish migrations and habitat, augmenting fish stocks in some places and decreasing them in others, perhaps causing stocks to be displaced permanently to new habitats. Over the next 50 years, temperatures in the Northeast Atlantic, and especially the Barents Sea, are expected to rise by 1 - 3 degrees. This is expected to lead to an increase of the Northeast Arctic cod stock and to displace it in a northeasterly direction, while capelin, another important stock in this area, is expected to retreat further north and northeast. The herring stock in the Norwegian Sea is expected to be favorably affected, and mackerel is expected to migrate to a greater extent into the Norwegian Sea. As a result of a warming of the North Sea, the cod stock is expected to decline while anchovy and sardine would become more abundant.[1]

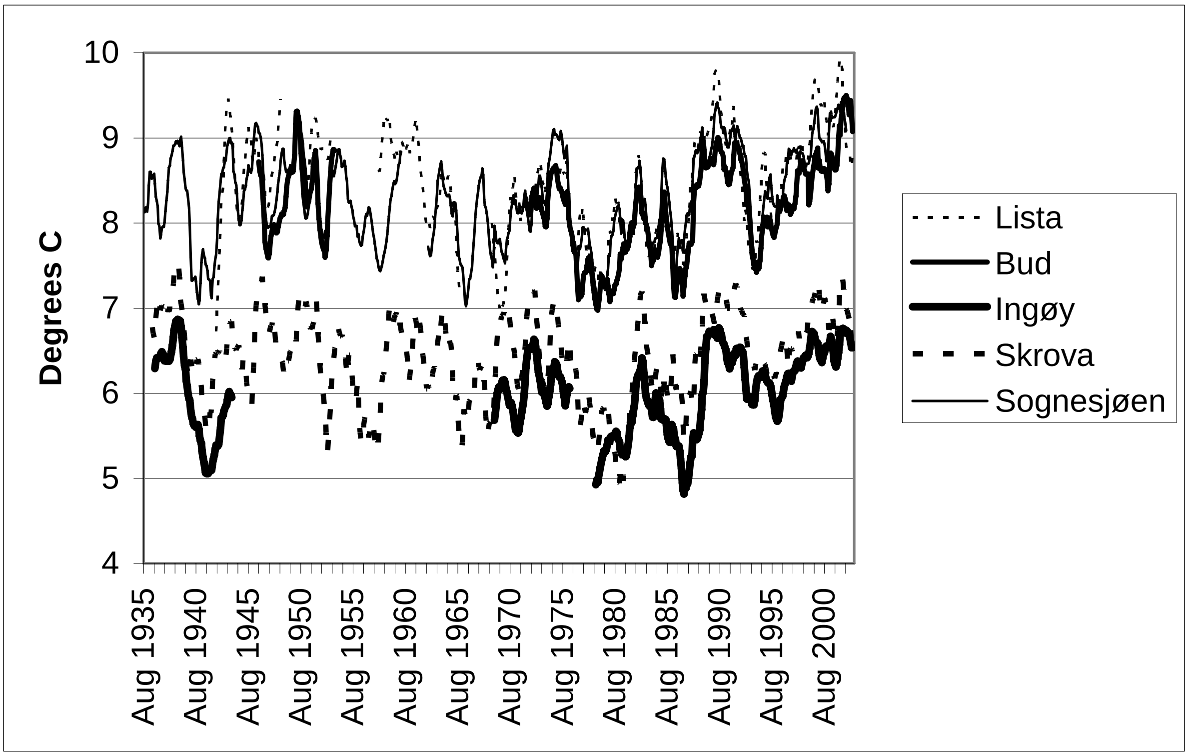

Figure 1

Twelve-months moving average of temperatures in the 1-50 m depth range, centered in month 6, at five locations along the Norwegian coast.

Temperature changes of this magnitude are not unparalleled in recent times. Figure 1 shows a 12-months moving average of temperatures at five locations along the Norwegian coast, from Lista in the far south to Ingøy in the far north.[2] The series are incomplete, and even more so than this figure shows, as we have interpolated for missing months when the gap in the data is no more than 8 consecutive months.[3] The difference between the highest and lowest average annual temperatures is 2 - 3 degrees. There is little or no trend in the series; the temperatures

[1] On these changes, see Stenevik and Sundby (2003).
[2] These observations are taken at less than 50 meters depth. Source: Institute of Marine Research, Bergen.
[3] On the interpolation, see Appendix.

in the beginning of this century were no higher (northern part of the coast) or just slightly higher (southern part of the coast) than in the mid- to late 1930s. The temperature series in the north (Skrova in Lofoten and Ingøy in Finnmark) show temperatures about two degrees lower than in the south (Bud in Møre and Romsdal, Sognesjøen at the mouth of the Sognefjord, and Lista in the far south). Table 1 shows the pairwise correlation of the moving averages of the temperatures. The series in the south (Lista, Sognesjøen, Bud) are closely correlated and so are the series in the north (Skrova, Ingøy), but there is also a significant correlation between series in the south and the north. Somewhat surprisingly, the correlation between the temperature series in the south is higher for Ingøy than for Skrova, even if Ingøy is further north.

Table 1

Pairwise correlation between 12-months moving averages of temperatures at five locations along the Norwegian coast.

	Lista	*Sognesjøen*	*Bud*	*Skrova*	*Ingøy*
Lista	1				
Sognesjøen	0.7959	1			
Bud	0.8006	0.8969	1		
Skrova	0.5415	0.6391	0.7637	1	
Ingøy	0.6813	0.6992	0.8201	0.8631	1

Some indication whether the expected temperature change of 1 - 3 degrees over the next 50 years will be associated with changes in fish migrations and abundance might, therefore, be gleaned from studying the changes in catches over the period covered by the time series in Figure 1. At the outset, it is necessary to warn against two possible reasons why this approach might not be fruitful. First, there have been major changes in fishing technology and demand for fish over this period. The fact that the catches of certain types of fish were low 50 years ago, say, need have nothing to do with climate change but everything to do with improved technology or a rising demand. The precipitous decline in herring catches around 1970 was most likely caused by overfishing due to a sudden improvement in technology (fish finding equipment and mechanical hauling of purse seines). The capelin fishery emerged as a result of disappearance of herring as feedstock for the fish meal industry. Only for stocks that have been fished at a reasonably even rate would changes in the pattern of catches reflect changes in stock abundance in different areas.

The other reason why past changes in catches in response to changes in temperature, or the lack thereof, might not reflect possible responses to a future rise in temperature is that since the early 20th century when observations began, ocean temperatures in the northeast Atlantic have fluctuated, but whether there is a rising trend can be debated.[4] If ocean temperatures rise as a result of global warming we would be experiencing an upward trend, but undoubtedly with substantial fluctuations around that trend. It is likely that the response of fish populations to changes in temperatures will not be smooth and continuous. Instead, qualitative changes are likely to be triggered as the temperature exceeds or falls below a certain threshold. A rising trend in the ocean temperature would at some point bring us across such a threshold, but the

[4] As Figure 1 shows, there has been no trend since the mid- to late 1930s, but there has been a rising trend since early in the 20th century, judging from the Kola-series (see Stenevik and Sundby, 2003). During the warm period in the 1920s and 30s a number of stocks moved further north, cf. Vilhjálmsson (1997) and Drinkwater (2005).

question arises what would occur as a result of temporary setbacks due to fluctuations around the trend.

In this paper we study changes in the catches of key fish species (cod, herring, mackerel, anchovies and sardines) in the North Sea and the Northeast Atlantic since the Second World War. Are these changes related to changes in temperature, indicating what might happen as a result of a temperature rise in this area? The catch statistics have been obtained from the ICES catch data base, which goes back to 1973, and its publication *Bulletin statistique des pêches maritimes* for earlier years.[5] The temperature statistics used are three of the series shown in Figure 1; Skrova in Lofoten, Bud in Møre and Romsdal just north of the 62nd parallel, and Sognesjøen just south of the 62nd parallel. These observations are taken close to the Norwegian coast, but their variability probably follows a pattern similar to temperatures further offshore where much of the fish is found and caught. We postulate a relationship where annual catches (C) are related to average temperatures (T) over a number of months for the same year and for earlier years:

$$C_t = a + \sum_{i=t}^{t-x} b_{t-i} T_i$$

In all cases, the Durbin-Watson statistic indicates problems of serial correlation in regression of variable levels. Hence differences in logarithms were used:

$$\ln C_t - \ln C_{t-1} = a + \sum_{i=t}^{t-x} b_{t-i} \left(\ln T_i - \ln T_{i-1} \right)$$

Below we report the significance (t-values) of the estimated *b*-coefficients, as well as the Durbin-Watson statistic for serial correlation of residuals.

2. ANALYSIS OF INDIVIDUAL FISH STOCKS

Cod

The Northeast Arctic cod stock supports a large fishery in the Norwegian Sea and the Barents Sea. The stock is shared evenly between Norway and Russia, with about 15 percent of the total allowable catch being set aside for third countries. This stock is the most important one exploited by the Norwegian fishing fleet, in terms of value.

As stated in the Introduction, rising temperature in the Norwegian Sea and the Barents Sea is expected to increase the productivity of this stock and to change its distribution towards the northeast. One way in which rising temperature would increase the productivity of the stock is through enhanced recruitment, i.e., improved survival of young cod (less than 3 years old). The results in Table 2 indicate a significant relationship between recruitment of 3 year old fish into the stock and average monthly temperature at Skrova in Lofoten in the period February to May.[6] This is the period when the cod spawn (which mainly occurs in the Lofoten area) and also the period when most fish are caught from this stock. The significance of the three year lag presumably reflects favorable effects of a higher temperature on the survival of eggs, as

[5] ICES is the acronym for the International Council for the Exploration of the Sea, an organization based in Copenhagen.
[6] Data on recruitment of 3-years old fish are from the ICES Arctic Fisheries Working Group 2004, Table 10.

this is the year when they were spawned, but the effect on one year old fish appears just as strong. No significant effect of higher temperature lagged one year (effect on two year old fish) was detected, however. Figure 2 shows recruitment of three year old fish and a 2-years moving average of temperatures at Skrova lagged two years. By an *x*-years moving average of temperature (*T*) lagged *h* years we mean that the last observation included in the average has been lagged *h* years, i.e.

$$T_{x,t-h} = \frac{\sum_{\tau=t-(x-1)-h}^{t-h} T_\tau}{x}$$

here and elsewhere in the paper, except for the 12-months moving average in Figure 1, which is centered on Month 6.

Table 2

Regressions of recruitment of 3-years old cod on average temperature at Skrova February to May. Here and elsewhere, ** denotes significance at the 5% level and * at the 10% level.

t-values for temperature		D-W statistic
Lagged 2 years	Lagged 3 years	
3.29**	3.18**	1.91

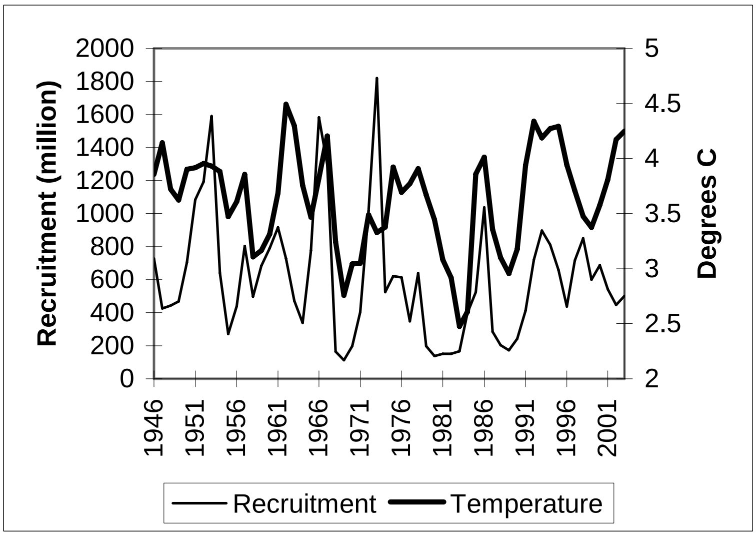

Figure 2

Recruitment of 3-years old cod to the Northeast Arctic stock and a 2-years moving average of average monthly temperature February to May at Skrova, lagged 2 years.

The increase in recruitment of young fish caused by higher temperature will in due course lead to an increase in catches, for any given rate of exploitation. This effect will come later than the effect on recruitment, because most of the fish caught are older than 3 years. Table 3 shows the results of regressing catches on average monthly temperature at Skrova in

February-May. The results indicate that catches rise in response to rises in temperature with a time lag of 4 to 5 years. If this improvement were due solely to a better recruitment we would have expected a time lag of 5 years or more, since most of the catches consist of fish 5 years and older, but it is possible that the growth of fish 4 years and older is also enhanced by a higher temperature, although this did not seem to be the case for 3 year old fish (cf. Table 2). Figure 3 shows catches of Northeast Arctic cod and a 2-years moving average of temperature at Skrova, lagged 4 years.

Table 3

Regression of catches of Northeast Arctic cod on average monthly temperatures at Skrova in February to May.

t-values for temperature		D-W statistic
Lagged 4 years	Lagged 5 years	
1.81*	1.35	1.90

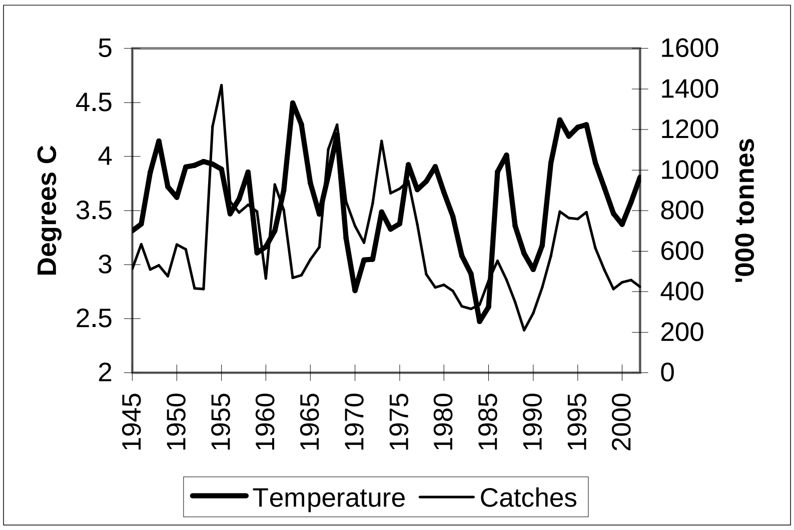

Figure 3

Catches of cod in the Norwegian Sea and the Barents Sea and a 2-years moving average of average monthly temperature February to May at Skrova, lagged 4 years.

The catches of Northeast Arctic cod occur in the Barents Sea and the Norwegian Sea (ICES statistical areas I and II, respectively). The northeasterly shift of the stock expected to happen as a result of rising temperature should be reflected in a larger share of the catches being taken in the Barents Sea in years when the temperature is high. A regression of the share of catches taken in the Barents Sea on the average monthly temperature at Skrova in February to May gives a significant positive result for temperature lagged three years (Table 4).[7] It is not clear why a change in temperature should affect the distribution of fish with a time lag of 3 years, and so it seems most reasonable to regard this result as spurious. Another reason for

[7] The first year in the regression is 1948, as the share of catches taken in the Barents Sea was very small in the first years after the Second World War. This could be due to the recovery from the war for the nations fishing in this area at the time (mainly Norway, the United Kingdom, and the Soviet Union).

dismissing this result is that serial correlation in the residuals is a serious problem. The share of catches taken in the Barents Sea is shown in Figure 4. There appear to have been periods when temperature and the share of catches taken in the Barents Sea moved together, but the relationship is not persistent enough to be statistically significant.

Table 4

Regression of the share of catches of cod in ICES areas I and II taken in the Barents Sea (Area I) on average monthly temperature at Skrova February to May.

t-values for temperature	D-W statistic
Lagged 3 yrs	
2.39**	0.67

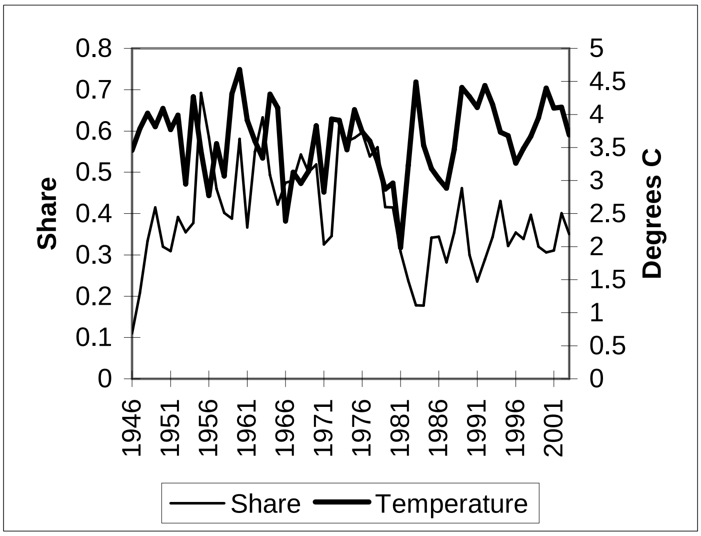

Figure 4

The share of catches of cod in the Norwegian Sea and Barents Sea taken in the Barents Sea and the average monthly temperature February to May at Skrova.

As to cod in the North Sea, Table 5 shows the results of regressing the catches of cod in the North Sea[8] on the average monthly temperature in Sognesjøen in the summer (June to September).[9] There is a significant negative correlation between catches of cod in the North Sea and temperature in Sognesjøen, with lags of up to 6 years. Figure 5 shows the catches and a 7-years moving average of the temperature series. The negative relationship between the catches of cod and temperature is striking. This is probably the result of the North Sea being a marginal area for the cod, in terms of ambient temperatures; North Sea cod has been heavily exploited for a long time, and there is reason to believe that variations in catches reflect

[8] ICES statistical area IV.

[9] Sognesjøen is just south of the 62nd parallel and thus in the very northern part of the North Sea. The series for Lista is probably more representative for the North Sea, but there are many more missing observations in that series. Two numbers that are missing in the series for Sognesjøen have been replaced by observations for Lista, after adjusting for higher temperatures at Lista in the adjacent years.

variations in the stock itself.[10] The present concern over overexploitation of the cod stock in the North Sea may thus be exaggerated; the recent decline in catches could be largely or wholly due to changes in environmental conditions.

Table 5

Regression of catches of cod in the North Sea on average monthly temperature June to September in Sognesjøen.

	t-values for temperature							D-W statistic
Lags	0	1	2	3	4	5	6	
	-2.94**	-2.07**	-3.66**	-2.56**	-2.54**	-1.90*	-2.49**	1.99

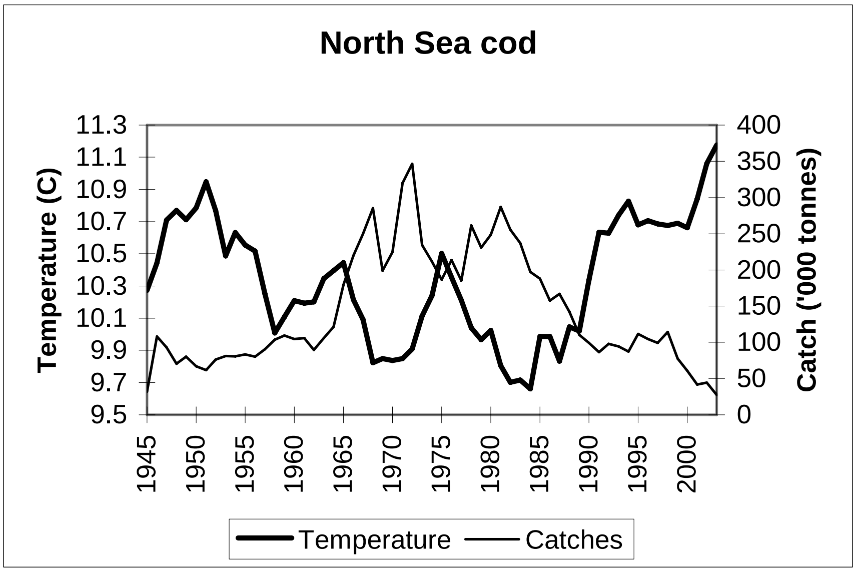

Figure 5

Catches of North Sea cod and 7-years moving average of temperatures in Sognesjøen.

Mackerel

Warming of the Norwegian Sea is expected to lead to greater occurrence of mackerel in this area. Figure 6 shows the catches of mackerel in the Norwegian Sea and the temperature at Bud in Møre and Romsdal in the summer months (June to September) since 1972.[11] Bud is on the Norwegian coast just north of the 62nd parallel and thus probably indicative of the temperature in the southern part of the Norwegian Sea (the correlation with the temperature at Skrova in Lofoten, in the northern part of the Norwegian Sea, is high, however; see Table 1). The catches of mackerel increased from almost nothing in the 1970s to a peak of 170,000 tonnes in the 1990s, but have fallen since. The temperature reached a low of 8.5 degrees in 1977 and has been on an increasing trend since then, exceeding 12 degrees in 2002. The figure suggests a correlation between temperature and catches of mackerel. This is, however,

[10] A regression of cod recruitment on temperature, both contemporaneous and lagged one year (North Sea cod are recruited to the fishery at an age of one year), was unsuccessful.
[11] Fishing of mackerel mainly takes place in August and September.

only weakly supported by statistical analysis. Table 6 shows positive correlation between contemporary temperature and lagged temperature of up to two years, but none of the t-values is significant.

Table 6

Regression of catches of mackerel in the Norwegian Sea on average monthly temperature at Bud June to September, 1972 - 2003.

	t-values for temperature			D-W statistic
Lag (years)	0	1	2	
	1.68	0.63	0.6	1.90

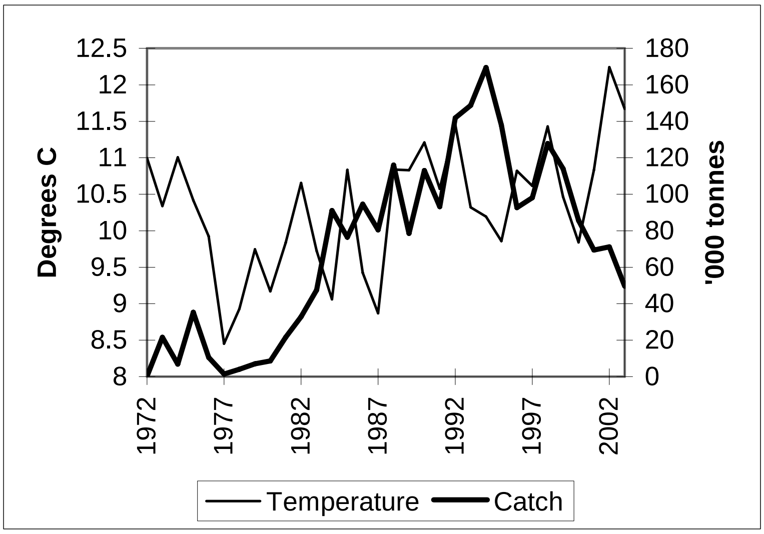

Figure 6

Catches of mackerel in the Norwegian Sea and average monthly temperature at Bud June to September.

Before the 1970s, there were hardly any catches of mackerel taken in the Norwegian Sea. Even if the water temperature in the Norwegian Sea has been higher periodically after 1970 than between then and the late 1930s, it is doubtful that this is the reason why the fishery for mackerel in the Norwegian Sea developed after 1970, as the temperature peaks before 1970 were not much lower than later. The reason probably is change in fishing technology and increased demand for mackerel.

Let us turn, then, to the North Sea. Figure 7 shows the catches of mackerel in the North Sea since the end of the Second World War. The catches increased tremendously and suddenly in the 1960s, only to fall back equally suddenly after a few years. This spike was most likely caused by the sudden and dramatic technological changes in the purse seine fisheries that occurred in the 1960s and hence are unlikely to reflect any temperature changes in the sea. Unsurprisingly, therefore, a regression of catches on temperature does not produce any significant results.

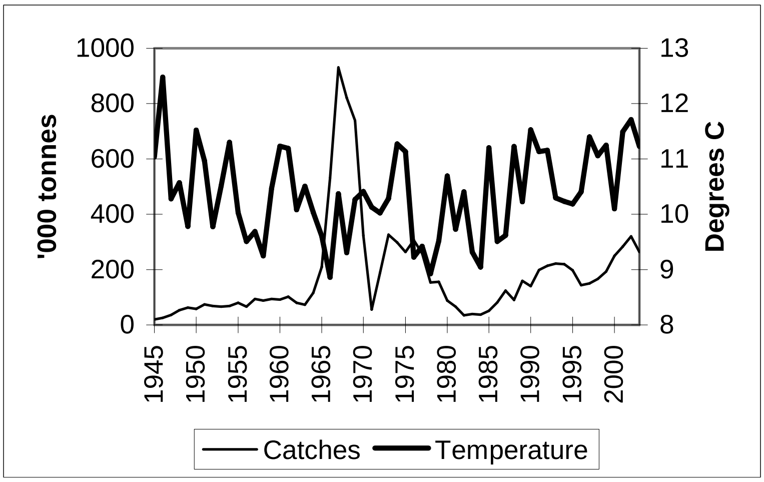

Figure 7

Catches of mackerel in the North Sea and average monthly temperature in Sognesjøen June to September.

Table 7

Regression of catches of mackerel in the North Sea 1972 - 2003 on average monthly temperature in Sognesjøen June to September.

	t-values for temperature					D-W statistic
Lag (years)	1	2	3	4	5	
	1.80*	1.59	1.61	1.87*	1.84*	1.36

It may be argued that times in the mackerel fishery have been more normal after the episode in the late 1960s. From Figure 7 it appears that there might be a correlation between catches and temperature from the early 1970s onwards. Table 7 reports the results of a regression of catches 1972 - 2003 on contemporary and lagged average summer (June to September) temperature in Sognesjøen. We get significant t-values for some temperature values lagged up to 5 years, but serial correlation is a potential problem (the Durbin-Watson statistic is inconclusive). One would have expected an immediate effect of temperature on the fishery, since mackerel is a migratory species that seeks food and lives on plankton with a short life-cycle. The lags could be due to better survival of young fish, which then return in subsequent years or maybe occupy the North Sea the entire year.

Herring

There are two distinct stocks of herring important for Norway's fisheries, the Norwegian spring spawning herring, which inhabits the Norwegian Sea, and North Sea herring. Figure 8 shows the landings of herring taken in the Norwegian Sea, Barents Sea, and at the Faeroe Islands and Iceland.[12] In earlier times these catches included a spring spawning stock at Iceland, which now appears to be extinct. The catch statistics also include a summer spawning

[12] ICES statistical areas I-V and XIV.

stock at Iceland, which still survives but is not very large. The bulk of the catches shown consist of Norwegian spring spawning herring.

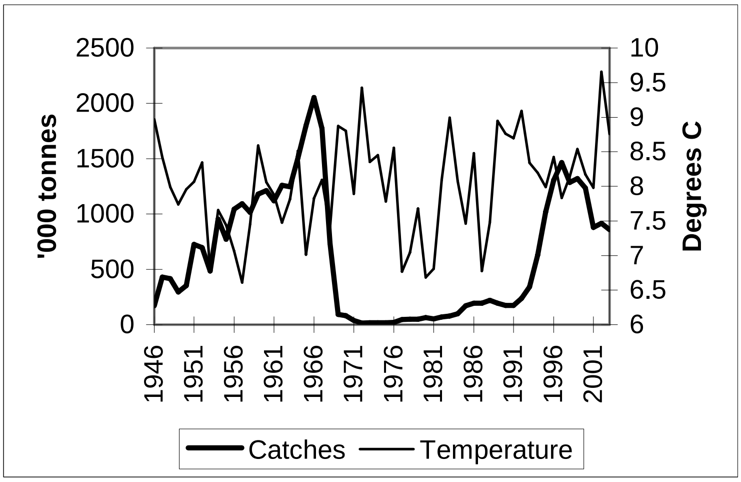

Figure 8

Catches of herring in the Northeast Atlantic and summer temperatures (May to September) at Skrova.

Figure 8 also shows the average spring and summer temperature at Skrova in Lofoten May to September (the herring fishery takes place in the summer). We have chosen this series because it is much more complete that the one from Bud in Møre and Romsdal, which would probably be more representative for the Norwegian Sea. The time pattern of these two series is similar, however, so the responsiveness of the fishery to changes in temperature should be uncovered by this series. There is no apparent correlation between herring catches and temperature. The collapse of the herring fishery in the late-1960s is evident and was brought about primarily by overfishing. This will, needless to say, mask any relationship there might be between temperature and catches. A regression of catch levels on temperature, both current and lagged values, for the period after 1974 (the low point of the catch series) did not reveal any statistically significant relationship between catch and temperature. This result is somewhat at odds with Thoresen and Østvedt (2000) who found a relationship between temperature and the spawning stock of herring, using a longer time period and a different methodology.

As to the catches of North Sea herring, we have again used average summer temperatures (June to September) from Sognesjøen. In Figure 9 we see exactly the same kind of collapse as happened for the herring catches in the Norwegian Sea and at Iceland and the Faeroes. Also here the cause was overfishing, brought about by a technological leap and the absence of control of the total catch. Glancing at the figure, it appears that there might be a relationship between temperature and catches in the period before the collapse occurred. A regression of catches on contemporary and lagged values of temperature for the period before 1973 did not produce significant results, however.

Anchovies and sardines

Warming of the North Sea is expected to attract anchovies and sardines into the North Sea. Figure 10 shows the catches of anchovies in the North Sea, together with the average monthly summer (June to September) temperature in Sognesjøen. Anchovies and sardines are mainly caught in the southern part of the North Sea, so the temperature in the northernmost part (Sognesjøen) will only be relevant to the extent it is closely related to the temperature fluctuations in the southern part. There have been several spikes of catches of anchovies in the North Sea, some apparently related to high temperatures, These catches are very small, however, seldom exceeding 2000 tonnes.[13] After 1973 there have hardly been any catches of anchovies in the North Sea, apart from a spike in 1995. Regressing catches prior to 1973 on the average summer temperature in Sognesjøen gave no significant results and thus provides no support for the hypothesis that higher temperature in the North Sea will lead to more catches of anchovies.

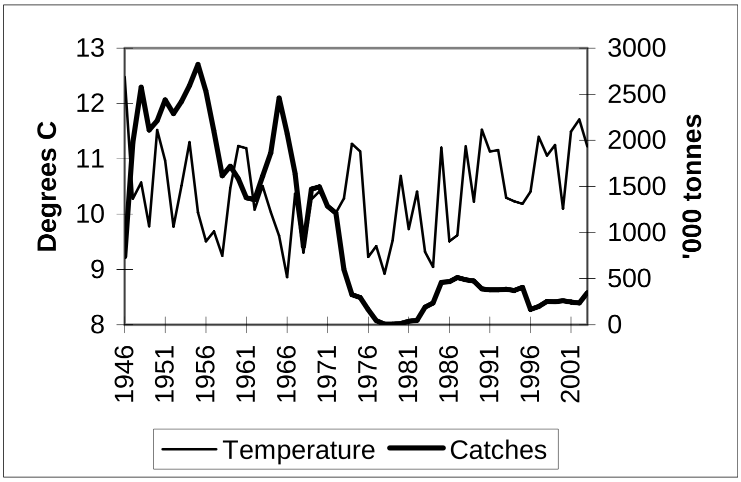

Figure 9

Catches of North Sea herring and average monthly temperature in Sognesjøen June to September.

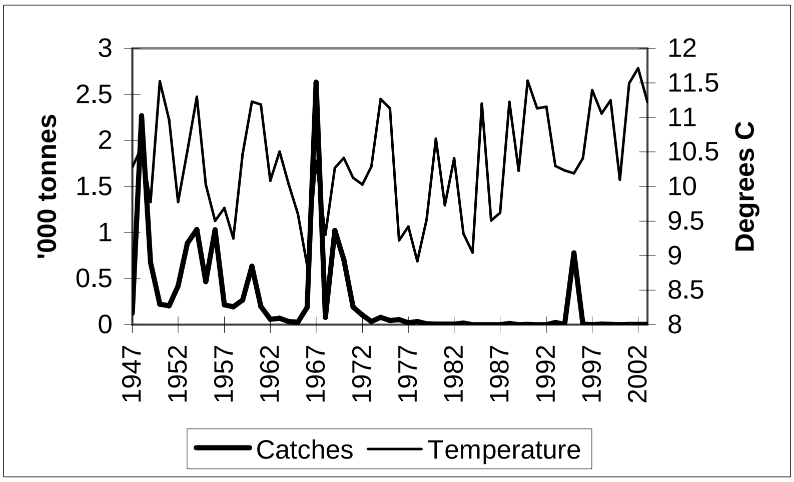

Figure 10

Catches of anchovies in the North Sea and average monthly temperature (June to September) in Sognesjøen.

[13] In the issues of *Bulletin statistique* the figures reported here as anchovies are classified as ”various clupeoids” or, prior to 1961, ”other pelagic fishes”. There may thus be other kinds of fish included in this than anchovies. The ICES data base shows the same figures for “European anchovies” in 1973 as the *Bulletin statistique* shows for “various clupeoids” for 1973.

Figure 11 shows the catches of sardine and the temperature in Sognesjøen. Before the 1990s there were a few spikes in landings, but in the 1990s there were suddenly relatively large landings, even if the temperature was no higher than in the early 1950s. Table 8 shows the results of regressing catches on temperature. There is a significant correlation between catches and contemporary changes in temperature. Hence there seems to be some support for the notion that higher temperatures in the North Sea will lead to a greater occurrence of sardines.

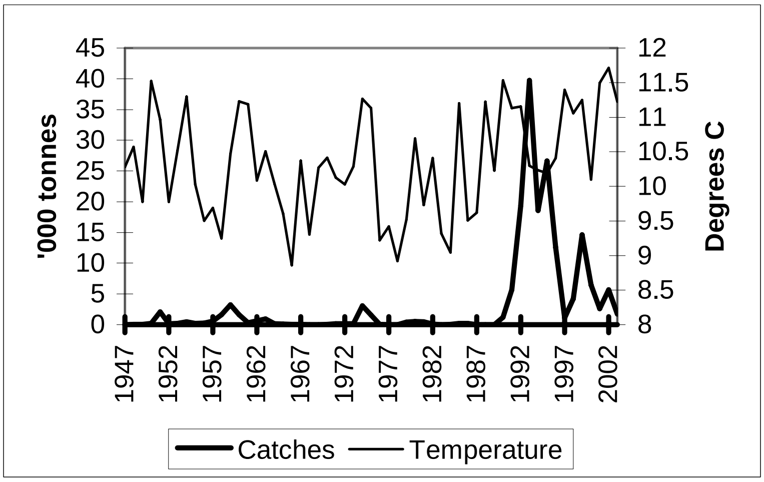

Figure 11

Catches of sardines in the North Sea and average monthly summer (June to September) in Sognesjøen.

Table 8

Regression of catches of sardine in the North Sea on the summer temperature (June to September) in Sognesjøen.

	t-values for temperature		DW-statistic
Lags	0	1	
	3.10**	1.11	1.47

3. CONCLUSIONS

The evidence with respect to the impact of temperature changes on the catches of fish in the North Sea and the Northeast Atlantic is mixed. There is strong evidence that the catches of cod in the North Sea are influenced by variations in temperature, with lower temperatures leading to increased catches and vice versa. This is presumably associated with variations in the stock, with low temperatures being favorable for the stock. North Sea cod has been heavily exploited for a long time, and so one would expect that variations in the catches are due primarily to variations in the stock. While overfishing could certainly be the reason for the fall in catches in recent years, there is reason to believe that it could to some extent, and perhaps even entirely, be due to the rise in temperature in the North Sea in recent years.

By contrast, the recruitment of Northeast Arctic cod was found to respond favorably to rises in temperature in the Norwegian Sea. The catches from this stock also respond favorably to rises in temperature, with a longer time lag. This supports the notion that rising temperatures in the Norwegian Sea and the Barents Sea would improve the productivity of this stock. Little or no evidence was found, however, for the hypothesis that higher temperatures would drive the cod further north and east. Higher temperatures in the Norwegian Sea do not seem to lead to a larger share of the catch being taken in the Barents Sea, except with a time lag that is difficult to explain.

The collapse of the herring stocks in the North Sea, and the Norwegian Sea and adjacent areas, makes it difficult to detect any effect of temperature on the catches of herring. Elsewhere it has been shown that the migrations of herring are sensitive to changes in ocean currents and temperatures (Malmberg, 1969; Malmberg and Jónsson, 2002; Vilhjálmsson, 1997), but the analysis in this paper fails to demonstrate an effect of temperature variability on the catches of herring.

There is some indication that the catches of mackerel in the Norwegian Sea increase with rising temperature in that area, but the correlation is not statistically significant. The sharp peak of the mackerel fishery in the North Sea in the late 1960s was brought about by technology. There is, however, a significant and positive correlation between temperature and catches of mackerel in the North Sea after the stock recovered in the 1970s. For anchovies in the North Sea no positive correlation between temperature and catches is apparent, while for sardines there is a significant correlation.

Overall, the conclusion is that in certain cases the past changes in temperature and fish catches are consistent with the expectations that currently are held by many people as to what might be the consequences of warming of the North Sea and the Northeast Atlantic on fish catches. For other stocks there is little or no support from changes in the past for these expectations. That does not prove they are wrong; the temperature may have to rise beyond a certain threshold value to have an effect on stock growth and distribution. Furthermore, catch fluctuations in the past for reasons that have nothing to do with temperature changes may mask an underlying relationship between the two. Finally, the areas being considered may be too large for detecting spatial displacements of stocks in response to temperature, at least within the relevant range. Recent work by Perry et al.(2005), using a much finer spatial resolution, indicates a northward displacement of some stocks in the North Sea in response to rising temperatures.

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APPENDIX

Interpolation of missing monthly temperatures (X_t)

The change in temperature from month t to month t+1 is

$$X_{t+1} = a_t X_t$$

or

$$\ln a_t = \ln\left(X_{t+1}\right) - \ln\left(X_t\right)$$

from which we take the average for all observations.

$$F_{t+1} = F_t \exp\left(\ln\left(a_t\right)\right) \quad t = 1, \dots, 13,$$

with the F's calibrated so that $F_1 = F_{13} = 1$; January = 1 and 13.

Missing X's:

t: last observation before gap, T: first observation after gap; $m = T - t$, number of months in the gap.

$$X_{t+i} = \frac{F_{t+i}}{F_t} X_t \left(\frac{F_t}{F_T} \frac{X_T}{X_t} \right)^{i/(m+1)} \qquad i = 1,..,m$$

This correction term in parenthesis is required because the ratio of the observed temperatures X_T/X_t can deviate from the average ratio F_T/F_t. Without the correction term we would get "jumps" from T-1 to T.