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FOCUS ON MARINE RESEARCH



CLIMATE AND FISH

How does climate affect our fish resources?



INSTITUTE OF MARINE RESEARCH
HAVFORSKINGSINSTITUTTET

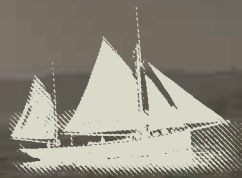


CLIMATE AND FISH

How does climate affect our fish resources?

There are obvious relationships between climate change and variations in fish stocks, but they are difficult to quantify. We know that climate change is occurring, and that it will affect the recruitment, growth and distribution of fish stocks. This makes it important for us to predict the future climate, and to determine how this will affect marine ecosystems. Any changes in fish stocks caused by climate change must not take us by surprise.

Variations in the availability of fish have preoccupied Norwegians for hundreds of years, though in times past we had different explanations than we do today. In his work "*Om Diur, Fiske, Fugle og Trær udi Norrig*" ("*About Animals, Fish, Birds and Trees in Norway*"), Peder Claussøn Friis put it thus: "Then God also reduced the herring fishery the following year and has since taken it completely away from us, so that in this year, 1599, no herring have arrived". According to Friis, one of the reasons for this was the godlessness of the fishermen, their thieving and unfaithfulness, drinking and fighting. But by the second half of the 19th century fishermen and marine scientists were already aware that environmental conditions and the temperature of the sea had significant effects on the Lofoten Fishery. At the beginning of the 20th century, scientists were starting to put variations in fish stocks into the context of changes in sea temperatures. In their book "*The Norwegian Sea*", Bjørn Helland-Hansen and Fridtjof Nansen stated clearly that the main reason for the unpredictable changes in the fisheries was variations in the temperature of the sea. After a symposium in Copenhagen in 1948, Gunnar Rollefsen, then Director of the Institute of Marine Research, said that little progress had been made in identifying relationships between the great variations in the marine climate and the distribution and quantities of the most important types of fish. In the course of the 1970s, more research began to be undertaken on the effects of climate changes on marine ecosystems, but because this is an extremely complex process, we still find it difficult to quantify the relationship between variations in climate and fish stocks.



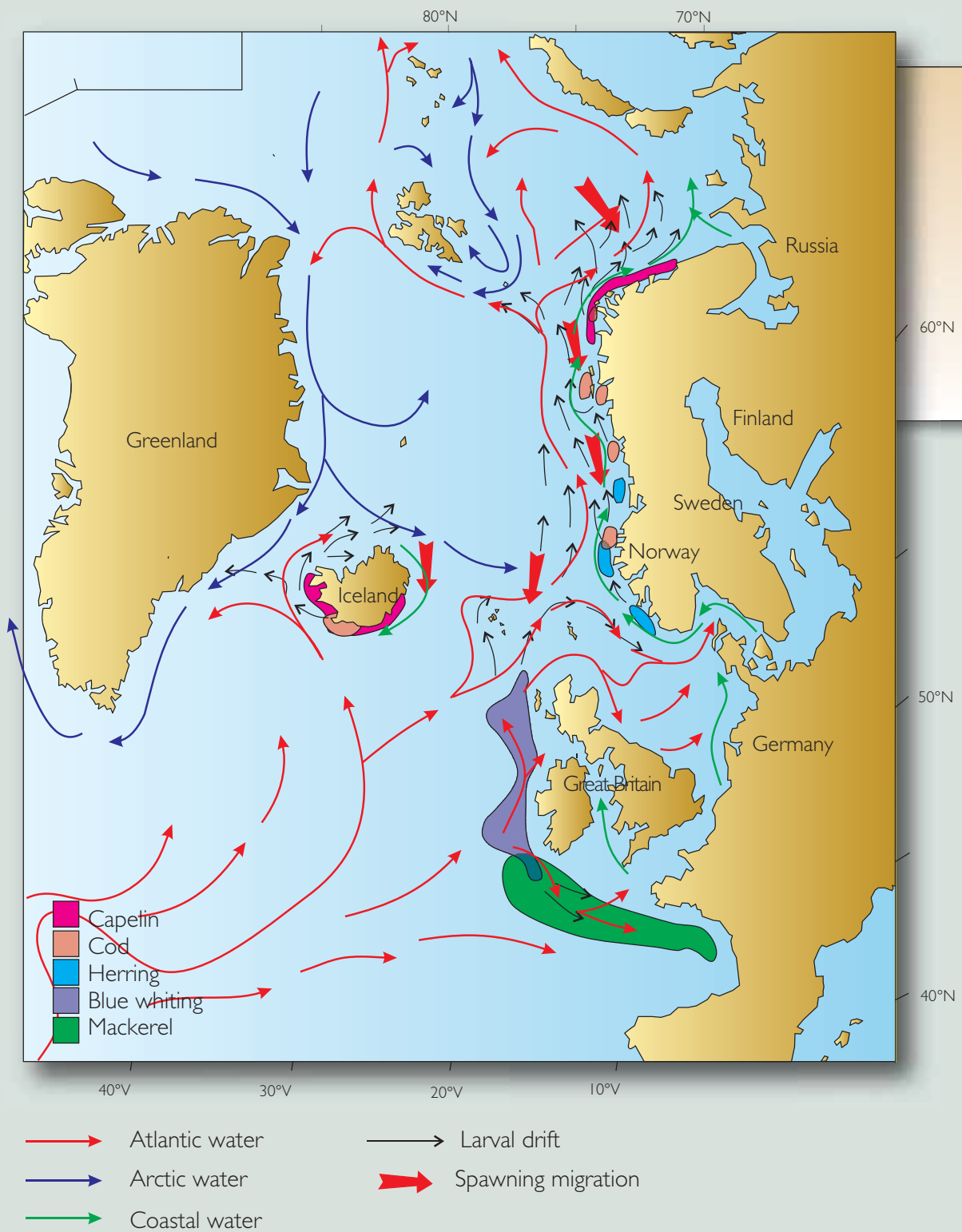


Figure 1: Spawning grounds of capelin, cod, Norwegian spring-spawning herring, blue whiting and mackerel (western stock) and the main lines of larval drift (narrow orange arrows) and spawning migrations (thick red arrows) relative to the current systems.



The major current systems

Atlantic water enters the Norwegian Sea and continues to flow north along the Norwegian continental slope. This Atlantic Ocean current divides as it enters the North Sea, the Barents Sea, the Greenland Sea and the Arctic Ocean. The Atlantic current transports warm water northwards, with the result that there are important fish resources farther north off the coast of Norway than anywhere else in the world at similar latitudes.

While warm Atlantic water flows north along the coast of Norway, cold Arctic water flows southwards along the eastern coast of Greenland. Cold water from the Polar Basin flows through the Fram Strait. Part of it continues south through the Denmark Strait, while some passes into the Greenland Sea, the Icelandic Sea and the Norwegian Sea, producing a front between a warm eastern side and a cold western side. This front plays a central role in the distribution of species in the sea.

FISH MIGRATION

The northerly flow of Atlantic water in the Northeast Atlantic not only carries heat but also acts as a large-scale transport system for the larvae of most of our commercial fish species. Mackerel spawn not far from the Bay of Biscay, blue whiting to the west of the British Isles, herring on the coastal banks off Western and Mid-Norway, cod for the most part in Lofoten and Vesterålen, and capelin off the Counties of Troms and Finnmark and the Kola Peninsula (Figure 1). The larvae are carried by the currents from their spawning grounds to suitable nursery grounds for the juvenile fish. For blue whiting these grounds lie in the Norwegian Sea and the North Sea, while for herring, cod and capelin they are in the Barents Sea.

As the juvenile fish grow, they perform large-scale seasonal migrations in search of food. During summer capelin move north in the Barents Sea, herring north and west and blue whiting northwards in the Norwegian Sea. The mature fish in the stock subsequently migrate back to the spawning grounds. The whole process locks the life-cycle of the fish into a geographical framework.

Evolution and ecological adaptations have enabled fish stocks to adapt to a dynamic environment and marine climate. Each individual stock has found its own solution to adapt to the dominant current patterns that transport its larvae, and in which the adult fish need to navigate. These solutions produce stocks of different sizes, depending on the environment that the fish inhabit. Even though the main features of the currents are relatively consistent from year to

year, there can be wide temporal variations in their strength, and to a certain extent their direction. Such current “pulses” affect the stocks, which may display major changes in response to variations in the ocean climate. Since most of the major Norwegian fish stocks live within the same current system (Figure 1), it is not surprising that individual stocks tend to vary in step with one another.

WHAT CONTROLS THE CLIMATE?

Although many people equate climate with temperature, many other factors are involved (see box ☞). In our region, two aspects in particular determine the climate: the major ocean currents and atmospheric circulation. Oceanic and atmospheric conditions are tightly coupled, and changes in either of them will affect the other.

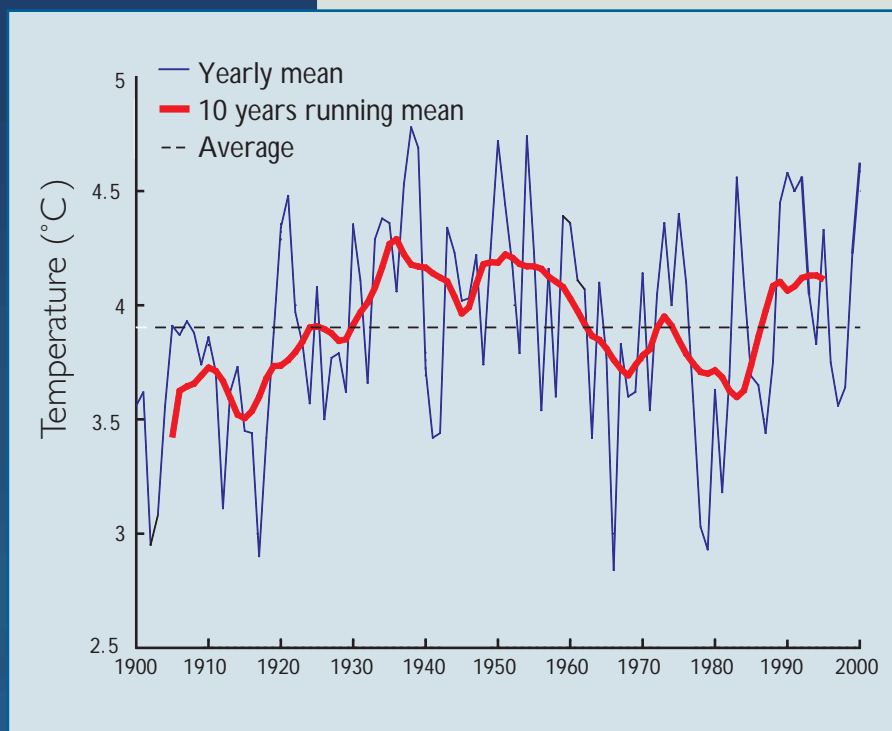
The ocean climate surrounding Norway depends primarily on the amount of Atlantic water that flows into the region. Also important are changes in atmospheric conditions such as wind speed and direction, air temperatures and cloud cover. The position and strength of the major pressure systems in the North Atlantic, such as the low-pressure system over Iceland, play a central role in the climate that we are experiencing today and will continue to experience in the future. The Institute of Marine Research is studying these factors in collaboration with the University of Bergen and the Nansen Center, via the Bjerknes Centre for Climate Research, which has been awarded a Centre of Excellence status by the Research Council of Norway.



NATURAL OR ANTHROPOGENIC CHANGES?

Figure 2 shows the temperature in the Barents Sea since 1900. There are wide annual variations, with the difference between the warmest and the coldest year almost 2 °C, which is large for this region. If we average the measurements over several years, we find what appear to be periodic oscillations. The curve in Figure 2, which has been averaged over a period of 10 years, shows that the temperature rose from the turn of the century until about 1940, after which it began to fall again. The minimum came at the end of the 1970s; since then the temperature has been rising through to the present day. At the end of 2005, we registered a record temperature level in the Barents Sea for that time of the year.

Figure 2: Yearly mean (blue curve) and 10-years running mean (red curve) temperature of the Kola transect in the Barents Sea, measured by Russian scientists since 1900. Average for the period 1900–2000 (dashed line).



Given that it appears as though we have a natural oscillation, we might expect to see a fall in temperature in the near future. However, anthropogenic climate change will affect this development, and the coming decade will tell us whether we are dealing with natural or anthropogenic variations. If the temperature curve flattens out, or if the trend is falling, there would be good reason to believe that we are looking at natural variations. If the temperature continues to rise during the next ten years, this would be a confirmation that a change is taking place in the climate.



THE CLIMATE OF THE FUTURE

According to models that simulate future climatic conditions, the rise in the temperature of the Arctic will be twice as great as the average global increase. This will produce a significant reduction in sea-ice coverage, mainly in spring and summer, while changes in winter ice cover will be much less dramatic. Some areas that are presently covered by permanent sea ice will become seasonal ice zones with open water in summer. Certain models suggest that the whole of the Arctic Ocean could be ice-free in the summer by the end of this century. Changes in winter conditions in comparison with the present day will be far less, although it is expected that the whole of the Barents Sea, for example, will be ice-free all year round as we approach 2100. In the Fram Strait, on the other hand, there will still be major ice transport coming from the Arctic during the winter months. Much of the multi-year ice will disappear from the Arctic while the amount of one-year ice will increase.

It is important to stress that these modelling results are highly uncertain. What the models do largely agree on is that the area of sea ice and the mean thickness of the ice will decrease, but by how much is very uncertain.

With such a change, we can expect temperatures in the Norwegian Sea and the Barents Sea to rise by 1–2 degrees. More wind from the west will lead to a slight increase in water transport along the Norwegian coast, in spite of the fact that the Gulf Stream system further south in the Atlantic is expected to weaken. Warmer air and more wind will bring more precipitation to the Northeast Atlantic, which together with a rise in run-off from the continental land-masses and glacier melting, will lower the salinity of the local seas. This will mean more low-density water near the surface, which could have significant effects on the production of heavy deep-water in the Greenland Sea. This deep-water formation is one of the motors driving the global current system, of which the Gulf Stream is a part. Many people fear that the Gulf Stream will be reduced if the formation of cold deep water is reduced.



LESS ICE – MORE PLANKTON

Primary production – i.e. the production of phyto- or plant plankton – in the ocean requires sufficient light levels which in the Arctic is largely controlled by ice conditions. Ice limits light penetration, and snow cover is particularly efficient in reducing light transmission. Algal growth is therefore extremely limited in ice-covered waters. Measurements made at different locations in the Arctic have demonstrated a clear relationship between the duration of the open-water period during the summer and annual production of phytoplankton.

With less ice in the summer, primary production in Arctic waters will probably increase. The rise could be quite marked, transforming a low to a fairly high rate of annual production. At first, the greatest change is expected to take place over the Arctic continental shelves and the continental slopes around the periphery of the deepwater basins of the Arctic Ocean, including water in the northern part of the Barents Sea. If the prognoses of reduced summer ice are fulfilled, the central parts of the Arctic Ocean would experience a significant increase in primary production in the course of this century.

The most important zooplankton species that acts as food for fish in Arctic water is the planktonic copepod *Calanus finmarchicus*, which mostly winters in the deep waters of the Norwegian Sea and is transported into the Barents Sea when it rises to the surface in the spring to spawn. The North Sea too is dependent on copepod transport from the Atlantic. It is not clear how climate change will affect copepods and other zooplankton species. A major international report entitled *Arctic Climate Impact Assessment (ACIA)* concludes that the amount of zooplankton will increase in the Arctic when the water temperature increases and there is less ice in the summer. However, Barents Sea zooplankton models suggest that there could be a slight decrease in the future. This is a crucial question that needs to be answered, and it will be a major challenge for future research.



Calanus finmarchicus



Photo: Monika Bilkas



FISH MOVING NORTH

In a warmer ocean, with less ice in the Arctic, we can expect that a number of species will extend their habitats further north. The change in the distribution of some species will depend on the fish finding new, more northerly spawning grounds and new adaptation to complete their life cycles.

The blue whiting could migrate northwards. During the past couple of years, with the relatively warm ocean climate, large numbers of young blue whiting were found in the southwestern Barents Sea; far more than there used to be when the temperature was lower. Blue whiting spawn for the most part to the west of the British Isles (Figure 1), though some spawning also takes place off the coast of Norway and in Norwegian fjords. If the blue whiting are able to successfully spawn and establish nursery areas in the Norwegian Sea under a warmer climate, these fish would be able to exploit the large plankton production in the Greenland Sea.

Capelin move eastward or westward in the Barents Sea in response to alternations between warm and cold years, respectively. However, capelin probably do not have much more of a range to exploit on their northerly food migration in the Barents Sea, with their spawning grounds currently located off the counties of Troms and Finnmark and the Kola Peninsula. Any further move to the north would probably involve a change in spawning grounds. Potential spawning grounds in a warmer sea include the shallow banks east of Novaya Zemlya and around Svalbard and the archipelagos in the northern Barents Sea. If such an easterly and northerly shift were to take place, it is likely that the capelin would disappear from the southwestern parts of the Barents Sea.

HERRING RETURN TO ICELAND

Before the collapse of the herring stocks at the end of the 1960s, Norwegian spring-spawning herring had important feeding grounds on the coastal banks north of Iceland, and a wintering area to the north and east of Iceland. In the mid-1960s there was a marked change in the climate of the coastal banks

in this region. The mean temperature fell by about 1.5 °C, while the front between the warm water of the Atlantic Ocean and the cold Arctic water moved to the southeast. This led to a fall in zooplankton production and the disappearance of the herring from the coastal banks north of Iceland.

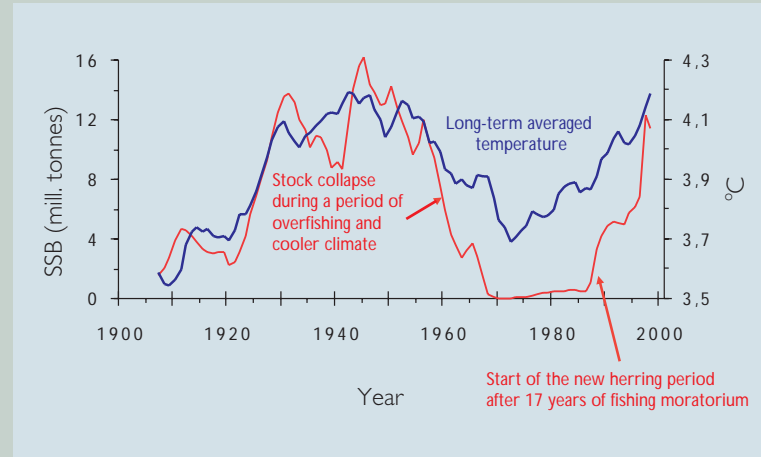


Figure 3: Spawning stock biomass of Norwegian spring-spawning herring and long-term averaged temperature (Toresen and Østvedt 2000).

The figure shows close correlation between the spawning stock biomass of herring and the long-term averaged sea temperature.

Since then, temperatures in this region have remained low. Stocks of Norwegian spring-spawning herring have recovered, but the herring have not returned to their feeding grounds off the northern Iceland. During the past couple of years, however, there have been suggestions of higher temperatures around Iceland, and the front between the warm and cold water masses appears to be on its way back to its position prior to the mid-1960s. Zooplankton production in the region has been rising, which increases the likelihood that feeding herring might reappear in this area. At the same time, we are seeing changes in their overwintering patterns, so it appears that there is a chance of herring resuming their old pattern of migration and return to their former feeding grounds.



Herring larvae



WIDE-RANGING COD

The Barents Sea cod stock has displayed wide variations in size over time. We had a crisis in the cod fisheries at the end of the 1980s that marked the bottom of a long-lasting downward trend in cod abundance that began around 1950. It is very likely that greater fishing pressure was an important cause of the fall, but climatic factors were also considered to have played a role.

Going back a hundred years to the beginning of the last century, there was also a crisis in the cod fishery in Northern Norway. This was the period that Helland-Hansen, Nansen and Hjort described and analysed in their classic books. The year 1903 was particularly bad, when the cod caught in Lofoten were small, and so thin that it is said that their livers sank in seawater.

An overview of the average weights of cod caught in the Lofoten fishery (Figure 4) shows clear long-term oscillations. The cod were small during the cold period around the turn of the previous century, increased in size during the warm period between the 1920s and the 1950s, and fell again in size during the colder period of the 1970s and 1980s. During the period of little mean growth at the beginning of the last century, the Lofoten fishery fell to a very low level, probably because stocks were low. Cod spawn not only in Lofoten but also on spawning grounds in the very southern part of Western Norway. During the cold period when the fishing in Lofoten was poor, the fishery for spawning cod off the County of Møre was at a record high level. This suggests that when the climate is cold, the cod migrate further south in order to spawn, while during the past few years, when it has been warm, we have seen that they have tended to spawn on grounds to the north of Vesterålen.

If the sea becomes warmer, we can expect that the cod in the Barents Sea will extend their grazing grounds to the east and north. However, cod have a wide migration range, so that they could continue to spawn along the coast of Northern Norway even if they move further north to graze. However, this would make it even more important not to harvest them too intensively or to remove too many of the large individuals such that the mean size of the fish would be reduced. It is important to maintain the genetic characteristics and range of variation in size and age in this species.

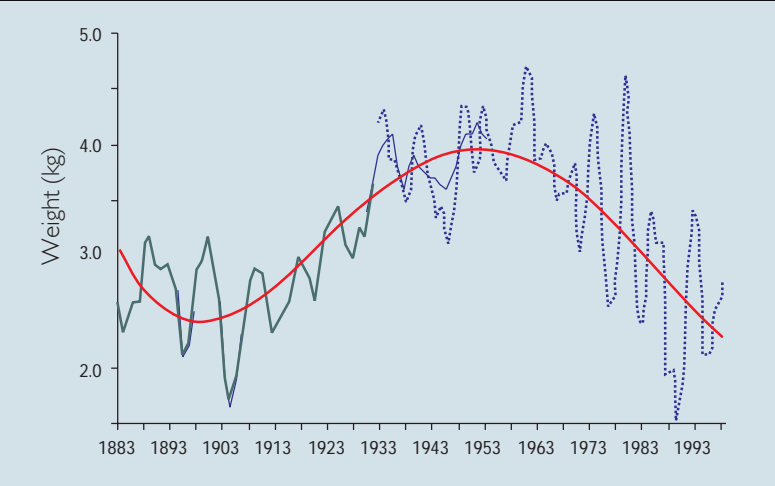
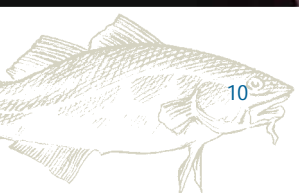


Figure 4: Average weight of cod taken by gill-net (1893–1953) and line (1932–1999) in the Lofoten fishery. The red line shows the long-term trend through these data series.





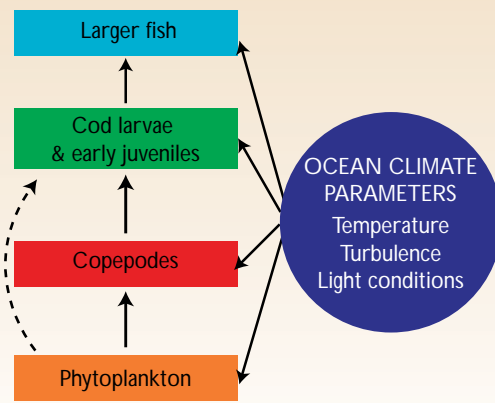
Ocean climate - more than a matter of temperature

Norwegian fishing grounds from the Barents Sea in the north to the Norwegian Sea, the coast of Norway and the North Sea in the south are located in several ocean ecosystems. The northern part of the Barents Sea is a pure Arctic ecosystem. As we move south towards the North Sea, the temperature rises, and the species composition becomes more temperate. The ecosystem changes from “arctic” in the north to “arctic-boreal” in the Norwegian Sea and “boreal-temperate” in the North Sea.

In arctic and arctic-boreal ecosystems, in which most organisms live in temperature ranges close to the lower limits tolerated by most species, a rise in temperature will lead to a corresponding rise in productivity throughout the ecosystem, including its fish species. In more temperate ecosystems, such as the North Sea, a rise in temperature will not have the same unambiguous effect on the ecosystem. The most heat-loving species will increase their productivity under such conditions, while those that originated in colder conditions will become less productive.

Temperature is an important ocean climate variable because it affects every link in the food chain from phytoplankton to fish. Any changes in temperature will therefore affect fish both directly and indirectly.

However, the ocean climate is more than a matter of temperature. Light, which changes with the state of the sky, and turbulence, which is affected by wind, also affect organisms, particularly drifting plankton. Ocean current systems also affect the transport and dispersal of plankton. There are thus many indirect effects of changes in the ocean climate on the marine ecosystem, including, for example, on cod. In correlations between temperature and the growth of a fish stock, a temperature relationship may thus act as a substitute for a number of other ocean climate variables. The figure shows the influence of ocean climate on different links in the food chain at individual and population levels.



Climate research predicts catches

After horse mackerel spawn off the west coast of Ireland, the adult fish move northwest to feed. When they arrive in Shetland waters, part of the stock chooses to migrate into the North Sea, where it is fished. The Institute of Marine Research has shown that there is a relationship between the inflow of Atlantic water to the North Sea in the winter and catches of horse mackerel the following autumn in the North Sea. This has given us a basis for making half-yearly prognoses for the fishery, and these have been calculated as a matter of routine since 1996. Figure 5 shows the prognosis vis-à-vis modelled water transport and reported catches. The prognosis for 2005 was 45,000 tonnes, while only 24,000 tonnes were actually taken. This was because fishing was stopped due to a high probability of excessive by-catch.

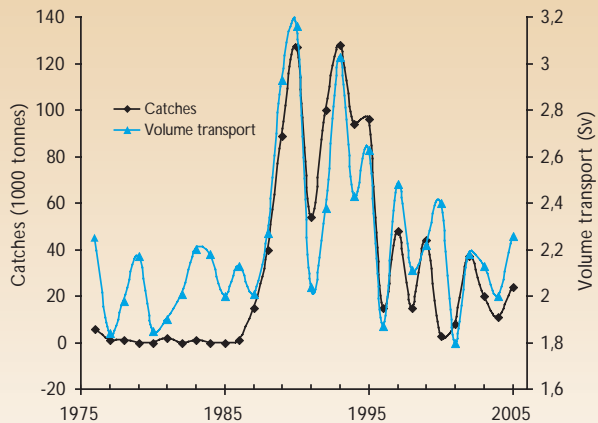
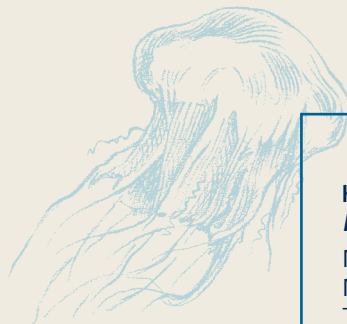


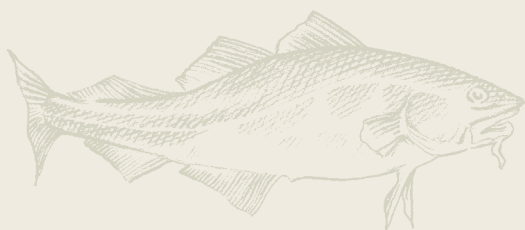
Figure 5: Mean modelled total first-quarter southerly water transport in the North Sea through a cross-section from Utsira to the Orkneys; 1976–2005 and catches of horse mackerel in the following autumn in the North Sea. (1 sv = 1 mill. m³/s)



**HAVFORSKNINGSINSTITUTTET
INSTITUTE OF MARINE RESEARCH**

Nordnesgaten 50 - Postboks 1870 Nordnes
NO-5817 Bergen - Norway
Tel: +47 55 23 85 00 – Fax: +47 55 23 85 31
E-mail: post@imr.no

www.imr.no

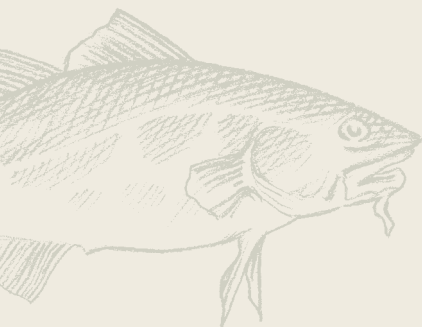


**HAVFORSKNINGSINSTITUTTET
TROMSØ DEPARTMENT**

Sykehusveien 23, Postboks 6404
NO-9294 Tromsø - Norway
Tel: +47 55 23 85 00 – Fax: +47 77 60 97 01

**HAVFORSKNINGSINSTITUTTET
FLØDEVIGEN RESEARCH STATION**

NO-4817 His - Norway
Tel: +47 37 05 90 00 – Fax: +47 37 05 90 01



**HAVFORSKNINGSINSTITUTTET
AUSTEVOLL RESEARCH STATION**

NO-5392 Storebø - Norway
Tel: +47 55 23 85 00 – Fax: +47 56 18 22 22

**HAVFORSKNINGSINSTITUTTET
MATRE RESEARCH STATION**

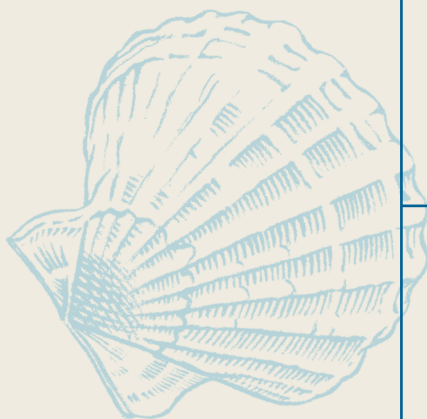
NO-5984 Matredal - Norway
Tel: +47 55 23 85 00 – Fax: +47 56 36 75 85

**REDERIAVDELINGEN
RESEARCH VESSELS DEPARTMENT**

Tel: +47 55 23 85 00 – Fax: +47 55 23 85 32

**INFORMASJONEN
INFORMATION**

Tel: +47 55 23 85 00 - Fax: +47 55 23 85 55
E-mail: informasjonen@imr.no



CONTACT PERSON

Harald Loeng
Tel. +47 55 23 84 66
E-mail: harald.loeng@imr.no

RESEARCH GROUP

Oceanography and Climate

Information adviser: Yvonne Robberstad
E-mail: yvonne@imr.no

