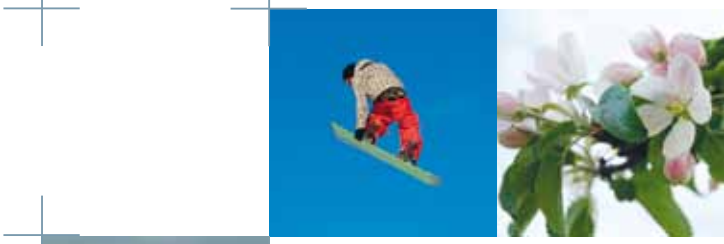
The Research Council of Norway

Arctic Climate Change in NORKLIMA

Large-scale Programme
Climate Change and Impacts in Norway – NORKLIMA



Large-scale Programmes

The RCN initiative to meet national research priorities

About the programme

Climate Change and Impacts in Norway – NORKLIMA

The NORKLIMA programme is the national Norwegian initiative on climate research established for the period 2004-2013.

The programme seeks to generate key knowledge about climate trends, the impacts of climate change, and how Norway can adapt to these changes. The NORKLIMA programme also encompasses research on instruments and policies for reducing emissions.

Read more about the programme here:
www.forskningsradet.no/norklima

Large-scale Programmes
As part of the effort to meet national research-policy priorities, the Research Council has established a special funding instrument called the Large-scale Programmes. This initiative is designed to build long-term knowledge in order to encourage innovation and enhance value creation as well as to help find solutions to important challenges facing society.

Content

The NORKLIMA Programme

A Large-scale Programme on Climate Change and Impacts in Norway

No matter how the world community manages to respond to greenhouse gas emissions, there are going to be changes to the climate. Norway needs sound knowledge in order to choose the best measures to counteract these changes.

To achieve Norway's ambitious climate objectives, more knowledge is needed about the climate of the future, the impacts of climate change on the natural environment and society, measures to reduce emissions, and adaptations to anticipated changes in the climate. In response to this, the Research Council has established the Research Programme on Climate Change and Impacts in Norway (NORKLIMA).

The NORKLIMA programme is administered under the Research Council's Large-scale Programme Initiative, and has a budget in 2010 of approximately NOK 111 million for R&D activities. For the Research Council as a whole, the budget for climate-related R&D activities is about NOK 240 million including the Norwegian IPY- projects.

The NORKLIMA programme will generate key knowledge about climate trends, the impacts of climate change, and how Norway can adapt to these changes. The programme has also encompassed research on instruments and policies for reducing emissions since the middle of the programme period.

The NORKLIMA programme seeks to:

> Ensure satisfactory distribution of tasks at the national level in order to utilise top national expertise in the various research areas;

> Foster climate research of top international calibre and ensure that Norwegian climate research utilises the potential inherent in cross-disciplinary cooperation;

> Maintain close contact between researchers and society and achieve effective dissemination of research results;

> Promote recruitment and develop new research managers in the area of climate research.

The programme encompasses basic and applied research , and its target groups are universities, university colleges and independent research institutes.

www.forskningsradet.no/norklima

The NORKLIMA administration

Jostein Kandal Sundet, Gørill Kristiansen (programme coordinator), Jon Børre Ørbæk, Camilla Schreiner, Malin Lemberget Lund, Stine Madland Kaasa and Catherine Krogstad. Not present; Julie Christiansen and Eva Hajnal. (Photo: Marius Omland)

The Research Council of Norway (RCN)
The Research Council of Norway is a national strategic body for research that advances and funds basic and applied research in all disciplines as well as innovation activities in all sectors and industries.

The Research Council provides input to government authorities on research policy matters and promotes international research cooperation. A key objective is to raise the general level of understanding about research in society as a whole. The annual budget is approximately NOK 6.8 billion.

Climate change may bring birch forest to Svalbard

The open plains of Svalbard will not remain treeless for long. Scientists are predicting both increased plant immigration and wider dispersal of existing plant species on the Arctic archipelago.

A milder climate will entail changes to the flora on Svalbard. Pictured in the foreground is a white dryad at Kongsfjorden, Spitsbergen. (Photo: Inger Greve Alsos)

Climate change is a reality in the Arctic regions, and major impacts are in store for Svalbard. It now appears that temperatures – rather than the archipelago's isolated location – have been the main obstacle to the establishment of new species there. So major ecological changes are looming as temperatures in the Arctic continue to rise.

New species to immigrate?
Professor Christian Brochmann of the National Centre for Biosystematics at the University of Oslo's Natural History Museum headed a project that examined the impacts of climate change on the flora of Svalbard.

"We analysed over 8,000 plant specimens belonging to 18 different species," Professor Brochmann recounts. "Nine of them already exist on Svalbard, so we studied where those originated and how many times the same species made its way to the archipelago. We studied the other nine species to calculate the probability of their spreading across the ocean to colonise Svalbard."

Temperate species ready to move in
"A milder climate can quickly give rise to more thermophilic species (those adapted to more temperate climates) in the Arctic, even in isolated areas such as Svalbard. For example, we expect mountain birch, juniper, and lingonberry (mountain cranberry) to establish there in the near future."

Question: To what extent does the distance across the sea pose a barrier to species immigration?

"Our analyses indicate that it is the hardiest plant species that have established themselves most frequently on Svalbard. From that we can deduce that for factors such as seed germination and subsequent establishment, local climatic conditions are a greater limitation to dispersal than distance from the mainland."

DNA tracing of "roots"
Professor Brochmann's project utilised a method known as DNA fingerprinting to obtain information about the source areas of plants and how often they have colonised the remote archipelago.

"In the plants' DNA profiles we find different genetic varieties within the same species and can compare them with varieties from other source areas in Russia, Greenland and Scandinavia," says the professor. "For instance, the white dryad (mountain avens) most likely dispersed to Svalbard thousands of times and most often from Russia, while bog bilberry (moorberry) has arrived from both Russia and Greenland."

Effects of climate change on ecosystems in Svalbard: Past and future immigration of thermophilous key species

> INSTITUTE: Natural History Museum University of Oslo

> PROJECT LEADER: Christian Brochmann

> DURATION: 2002–2007

> FUNDING FROM RCN: NOK 6,1 million

The researchers also applied DNA fingerprinting to estimate the dispersal abilities of certain species not yet found on Svalbard. Matched with information about a plant's climatic requirements, the method can calculate the likelihood that a species will gain a viable foothold there.

Ecological ripple effects
Question: Will there come to be birch forests on Svalbard?

"Yes, it's quite likely that mountain birch will colonise Svalbard as temperatures rise. And this will generate ecological ripple effects, since other plants and animals that thrive among mountain birch will have a new habitat in which to flourish," concludes Professor Brochmann.

Published in Science
The project was carried out by a team of six women post-doctoral research fellows, fellowship-holders and masters students, in addition to Professor Brochmann and his colleagues.

Their findings were published in *Science* in 2007 (316: 1606-1609).

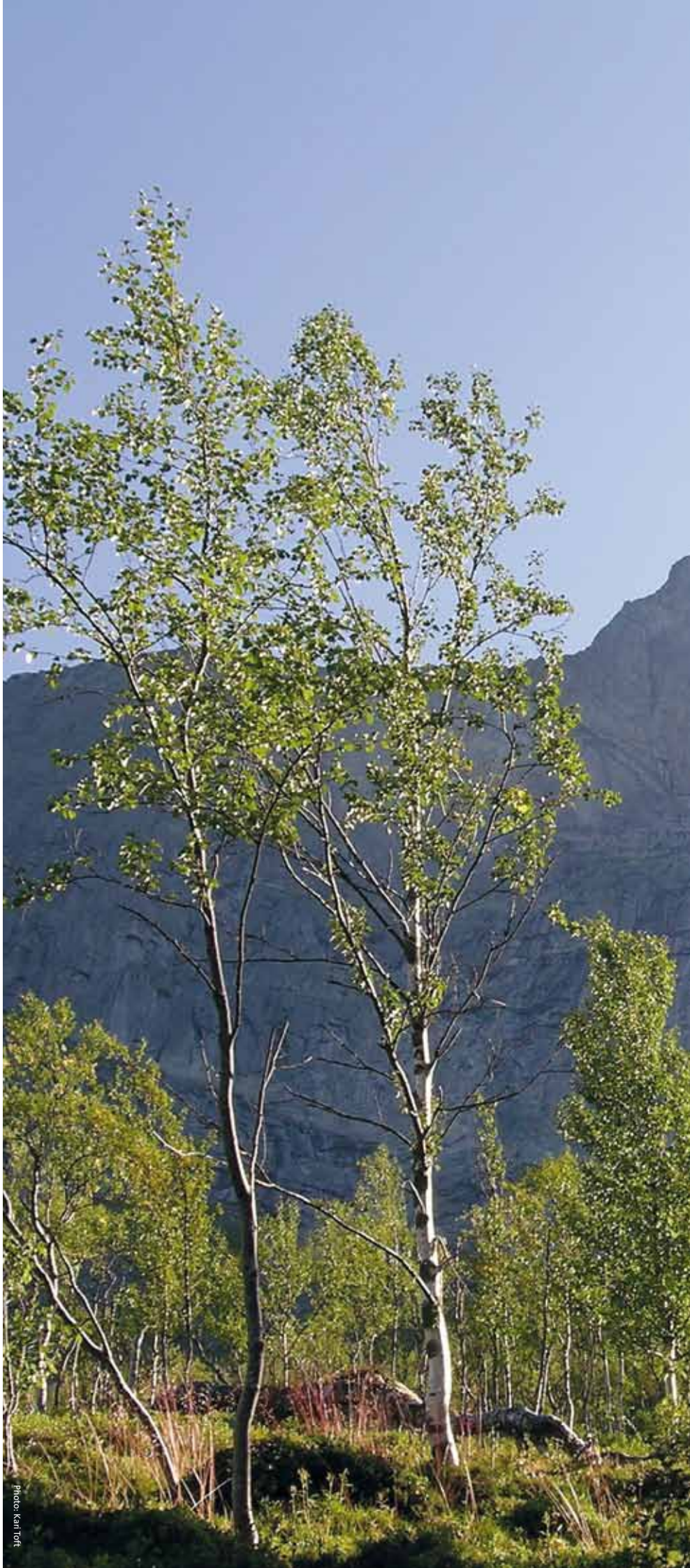


Photo: Kari Toft

Study of climate change from front-row seats

In 2006, 2007 and 2008 researchers on Svalbard were able to study in detail the direct impacts of dramatic climate change on an entire ecosystem, from plankton to marine birds.


Photo: Philip Riel, Norwegian Polar Institute


Photo: Hallvard Strøm, Norwegian Polar Institute

What happens when an Arctic environment turns much milder?

In northwest Svalbard, an Arctic fjord slices 26 kilometres inland. Known as Kongsfjorden, it is home to Ny Ålesund, the world's northernmost permanent civilian research station. Chosen as the team base for the research project "Marine ecosystem consequences of climate-induced changes in water masses off West Spitsbergen" (MariClim), the station supported biologists, oceanographers and ice researchers from seven countries who converged there to study a polar ecosystem within a specific geographic area.

As luck would have it, the project started up in 2006 – precisely when a rapid climate change triggered a chain reaction in the polar food web. Already in place, the researchers had a golden opportunity to record all the events from the front row.

Two species of seagulls, kittiwakes (pictured) and little auks, reacted differently to the change in climate. (Photo: Geir Wing Gabrielsen, Norwegian Polar Institute)

Milder winters

In the winter of 2006, warmer waters from the Atlantic Ocean began flowing into Kongsfjorden due to an unusual combination of wind conditions and ocean currents. An enormous volume of temperate, salty seawater supplanted much of the fjord's cold Arctic water mass. Never before have such high water temperatures and so little ice been recorded there; even in summertime, 8°C at a depth of 80 metres is extremely warm for an Arctic fjord.

This warm influx recurred in both 2007 and 2008.

Altering the food chain

Kongsfjorden's ecosystem has always been characterised by a mix of species from Arctic and sub-Arctic biomes. But from 2006 on, the Arctic species were quickly being displaced.

The warmer Atlantic waters carried boreal plankton into the fjord. This species, smaller than Arctic plankton, provides less energy in the form of lipids (fats) – a change that shook up the entire food chain.

Arctic cod abandoned the fjord, replaced by swarms of krill, which are better suited to utilising the smaller plankton species. The krill, in turn, became food for an increasing stock of capelin.

"Basically, we observed Kongsfjorden being taken over by conditions that are common farther south. So a fjord that previously had Arctic conditions was transformed into a warmer Atlantic ecosystem," says Haakon Hop, Senior Research Scientist at the Norwegian Polar Institute.

Hungry seagulls at the top

Highest in the food chain in this Svalbard fjord are 15,000 pairs of kittiwakes and little auks. Studying these two seagull species was a major component of the MariClim project.

In order to feed their offspring, both species depend on zooplankton and fish that are rich in energy. So when the Atlantic waters filled the Arctic fjord with a less-nutritious food source, the gulls were forced to eat more and to venture farther out to sea to acquire enough food for themselves and their young.

Bird's-eye view of impacts
Kongsfjorden's change in climate had an impact on both these marine bird species, but in very different ways.

Kittiwakes are seagulls that nest in steep cliffs as far south as Portugal and as far north as Svalbard. Kongsfjorden's kittiwakes were accustomed to a diet of mainly Arctic cod, but had to switch to the more plentiful capelin. Fortunately, this fish species is high in fat; in fact, kittiwake colonies of other regions routinely feed on capelin. So Kongsfjorden's kittiwakes were spared any dramatic impact from the fjord's climate change.

Little auks, however, unlike their kittiwake neighbours, are gulls that live only in the Arctic and feed on lower trophic species. Copepods are a favourite meal.

When the fjord's highly nutritious zooplankton were replaced by smaller plankton with as little as one-thirtieth the energy content, the impact on little auks was striking. Monitoring devices fitted on some Kongsfjorden specimens of little auk revealed that the gulls had to fly as far as 200 kilometres in search of food.

The study also showed the little auk capable of adapting to climate-induced changes. The gull can adjust its metabolism and energy use – but even with this flexibility the survival rates in both chicks and adults were still reduced.

Corresponding readings of energy consumption and energy use in Kongsfjorden kittiwakes indicated that this gull's metabolism is already maximised and is thus less adaptable than the little auk's.

"Changes in food availability in Kongsfjorden primarily affected the little auks," confirms biologist Geir Wing Gabrielsen, who headed the MariClim project. "Kittiwakes adapted better by switching to a new food supply, capelin. But the two gulls' metabolisms reacted completely differently to the changes."

Extreme event with lasting impact
The events of January-February 2006 evidently created a tipping point for Kongsfjorden. A short-lived extreme occurrence, repeated to a lesser degree the following winters, led to prolonged changes in the physical system. As the MariClim researchers explain it, a positive feedback mechanism develops when a warm, high-salinity water mass flows across the shelf west of Svalbard and into a fjord such as Kongsfjorden.

Their research demonstrated that climatic changes caused an impact on Kongsfjorden, both beneath and above the surface, within a very short period of time.

Interdisciplinary, international cooperation
The MariClim project consisted of six sub-projects studying the ocean, sea ice, phytoplankton, zooplankton, fish and marine birds.

Researchers were able to study a wealth of data, collected in the same area over time, on plankton and marine birds.

The winter of 2006 brought a change in climate to Svalbard's Kongsfjorden – with dramatic impacts on the fjord's entire ecosystem.
(Photo: Kim Holmén, Norwegian Polar Institute)

There are oceanographic and sea-ice records for Kongsfjorden dating back more than 100 years.

A distinct benefit of the MariClim project was its diversity. Researchers from seven countries and many scientific disciplines succeeded in collaborating closely to study a single geographic area and formulate interdisciplinary hypotheses. Data compiled from the six sub-projects have provided a more complete explanation of the big picture concerning changes in an Arctic fjord.

Marine ecosystem consequences of climate induced changes in water masses off West-Spitsbergen

> INSTITUTE: Norwegian Polar Institute

> PROJECT LEADER: Geir Wing Gabrielsen

> DURATION: 2005–2009

> FUNDING FROM RCN: NOK 12,1 million

Currents influence fish stocks:

More cod in warmer Barents Sea

Back in the 1920s and 1930s, the Barents Sea was teeming with cod. That was before its waters substantially cooled off in the decades to follow. Now, with ocean temperatures higher once again, fishermen are seeing more fish.

Project leader Ken Drinkwater. (Photo: private)

More and larger fish further north. (Photo: Seafood of Norway)

The entire North Atlantic warmed up during the 1920s and 1930s. More fish appeared not only in the Barents Sea but also off Iceland and Greenland. This warm period reached its peak at the end of the thirties and lasted until roughly 1960, when the waters began turning colder again – and fisheries resources declined once more.

In recent years, the North Atlantic has shown signs of a new period of warming.

Warm waters then and now

Ken Drinkwater is a senior research scientist at both the Institute of Marine Research and the Bjerknes Centre for Climate Research, located in Bergen. He and his colleagues have been studying the causes of this latest warming trend – and are finding many answers by poring through the literature describing conditions 80-90 years ago.

Dr Drinkwater rejects the common explanation that the Barents Sea is getting warmer because the atmosphere in the polar regions has warmed.

"This warming is primarily due to currents – a greater amount of warm Atlantic water is flowing into the North Atlantic and up to the Barents Sea," asserts Dr Drinkwater.

That is what happened in the first half of the 20th century. Although there were large year-to-year temperature fluctuations then, the North Atlantic on the whole remained more temperate than normal until well into the 1960s.

"Many people recorded what they observed taking place in the ocean nearly 90 years ago. If we can determine what occurred during that warming period," believes Dr Drinkwater, "we will better understand what is going on today, plus we'll have more reliable input as to what we can expect in the future."

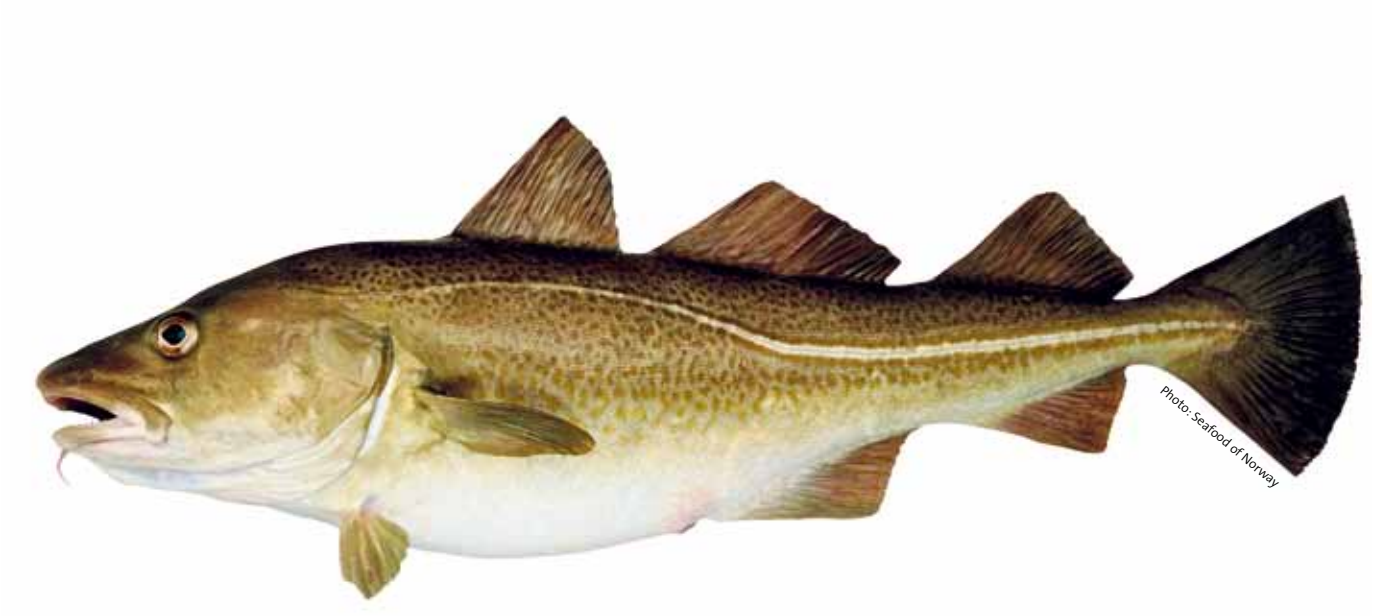
More and larger fish farther north

The warm period between the world wars led to some major changes in the ecosystem. In the Barents Sea and off Iceland and Greenland, cod catches reached record highs.

"In the 1920s and 1930s, the Arcto-Norwegian cod stock moved north. Fishing of cod was organised around Bjørnøya (Bear Island in the Svalbard archipelago) and more cod were being caught in Russian waters as well. The fishermen were catching cod that were about 50 per cent larger than in the previous decades."

The Arcto-Norwegian cod were not the only fish affected by the milder ocean waters of that period. Capelin and Arctic cod also relocated farther north. Haddock moved towards Novaya Zemlya in nearby Russia. In the 1930s, Norwegian spring-spawning herring had gravitated so far east that a dedicated Soviet fishery emerged off the coast of Murmansk.

Herring was more abundant in the Norwegian Sea than ever before. Off the coast of West Greenland, cod were being hauled in 1,200 kilometres north of their usual range. Icelandic herring flourished, and continued to do so until the late 1960s – when the herring stock collapsed.



More plankton benefits entire food chain

In explaining how warmer seas could lead to so much more fish in the North Atlantic, all the way to the Arctic, scientists point to the bottom-up effect: Warmer seas result in more phyto-plankton, which feeds more zooplankton, providing more nourishment for the herring and capelin that serve as a food supply for cod and other larger fish.

Scientific literature confirms that cod reproduction is typically higher in warm-water years and lower when waters are cold.

Link between ocean temperature and spawning

As part of the recently concluded research project Norwegian Component of the Ecosystem Studies of Sub-Arctic Seas (NESSAS), researchers Svein Sundby and Odd Nakken studied the relationship between ocean temperature and cod spawning.

When the two charted spawning along the Norwegian coast in a 1900-1976 timeline, the correlation was unmistakable: In coldwater years, southern coastal areas were of highest importance. When waters warmed up, spawning was most active in the northern areas. Seen over time, their research showed that cod reproductivity was markedly higher when the ocean warmed up, and that spawning moved north.

Spawning grounds off northern Norway

Since 2003, Arcto-Norwegian cod have been observed spawning once again along the coast of Finnmark, Norway's northernmost county. This had not seen since the early 1960s.

Recently, cod catches in the Barents Sea have been on the rise. Within the last few years, catch levels have reached those of the 1920s and 1930s warm period. Off Iceland and Greenland, however, no corresponding increase has been recorded.

Research indicates that knowledge about natural climatic variations in fish stocks deserves a role in the future management of the northern fisheries resources.

US observations corroborate

The correlation between warming ocean waters and more fish has also been investigated in a comparative study carried out by the NESSAS researchers in collaboration with US researchers. They have compared developments in three ocean areas: off the coast of Norway, in the waters of the Gulf of Maine (off the northeast coast of the US), and off Alaska and in the Bering Sea (between Alaska and Russia).

"This comparative study has been interesting," says Dr Drinkwater, "in that the causal factors are completely different for the warming of these three northern seas. Yet in each area, warmer waters have led to longer growing seasons, more plankton and more fish."

Norwegian Component of the Ecosystem Studies of Sub-Arctic Seas (NESSAS)

> INSTITUTE: Institute of Marine Research

> PROJECT LEADER: Kenneth Drinkwater

> DURATION: 2005–2009

> FUNDING FROM RCN: NOK 10 million

Winds from Siberia reduce Arctic sea ice cover

The ice cover in the Arctic has decreased dramatically in recent years. Norwegian researchers have discovered that changes in air circulation patterns create winds that push away the ice.

Associate professor Asgeir Sorteberg.
(Photo: Jill Johannessen, BCCR)

In recent years, satellite images have shown large variations in the ice cover around the North Pole. The images have also shown that the ice cover in the Arctic has diminished considerably over the past 30 years, with the most drastic reductions occurring in recent years.

Climate change or other causes?
The media regularly cite sources who believe that it is now only a matter of decades before climate change results in a totally ice-free Arctic during parts of the year. For instance, the UN Intergovernmental Panel on Climate Change (IPCC) projects that this may occur by the end of this century.

How much of the change in ice cover is caused by dramatic changes in the climate, and how much is the result of other factors? And what is causing the ice cover in the Arctic to disappear even faster than the climate models project?

The Arctic climate paradox
A few years ago, US researchers discovered what they termed the "Arctic climate paradox". Since 1980, the researchers had been observing a decrease in ice cover. They explained this through a slow process of climate change combined with fluctuations in patterns of atmospheric pressure and air currents over the Arctic. It was believed that the positive phase of the Arctic Oscillation (AO) was a major cause of the receding ice cover.

The AO is normally influenced by three pressure systems located over the Azores, Iceland and the Northern Pacific Ocean. Since 2000 the AO has been in a negative phase. As a result, researchers predicted that the pace of reduction in the ice cover would slow down.

Instead it accelerated.

Unknown factor
"The US researchers argued that the ice was responding to something else, another factor that nobody had considered," explains Asgeir Sorteberg, Associate Professor at the Geophysical Institute at the University of Bergen. He has been investigating this phenomenon along with his colleagues in the project entitled the Norwegian Component of the Ecosystem Studies of Sub-Arctic Seas (NESSAS).

When the Norwegian researchers began their work, they noticed in particular a dramatic change in the weather pattern in the Arctic beginning about the year 2000. The change corresponded to the point in time when the reduction of ice cover in the Arctic began to accelerate.

The answer is blowing in the wind
The researchers began to analyse the circulation patterns over the Arctic.

"We found that these patterns can explain in large part why the ice cover decreased so much more rapidly after 2000. Wind patterns depend on the position of major high-pressure and low-pressure systems. We discovered that months with very little ice cover and high temperatures corresponded with crucial variations in the wind patterns," explains Mr Sorteberg.

"Up until 2000, the Arctic Oscillation (AO) had the greatest impact on the winter ice cover in the Arctic. But the change around 2000 meant that more of the weather and wind over the Arctic after that year was determined by high-pressure and low-pressure systems

The Arctic ice cover has decreased considerably in recent decades. Changes in weather patterns mean that there is more wind from Siberia.
(Photo: Shutterstock)

A change in wind direction explains the reduction in ice cover. (Illustration: Shutterstock)

in northern Russia. In other words, the AO, which was usually so crucial, played a much less important role."

Ice is pushed away

"We have now managed to document what has occurred in connection with this change," says Mr Sorteberg.

The changed wind direction pushes large ice masses away from the Arctic and down along the eastern coast of Greenland. At the same time, less ice forms when the winds over the Arctic are determined by the pressure systems in northern Russia rather than those over the North Atlantic and the Pacific Ocean, as is normally the case.

Extent of ice a poor indicator

The conclusion from this research is that we should be cautious about using the extent of the ice cover as an indicator of the ice's climatic "state of health".

The extent of the ice cover is highly dependent on the wind direction, and short-term changes in the ice cover give very little indication of whether climate change is occurring in the Arctic.

"The dramatic changes in the extent of Arctic sea ice in recent years have mainly been caused by atmospheric circulation patterns that have tended to reduce ice cover, combined with a slow process of climate change. Variations in the circulation patterns are part of the natural fluctuations in the weather. In certain periods these fluctuations will reinforce manmade changes, while at other times they will mask them," says Mr Sorteberg.

Climate change leads to thinner ice

Mr Sorteberg believes we should be cautious about interpreting the dramatic decrease in Arctic ice cover in the past decade as an indication that the Arctic will be ice free in 10 to 20 years.

However, he emphasises that he and his colleagues do not reject the assertion that climate change is affecting Arctic ice cover or that the IPCC is wrong when it states that the Arctic may be nearly ice free in summer towards the end of this century.

"There is no doubt that the Arctic sea ice has become thinner in recent years. The thickness of the sea ice is a much better indicator than the extent of the ice cover if we want to study how climate change may affect the ice in the Arctic," says Mr Sorteberg.

Norwegian Component of the Ecosystem Studies of Sub-Arctic Seas (NESSAS)

> INSTITUTE: Institute of Marine Research

> PROJECT LEADER: Kenneth Drinkwater

> DURATION: 2005–2009

> FUNDING FROM RCN: NOK 10 million

Getting a grip on soot pollution

After CO2, soot and methane are probably the biggest contributors to global warming. An interdisciplinary Norwegian research project has now concluded that efforts to reduce emissions of soot (black carbon) should focus on China rather than the Arctic.


Photo: Shutterstock

Politicians and the media have been especially concerned about soot (also called black carbon) darkening the ice and snow of the Arctic. But soot's worst impact on climate occurs in the atmosphere – where the warming effect of black carbon particles is thought to be four times greater than when they are deposited on ice and snow.

Important research on climate impact
The climate impact of black carbon particles first gained serious attention as part of the climate change agenda when President George W. Bush cited the phenomenon as one reason why the US did not want to adhere to the Kyoto Protocol on reducing greenhouse gas emissions.

But until recently, even less was known about the climate effects of black carbon than those of CO_2 emissions. The research project "Climate effects of reducing black carbon emissions", is generating more knowledge.

What should be done
Researchers from CICERO, the Norwegian Polar Institute, and the University of Oslo teamed up with the aim of tracing the complete life cycle of the world's soot emissions.

The primary objective of this ambitious project has been to provide decision-makers and the public with knowledge about where to direct initial efforts toward reducing the impact of soot emissions on the climate.

The project's researchers have studied where soot is emitted and have run various models on supercomputers to calculate soot dispersion in the atmosphere. In Svalbard and Alaska, researchers have measured the effect of black carbon particles lying atop snow. Other researchers have calculated the costs of cutting soot emissions in different parts of the world. The results were then examined within the context of what is considered politically feasible to accomplish.

Short but destructive lifetime
Atmospheric black carbon particles cause the surrounding environment to absorb excess heat which takes five to ten years to dissipate. Fortunately, black carbon actually has a very short lifetime in the atmosphere; if the world were to cut all soot emissions today, the black carbon particles would be virtually gone in two to three weeks.

This contrasts sharply with current CO_2 emissions, which we know will remain with us for at least 100 years to come.

Black carbon particles in the atmosphere are primarily a product of incomplete combustion of carbonaceous fuels. Examples of measures that can greatly reduce black carbon emissions include upgrading to modern wood-burning stoves and equipping coal-fired power plants and diesel vehicles with particulate filters.

Black carbon is a complex factor in climate change. As opposed to CO2, black carbon particles are not evenly dispersed throughout the earth's atmosphere. Their short lifetime leads to great regional differences in distribution. Another significant point is that black carbon particles may also have some cooling effect on the atmosphere due to complex processes in noctilucent clouds, about which little is known.

Encouraging improvement in the north
One uplifitng finding of the Norwegian project was that the amount of black carbon on the Svalbard archipelago appears to have halved compared to 25 years ago. Samples from the Greenland Ice Sheet indicate similar developments. These findings contradict recent portrayals in the media but are consistent with the

major reductions in pollution from Eastern Europe in particular.

In essence, soot particles warm the climate in two ways. The first is indirect, by darkening snow cover and hence reducing its reflectivity. The second, which is more direct and thought to have four times more impact on global climate warming than the first, is by magnifying atmospheric warming from solar radiation.

Burning coal in China

In our corner of the world, major causes of soot formation in the atmosphere are farmers burning stubble, forest fires, and the use of outdated types of wood-burning stoves. Also significant sources but probably causing less impact are industrial activities and road traffic.

"Globally, if we are to implement cost-effective measures against soot emissions – beyond those already agreed upon – there are other places than here we should be focusing our efforts," says Professor Terje Berntsen of the University of Oslo and the Center for International Climate and Environmental Research - Oslo (CICERO). "Regardless of how we analyse our findings, it is clear that the most beneficial action would be to prioritise measures against soot emissions in China and partly in India."

Focusing on China is critical: it is the largest soot emitter by far, and emissions appear to be on the rise. Furthermore, local pollution from coal is causing enormous health problems for the country, so there is likely to be both political and social will to enact change.

Positive results can be achieved on soot emissions in China, India and the developing world by applying relatively simple technology that developed countries have been using for several decades.

Photo: Shutterstock

Climate effects of reducing black carbon emissions

> INSTITUTE: CICERO Center for International Climate and Environmental Research Oslo

> PROJECT LEADER: Terje Berntsen

> DURATION: 2005–2009

> FUNDING FROM RCN: NOK 8,1 million

Natural changes in marine climate:

Ocean temperatures may predict fish stocks

Natural changes in marine climate are occurring in the Norwegian Sea, and certain physical parameters can explain them. This discovery could enable scientists to forecast fluctuations in important fish stocks.

Researchers are basing their new insights on findings from Norwegian-funded research on variations in the large water mass system located south of Greenland and Iceland.

Fluctuating stock of blue whiting
The stock of blue whiting, a smaller member of the cod family, began increasing dramatically in the mid-1990s. Within a few years this fish became the most plentiful species in the entire North Atlantic. The Norwegian catch of blue whiting approached one million tonnes in 2004 – after which catch volumes fell drastically.

"This matches well with what we would expect," says Hjálmar Hátun, who headed the research project *Decadal variability in the North Atlantic Ocean/ Nordic Seas (DEC-OCEAN)*.

Only partly due to overfishing
While Dr Hátun does not rule out extensive overfishing as part of the reason behind this precipitous drop in the blue whiting stock, he also sees a clear connection between this important stock and the ocean's natural changes in climate.

Dr Hátun, an oceanographer at the Faroe Marine Research Institute, believes that knowledge about changes that occur in large water masses in the Norwegian Sea will soon enable scientists to reliably predict future fluctuations in the stock of blue whiting – and possibly mackerel as well.

The Subpolar Gyre
Dr Hátun and his DEC-OCEAN project colleagues have studied variations in the Subpolar Gyre – an enormous, cold, low-salinity seawater mass. One of just 11 major circulation systems in the earth's oceans, this gyre rotates counter-clockwise in the waters south of Greenland and Iceland, driven primarily by winds and heat convection from the seas to the atmosphere.

"Even before embarking on this project, we knew that the Subpolar Gyre's circulation exerted a surprisingly strong effect on the temperature and salinity of the water masses flowing from the Atlantic Ocean up into the Norwegian Sea. The questions we wanted to answer were: a) What controls this gyre? b) How does the gyre affect marine life? and c) Could we somehow predict the gyre's development?"

Predicting changes
Northern Europe's climate on land and at sea is greatly influenced by the flow of the Gulf Stream. In previous research, winds had been considered the main driver in the Gulf Stream's northward transport of seawater masses into the Norwegian Sea.

"Winds undoubtedly play a role," acknowledges Dr Hátun. "But we have concluded from our research that there is another important force in these events: convective heat loss from the ocean, which leads to cooled water sinking into the ocean's depths."

Using wide-ranging computer models, the DEC-OCEAN researchers found that when atmospheric changes that will affect the Subpolar Gyre take place, for instance those as far-off as the El Niño weather phenomenon of the Pacific Ocean, the effects may not emerge until one to two years later. Then slowly, after another two to three years, the effects will reach the waters of the Norwegian Sea and the Greenland Sea.

These findings make scientists optimistic that they will soon be able to predict developments in the marine environment a few years in advance.

More plankton, fish and marine birds
As Dr Hátun explains it, the Subpolar Gyre undergoes natural changes in its climate, growing stronger or weaker depending on the amounts of convective heat loss from the various currents feeding into it. In all likelihood, these changes have always been occurring and are not the product of anthropogenic climate change.
From a variety of sources as far back as the 1700s (such as reports of whales caught off the Faroe Islands through the years), the project's researchers found evidence of fluctuations they

These robotic, free-manoeuvring Seagliders, developed by the University of Washington, help researchers to collect a variety of oceanographic data. (Photo: private)

Dr Hjálmar Hátun headed the recently concluded DEC-OCEAN project, funded under the NORKLIMA programme. (Photo: private)

The Subpolar Gyre is an enormous circulating system comprising four ocean currents: the East Greenland Current (south-flowing and cold), the West Greenland Current, the Labrador Current, and the North Atlantic Drift (a north-flowing branch of the Gulf Stream). (Illustration: National Oceanography Centre, UK)

believe stemmed from changes in the gyre. The earliest numerical data, from 1960, indicate the gyre was very weak – meaning warm waters – in the 1960s, followed by a strengthening trend culminating in historically high gyre strength in the early 1990s. This is why the Norwegian Sea was so cold.

"Towards the end of the 1990s, the gyre was weakened substantially, making the Norwegian Sea milder. This led to more phytoplankton and more species of warmwater zooplankton, which supported a tremendous surge in the stock of blue whiting and generated the basis for the largest fishery in the entire North Atlantic."

Cod stocks moved north, herring thrived and extended its range farther into the Norwegian Sea. Many more warmwater fish species have been observed in the northern seas in the past decade. Changes are also being seen in marine bird stocks and the number of long-finned pilot whales off the Faroe Islands. The Subpolar Gyre has become stronger in the last four to five years, although not to earlier levels.

Sudden changes with impact

"We now know that changes in the Subpolar Gyre can occur very abruptly," says the oceanographer, "bringing about major consequences for marine life – and for the economics of the fisheries industry."

"Findings from the DEC-OCEAN project clearly indicate that knowledge about the relationship between natural climate change and the marine environment must be given a place in fisheries research and in the establishment of fisheries quotas in the years to come," asserts Dr Hátun.

Decadal variability on the North Atlantic Ocean/Nordic Seas

> INSTITUTE: Nansen Environmental and Remote Sensing Center

> PROJECT LEADER: Hjálmar Hátun

> DURATION: 2007–2010

> FUNDING FROM RCN: NOK 1,2 million

Many Arctic species on thin ice

Polar bears are not the only species struggling as the Arctic ice retreats. Sea ice algae are also threatened, and their troubles make themselves felt throughout the ecosystem.

Once the spring sun finally emerges over the horizon in the Barents Sea, life explodes along the ice edge. The algae bloom in droves. Small crustaceans awake from their winter diapause, surrounded by food, and reproduce by the millions to the delight of hungry animals higher up in the food chain such as fish, walrus and polar bears.

Now, however, climate change has begun to disrupt this delicately balanced ecosystem. The northern hemisphere's sea ice is receding. Ice algae survive by clinging to the underside of the ice, so their habitat is dwindling as the ice cover shrinks. In 2007, the greatest retreat of Arctic sea ice in history was observed.

Extremely temperature-dependent
The problems actually begin long before the ice disappears.

"Ice algae have adapted to a very specific habitat," explains Else Nøst Hegseth. "They require a precise temperature range of -1.7ºC to -1.8ºC. The tiniest rise in water temperature causes the algae to lose its grip on the ice – long before the ice actually melts."

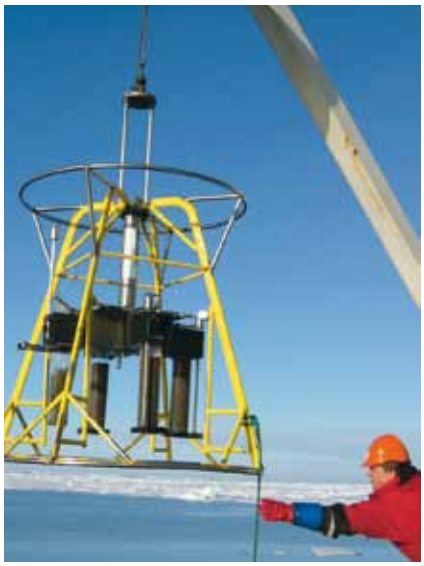
Dr Hegseth is an associate professor at the Norwegian College of Fishery Science, which is part of the University of Tromsø. A few years ago she took part in a project titled *On thin ice? Climatic influence on Energy Flow and Trophic Structure in Arctic Marine Ecosystems* funded under the NORKLIMA programme. The project focused on the impacts of climate change for Arctic marine ecosystems, and was headed by Dr Michael Carroll, a senior consultant at Akvaplan-niva.

First to grow, first to vanish?
In the polar regions, it is the ice algae that initiate the spring's explosion of growth. These algae can subsist on very weak light – as little as 0.01 per cent of surface light – and thus can begin blooming in March, weeks before the free-floating algal species can bloom.

Ice algae are the first species to come to life in the spring, but are also among the first that risk disappearing completely as a result of climate change. Their absence would have dire consequences for other parts of the ecosystem.

Vital source of food
Dr. Janne Søreide's doctoral research project studied the role of ice algae as feed for zooplankton and benthic (bottom-dwelling) animal species in the Barents Sea. Based on a variety of measurements, she calculated that ice algae typically comprise five to 25 per cent of the dietary intake for the next link in the food chain. But in the early spring, this figure can reach up to 50 per cent.

Food chains in Arctic regions are short, with only a few links from algae to fish and mammals. The ice algae are therefore a critical food source in the ecosystem.



Senior Consultant Michael Carroll collecting seabed samples.

"Ice algae are highly nutritious since they are rich in polyunsaturated fats," confirms project manager Michael Carroll. "Both their nutritional content and early bloom are pivotal for the ecosystem."

Spring banquet for shellfish threatened
Many organisms thrive on the spring's first feast. Multitudes of ice algae sink down to feed bottom-dwelling species such as shrimp, shellfish and sea

Ice algae are single-celled but can associate to form large colonies that cling to the undersurface pores of the ice. (Photo: Nathalie Morata)

Infiltration layer. (Photo: Else Nøst Hegseth)

cucumbers – species that are snapped up by higher animals. The walrus, for instance, picks shellfish in much the same way that humans dig up potatoes.

"One hypothesis of our project was that the decline of the ice algae would have negative consequences for organisms living on the seabed," says Dr Carroll. "Our findings confirmed this hypothesis."

While fish are able to swim off in search of meals if the polar ice recedes, many benthic animal species are slow-moving organisms reliant on their food (such as ice algae) falling from above.

Unexpected discovery

"In the Arctic, one is always finding something new and surprising," says Michael Carroll excitedly. "On our expedition we noticed distinct brown layers as we navigated the ice by boat. Upon closer inspection these turned out to be an infiltration layer, that is, algae on top of the ice, in the stratum between the ice and snow."

"We found algal species *(Phaeocystis)* which are common in the water mass," explains Dr Carroll. They are carried in the water that washes onto the ice, and they continue multiplying there. This phenomenon had been documented in the Antarctic, but never before in this part of the world."

The project *On thin ice? Climatic influence on Energy Flow and Trophic Structure in Arctic Marine Ecosystems* was a collaboration between Akvaplan-niva, the Norwegian Polar Institute, and the Norwegian College of Fishery Science, as well as participants from the US, Australia, Poland and Canada.

On Thin Ice? Climatic influence on Energy Flow and Trophic Structure in Arctic Marine Ecosystems

> INSTITUTE: Akvaplan-niva AS

> PROJECT LEADER: Michael L. Carroll

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