136 REPORT SERIES
NORWEGIAN POLAR INSTITUTE

NorACIA
www.noracia.npolar.no

NORWEGIAN POLAR INSTITUTE

CLIMATE CHANGE
IN THE NORWEGIAN ARCTIC

Consequences for life in the north

CLIMATE CHANGE
IN THE NORWEGIAN ARCTIC

Consequences for life in the north

Address:
NorACIA Secretariat
Norwegian Polar Institute
Fram Centre
NO-9296 Tromsø
Norway
noracia@npolar.no
www.noracia.npolar.no

Author: Ellen Øseth, Norwegian Polar Institute
Technical editor: Marte Lundberg, Norwegian Polar Institute
Design/layout: Rudi Caeyers
Cover image: Øystein Overrein
Translation: Språksenteret DA
Printed: January 2011, Grøseth Trykk AS
ISBN: 978-82-7666-283-2
ISSN: 0803-0421

This report is an English translation of Report Series 136: Klimaendringer i norsk Arktis - Konsekvenser for livet i nord

No. 0004
CARBON NEUTRAL PRINTED MATTER

MILJØMERKET
241 TRYKKERI 148

Foreword

Global warming is one of the major challenges facing the world's population. The climate in the Arctic is important for the global climate, and in recent years, large changes have been charted in the region. The northern regions are in focus and it is important that the best and most updated information concerning ongoing and future climate change in the Arctic is available to decision makers.

Norwegian Arctic Climate Impact Assessment (NorACIA) is an initiative taken by the Norwegian government as a follow-up to the Arctic Climate Impact Assessment (ACIA), a project organised by the Arctic Council. ACIA's main report, published in 2004, was the first comprehensive compilation and analysis of knowledge concerning climate change in the Arctic. It called for several further studies and a better understanding of climate change on a regional scale. NorACIA, in line with these recommendations, aims to assemble and raise awareness of existing knowledge and to develop new expertise concerning climate conditions in the Norwegian part of the Arctic, and to identify areas in which knowledge is incomplete. Within the framework of NorACIA, focus is on communication, advice to the government on management issues and compilation about climate change in the Norwegian Arctic. The main objective of NorACIA is to bring together knowledge of climate change in the region that can form the basis for further assessment of initiatives associated with climate change and the consequences of these.

NorACIA has issued five sub-reports within five themes, that all have the sub-title 'Climate change in the Norwegian Arctic':

Sub-report 1: Climate development in northern Norway and Svalbard during 1900–2100.
Sub-report 2: Physical and biogeochemical processes.
Sub-report 3: Effects on ecosystems and biodiversity.
Sub-report 4: Effects on people and society.
Sub-report 5: Adaptation and mitigation.

In addition to the above, a separate report was published in 2008, concerning climate change in the Barents Sea.

This synthesis report is based on these sub-reports and other relevant knowledge. The objective has been to collect available knowledge about the Norwegian Arctic, i.e. northern Norway, Svalbard and the surrounding oceans, in order to form a basis for decisions regarding initiatives, adaptations and further studies to improve our understanding of the interconnections and effects within the Arctic climate system. The synthesis report presents eleven key findings from the NorACIA process, presented in a form intended to appeal to a broad readership.

The NorACIA project and the preparation of this synthesis report has been organised by a steering group, led by the Ministry of the Environment with representatives from the Norwegian Directorate for Nature Management, the Norwegian Climate and Pollution Agency and the Norwegian Polar Institute. The following members have participated in the preparation of the synthesis report: Håvard Toresen (Ministry of the Environment), Else Løbersli (Norwegian Directorate for Nature Management), Øyvind Christophersen (Norwegian Climate and Pollution Agency) and Bjørn Fossli Johansen (Norwegian Polar Institute). The Norwegian Polar Institute has held the secretariat for the project and had the operational responsibility for the collation of the report.

Oslo, March 2010
Håvard Toresen
Chair of NorACIA Steering Group

Contents

Summary of key findings

Climate change will affect the ecosystems as well as the communities in the north. Presented here is a summary of the eleven key findings that have been identified in the NorACIA (Norwegian Arctic Climate Impact Assessment) for Svalbard, northern Norway and the surrounding oceans. The model calculations seek to predict future climate change. The mechanisms that control climate are, however, so numerous and so complex that that we may never be able to create detailed and 100% correct calculations of all effects that follow on from a changed climate. This uncertainty – which will always exist – must not prevent us from reducing emissions and preparing ourselves for climate change and its effects. This report is therefore a compilation of possible future events and probable effects and consequences for the next 90 years, based on currently available knowledge.

Image: © Kerstin Mertens, Samfoto

Image: © Odd Harald Hansen, Norwegian Polar Institute

Key finding 1: The Norwegian Arctic is getting warmer and wetter, with large local variations

- The average annual temperature north-east of Svalbard may increase by as much as 8°C towards the end of this century. On the Norwegian mainland, an increase of 2.5–3.5°C has been calculated, with the smallest increase along the coast and the greatest on the Finnmark Plains. All seasons will see a rise in temperature; however, the increase appears to be the greatest in the autumn and winter, and greater over land areas than ocean areas.
- Precipitation is expected to increase throughout the entire region, during all seasons, but mostly during the autumn and winter. Regional variations will, however, be considerable. Towards the end of this century there may be a noticeable reduction in the annual snow season; a two-month reduction per year in the coastal areas of northern Norway; one month per annum on the Finnmark Plains.
- Extreme weather, in the form of strong winds and extreme precipitation can occur more frequently.
- Permafrost is thawing more rapidly than previously estimated, and the trend has intensified in the past ten years. In general, a gradual warming of the permafrost is anticipated. With an increasing frequency of extreme, high temperatures, warming may become increasingly irregular.

Key finding 2: Feedback processes in the Arctic increase global climate change

- Ice and snow have light surfaces that reflect sunlight and counteract warming. Temperature increases lead to the melting of ice and a shorter snow season, which in turn contributes to an increase in warming.
- When soot (black carbon) deposits fall onto ice and snow, the melting process accelerates. There is commercial technology available that can reduce soot emissions from energy pro-

Dead glaucous gull on the nest, with still-living young – death was most likely caused by environmental pollutants. Image: © Hallvard Strøm, Norwegian Polar Institute

duction, industry and ships, and these reductions can contribute to slowing down climate change in the short term.

- The influence of clouds on the climate system in the Arctic is complex and not completely understood. Reliable calculations of future cloud cover have not yet been made for the Arctic.
- Calculations of the effect of climate change on ocean and air current systems are unreliable, and further knowledge is required in order to understand exactly how these key processes within the global climate system will change.

Key finding 3: Climate change makes the Arctic more vulnerable to environmental pollutants and ultraviolet radiation

- Levels of some environmental pollutants are increasing in the Arctic, despite the decline in international use. Changes in climate systems may be the reason for this.
- Transport via air and ocean currents and deposition of environmental pollutants in the Norwegian Arctic may increase, depending on whether these transport mechanisms change along with the climate.
- Environmental pollutants that were previously intercepted and stored, in for example permafrost, glaciers and sea ice, may be released and thus increase the levels of environmental pollutants in Arctic rivers, fjords and lakes.
- Climate change at lower latitudes may lead to an increase in forest fires – which in turn may cause a further airborne influx of environmental pollutants to the Arctic.
- Animals that are already stressed due to climate-related circumstances, e.g. starvation or loss of sea ice cover, will become more vulnerable to environmental pollutants.
- Arctic organisms are vulnerable to ultraviolet (UV) radiation. Emissions of large amounts of ozone-destroying gases have been reduced considerably, and for the first time, in


Image: Tor Ivan Karlsen, Norwegian Polar Institute

2003–2004, a decline was registered in the concentration of ozone-destroying gases over Svalbard. However, a return to the levels of the 1980s is not anticipated until 2050–2070.

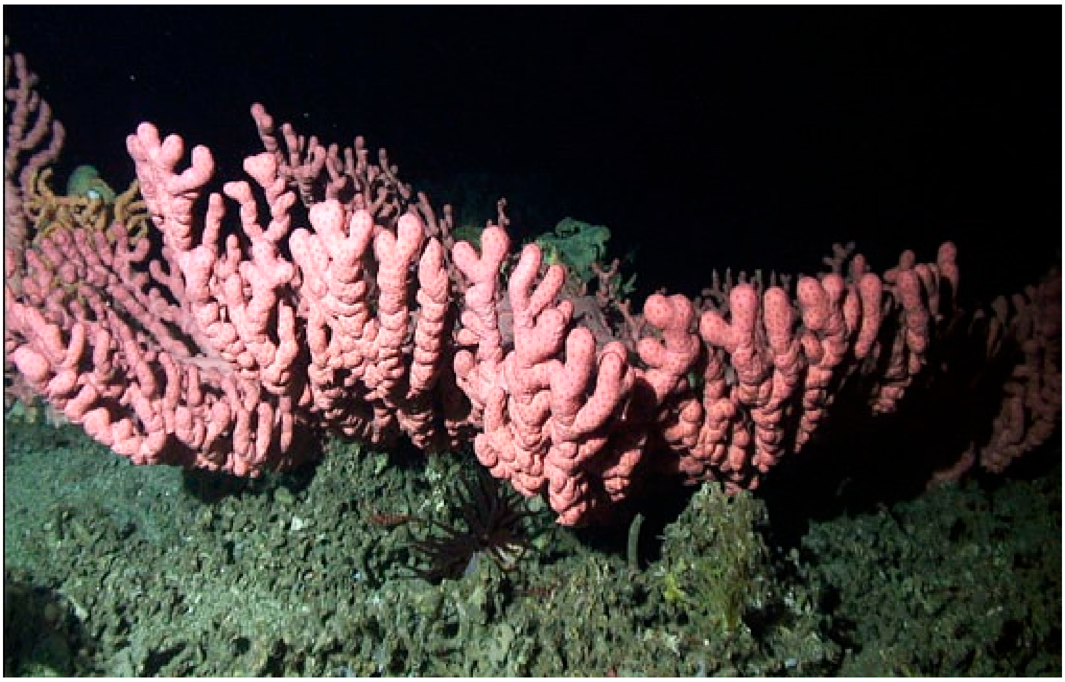
Capelin (Mallotus villosus). *Image: © University of Tromsø, Faculty of Biological Sciences, Fisheries and Economy*

Key finding 4: Sea ice is diminishing, threatening ice-dependent species

- Recent studies indicate that sea ice is retreating more quickly than first calculated in models that were applied as a basis for the ACIA (Arctic Climate Impact Assessment) and the fourth main report of the UN Climate Panel (IPCC).
- The absence of sea ice in itself leads to more rapid warming, due to the feedback mechanisms associated with the absorbance of sunlight.
- The trend for the extent of sea ice in the Arctic since measurements began in 1979 is decreasing and during the last three years this extent has been at an historical minimum.
- The amount of thick, multi-year ice in the Barents Sea and the Arctic as a whole is declining. This leads to accelerated melting, as the thinner first-year ice is more vulnerable to melting.
- The melting of sea ice can lead to a reduction in biological diversity. Several species are dependent on sea ice, such as ice algae that grow in and under the ice, seals that need sea ice to give birth to their young, polar bears that prey on seals, and several species of sea-birds, as many aspects of their lifecycle are associated with sea ice.

Key finding 5: The ocean is getting warmer and the ecosystems are changing

- Warmer seawater can lead to more phytoplankton and zooplankton; however it is not certain that fish and other animals can actually utilise this extra food source.
- With a steadily increasing ocean temperature, species that prefer warmer waters can begin to migrate to Arctic areas; these may out-compete some species that already inhabit the area.
- The zooplankton *Calanus finmarchicus* is an important species in the polar marine ecosystems. An increase in water temperature will mean that it will be exposed to competition from other, more southerly species that are not equally nutritious food sources for fish. Cor-



*Bubblegum coral (*Paragoria arborea). *Image: © Institute of Marine Research*

Øvre Pasvik National Park in Sør-Varanger, Finnmark. Image: © Ove Bergersen, Samfoto

respondingly, *Calanus finmarchicus* may replace fattier Arctic species of zooplankton further north and thus provide a poorer nutritional basis for, among other species, Arctic fish.

- Commercially important fish species such as cod and capelin may change the range of their distribution toward the north and east, and into Russian areas.
- The marine ecosystems have developed during, and adapted to, natural climate variations, and they appear to be fairly robust. However, if temperature exceeds the normal climate variation, uncertainty to the ecosystem's response and resiliency increases. Climate is only one of several factors that influence these ecosystems – it is the collective impact of these that will determine the overall effect.

Key finding 6: The acidity of the ocean is increasing and coral species may disappear

- Increased CO_2 concentrations in the atmosphere are expected to lead to ocean acidification during the next hundred years, the like of which has not occurred during the last 20 million years.
- The water chemistry is changing such that the formation of calcium will be difficult for organisms with calcareous shells, such as corals. Much of the deep-water coral in Norway grow at a depth at which the water chemistry can reach critical levels towards the end of this century.
- Organisms with calcareous shells are expected to relocate to other areas or undergo a sharply reduced distribution as a consequence of ocean acidification.
- In a global perspective, the Arctic oceans are the most sensitive to this type of change.

Fishing in the Tana River. Image: © Øystein Overrein

Key finding 7: Forests are spreading northwards and to higher elevations

- Birch and coniferous forests are expected to move northwards and to higher elevations, to the detriment of mountainous areas and plains. Increased plant growth and longer summers can lead to increased stocks of herbivores.
- There may be an increase in the infestation of forests by parasites and other pests. More frequent parasite attacks on animals are also expected.
- The phenomenon of 'lemming years' can disappear. Species that prey on small rodents, such as Arctic foxes and snowy owls, may disappear from northern Norway.

Key findings 8: Freshwater ecosystems are vulnerable to climate change

- The anticipated climate change will affect lakes and rivers in different ways; e.g. changes in water temperature, permafrost in the ground surrounding lakes, the ice thickness in winter, the composition of the ice (snow and ice layers), the length of time the ice remains on lakes and rivers, the inflow of nutrients from land and possible effects from glaciers and floods. All of these factors may weaken the stability of freshwater ecosystems.
- Climate change may disturb the migration of anadromous Arctic char in Svalbard.
- A milder climate in the coastal areas of northern Norway may lead to a shorter period of ice cover in rivers and higher mortality rates for salmon fry. Higher water temperatures in rivers during the summer months may, however, lead to increased growth and thereby increase production of salmon in the rivers.
- A rise in ocean temperature may provide an opportunity for new species to migrate upwards in watercourses, for example the stickleback in Svalbard.

Slush avalanche of melting snow across the E6 highway in Illhølia in Rana. Image: © Øyvind Bratt, Rana Blad

Key finding 9: The infrastructure in the north is vulnerable

- The effects of climate change on the transport sector appear to be largely negative; there will be a greater danger of landslides/avalanches and floods, and problems for the regularity of traffic.
- Municipal installations such as water supplies and sewage, also buildings, may be exposed to floods, greater precipitation and more frequent extreme weather.
- An ice-free Arctic Ocean in the summer opens the opportunity for new sailing routes, and it is anticipated that shipping traffic will increase, both arround Svalbard and along the Norwegian coast.
- Recent studies indicate that the global ocean level can be expected to increase more than anticipated by the IPCC in 2007. This may lead to the sea level in northern Norway rising by 40–95 cm (corrected for land uplift) before the end of the century, which will mean that the infrastructure along the coast will become more vulnerable to wear and damage, especially during storm surges.

Key finding 10: Nature-based enterprises will gain new opportunities – and face new challenges

- Agriculture in northern Norway – provided that it can adapt to the new situation – may actually *gain* from climate change, for example if it becomes possible to harvest crops twice a year instead of once.
- Northern ecological plant production currently has a special advantage due to the climate. This advantage may be lost due to higher temperature and humidity, which will lead to the greater likelihood of disease and attacks from parasites.
- Grazing areas for reindeer farming are expected to shrink when forests spread northwards and to higher elevations. This may lead to increased conflict in respect of area usage.

Fish farming at Purkevik, Loppa in Finnmark. Image: © Per Eide, Samfoto

In addition, temperature fluctuations around freezing point may make it difficult for reindeer to find food due to icing. Higher summer temperatures may lead to more disease and increase the spread of parasites. Both the industry itself and the basis for reindeer-herding Sámi culture will be challenged by climate change.

- Fisheries will have to address the new distribution of fish species. New fish species, such as mackerel, may become more common in the region.
- Aquaculture in northern Norway may profit from increased ocean temperature, as warmer water, up to a certain temperature, leads to more rapid growth in fish. Further south in Norway, the higher water temperature may become less favourable for certain species, for example salmon. Higher water temperatures may, however, lead to increased vulnerability to diseases and attacks from parasites.

Key finding 11: Society can – and must – adapt

- The melting sea ice in the Arctic will open up opportunities for new business enterprises and new sailing routes. This will lead to a need for heightened regulation of human activity in the northern ocean areas, focus on emissions and potential accidents and improved contingency plans. An increase in shipping may lead to further strain on ecosystems and species that are vulnerable to climate change.
- An increase in temperature, a rise in ocean levels, increased precipitation (which will lead to a greater risk of landslides and floods) will mean that infrastructure such as roads, airports, railways, water and sewage systems, power lines and buildings in northern Norway must be adapted to the new climate situation.
- Agriculture, with appropriate adaptation, may be able to exploit climate change to increase production in northern Norway.

- Fisheries can relocate to other areas when fish species move northwards and eastwards and it may also be possible to exploit new species commercially.
- The established migration routes of reindeer will face challenges due to earlier thawing. The collective effect on the reindeer herding industry may lead to a need for changes in both area usage and herd structure.
- Typical Sámi enterprises (reindeer herding, coastal fishing, agriculture etc.) play important roles as pillars of Sámi culture. This strong connection between commerce and culture means that climate change and its impacts may lead to considerable strain on Sámi culture, and adaptation will be particularly challenging.

Image: © Tom Schandy, Samfoto

Recommendations to decision makers

Making the right decisions in a situation in which there are a number of elements of uncertainty is a major challenge. However, we know that the climate has *already* changed and we possess considerable knowledge about future climate change and the possible effects. Furthermore, the long lifetime of infrastructure and the inertia associated with changes in society and industrial structure, means that in many areas we need to act *now* in order to be prepared for the anticipated climate change. Further work in respect of climate change in the Norwegian Arctic should, among other things, take into consideration:

- Climate change in the Norwegian Arctic is first and foremost determined by greenhouse gas emissions in other regions. However, the physical effects of climate change in the Arctic affect the entire globe. Emissions directly in the Arctic, for example of black carbon, can also have an effect on the climate in the Arctic. In addition to the need to reduce global emissions, there is a need to focus on local emissions and in surrounding areas.

- Restrictions on black carbon emissions, both regionally and globally, are possible; this can reduce climate change in the short term. However, this type of initiative will not replace the need for dramatic reductions in global greenhouse gas emissions, in order to limit and prevent climate change in the long term.

- An increase in shipping traffic and industrial activity in the Arctic is one possible adaptation to a changed climate; however, this may also increase climate change, for example due to the emissions of greenhouse gases and carbon particles.

- It is necessary to secure a framework which can effectively take into account potentially increased activity in the Arctic as a consequence of easier access. There is both a need to reduce emissions from this activity and for more comprehensive monitoring and contingency plans in the event of accidents along the coast and at the open sea, to offset this increased environmental risk.

- Climate change makes the Arctic more vulnerable to both old and new environmental pollutants. There is therefore a greater need to monitor the effects of environmental pollutants. On a global basis, emissions of many older environmental pollutants are being reduced, and new regulations are steadily introduced to control new environmental pollutants. Even so, emissions of environmental pollutants in the Arctic may actually increase, due to changes in the climate system. Stricter regulation of the global emissions of environmental pollutants must be considered, especially for the types of pollutants that are not adequately regulated today.

- The development in central climate parameters, the composition of the atmosphere and ecosystems in northern Norway, in Svalbard and in the oceans must be ensured overall and complete monitoring. Without this, it will be difficult to monitor and to understand the effects of climate change.

- A review of protection policies must be carried out, with the aim of establishing a continuation of protected areas – from the coast, through valleys and up on the mountains. Such continuous protected areas will ease the distribution routes for the species that will have to adapt to climate change.

The gateway to North-Norway over the E6 highway, at the border between Nord-Trøndelag and Nordland counties. Image: © Bjørn Jørgensen, Samfoto

- In several areas, there is a need to begin the task of adapting to climate change. Even though we are not certain of all the details concerning future climate developments, we have a sufficient basis as a starting point for social planning. In areas in which we know enough to be certain that the consequences of failing to implement initiatives may be significant, for example construction and upgrading of infrastructure, the adaptation process can begin quickly. Adaptation will not stop climate change; however, without initiatives against climate change society may be facing challenges that cannot be solved through adaptation.

- Thawing permafrost, increased precipitation, avalanches, landslides, floods and extreme weather will represent major challenges to the existing infrastructure. Future climate developments must form the basis for planning, maintenance and construction of all new infrastructures.

- The 'gaps' in our knowledge in a number of areas can be filled. Sufficient resources must be allocated to research in order to update our knowledge basis concerning climate change and its effects.

- Local and indigenous peoples' knowledge must be incorporated in the assessment of challenges and opportunities that future climate change will represent. By doing so, our understanding of climate effects and the possible alternatives for adaptation may improve.

Climate change in a regional perspective – background

Since 1990, the UN Climate Panel has issued four main reports that document scientific results concerning global climate change.

UN Climate Panel – IPCC

The UN Climate Panel – IPCC (Intergovernmental Panel on Climate Change) – was established by the UN Environmental Programme and the World Meteorological Organisation in 1998, with the objective of promoting the best possible professional knowledge concerning climate change and potential environmental and socio-economic consequences. The panel's reports are drafted by the world's leading climate researchers. They review and compare all new research, technical and socio-economic information that is relevant to the understanding of climate change. IPCC does not itself carry out research or monitoring; however, thousands of researchers from all over the world contribute to the task.

Thorough quality control procedures in respect of the reports and processes, in which both researchers and member countries' representatives are involved, means that the climate panel is a unique tool for the communication of exact and balanced scientific information to decision-makers. The work of the IPCC is therefore relevant for policy development; however, political solutions are not developed through the IPCC.

IPCC's fourth assessment report in 2007 made the correlation between global warming and man-made emissions of greenhouse gases (GHG) even more clear than in previous reports. It also highlighted the fact that the temperature in the Arctic has increased almost twice as quickly as the global average for the last hundred years. The fact charts below summarise some of the main findings of the IPCC fourth assessment report.

IPCC's fourth assessment report 2007

- Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic GHG concentrations.

- Advances since the Third Assessment Report show that discernible human influences extend beyond average temperature to other aspects of climate, including temperature extremes and wind patterns.

- Approximately 20 to 30% of plant and animal species assessed so far are likely to be at increased risk of extinction if increases in global average temperature exceed 1.5 to 2.5°C.

- Anthropogenic warming could lead to some impacts that are abrupt or irreversible, depending upon the rate and magnitude of the climate change.

- If we are to reach the goal of limiting the global temperature increase to 2 degrees C, the emissions must peak before the year 2015 and be reduced by 50-80% in relation to the 2000-level.

- There is high agreement and much evidence that all stabilisation levels assessed can be achieved by deployment of a portfolio of technologies that are either currently available or expected to be commercialised in coming decades, assuming appropriate and effective incentives are in place for development, acquisition, deployment and diffusion of technologies and addressing related barriers.

- A wide array of adaptation options is available, but more extensive adaptation than is currently occurring is required to reduce vulnerability to climate change. There are barriers, limits and costs, which are not fully understood.

- The UN Climate Panel considers the Arctic to be a region that is especially susceptible to climate change, and the tundra as an especially vulnerable system. The extent of sea ice and permafrost is declining in the Arctic, and at the same time thawing of the permafrost goes deeper in the summer. Glaciers and inland ice in the Antarctic and Greenland is reducing in thickness and extent.

In 2004, ACIA (Arctic Climate Impact Assessment) published a comprehensive regional report. This was a project carried out by the Arctic Council. The report addressed climate change in the Arctic in particular and highlighted possible effects on nature and society. This was the first complete review of the theme relative to the northern areas, and contributed to an improved understanding of climate change in the Arctic and the global and regional consequences. The ACIA process contributed with important input to the IPCC's fourth assessment report. ACIA was an important initiative from a Norwegian perspective; Norway is in a rather special situation in an Arctic context, due to its relatively mild climate and high amount of precipitation. Norwegian northern areas, as other Arctic areas, will be susceptible to climate change; however the range of consequences will be somewhat different. This means it was especially important to participate as an active party and contributor to the comprehensive international ACIA process.


Coastal storm. Image: © Stein Ø Nilsen, tromsofoto.net

Several of the main and associate authors participating in the international ACIA process were from Norwegian research communities. In addition, in Norway, a separate national process was instigated, initially titled ACIA-Norge. A separate national steering committee was formed, led by the Ministry of the Environment, with the Norwegian Polar Institute as secretariat. During the autumn of 2001 and winter of 2002, the national steering committee for ACIA held three specialist meetings to address the consequences of climate change in northern Norway, and in April 2002 a fourth meeting was held, to address the consequences of climate change in Svalbard. At these meetings, delegates from various departments and organisations with an interest in the particular themes, came together to discuss problem issues from their particular perspective. The conclusions from the discussions were then passed on to the international ACIA process and to relevant Norwegian authorities.

After ACIA began its work in 2000, the intention from the Norwegian side was that this report was to represent the start of a long-term national and international process in order to improve knowledge pertaining to climate processes, climate change and the effects of these in the Arctic. ACIA highlighted the need to follow up with regional studies in the Arctic, and on this basis the Ministry of the Environment established NorACIA – Norwegian Arctic Climate Impact Assessment. Norway has an overall vision of being at the forefront of climate studies and will therefore contribute to the follow-up of ACIA, both nationally and internationally. NorACIA's objective is to contribute to the process of developing, compiling and distributing knowledge about climate change, its effects and adaptation in the Norwegian areas of the Arctic.

NorACIA's geographical focus area

The geographical area defined for NorACIA is the Norwegian Arctic. In this context, the Arctic is defined in line with the particular definition as employed in the ACIA process. The area therefore encompasses the three northernmost Norwegian counties, Svalbard, the Barents Sea and the northern sector of the Norwegian Sea. Within this area there are many different types of nature, plants, animals and other organisms, and different communities in which people live and work.

The report addresses changes in physical systems and changes in the ecosystems in the oceans, on land and in freshwater areas. In addition, the impacts on society in northern Norway and in Svalbard are also addressed, as are initiatives needed to meet these challenges.

For some themes, contexts and sectors it is not possible to treat the Norwegian Arctic separately from the Arctic as a whole, or from Norway as a whole. This may either be because we do not have sufficient knowledge concerning regional connections at this time, or there may be themes that are not suitable for study on such a small scale. Man-made climate change in the Norwegian Arctic is also mainly controlled by emissions in the rest of the world.

The project, via five sub-assessments and several reports, has highlighted anticipated climate change and its effects in the Norwegian Arctic. The time perspective for calculations and discussions is towards the year 2100.

Figure 1: Map of the area that in NorACIA context is defined as the Norwegian Arctic. Source: Norwegian Polar Institute

As previous climate models have mainly focused on the more populous areas of Europe, the Norwegian Arctic has been on the periphery of these models. NorACIA's climate models, however, place northern Norway, Svalbard and the ocean areas in the north in the centre. This leads to improved accuracy in these areas and local differences in climate can be exposed.

Regional perspectives on climate change make it possible to be prepared for the actual changes we are facing in the Norwegian Arctic. Through its regional focus, NorACIA has shown that this factor is decisive in order to understand the impacts upon nature and societies. Global trends are required as a backdrop, but on a local and regional plan, climate change has had very different consequences. If Norway is to be able to limit and adapt to climate change as effectively as possible, we must gain a better understanding of how it works, also locally and regionally. It is not enough to maintain a national focus; attention must also be turned to the effects on individual regions and local areas.

Uncertainty

Climate models and evaluations of the effects of climate change are based on many reliable and well-understood premises. However, uncertainties in the models represent a general challenge in respect of climate change. Consequently, NorACIA's results are no exception in this respect.

There is a degree of uncertainty in the climate models' calculations of the future climate. This is due to the fact that we do not know enough about exactly how natural variations will occur; we do not know enough about eventual human contribution to climate change and we do not know how well many of the basic premises in our climate models correspond to reality. The understanding of the processes that control climate development is still not complete. One example is the influence of clouds on climate. Due to the fact that we do not fully understand the mechanisms of cloud and climate processes, the premises that are assumed in the climate models may be imprecise or simply erroneous. Processes may be found in nature that we – at this time – are unaware of and thus have not included in the models. Models will always be a simplification of known processes. In the complex climate system there are also many mechanisms that interact together, in which individual elements can reinforce or weaken each other.

NorACIA's climate calculations are based on reduced-scale global climate models, thus any inaccuracies or errors in the global models may lead to significant differences in the calculations of the local and regional climate. When the local and regional calculations, in addition, are based on a limited number of models, the uncertainty associated with the calculations becomes even more marked.

Image: © Norwegian Polar Institute

When the basis for describing climate development is uncertain, uncertainty in relation to the impacts on the ecosystems and biodiversity will also increase. At present, we do not have a perfect understanding of how the various species or the whole ecosystem will be altered in a changed climate.

Exactly how societies are affected by the changes is even more uncertain. Put simply and in general terms, one can say that uncertainty increases from level to level. Uncertainty that is due to indefinite climate estimates is multiplied when the climate effects on the ecosystem and biodiversity are described. The effects upon society, in turn, are even harder to specify exactly, due to the uncertainty in both underlying levels, in addition to the uncertainty of societies' reactions and adaptation.

NorACIA has not attempted to estimate percentage evaluations of the probability of different consequences. In many areas, this in itself will be an exercise that involves uncertainty. Rather, focus is aimed towards what is required in order to reduce uncertainty in relation to climate change in the area, i.e. the identification of knowledge gaps that need to be filled.

Research is steadily being updated, and new findings in relation to anticipated climate development are published frequently. The systems that influence our climate are so complex that it is difficult to predict the future with absolute certainty. However, our understanding of climate systems is improving all the time, which contributes to the further development and improvement of climate models. Thus we continually build upon our ability and opportunity to understand and improve in regard to the changes that are occurring.

At the same time, it is important to remember that the regional model calculations that have been developed through NorACIA have certain weaknesses. The work in improving models and obtaining further knowledge of the complex connections that control the climate will make calculations of the impacts more robust and accurate. Despite these uncertainties, we know enough to act now.

Variations in the climate are natural, and may mask man-made climate change

The climate has always varied, regardless of the time scale applied. This is especially obvious in northern areas. The temperature varies from day to day, from year to year, from decade to decade, between centuries and in a millennial perspective. Climate researchers often refer to these natural variations as 'noise', as variations over a shorter time perspective may 'camouflage' long-term developments in the climate – the climate signals. Estimates of future temperature developments are often described as anticipated changes in average values. Also in the future, we will experience significant variations around these average values. It is vital that we remain aware of this fact in order to improve our understanding of what is actually occurring. If natural variations indicate a cooling period, man-made warming may be masked and the situation may appear to be one of zero change, if it is studied in a short-term perspective. Even if, during the next 10 years, we experience that the temperatures in northern Norway and in Svalbard do not in fact increase, we cannot draw the conclusion that there has been no man-made influence on climate. If these natural variations indicate warming, this may lead to an exaggerated picture of man-made temperature increases. The climate must therefore be studied in a long-term perspective in order to be able to make reliable conclusions concerning man-made climate change.

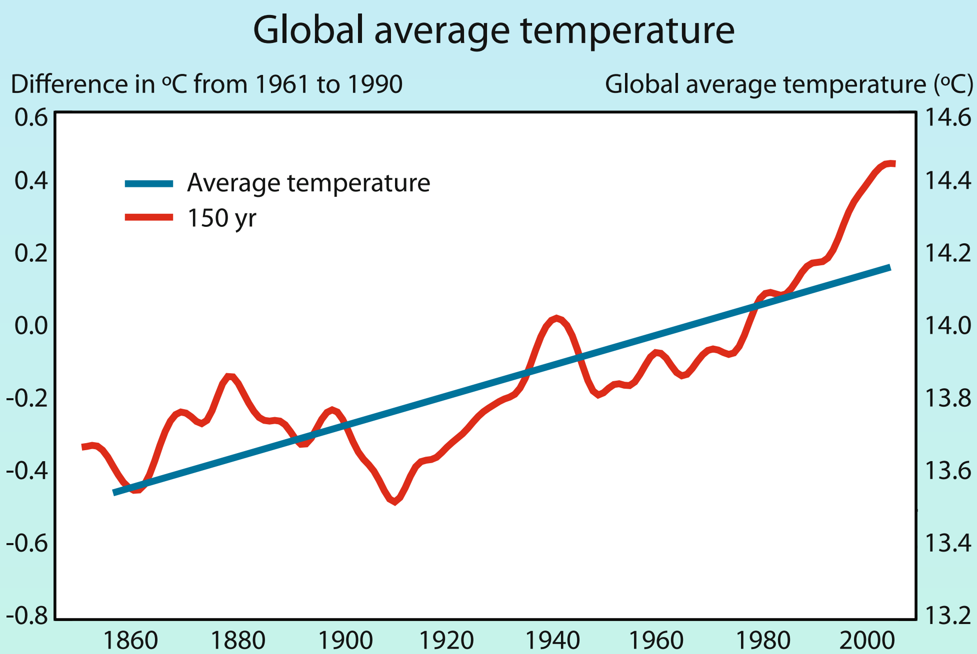
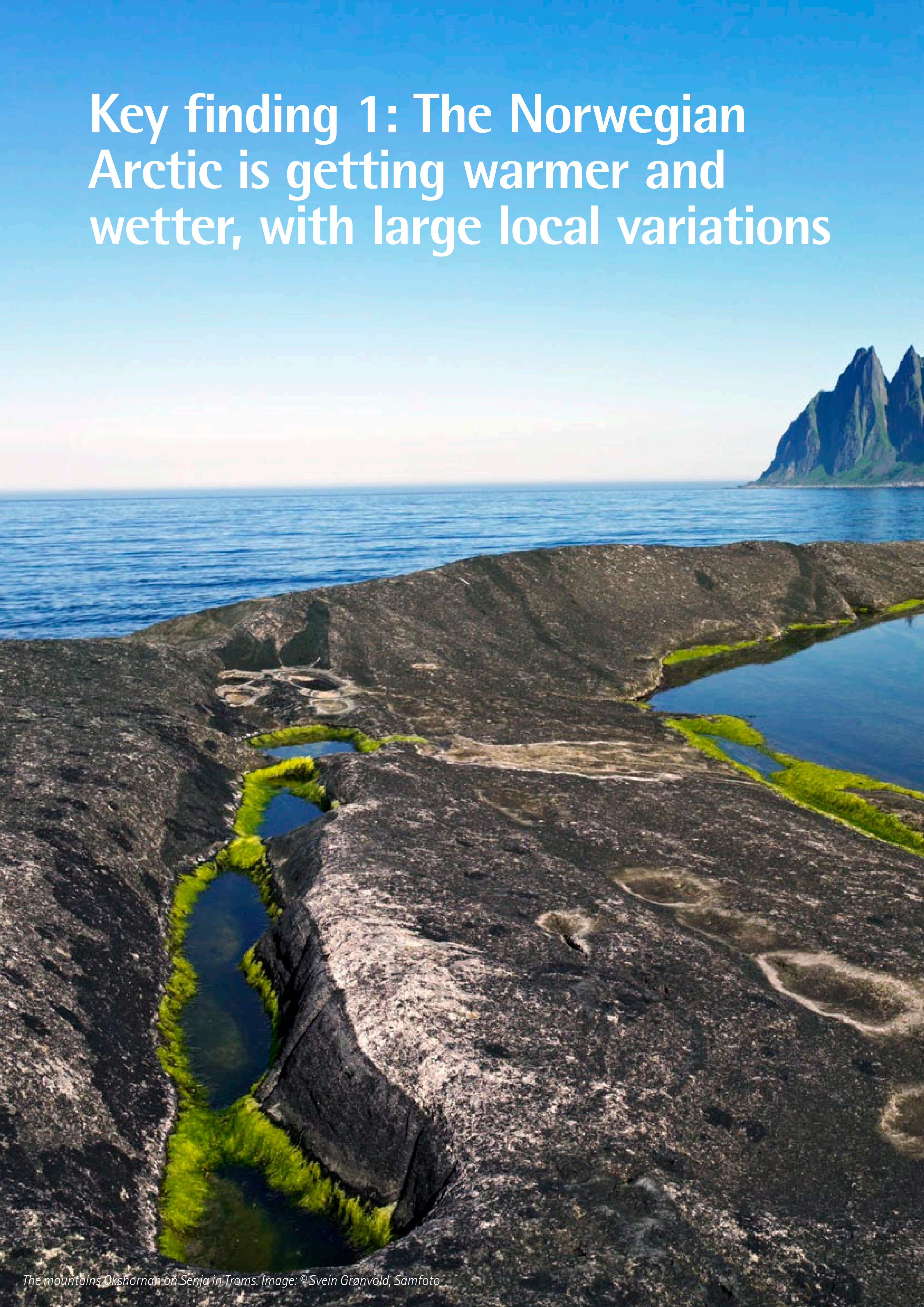


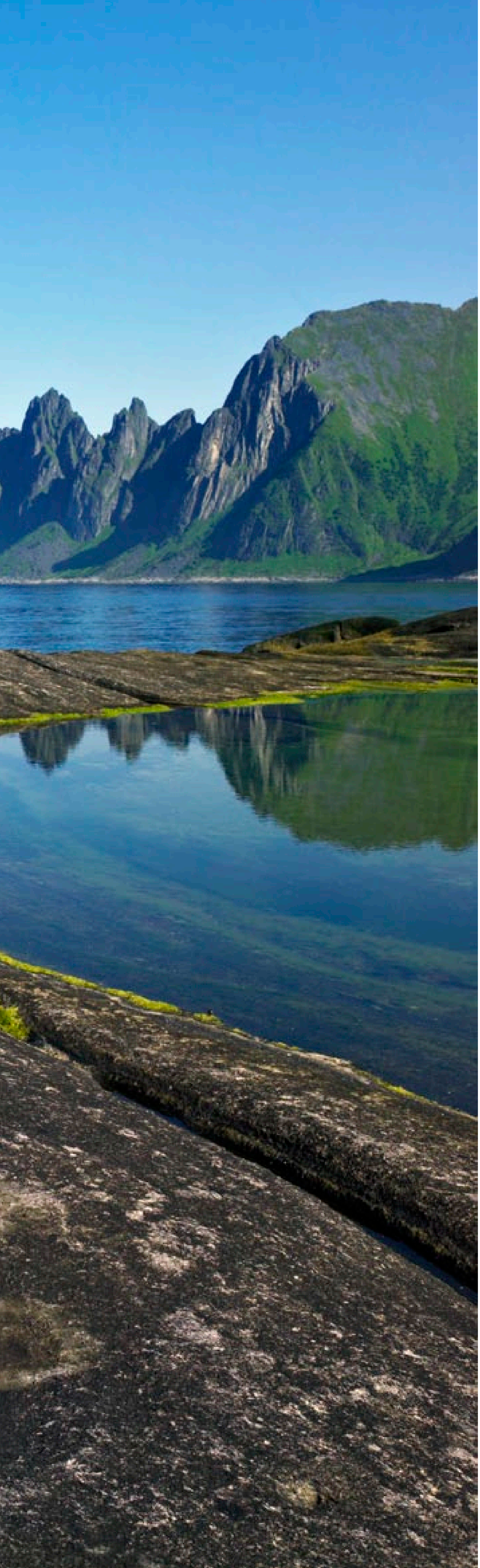
Figure 2: Observed temperature variations around a rising average. The blue line denotes a 150-year average, whilst the red curve indicates the annual average in global temperature. Source: adapted from IPCC 2007

Image: © Stein Ø Nilsen, tromsofoto.net

Key finding 1: The Norwegian Arctic is getting warmer and wetter, with large local variations



The mountains Okshornan on Senja in Troms. Image: © Svein Grønvold, Samfoto



The land areas in the Arctic have experienced greater warming during the last 20–30 years than any other area on Earth. The UN Climate Panel (IPCC) concluded that most of the global temperature increase since 1950 is due to an increase in the concentration of man-made greenhouse gases. Climate models estimate that man-made warming will still be greater in the Arctic than in other areas, due to feedback mechanisms. Climate change in the Arctic has already caused significant changes in the environment and has affected economic activity. If climate change continues as estimated, we will see an increase in effect on ecosystems, culture, lifestyle and economy throughout the Arctic. A number of characteristic Arctic conditions and processes have considerable influence on the global climate.

Nordenskiöld glacier in Billefjord on Spitsbergen. Image: © Norwegian Polar Institute

Climate development during the last hundred years: natural variations and the beginning of man-made warming

In relation to latitude, both the Norwegian Sea and The Barents Sea are warm oceans. The Norwegian Sea is ice-free all year round, with the exception of the northernmost point in the Fram Strait. In the Barents Sea, the Atlantic water masses are ice-free, whilst the Arctic water masses are covered in ice during certain times of the year. The extent of the ice naturally varies a great deal from year to year. In recent years, the Barents Sea has remained ice-free during the summer, with the exception of a small area in the north-eastern region.

The coast of northern Norway has normally experienced a fairly mild winter climate with cool summers; inland areas have a more continental climate with low temperatures in the winter and relatively high temperatures during the summer. There are major regional differences in the amount of annual precipitation; in parts of Nordland, more than 3 000 mm falls annually, whilst some weather stations in inner areas of northern Norway have registered an annual precipitation of less than 300 mm.

In the Svalbard area, there are especially significant variations, which are due to ice conditions on and around the archipelago. When the sea is ice-covered, the climate is colder and drier, i.e. more continental in character, whilst it is milder and more humid when the sea is ice-free. This is due to the fact that the sea ice functions as an insulation from heat input from the water, and it reflects more of the solar radiation. The amount of precipitation in the Svalbard area is normally minimal due to stable air masses with low humidity. Over Spitsbergen, the largest island in Svalbard, most of the precipitation falls in the south-west, with the least amount in the north-eastern areas.

The island Vengsøya in Troms. Image: © Rudi Caeyers, rudicaeyers.com

When studying climate change in the Arctic, it is important to be aware that there are large natural variations in the climate in these areas, from year to year, from decade to decade and extended timescales. Despite the fact that climate models predict significant man-made temperature increases in the Arctic, there will still be considerable natural variations. Another factor to be considered is that there are a limited number of weather stations spread over a relatively large area, and harsh weather conditions mean that exact measurements of precipitation, for example, are difficult to obtain.

Temperature

The ongoing warming process is global; however, warming is greatest at high northern latitudes. The temperature in the Arctic as a whole has increased by 0.1°C on average per decade during

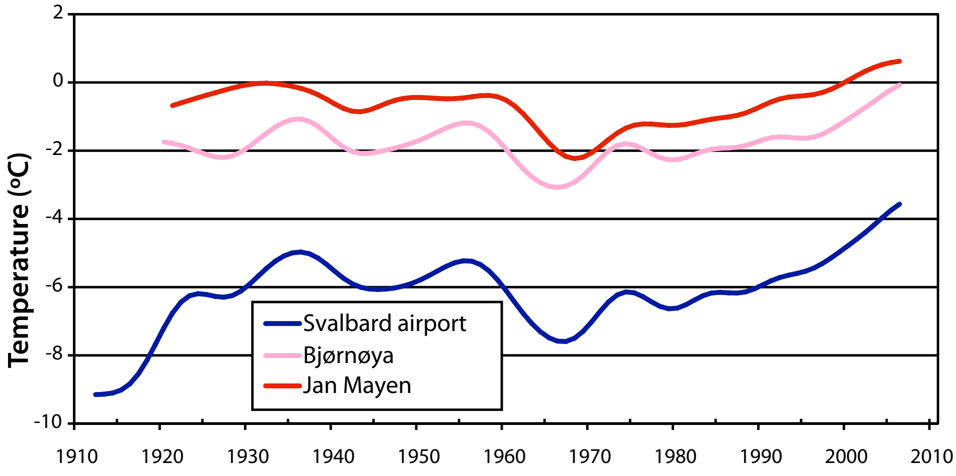


Figure 3: Long-term variations in the annual mean temperature at weather stations in Svalbard, on Bjørnøya and Jan Mayen. The smoothed curves show variability on a decadal scale, and therefore the last three years are not shown. Source: Førland et al. 2010

the last century; however, there have been periods of both warming and cooling. Similarly to the rest of the world, there was a temperature increase in the Arctic from the 1920s until the middle of the 1940s, followed by a temperature decrease until the middle of the 1960s. Thereafter, there has been a significant increase of 0.4°C per decade. In the 1930s, the air temperature in the Arctic was almost as high as we have experienced in recent years. The UN Climate Panel points out however, that the geographical distribution of warming in the 1930s was different than it is at present.

In northern Norway, the average temperature has increased by 0.1°C per decade during the last hundred years, corresponding to the average for the Arctic as a whole. For all parts of northern Norway, with the exception of the Finnmark Plains, there has been an increase in temperature in the spring, summer and autumn seasons.

The Norwegian High Arctic weather stations also report a temperature increase. In Longyearbyen, the average annual temperature has increased by approximately 0.23°C per decade since measurements began in 1912, i.e. somewhat higher than the average for the Arctic as a whole during the same period. Data from Svalbard indicate an increase up to the 1930s, a relatively warm period in the subsequent two decades, a fall in temperature in the 1950s and 1960s – thereafter a general increase in temperature. After 2000 there have been several unusually warm years in Svalbard and on Jan Mayen.

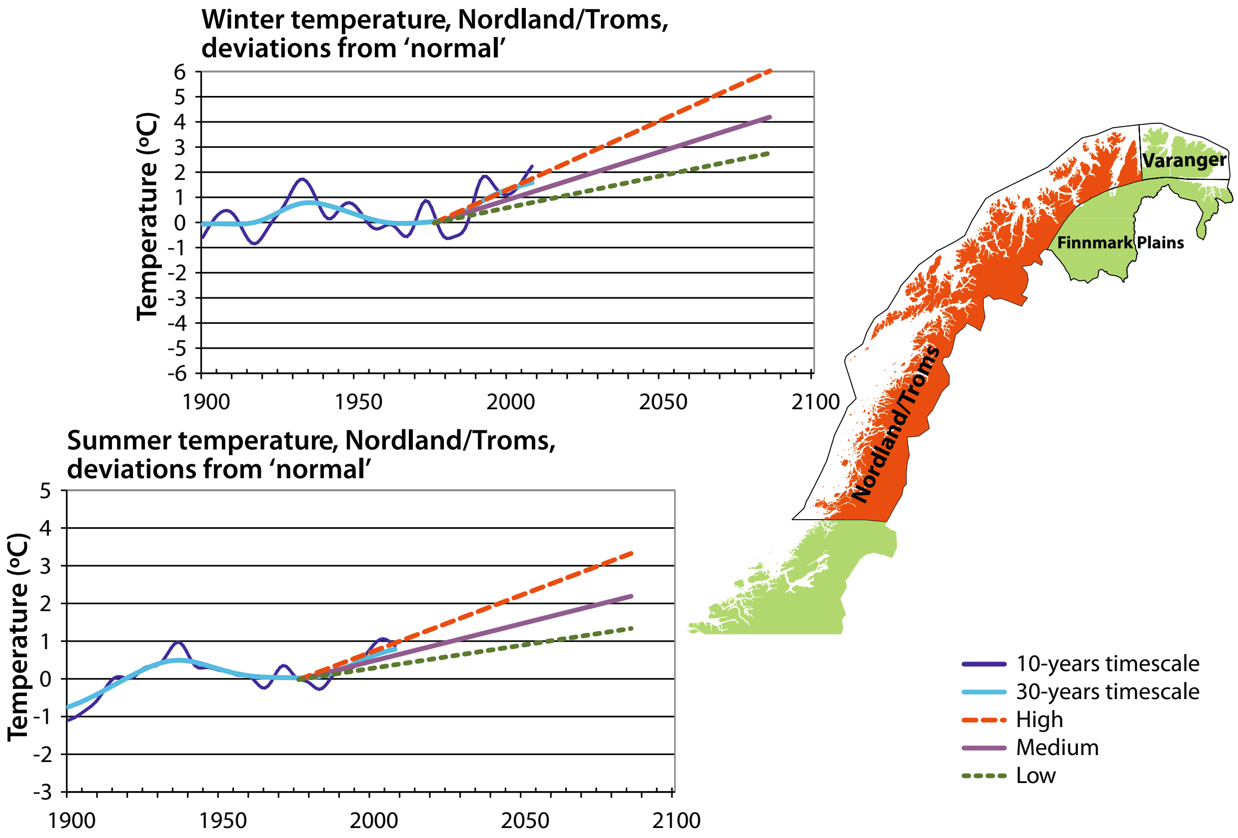
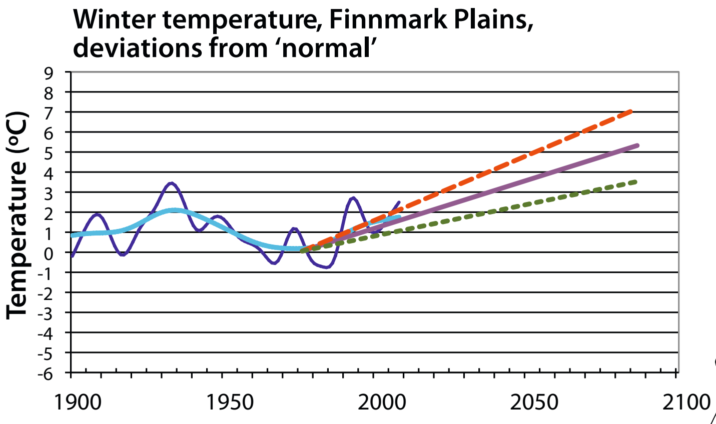
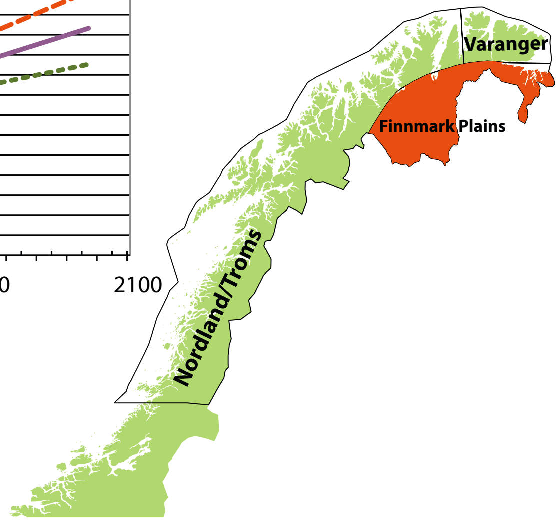
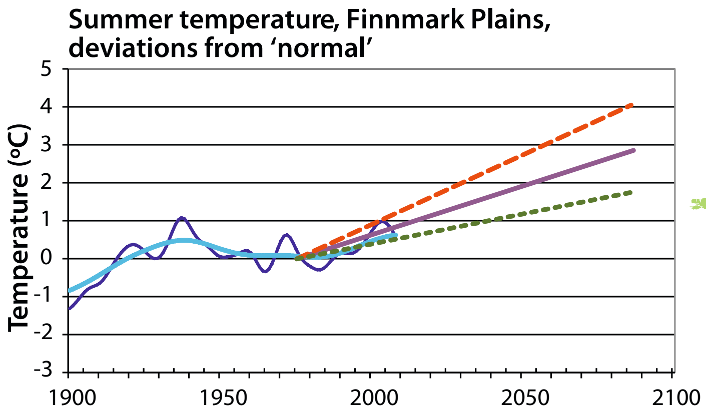
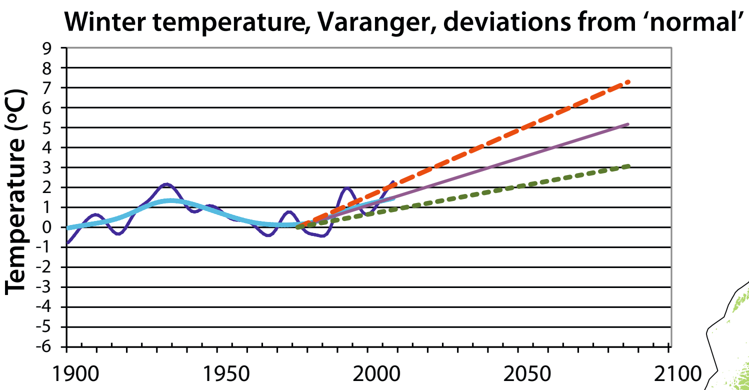


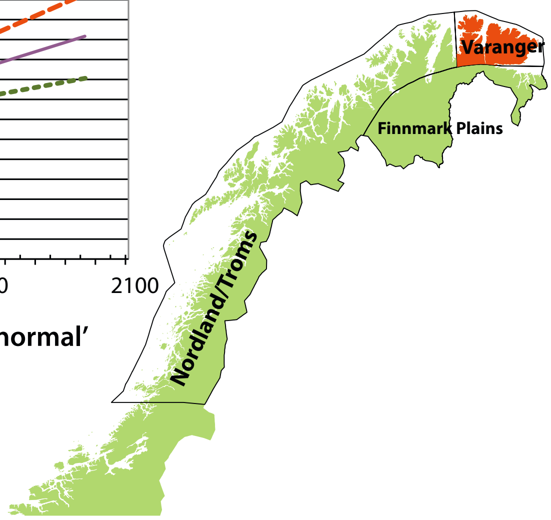
Figure 4: Observed historical and estimated future temperature developments, winter and summer for Nordland/Troms, the Finnmark Plains and Varanger. Within each area, the long-term developments in temperature have been very similar. The values are indicated as deviations from observed mean temperatures during the period 1961–1990. Observed temperature developments (1900–2008) are shown as smoothed curves on a decadal (dark blue) and 30-year (light blue) timescale. The future prediction of the temperature development for the 21st century is shown as the calculated average trend. High (red) and low (green) predictions are shown as dotted lines, whilst median predictions are solid lines. All predictions are based on a large number of calculations.
Source: Adapted from Hanssen-Bauer et al. 2009

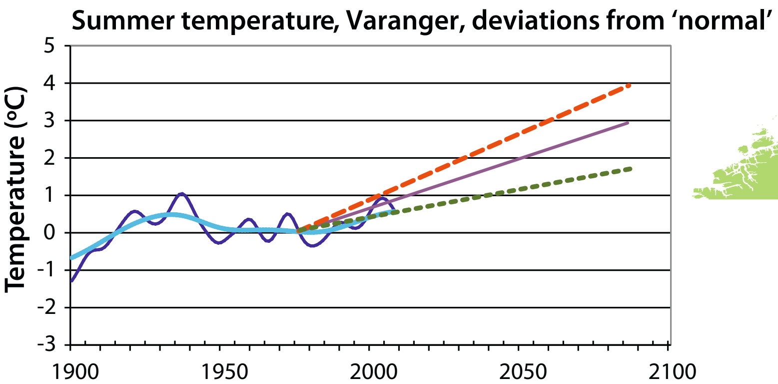

Winter temperature, Finnmark Plains, deviations from 'normal'
Temperature (ºC)
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
1900
1950
2000
2050
2100


Varanger
Finnmark Plains
Nordland/Troms


Summer temperature, Finnmark Plains, deviations from 'normal'
Temperature (ºC)
5
4
3
2
1
0
-1
-2
-3
1900
1950
2000
2050
2100

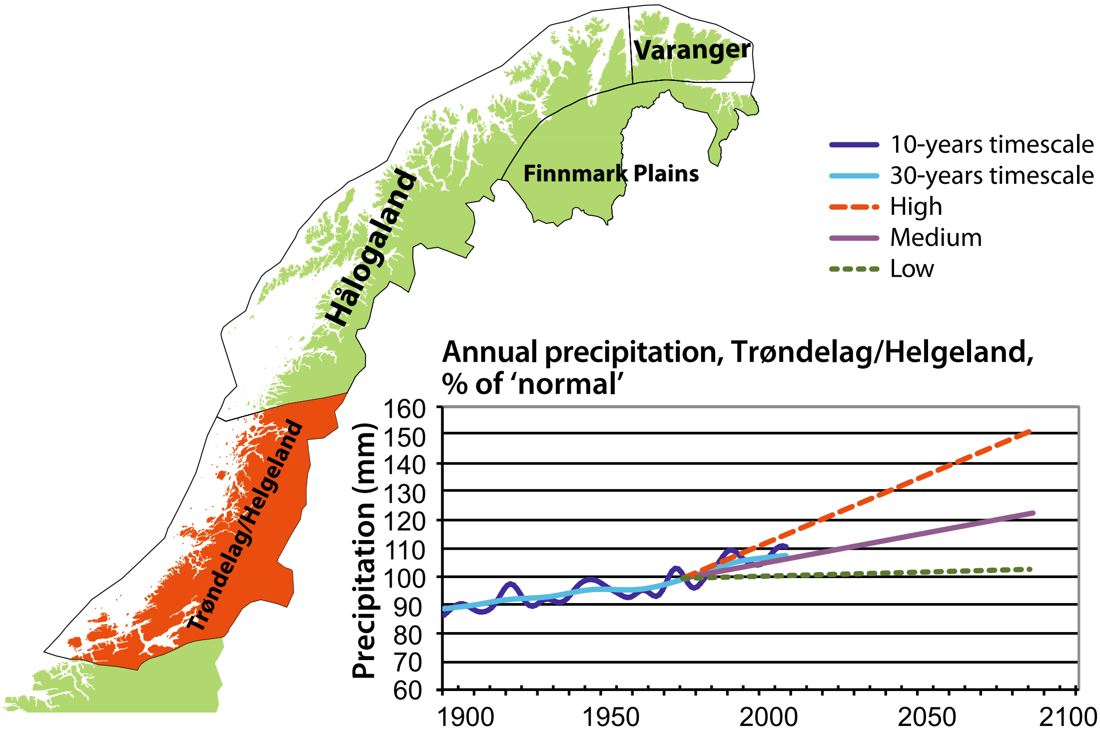

Winter temperature, Varanger, deviations from 'normal'
Temperature (ºC)
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
1900
1950
2000
2050
2100

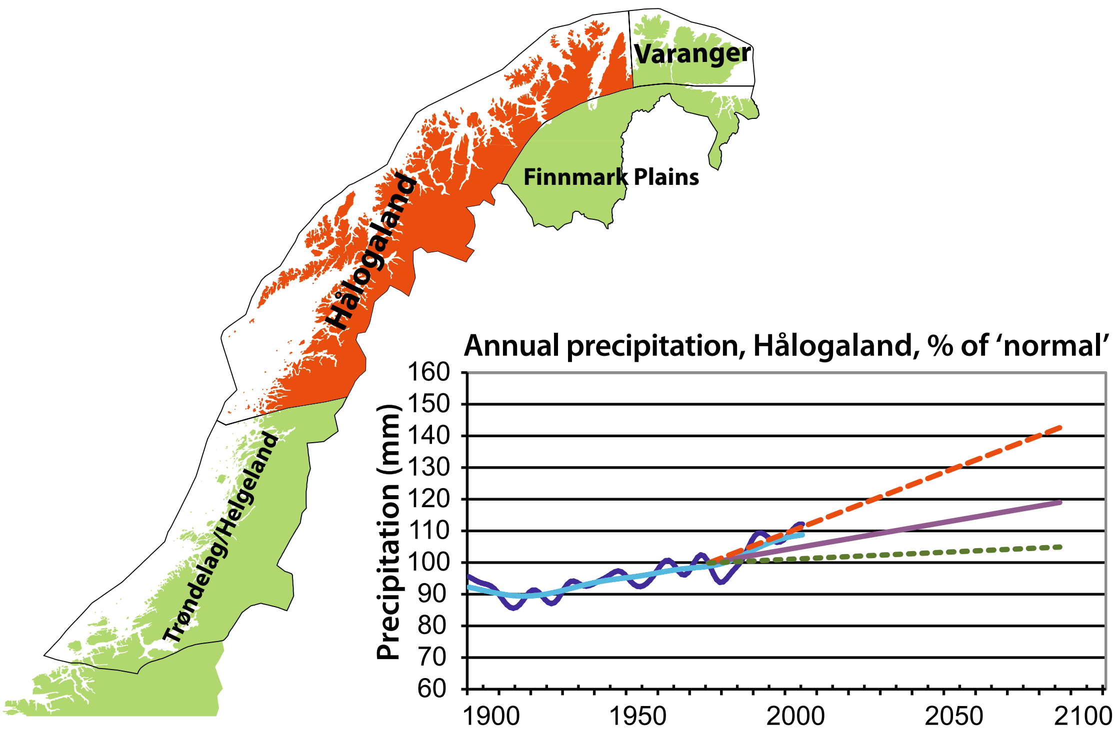

Varanger
Finnmark Plains
Nordland/Troms


Summer temperature, Varanger, deviations from 'normal'
Temperature (ºC)
5
4
3
2
1
0
-1
-2
-3
1900
1950
2000
2050
2100

Precipitation

Average annual precipitation has increased in the whole of the Arctic during the last century. In northern Norway, with the exception of the Varanger peninsula, annual precipitation has increased by approximately 2% per decade during the last hundred years. All weather stations in Svalbard and on Jan Mayen indicate an increase in precipitation during the period the stations have been in operation. At Svalbard airport there has been an increase in annual precipitation of 2% per decade and on Bjørnøya 3% per decade.





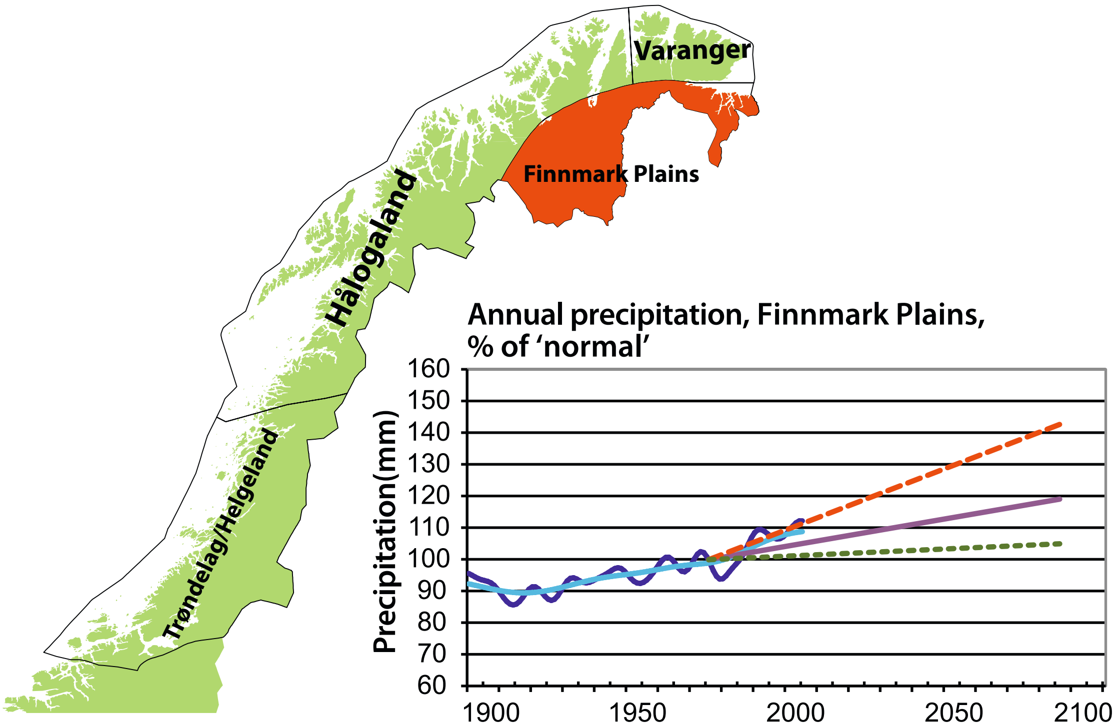
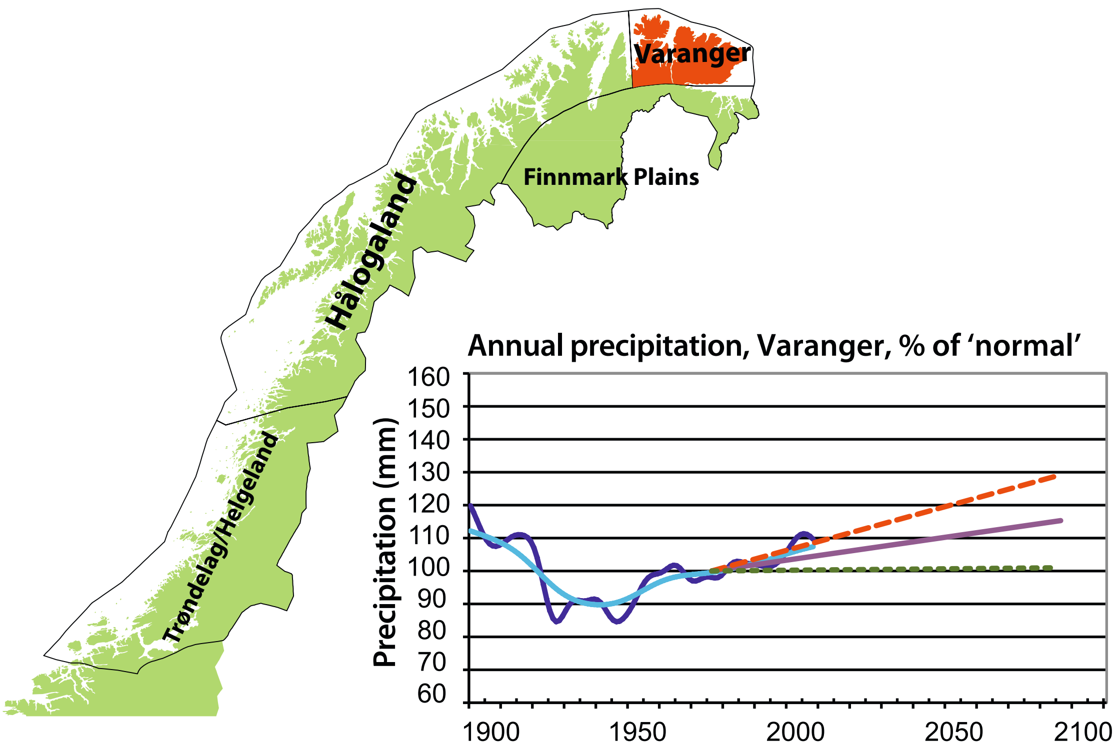


Figure 5: Observed historical and calculated future development of annual precipitation for the Trøndelag/Helgeland region, the Finnmark Plains and Varanger. Within each region the long-term development in precipitation has been very similar. The values are shown in percentages of observed mean precipitation in the period 1961–1990. Observed precipitation developments (1900–2008) are shown as smoothed curves on a decadal (dark blue line) and 30-year (light blue line) timescale. The future predictions are shown as the calculated average trend. High (red) and low (green) predictions are shown as dotted lines, whilst medium predictions are solid lines. All predictions are based on a large number of calculations. Source: Adapted from Hanssen-Bauer et al. 2009



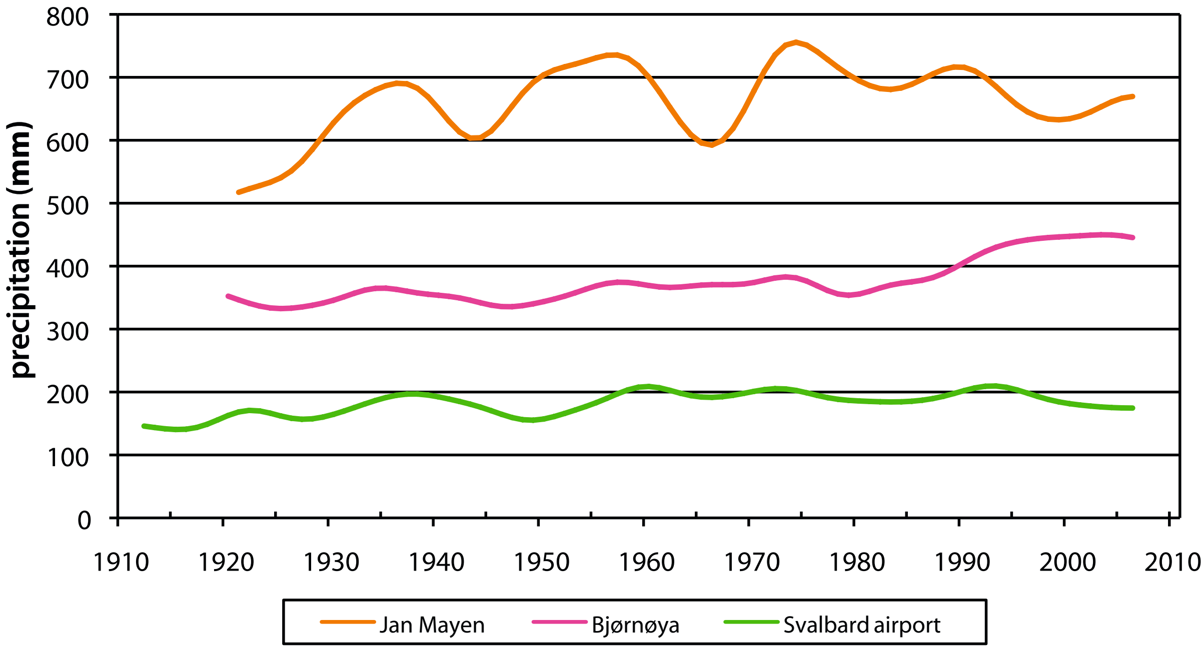


Figure 6: long-term variations in average annual precipitation at weather stations on Jan Mayen, Bjørnøya and in Svalbard. The curves show smoothed curves on a decadal scale, thus the last three years' values are not shown. Source: Førland et. al. 2010

Permafrost

The temperature in the upper part of the permafrost layer is increasing. For example, in Longyearbyen (Janssonhaugen), it has increased by 0.7°C per decade during the last 30 years at a depth of approximately 2 m. The temperature at a depth of 30 m in the permafrost layer is now increasing by approximately 0.35°C per decade, and at 60 m 0.05°C per decade. An intensified temperature increase in the permafrost layer has also been observed, especially during the last 10 years. This may mean that the Arctic is experiencing rapid climate change and an increasing frequency of high temperatures – thus the future warming of the permafrost layer may occur more rapidly than previously estimated.

Extreme thawing of permafrost in 2006

The average winter and spring temperatures were extremely high in Svalbard in 2005/2006. Weather stations registered one of the largest temperature deviations ever measured in recent times. The effect on the permafrost was considerable – at Janssonhaugen in Longyearbyen the average temperature at a depth of 2 m had risen by 1.8°C in relation to the average for the six preceding years. In addition, the temperature at a depth of 15 m was 0.3°C higher than the average for the period 1999–2005. This occurred after a long period of significant and steadily accelerating temperature increases in the permafrost, which makes this particular incident alarming. The depth of the top layer of soil that thawed in the summer of 2006 was the deepest ever measured at Janssonhaugen, and it had increased by approximately 11% in comparison to the average for the six preceding years and it was as much as 1.8 m at the deepest point.

The river Tana, Finnmark. Image: © Helge Eek, Samfoto

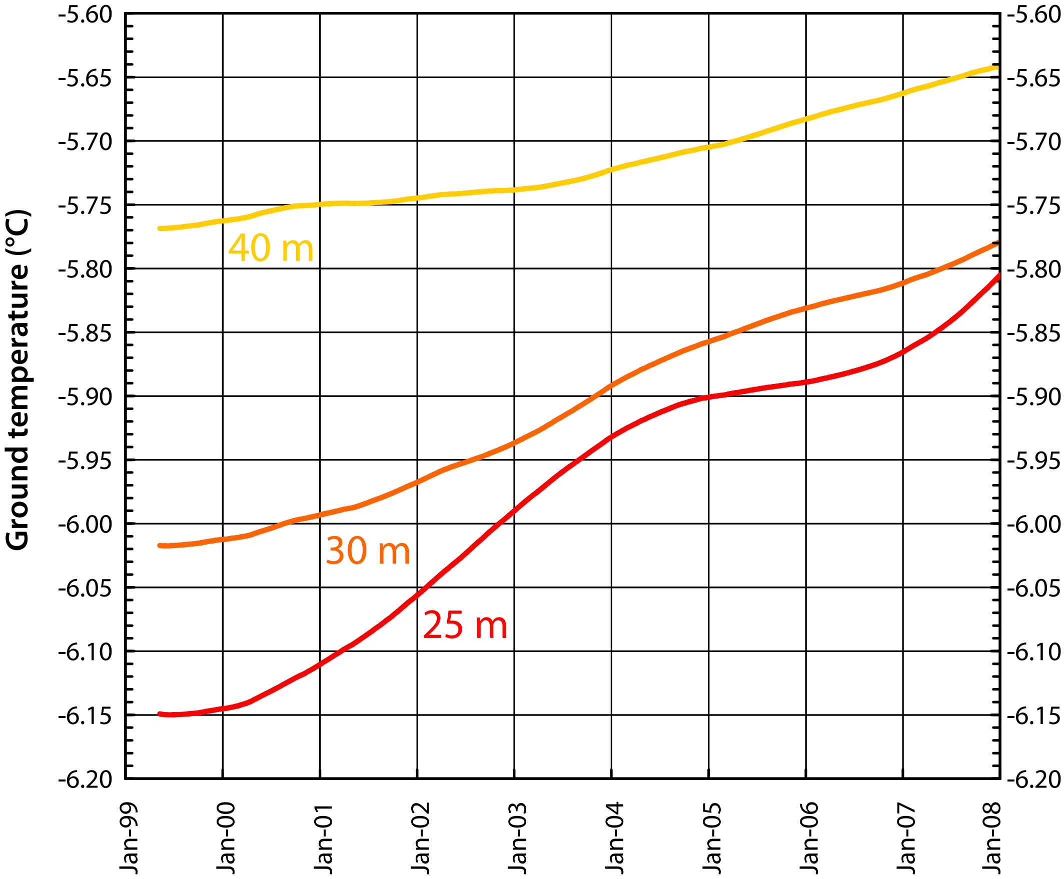


Figure 7: Observed temperature changes since 1998 at 25, 30 and 40 m depth in the ground at Janssonhaugen nearby Longyearbyen. Source: Isaksen et al. 2007

Impact of thawing permafrost

Buildings in Svalbard are built upon permafrost, and they are therefore vulnerable to increasing ground temperatures. When the permafrost thaws, the ground becomes unstable. Eventually this may necessitate reconstruction of the infrastructure, including roads and houses, on the island of Spitsbergen. Thawing permafrost has already caused enormous material damage of this type in Siberia (Russia), where many buildings have been damaged by subsidence. We have also seen several other examples in other areas of the Arctic, that permafrost thaw causes shallow lakes and rivers to change their course or disappear altogether.

In a global context, the large areas in the Arctic with thawing permafrost are of significant importance in the climate system. When the ground thaws, considerable amounts of methane (CH_4) and carbon dioxide (CO_2) that were previously frozen in the ground, are released. These gases increase the greenhouse effect and contribute to a further increase in temperature. There is a limited amount of organic material in the permafrost in Svalbard, and the greenhouse gases from thawing permafrost will probably be of limited importance; however, the role of local sources in methane emissions in Svalbard may need to be examined more closely.

Common marsh marigold. Image: © Stein Ø Nilsen, tromsofoto.net

Longyearbyen, Svalbard. Image: © Tor S Larsen, Norwegian Polar Institute

Prospects for climate development in this century: warmer and wetter

Emissions scenario from IPCC

Two scenarios are especially highlighted both in ACIA and NorACIA (more exactly A2 and B2): In the Special Report on Emissions Scenarios (SRES), the IPCC has presented a number of emissions scenarios for the 21st century, based on various assumptions of how population, economic growth, technological development and other relevant factors will develop. In all of the scenarios, it is expected that the global CO_2 levels, the average ground temperature and ocean level will rise during the 21st century. From the year 2000 until 2100, warming is expected to be between 1.4 and 5.8°C. None of these scenarios take into account major policy interventions in order to reduce climate gas emissions; they are based on assumptions from other circumstances that may influence the emission of climate gases.

The B2 emissions scenario assumes that the world will become concerned about environmental issues and social equality with a focus on regional and local solutions. Within the year 2100, the global population will be 10.4 billion, there will be moderate economic development and various technological developments will take place all over the globe. Within 2100, coal will represent 22% of primary energy, whilst 49% of all energy will come from sources without CO_2 emissions. Emissions of CO_2 will be slightly under the average for the SRES scenarios.

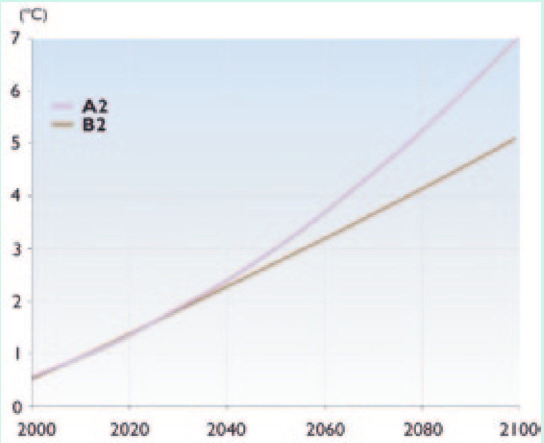


Figure 8: Emissions scenarios from IPCC. Source: ACIA 2004

The A2 scenario, similarly to the B2 scenario, describes a world with a focus on self-help and the preservation of local identity. However, the A2 scenario has a stronger focus on economic growth than environmental conservation and social equality. Within the year 2100, the global population will reach 15 billion and economic growth will be unevenly distributed throughout the regions. Technological developments occur slowly and fragmentally. Coal represents 53% of the world's primary energy requirements in 2100, and only 28% of the world's energy is produced from sources without CO_2 emissions. In this scenario, emissions of CO_2 will be slightly above the average for the SRES scenarios.

In connection with the preparation of the IPCC's next main report, new scenarios are being developed that are expected to show an improved representation of anticipated developments.

NorACIA has utilised advanced modelling tools in order to estimate future climate developments and has made global climate models applicable on a regional scale. Simulations with both global and regional climate models estimate that the temperature in the Arctic will rise by 7°C and 5°C respectively towards the end of this century for the A2 and B2 emissions scenarios from IPCC. The most intense warming will take place during the autumn and winter.

By applying results from the regional climate models NorACIA-RCM, climate statistics (mean values, extremes etc.) have been estimated for 'today's climate' (corresponding to the period 1961–1990) and for a future 30-year period (2071–2100). The differences between the model values for 'today's climate' and the future climate have been used to describe how we can expect the climate to develop.

Simulations carried out towards the year 2050 indicate an increase in the annual mean temperature of approximately 1°C in coastal areas in Nordland and Troms, and 1.5–2°C in eastern

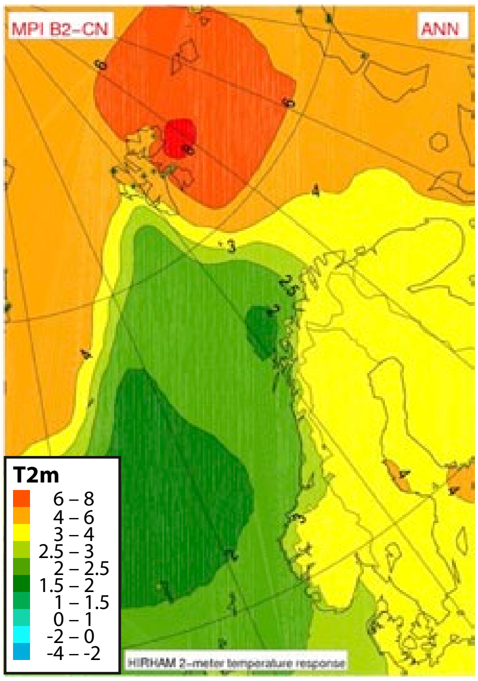


Figure 9: Anticipated changes in the annual mean temperature from the 30-year period 1961–1990 to the 30-year period 2071–2100 based on NorACIA's regional climate model, NorACIA-RCM. The green colour shows the smallest anticipated temperature increase, the red colour indicates the largest anticipated increase. Note the major temperature increase anticipated furthest east in Svalbard and the significant difference across Svalbard. Source: Førland et al. 2010

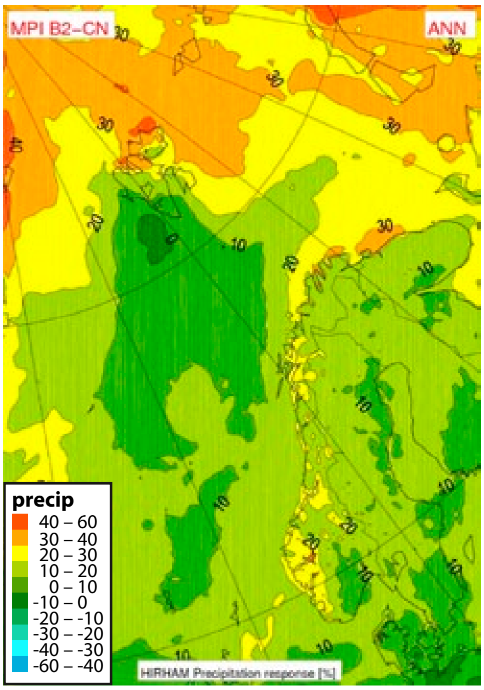


Figure 10: Anticipated changes in the annual mean precipitation from the 30 year period 1961–1990 to the 30 year period 2071–2100 based on NorACIA's regional climate model, NorACIA-RCM. Note that the increase and reduction is indicated as a percentage. Source: Førland et al. 2010

parts of Finnmark and south-west of Spitsbergen. In Svalbard there is a considerable difference in temperature increase in south-western areas (approx. 2°C) and north-eastern areas (over 4°C). Here, the change in the extent of sea ice has a significant influence on the geographical differences in warming.

The calculated changes towards the end of this century indicate that warming will continue after 2050. For large parts of northern Norway, the estimated temperature increase before the end of the century is of 2.5–3.5°C, with the smallest increase in western coastal areas and the greatest increase in the Varanger area in the interior region of Finnmark. For Svalbard, the increase in the average annual temperature is 3°C in the south-west and approximately 8°C in the north-east. The model indicates the least amount of warming during the summer and the greatest amount in the autumn and winter, especially for the inland areas. For the ocean areas between Svalbard and Novaya Zemlya, a significant increase in air temperature is anticipated – especially in the period between September–May. It is in these areas, in which the sea ice is expected to be replaced by open ocean, that we will see the largest increases in temperature. Further south in the region, it is expected that the temperature increases will be greater over land areas than ocean areas.

The IPCC found in 2007 that it is highly likely that there will be a greater amount of precipitation at higher latitudes. The calculations in NorACIA-RCM shows that for large parts of northern Norway there will be an increase of 20–30% in annual precipitation before the end of the century. For the north-eastern areas of Spitsbergen the calculated increase will be up to 40%. Precipitation will increase throughout the entire region during all seasons; however, the greatest increases will be during the winter and spring. It is, however, important to be aware that there are currently limited amounts of precipitation in the winter on Spitsbergen, and that the absolute precipitation increase therefore represents only a few millimetres. On the mainland, the absolute precipitation increase will be greater, as there is more precipitation initially. The estimates also indicate that there will be several days with relatively greater amounts of precipitation throughout the entire region. Fewer days of heavy snowfall are anticipated, i.e. over 10 cm of snowfall per 24-hour period, in the coastal areas in northern Norway and in the south-western areas of the Svalbard region. In inner areas of northern Norway and in northern parts of Svalbard, the number of days of heavy snowfall is expected to increase.

The climate scenarios in ACIA indicate that snow cover in the Arctic will continue to decline, with the largest reduction during the spring and in the autumn. During the last 30 years, the extent of snow cover in higher northern latitudes has been reduced by approximately 10% and the models indicate a further reduction of 10-20% before the end of this century.

For northern Norway, the models indicate that the snow season will become considerably shorter towards the end of this century. The greatest reduction, of more than two months per year, will be in coastal areas in northern Norway, whilst the period of snow cover on the Finnmark Plains will be reduced by approximately one month. It is something of a paradox that in the first part of this century, the maximum snow depth may increase in parts of the Finnmark Plains, in mountain areas in northern Norway and for parts of the Svalbard region. The reason for this is that even though the snow season will be shorter in a warmer climate it will be counteracted by considerably greater amounts of precipitation in the form of snow in the winter.

Estimates of future changes in wind conditions do not provide reliable results. For northern Norway, simulations indicate minimal changes in wind speed. North and east of Svalbard there is a tendency towards an increase in the average maximum wind speed per twenty-four hours. The estimates also indicate that extreme wind speeds will occur more frequently than in the current climate. The Norwegian Sea and the Barents Sea are two particular areas in which hazardous weather situations may occur due to so-called polar lows, caused by cold air masses moving over relatively warm seas. This type of situation is often observed in cold air on the western side of a regular low over northern Europe. Model estimates indicate that there can be fewer polar lows off the coast of northern Norway in the future, and thus there can be fewer incidences of sudden weather changes and wind at sea caused by this weather phenomenon.

It is somewhat difficult to calculate incidences of bad weather with strong winds and heavy precipitation. Regional climate models indicate more frequent incidences of extreme weather in this century over most of the area; however, there is a great deal of uncertainty associated with these estimates, especially in regard to wind.

An ocean simulation, i.e. a calculation of future conditions in the Arctic Ocean and the Barents Sea, has been carried out using a regional modelling system. These simulations show that rather less Atlantic Ocean currents will flow into the Barents Sea during the middle of this century; however, since this water is warmer than today's Atlantic Ocean currents, the same amount of heat will be transported into these ocean areas.

It is important to remember that all the estimates and calculations of local and regional climate change are uncertain; this is due to the fact that climate models are simplifications of reality and that there are significant natural variations in the factors that influence climate.

Finnmark Plains near Kautokeino. Image: © Bård Løken, Samfoto

Sea ice in the Fram Strait. Image: © Rudi Caeyers, rudicaeyers.com – BFE/UIT

Key finding 2: Feedback processes in the Arctic increase global climate change

Climate change occur first, they occur more quickly and will be greater in scope in the Arctic compared to many other areas on Earth. When snow and ice melt, the surface becomes darker. This darker surface absorbs more sunlight, which in turn leads to further warming and melting. There are many variants of feedback mechanisms, and they play an important role in the Earth's climate system, as the climate in the Arctic is closely connected to several physical processes that are of central importance to the global climate. Therefore, it is important to understand the physical processes that control climate development in the Arctic.

The albedo of the Earth's surface is changing

Albedo

An albedo value specifies how much sunlight is reflected from the surface. A light surface reflects more of the sun's rays and therefore has a higher albedo than a dark surface. The albedo scale runs from 0 to 1. A value of 1 indicates maximum reflection and zero indicates no reflection. Albedo is an important parameter for the climate system in the Arctic; it represents a significant difference in the energy balance if the surface is covered by snow and ice, or not. If there is a lot of snow on a surface it may have an albedo of approximately 0.9, whilst a dark ocean surface has an albedo of less than 0.1. This means that an ice-free ocean surface absorbs considerably more energy than an ice or snow-covered surface. If the sea ice cover or the snow and glacier surfaces in the Arctic are reduced, this will in turn lead to a reduction in albedo. More solar energy is absorbed and the warming of the ocean surface increases. A higher temperature then leads to more ice melting and an even larger area with decreased albedo. Open water in channels and between ice floes, or bare patches on the tundra will therefore absorb energy and lead to snow and ice-free areas becoming larger. This is a feedback effect that contributes to increasing the rate of ice melting and temperature increase.

Optical measurement of albedo in the Fram Strait. Image: © Sebastian Gerland, Norwegian Polar Institute

Albedo and the feedback effect associated with it, is an important factor in the explanation and understanding of ice and snow melting processes in the Arctic. Whether there is a great deal or limited amount of snow, and how the snow changes due to the physical conditions, are important elements in understanding albedo effects. This has not been considered in sufficient detail in previous climate models. Since these details play such an important part of the climate system, climate models are currently being developed to include much more information concerning the effects of albedo. For ice and snow-covered areas in the Barents Sea, the Greenland Sea and in Svalbard, albedo is a significant factor in explaining the melting processes, especially during the summer when there is high level of solar radiation in these areas. During the last decade, a number of studies of albedo and how changes in albedo affect climate change have been carried out in Norwegian Arctic areas.

Can soot accelerate warming?

Human activity can affect albedo in the Arctic via the deposits of black carbon (soot) on the snow and ice cover, which leads to a more direct influence on the climate than previously thought. Soot is comprised of small black particles that are formed during the incomplete combustion of fossil fuels. Due to the dark colour of these particles they will absorb energy from the sun and can directly influence the climate. In addition, these particles can affect the properties of clouds, which indirectly influence the climate. Most soot particles are deposited close to the emission sites. On a global basis, most soot emissions originate from central and lower latitudes; these areas are more heavily populated, larger amounts of fossil fuels are burned and forest fires occur more frequently. Some of the soot emissions are transported to the Arctic. These are then deposited on snow and ice and even small amounts of soot can affect the albedo of a surface considerably. Soot can also contribute to warming, as the particles absorb the sun's energy as they are carried on wind currents – this leads to warming in the atmosphere. The effect on climate from soot in the Arctic can be significant, as the climate system is extremely sensitive to changes in albedo because of its feedback effect. However, further studies of carbon deposits in the Arctic are required in order to be able to calculate the scope of the effect with greater accuracy.

The biggest sources of soot emissions, in global terms, are found in China, especially from the use of coal as an energy source. Soot also comes from Europe, North America and some other parts of Asia. However, emissions of soot are declining as emission controls and initiatives have been implemented in several countries. In Russia and parts of Eastern Europe, the burning of biomass in agriculture (burning off in fields and forest fires) is a major source of soot. In Europe, the largest source of soot comes from the transport sector and domestic sources.

In 2007, a survey carried out in Svalbard indicated large geographical variations in the amount of soot in snow; however, in general the concentrations were relatively low. There is a clear trend that more soot is deposited in the eastern part of Svalbard compared to the western part, due to landscape formations and wind direction. There are no reliable soot measurements from the Barents Sea; however, it has been shown that shipping is already affecting the atmosphere in the Arctic during the summer. Samples taken from glaciers have given us a good picture of soot concentrations from previous time periods. An ice core sample from Greenland, which in general is affected by North American soot sources, showed that the amount of soot in precipitation increased sevenfold during the hundred years from 1850 until 1950. Soot deposited in the Norwegian Arctic comes mainly from Russian and European sources. Only a minor amount of the soot emitted further south is transported to the Arctic. A reduction in the amount of soot deposited in the Arctic may slow down the warming of the atmosphere and the melting of snow and ice. A considerable increase in the amount of soot deposits has been discovered in areas with significant shipping in the Arctic. Less sea ice (and thereby a greater possibility of an increase in shipping in the Arctic Ocean) may lead to increased soot emissions directly in the

Arctic. This means that it is important to limit and regulate emissions from shipping, the petroleum industry or other activities that release soot directly into the Arctic. Commercial technology is available that can reduce soot emissions considerably from most sources.

Ocean currents

The most important ocean current in the ocean off the coast of northern Norway and in the Barents Sea is the Norwegian Atlantic current, which is an extension of the Gulf Stream. The effect of this current means that Norway and the surrounding ocean areas have an exceptionally warm climate in relation to latitude. The Atlantic current enters the Norwegian Sea from the Atlantic Ocean on both sides of the Faroe Islands and continues northwards to the Barents Sea in two branches. In addition, the Norwegian coastal current has its origins in the Baltic Sea, and it heads northwards along the Norwegian coast, where it receives fresh water from rivers. There are three types of water masses in the Norwegian Arctic; Atlantic ocean water, which is warm and saline, coastal water, which is warm and less saline, and Arctic water that is cold and less saline. The different water masses are mixed to a limited extent in the sea and there can be a fairly distinct separation between water with different temperatures and salinity. We cannot distinguish these with the naked eye; however they represent clear barriers for organisms that inhabit the sea.

Plankton and fish larvae are transported to the Barents Sea by Atlantic water from the southwest. On average, 1.7 million cubic metres of water per second flow into the Barents Sea along with the Atlantic current. There are large variations in flow, both between seasons and interannually, which are mainly controlled by wind conditions. Since the Atlantic water is warmer than the Arctic water, it is this inflow that controls the transport of heat into the Barents Sea.

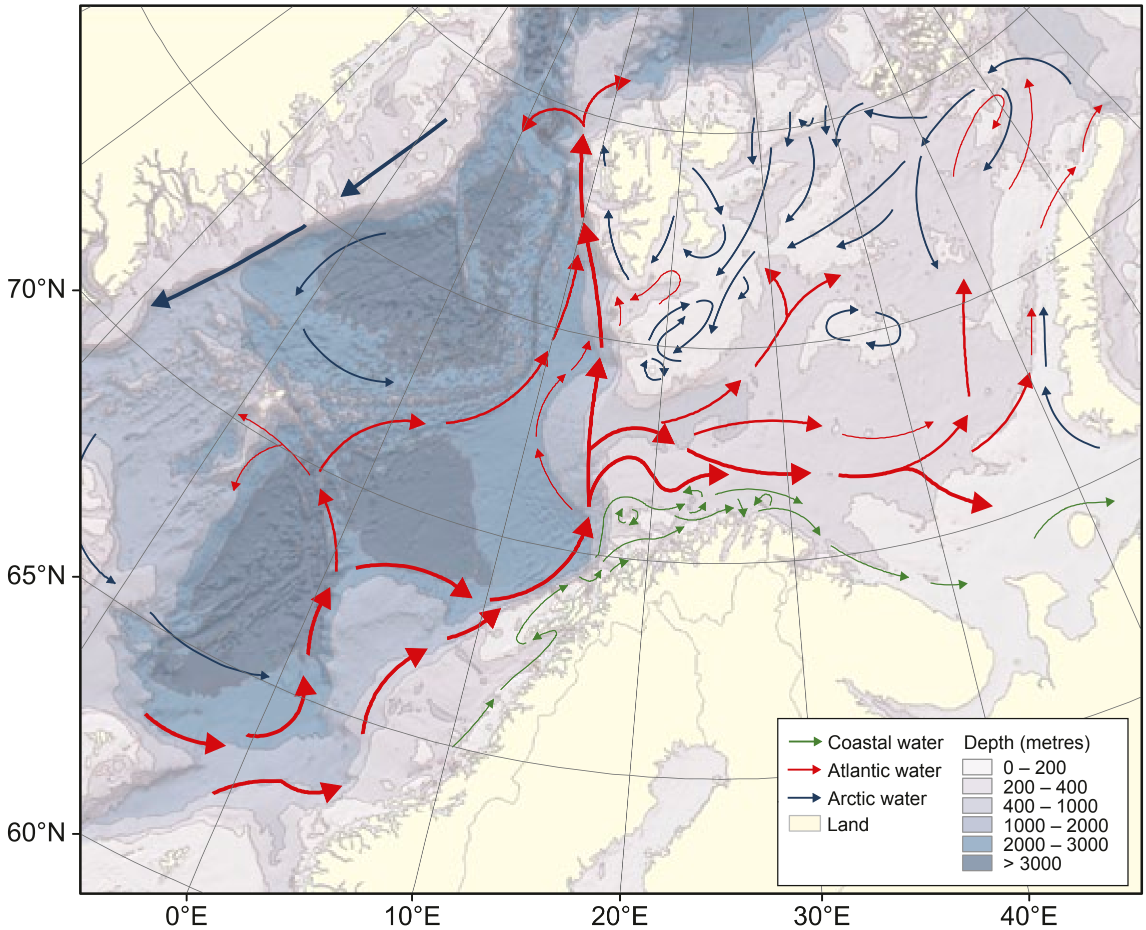
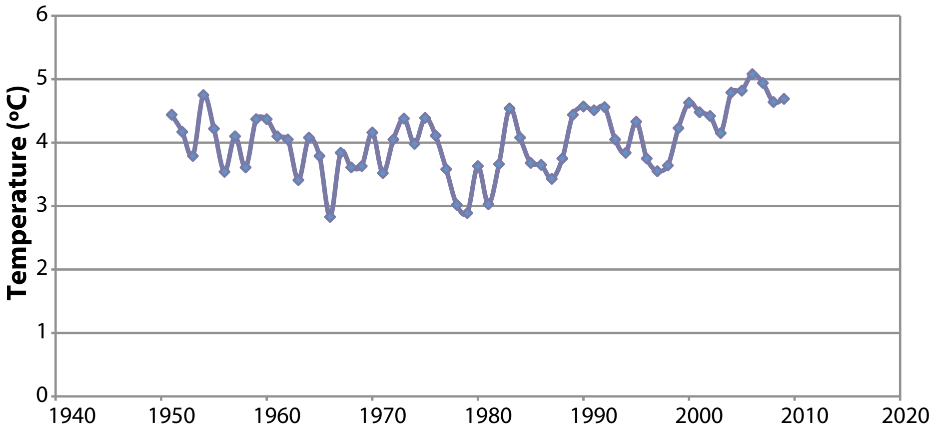


Figure 11: Simplified image of ocean currents in the Norwegian ocean areas. It is due to the Atlantic Ocean current that we have relatively high temperatures in Norway. Source: Loeng & Drinkwater 2007

Figure 12: Average annual temperature from 0–200 metres in the Kola section during the years 1951–2009. The Kola section runs northwards along the meridian from 33° 30' E to 75°N, just north of the Kola Bay. The Russian marine research institute PINRO has monitored the temperature in the area since the early 1900s. Source: Data from PINRO.



The Atlantic water and the Arctic water meet at a front known as the polar front. Due to the significant differences in these two water masses, the polar front denotes a fairly clear demarcation for the spread of many species of plankton and fish.

In the western Barents Sea, the polar front is stable, as it follows the ocean floor along the slopes from Spitsbergen to the Central Bank. In the eastern part it has a wider and more variable front. In the more stable western areas, no significant movement of the polar front is anticipated; however, in the east, models indicate that the front is being pushed northwards as the climate changes. When sea water freezes to ice, salt is deposited, which leads to the formation of saline, heavy water that sinks to the bottom. This water sinks and flows out of the Barents Sea through Bjørnøyrenna (the Bjørnøy channel) into the deep water in the Norwegian Sea. In a climatic context, this process is important, as the water that sinks and flows out of the Barents Sea is replaced by water from the Norwegian Sea or the Arctic Ocean. Changes in the current system in the Barents Sea appear to be a feedback mechanism. Increased inflow of warm Atlantic Ocean water will lead to the Barents Sea becoming warmer, which in turn will lead to increased melting of sea ice. Less sea ice will lead to an increased warming of the atmosphere in the area, which again will affect air pressure and wind. Changes in wind currents will then affect the inflow of Atlantic Ocean water. However, the main elements in the current patterns are associated with the formations on the ocean floor, such that no major changes are anticipated in the future.

Possible methane emissions from methane hydrates

In global terms, large amounts of methane are stored in frozen form – methane hydrates – at a relatively shallow depth in cold ocean sediments. If the temperature in the water at the ocean floor increases by just a few degrees, this may lead to a breakdown of methane hydrates, thereby releasing methane into the atmosphere. There is still a great deal of uncertainty associated with this type of methane emission; the potential effect on the climate system is however, considerable, as methane is a very potent greenhouse gas. Studies are currently being carried out in the Norwegian Arctic ocean areas that will provide further knowledge as to what degree the warming of the ocean areas will contribute to an increase in this type of climate gas emission.

Image: © Norwegian Polar Institute

Clouds

Large areas of the Arctic are covered by ice and snow for the whole or parts of the year. This light surface reflects shortwave radiation from the sun. At lower latitudes, without snow and ice cover, the surface is darker, such that the ground absorbs more solar radiation. If there are low, white clouds at lower latitudes, the clouds reflect the solar radiation before it reaches the Earth's surface, and so the clouds have a cooling effect in these areas. In the Arctic, low, white clouds will not cause a similar effect, as the surface already is light and reflects much of the incoming solar radiation. All clouds (and not just high and thin clouds as at lower latitudes) may cause warming in the Arctic, as they reflect longwave radiation from the ground back to the Earth. The future distribution and types of clouds are thus significantly uncertain elements in the knowledge of how climate change in the Arctic will develop. For example, it has been shown that Arctic clouds contain far more liquid water than is to be expected, considering the low temperatures in the area. Due to the effect of clouds on warming in the Arctic, it is important that we gain further knowledge of their particular role in the climate system. We have a limited knowledge of exactly how the properties of clouds and their effect on radiation will change further in the event of global warming. Climate models are being steadily developed in order to include clouds and their interaction in relation to radiation. However, this is still one of the more uncertain aspects in estimating future climate developments.

Glaciers

Most of the glaciers in the Norwegian Arctic are found in Svalbard, where glaciers have a total volume of approximately 7 000 km^3 and an area of 36 000 km^2. In northern Norway, the volume of glaciers is only 64 km^3 with an area of 1 000 km^2. Thus the glaciers in Svalbard are most important in relation to their role in the climate system. Changes in the glaciers in northern Norway will be of less importance in this context, due to their limited scope and volume. Since Svalbard is closer to the northernmost outer points of the warm North Atlantic current, Svalbard glaciers are more susceptible to changes in climate. Early in the 1990s, significant warming took place and Svalbard's glaciers began to retreat. This process has continued over several decades, throughout the entire archipelago and for almost all glaciers. It has been shown that summer melting has led to a reduction of ice in the glaciers, whilst the build-up of these during the winter has been more constant. The glaciers in Svalbard are important contributors to the rise in sea level, as the archipelago has approximately 11% of Arctic land ice, apart from Greenland. The melting of the glaciers in Svalbard is considerable and in line with both global trends and developments in the Arctic in general. The white surface of the glaciers reflects solar radiation and if the glaciers decrease in size and underlying dark surfaces are exposed, this will lead to a further increase in temperature.

View of the Kongsvegen glacier which terminates in Kongsfjorden, Svalbard. Image: © Kim Holmén, Norwegian Polar Institute

Key finding 3: Climate change makes the Arctic more vulnerable to environmental pollutants and ultraviolet radiation

Environmental pollutants are substances that even in small concentrations can cause harm to the natural environment. Environmental pollutants are transported into our northern areas via the atmosphere and the ocean. Large scale changes in the climate system, for example in air and ocean currents and in conditions such as temperature and precipitation, will influence the transport and the deposit of environmental pollutants in the Arctic. In addition to increased transport to the Arctic, environmental pollutants stored in e.g. snow, glaciers, permafrost and sea ice may be released when these begin to melt. Animal and plant species may thus be exposed to higher levels of certain environmental pollutants. Climate change may also lead to new species of phytoplankton and zooplankton in the marine ecosystems and so the flow of environmental pollutants throughout the food chain might be affected. It has already been shown that environmental pollutants affect the health of several species of seabird in Norwegian regions: these affect their breeding behaviour, feeding habits and fertility. Some species in the Norwegian Arctic such as glaucous gulls, ivory gulls and northern fulmars have been shown to have the highest ever measured levels of environmental pollutants. For some time, polar bears have been in focus due to the influence of environmental pollutants on the species. Arctic foxes in Svalbard have three times the level of environmental pollutants than Arctic foxes in other areas of the Arctic.

The connection between climate change and environmental pollutants is extremely complex. This is due both to the very different physical, chemical and biological properties of environmental pollutants, and the complex interaction between the atmosphere, oceans, sea ice, freshwater and land – with varying vegetation and ice cover – and organisms that all play a role in the relevant processes, which occur over time scales ranging from a few days to decades.

The ozone layer has been depleted by emissions of a number of ozone-destructive gases during the last 60 years. There have been significant reductions in emissions of these gases; however, it is not expected that the ozone layer will return to 1980-levels before the second half of this century.

Environmental pollutants

Persistent organic pollutants (POPs) are characterised by being toxic, slowly biodegradable, accumulative in organisms and that they accumulate upwards in the food chain and are spread over great distances. PCBs and dioxins are examples of POPs (see fact chart for further examples). Organic environmental pollutants are fat-soluble and slowly biodegradable and are stored in the fatty cells in organisms and transferred to the next level in the food chain when the animal is eaten by predators. The concentration of environmental pollutants is therefore greater further up in the food chain and is at the highest level in marine food chains. This may be due to the fact that marine food chains often have higher levels. As a result, fat-rich Arctic animals higher up in the food chain have higher levels of environmental pollutants. The low temperatures in the Arctic mean that the slowly biodegradable substances are stored in the environment for a long time.

Many other toxic substances also cause harm to the environment – such as, for example, carbon monoxide (CO), hydrogen sulphide (H_2S), nitrogen oxides (NOX) and sulphur dioxide (SO_2). These are not characterised as environmental pollutants even though they may in fact be both toxic and pollutant. This is because they are biodegradable and do not increase in concentration further up in the food chain.

The glaucous gull is highly exposed to environmental pollutants. The breeding season is especially challenging to the birds, and environmental pollutants cause additional stress which may reduce their chance of survival. Image: © Hallvard Strøm, Norwegian Polar Institute

Environmental pollutants

Environmental pollutants are slowly biodegradable, accumulative and are stored in living organisms. They are extremely toxic even in small concentrations. They can lead to irreversible damage to health and the environment. Some substances can cause long-term effects such as cancer and damage to reproductive and genetic systems in living organisms.

HCB

Hexachlorobenzene (HCB) is a white crystalline substance, which, among other applications, was used as a pesticide in some countries up to 1965, and has had a global distribution in nature. HCB can cause serious harm to the environment and may cause cancer and serious health issues after long-term exposure. From 1995 to 2006, Norwegian emissions were reduced by 90%. The use of HCB is now prohibited in most countries and the concentration in nature has been reduced. Several international agreements oblige countries to phase out HCB altogether.

PCBs

Polychlorinated biphenyls (PCBs) are a group of synthetic chlorine compounds. In Norway, PCBs have been prohibited since 1980; however, seepage from soil and sediment means that PCBs continue to leach into the environment. In addition, PCBs are carried into Norway via global wind and ocean currents, transported over great distances from other parts of the world. Levels of PCBs in the environment are steadily decreasing; however, high levels of PCBs have been found in certain places, and PCBs are the reason that the harvesting of food resources from several Norwegian fjords is subject to restrictions. In Norway, PCBs are found in the air, water, sediments, soil, foodstuffs and in most living organisms. Humans, predatory animals and predatory birds are vulnerable. Infants and foetuses are especially vulnerable, as PCBs are transferred via breast milk and to the foetus through the mother. In the Norwegian Arctic, there is clear evidence of raised levels of PCBs in predatory birds' eggs, in glaucous gulls, Arctic foxes, polar bears and other species at the top of the food chain. PCBs can affect the immune system, it can damage the nervous system, cause liver cancer and damage to foetuses and cause harm to reproductive systems. PCBs have also been shown to have a negative influence on learning ability and development in humans. Several international agreements have been reached to reduce the use of PCBs.

HCH

Hexachlorocyclohexane (HCH) was used as a pesticide throughout most of the western world until it was prohibited in the 1990s. The substance is found in several variants, called isomers, and these have differing effects and varying ability to accumulate in the food chain. The general trend is that the incidence of HCH in nature is declining. Several international agreements have been reached to phase out the use of HCH.

DDT

Dichlorodiphenyltrichloroethane (DDT) was used as an insect and plant pesticide after the Second World War. The substance can cause harm to reproductive systems, especially in animals higher up in the food chain. DDT can also be transported via air and ocean currents. The use of DDT was prohibited in Norway in 1970, and in the following decades a number of other countries in the world banned the use of the substance. The use of DDT is prohibited in accordance with several international agreements. However, DDT is important in combating malaria, and so the use of the substance for this purpose is exempt and DDT is still used in significant quantities in Africa.

PAHs

Polyaromatic hydrocarbons (PAHs) are comprised of many different compounds. Some of these are toxic and cause damage to genetic material; they can also cause cancer. They are formed during the incomplete combustion of organic materials. The aluminium smelting industry and domestic wood-burning are the largest sources of emissions of PAHs in Norway. Initiatives in industry have reduced the incidence of the substance in species such as blue mussels and horse mussels in several Norwegian fjords. The Convention on Long-Range Trans-boundary Air Pollution commits countries to reducing PAHs.

Mercury

Mercury exists as non-organic and organic chemical compounds that can cause chronic toxic effects even in extremely small concentrations. Mercury can be transported over great distances and the transport of mercury into Norwegian areas is estimated to be three times as great as Norwegian emissions of mercury. The extended transport of mercury via oceans and rivers to the Arctic means that levels of mercury in the environment are particularly high. Mercury compounds are extremely toxic to many aquatic organisms and to mammals. The substance can cause kidney failure and motoric and psychological disturbance as a result of damage to the central nervous system. Organic mercury compounds are especially toxic and can cause harm to foetuses. A global agreement to reduce mercury emissions is currently under development.

'New' environmental pollutants

New environmental pollutants are continually drawing attention – either because they occur in amounts that are surprisingly high, or they are found in unexpected areas. Brominated flame retardants and perfluorooctane sulfonates (PFOS) are among these 'new' substances. As environmental pollutants are relatively non-biodegradable, they have the potential to eventually make their way into the Arctic. It is therefore important to monitor new environmental pollutants and also to increase our knowledge of their particular characteristics.

Long-distance transport of environmental pollutants is a serious problem in the Arctic, especially in the Norwegian and European sectors. Transport is via wind and ocean currents, through the food chain and via the migration of animals. Changes in climate and in the major wind and ocean systems are thus of major importance for the spread of environmental pollutants to the Arctic. This also has consequences for the stores of environmental pollutants that are bound up in the permafrost, in the ice and oceans in the Arctic – stores that have been built up as a result of previous influxes of pollutants.

In an international context, the use of some of the most harmful environmental pollutants has been reduced, and this has also had an effect on levels in the Arctic. Long-term trends in the Arctic indicate a clear decline in pollutant levels in the environment and organisms immediately after a reduction in use. Measurements of air quality indicate that the incidence of pollutants was reduced during the 1990s and early in the 2000s; however, from 2000 to 2006, PCBs, HCB and DDT have once again been shown to have increased in the Norwegian Arctic, despite the fact that the use of these has not increased and several more countries have reduced the use of these substances. There are several probable explanations that can be attributed to changes in the climate, air and ocean currents and ice extent; the most likely reason is that transport routes and mechanisms for environmental pollutants have changed. If this is the case, this must be attributed to changes in large-scale weather phenomena, for example major current systems, that have shown irregular patterns during the last few years. However, this fact alone is not a complete explanation of the changed concentrations in certain seasons and years.

Recently, there have been indications that the Arctic Ocean itself may be a source of environmental pollutants. The seawater absorbed large amounts of these substances during the periods they were found in greater concentrations in the atmosphere. The environmental pollutants are now being gradually released into the atmosphere again. This process is controlled by the ocean circulation and the contact between the ocean surface and the atmosphere. This contact varies throughout the year, and from year to year, due to the variations in the extent of sea ice. Ice forms a protective cover on the sea which counteracts the emission of environmental pollutants into the air. However, due to a drastic reduction in ice cover in the Arctic Ocean, evaporation and thereby emission of environmental pollutants into the air has increased.

Other possible sources of environmental pollutants that lie close to the Arctic are the large forests in Eurasia and North America. Trees can absorb environmental pollutants, which in turn can be released to the air when biomass is burned. This theory is supported by measurements that indicate an increased incidence, among other things, of certain types of PCBs in the air in the Arctic during the summer – which can be associated with forest fires in Alaska. Such an incident occurred in April/May 2006, when heavily polluted air from the burning of biomass in Eastern Europe was transported to Svalbard, where it caused smog (fog mixed with smoke). In the aftermath of this incident, considerably higher levels of PCBs have been measured in the air in Svalbard.

The Arctic dome

Air currents transport pollutants into the Arctic. The significant cooling that is occurring around the North Pole during the winter means that warm, polluted air from lower latitudes slides over the cold air such that the pollution is not deposited in the Arctic. This is known as the Arctic dome – since cold air forms a layer almost like a protective cover in the lower troposphere. During periods of irregular warming, such as for example the winter of 2006, this cold air insulation mechanism did not function and polluted air was able to find a way into the central Arctic, close to the ground, leading to pollution deposits. If this type of warm winter occurs more frequently due to the retreat of the sea ice, this may increase the amount of deposited pollution dramatically.

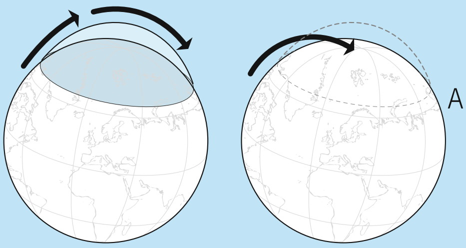


Figure 13: The Arctic dome. A cold air 'cover' protects against the deposit of airborne pollution. In cold conditions, the Arctic dome insulates and the polluted air masses pass over the Arctic without depositing pollutants; however, pollutants are deposited when the protective air cover is absent. Warming in the Arctic may lead to a reduction of the effect of this Arctic dome, and thus more airborne pollution will be deposited. Illustration: A. Igesund, Norwegian Polar Institute

Warmer climate will lead to thawing of permafrost and lead to changes that will cause an increased influx of soil and organic material into rivers, lakes and fjords. Many environmental pollutants are bound up in soil and organic materials and are then released and actually become more water-soluble due to the increased temperature.

Melting of the ice cover may release environmental pollutants that are stored in the ice and increase the flow to the water below where they become more accessible to aquatic organisms. Several of the environmental pollutants found in the Arctic are extremely toxic to aquatic organisms and have the potential to cause long-term damage to the aquatic environment. Snow and ice masses in the Arctic contain stores of environmental pollutants that are sealed in the ice structure, dissolved in water pockets in the ice or bound to organic material. There is a risk that the melting of ice cover and snow may lead to a considerable addition of stored environmental pollutants to the environment. Long-term studies of glaciers in the Arctic have also shown that melting of ice has led to a significant increase in environmental pollutants such as PCBs, HCH and DDT in the meltwater. As many glaciers were formed in the pre-industrial era, it is assumed that this applies mainly to more recent ice. Research shows that ice melting is of the greatest importance for the local levels of DDT in ocean water close to glaciers, and for a limited time period.

Måsøy, Finnmark. A sign warns of polluted water in a river. Image: © Bård Løken, Samfoto

A warmer climate may increase airborne transport, and deposit environmental pollutants in the Norwegian Arctic. An increase in temperature will affect the distribution of environmental pollutants between the ocean, soil and air masses. Large amounts of environmental pollutants may then be transferred from the soil and ocean to the air masses above. Several environmental pollutants that are bound up in air particles will be released and transported more rapidly to the Arctic. Certain environmental pollutants are broken down by sunlight; if climate change causes more cloud formation, this breakdown process may be reduced. It has been found that changes in air currents and increased precipitation may lead to increased deposits of PCBs, PAHs and heavy metals in the Norwegian Arctic.

When animals that live in the Arctic are subjected to stress due to climate change, through both changes in their natural habitat and reduced availability of prey, in particular animals that are higher up the food chain may be more vulnerable to environmental pollutants. Stress and hunger make animals more exposed to diseases and the effects of environmental pollutants. In addition, environmental pollutants such as PCBs may weaken their immune systems. When animals starve, fat in the body is broken down, and environmental pollutants are released into the body's bloodstream and these reach harmful levels. Polar bears are especially vulnerable when they cannot hunt for seals on the ice, in especially warm spring periods. Polar bears have a cocktail of the worst environmental pollutants known, stored in their fat reserves, and are already affected by environmental pollutants such as PCBs.

The connection between climate and transport of environmental pollutants and deposits in the Arctic is complex and not fully understood. There are many different processes that must be considered in order to state anything certain about the effect of climate change on the amount of environmental pollutants in the Norwegian Arctic. This applies especially to mercury; the mechanisms of mercury deposits in the Arctic are highly complex and dependent on many factors that are influenced by climate. In order to understand the reasons why the concentration of environmental pollutants in the air over the Arctic varies, and how this in turn affects animals and plants in the area, it is vital that we gain better knowledge of the processes involved in the transport and deposit of environmental pollutants in the Arctic and how climate change affects these. Improved knowledge of environmental toxin concentrations, both in old and recently formed sea ice, in oceans with year-round ice cover and oceans with ice cover for parts of the year is also required. The same applies to coniferous forests and soil in northern areas. It is also important to gain more knowledge of the effects that climate can have on the vulnerability of animals in the Arctic in regard to environmental pollutants and the correlation between climate influence on ecosystems, stress imposed by environmental pollutants and biodiversity.

UV radiation and the ozone layer

The ozone layer protects life on Earth against harmful UV radiation, which is the most energy-intense part of solar radiation that reaches the Earth. Regular UV monitoring was not introduced until the middle of the 1990s. Therefore we do not have a broad enough range of data to form the basis for reliable trends and predictions. Model estimates show a slight reduction in UV radiation in the Norwegian Arctic during the last 30 years, and measurements taken during the last 11 years support these findings. This is most likely due to an increase in the amount of cloud during the same period. In certain years there have been periods of higher UV radiation due to reduce ozone levels, as for example in 1997.

The emission of chlorofluorocarbons (CFCs) and other man-made compounds during the last 60 years has led to a dilution of the ozone layer. The Montréal Protocol from 1987 led initially to a rapid reduction in CFC emissions; however as ozone-destroying substances remain in the atmosphere, it may take some time before the ozone layer recovers. Therefore, there is a great deal of uncertainty associated with ozone developments in the future – more so in the Arctic than globally. The most significant extent of ozone breakdown in the Arctic during the last 15 years was observed in the winter of 2004/2005; it was caused by low temperatures in the stratosphere and ozone-destroying compounds. Considerable variations in the ozone layer over the Arctic have been observed. Measurements taken in Ny-Ålesund in Svalbard in 2003 and 2004 showed, for the first time, a reduction in the concentration of the important ozone-destroying CFC gases in the atmosphere in Svalbard. Halon gases, that also break down the ozone layer, were not found to have been reduced. However, an increase in hydrofluorcarbons (HCFCs – the replacement for CFCs) was registered. According to the Montréal Protocol, the production and use of HCFCs in developing countries is to be suspended before 2013. It is too early at this stage to assert that the ozone layer is 'healthy', and it is not anticipated that the ozone layer will be back at the 1980 level before 2050-2070. This is dependent on all countries phasing out ozone-destroying substances in accordance with the deadlines specified in the Montréal Protocol.

The Montréal Protocol

A global cooperation with the aim of protecting the ozone layer began with the Vienna Convention in 1985. Two years later, the Montréal Protocol was signed. Emissions of ozone-destroying substances have been reduced by over 95% since the agreement was signed.

The Montréal Protocol has specific objectives and a schedule for the reduction and elimination of individual ozone-destroying substances. The Protocol has been amended several times and the specified requirements have been intensified. The last amendment was in 2007. All countries in the world have ratified the Montréal Protocol of 1987. Later amendments to the Protocol have been ratified in some countries. The Montréal Protocol offers an economic support scheme to developing countries that provides economic and technical assistance in order to phase out ozone-destroying substances.

Environmental pollutants can disturb the hormone balance in kittiwake (Rissa tridactyla). *Image: © Stein Ø Nilsen, tromsofoto.net*

UV radiation can be harmful to certain marine organisms that live close to the ocean surface, such as fish larvae. Many Arctic species are adapted to low levels of UV radiation (they often have less protective pigments). The harmful effects of increased UV radiation may therefore be greater in Arctic regions than in other places. The ice cover on the ocean protects marine organisms against UV radiation. Studies indicate that a reduction in ice cover causes considerable changes in UV levels and thereby an increased risk of damage to Arctic marine ecosystems. In the same way, organisms in lakes and rivers may be harmed by increased UV radiation, if the ice cover is reduced or disappears completely.

Polar bear, Svalbard. Image: © Rudi Caeyers, rudicaeyers.com - BFE/UIT

Image: © Rudi Caeyers, rudicaeyers.com

Key finding 4: Sea ice is diminishing, threatening ice-dependent species

Sea ice is ice that covers parts of the sea in polar regions. The extent of the ice varies according to the season, ocean currents, atmospheric conditions and a number of other factors. Principally, sea ice is formed when sea water freezes to ice; however, a certain contribution to sea ice comes from precipitation. Several animal and plant species are dependent on sea ice. Some species live on, under or in the ice itself, whilst others inhabit the water masses in sea ice areas. Less sea ice in the Barents Sea may lead to significant ecological changes in the ocean. Light conditions in the water will change significantly if the ice is reduced or disappears completely and this will affect growth conditions for phytoplankton. Reduced ice cover in itself will lead to greater light penetration and therefore greater growth. If there is no ice on the ocean, the evaporation of seawater increases, which will lead to increased formation of clouds. More clouds reduces light penetration in the water, thereby increasing the growth of phytoplankton. The total effect of a reduction in sea ice is not clear; however, it will affect the composition of and production in the marine ecosystems.

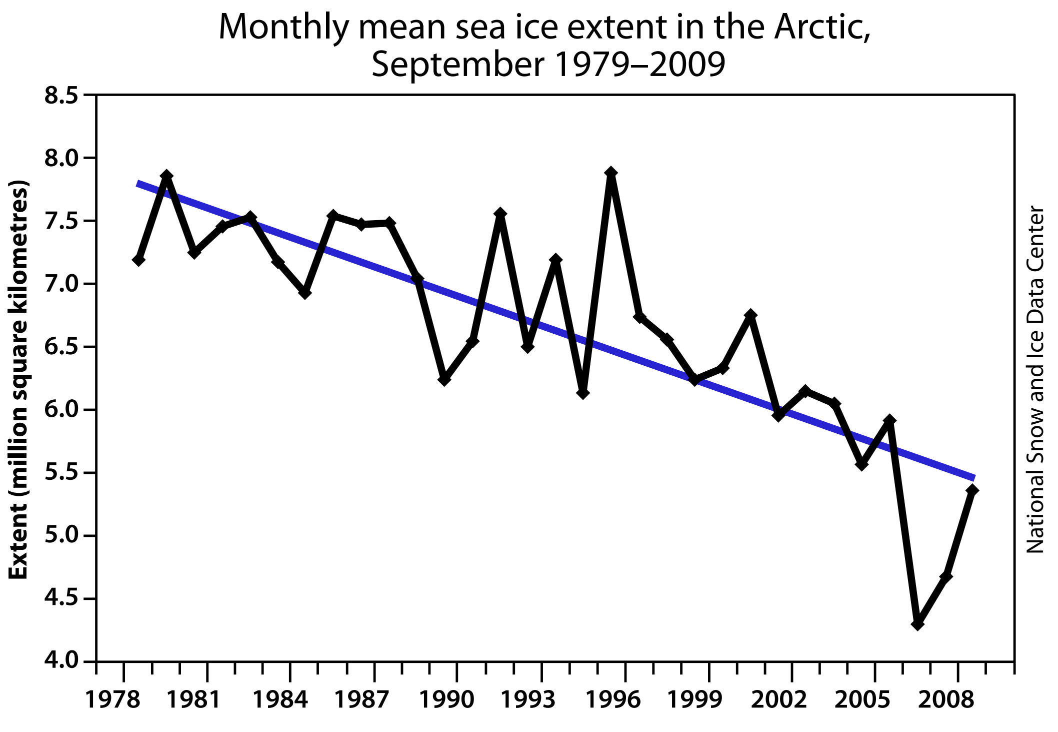


Figure14: The extent of sea ice in the whole of the Arctic in September, when the ice extent is normally at a minimum level, during the years 1979–2009. Source: National Snow and Ice Data Center 2010

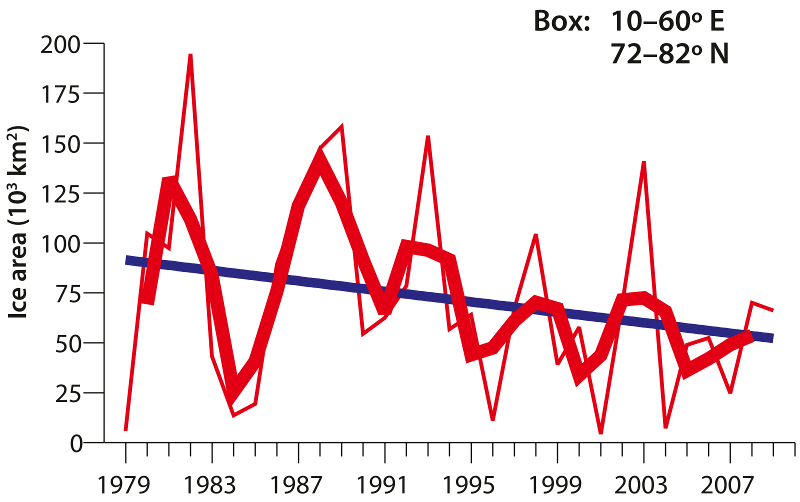


Figure 15: The extent of sea ice in the Barents Sea, September 1979–2009. Ice-covered ocean is defined as ocean with more than 15% ice cover. The narrow red curve shows the monthly mean value; the broad red line indicates ongoing mean values over three years, and the blue line shows the linear trend. It is clear that the year-to-year variation is large and at the same time, the trend throughout the period indicates that the ice cover is shrinking. September is normally a month with the least amount of ice in the Barents Sea. Source: updated according to Holmén & Dallmann 2010

Sea ice has already been reduced

The sea ice in the Arctic is clearly undergoing change. During the last 30 years, we have registered a considerable reduction in the extent of sea ice, especially during the summer. During the last three years, the extent of sea ice in the Arctic in September (annual minimum) has been lower than the average for the period 1979–2009. In 2007, the extent of the ice was at its lowest ever. The age of the sea ice is also of importance, as ice that is several years old is often thicker and therefore melts more slowly than thin first-year ice. During the last three years, the total amount of ice has been reduced considerably, a fact that has attracted significant attention. Large amounts of sea ice flow out of the Arctic Ocean with the ocean currents, which along with the melting processes means that the sea ice, to a certain degree, is renewed each winter. Therefore, sea ice is seldom more than a few years old, and sometimes only a few weeks old, before it melts. Various measurements show a reduction in the sea ice thickness in the Arctic Ocean and in some places in the Barents Sea, whilst in other places – such as north of Siberia – no clear trends have been observed. The problem is that the monitoring of sea ice thickness is not satisfactory and does not adequately cover the Barents Sea, the Norwegian Arctic or the entire Arctic. Therefore we do not have enough information about the actual amount of ice and thickness – which is important in order to be able to state anything specific about the overall condition of the sea ice. Methods that will provide a more precise monitoring of these parameters are under development; however, it will take some time before these can provide continual and reliable results.

In regard to smaller regions in the Norwegian Arctic; changes in the ice extent are more obvious in another way than for the Arctic as a whole. Some areas may totally change character as they go from being ice-covered for almost all of the year, to being covered during only certain times of the year. This leads to many consequences, both for the ecosystem and for human activity in the area. The extent of sea ice in the Greenland Sea and Barents Sea has been reduced during the last 30 years. The ice in the Greenland Sea is different to the ice in the Barents Sea. The Greenland Sea ice is largely comprised of ice that has been transported out of the Arctic Ocean, in addition to a certain amount of ice that has formed locally during the winter months. In the Barents Sea, the ice is largely comprised of ice that is formed locally during the autumn and winter, which partly melts during the summer, with only minimal amounts of ice from the Arctic Ocean.

Studies are being carried out in order to find the reasons why and how the ice in the Arctic has been reduced to such a degree in recent years. The studies will attempt to predict future developments. This is carried out by collating all of the elements that influence, or may influence, ice conditions in the various regions. One issue that has already been revealed is that the models for ice development must account for the collective influence of many different factors that may also reinforce each other – for example that melting pools on the surface of the sea ice increase the rate of the melting process.

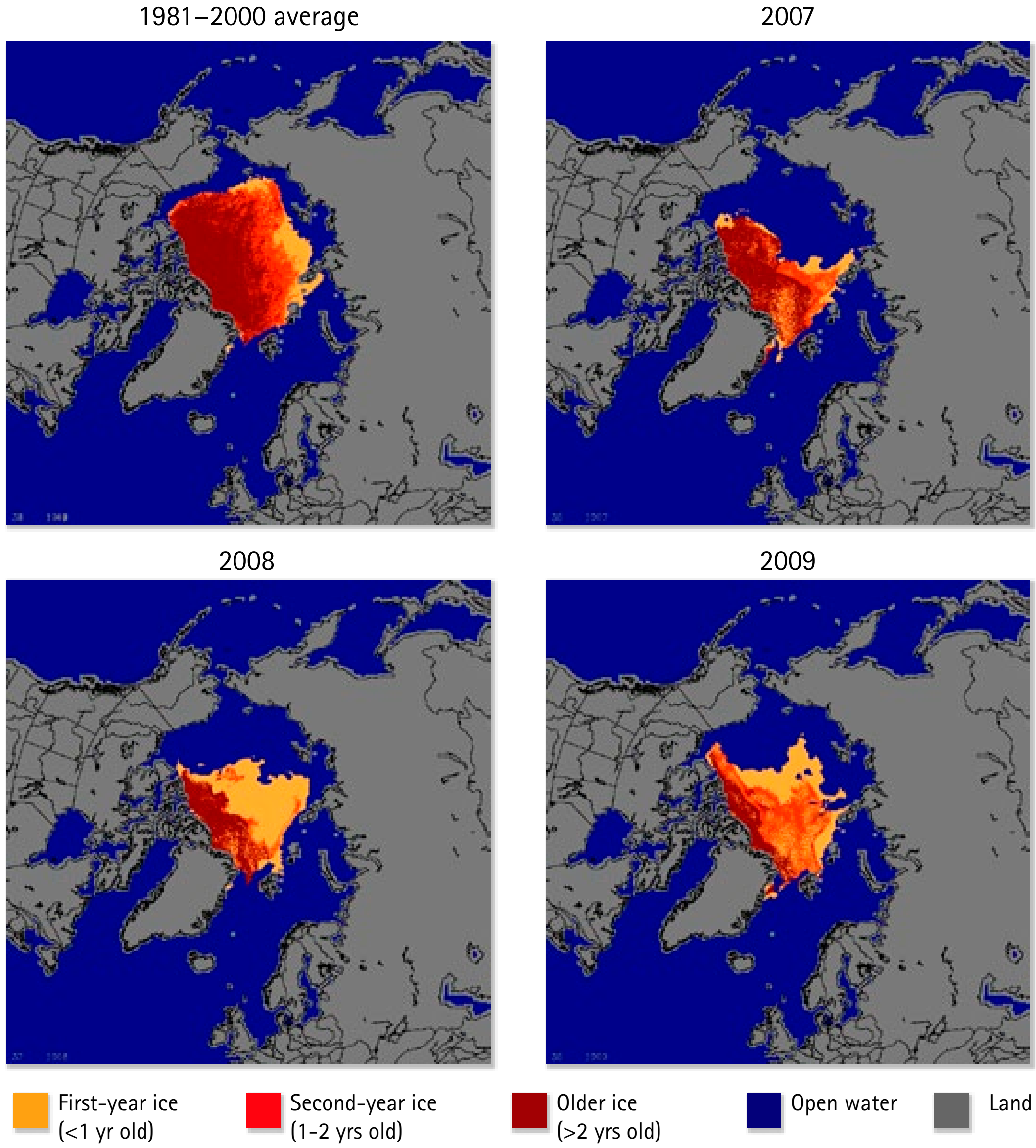


Figure 16: In the Arctic, thin first-year ice is now replacing the thicker multi-year ice. The maps compare the age of the ice, based on the thickness in 2007, 2008, 2009 and the average for 1981–2000. In 2009, the amount of second-year ice had increased compared to 2008, and at the end of the summer 2009 it represented 32% of the ice cover. Ice that was three years old or older represented only 19% of the total ice cover, the lowest proportion since satellite monitoring of the ice thickness began in 1979. Source: National Snow and Ice Data Center, with permission from C. Fowler & J. Maslanik, University of Colorado, Boulder.

During the melting season, the fresh water from melted sea ice will stabilise the surface layer in the ocean, since fresh water is lighter than seawater. The physical divide between the surface layer and the deeper water masses prevents plankton algae from sinking out of the productive, light surface layer, thereby promoting plankton production. Several species of crustaceans feed on plankton, and they themselves are important prey for fish, birds and sea mammals. Under the ice, algae grow in the form of threads or 'mats', and in ice that is several years old, these algae threads may be up to 2 m in length or form thick matted layers. Ice with the richest ice edge flora and fauna may be reduced or disappear completely.

Without ice, the ice algae will disappear

In the Barents Sea there are several species of algae that grow on, in or under the sea ice. The age and thickness of the ice is of major importance for the diversity of species and growth, and there is considerable variation, both from year to year and from region to region. These algae form the nutrient basis for grazing animals in the sea. The ice algae currently represent approximately 20% of the total primary production in the northern part of the Barents Sea. The anticipated reduction in ice extent and type will reduce the diversity of species in the area, if certain types of ice algae groups are reduced or disappear completely.

Newborn seal cub on the ice. Image: © Bjørn Frantzen, Norwegian Polar Institute

Polar bears, seals and whales in the Arctic depend on sea ice

The threat to the climate is likely to have a greater effect on marine mammals than on most land-based mammals. This is due to the fact that many of the sea mammals in Arctic ecosystems are specially adapted to a life at the ice edge. Sea ice is essential for these animals and a reduction or complete disappearance of the ice may change Arctic marine ecosystems – as we currently know them – completely. For example, we expect that there will be fewer polar bears already during the next few decades.

Seal species that live on the ice such as ringed seals, bearded seals, harp seals and hooded seals are likely to experience both a reduction in distribution and in numbers. For harp seals and ringed seals that give birth to their young on the ice, reproduction levels have been extremely low in the warmer seasons in recent times, and mortality rates for harp seals have been high. These species have difficulty in adapting to a situation with less sea ice. If the ice limit changes and remains in the Arctic Ocean all year round, species such as harp seals, narwhal and white whales (belugas), will relocate and simply move their habitat northwards. However, species such as bearded seals, ringed seals and walrus gain an advantage from the production of nutrients at the ice edge when this lies close to the coast or in shallow areas; they may then experience reduced distribution areas and stocks when the ice edge retreats north and east of Svalbard, away from the coast.

The West Ice (west of Norway, but east of Greenland) is an area of floating ice that freezes each year in the Jan Mayen current. Temperature increases have led to changes in the formation of ice in the West Ice area. Hunting was previously carried out on both harp seals and hooded seals, and stocks are smaller now than before seal hunting began. Both species of seal give birth to their young on the ice and the seal pups live on the ice until they are weaned. When the West Ice disappears or the extent is dramatically reduced, the seals will be forced to find another, perhaps less suitable area in order to give birth. Birth rates for hooded seals on the West Ice in 2005 were only 60% of those in 1997. This cannot be explained by hunting during the period, as insufficient numbers of animals were hunted to create such an effect. The reduction may be a consequence of reduced ice extent and/or a change in ice properties.

The polar bears that live in the Barents Sea area are one of the most threatened polar bear groups in the world. Their diet is dominated by ice-dependent seal species, such that a reduced ice extent affects their access to prey. The sea ice is also important as a transport route in order to reach suitable den areas on land to give birth to their young.

Will the whales disappear?

There are only three whale species that are found all year round in the Norwegian sector of the Barents Sea; white whales, narwhal and bowhead whales. They spend a great deal of time under the ice or at the ice edge. Exactly what will happen to these species when the ice melts is uncertain, as we do not know for sure why they are so strongly attached to the ice. Ice-dependent animals provide food for the whales and the ice may offer them the necessary protection – this may possibly explain their strong attachment. These are all whale species that grow slowly and can be over 100 years old, in fact bowhead whales may live to be 200 years old. They give birth to very few young during their life, such that a warmer climate may lead to greater competition from other species that reproduce more quickly, which gives them an advantage. In addition, Arctic whales can become exposed to greater threat from attacks by orcas – and it is anticipated

Image: © Rudi Caeyers, rudicaeyers.com - BFE/UIT

these will increase in numbers in a warmer climate. The marine mammals that are currently seasonal visitors will most likely change their distribution areas in a northerly direction as the ice retreats. An increase in the number of observations of fin whale north of Svalbard has already been registered; this indicates that this development has in fact already started. Several more southerly whale species such as sei whales and porpoises have been observed much further north.

Ice-dependent seabirds are affected by climate change

There is very little doubt that a significant change in climate will lead to considerable consequences for the species composition of seabirds. A steadily shrinking sea ice may even – in some cases – lead to the complete extinction of some ice-dependent species. Several Arctic seabird species are dependent on ice during part or the whole of their life cycles. Ivory gulls, for example, find food at the ice edge or in channels in the ice. For other species, climate change may be more positive; if a reduction in the ice cover leads to easier access to food, certain seabird species may be able to exploit this extra resource and stocks may increase.

Retreating ice offers new opportunities – and challenges – for human activity

Sea ice functions as an effective barrier to human activity. A reduction in the extent of sea ice will partly remove this barrier and offer new opportunities. Shipping companies (both cargo transport and tourism) could extend their routes into new areas and thereby increase the scope of their activities. Better conditions could arise for petroleum activity in new areas. New and increased activity will lead to a number of challenges associated with environmental hazards and emergency preparedness. These issues are described in further detail in Key finding 11.

Gimsøya, Lofoten. Image: © Bård Løken, Samfoto

Key finding 5: The ocean is getting warmer and ecosystems are changing

Large parts of Norway's northern areas are covered by ocean. The ocean has always been important to the people who live in northern Norway, and even today, many people along the coast make their living from the resources provided by the ocean. It is highly probable that climate change will alter the ecosystems in the oceans, such as we know them today; however, there is considerable uncertainty associated with exactly what these changes will involve. There are two large ocean areas in the Norwegian Arctic; the Barents Sea and the Norwegian Sea. These two oceans are different, both in relation to water mass and the type of inhabitant species; there are several species that are found in both areas – however, these are found at different times of the year or in different phases of their life cycle.

What is an ecosystem?

A species or a stock of a species must be seen in the context of the total ecosystem they are a part of. An ecosystem is comprised of plants, animals and microorganisms in an area in which the interaction between them and the outer environment within the same area represents a functional system. Ecosystems are not closed, limited systems; however, in order to study the connection between various species and their environment we must define certain boundaries, either based on the particular species to be studied or based on the physical environment. Often, these boundaries are based on a specific area – for example a lake, a fjord, a certain deepwater area or a type of forest.

Figure 17: Simplified image of an ecosystem in the Barents Sea. In relation to exactly how far north the Barents Sea is located, the biological diversity is considerable. For example, over 3 000 species of benthic invertebrates have been registered. In addition there is a great number of different species of plankton, fish and other groups of organisms. There are also several types of ice-dwelling colonies, in which algae, in or under the ice, is an important component. Source: Institute of Marine Research

Climate change affects the ocean

Climate change may affect organisms in the ocean via many different processes, and the correlations between these can be complex and difficult to estimate. Climate effects in the ocean depend, among other things, on the extent of warming. Also, during the next hundred years we can expect that other types of man-made effects can become noticeable, such as for example the effect of fishery and ocean pollution. These types of effect may combine to cause a greater effect than the sum of each individual element. It is therefore difficult to state exactly what the consequences of man-made influence on the ecosystems in the ocean will be.

During the last six years alone, the Atlantic Ocean water in the Norwegian Sea has been unusually warm and saline. In 2007, the temperature was 0.8°C warmer than normal, the warmest temperature registered after 1977, when measurements began. There has been a decline in the amount of zooplankton in the Norwegian Sea in recent years, and in 2009 the minimum amount was registered for the last 10 years. The reason for this may be the large stocks of fish that feed on zooplankton. Sporadic incidences of foreign zooplankton species have been observed – these come from areas further south in the Norwegian Sea, and these incidences appear to be increasing in frequency. This may be due to a higher temperature in the inflow of water from the south, which transports the more southern species.

Phytoplankton, the 'grass' in the oceans' ecosystems

Higher temperatures in the ocean are expected to lead to the increased production of phytoplankton, the so-called primary production. Even though warming, viewed in isolation, will lead to increased production, other consequences of this warming may counteract this or lead to relocation of production to other new areas. Exact calculations for production of phytoplankton under changed climate conditions are not currently available. Increased storm activity may lead to more unstable growth conditions for phytoplankton, as the light conditions in the water become less favourable and the influx of nutrients may be reduced. The species composition of algae may also change. We do not know exactly what the consequences will represent for zooplankton, which feed on algae, nor can we be certain about any further consequences further upwards in the food chain. Warmer water means that certain species of phytoplankton grow more quickly. The temperature increase may also have an indirect effect on phytoplankton through changes in ice extent and mixing processes in the water. Comparative studies of the plankton composition in the Norwegian Sea in recent years have shown that the proportion of more southern species along the Norwegian coast is increasing.

Ice algae that live on and in the ice are important to the ecosystems at the ice edge. Changes in the ice edge and melting sea ice may lead to a significant reduction in the species - in a worst case scenario they may disappear completely.

Zooplankton – the 'grazers' of the ocean

Climate change may have a greater direct effect on phytoplankton than on zooplankton. The indirect effect on zooplankton is via the effects on it's food, namely phytoplankton. Various species of phytoplankton and zooplankton have different abilities to adapt to the climate changes in the ocean. Therefore, the relationship between the species and the composition of the ecosystems may be altered. One factor that limits the amount of zooplankton is fish and other animals that exploit them as a food source. Physical factors such as temperature, light and currents in the water are also important elements. A warmer climate may lead to increased stocks of zooplankton, both due to the potentially increased numbers of phytoplankton and due to increased growth in the zooplankton itself. In general, zooplankton grows more rapidly when the temperature is higher, and rapid growth means that mortality rates decline. This is due to the fact that the zooplankton grows to such a size that they are less likely to be eaten.

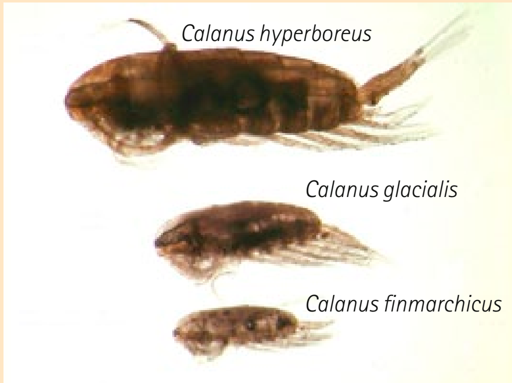
Some estimates indicate that the changed climate conditions will lead to more zooplankton in the Norwegian Arctic, whilst other estimates indicate the opposite. Estimates are difficult to make, as there are several climate effects that work together and some work against each other. Temperature increases, viewed in isolation, can lead to both improved access to food and better growth for zooplankton. Temperature increases may also lead to another effect, namely that less Atlantic Ocean water, and thereby less zooplankton, flows into the Barents Sea with the ocean currents. In addition, an increase in temperature may lead to larger stocks of fish that feed on zooplankton, for example mackerel and blue whiting, both in the Norwegian Sea and the western part of the Barents Sea. Both temperature and the absence of ice can change the composition of species of zooplankton, such that there is a greater number of small and less energy-rich zooplankton. For animal species that have a specialised diet of certain zooplankton species, this may lead to serious consequences for their access to nutrients.

Calanus finmarchicus – a key species

The dominant species of zooplankton in Atlantic waters in the Norwegian Sea and the Barents Sea is the small copepod *Calanus finmarchicus*. It is found in most of the Norwegian Sea, and the largest stocks are found in the central areas where the temperature lies between 4–7°C. *C. finmarchicus* is well adapted to a life in the northern part of the North Atlantic and has such an important position in the ecosystem that a change in the numbers of *C. finmarchicus* will lead to enormous consequences for many organisms in the ocean areas in the Norwegian Sea/Barents Sea region. Also, the hatching period for zooplankton eggs and the time taken to develop into mature zooplankton is dependent on temperature (given that there is adequate access to food). Put simply, the higher the temperature, the more rapid the process. If zooplankton is the most vital source of food for several fish species whilst they are small, it is clear that access to zooplankton during the time that fish fry begin to eat is decisive. Disturbances in the interaction that exists between the time and place of phytoplankton growth, zooplankton development and the hatching of fish eggs will lead to changes in the ecosystem.

Increased ocean temperatures also lead to the risk that *C. finmarchicus* may be replaced by the more southerly species *C. helgolandicus*. This species is not as nutrient-rich as *C. finmarchicus*, and this may have a negative effect on commercial fish species. In the same manner, the even more nutrient-rich species *C. glacialis* and *C. hyperboreus* may be replaced by *C. finmarchicus* further north.

Calanus finmarchicus
Image: © Malin Daase, Norwegian Polar Institute



Calanus hyperboreus, C. glacialis *and* C. finmarchicus.
The comparative difference in size is remarkable.
Image: © Slawek Kwasniewski, Polish Academy of Sciences

Animals and plants on the ocean floor

There are several factors that influence the distribution and growth of seaweed and kelp; ocean temperature, salinity, light conditions, sea ice, currents and wave activity. The temperature of the water is the most important factor for the distribution of seaweed and kelp in the Arctic; however, this plays a lesser role in regulating growth. This means that increased temperatures will initially affect species composition in seaweed and kelp colonies. Seaweed and kelp, similarly to other plants, are dependent on light in order to grow, and if the water allows less light down to the ocean floor this will reduce growth. This type of light condition may occur due to the increased suspension of sediment or greater amounts of phytoplankton in the water. Sea ice also restricts light penetration, such that a reduction in ice cover will lead to greater growth of seaweed and kelp. Increased amounts of freshwater flowing from land as ice and snow melts, may lead to lower salt levels in the tidal zone and thereby less favourable growth conditions. The result may be that certain species that inhabit the tidal zone either disappear or relocate to greater depths.

Cod (Gadus morhua). *Image: © Fredrik Naumann, Samfoto*

At the ice edge in the Barents Sea, there is significant biological production, often for a very brief period. Not all of the organisms in the water column are consumed, and some of the zooplankton and phytoplankton sink to the bottom, providing more nutrients for benthic species in the area. Less ice in winter and retreat of the ice edge northwards will reduce and dislocate this source of nutrients for benthic fauna in the Barents Sea.

Fish move to new areas

Increased water temperatures over longer periods will mean firstly that species that are already found in Arctic areas will show signs of extended distribution. Secondly, species that up to this point have had a more southerly distribution may become established in the Norwegian Sea. Over a longer time perspective there is one particular factor that is extremely important for the development of fish stocks in the Norwegian Arctic – the distribution of *Calanus finmarchicus*. *C. finmarchicus* is the most important food source for fish fry migrating northwards, and it will thus be decisive for the growth conditions of fish stocks. It is difficult to predict how each individual fish species will respond to climate change. Viewed in isolation, a warmer and more ice-free Barents Sea should lead to increased distribution; however, the fish are also dependent, among other things, on finding suitable spawning grounds, and not least protection against predators.

Capelin almost exclusively migrate to regular spawning grounds off the coast of Troms, Finnmark and the Kola Peninsula. A displacement of stocks eastwards and northwards is the most probable result of warmer ocean waters. Capelin are unlikely to be able to make long journeys to spawning grounds; this means that capelin will have to find new suitable areas to spawn, for example the shallow areas west of Novaya Zemlya, around Svalbard and the other archipelagos in the northern Barents Sea, which appear to be suitable for capelin. A likely consequence of this will be that capelin will disappear from the south-western areas of the Barents Sea, where they are currently widespread.

Cod stocks, historically, have shown significant fluctuations over time. This phenomenon, along with overfishing, can be explained by variations in climate. A temperature increase of the antici-

Polar cod (Boreogadus saida). *Image: © Erling Svensen, UWPhoto.no*

pated range during this century may, in principle, lead to an increase in cod stocks; however, if the temperature should increase beyond the optimal temperature for the species, stocks may still be reduced.

Polar cod is one of the most common fish species in the Arctic. This fish is the most important prey for ringed seals, white whales and a number of seabird species, and it represents approximately 1/10 of the food source for cod stocks in the area. This means that it is a vital element in the ecosystem of the Barents Sea. Polar cod is an Arctic species adapted to a life in cold water, and if the water becomes warmer, distribution is likely to shift northwards and eastwards. In addition, there is a risk that other species that move northwards may also compete with Polar cod for food.

Figure 18: Expected changes in the distribution of our most important fish species. Source: AMAP 2003

Seabirds face threats from several sources

Seabirds in the Norwegian Arctic feed largely on plankton and small fish species such as capelin, sand lance, herring and Polar cod. If the stocks and distribution of prey change along with a changing climate, this will lead to consequences for the seabirds. It is anticipated that the birds, as far possible, will follow their prey to new areas.

Climate change is expected to have a greater effect on reproduction and the survival of young birds than a direct effect on the adult population. This will especially

Puffins (Fratercula arctica) *on Bjørnøya. Image: © Odd H Hansen, Norwegian Polar Institute*

apply if the changes lead to reduced access to food. Seabirds are dependent on finding food close to suitable breeding grounds. If climate change lead to birds having to fly further away from breeding grounds in order to find food, this may lead to dramatic consequences for seabird populations. Breeding success for seabirds – and also whether breeding actually produces thriving young – is also dependent on the coincidence of the breeding period and access to food. Studies of puffins have shown that there is a correlation between successful breeding and the availability of small herring that move northwards off the Norwegian coast. If the puffins do not begin to breed at the same time that the young herring are available in a particular area, this may mean that much fewer young survive.

New species in the ocean – uninvited guests with unknown consequences

Changes in the composition of species in an area can occur in several ways. Foreign species are species that have been introduced by humans – they have either been introduced to an area by accident, for example in ballast water, or deliberately, by being released in the area. New species are species that have relocated to a new area, either because a new opportunity for establishment has arisen or because environmental conditions have changed such that this has become possible. In addition, a species may become established through a combination of these factors; a species introduced into the North Sea by humans may, for example, spread and invade the Norwegian Sea and the Barents Sea. The most important transport route for new species into the Norwegian Arctic is via ocean currents.

Perhaps the most well-known occurrence of foreign species in Norwegian waters is the red king crab in the Barents Sea. After Russian researchers collected millions of red king crab larvae and several thousand adult crabs in the Pacific Ocean and released them in the Barents Sea at the end of the 1960s, the red king crab has spread along the coast of northern Norway. The crab is now found as far as northern Troms, which is probably due to the spread of larvae and natural

Red king crab (Paralithodes camtschaticus). *Image: © Andrey Nekrasov, UWPhoto.no*

migration. Some individuals have been observed as far south as the coast of Bergen; however, these are most likely crabs that have been transported on board fishing vessels. In the Varanger fjord, the red king crab has had serious consequences for benthic fauna, especially on the larger species. The red king crab is also the host for a parasite that can infect cod, and increased numbers of red king crab exacerbates this hazard. Overall, there is a great deal of uncertainty concerning the exact effects of the red king crab on the ecosystem in the Barents Sea. In principle, the red king crab is a cold-water species that prefers temperatures of between 2 and 7°C; however, it can survive in temperatures up to 18°C and has proved to be especially resilient and adaptable to its new environment.

Snow crab (Chionoecetes opilio) *Image: © Eva Farestveit, Institute of Marine Research.*

Snow crabs were first observed in the far east of the Barents Sea by Russian researchers in 1996. Since that time, several more observations have been made, also off the coast of Finnmark. It is not known how the snow crabs migrated to the Barents Sea from their natural habitat on the eastern and western coasts of the USA; however, there is no evidence to indicate that they were introduced deliberately as is the case with the red king crab. The effects of climate change on the further distribution of red king crabs and snow crabs is uncertain; however, as the snow crab prefers temperatures under 3°C, with the current ocean temperature it is unlikely to spread southwards in significant numbers. Further temperature increases are expected to limit the south-

Herring (Clupea harengus) *school. Image: © Erling Svensen, UWPhoto.no*

erly distribution of both the red king crab and the snow crab; however, the limit for northerly distribution is unknown.

In regard to benthic species; those that live in temperate ocean areas often have a greater tolerance towards changes in temperature than the Arctic species. Therefore, warming of the oceans will mean that southern species quickly will be able to become established in the Barents Sea. The likelihood of this is also increased as benthic species that currently inhabit the Norwegian Sea, but not the Barents Sea, often have larvae that can live for a considerable time in free water masses and may thereby be transported with ocean currents into the Barents Sea. If the temperature conditions in the Barents Sea are within the tolerance limits of these organisms they may become established there.

Several new species have become established in, or close to the borders of Norway, for example Japanese wireweed *(Sargassum muticum)*, *Heterosiphonia japonica*, Japanese skeleton shrimp and sea walnut *(Mnemiopsis leidyi)*. It is not easy to predict the consequences of an eventual spread of new species northwards with the Atlantic Ocean currents or coastal currents – however there is reason to believe that this may have a considerable effect.

Climate change in an ecosystem perspective

It is difficult to say exactly how the individual parts of the ecosystem in the ocean will change due to climate change. Thus it is even more complex to state anything certain about how the overall picture will be. The ecosystems in the Barents Sea, off the coast of Svalbard and northern Norway have developed during – and have adapted to – natural climate variations, and appear to be highly resilient to influence before dramatic changes occur. If the temperature increases beyond a normal climate variation, the uncertainty associated with the ecosystem's response and resilience increases.

In any case, we must expect that climate change will lead to changes in the balance of species, and the more rapidly these changes occur, the greater the consequences might be. Species that are able to alter their diet in the event of changes in access to prey will be far more resilient than those that have specialised and become dependent on one or a few types of prey. Higher temperatures may lead to an increased number of species in the Norwegian Arctic; however, there may be fewer individuals of each species. In addition to the direct climate effects such as higher temperature, the ecosystems must also cope with the indirect effects of the changes in composition and distribution of species. Ecosystems must adapt to the collective effect of these influences. It is therefore important to point out that further man-made influence on ecosystems in addition to climate change, increases the likelihood of negative consequences. These influences may be, for example, overfishing, emissions from petroleum activities, shipping traffic and other forms of pollution.

Variations in climate cause obvious effects on the scope of stocks of species in northern areas. One example of this is the herring; stocks typically increase during years in which it is warmer than usual. The herring feed on capelin larvae when they are in the Barents Sea, thereby reducing capelin stocks. This has occurred several times. If a warmer climate leads to increased stocks of herring, this may also affect other fish species. Capelin are also an important food source for cod, and variations in capelin stocks, in turn, affect cod stocks.

The anticipated changes in the distribution of fish may also affect the ecosystems in the Barents Sea; for example, if southern species such as blue whiting and mackerel move into the western areas of the Barents Sea and begin to deplete the stocks of zooplankton brought in by currents. For species that inhabit areas further east, that are dependent on the zooplankton, this may reduce the availability of food. Warming of the ocean may also move the boundary between Arctic and Atlantic water. These boundary areas have a high production rate, and fish, sea birds and marine mammals find their food there. The consequences of this type of shift are difficult to determine.

Beach in Moskenes, Lofoten. Image: © Trym Ivar Bergsmo, Samfoto

Key finding 6: The acidity of the ocean is increasing and coral species may disappear

Up to the present time, the oceans have effectively buffered for climate change, as they have absorbed more than 25% of the man-made CO_2 that has been released since the beginning of the Industrial Revolution at the end of the 1700s. The oceans are enormous stores of CO_2; however, the cost of this storage is high: CO_2 that is dissolved in seawater reduces pH levels – in other words, the ocean water is becoming more acidic due to our emissions.

Rapid and measurable acidification

The oceans have already become measurably more acidic in several places, and it is anticipated that a reduction of 0.2-0.3 pH units in surface layers will take place during the next hundred years, if emissions of CO_2 continue to increase at the current rate. Acidification is expected to be greater in cold, Arctic water than at the tropics. This means that we will notice the effects earlier in the northernmost Norwegian ocean areas. It is probable that the average pH in the ocean has not been below 8.0 for many millions of years. Calculations for the next hundred years indicate that we may see pH levels in the oceans that have not occurred during the last 20 million years.

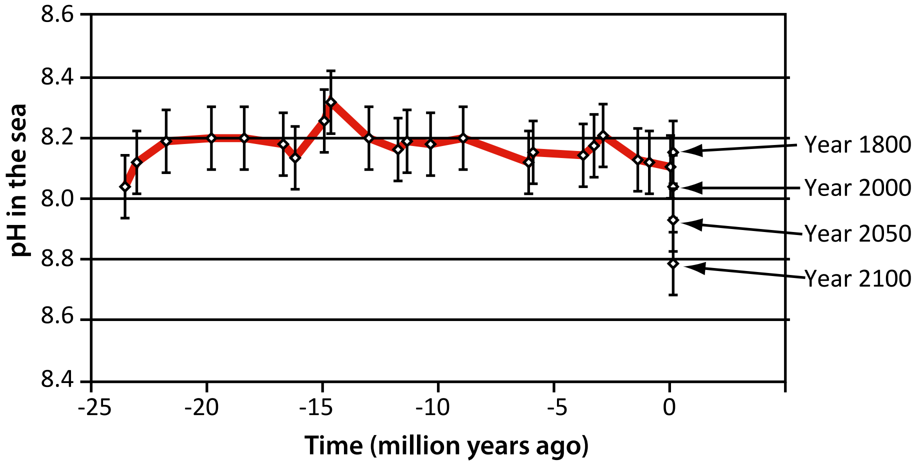


Figure 19: Probable prehistoric development of pH levels in the ocean combined with calculations of future levels. Source: Blackford & Gilbert 2007, modified according to Pearson & Palmer 2000

How low can pH levels fall?

Model estimates indicate that both the Norwegian Sea and the Barents Sea will experience increased acidification, but the levels of acidification will vary regionally. This is due to the large current systems and the chemical and physical properties of the water masses.

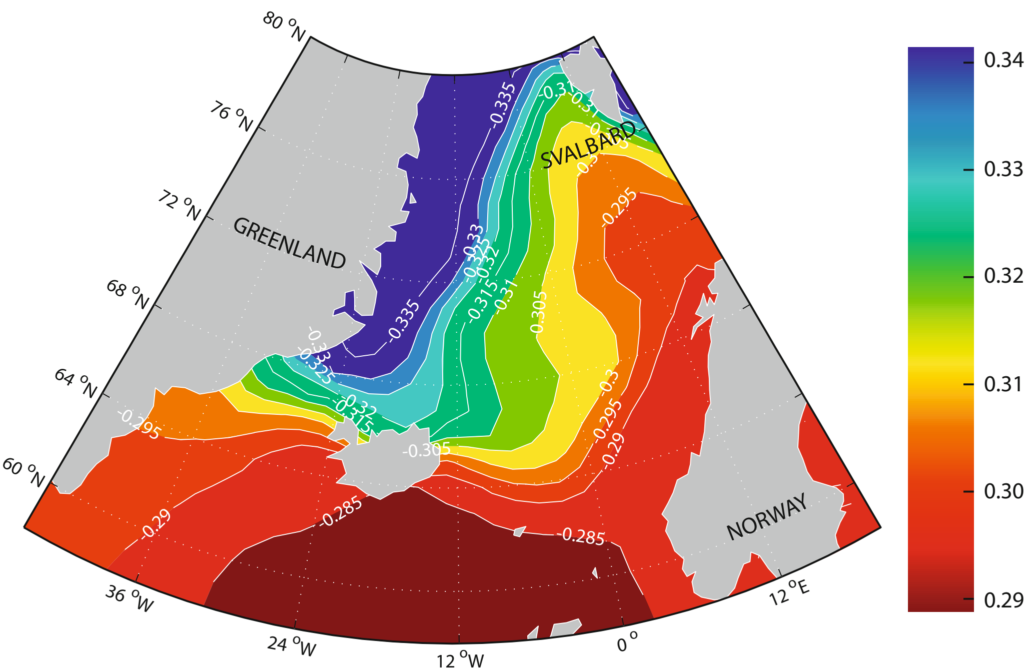


Figure 20: Changes in the surface pH in the Norwegian Sea predicted for the year 2075, based on a doubling of the concentration of CO_2 in the atmosphere. The ocean acidification will be most serious in the Arctic areas. Source: Adapted from Bellerby et al. 2005

It has been found that the greatest reduction in surface pH may occur in the western part of the Norwegian Sea, and the least reduction south of the Iceland-Faroe Islands Ridge. The biggest concern in regard to acidification is that it appears to be increasing rapidly, and at the same time we do not know enough about the consequences, either for individual species or ecosystems. In parallel with the initiatives introduced in order to limit acidification we must also carry out further research in this area. We have limited knowledge of acidification processes on a regional scale, such that it is not possible to describe specific indications in the individual areas of the ocean. Certain species have also been shown to be more tolerant of a reduction in pH level; acidification can thus result in local and regional effects on species composition.

Double trouble

Acidification is a threat that comes in addition to climate change, and the species that are threatened by acidification are therefore under strain on two fronts. Acidification will represent a challenge to marine calciferous organisms, as it will require more energy to form calcium shells, mollusc shells and corals, as the calcium carbonate in the water is less available to them. Calcium shell is formed by two types of calcium; aragonite (in for example corals and sea butterflies) and calcite (in a number of plankton species, snails and molluscs). Aragonite is more soluble than calcite, such that organisms that build their shells of aragonite will be affected earlier as a result of acidification. If the ocean reaches critical values, the shells of molluscs and snails may ultimately dissolve. Processes are already occurring that affect the shells of, for example, sea butterflies. Corals are among the benthic species that will be the first to be affected by the consequences of acidification and changes in the amount of CO_2 in the water. Further negative developments are therefore of great concern. We are likely to see an effect on corals as early as 2025. A large proportion of deepwater corals in Norway live at a depth at which the water chemistry can reach critical values towards the end of this century. A reduced pH value may also affect algae, phytoplankton and seaweed/kelp. Calciferous algae are especially vulnerable. As is the case for other animals, it will require more energy to build calcium shells and if pH values reach critical levels, there is a risk that some species will disappear from our ecosystems. In regard to benthic organisms, it has been shown that the larvae are more sensitive to acidification than mature individuals, which may change the composition of benthic fauna.

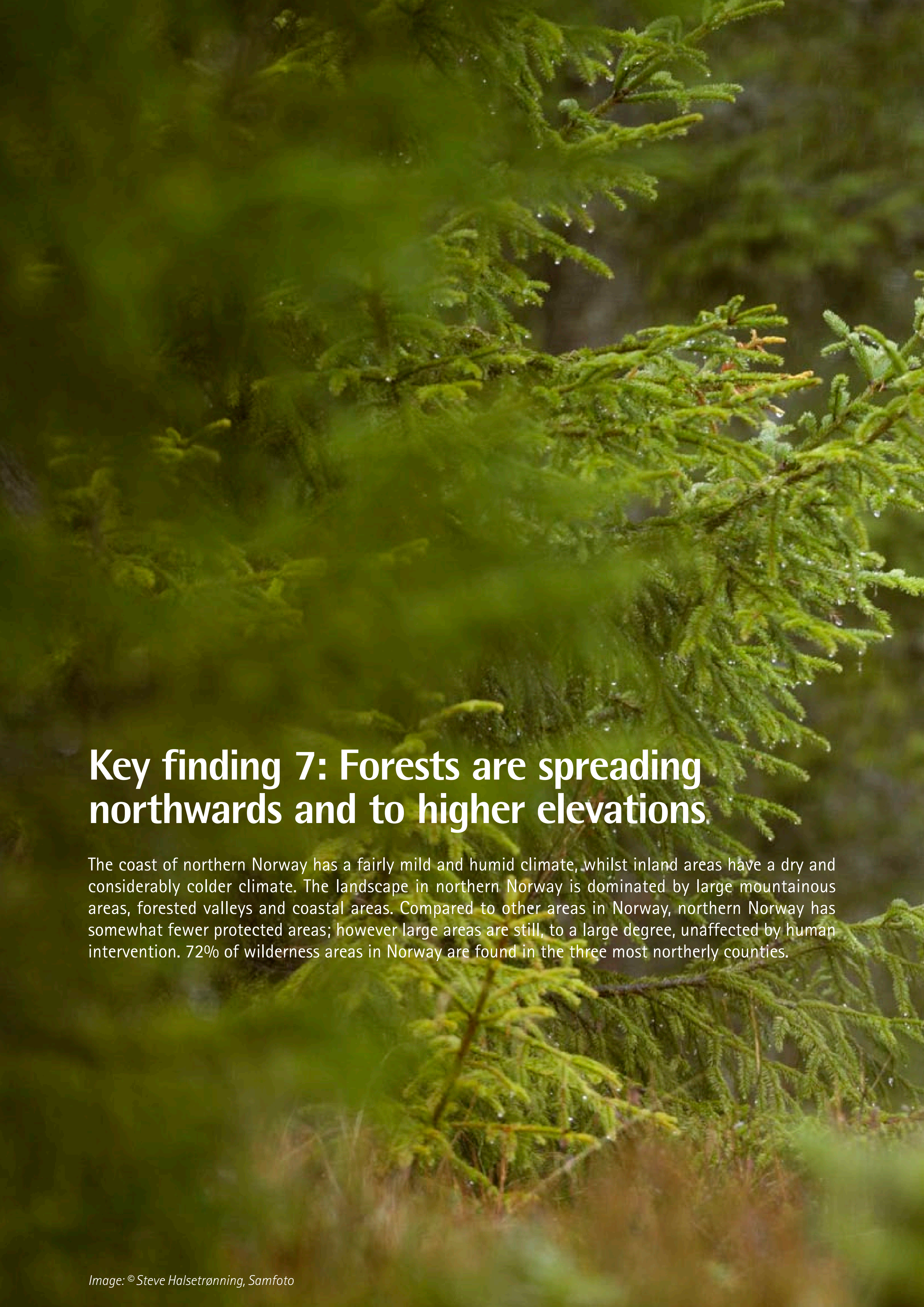
White coral (Lophelia pertusa). *Image: © Pål B Mortensen, Institute of Marine Research*

Sea butterfly (Limacia helicina). *Image: © Erling Svensen, UWPhoto.no*

Many of the zooplankton species in the Norwegian Arctic have shells of calcium and so may be vulnerable to acidification. Both direct physiological and indirect ecological effects of acidification are anticipated; however, for the time being there is a great deal of uncertainty as to what exactly will happen. Tests carried out on organisms have shown significant variation in response to reduced pH levels, both between related species and within the same species. Several studies have also been carried out on much lower pH levels than those calculated for the oceans in the Norwegian Arctic; however, the results from these are not directly transferable to the anticipated pH development in the Norwegian Arctic.

In addition to negative consequences for shells and molluscs, acidification will also affect the condition of other organisms; physiological processes may require more energy in an ocean environment with a lower pH value. This will mean that they will have to invest more energy to maintain their normal life functions. Mature fish are probably less vulnerable to acidification of the ocean than bottom dwelling, calcium forming organisms, and there have been no studies that have shown any effects on fish with the level of acidification that is anticipated towards 2025. However, tests have already been carried out that indicate that anemone fish lose their olfactory sense in water with low pH and high CO_2 levels, and that cod invest more energy in maintaining vital functions. Early life stages such as embryos and larvae, however, may be far more vulnerable to acidification than mature fish. If this is the case, this is a major problem, as stocks may be reduced if great numbers of embryos and larvae die. In addition, fish may be affected indirectly if their prey is affected and established food chains break down.

Grøtfjorden on Kvaløya near Tromsø. Image: © Bjørn Jørgensen, Samfoto



Key finding 7: Forests are spreading northwards and to higher elevations

The coast of northern Norway has a fairly mild and humid climate, whilst inland areas have a dry and considerably colder climate. The landscape in northern Norway is dominated by large mountainous areas, forested valleys and coastal areas. Compared to other areas in Norway, northern Norway has somewhat fewer protected areas; however large areas are still, to a large degree, unaffected by human intervention. 72% of wilderness areas in Norway are found in the three most northerly counties.

Image: © Steve Halsetrønning, Samfoto

Land ecosystems are undergoing changes

Climate affects the distribution and density of land-based species. Plant and animal species have a limit as to how low a temperature they can tolerate, and they are dependent on suitable snow conditions and the length of the snow season. A milder climate may lead to an increased movement of many species into traditionally colder areas. In general terms, we can say that a warmer and more humid climate will greatly affect the ecosystems. This applies to the composition of species, how the various species influence each other and which particular species will dominate. The most significant changes will be due to a longer summer season when the temperature increases. This will generally provide plants with better growth conditions, and offer the opportunity for southern species to become established in more northerly areas, and that species that are already found in the area may grow at higher elevations than at present.

An earlier spring will give an early seasonal start to both plants and animals, and the growth season will also be extended. The overall effect of climate change is difficult to predict, as species are closely connected in an ecosystem. They compete for food or habitat, some species provide food for other species and they are affected by any rise in the numbers of parasites. These complex connections may lead to other consequences than those anticipated. In addition, to a certain degree, random circumstances will dictate which species migrate from the south and which local species die out; such changes can lead to unexpected developments in ecosystems.

Forests spread into new areas and animals follow

The most obvious change in northern Norway will be the increased distribution of coniferous forests. Coniferous forests will spread northwards and to higher elevations in the mountains during the next hundred years, as a consequence of increased temperatures. In the same way, birch forests are also expected to spread northwards and at higher elevations such that forested area in northern Norway will increase considerably. A temperature increase of 2°C can move the tree line up the mountainside by approximately 300 m. In Nordland and Troms, the zone between 300 m and 600 m above sea level represents almost 30% of the land area that is assumed may be covered by productive forest. In Finnmark, the potential for the expansion of forest areas is greater; 95% of the area is below 600 m and 42% is less than 300 m above sea level. In addition to climatic conditions, the distribution of birch forest is limited by reindeer grazing and insect larvae at certain elevations. Birch forest is limited at lower elevations by expanding coniferous forest. If birch forests are reduced and divided, stocks of lichen, fungus and insect species that are closely connected to birch forest may be reduced. Stocks of grouse may also suffer, which will affect hunting opportunities. A reduction in the area of mountainous regions and birch forest may have an effect upon species such as wolverines, reindeer, hares and lemmings. Animals and plants that inhabit coniferous forests will increase in numbers and reach larger numbers when the coniferous forests expand. In northern Norway, this applies to animals such as bears, moose, pine martens, squirrels, capercaillie and black grouse. Roe deer are found in very limited numbers and are probably limited by long winters and large amounts of snowfall in the forests; milder and shorter winters with less snowfall will give these and red deer more favourable conditions and increased stocks in northern Norway.

Snow protects vegetation against weather, wind and grazing. Both the depth of the snow and its structure is important to many species. Blueberries, for example, depend on a protective layer of snow, and too little snow in the winter can cause great damage to blueberry plants. Small animals that live under the snow are protected against predators. Reindeer and other animals that are dependent on plants found under the snow may experience that their food is difficult to reach when there is a great deal of snow. Warm periods with melting and rain in the winter season followed by cold periods can form ice on the ground. Milder winters increase the risk of icing on bare ground, which causes plants to perish, thus leading to less food being available to herbivores.

Infestation by larvae in forests in northern Norway

The two species, the winter moth and autumnal moth have both increased in distribution significantly during the last hundred years due to increased winter temperatures. These moths can cause enormous damage to forests when their larvae defoliate the birch forest several years in a row. The winter moth has had a noticeable increase in the north and east, whilst the autumnal moth has spread into the coldest inland areas in northern Norway. This means that we can now experience moth outbreaks that have a significant effect on the birch forest throughout the whole of northern Norway. Both of these moth species spend the winter as eggs, and the eggs have a higher mortality rate at low temperatures. During the last 15 years, the number of incidences of extremely low winter temperatures has been reduced, which would appear to be the main reason for the moths' increased distribution.

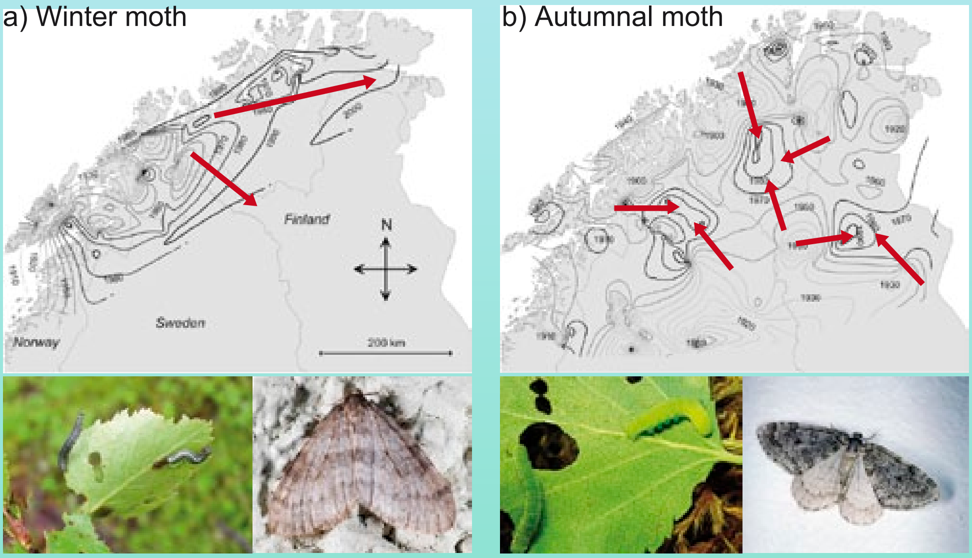


Figure: 21 a) Winter moth and b) autumnal moth can cause considerable damage to birch forests, due to defoliation caused by larvae. The contour lines indicate the year for the first reported outbreak, whilst the red arrows indicate the direction of the increase in distribution. Source: Adapted from Jepsen et al. 2008. Image of larvae from www.birchmoth.com. Image of adult moths: Arne C. Nilssen

Many insects and other invertebrates will be significantly affected by increased spring and summer temperatures, as they then develop more quickly from the egg to adult stage at higher temperatures. This may lead to a greater incidence of insect species that can reproduce several times within the season than they do at this present time. An earlier spring has also been shown to cause many species of birds to move earlier to breeding grounds. It is important for most bird species that the breeding season coincides with periods of ready access to food in order to ensure adequate food for their young. The numbers of insects is especially important to many species. Migrating bird species that have managed to adjust the breeding season according to seasons with good access to food have thrived well in the last 50 years, whilst those who have not been affected equally badly.

The effect on predator stocks will probably occur indirectly via climate effects on the stocks of their prey. In addition, forest-dwelling species, for example lynx, may increase in distribution and in numbers. The anticipated absence of 'lemming years' will be of major importance to the mountain ecosystem in northern Norway as we know it, in that many species such as Arctic foxes, snowy owls, weasels and long-tailed skua have a diet largely based on lemmings and other small rodents.

‘Lemming years’ may be thing of the past

Lemming (Lemmus lemmus). *Image: © Pål Hermansen, Samfoto*

Small rodents in northern areas are known for their relatively predictable fluctuations in stocks and their major importance in the ecosystems. Since the beginning of the 1990s, it appears that these variations in small rodent stocks have ceased in northern Norway, since there have been no 'lemming years' observed since the end of the 1980s. Poor snow conditions due to mild winters may be the main reason that ‘lemming years’ have ceased to occur both in southern and northern Norway.

The enormous density of small rodents that can be experienced in peak years, so-called mouse and lemming years, can both have a significant effect on vegetation and represent a major food source for medium-sized predators. If lemming years continue to be absent this will be of significant importance to the mountain ecosystem in northern Norway as we know it today. Many predators, such as Arctic foxes, snowy owls, weasels and long-tailed skua have a specialised diet of small rodents and this may lead to reduced stocks. There is reason to believe that snowy owls and Arctic foxes on the mainland may disappear completely without comprehensive, ongoing preservation initiatives.

Bare mountainous areas are shrinking

The mountain ecosystems that are not covered by forest are also expected to be reduced due to the forest spreading northwards and to higher elevations. This will lead to limited areas for the species that live in the mountains. In addition, these ecosystems are already significantly affected by climate change, via reduced stocks of small rodents, which in turn leads to reduced stocks of the predators that have these as their main food source. Further development towards milder winters provides little hope that, for example, the stocks of snowy owls and Arctic foxes will be able to be saved without comprehensive and continual preservation initiatives. Reindeer will also experience the negative effects of reduced bare mountainous areas and birch forest areas, and milder winters may make winter grazing more difficult due to icing. During the summer, an increase in temperature may mean that food becomes more easily available; however, there will be greater problems with parasites and mosquitoes. There is no reason to believe that reindeer herding will cease to exist due to these circumstances, but it is likely that some of the area that is currently used will become unsuitable for reindeer husbandry. Scrub is important for a number of species in mountain areas, both as a food source and as protective habitat. This applies to grouse, hares, passerine birds and many species of insects. In total, throughout the Arctic, the distribution of scrub has increased with higher temperatures; however, for northern Norway the opposite appears to be the case. The reasons are not clear, but it may be due to overgrazing from the increased reindeer stocks in the area. In such case, these reindeer stocks may be contributing to a reduction in the stocks of grouse and hares.

Isolated ecosystems in Svalbard and on Jan Mayen

Svalbard is an isolated archipelago covered by large mountainous areas, divided by fjords, valleys and glaciers. Over half of the area on the islands is designated as a national park and nature reserve. All areas in the archipelago are characterised by an Arctic climate, permafrost and little vegetation.

New species must first be able to spread to the islands in order to become established. Plants, microorganisms, invertebrates and birds, in general, will be able to spread and become established on remote islands if climatic conditions allow. Land mammals, however, have greater problems in travelling across larger ocean areas. This protects the existing land mammals in Svalbard against increased competition from invasive southern species. The Arctic fox in particular may gain an advantage in this respect, as in Svalbard it will not be in competition with invading red foxes, such is the case with populations in continental areas. Conversely, if future climate change leads to the disappearance of land mammals, there is little reason to believe that new corresponding species will take over. Their important function in the ecosystems can therefore disappear, with the result that the ecosystems become changed completely. If the prey of the Arctic fox is affected, this may also affect the Arctic fox itself. In particular, the development of populations of the most important prey during the winter will be decisive; seal, reindeer and ptarmigan. Currently, we have insufficient knowledge about Svalbard ptarmigan in order to draw definite conclusions about how the species will react to climate change. Svalbard reindeer may be favoured, in that plant growth will increase and summers will be longer; on the other hand, however, this may lead to problems as winters will be milder with increased rainfall. Higher summer temperatures will lead to an increase in the numbers of mosquitoes and other parasitic pests. New species of parasites may also become established, causing problems for reindeer. The growth in stocks during the last 10 years indicates that the positive effect of better access to food during the summer may have been greater than the negative effects of increased icing in the winter; however, we do not know how this will develop further. The development of populations must be studied over a longer period in order to draw any definite conclusions.

With increased summer temperatures and an extended growth season, plants will flourish, which will reduce the current dominance of mosses. We may also see that some more southerly plant species will be able to become established on the islands; however, there is no reason to believe that climate change will lead to the establishment of trees and scrub in Svalbard during the next 50 years.

Jan Mayen is an isolated island, and can principally be characterised as untouched wilderness. The climate is relatively mild in the winter; it is cold with a great deal of fog during the summer. Our knowledge of Jan Mayen is limited, but it is likely that plants that thrive in warmer conditions, also fungi, lichens and invertebrates will increase in extent on the island in a warmer climate.

Parasites – the winners in a new climate?

A parasite is an organism that lives on or in another organism, both plants and animals, and causes harm to the host. As in the case of many other types of organisms, climate may also affect the distribution and numbers of parasites. Many parasites will develop more quickly, and host-seeking species may be more active in warmer conditions. Many parasites spend some of their life living in bloodsucking insects such as mosquitoes, midges or ticks, and are spread via these. The interim hosts are also more active at higher temperatures than low. These types of conditions mean that several of the parasites that live on and in reindeer will thrive at higher temperatures. Most parasites are dependent on a specific species, and naturally they spread much more easily when there are greater numbers of the host species. When climatic changes lead to the establishment of new species or increased numbers in an area, this also often leads to new parasites becoming established in the area, and in turn the level of infection increases. Climatic conditions may also weaken the immunity of hosts against parasitic infection. One example of this is Brunchorstia disease in Scots pine trees. It normally infests trees only when the trees have been damaged during the winter.

Ticks – small bloodsuckers, about to invade northern Norway?

Ticks are small bloodsucking parasitic mites that in recent years have been observed several times in northern Norway, as far north as Finnmark. We do not know whether the apparent increased numbers of ticks means that the species has become established or whether these are ticks that have been brought to the region by birds or by other means. A humid and mild coastal climate appears to make it easier for ticks to become established, and they may be able to expand their habitat as the climate changes. Red deer and roe deer are the ultimate host for ticks in southern Norway. In northern Norway it is a mystery as to which species is the ultimate host, as red deer and roe deer are relatively sparse. Reindeer and moose do not appear to be effective hosts for ticks. Ticks may be carriers of serious diseases; in recent years an increasing number of cases of the tick-borne bacterial illness Lyme disease have occurred. The number of registered tick bites in northern Norway has also increased.

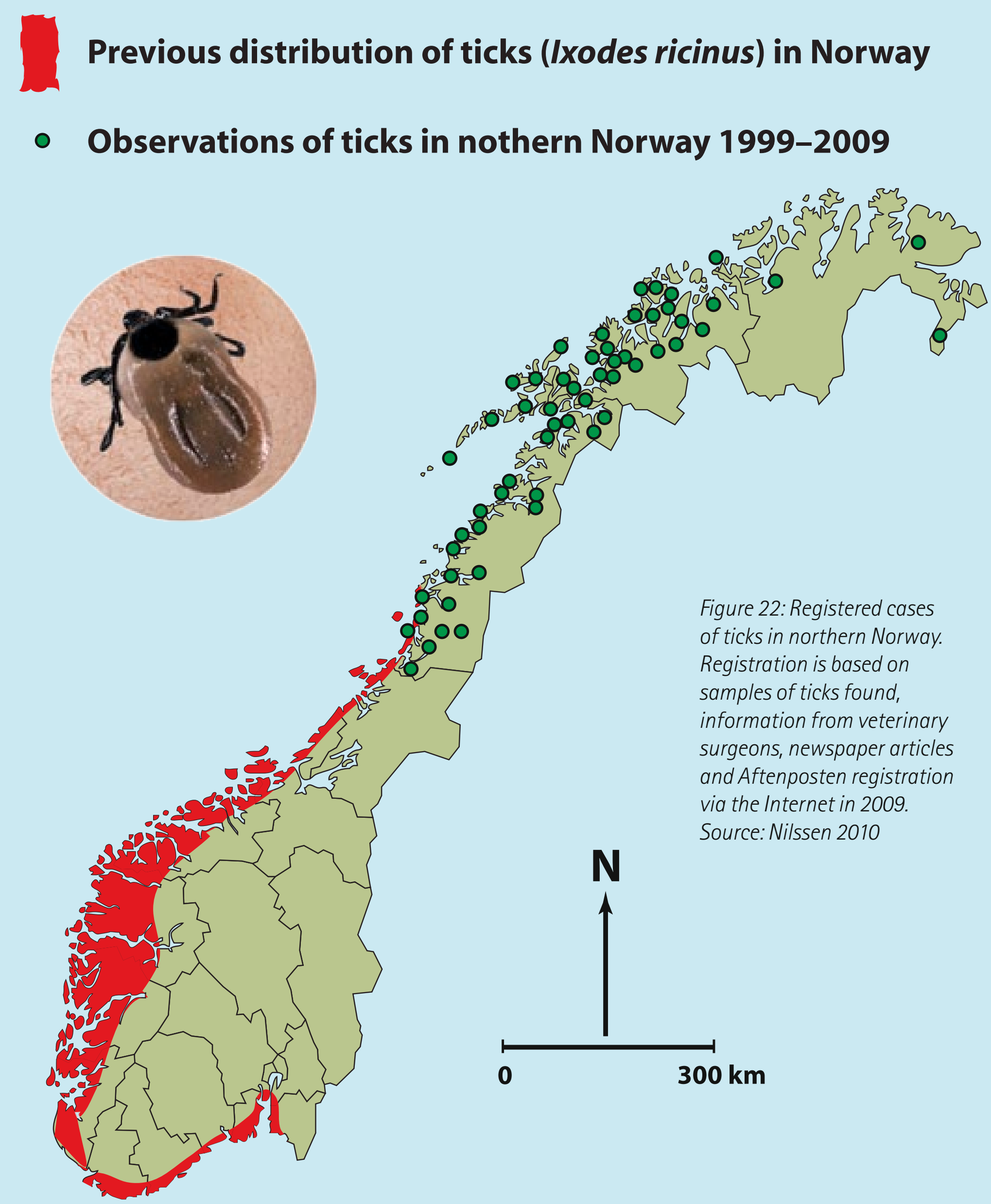
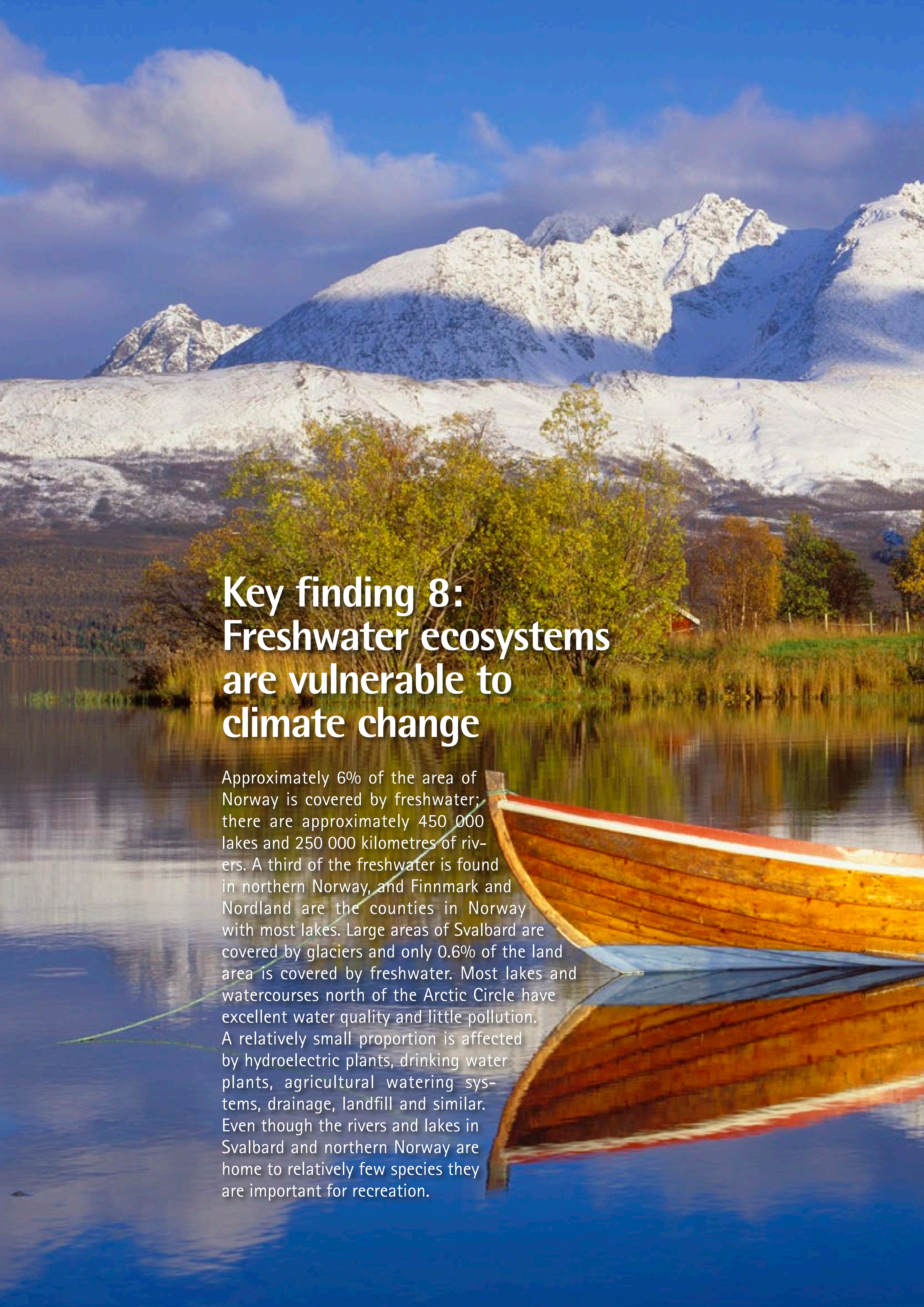


Figure 22: Registered cases of ticks in northern Norway. Registration is based on samples of ticks found, information from veterinary surgeons, newspaper articles and Aftenposten registration via the Internet in 2009. Source: Nilssen 2010

Midnight sun at Skjellesvikskaret in Ballangen, Nordland. Image: © Bård Løken, Samfoto



Key finding 8: Freshwater ecosystems are vulnerable to climate change

Approximately 6% of the area of Norway is covered by freshwater; there are approximately 450 000 lakes and 250 000 kilometres of rivers. A third of the freshwater is found in northern Norway, and Finnmark and Nordland are the counties in Norway with most lakes. Large areas of Svalbard are covered by glaciers and only 0.6% of the land area is covered by freshwater. Most lakes and watercourses north of the Arctic Circle have excellent water quality and little pollution. A relatively small proportion is affected by hydroelectric plants, drinking water plants, agricultural watering systems, drainage, landfill and similar. Even though the rivers and lakes in Svalbard and northern Norway are home to relatively few species they are important for recreation.

The lake Jægervatnet in Lyngen, Troms. Image: © Bård Løken, Samfoto

Image: © Øystein Overrein

Freshwater life is controlled by environmental conditions

Freshwater ecosystems are sensitive to climate change. The amount of nutrients forms the basis of the production of algae and other plants. The plant material forms the food basis for benthic organisms and invertebrates that in turn are food for fish. Increased water temperatures may lead to an increased growth of algae and this may affect all other parts of the ecosystem. The nutritional conditions in lakes in northern Norway and in Svalbard and therefore the growth of organisms that live in these areas vary in accordance with the climatic conditions. In addition to the fact that the amount of nutrients determines the degree of algae growth in water, temperature and snowfall also affect the ecosystems. Some lakes actually receive substantial amounts of nutrients from the ocean, such as the lake Ellasjøen on Bjørnøya. Thousands of little auk nest on the bird cliffs close to the sea, and kittiwakes use the lake for bathing. The seabirds feed on fish and crustaceans from the sea, and deposit considerable amounts of organic material in the form of guano (bird droppings) in Ellasjøen. Ellasjøen is therefore particularly rich in nutrients; however, there are also other lakes in the Norwegian Arctic that have a high nutrient production due to seabirds in the immediate area.

In general, there are relatively few species in the freshwater systems in northern Norway and Svalbard. This is due to the limited dispersion opportunities after the last Ice Age, the species' particular environmental requirements and the special environmental conditions. On the west and north-west coast of Svalbard there are several watercourses containing Arctic char, which is the only freshwater fish found in Svalbard. In some of these watercourses, the Arctic char migrates to the ocean to find food in the summer, if the rivers are open. Changes in climate may affect the living conditions of fish and animals in the lakes, and the migration of the Arctic char.

Ice conditions in winter

Environmental conditions such as temperature, precipitation and solar radiation vary considerably from area to area in the Norwegian Arctic. Most lakes in Svalbard and on Bjørnøya are

Arctic char (Salvelinus alpinus) *in a glass-clear river in inland Troms. Image: © Henrik Strømstad, Samfoto*

ice-free for approximately two months per year, and the water temperature can rise to 6–7°C in late summer. In several other lakes on Nordaustlandet in Svalbard the ice does not thaw every year, and the water temperature during the summer is most often between 0–4°C. The supply of nutrients is extremely low in these lakes. Lakes close to the coast in northern Nordland and southern Troms, however, may be ice-free for six months from the middle of May until November and the surface temperature may be as high as 20°C in late summer. Lakes in northern Troms and Finnmark, and those at higher mountain elevations, have approximately the same characteristics as typical Svalbard lakes, with the exception of one aspect: there is more precipitation on the mainland than in Svalbard, something that has significant influence on nutrient conditions and ice conditions of the lakes. The lake ice in Svalbard is normally thick, clear and transparent due to limited precipitation and low temperatures during freezing. In areas with more precipitation, snow layers are frozen into the ice which makes it opaque and impenetrable to sunlight. This is important for growth of organisms in the lakes, as the production of phytoplankton is dependent on sunlight for photosynthesis.

Increased temperatures and more precipitation

During the next hundred years, it is expected that both the temperature and amount of precipitation will increase in the Norwegian Arctic, which will affect the water temperature in lakes and rivers, the permafrost in the ground surrounding the lakes, the ice thickness through the winter, the composition of the ice (snow and ice layers), how long the ice remains, nutrient inflow from land and the possible effects of glaciers and floods. The length of the summer season and the water temperature in this period appear to be the most important factors. The lakes along the coast of northern Norway are expected to have a longer ice-free period and higher water temperature during the summer. However, in regard to lakes furthest east in Finnmark, some lakes in Svalbard and lakes in high mountain areas in northern Norway, it is expected that the increased precipitation will fall as snow, which may actually lead to a longer period of ice cover.

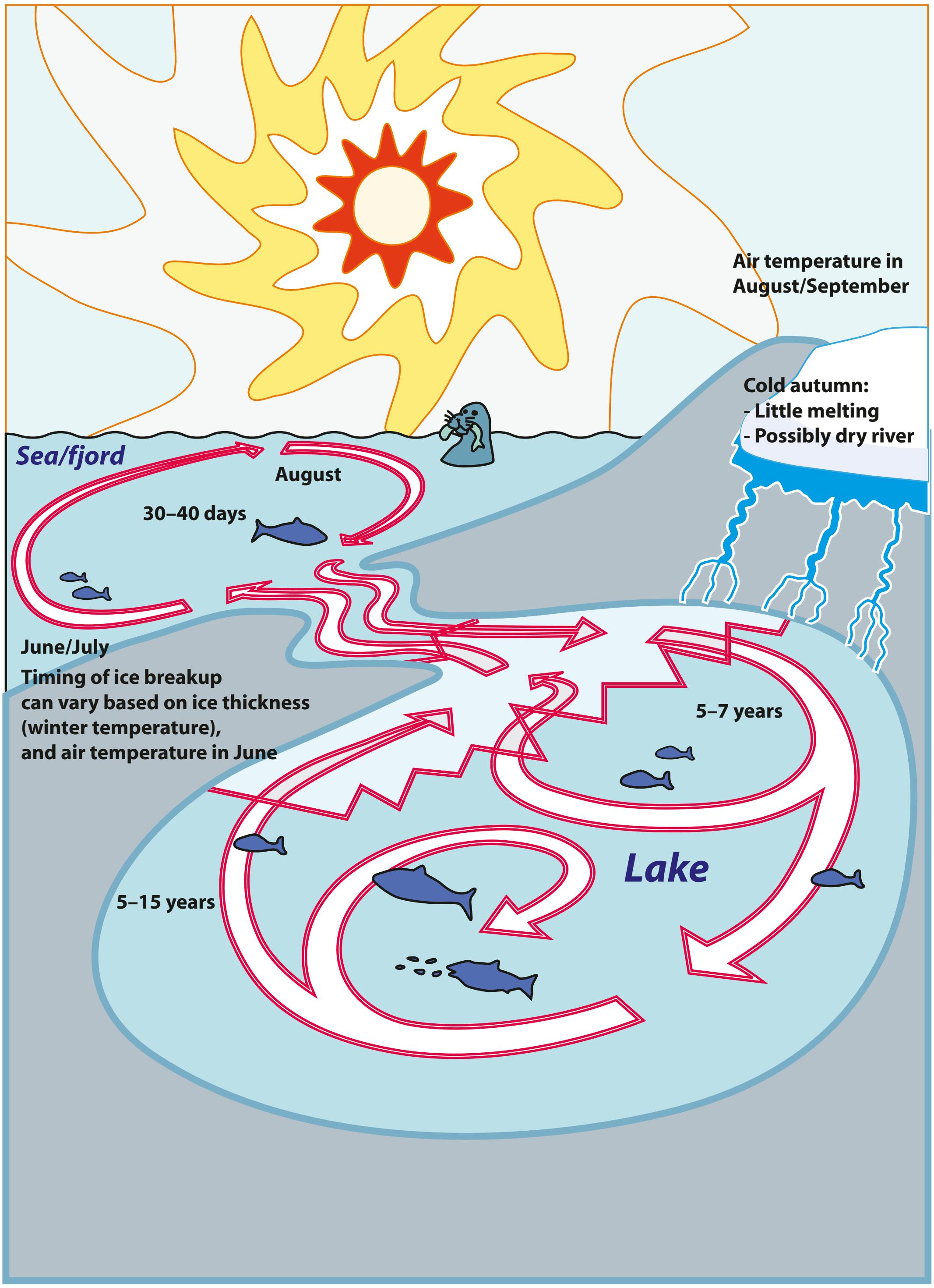


Figure 23: Arctic char spawn in freshwater lakes in the autumn and the fry hatch the following spring. When the Arctic char are 6 to 7 years old and 15–20 cm, some of the fish migrate to the sea in order to find food during the summer, i.e. they become saltwater char. After 5 to 6 weeks they return to the lake for the winter. The following summer, this migration is repeated and after a few years of migration the seawater char have become large, ready to spawn and of excellent quality. Due to the favourable food conditions in the sea, the seawater char may double their body weight during a brief period in the sea. Tributary rivers in the lakes in Svalbard are either frozen or dry for approximately 10 months of the year and therefore function as transport routes for the seawater char for just two months each year. The fish migrate into the sea as soon as the ice on the lakes melts, and after a brief, hectic period they will migrate back to freshwater before the rivers freeze (or dry up) again. The period that the rivers are open will depend on the thickness of the ice, snowfall and the air temperature. In the autumn, small changes in the air temperature will directly affect the period during which glaciers supply melt water and thereby migration opportunities for char. In some years, the rivers dry up or freeze so early that large amounts of seawater char perish during that time they are in the sea. Future climate change, with higher air temperatures and increased precipitation, may change the migration patterns of seawater char. Source: Loeng el al. 2010

Most larger rivers in northern Norway will probably freeze later in the year, become ice-free earlier in the spring and experience higher flood levels due to increased precipitation. In Svalbard, the conditions in rivers are somewhat different. The rivers are open for only a couple of months per year due to permafrost and a limited amount of precipitation. In general, the estimated climate change, with increased precipitation and higher temperatures during the summer, will lead to higher water levels in rivers and improved migration conditions for Arctic char. The most critical issue in the long-term, however, is whether glaciers will retreat to such an extent that melting during the autumn ceases and the rivers dry up before the Arctic char have migrated back into freshwater. The presumed greater snowfall in the winter may lead to a delayed spring thaw, such that the period that Arctic char are able to migrate out into the fjord in order to feed, does not coincide with the availability of prey.

For lakes in Svalbard and in the mountains in northern Norway, increased precipitation in the form of snow may lead to reduced primary production, later ice drift, lower water temperature and delayed thawing of ice in rivers. This is due to the fact that the ice becomes thicker, as snow layers freeze in the ice. White, opaque ice also reflects sunlight to a greater degree, and so it melts later than clear, transparent ice. In low-lying coastal watercourses along the coast of northern Norway, precipitation and higher temperatures are likely to lead to longer ice-free periods and higher summer water temperatures. This may increase mortality rates among salmon fry, as they lose the protection offered by the ice against predators and they invest more energy at high water temperatures than low. The fat reserves stored by salmon fry during the summer are decisive for their survival in the winter. If the water is warmer during the winter, these fat reserves are consumed more quickly. High water temperatures in the summer months may also lead to increased growth in salmon, which may increase stocks.

A large proportion of existing lakes in the Arctic are shallow ponds. If the permafrost thaws, this may lead to the disappearance of these ponds, as the water will be absorbed into the ground. This process has already been observed in Siberia and Alaska.

With increasing ocean temperatures, such as we have seen in ocean areas off the coast of Svalbard in recent years, species attracted to warmer conditions will move northwards. The stickleback is a species that can live in both saltwater and freshwater, and in recent years sticklebacks have been found in two lakes in the Isfjord area in Svalbard. It is still uncertain as to whether the stickleback will be able to become established on the islands; higher ocean temperatures will increase the likelihood that new species are able to migrate upwards along the water courses.

In summary, we can say that changes in climate are likely to have significant and wide-ranging effects on several aspects of the ecosystems in freshwater in northern Norway and Svalbard. Increases in temperature and precipitation will affect ecosystems in a complex way causing both short-term and long-term effects. Up to this point, the freshwater systems in the Arctic, in general, have been mapped and explored to a rather limited degree, and therefore it will represent a major challenge to concretise the collective effects of climate change.

Key finding 9: The infrastructure in the north is vulnerable

'Infrastructure' refers to facilities of a permanent character that are essential in society, for example, buildings, railways, roads, airports, harbours, power stations, power lines, water supplies and sewage systems. Climate change may influence significant areas of society's infrastructure, both in respect of design, localisation and selection of materials. Different types of infrastructure are affected in different ways by climate change. For example, some buildings and installations will be affected by increases in precipitation, whilst other buildings will be more affected by more frequent extreme winter storms. In many cases it is a combination of different climate conditions, for example simultaneous changes in precipitation and wind direction that have the greatest consequences. Effective contingency plans in all areas are dependent on a sound infrastructure. A critical review of road systems and power supplies is necessary, especially in regard to the increased frequency of extreme weather. For the road and transport sector in northerly areas, adaptation to new climatic conditions will present certain technical challenges. A less vulnerable infrastructure may require new solutions and new materials; for example road construction materials that are less susceptible to the anticipated temperature and water conditions. These challenges also offer potential for the development of 'cold-climate-technology' and special technical solutions to some of the climate challenges. Climate change will also lead to one challenge for the transport sector in particular: the need for increased investment in the maintenance and operation of roads, railways, seaports and airport installations. It will be necessary to make the infrastructure more robust in respect of climate change and to improve contingency measures for undesirable incidents.

The LNG carrier Arctic Discoverer awaits a cargo of gas just outside of Melkøya in Hammerfest. Image: © Bård Løken, Samfoto

The sea level may represent a challenge along the shoreline

Compared to other parts of the world, northern Norway and Svalbard will not experience any dramatic effects from a rise in sea level, as the land is still rising after the previous Ice Age and the coast is relatively steep. Areas such as Bangladesh, with low-lying delta areas, will lose far larger land areas than Norway. A rise in sea level will lead to dramatic consequences for the population of these regions. Data collected from tidal measurements indicate a global sea level rise of 1–2 millimetres per year throughout the 1990s, and reconstructions show that the sea began to rise as early as the 1800s, and at a steadily faster rate. After 1992, satellite observations have been used in order to monitor the global sea level; these measurements show an increase of slightly more than 3 mm per year in the period from 1993 to 2008. The rise in sea level in the 1900s is largely explained by the fact that the surface water has expanded due to warming, and that the ice on Greenland and in the Antarctic as well as several smaller glaciers are melting. Recent studies show that a shift has occurred in which the melting of ice on land is the dominant factor controlling the rise in sea level, and to a lesser degree the expansion of water via temperature increases.

What causes land uplift?

At the end of the previous Ice Age, parts of northern Europe and North America were covered by a layer of ice that was up to 3 km thick. Due to the weight of the ice layer, the Earth's crust was pushed down into the Earth's mantle, which is a viscous layer of partially melted rock mass under the Earth's crust. When the ice melted, the land began to rise again. The Earth's mantle is so viscous in the outer layers that this process takes thousands of years. Land uplift was greatest immediately after the ice melted and it is still occurring – it is estimated that land uplift will continue for approximately another 10 000 years.

Beerenberg on Jan Mayen. Image: © Johan Hustadnes, Norwegian Polar Institute

Local and regional calculations of the sea level will be required, since the oceans are not expected to rise equally all over the globe. Studies indicate that Norway can expect an approximately 10 cm greater rise in sea level than the global average within the year 2100. Internally within the region, smaller variations are anticipated. This is due to the fact that differing future levels of climate gas emissions are used as a basis and that the calculation of melting of, for example, the ice cap on Greenland varies somewhat in different studies – such that there is some uncertainty regarding the scope of the rise in sea levels; however there is broad agreement that sea levels will rise.

Estimates of sea levels are difficult to carry out, and in the Arctic it is especially demanding, as monitoring satellites cannot perform precise measurements at higher latitudes. In predicting sea level development, we must apply global emissions calculations as a basis, as these contribute to controlling climate development. Ongoing land uplift after the last Ice Age varies in northern Norway and in Svalbard, and the ocean's local heat absorption also varies. All of these factors lead to uncertainty in predicting sea levels. IPCC calculated a global increase in sea levels of 10–90 cm during the current century. In addition, recent studies indicate that we can expect greater global sea level increases, as the rise in temperature and melting of glaciers appears to be occurring more rapidly than the IPCC concluded in 2007. In the report that was drawn up for NOU Climate Adaptation in 2009 (see fact chart under Key finding 11), the estimate was an approximate 40–95 cm rise in sea level in northern Norway for the period up to 2100, corrected for land uplift. This may lead to problems along the coast especially during storm surges.

More floods and avalanches affect roads and railways

Increased precipitation and higher temperatures are expected to lead to more frequent flooding in northern Norway. Substantial areas of today's major and minor roads have inadequate

New housing complex constructed on landfill just above sea level. Tomasjordnes in Tromsø. Image: © Torgrim Rath Olsen, Nordlys or poor drainage systems. There is also the issue of a considerable lag in maintenance programmes. Since we can expect more frequent flooding and a change in precipitation patterns leading to greater amounts of rain/snowfall in a short time, road standards will become even worse, and we must expect that roads will be closed more frequently than at present. More extreme weather will require greater investment in maintenance and operation of roads and railways. In addition, we can expect that there will be an increased number of roads closed in winter due to avalanches. In turn, this will affect goods transport and navigability in general. Bridges may be weakened if they are exposed to high water levels and stronger currents. More frequent avalanches and landslides all year round will also limit the navigability of roads. The two municipalities that are most vulnerable to avalanches, Moskenes and Flakstad, experience landslides on roads 2 to 3 times more frequently than other municipalities in northern Norway. There is a need for more detailed study of how this will affect road users and the overall effect that this will have on economy, security and mobility in the region.

In the same manner as for roads, we can expect that more frequent floods and landslides will limit navigability for trains on the Nordland rail line. As railways that cross mountainous areas are especially exposed to landslides, the Nordland rail line will be affected by climate change, and as a consequence there will be a need for more maintenance resources. Increased precipitation and higher temperatures, over time, will reduce the load-bearing capacity of the railway network. In addition, it is expected that more frequent freeze-thaw cycles will occur from North-Trøndelag and northwards. This may lead to increased frost weathering on mountains – which in turn will require closer monitoring of the quality of rock in tunnels, cuttings and along steep routes. The increased growth of vegetation may lead to a greater need for forest clearing along railway lines; however, this will depend on whether we experience increased grazing from animals and developments in forest agriculture.

Delayed flights

All airports in Norway are expected to be affected by climate change. The airports in northern Norway and along the coast are likely to be affected to a greater degree than those in inland areas and in the eastern part of Norway. Many airports are located on low-lying landfill or flat areas close to the sea; several of these are just a few metres above sea level. Therefore, at certain times these are vulnerable to the influence of the ocean – this is expected to increase with climate change. In addition, operations at airports will be affected by other aspects of climate change: more precipitation, changes in wind direction and wind force, more powerful storms, variations in temperature, intense low-pressure fronts, icing and fog.

New sailing routes and new challenges

Reduced amounts (or the absence) of sea ice may lead to increased shipping traffic through the Northern Sea Route, which is expected to be open for shipping for most of the year. Ships sailing to and from East Asia will be able to reduce voyages by up to 40% by sailing through the Northern Sea Route, and even more by sailing across the Arctic Ocean, which will lead to economic and time savings. Increased shipping traffic in the north will lead to greater emissions of harmful substances directly into the Arctic and an increased need for ocean surveys, oil contingency preparedness, other contingency planning and improved harbour facilities. It will also lead to challenges in respect of maritime legislation and liability issues in the event of accidents and emissions. Traffic is expected to increase off the coast of northern Norway, and this also applies to the transport of oil. Climate change may lead to significant changes in wind and wave activity in the Barents Sea, also more frequent and more violent storms. Overall, this will make eventual clean-up operations after accidents more difficult than at present, and create a need for a more robust oil contingency preparedness and other contingency plans. The ecosystems in these vulnerable areas are especially vulnerable if accidents should occur. Ships

Nordland rail line. Image: © Espen Bratlie, Samfoto

that are not constructed to withstand high waves will be unable to sail with the same regularity as at present, and passenger boats are perhaps the type of vessels that will be most affected by climate change. Breakwaters constructed according to current climate and weather standards may not be adequately engineered for future extreme weather.

Along with an increase in shipping traffic, there is the risk of introduction of new species, in among other things ballast water, and organisms and algae that grow on ships' hulls. Many marine organisms have development stages in which they float freely in the water mass, and may therefore be transported to new areas in ships' ballast tanks. Increased shipping traffic may thus lead to further strain on ecosystems and species that are vulnerable to climate change.

An increase in petroleum enterprises – new challenges?

Raised sea levels, more frequent storm surges and changes in wind direction may lead to harbours and other oil and gas installations becoming more exposed to waves. This will increase the need for changes to the constructions that are currently used, and in the long term it may lead to increased costs in connection with the extraction of oil and gas. Icing during the winter is also a major challenge when operating in Arctic regions. The ocean areas in the northern sector of the Barents Sea are currently covered in ice for parts of the year, and only the southerly part of the Barents Sea is open for petroleum enterprises. The main reason for this is the concentration of important and vulnerable biological resources associated with the polar front and the ice edge. If the sea ice disappears, this may lead to increased interest in opening this particular area to petroleum enterprises. This type of development will lead to major challenges associated with the regulation of enterprises, both in respect of emissions and emergency preparedness.

Effects on water and sewage systems

Municipal piping systems for water supplies and sewage will be affected by increased precipitation. Floods may cause underground pipes to become displaced, damaged or blocked by sediment. Floods may also cause damage to pumping stations and sewage filtration plants. If pumping stations cease to function, the result may be emissions of raw sewage into the environment and damage to property and goods.

Electrical power lines in mountain landscape, Nordland. Image: © Jørn Areklett Omre, Samfoto

Municipal water supplies are vulnerable to extreme precipitation, changes in temperature, precipitation and sea level. The effects involve the risk of reduced water hygiene, increased amounts of organic material in drinking water, incidence of algae and toxic substances and pollution caused by raised sea levels. Water sources may be affected, and piping systems may be exposed to the formation of algae layers and microorganisms in the pipes if water quality is reduced. Failures in water supplies can have extremely serious consequences for people and communities.

Buildings

Buildings are exposed to climate-related effects directly through weather, and both long-term climate change and sudden changes in weather can affect materials in buildings. In the same manner as for other types of infrastructure, changes in ground conditions, floods and landslides due to increased precipitation and higher temperatures will affect buildings. Storm surges may cause damage to buildings constructed at or near sea level. Actual vulnerability varies a great deal according to local conditions; in some towns, it has become normal practice to construct new housing on landfill areas along the shoreline, and there is a great deal of uncertainty associated with the effects of rise in sea level and the increased frequency of harsh weather on these buildings. Landslides, avalanches and rockslides that affect dwellings, are normally dramatic incidents in which both people may be harmed and buildings destroyed. Temperature fluctuations around freezing point combined with rain may cause porous construction materials to be exposed to frost damage, and a milder and more humid climate will mean that construction materials rot more easily. In Svalbard, where all infrastructure is constructed on permafrost, thawing permafrost may lead to challenges in the future.

Energy supply and power production

Hydroelectric power dominates Norway's electricity supplies, and both production and distribution of hydroelectric power may be affected by climate change. Firstly, climate change may lead to a change in the amount of precipitation throughout the year. The expected changes in precipitation in northern Norway may have consequences for surface run-off and the amount of water stored in reservoirs. It is expected that changes will have to be made to the design and engineering of installations, dams and power line networks. Increased precipitation may also lead to increased energy production in the region – on the premise that installations are upgraded in order to exploit this potential. A combination of ice and wind may represent a threat to power lines. Electricity supply systems are vulnerable to extreme weather, and power lines in outlying areas of northern Norway are more vulnerable than those in inland areas. Wind power generation will be affected somewhat less by climate change than hydroelectric power, as the overall picture is that the changes in normal wind conditions are expected to be relatively minor. However, extreme wind speed and the formation of ice on wind turbines may affect the technologies and materials that will need to be employed in the future, wherever windmills are located.

The most significant effect on the energy system in the north is expected not to come directly from climate change, but rather from global development trends that involve increased focus on energy economy, energy readjustment and the transfer from fossil fuels to renewable energy sources. The increased demand for renewable energy may form the basis for the export of energy and the need to expand power line networks in order to transport electricity from the region.

Havøygavlen windmill park in Havøysund, Finnmark. Image: © Bård Løken, Samfoto

The electricity supply failure in Steigen municipality in January 2007, which affected 1097 households, 134 commercial customers and 587 cabin owners and left them without electricity for almost six days, is an example of how older and/or poorly maintained electricity supply infrastructure can be vulnerable to extreme weather. Strong winds were the cause of direct damage to power lines and pylons, these were also indirectly damaged by falling trees, causing a breakage of power network cables. Image: © Nord-Salten Kraftlag

Farm in Kassfjorden near Harstad in Troms. Image: © Trym Ivar Bergsmo, Samfoto

Key finding 10: Nature-based enterprises will gain new opportunities – and face new challenges

Climate change in northern areas will affect the basis for nature-based industries, both at sea and on land. The effects may have different consequences for different industries, and in most areas we do not possess adequate knowledge of the potential consequences of a change in climate.

Agriculture may benefit

An important factor that influences plant growth is the length of the day, i.e. how much light plants receive per day. This is something that will not alter with climate change, such that vegetation and plants that are adapted to a northerly annual pattern will not necessarily be able to utilise a longer growth season, even though the climate changes and temperatures increase.

However, climate conditions may affect agriculture throughout the year. The climate during the autumn is important for plants; it enables them to become prepared for the winter and to survive the winter frost. Winter is decisive for whether plants survive from year to year, as frost depth, snow cover, bare ground frost and weather conditions during the spring thaw – in a worst case scenario – may mean that plants do not survive. The weather in the growth season may cause significant variations in crop yields, and affect the quality of the crops. Climate change mean that agriculture must replace some types of plant materials in favour of plants that utilise a longer growth season, milder and shorter winters and varying dry weather periods.

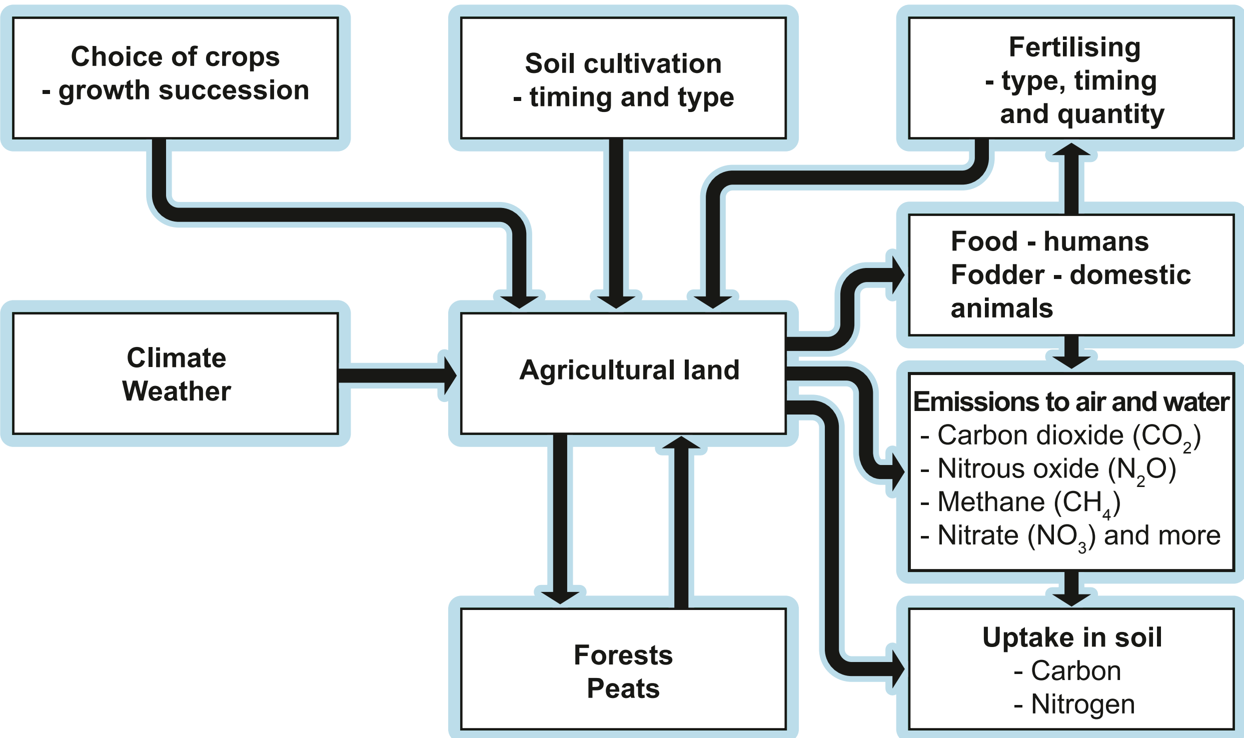


Figure 24: Connection between agriculture and climate change. Carbon and nitrogen is bound in the soil when dead vegetation is turned into humus. Carbon is released when humus is converted. Most of the methane comes from domestic animals (ruminants), 85% directly from the animals (expired air) and the rest from fertiliser. Nitrous oxide (NO_2) is largely the product of fertiliser use. A loss of nitrous oxide occurs when ammonia (in the soil) is converted to pure nitrogen gas. Source: Buanes et al. 2009

In parts of northern Norway, frost damage represents the main challenge in agriculture. With the anticipated changes in climate, problems with frequent winter damage may spread inland and northwards in the country, to areas where the winter climate has historically remained stable and cold. These areas can be expected to experience a more unstable winter climate with fluctuations between mild weather and cold periods.

It is possible to project both positive and negative effects for agriculture in northern Norway. The timing of snow melt in the spring can be of considerable importance to the survival of plants. In areas with a dry climate and cold, clear spring nights, early snow melt may cause plants to dry out and perish. In areas with a great deal of precipitation we may see outbreaks of fungus invasion, which will damage the plants if the snow lies on the ground for longer than normal. If climate change leads to earlier snow melt in these areas, this may counteract the effects of fungus invasion on crops. An early start to the growth season in the spring may extend the growth season in total and thus increase crop yields. If the climate changes such that two harvests are possible within one year, and new types of plants are developed that are adapted to the new climate, agriculture may actually become more profitable. It may also be possible to utilise new types and new species of plants, potatoes, vegetables and berries in the region. Domestic animals that graze in outlying fields, especially sheep, often follow young, nutrient-rich vegetation. If forests grow more quickly than at present, this may mean that the high-quality grazing season can be shorter in some areas. It is not possible to give precise and complete answers to the effects of climate change on agriculture in northern Norway, both because there are considerable local differences in climate and significant local differences in operative methods. The anticipated change will, however, lead to major challenges in regard to plants and vegetation and investments in operational initiatives and knowledge. New plants that are adjusted to the new conditions must be developed, and challenges such as increased strain from fungi and pests must be carefully considered. The special advantage of northern ecological plant production, which does not require synthetic pesticides, may also be lost due to increased temperatures and humidity. However, increased temperatures will largely lead to positive effects on agriculture in the north.

Effects on forestry

Throughout the whole of Europe, it is only in Scandinavia and North-West Russia that forests continue to dominate the landscape. Principally, it is expected that the positive effects of climate change will outweigh the negative: greater growth is expected as is greater carbon storage in forests and increased production of timber and bioenergy. However, there are certain issues that make the effects on forestry more complex. On the one hand, estimates indicate that productive forest in Norway is expected to increase considerably as a consequence of climate change, with both more rapid growth in forests and larger forest areas. On the other hand, an increase in winter temperatures may lead to more frequent freeze-thaw cycles, which will cause greater frost damage to forests. This is due to the fact that warm periods in winter reduce the resistance of trees and their tolerance for frost – this will particularly affect inland areas in northern Norway. Incidences of disease and pest invasion are expected to become a greater problem in forestry in the future, due to new pests that can move rapidly northwards if the climate changes. Increased temperatures will mean that insects will be able to reproduce in two generations in one year, compared to one at present. This is possible, for example, for the European spruce bark beetle, which can cause severe damage to spruce trees with an extra invasion in late summer. Fungal invasions are expected to increase in a more humid and warmer climate. Despite the fact that in total, greater growth is expected in forests, forestry itself may be affected by climate change, as less stable soil and more precipitation in winter may make it more difficult to fell and transport timber. The use of vehicles in humid areas may lead to ground damage, and forest roads and public highways might be affected.

Image: © Trym Ivar Bergsmo, Samfoto

Reindeer husbandry – both positive and negative effects

Reindeer husbandry is more than an industry; it is also an important element in Sámi culture and history. The reindeer industry is particularly dependent on natural conditions, as it is based upon reindeer grazing in natural areas all year round. Climate change will affect grazing conditions and the accessibility of terrain during all seasons, and may lead to increased conflict in respect of area usage. In the various geographical areas in which reindeer husbandry is carried out, we may see various challenges and changes. We can expect to see both positive and negative climate effects on reindeer husbandry. For example, increased plant growth due to an increase in temperature may lead to better availability of food during summer grazing, and an early spring can benefit the industry in the form of an extended grazing season. Less snowfall in winter may facilitate easier access to food during winter grazing. Negative effects may be, for example, icing on the ground in winter, thus making food inaccessible. An unstable early winter, during which rivers and lakes do not freeze properly, will make it more difficult to move reindeer to winter grazing areas. Increased incidences of disease, insects and parasitic pests may occur due to higher temperatures and increased humidity. In total, there is a great deal of evidence to indicate that the overall effect on reindeer husbandry will be negative, especially in the long-term.

The possibilities of adapting to changed conditions vary considerably. In Finnmark, reindeer flocks graze in close proximity and there are few alternative grazing areas. Even if climate change leads to better growth and more vegetation, the size of flocks and density of reindeer will continue to limit opportunities to adapt. In other reindeer grazing areas in Troms and Nordland, alternative areas can be used as needed. The disadvantage here is that this may come into conflict with other user groups, such as owners and builders of recreational cabins, agriculture and forestry. An alternative form of adaptation may be to utilise grazing areas across land borders between Norway, Sweden and Finland, or to change the flock structure with regard to age and gender composition. The provision of extra feed for reindeer when food is unavailable due to ice on the ground is also possible. Physical area intervention and intrusions have previously been named as individual factors that will represent the greatest challenges to reindeer husbandry in the future. Climate change comes in addition to other problems and challenges facing the reindeer herding industry. The reindeer industry must adapt to these changes in the future; however, adequate adaptation opportunities are unclear.

Special considerations for Sámi as indigenous people

Internationally, the debate on climate adaptation in northern areas places decisive emphasis on the involvement of indigenous peoples. Through its acknowledgement of Sámi status as indigenous people with a distinctive character and special need for protection, Norway has a legal obligation to give special attention to Sámi enterprises and industry. Norway has ratified the ILO-Convention No. 169, which determines that "...handicrafts, community and locally-based enterprises, natural economy and traditional enterprises for relevant groups, such as hunting, fishing, trapping and gathering shall be recognised as important factors in maintaining their culture, economic self-support and development. When this is relevant, governments shall ensure that such enterprises are supported and promoted, with the participation of the people". As most activities and enterprises explicitly stated in the convention are associated with nature, it appears to be clear that climate change that will lead to especially negative consequences for Sámi activities mentioned here, must be given special attention. One particular important aspect is to also include the knowledge of natural conditions that Sámi people have developed, and to use this in the process of climate adaptation. At this current time, various projects have been implemented in which scientific knowledge and the traditional knowledge of indigenous peoples are being brought together in order to gain a better understanding of the correlation between nature and climate. The results from these projects indicate that this type of cooperation has considerable value, as this research focus is relevant for the Sámi population and because this type of connection provides a deeper and broader understanding of the cohesion between humans and nature. It will therefore be vital to continue to bring together these two types of knowledge in the future process of understanding climate change and its effects.

Greater conflict in fisheries?

Fisheries have a broad social significance, as a workplace for the population living along the coast, both in economic terms and as a bearer of coastal culture. As boats, fishermen, landing stages and production plants are irregularly distributed geographically, climate effects on the industry as a whole will be different in different areas.

For fisheries, the task of adapting to variations in the resource basis is part of the experience-based knowledge possessed by fishermen. On a general level, one can say that fisheries management will be important in order to safeguard commercial fish stocks, so that these are sufficiently robust when climate change is to be faced. This does not necessarily allow for a continuance of current management regimes, so it is possible that management tools in the fisheries sector must be amended and updated in order to handle the situation of a climate undergoing change. There are major deficiencies in respect of knowledge of climate change and how these will affect fisheries, thus it is important to give priority to research in this area so that we will be properly prepared to meet tomorrow's challenges.

Increased temperatures in the ocean are expected to lead to expanded or new habitats for several fish species, including commercially important species such as cod and herring. For example, we may find that larger stocks of cod are found in the so-called 'Loophole' in the Barents Sea, an area which lies outside of national jurisdiction, where it is therefore more difficult to regulate fisheries. Agreements between Norway, Russia and other countries in this area may be placed under considerable strain if larger stocks of cod are found there. Another consequence

Fishing boats in Lofoten. Image: © Tor Ivan Karlsen, arcticphoto.net

of changes in geographical distribution is that the stocks that are currently divided between Norway and Russia will, to a greater degree be found in the Russian zone. This type of development may also affect Norway's relationship with the European Union, as the fishing agreements between Norway and the EU, Iceland, Greenland and the Faroe Islands are based on the premise that these countries are granted access to fishing in the north. In total, fisheries may experience improved conditions. However, individual fishermen and fishing communities may experience the opposite, as climate conditions may lead to changes in the type of vessels that have the opportunity to catch fish in the new areas.

The specific significance of fisheries in regard to employment, economy and value creation varies among local communities. The geographical distribution of boats, fishermen, landing stages and production plants means that climate effects on fisheries will lead to different consequences in different areas. Over time, this distribution will be influenced by general developments within the industry, that in the short term will be characterised by economic issues, enterprise dynamics and fisheries policies, rather than by climate change. Fisheries policies and fisheries management may become more difficult due to climate change. Again, this indicates that it is important to consider climate change and its social consequences in a broader social, political and economic context.

Aquaculture in northern Norway may flourish

The aquaculture industry is important for northern Norway and a number of local communities within the region. Salmon farming is an important rural industry, despite the fact that direct employment is somewhat limited. Warmer water in the ocean will, up to a certain point, lead to more rapid growth in farmed fish. This temperature point may be exceeded in southern Norway, whilst in northern Norway increased production is anticipated due to higher water temperature.

Fish farm in Brønnøy municipality, Nordland. Image: © Erlend Haarberg, Samfoto

Reducing the number of, or closing down fish farms in areas that experience less favourable natural conditions and establishing new ones in the areas that gain better conditions, may be an expression of adaptation in the industry. We may also see other strategies such as breeding programmes, genetic engineering and/or the development of new enclosure technology. This type of development naturally depends on the general regulation of food production and biotechnology. In any case, the overall picture in relation to fish farming is far from being as simple as may be believed. An increase in water temperature may also lead to increased vulnerability to disease and infestation by parasites. Cod farming, for example, may become impossible along large areas of the Norwegian coast due to pathogenic bacteria that are currently only found south of Stadt. The biological effects on the aquaculture industry must be seen in context with other relevant conditions for the industry, not least issues in respect of infrastructure. This also applies to the fisheries sector in general - for example, fisheries harbours are often in areas in which weather and wind can lead to problems. A rise in sea level, increased wave force and more extreme weather may lead to increased costs for the fisheries and aquaculture sector due to damage to the infrastructure.

Travel and tourism – experiences in changed conditions?

The tourism industry can be affected by climate change in several ways: Changes in the weather may influence tourists' choice of holiday destination; however, more long-term consequences can also be expected. Changes in the types of vegetation may affect the attraction of certain areas – both positively and negatively – and nature experiences are the greatest attraction in large sectors of the tourism industry in Norway. The relationship between the tourism industry and climate change has only been investigated to a limited degree, and we do not know enough about what role climate and weather conditions play when tourists select their holiday destinations. The anticipated reduction in snow cover in the region may negatively affect ski tourism, and it is by no means certain that a reduction in winter tourism will be compensated by an increased number of summer visitors. Winter destinations that are located in boundary areas for guaranteed snow cover and that are difficult to access by public transport are twice as vulnerable in respect of climate: not only do they risk the effect of a shorter snow season; they also risk negative effects due to climate policy initiatives such as increased taxes on air and road transport.

Tourism in Svalbard may increase, due to the fact that, among other things, there will be less ice in the fjords on the north and eastern side of the islands. In itself, this offers easier access; however, this will depend on how the industry is regulated. Increased numbers of cruise ships and passengers and more opportunities to disembark on land may lead to increased emissions that will affect the climate and environment, lead to increased wear and tear on nature and the destruction of cultural heritage sites, and lead to an increased risk of accidents that may have significant consequences both for the environment and for human life. For the tourism industry, it is a challenge to allow for – and to exploit – changes in climate conditions in their operations. Nature and the cultural landscape are important resources for the Norwegian tourism industry, and this requires that nature and cultural heritage is safeguarded in a proper manner.

The effect on employment

Due to great uncertainty concerning the effects of climate change and their influence on various industries, it is by no means simple to estimate which particular effect climate change may have on employment in northern Norway and Svalbard. However, a comparison of available estimates may be useful in order to highlight regions that appear to be especially vulnerable in regard to employment.

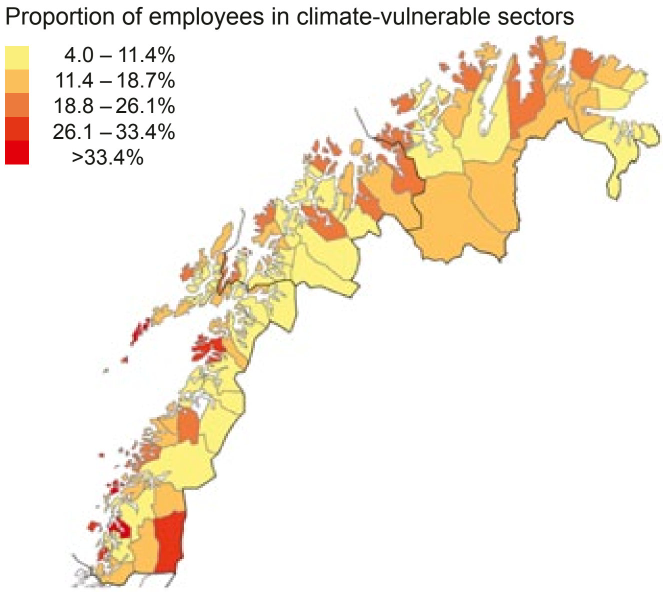


Figure 25: Map indicating the proportion of persons employed in climate-vulnerable sectors in northern Norway. Climate vulnerabilities are measured here based on a number of indicators, for example exposure to avalanches and floods, and an evaluation of the industry's climate vulnerability, infrastructure and the competence, economy and population composition of the municipality. Source: Groven et al. 2006

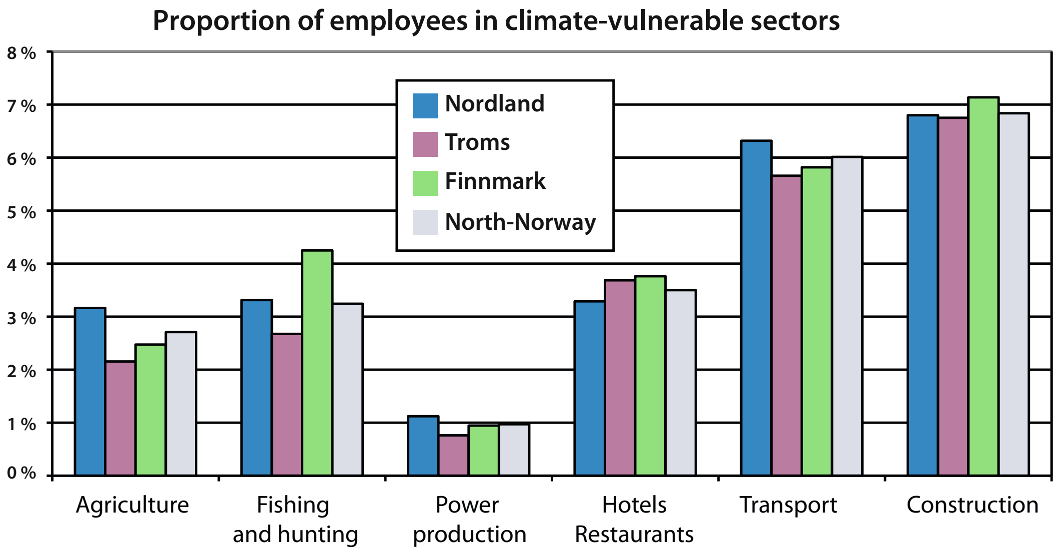


Figure 26: The proportion of persons employed in climate-vulnerable sectors in northern Norway 2004. Source: West & Hovelsrud 2008

Key finding 11: Society can – and must – adapt

It is important to identify exactly how vulnerable society is to climate change in order to develop effective adaptation strategies and initiatives. Vulnerability to changes can be identified on several levels; individuals, local communities, industries, specific community structures and sectors that are vulnerable to climate change – which requires different strategic approaches.

Image: © Bjørn Rørslett, Samfoto

Anticipated effects of climate change on society are uncertain. Not only is there a certain amount of uncertainty concerning the degree of climate change in itself; we do not know exactly how ecosystems and nature will be affected by these changed conditions. When social planning is based on this premise, it is clear that this will be an exercise involving an uncertain framework. In many ways, adaptation to climate change is planning under conditions of increased and amended risk.

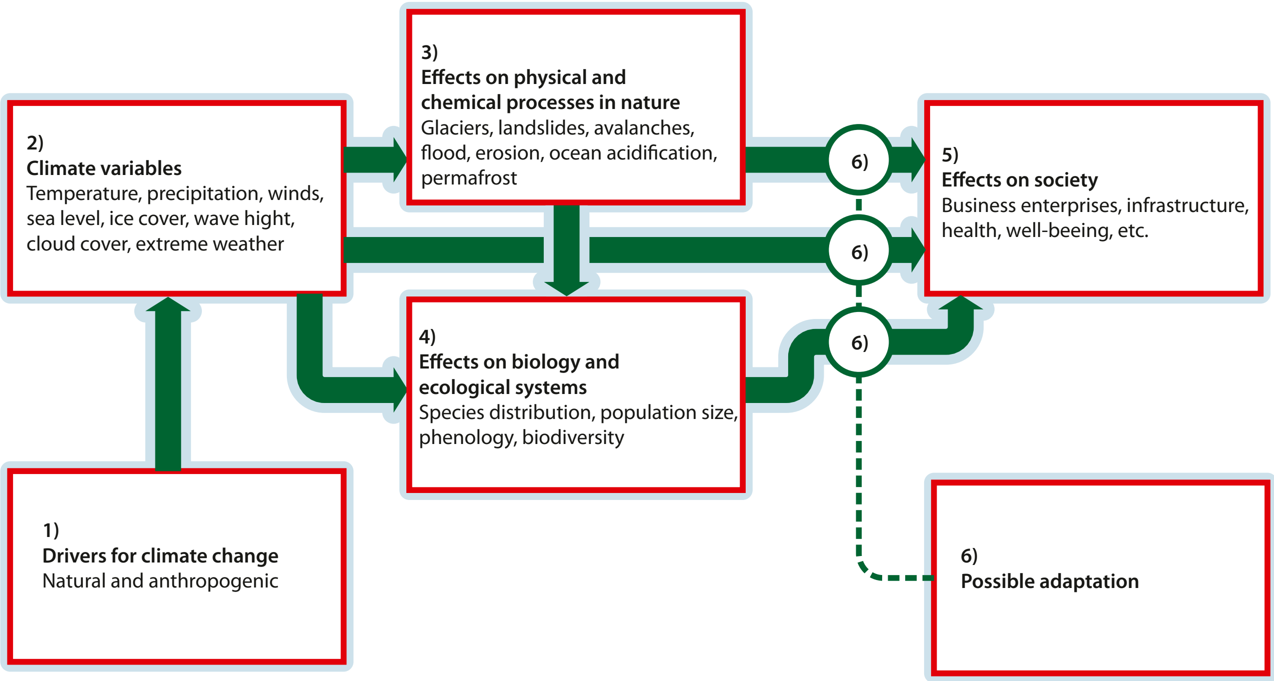


Figure 27: The effects of climate change on nature and society. Box 6 indicates where the possible opportunities for adaptation lie. Source: Kleven 2005

Overall social perspective

When climate and ecosystems change, society will attempt to adapt to these changes and to introduce various countering initiatives. Therefore, we cannot create a simple model that shows a direct correlation between a certain change in climate and a definite permanent change in society. The various elements of society are developed through processes other than climate change, such as for example, changes in technology, economy, knowledge and social and political organisation. These processes, in turn, make society more or less vulnerable to climate change. There is considerable uncertainty associated with calculations of climate effects at a regional level, and also in relation to exactly which effect this will have on ecosystems and the physical environment. If we also add complex interactions in society into this calculation, this leads to obvious uncertainty in an estimation of the effects on people and society. However, it is possible to consider anticipated effects, and this is important in order to be prepared for any changes.

Changes in nature and changes in weather – in the short and long term

People and society are exposed to effects of climate change through changes in weather (temperature, wind and precipitation), through effects on natural systems (sea levels, waves, erosion, cloud cover and ecological changes) and via influences on among other things infrastructure and industry.

Many of the climate-related changes that are underway occur gradually, such as for example an increase in sea level. Subtle temperature changes over several decades are also expected to gradually influence both physical conditions and ecosystems. Some species and systems may, however, have unpredictable marginal limits that lead to more rapid and more comprehensive system changes. In addition, an even, gradual temperature increase is not expected; there will be fluctuations around a steadily increasing average. The fact that the processes take a long time may mean that we perceive them as being less dramatic than for example, an increase in the occurrence of violent storms; however, the changes will in any case have considerable consequences for industry, groups and local communities. More frequent and more destructive storms, floods and landslides are expected to become an increasing challenge, with damage to among other things roads, bridges and tunnels and buildings and are likely to negatively affect the transport sector. More frequent and more powerful extreme weather is an effect that possibly will occur in addition to the slower and more gradual climate change.

Climate-related emissions in Svalbard are increasing

Climate-related emissions in Svalbard have increased dramatically since the year 2000. In 2007, emissions in Svalbard accounted for approximately 1% of emissions in Norway; however, local emissions of substances that affect the climate in the vulnerable Arctic may prove to make a difference, both in respect of harmful environmental effects and climate change. A recently published report from the Climate and Pollution Agency shows that most emissions of climate gases in Svalbard, come from coal-based energy production and shipping transport, especially cruise traffic. Emissions from shipping traffic in the Svalbard area increased by 28% from 2000 to 2007, and the greatest increase was in connection with cruise traffic where emissions increased by as much as 70%. Estimates indicate that emissions of climate-related pollutants can increase considerably, both in the short and long term if initiatives are not implemented in order to reduce these emissions. The emission of climate related pollution will continue to increase by around 30% towards 2012, even if current plans that call for a 50% reduction in Norwegian coal production in relation to the 2007 level are realised. Emissions are increasing due to the assumed growth in activities related to tourism and research.

Increased maritime activity must be taken into consideration

The sea ice in the Arctic is melting quicker than previously estimated (among others, the ACIA report). Less sea ice offers new opportunities for shipping and industrial activity in the Arctic. There may be increased shipping both around Svalbard and along the Norwegian coast, increased oil transport from North-West Russia, increased cruise traffic around Svalbard and more frequent sailings in the Northern Sea Route and across the Arctic Ocean. New sailing routes may offer considerable time savings. Increased activity and traffic may, however, increase emissions of harmful substances, increase the risk of accidents and oil spills along the coast and will require improved emergency preparedness against accidents and more robust oil spill contingency planning. Reductions in sea ice and other effects of climate change may make further extraction of petroleum products possible, as well as minerals and metals along the northern coast of Canada and Russia. Shipment of these products may contribute to a further increase in maritime transport in the north. In total, this will place greater demands on monitoring and contingency plans both in relation to oil spill contingency in connection with accidents and to maritime safety in general. In Svalbard, the risk of a cruise ship or cargo vessel running aground and releasing oil into the ocean is the greatest environmental risk associated with shipping. If this should occur, the consequences may be of great concern. Oil breaks down more slowly in the cold climate, and the environment in Svalbard is vulnerable to this type of pollution. A steadily more ice-free Svalbard increases accessibility for cruise ships, thereby also increasing the risk of accidents in areas in which there are inadequate marine charts – or none at all. Initiatives already implemented include the prohibition of heavy oils in certain areas, the right of the Governor of Svalbard to require vessels to use tugboats and pilots in certain areas

Figure 28: Three potential sailing routes from Western Europe to the Bering Strait: The Northern Sea Route (far right) runs along the coast of Russia and is already being used by ships parts of the year. The route in the centre represents the shortest route through ice outside of Russian territorial waters (based on an average ice extent). The direct route across the North Pole (left) utilises the ice-free area along the west coast of Svalbard before it crosses the central Arctic Ocean. Source: Norwegian Polar Institute

and giving priority to surveys of areas that become accessible due to reduced amounts of ice. There is a need to intensify monitoring and control of traffic and other enterprises in Svalbard in order to limit their effect and to reduce the risk of accidents. In total, increased access and opportunity for more shipping in the Arctic lead to a need for improved regulation of human activity in the northern ocean areas, focus on emissions and potential accidents, and more effective contingency plans are required than at present. An increase in shipping traffic may place further strain on ecosystems and species that are vulnerable to climate change.

Infrastructure must be adapted

Infrastructure such as roads, airports, railways, water and sewage systems, power lines and buildings in northern Norway have always been exposed to a severe climate with cold temperatures, heavy snowfall and frequent inclement weather. However, some elements of this infrastructure that exist today are in any case vulnerable to changes in the climate. In Svalbard, there is an additional challenge in that all physical infrastructure is built upon permafrost. Increased thawing of the uppermost layer of the permafrost can lead to serious consequences, both in respect of settlement and other infrastructure. Thawing permafrost must be taken into consideration when buildings and other infrastructure are constructed in the future.

A critical review of the road network has been initiated, focusing on vulnerability assessment in relation to the effects of climate change. The road sector in northern Norway faces climate challenges in the future along with an already existing problem: even based on the current climate situation, the roads are of an inadequate standard. The Norwegian Public Roads Adminitration has initiated a project for planning the construction and operation of roads under a changed climate situation; however, the lag in maintenance programmes means that adaptation in the road sector will be a major challenge. Climate change will mean that the roads will be exposed to greater precipitation, several areas will be exposed to landslides and roads will be closed more frequently in the winter due to increased snowfall. Therefore it is vital that the guidelines created for maintenance and operation of the road network allow for climate change, and that this is followed up with the allocation of funds that correspond to requirements.

Energy production and supplies in northern Norway face major challenges, and climate change will increase these challenges considerably. There is a need for a critical review of power supply systems in the region in order to pinpoint weaknesses. Most hydroelectric plants in northern Norway are constructed principally to supply local and regional power requirements and are constructed for dry years such that they do not exploit the energy potential of periods with increased precipitation. Increased precipitation will mean that power stations will need to be reconstructed, both to prevent flood damage and to fully exploit the energy potential. The power line network will also be more vulnerable to influence from snow and temperatures fluctuating around freezing point. This, along with the need to extend the electrical power network in northern Norway, means that there is a considerable need for investment in this sector in the near future.

Nature-based industry and adaptation – a complex picture

Climate change may lead to less favourable agricultural conditions in many regions of the world, whilst at the same time the production potential in the north may be improved. Overall, agriculture in the north may gain positive opportunities; however there is some uncertainty in regard to the geographical distribution of these effects, and the collective effect of several factors, for example increased frequency of (and longer) mild weather periods, as along with more precipitation. This, along with changes in growth conditions and the incidence of pests, will lead to a need for more research on both the effects of climate change and the adaptation of agriculture. The main challenge for agriculture is to exploit the opportunities provided by climate change and at the same time limit the amount of emissions and increase the uptake of climate gases. Forests currently have a net annual CO_2 uptake that corresponds to approximately half of the total Norwegian climate gas emissions, whilst the net contribution from agriculture is approximately 1/10 of Norway's total emissions. Active forest management initiatives in order to promote the growth of forest within a viable framework for conservation of biological diversity and recreational and landscape values, may contribute to a continued increase in the annual uptake of CO_2 in Norway.

Several industries that base themselves on natural resources must be prepared to make purely geographical changes, to the location where the enterprise is carried out. Fisheries can move further north and east; the aquaculture industry, in changed climate conditions, must relocate more of its enterprises to northern Norway. Fisheries have always had to relate to variations in resources in regard to stocks, species and the location of fishing grounds. Knowledge and adaptation to these variations are part of the experience-based knowledge possessed by fishermen. In addition, climate change may lead to a need for changes in regulation and management of fisheries, due to the overall strain on stocks. For example, it may be appropriate to reduce strain on fish stocks that are exposed to stress from climate change, as these are often more vulnerable to several simultaneous stress factors. The selection of management regime will be more important than the effects of climate change alone in the immediate future. Current management tools are not sufficiently dynamic to be able to handle the changing environmental conditions and must therefore be developed further. For the fish farming industry, other more pro-active strategies such as breeding programmes and genetic engineering may also be relevant adaptation strategies. In addition, there will be a need for technical product development in the equipment industry in order to meet requirements for more robust constructions in the fish farming industry.

It is anticipated that the reindeer farming industry will have to consider other grazing areas; however, the competition for areas is already considerable, both between various reindeer farmers and between the reindeer industry and agricultural interests, cabin owners and other recreational interests. The reindeer industry is also faced with competition for outlying grazing areas due to area allocations in accordance with legislation and external institutions such as municipal area planning, state-determined protection policies and other regulations, such as predator policies. The emergence of a modern motorised and market-oriented reindeer industry has led to changes in the composition of reindeer flocks in all areas. The proportion of females in reindeer flocks has increased and the proportion of older male animals has been reduced in order to increase meat production per animal. A disadvantage of this type of flock structure is that it may reduce the opportunity for adaptation to climate change. With an increased frequency of freeze-thaw cycles, reindeer may have problems in finding food, as the vegetation is trapped under the ice layer. Older male animals, especially castrated males, have greater strength and are able to break through ice and snow in poor grazing conditions. Thus, climate change may mean that flock structures must be changed such that the flocks contain a greater proportion of animals that in themselves are not directly the most effective for meat production. When grazing conditions are so difficult that the reindeer cannot break through the ice and snow, the reindeer flocks must be given additional feed. This is an expensive alternative to natural grazing; however, it may become necessary in the future. Climate change may also mean that traditional operating models in the reindeer industry, spanning national boundaries in northern Fennoscandia, may need to be reconsidered in order to properly adapt the industry to future challenges.

Can protection policies limit negative effects?

Increased protection cannot stop climate change; however, protection of areas may lead to species and other parts of the ecosystem being less threatened by interventions. Robust ecosystems and species with large enough populations may also be able to adapt to climate change through natural selection. In this way, increased areal protection can enhance safeguarding of biological diversity also in the future, and may thereby also be considered an adaptation in itself. Protection policies shall ensure that unique nature areas are preserved for the future and limit damage to cultural heritage. Not least, it is important to include climate considerations in overall ecosystem-based nature management; to see climate change in context with other factors that are of importance for biological diversity and to use this knowledge in the planning process. Protected areas in Norway will, after the ongoing protection plan for national parks and larger protected areas has been completed, cover approximately 15% of Norway's mainland area. The selection of areas to be protected has been carried out over some time; however, most of them have been selected according to a report from 1986 and thus the knowledge that we possess today concerning the importance of climate change for biological diversity was not part of the basis for the selection of the areas. When the temperature increases, plants seek out higher elevations in order to find satisfactory climatic conditions, a factor that is not often con-

An old tractor on the beach at Gipsvika, Svalbard. Image: © Kristin Prestvold, Governor of Svalbard

sidered in the planning of protected areas. One solution in order to halt this development is to establish so-called 'biological lanes'. This means that elevation above sea level is also considered when protected areas are selected, thus safeguarding intact natural 'corridors' from lowlands to mountainous areas. In this way, the protected nature type remains protected after it has relocated higher up on the mountainside. As previously discussed, it is expected that the tree line will move much further up mountainsides in northern Norway before the end of this century, and this is currently being worked into nature preservation policies. In this way we will be in a better position to meet climate change, and the risk of a loss of biological diversity is reduced.

Climate change may affect cultural heritage in the region. In particular, cultural heritage sites in Svalbard may be threatened due to thawing permafrost and more rapid erosion. Cultural heritage sites are also exposed to rot, fungus, bacteria and the formation of rust in a warmer and wetter climate. Both fixed cultural heritage sites and loose objects of biologically degradable materials are in danger of being lost, and an adaptation to this may be that archaeological digs must be carried out and that buildings and objects be secured and/or removed. At the same time we must accept that a great deal of cultural heritage will inevitably be lost.

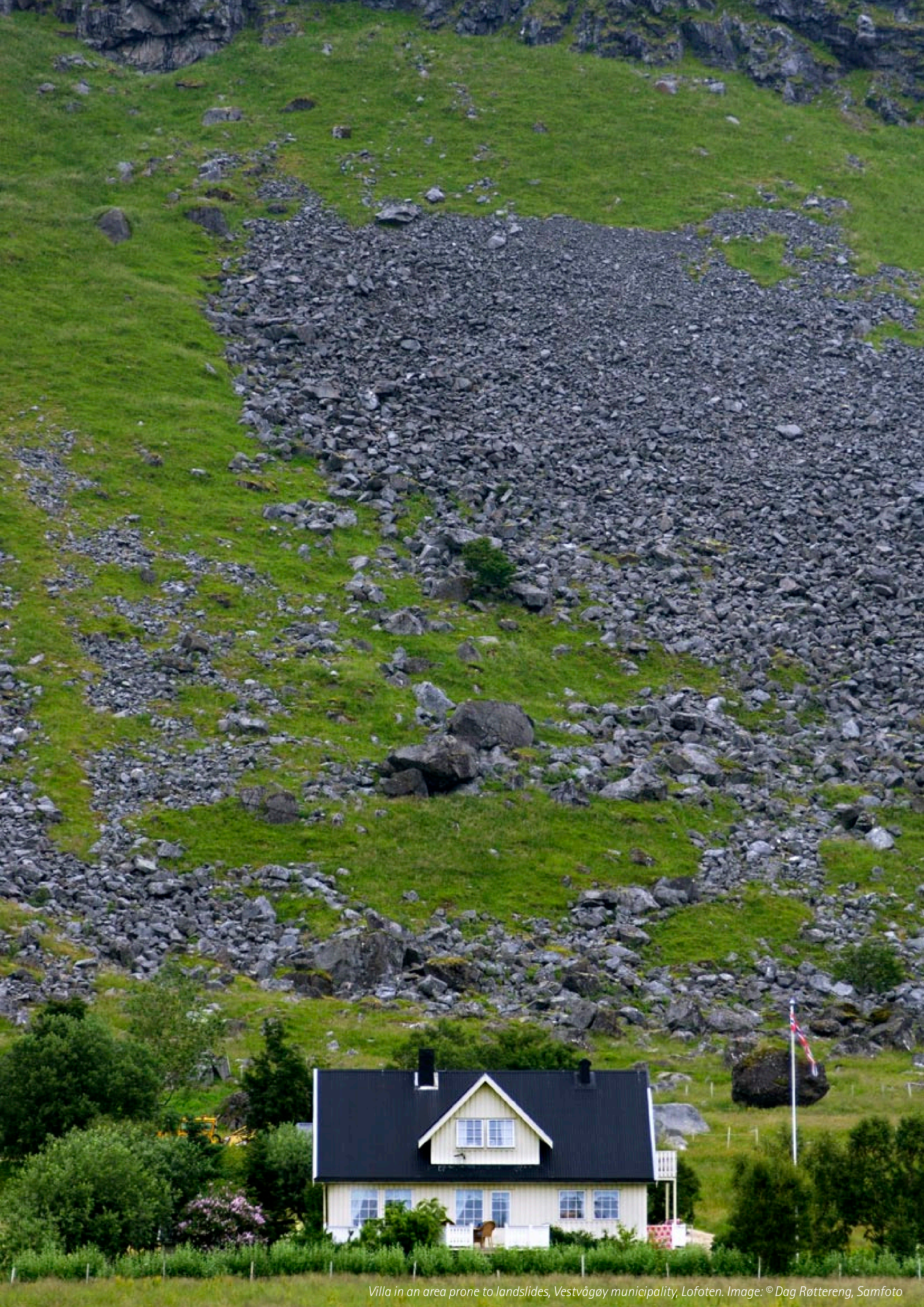
Climate adaptation through area planning in municipalities

After the most recent revision that was carried out, the Norwegian Planning and Construction Act has become a central policy instrument for long-term handling of climate challenges. Municipal planning must take the security of community into consideration. At the same time it will be important to develop planning tools such that these also protect the natural environment's opportunity to adapt to a changed climate. Area planning has a sectoral character, which makes it suitable as a policy instrument in order to view various social sectors in context. The new Planning and Construction Act strengthens municipalities' opportunity to take climate considerations in area planning processes. A changed climate may change the risk situation in relation to storm surges, floods, landslides and severe winds, which are of importance in allocating areas. The responsibility for area planning belongs in principle to the municipalities; however, they depend on access to updated knowledge of their areas. County governors have a special responsibility for this, and they can notify municipalities if plan proposals are drawn up that do not take adequate consideration in respect of security issues. The municipalities, through the same Planning and Construction Act, are required to carry out risk and vulnerability analyses, and areas exposed to hazards, risk or vulnerability must be noted in the plans as special zones.

Do adaptation measures pay?

The economic effects of climate change will be of several different types. It is especially important to quantify future economic effects, as there is some uncertainty associated with both the technical and the ecological effects of climate change. In any case, if satisfactory cost estimates can be created for what the cost will be to society if adaptation initiatives are not implemented, we will be able to create cost and benefit analyses in order to map which particular sectors the initiatives should be applied to. In the regional framework for NorACIA, a collective evaluation of the possible economic effects of climate change for various municipalities and regions will mean that we will have to summarise costs and benefits for all effects in all sectors. This is not a viable strategy in the immediate future, as we have a limited understanding of mechanisms and complex correlations in society.

The anticipated effects on infrastructure will lead to costs associated with damage caused by wind, precipitation, floods, landslides, silting and rot. Potential benefits are associated with general strategies such as innovation and the development of new materials and new technologies in order to reinforce the infrastructure. Due to the localisation of the industrial research environments there is reason to believe that without determined efforts in education policy and research and development efforts, these positive effects are likely to end up outside of the region. In the agricultural sector the economic consequences are more complex. There is naturally a great deal of uncertainty associated with the effects; however, it appears that agriculture will be able to adapt and to exploit opportunities offered by a new climate situation, with an economic advantage. Fisheries may experience improved conditions due to warmer



Villa in an area prone to landslides, Vestvågøy municipality, Lofoten. Image: © Dag Røttereng, Samfoto

Sámi handicrafts, duodji. Tools made from reindeer horn. Image: © Trym Ivar Bergsmo, Samfoto

oceans; however, the challenges and uncertainties associated with localisation of fish resources in the changed conditions make it difficult to quantify economic effects, also for this industry. Climate change will lead to changes in risk profiles for the insurance industry, and represent both increased risk and new opportunities for profit in that the product range in the industry can be expanded. An increase in climate generated damage caused by floods, landslides and storms will result in larger compensation claims. At the same time, the development of climate-related insurance products will mean that the companies will impose terms and conditions on their customers which will mean they will need to implement initiatives, both to prevent damage and to reduce the consequences of damage, something that will contribute to reducing vulnerability for customers and for the companies themselves.

The vulnerability of indigenous peoples to climate change – and climate adaptation

Sámi culture is strongly connected to nature in the Sámi settlement areas, and the Sámi commercial industries (reindeer herding, coastal fishing, agriculture etc.) play important roles as bearers of culture. This strong connection between commerce and culture means that it is of decisive importance that Sami people continue to be able to carry out traditional business enterprises. At the same time, we now know that nature-based industries are under strain, due to, among other things, climate change. Internationally, there has been some focus on the consequences of climate change for indigenous peoples' economy and culture, especially highlighted in the ACIA Report from 2004. Climate change challenges the flexibility and adaptability that has been the key to indigenous peoples' handling of variation and unpredictability in nature and climate through many generations. In 2007, the Sámi parliament identified a central challenge in climate policies:

"Indigenous peoples have a close dependence on and association with nature and are therefore more strongly affected by climate change than others. They are therefore more affected by national strategies for adaptation to a changed climate, and to initiatives that contribute to reaching national CO_2 reduction objectives. Indigenous peoples' rights must be given emphasis when climate change initiatives are planned in vulnerable Sámi settlement areas".

Climate change is only one of many challenges that Sami communities are facing. The main principle in the ILO-Convention no. 169 concerning indigenous and tribal peoples in independent states, ratified by Norway in 1990, is indigenous peoples' right to preserve and develop their own culture, and the authorities' duty to implement initiatives in order to support this work. In order to fulfil the terms of this convention, the design of choices and strategies and initiatives must be based on analyses of the collective effects of such changes. It is therefore necessary to develop a well-funded and relevant knowledge base which makes it possible to take action. In the national and international debate on climate adaptation and indigenous peoples, we see an increasing focus on cooperation between scientific environments and practitioners within nature resource-based production (for example reindeer herders, fishermen, farmers and users of outlying field resources). The object is to provide for mutual learning between sciences and traditional ecologic knowledge. There are considerable challenges in such ambitions – however, there are also many opportunities. The development and realisation of these opportunities will also need to relate to the fact that strategies and initiatives for climate adaptation will increasingly be developed within a framework in which national and international indigenous peoples' policies and environmental policies come together and collaborate.

www.klimatilpasning.no

The aim of the web portal Norwegian Climate Change Adaptation Programme is to facilitate climate adaptation through information concerning the effects and consequences of climate change and examples of adaptation initiatives and strategies.

Official Norwegian Report (NOU) on vulnerability and climate change adaptation

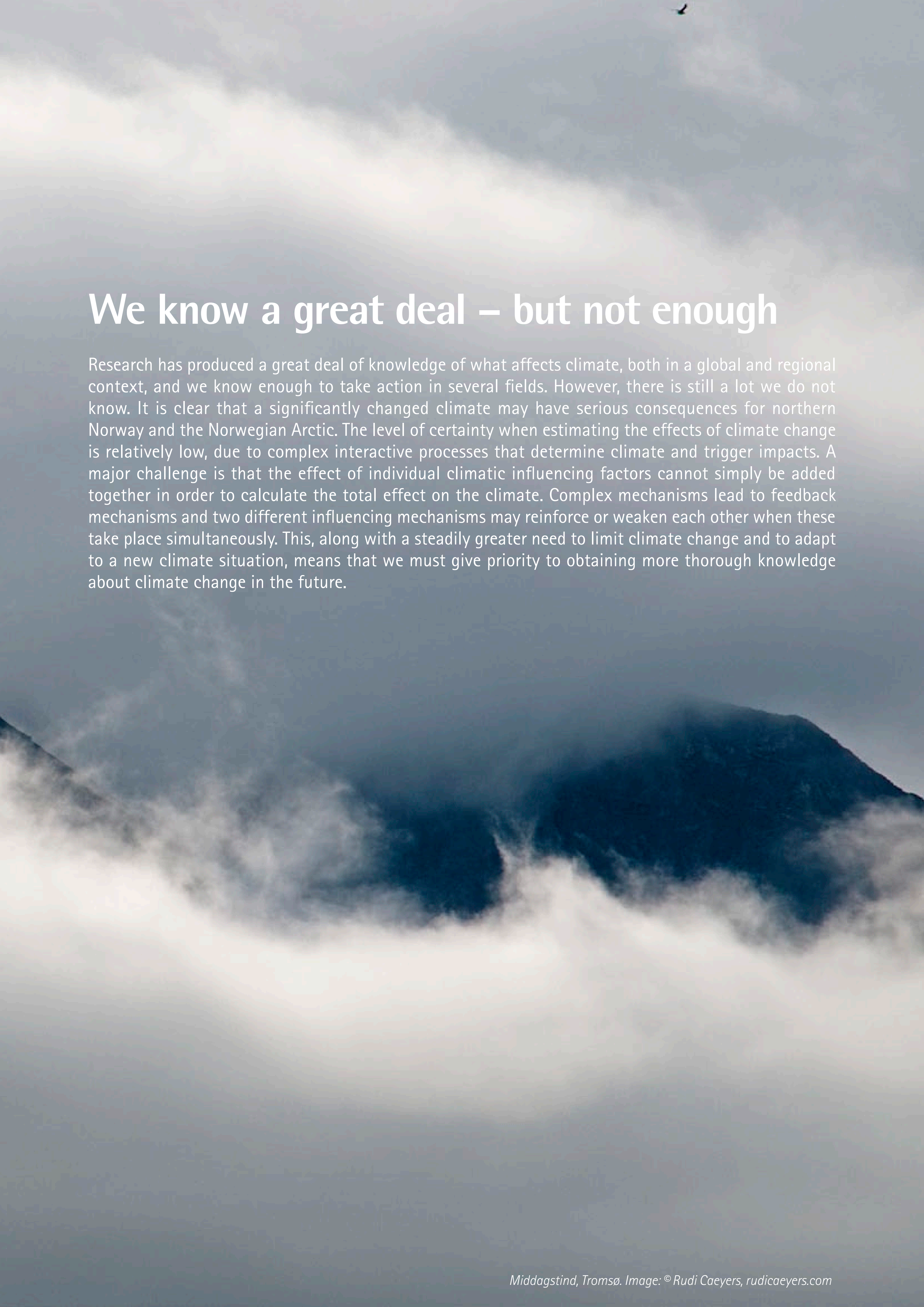
In December 2008, the Norwegian government formed a working group which was delegated the task of investigating Norway's vulnerability and need for climate change adaptation. The group's mandate is to carry out an overall review of challenges and opportunities that climate change represents in various areas of society. Focus is especially aimed at the consequences in respect of:

- Human health and safety
- Physical infrastructure and buildings
- Commerce
- Primary industries and the natural environment

The group is broad-based and will discuss policy instruments and initiatives in order to reduce society's vulnerability, to strengthen our ability to adapt, to assess responsibility and role distribution between authorities at different levels, to review relevant research programmes and to discuss the areas in which there is a particular need for more knowledge about the consequences of climate change. Issues of importance for traditional Sámi culture and commerce are also elements that will be discussed. The work has been completed and relevant strategies and adaptation initiatives were published as an NOU report 15 November 2010.

We know a great deal – but not enough

Research has produced a great deal of knowledge of what affects climate, both in a global and regional context, and we know enough to take action in several fields. However, there is still a lot we do not know. It is clear that a significantly changed climate may have serious consequences for northern Norway and the Norwegian Arctic. The level of certainty when estimating the effects of climate change is relatively low, due to complex interactive processes that determine climate and trigger impacts. A major challenge is that the effect of individual climatic influencing factors cannot simply be added together in order to calculate the total effect on the climate. Complex mechanisms lead to feedback mechanisms and two different influencing mechanisms may reinforce or weaken each other when these take place simultaneously. This, along with a steadily greater need to limit climate change and to adapt to a new climate situation, means that we must give priority to obtaining more thorough knowledge about climate change in the future.



Middagstind, Tromsø. Image: © Rudi Caeyers, rudicaeyers.com

Monitoring of climate change must be ensured

It is vital that the climate in the Arctic is monitored over a longer period, in order to map actual trends, to increase the understanding of processes and to evaluate the accuracy of climate models. The Norwegian weather stations in the Arctic provide a good platform in order to monitor climate on Spitsbergen, Bjørnøya, Hopen and Jan Mayen. It is important that distinctive characteristics and special conditions that characterise the climate in the Arctic are a part of future and improved climate models, especially in relation to the effect of sea ice on climate.

Monitoring of nature in general is also important in this context. It is only through a sound understanding of changes in the ecosystem in new climatic and environmental conditions that climate models can be used to describe the effects in nature.

Even though the NorACIA process has generated a separate regional climate model for the Norwegian Arctic, NorACIA-RCM, this model still has too large a scale in order to state anything specific about local weather and climate conditions. The model uses a matrix of areas of 25 km x 25 km, and actual local weather conditions and local climate should be included in the model in order to achieve greater precision on a smaller scale. An example of local conditions is snowfall on land. The coordination of several climate models will also adjust the picture somewhat, so that we will achieve more precise estimates of the climate. In addition, there are certain premises in the model that are obtained from the global models. Inaccurate data in basic variables may lead to errors in the results.

In general we have an inadequate understanding of the large and small physical systems that control the climate in the Arctic. We still do not have an adequate understanding of how ocean currents may change with changes in temperature and increased run-off of freshwater from land, we do not understand all the effects of the large air current systems, neither do we fully understand the influence of clouds on the climate in Norwegian Arctic areas. Calculations of the melt rate of glaciers and ice caps on land (and thereby their contribution to raised sea levels), and the melting of sea ice in the Arctic, have not intercepted the rapid changes that are actually taking place. Thus, we have inadequate knowledge in certain areas about exactly what controls climate development. These are areas that we must prioritise in order to create better calculations of the climate in northern Norway, in Svalbard and in ocean areas, and the consequences that the climate in these areas may have on the global climate.

Mapping, monitoring and contingency planning

A gradual adaptation to a new climate regime demands continous study of both current and anticipated climate change, about the effects of and vulnerability to climate change and about cost effective initiatives to alleviate negative effects. Mapping and monitoring of climate change and its effects will be decisive for adapting society and finding the right mitigating initiatives. This must be done through continuance of the monitoring programmes that already exist, and the introduction of new programmes. The Directorate for Nature Management, the Norwegian Polar Institute, the Norwegian Meteorological Institute, the Institute of Marine Research, the Directorate for Cultural Heritage, the Climate and Pollution Agency and the Norwegian Radiation Protection Authority are central figures in the process of collecting and systemising environmental data. Overall, a considerable amount of monitoring is being carried out within nature management at a national level; however, little of this is especially aimed at observing the effects of climate change. Current monitoring programmes for the ecosystems in northern Norway are very limited, and make it difficult to intercept changes that are caused by climate change. In order to intercept important changes at an early stage, we must consider establishing monitoring programmes that focus on monitoring the part of the ecosystem in which significant changes are anticipated; in respect of vulnerable species or areas and that

Image: Rudi Caeyers, rudicaeyers.com

have potential to intercept any surprises. Substantial changes are anticipated in the ecosystems' functions and distribution in mountain areas, in birch forests and coniferous forests, which should provide a basis for goal-oriented monitoring programmes.

Via MOSJ (Environmental Monitoring of Svalbard and Jan Mayen), data is collected in order to monitor a number of physical and biological parameters. With the large temperature difference from the west to east in Svalbard and the significant temperature increase that is expected in the east, it will be especially important to monitor changes in ecosystems on the east side of Svalbard. The nature reserves on the east side of Svalbard are protected, among other things as reference areas for research. On Jan Mayen, several more aspects of the ecosystem should be included in a long-term monitoring programme, as our knowledge of the ecosystem on the island is inadequate at present.

A major challenge associated with the acidification of the oceans is that the biological and ecological effects have not been adequately mapped. Organisms that have been examined also show significant variation in the effects of reduced pH levels, both between related species and within the same species. Several studies have also been carried out on much lower pH levels than those calculated for the oceans in the Norwegian Arctic, and the results from these cannot be directly transferred to the anticipated pH development.

... before it's too late ...

We are already observing a number of effects of climate change, about which we have limited knowledge. One example is the acidification of the oceans due to increased emissions of CO_2. Thorough studies, both of future pH levels in the oceans and the effects on all types of organisms are important in order to map ecosystem effects and secondary effects on humans, commerce and society. More detailed and reliable calculations of weather conditions, ocean levels and temperature in the air, water and on land are important in order to plan the future development of society in such a way that significant values are not lost. Neither is it the case that all changes will be gradual and in-line with the anticipated climate change; individual species and parts of the physical environment may also have tipping points – threshold values that if exceeded, produce rapid and sudden effects. These threshold values are important to be aware of, such that any initiatives can be introduced before we see sudden effects with serious consequences on ecosystems and society.

Investments in infrastructure that is expected to last a long time must be carried out in relation to the anticipated climate change. If not, major road construction projects and avalanche prevention projects, for example, may prove to be unnecessary or inefficient in relation to future climate, and society's resources have thereby been wasted. Climate may also influence settlement patterns, for example via changes in commerce. It is also important to make allowances for this in social planning in other fields.

Interdisciplinary cooperation is needed to understand climate change

In order to understand the complex picture of natural fluctuations and climate change, with effects on the different ecosystems, a better cooperation is required within the disciplines of oceanography, sea ice research, meteorology and biology. Even though the global calculations of climate change are unambiguous, it is important to remember that regional differences may be significant. In order to understand the future consequences for society and commerce caused by changes in ecosystems, there should be a cooperation between the more pure science areas in climate research and social science. This is currently the case in a number of projects concerning adaptation and vulnerability in northern areas, which shows how important this kind of cooperation is in order to understand the complex connections between humans and the environment.

Interdisciplinary cooperation will also make it possible to calculate both direct and indirect effects of climate change more precisely. For example, a cooperation between meteorology, oceanography and biology will be much more effective in determining how the Arctic species in the Barents Sea will be exposed to competition from more southern species. This will be able to provide an understanding of the types of environmental conditions that will exist in the various parts of the ocean and to associate anticipated biological effects with these. One example of our inadequate knowledge is the relationship between timing and physical location of biological processes on land, in the ocean and in freshwater. If the growth of algae and thereby the occurrence of zooplankton in the ocean happens at times or in places where fish fry are not present at the same time, we then have a mismatch in time and/or space that means that the fish fry cannot utilise the plankton as food, with potentially significant consequences for future fish stocks.

Klima 21 (Climate 21)

In 2008, the government established a strategic forum for climate research, called Klima 21. This is led by a broad-based steering group comprised of members from research environments, environmental organisations, public departments and commerce. Klima 21 will concentrate its work around four themed areas, which have been highlighted as the most important knowledge-deficient areas:

- Climate developments and climate change
- The consequences of, and adaptation to, climate change
- Climate policies
- Initiatives and reductions in emissions

Across all of these subjects, globalisation, commercial development and premises for research are important themes.

Adaptation also requires knowledge

Adaptation of society must take a starting point in the anticipated climate situation. Knowledge of climate adaptation must be obtained and developed in cooperation between experts and practitioners, users and those who live in the affected areas. It is especially important that considerations are made for knowledge of special local conditions that may be relevant to climate adaptation, even if these are not directly connected to climate change. National experts on climate change may have difficulty in understanding connections to all relevant local conditions, that the population in an area and those involved in commerce are able to see. The knowledge bases for decisions concerning initiatives and policy instruments in respect of climate adaptation will be broader and more detailed if local residents and commercial interests contribute.

Some studies have been carried out regarding the regional differences in anticipated climate effects. These studies show that it is important to have a regional and local focus on adaptation. Some industries will meet totally opposite challenges in different parts of Norway; for example fish farming is expected to flourish in northern Norway (provided that the right actions are taken in relation to adaptation), whilst the fish farming industry further south in the country may have to adapt to less favourable conditions for salmon. In many areas it will be important to be able to identify such regional differences in order to meet future challenges with the right course of action.

A centre for climate and environment in Tromsø – the Fram Centre

In the government's northern area strategy it has been emphasised that Norway shall be prominent internationally in respect of the development of knowledge about, for and in northern areas. A central initiative is the establishment of a centre for climate and environment in Tromsø in 2010, with the ambition of creating an international leading centre in the north. The centre will be co-ordinated with existing competence centres in Norway, and will be part of the escalation plan for climate research and Klima 21.

Via the centre for climate and environment, the government will provide a basis for knowledge development to make Norway able to manage our resources and ecosystems in the oceans and the land in the north in a sustainable manner, and provide important contributions to knowledge of global significance associated with climate and environment changes in the Arctic. Norway has large ocean and land areas in the north and thus we are obligated to provide sound management in these areas. Indigenous peoples are facing special challenges in the north in respect of living conditions, culture and commerce. We require increased interdisciplinary cooperation between scientists, technology specialists and social scientists in order to meet complex challenges in a demanding and exposed climate. By strengthening research and education in the north and building up knowledge-based management, Norway can be at the forefront of development and develop new initiatives in order to meet the challenges and to utilise the opportunities that arise. The main objectives of the Centre:

- The centre for climate and environment shall contribute with knowledge that will make northern Norway the leading manager of the environment and natural resources in the northern areas.
- The centre shall be further developed, into a leading international centre for management-relevant research on climate and the environment in the northern areas.

Proposals for professional flagships in the centre for climate and environment

- Sea ice in the Arctic Ocean and adjacent ocean areas
- The effects of climate change on coastal and fjord ecosystems, including social development and commerce
- Acidification of oceans
- The effect of climate change on ecosystems on land, including social development and commerce
- Environmental pollution

Midnight sun on the mountain Tromsdalstind in Tromsø. Image: © Arvid Sveen

The scientific basis for this report

This report is mainly based on the five sub reports of NorACIA, supplemented with information from other sources. The NorACIA sub reports are:

Førland EJ, Benestad RE, Flatøy F, Hanssen-Bauer I, Haugen JE, Isaksen K, Sorteberg A & Ådlandsvik B 2010. Klimautvikling i Nord-Norge og på Svalbard i perioden 1900–2100 – Klimaendringer i norsk Arktis (Climate development in North Norway and Svalbard during 1900–2100 – Climate change in the Norwegian Arctic). NorACIA delutredning 1. Norwegian Polar Institute Report Series 135

Holmen K & Dallmann W (red) 2010. Fysiske og biogeokjemiske prosesser – Klimaendringer i norsk Arktis (Physical and biogeochemical processes – Climate change in the Norwegian Arctic). NorACIA delutredning 2. Norwegian Polar Institute Report Series 134

Loeng H, Ottesen G, Svenning M-A & Stien A 2010. Effekter på økosystemer og biologisk mangfold – Klimaendringer i norsk Arktis (Effects on ecosystems and biological diversity – Climate change in the Norwegian Arctic). NorACIA delutredning 3. Norwegian Polar Institute Report Series 133

Buanes A, Riseth JÅ & Mikkelsen E 2009. Effekter på folk og samfunn – Klimaendringer i norsk Arktis (Effects on people and society – Climate change in the Norwegian Arctic). NorACIA delutredning 4. Norwegian Polar Institute Report Series 131

Buanes A, Riseth JÅ & Mikkelsen E 2009. Tilpasning og avbøtende tiltak – Klimaendringer i norsk Arktis (Adaptation and mitigation – Climate change in the Norwegian Arctic). NorACIA delutredning 5. Norwegian Polar Institute Report Series 132

Sources of additional information

Key finding 1: The Norwegian Arctic is getting warmer and wetter, with large local variations
Hanssen-Bauer I, Drange H, Førland EJ, Roald LA, Børsheim KY, Hisdal H, Lawrence D, Nesje A, Sandven S, Sorteberg A, Sundby S, Vasskog K & Ådlandsvik B 2009. Klima i Norge 2100 (Climate in Norway 2100). Bakgrunnsmateriale til NOU Klimatilpassing. Norsk klimasenter

Key finding 2: Feedback processes in the Arctic increase global climate change
Hanssen-Bauer I, Drange H, Førland EJ, Roald LA, Børsheim KY, Hisdal H, Lawrence D,Nesje A, Sandven S, Sorteberg A, Sundby S, Vasskog K & Ådlandsvik B 2009. Klima i Norge 2100 (Climate in Norway 2100). Bakgrunnsmateriale til NOU Klimatilpassing. Norsk klimasenter

Westbrook GK, Thatcher KE, Rohling EJ, Piotrowski AM, Pälike H, Osborne AH, Nisbet EG, Minshull TA, Lanoisellé M, James RH, Hühnerbach V, Green D, Fisher RE, Crocker AJ, Chabert A, Bolton C, Beszczynska-Möller A, Berndt C & Aquilina A 2009. Escape of methane gas from the seabed along the West Spitsbergen continental margin. Geophysical Research Letters 36, L15608, doi 10.1029/2009GL039191

Key finding 3: Climate change makes the Arctic more vulnerable to environmental pollutants and ultraviolet radiation
AMAP 2009. Arctic Pollution 2009. Arctic Monitoring and Assessment Programme

AMAP 2009. Update on selected climate issues of concern. Arctic Monitoring and Assessment Programme

AMAP 2003. AMAP Assessment 2002: The Influence of global change on contaminant pathways to, within, and from the Arctic. Arctic Monitoring and Assessment Programme

Key finding 5: The ocean is getting warmer and the ecosystems are changing
Oug E & Sundet JH 2008. Alteration in soft bottom fauna in the Varangerfjord after the red king crab introduction. In Sundet JH & Berenboim B (eds): Research on the red king crab (*Paralithodes camtschaticus*) from the Barents Sea in 2005–2007. Pp. 40–43. IMR/PINRO Joint Report Series 2008 (3)

Key finding 6: The acidity of the ocean is increasing and coral species may disappear
Caldeira K 2007. What corals are dying to tell us about CO_2 and ocean acidification. Oceanography 20 (2), 188–195

Golmen LG, Berge JA, Dale T, Durand D, Johnsen TM, Lømsland E, Pedersen A, Bjørge A, Christensen-Dalsgaard S & Hareide NR 2008. Forvaltningsplan for Norskehavet. Deltema forsuring av havet (Management Plan for the Norwegian Sea. Sub-theme acidification of the ocean). NIVA Rapport LNR 5526

Børsheim KY 2008. Forsuring av havet medfører nye utfordringer for biologisk forskning (Acidification causes new challenges for biological research). Fisken og havet 3. Havforskningsinstituttet

Key finding 11: Society can – and must – adapt
Vestreng V, Kallenborn R & Økstad E 2009. Climate influencing emissions, scenarios and mitigation options at Svalbard. Klima- og forurensningsdirektoratet, TA-2552

References to figures

Figure 2, p. 24: IPCC 2007. Summary for policymakers. In Solomon S et al. (eds): Climate change 2007: The physical science basis. Contribution of Working Group I to the Fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press

Figure 3, p. 29, figure 6, p. 34, figure 9 p. 40, figure 10, p. 40: Førland EJ, Benestad RE, Flatøy F, Hanssen-Bauer I, Haugen JE, Isaksen K, Sorteberg A & Ådlandsvik B 2010. Klimautvikling i Nord-Norge og på Svalbard i perioden 1900–2100 – Klimaendringer i norsk Arktis (Climate development in North Norway and Svalbard during 1900–2100 – Climate change in the Norwegian Arctic). NorACIA delutredning 1. Norwegian Polar Institute Report Series 135

Figure 4, p. 30–31, figure 5, p. 32–33: Hanssen-Bauer I, Drange H, Førland EJ, Roald LA, Børsheim KY, Hisdal H, Lawrence D, Nesje A, Sandven S, Sorteberg A, Sundby S, Vasskog K & Ådlandsvik B 2009. Klima i Norge 2100 (Climate in Norway 2100). Bakgrunnsmateriale til NOU Klimatilpassing. Norsk klimasenter

Figure 7, p. 36: Isaksen K, Sollid JL, Holmlund P & Harris C 2007. Recent warming of mountain permafrost in Svalbard and Scandinavia. Journal of Geophysical Research 112, F02S04, doi 10.1029/2006JF000522

Figure 8, p. 39: ACIA 2004. Impacts of a warming Arctic: Arctic Climate Impact Assessment. Cambridge University Press

Figure 11, p 47: Loeng H & Drinkwater K 2007. An overview of the ecosystems of the Barents and Norwegian Seas and their response to climate variability. Deep Sea Research Part II: Topical Studies in Oceanography 54, 23–26

Figure 15, p. 62: Adapted from Holmen K & Dallmann W (ed) 2010. Fysiske og biogeokjemiske prosesser – Klimaendringer i norsk Arktis (Physical and biogeochemical processes – Climate change in the Norwegian Arctic). NorACIA delutredning 2. Norwegian Polar Institute Report Series 134

Figure 18, p. 72: AMAP 2003. AMAP Assessment 2002: The influence of global change on contaminant pathways to, within, and from the Arctic. Arctic Monitoring and Assessment Programme

Figure 19, p. 80: Blackford J & Gilbert F J 2007. pH variability and CO_2 induced acidification in the North Sea. Journal of Marine Systems 64, 229–242. Adapted from Pearson PN & Palmer MR 2000. Nature 406, 695–699

Figure 20, p. 80: Bellerby GA, Olsen A, Furevik T & Andersson TG 2005. Response of the surface ocean CO_2 systems in the Nordic Seas and Northern North Atlantic to climate change. In Drange H et al. (eds): The Nordic seas, an integrated perspective. AGU Geophysical Monographs

Figure 21, p. 87: Jepsen JU, Hagen SB, Ims RA & Yoccoz NG 2008. Climate change and outbreaks of the geometrids *Operophtera brumata* and *Epirrita autumnata* in subarctic birch forests: evidence of a recent outbreak range expansion. Journal of Animal Ecology 77, 257–264

Figure 22, p. 90: Nilssen AC 2010. Er skogflåtten i ferd med å innta Nord-Norge? (Are the ticks about to invade North Norway?) Ottar 1. Tromsø University Museum – University of Tromsø

Figure 23, p. 96: Loeng H, Ottesen G, Svenning M-A & Stien A 2010. Effekter på økosystemer og biologisk mangfold – Klimaendringer i norsk Arktis (Effects on ecosystems and biological diversity – Climate change in the Norwegian Arctic). NorACIA delutredning 3. Norwegian Polar Institute Report Series 133

Figure 24, p. 107: Buanes A, Riseth JÅ & Mikkelsen E 2009. Tilpasning og avbøtende tiltak – Klimaendringer i norsk Arktis (Adaptation and mitigation – Climate change in the Norwegian Arctic). NorACIA delutredning 5. Norwegian Polar Institute Report Series 132

Figure 25, p. 113: Groven K, Sataøen HL & Aall C 2006. Regional klimasårbarhetsanalyse for Nord-Norge (Regional climate vulnerability analysis for North Norway). Norsk oppfølging av Arctic Climate Impact Assessment (NorACIA). VF-rapport 4/06. Vestlandsforskning

Figure 26, p. 113: West J & Hovelsrud GK 2008. Climate change in Northern Norway. Toward an understanding of socio-economic vulnerability of natural resource dependent sectors and communities. Cicero Report 2008:04

Figure 27, p. 116: Kleven T 2005. Klimaendringer og lokal såbarhet: Noen faglige overveielser for et forskningsopplegg (Climate change and local vulnerability: Scientific considerations for research programme). NIBR-rapport 2005:15. Norsk institutt for by-og regionforskning

The Fram Strait. Foto : © Rudi Caeyers, rudicaeyers.com - BFE/UIT

Global warming is one of the biggest threats facing the Earth's population. Climate change will be especially discernible in the Arctic, where the temperature rise relatively will be larger than in many other areas of the world. The Arctic plays an important role in the global climate system, and change in the climate there may lead to consequenses all over the world.

This report assess and sum up some of the most important findings from NorACIA (Norwegian Arctic Climate Impact Assessment), the Norwegian follow-up after ACIA (Arctic Climate Impact Assessment) from 2004 about climate change and impacts in the Arctic.

The report presents an assessment of possible future events and probable effects and consequenses for the future 90 years, based on knowledge available today. This gives evidence for that the climate will affect both ecosystems and societies in the north.

NorACIA is the first complete assessment of knowledge of climate change in Northern Norway, Svalbard and the adjacent oceans.

RAPPORTSERIE 136/REPORT SERIES 136
NORSK POLARINSTITUTT/NORWEGIAN POLAR INSTITUTE 2010