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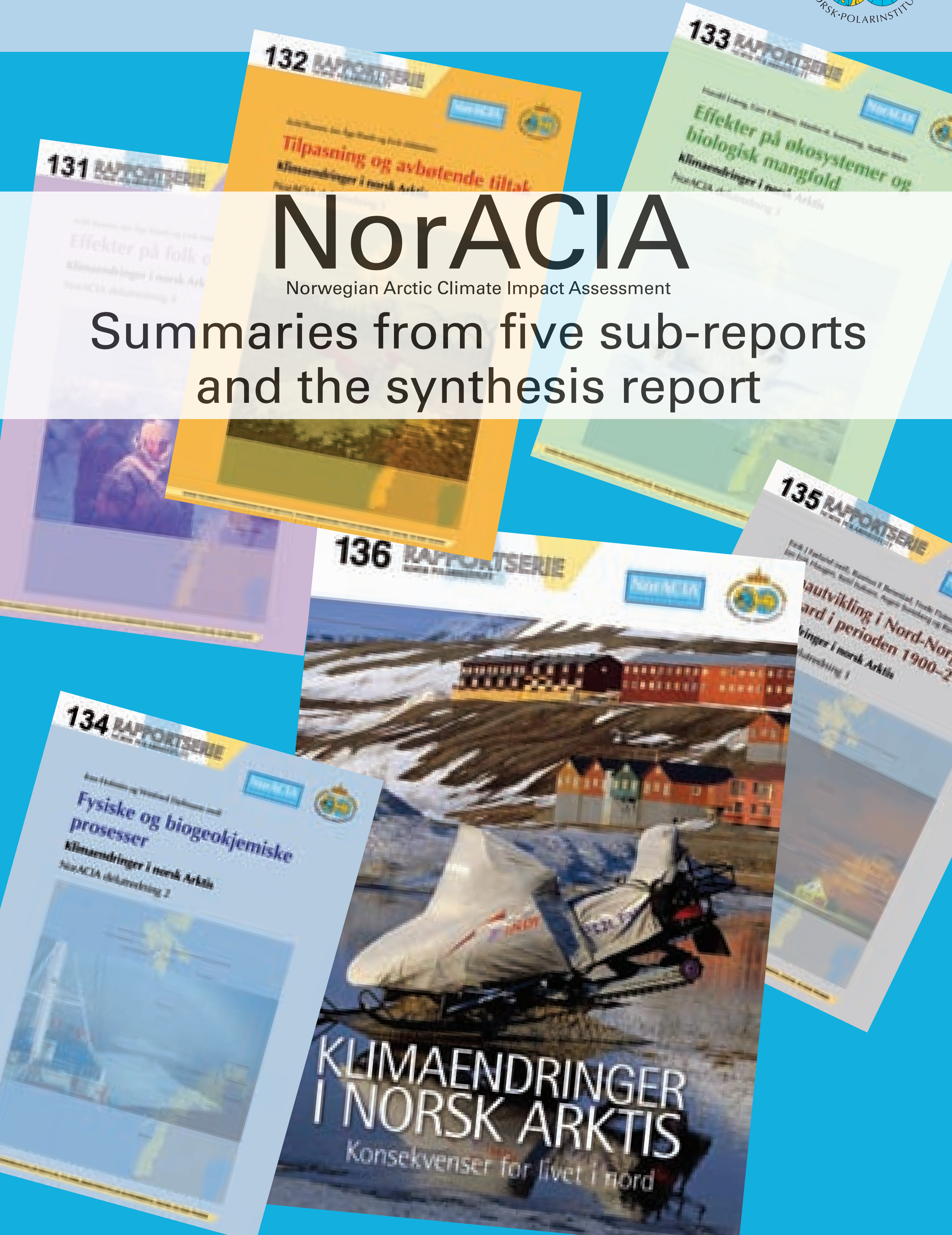
NorACIA

Norwegian Arctic Climate Impact Assessment

Summaries from five sub-reports and the synthesis report



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NorACIA

Norwegian Arctic Climate Impact Assessment
Summaries from five sub reports and the synthesis report

NorACIA secretariat
Norwegian Polar Institute
Polarmiljøseteret
NO-9296 Tromsø
Norway
noracia@npolar.no
www.npolar.no
www.noracia.npolar.no

Editor: Ellen Øseth, Norwegian Polar Institute (NPI)
Cover photos: NPI report 135 Stein Ø Nilsen, tromsophoto.net, NPI report 134 Bjørn Fossli Johansen, Norwegian Polar Institute, NPI report 133 Bjørn Frantzen, Norwegian Polar Institute, NPI report 131 Trym Ivar Bergsmo, Samfoto, NPI report 132 Mikael Andersson, Samfot, NPI report 136 Øystein Overrein.
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Preface

NorACIA is an initiative taken by the Norwegian government in order to follow up on the findings of the project ”Arctic Climate Impact Assessment” (ACIA) which was undertaken by the Arctic Council. NorACIA will contribute to the development, consolidation and dissemination of the current understanding of climate change, impacts of climate change and adaptation to climate change in the Norwegian Arctic, i.e. northern Norway, Svalbard and the Barents Sea.

NorACIA is organised with a steering committee with representatives from the Ministry of the Environment (chair), the Norwegian Directorate for Nature Management, the Norwegian Polar Institute and the Climate and Pollution Agency, and has a secretariat coordinated by the Norwegian Polar Institute.

Within the framework of NorACIA focus is on communication, providing advice and conducting assessment studies related to climate change in the Norwegian Arctic. The main goal for NorACIA is to consolidate updated and known knowledge about climate change in the Norwegian Arctic as a basis for further consideration of actions related to climate change and consequences of climate change in this region.

The assessment studies in NorACIA have been concluded with the production of five scientific reports, as well as one easy accessible synthesis report. The scientific reports cover the following topics:

- Climate scenarios for the Norwegian Arctic
- Physical and biogeochemical processes
- Impacts on ecosystems and biodiversity
- Consequences for people and society
- Adaptation and mitigation measures

A large number of research and management institutions in Norway have contributed to the work. The scientific reports and the final synthesis report are finalised in 2009 and 2010.

This report gives an English translation of the summaries from the six reports – the synthesis report and the five scientific sub-reports.

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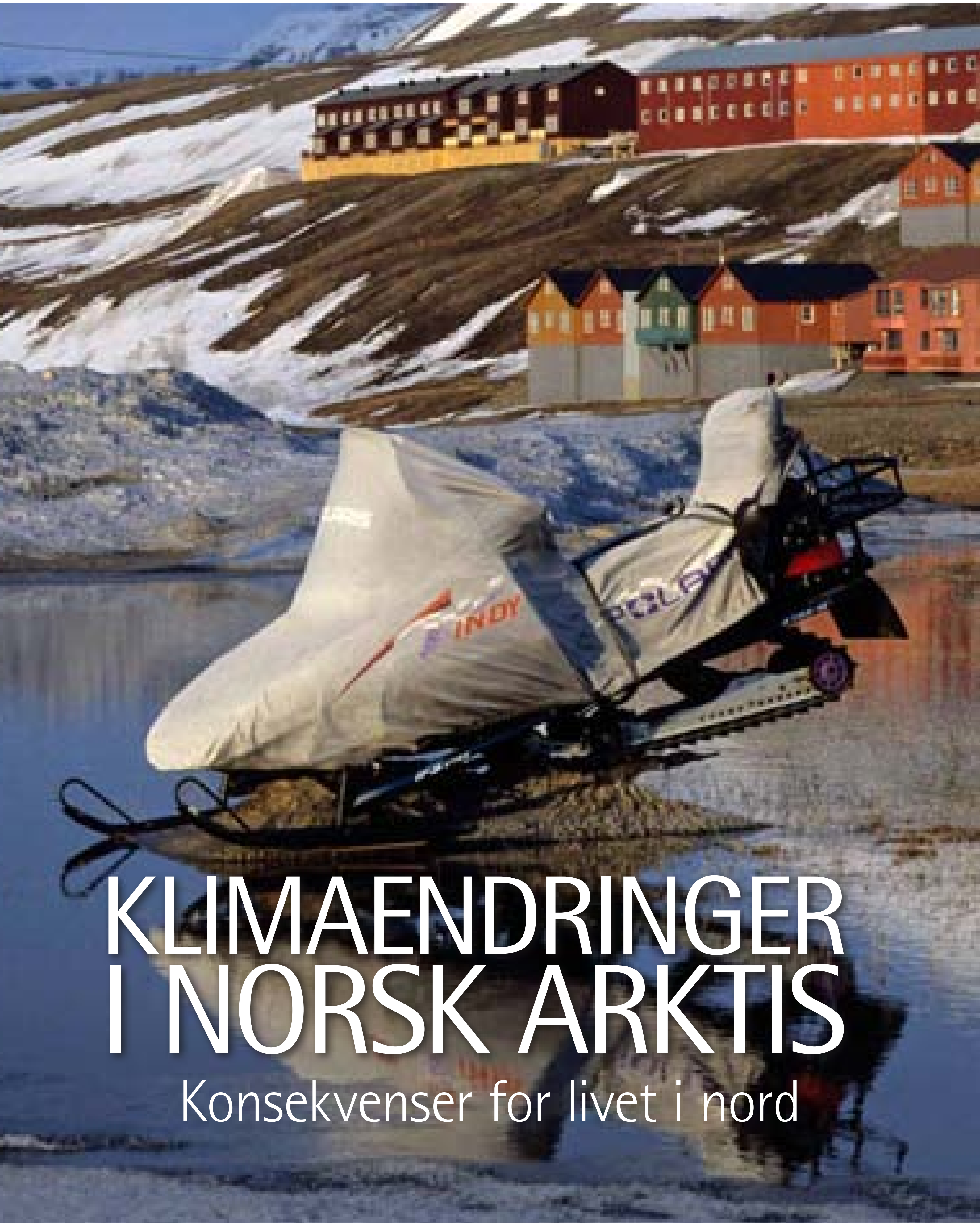

KLIMAENDRINGER I NORSK ARKTIS

Konsekvenser for livet i nord

Summary of the synthesis report “Climate changes in the Norwegian Arctic – consequences for life in the north”

Changes in climate will have an impact on both ecosystems and communities in the North. A summary is presented here of the eleven key discoveries identified in the NorACIA (Norwegian Arctic Climate Impact Assessment) project concerning Svalbard, northern Norway and adjacent maritime areas. Model calculations seek to predict the future development of the climate. The mechanisms controlling climate are, however, so numerous and complex that we may never succeed in constructing detailed and completely correct calculations of every impact that accompanies a change in climate. The uncertainty, which will always exist, must not mean that we refrain from reducing emissions and preparing ourselves for changes in climate and their impacts. This report is therefore a compilation of possible future events and probable impacts and consequences for the coming 90 years based on currently available knowledge.

Key discovery 1: The Norwegian Arctic will become warmer and wetter, but with large local variations

• The average annual temperature north-east of Svalbard may rise by as much as 8°C towards the end of this century. In mainland Norway, the rise is expected to be 2.5–3.5°C, least on the coast and most on the Finnmarksvidda plateau. Every season will experience an increase in temperature, but it seems likely to be greatest in autumn and winter, and higher over land than sea.
• Precipitation is expected to increase throughout the region in all seasons, but most in autumn and winter. However, there will be large differences within the region. Towards the end of this century, there may be a noticeable reduction in the snow season, two months shorter per year on the coast of northern Norway and one month on Finnmarksvidda.
• Extreme weather in the shape of strong wind and unusual amounts of precipitation may occur more frequently.
• The permafrost is thawing more rapidly than estimated earlier, and the trend has intensified in the past ten years. In general, the gradual warming of the permafrost is expected to continue, but an increasing frequency of extremely high temperatures may cause more irregularity.

Key discovery 2: Feedback mechanisms enhance global changes in climate

• The surface of ice and snow is light coloured and thus reflects the sunlight, which counteracts warming. The rise in temperature leads to the melting of ice and a shorter snow season, which in turn helps to increase the warming.
• Melting processes are reinforced when soot is deposited on ice and snow. Technology is commercially available that can help to reduce the discharge of soot from power generation, industry and ships, and this can help to slow down the changes in climate in the short term.
• The effect of clouds on the climate system in the Arctic is complicated and inadequately understood. Reliable estimates of the future cloud cover have still not been made for the Arctic.

• Calculations of the impacts of climate change on ocean currents and atmospheric systems are uncertain and more needs to be known to better understand how these key processes in the global climate system will change.

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

• Some pollutants are increasing in the Norwegian Arctic despite a large reduction in their use internationally, and changes in the climate system may be one reason for this.
• Transport of pollutants to the Norwegian Arctic by air and ocean currents, and their deposition there, may increase depending on how these transport mechanisms change with the climate.
• Pollutants which have previously been encapsulated in, for example, permafrost, glaciers and sea ice may be liberated to raise the levels in arctic rivers, fjords and lakes.
• Changes in climate at lower latitudes may lead to an increase in forest fires, which may increase the airborne supply of pollutants to the Arctic.
• Animals that are already under stress due to climate-related factors, such as loss of ice cover or hunger, will become more vulnerable to pollutants.
• Arctic organisms are vulnerable to ultraviolet (UV) radiation. Large quantities of ozone-depleting gases are no longer being emitted, and 2003–2004 was the first time a reduction in the concentration of important ozone-depleting gases was recorded over Svalbard. However, the ozone layer is not expected to return to its 1980 level before approximately 2050–2070.

Key discovery 4: The sea ice is diminishing, threatening species that depend upon ice

• Recent studies indicate that the extent of sea ice is decreasing faster than was calculated in models which formed the basis for ACIA (Arctic Climate Impact Assessment) and the fourth main report to the UN climate panel (IPCC).
• The absence of sea ice in itself leads to more rapid warming because of feedback mechanisms associated with incoming solar radiation.
• The trend for the extent of sea ice in the Arctic since measurements began in 1979 is declining, and in the last three years its extent has been at an historic minimum.
• There is less and less of the thick multi-year ice in the Barents Sea and the Arctic as a whole. This reinforces the melting because the thin, first-year ice melts more readily.
• Melting of the sea ice can lead to loss of biological diversity. Several species are strongly associated with the ice. Examples are ice algae which grow beneath and in the ice, seals which need ice on which to pup, polar bears which live on seals, and several species of seabirds which have much of their life cycle associated with the ice.

Key discovery 5: The ocean is becoming warmer and the ecosystems are changing

• Warmer seawater can give more phytoplankton and zooplankton, but there is no guarantee that fish and other creatures can turn this additional source of food to account.
• Owing to the ever-rising temperature of the ocean, more warmth-loving species may spread to the arctic regions and out-compete some species living there today.
• *Calanus finmarchicus* is extremely important in the polar marine ecosystems, and the rising temperature of the water puts it at risk of being out-competed by a southerly species that is a less nutritious source of food for fish. Likewise, *Calanus finmarchicus* may replace fattier, arctic species of zooplankton further north and give a poorer nutrient basis for, among others, arctic fish.
• Commercially important species of fish like cod and capelin may move further north and east, and into Russian waters.
• The maritime ecosystems have so far evolved under, and adapted to, natural variations in climate and seem quite capable of tolerating variations before dramatic changes occur. If the temperature exceeds the normal variations in climate, there will be more uncertainty regarding the response and toleration of the ecosystems. Climate is, nevertheless, only one of several factors that influence the ecosystems and it is the combined effect that determines the impacts.

Key discovery 6: Seawater is being acidified and the corals can die out

• The rising CO_2 concentration in the atmosphere is expected to lead to an acidification of seawater in the next hundred years that has not taken place during the past 20 million years.
• The water chemistry in the sea is changing, making it difficult for organisms with calcareous skeletons, like corals, to produce carbonate. Large parts of the deepwater coral reefs in Norwegian waters grow at depths where the water chemistry may reach critical values by the end of this century.
• Organisms with calcareous shells are expected to have to move to other areas or will have their range greatly reduced due to acidification of the seawater.
• In a global perspective, the arctic seas are most sensitive to this type of change.

Key discovery 7: Woodland is spreading northwards and upwards

• Birch and coniferous woodlands are expected to spread northwards and upwards onto non-wooded mountains and upland plateaus. Increased plant production and longer summers may give larger populations of many herbivorous species.
• Pests and parasites may increasingly attack woodland and forest. Animals are expected to suffer more parasite attacks.
• The phenomenon of lemming years may cease, and creatures which live on small rodents, like arctic foxes and snowy owls, may die out in northern Norway.

Key discovery 8: Freshwater ecosystems are vulnerable to climate change

• The changes in climate that are expected will have various kinds of impact on lakes and rivers, partly through changes in the water temperature, the permafrost in the ground around the lakes, the thickness of ice through the winter, the composition of snow and ice layers in the ice, how long the ice lasts, supply of nutrients from land and possible impacts from glaciers and floods. All this will help to weaken the stability of the freshwater ecosystems.

• The changes in climate may limit the opportunities for sea char to migrate in Svalbard.

• A milder climate in coastal parts of northern Norway may give a shorter period of ice cover on rivers and higher mortality among salmon parr. Higher water temperatures in rivers in summer may, however, lead to increased growth and thus raise the production of salmon in the rivers.

• Increasing seawater temperatures open the way for new species to migrate up watercourses, for example sticklebacks in Svalbard.

Key discovery 9: Infrastructure in the North is at risk

• The effects of climate change on the transport sector seem to be largely negative; greater risk of avalanches and floods, and problems with regard to the regularity of traffic.

• Municipal utilities like water mains and drains, and buildings, are exposed to floods, larger amounts of precipitation and more extreme weather.

• An ice-free Arctic Ocean in summer opens the way for new shipping routes, and more ships are expected to sail near Svalbard and along the Norwegian coast.

• Recent studies suggest that the global sea level can be expected to rise more than the IPCC predicted in 2007. This may give a rise in sea level in northern Norway of 40–95 cm (corrected for land uplift) by the end of the century, which may make the infrastructure along the coast more prone to wear and tear and destruction, especially during storm surges.

Key discovery 10: Nature-based industries get new opportunities – and problems

• Provided it manages to adapt to the new conditions, agriculture in northern Norway may perhaps profit from the changes in climate, if, for example, it proves possible to harvest grass twice during the summer instead of just once.

• Organic plant production in northern areas now enjoys advantages because of the current climate, but rising temperatures and more moisture may increase the likelihood of diseases and attacks by parasites.

• The area available for reindeer grazing is expected to shrink as the tree line creeps upwards and northwards, and this may, among other things, result in increasing land-use conflicts. In addition, when the temperature is oscillating around the freezing point, the reindeer may not be able to get to their food due to icing, and higher summer temperatures cause more trouble with diseases and parasites. Both the industry itself and the basis for Sámi culture linked with reindeer husbandry will be hit by the climate change.

• Fisheries will have to adapt to the fish changing their distribution. Some species, mackerel for instance, may become more common in these waters.

• Aquaculture in northern Norway may benefit from higher temperatures in the sea and because warmer water, up to a certain temperature, helps fish to grow more rapidly. Further south in Norway, the water temperature may be too high for salmon, for example. An increase in temperature may also make fish more vulnerable to diseases and parasite attacks.

Key discovery 11: Society can and will have to adapt

• The melting of sea ice in the Arctic opens the way for new commercial activity and new shipping routes. There will be a need for more regulation of human activity in northern waters, focus on discharges and potential accidents, and better readiness than today. More shipping may put further pressure on ecosystems and species which are vulnerable to climate change.
• Higher temperatures, a rising sea level, more precipitation and thus a greater risk of avalanches and flooding mean that infrastructure like roads, airports, railways, water supply and sewerage systems, power lines and buildings in northern Norway must be accommodated to the new climate situation.
• With appropriate adaptation, agriculture can succeed in exploiting the changes in climate to increase production in northern Norway.
• Fisheries can move to other areas when fish move northwards and eastwards, and new species may perhaps be commercially exploited.
• The migratory routes established in reindeer husbandry will be affected by an early thaw. The combined impacts on reindeer husbandry may call for changes in both land use and herd structure.
• Sámi occupations (reindeer husbandry, coastal fishing, farming, etc.) play important roles as pillars of Sámi culture. This strong interlock between occupations and culture means that changes in climate and their consequences will exert significant pressure on Sámi culture, and adaptation will be particularly challenging.

Recommendations to decision makers

It is difficult to take the correct decisions in a situation where a number of uncertain factors exist. We know, however, that the climate has already changed, and we know a great deal about future changes in climate and their possible impacts. Moreover, the long lifespan of the infrastructure and the sluggishness associated with changes in the structure of society and occupations mean that in many areas it is essential to act now to be prepared for the expected changes in climate. Future work on climate change in the Norwegian Arctic should take into account, among other things:

• The changes in climate in the Norwegian Arctic are first and foremost determined by greenhouse gas emissions in other regions. Yet the physical impacts of climate changes in the Arctic affect the entire planet. Pollution occurring directly in the Arctic, like discharges of soot, may also have an impact on the climate in the Arctic. In addition to the necessity to reduce global discharges and emissions, there is a need to focus on local ones and those in neighbouring areas.

• It is possible to reduce soot discharges both regionally and globally, and to slow down climate change in the short term, but these measures will not replace the need for dramatic cuts in global greenhouse gas emissions to limit and prevent long-term climate change.

• More shipping and commercial activity in the Arctic is a feasible adaptation to a changed climate, but may also reinforce the climate changes by, for example, producing greenhouse gas emissions and discharges of soot particles.

• It is necessary to secure a framework which can, in a good way, take into account increased activity in the Arctic as a consequence of easier access. It is necessary to reduce pollution from this activity and also increase monitoring and contingency to avoid major environmental disasters resulting from accidents along the coast and on the open sea.

• The changes in climate make the Arctic more vulnerable to both old and new pollutants. There is therefore a growing need to monitor the effects of the pollutants. Emissions of many old pollutants are now being reduced globally, and regulations of new ones are continually being introduced. Even so, the influx of pollutants to the Arctic may increase because of changes in the climate system. More stringent regulations of global emissions and discharges of pollutants must be considered, particularly for substances that are inadequately regulated today.

• Comprehensive monitoring of the trend in central climate parameters, the composition of the atmosphere and the ecosystems in northern Norway, Svalbard and surrounding seas must be ensured. Without this, it will be difficult to map and understand the impacts of the changes in climate.

• Protection policy should be reviewed with the aim of establishing links between protected areas from the coast, along valleys and up into the mountains. Such unbroken protected areas provide easier dispersal routes for species which must adapt to the changes in climate.

• In several fields, it is necessary to start the task of adapting to the changes in climate. Even though we do not know all the details of how the climate will develop in the future, we have a sufficiently good basis to begin re-planning society. The adaptation effort can start particularly quickly in areas where we already know enough to be aware that the consequences can be great if we do not get measures underway, for instance in the development and upgrading of infrastructure. Adaptation does not slow down the changes in climate, but if countermeasures are not introduced, society may meet challenges that adaptation cannot solve.

• Thawing permafrost, increasing precipitation, avalanches, floods and extreme weather will put pressure on existing infrastructure. The future development in the climate must form a basis for planning, maintenance and construction of all new infrastructures.

• Gaps in knowledge in many spheres can be closed. Sufficient resources must be made available for research to update the knowledge base on climate change and its impacts.

• Knowledge held by local and indigenous people must be utilised when we are assessing the problems and opportunities future changes in climate will bring. This will be able to improve our understanding of climate impacts and the space we have to adapt.

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Eirik J Førland (red), Rasmus E Benestad, Frode Flatøy, Inger Hanssen-Bauer, Jan Erik Haugen, Ketil Isaksen, Asgeir Sorteberg og Bjørn Ådlandsvik

Klimautvikling i Nord-Norge og på Svalbard i perioden 1900–2100

Klimaendringer i norsk Arktis

NorACIA delutredning 1

NORSK POLARINSTITUTT/NORWEGIAN POLAR INSTITUTE, POLARMILJØSENTERET/POLAR ENVIRONMENTAL CENTRE, NO-9296 TROMSØ

Summary of the report “Climate development in North-Norway and Svalbard during 1900–2100. Climate changes in Norwegian Arctic”

Introduction

Over the past two to three decades, Arctic land areas have experienced more warming than any other region on Earth and the sea-ice cover has decreased by about 10 % in the same period.The climate in the Arctic varies greatly from year to year, and on a decadal scale. A warm period, almost as warm as the present one, occurred in the Arctic from 1925 to 1945, but it did not have a global extent.

IPCC (2007) states that most of the recorded rise in globally-averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations and that there has probably been significant anthropogenic warming over the past 50 years, averaged over each continent except Antarctica.

Climate models furthermore indicate that anthropogenic global warming will be enhanced in high northern latitudes due to complex feedback mechanisms in the atmosphere – ocean – ice system. The climate change seen in the Arctic has already had major impacts on the environment and on economic activities. If the present warming continues as projected, these impacts are likely to increase, greatly affecting ecosystems, cultures, lifestyles and economies across the Arctic. The Arctic climate is a complex system and has multiple interactions with the global climate system. Changes in the Arctic climate are thus very likely to have significant impacts on the global climate system. Any regional attribution study for the Arctic must recognise the importance of natural variability. In climate model simulations, the Arctic signal resulting from human-induced warming is large, but the variability (noise) is also large. Hence, the signal-to-noise ratio may be lower in the Arctic than at lower latitudes. Scarcity of data and difficulty in obtaining measurements are other important issues for Arctic climate studies.

The present climate in the Norwegian Arctic

The Norwegian and Barents seas are exceptionally warm for their latitude. The Norwegian Sea is ice free except furthest north, in the Fram Strait. The Atlantic-derived water in the Barents Sea is also ice free, but most of the Arctic water has a seasonal ice cover. The Barents Sea is now essentially ice free in summer, with ice typically covering only a small area in the north-east. The ice cover, however, varies greatly from year to year.

Coastal parts of northern Norway usually experience a rather mild winter climate and cool summers, whereas the interior is dominated by a continental climate, with low winter temperatures and high summer temperatures. Svalbard weather stations record a maritime climate (relatively mild and humid) in years (or periods) when the sea around the stations is ice free. When the stations are surrounded by sea ice, the climate is continental (cold and dry) because the sea ice insulates the air from the latent and sensible heat sources in the sea, and also reflects much of the solar radiation. Thus the high-Arctic temperatures show great inter-annual fluctuations, considering the high latitude.

In northern Norway, there are large gradients in the annual precipitation. The highest average values are close to 3000 mm/year at weather stations in southern Nordland, whereas some stations in interior parts of northern Norway record an annual precipitation below 300 mm. In the Svalbard region, the annual precipitation is low because air masses are usually stably stratified and contain small amounts of water. On Spitsbergen, there is a gradient from relatively high values in the south-west to lower values in the north-east.

Climatic variability and trends in the 20th century

The recent global warming is widespread, with a maximum in high northern latitudes. The average surface temperature in the Arctic has risen by approximately 0.09 °C per decade over the past century, and the pattern of change is similar to the global trend (i.e. an increase up to the mid-1940s, a decrease from then until the mid-1960s and a steep increase thereafter with a warming rate of 0.4 °C per decade). It should be stressed that in the Arctic, a warm period, almost as warm as the present one, was observed from the late-1920s to the early-1950s.

The annual temperature in northern Norway has increased significantly in the past 100 years, with a linear trend of about 0.1 °C per decade. The warm period in the 1930s is very evident. All parts of northern Norway except the Finnmarksvidda plateau record significant positive temperature trends in spring, summer and autumn. The high-Arctic stations have a variability on a multi-decadal scale, leading to mainly positive temperature trends before the 1930s, a rather warm period in the next couple of decades, a temperature fall from the 1950s to the 1960s, and thereafter a general rise in temperature.

In the Longyearbyen area, the annual mean temperature has increased significantly from 1912 to the present day. The linear seasonal temperature trends at Svalbard Airport/Longyearbyen from 1912 to 2007 are +0.22 °C per decade (annual), +0.21 °C per decade (winter), +0.45 °C (spring), +0.10 °C (summer) and +0.16 °C (autumn). Except in winter, all the seasonal trends are statistically significant, at least at the 5 % level.

Observations suggest that the total annual precipitation has probably increased in the Arctic north of 60 °N over the past century. In northern Norway, except the Varanger Peninsula, the annual precipitation has increased by approximately 2 % per decade in the last 100 years. All Norwegian high-Arctic series show a positive trend in the annual precipitation throughout the period of observations. At Svalbard Airport, the annual precipitation has, on average, increased by 2 % per decade, while the increase on Bjørnøya is 3 % per decade.

In the last 2-3 decades, the temperature in the uppermost part of the permafrost layer (~2 m depth) at Janssonhaugen, near Longyearbyen, has been increasing by an average of 0.7 °C per decade. The average temperature increase at 30 m depth is about 0.35 °C per decade and at 60 m 0.05 °C per decade. The analyses also show that the temperature increase in the permafrost is accelerating, particularly during the last decade. With an Arctic undergoing rapid change, including an increased frequency of temperature extremes, the future warming of the permafrost can to a greater degree be more irregular than regular.

With around 140 individual cyclones and a mean residence time of 2.6 days, cyclones entering the Arctic are a common feature. Cyclones entering the Arctic from the Greenland or Norwegian seas show positive trends in both their mean intensity and in the intensity of the most intense cyclones. The cyclonic activity index has increased in all seasons, with an annual increase of 27 % over the 1950-2006 period.

Data on sea-ice cover back to the 1970s show a decline for the whole Arctic and for the Barents Sea in particular. ACIA stated that the average extent of Arctic sea ice has very probably been decreasing for at least 40 years. The time series of ice cover for April shows a strong reduction. For summer ice, the reduction is even more pronounced. After 2000, there have been four years with essentially no summer ice. Fewer data are available on ice thickness, but a time series from Hopen shows a reduction over a 40-year period.

Climate projections for the 21st century

The most sophisticated tools available for projecting global climate development are comprehensive Atmosphere Ocean General Circulation Models (AOGCMs) which include dynamical descriptions of atmospheric, oceanic and sea-ice processes and often land-surface processes. The resolution in the AOGCMs is currently adequate to model most large-scale features, but generally too poor to enable the models to reproduce the climate on regional or local scales. When more detailed climate data are needed, output from AOGCMs has to be “downscaled” by either dynamical (Regional Climate Model, RCM) or Empirical-Statistical (ESD) methods. Both these approaches were used by NorACIA.

Global climate model simulations indicate that by the end of the 21st century the Arctic temperature will increase by 7 °C and 5 °C for the A2 and B2 emission scenarios, respectively. The strongest warming will occur in autumn and winter. The Multi-Model Dataset used in the regional climate projections for IPCC (2007) predicted an annual warming of the Arctic of 5 °C by the end of the 21st century.

There are large discrepancies in how different global and regional climate models describe present and future ice conditions in the Norwegian Arctic, and the uncertainties in the Arctic climate projections are thus considerable. The dedicated NorACIA-RCM seems to give a realistic description of the present climatic conditions in northern Norway and the Svalbard region. Assuming that the input data are reasonable, the model probably also gives an adequate description of future climatic conditions. However, only a few global climate models are currently downscaled by the NorACIA-RCM. To provide a more robust description of the future climate in the Norwegian Arctic, Table 1 summarises the projections of temperature and precipitation given by various analyses.

Results from the NorACIA-RCM simulations up to 2050 indicate an increase in the annual temperature of approximately 1 °C in coastal areas of Nordland and Troms, and 1.5-2.0 °C in eastern parts of Finnmark and south-west of Spitsbergen. A large gradient in the magnitude of the increase is present from south-western to north-eastern parts of the Svalbard region. This pattern is found in many scenarios. The projected decrease in the sea-ice cover will largely influence the temperature in the lower atmosphere.

A stronger annual warming is projected from 1961-90 to 2071-2100 than up to 2050. In large parts of northern Norway, the temperature is expected to increase by 2.5-3.5 °C, least in western coastal areas and most in the Varanger area and interior parts of Finnmark. In Svalbard, the annual temperature is expected to rise by about 3 °C in the south-west and about 8 °C in the north-east. The projected warming is least for the summer season and most for autumn and winter. This is particularly valid for inland areas. A substantial increase in the air temperature is also projected for the waters between Svalbard and Novaya Zemlya, particularly in September to May. The rise will be greatest where sea ice is replaced by open water.

The ACIA climate scenarios projected that the annual total precipitation over the Arctic (60-90 °N) will increase by roughly 12 % from 1981-2000 to 2071-2090. IPCC (2007) reported that precipitation is very likely to increase at high latitudes. The percentage increase is largest in winter and smallest in summer, consistent with the projected warming.

For large parts of northern Norway, the projected increase in the annual precipitation from
1981-2010 to 2021-2050 is 20-30 %, whereas north-eastern parts of Spitsbergen will experience an increase of up to 40 %. The seasonal precipitation is projected to increase over the whole region in all seasons, the largest increase being in winter and spring. It should, however, be stressed that very little precipitation now falls in this region in winter, implying that, despite the large percentage increase, the absolute increase may be just a few millimetres.

The ACIA climate scenarios project that the Arctic snow cover will continue to decrease, with the greatest decreases projected for spring and autumn. The snow cover extent over higher northern latitudes has declined by about 10 % over the past 30 years, and model projections suggest that it will decrease by an additional 10-20 % before the end of this century. Projections for northern Norway indicate that the duration of the snow cover will be reduced substantially by the end of the 21st century. The biggest decrease (more than two months) is projected for coastal areas, while interior parts (the Finnmarksvidda plateau) will experience a decrease of less than one month. On the other hand, interior parts of Finnmark, mountainous regions and large parts of Svalbard may experience an increase in the maximum snow water equivalent. The reason is that although the snow season in these areas will be shorter in a warmer climate, the large increase in winter precipitation falling as snow will compensate for this.

The downscaled projections of changes in wind conditions do not give robust signals and result in large uncertainties. The NorACIA-RCM simulations of the average daily maximum wind speed for 1980-2050 indicate small changes in summer, but an increase north and east of Svalbard in the other seasons. Rather small changes are also projected for northern Norway up to the end of the 21st century. However, a more than 10 % increase in the average maximum daily wind speed in winter is indicated for the area north and east of Svalbard. This is linked with the extensive shrinking of sea ice modelled for this area. The NorACIA-RCM simulations for changes in the maximum wind speed indicate that values exceeding the 95 percentile will occur more frequently in future. The largest increase (1.5-2 times more frequent than the present level) is indicated for an area between Spitsbergen and Novaya Zemlya.

For heavy 1-day rainfall, the 5 % exceedance value (”95 percentile”) was used as an indicator. The results suggest that over most of the area at the end of this century this 95 % value will be exceeded 1-1.5 times more frequently than in the present-day climate. An increase in the number of days with precipitation exceeding 20 mm was also projected for the whole region. However, except for parts of Nordland, the number of days with heavy rainfall will still be quite modest over large parts of the region.

Projections for the number of days with heavy snowfall (>10 cm per day) indicate a decrease in coastal parts of northern Norway and south-western parts of Svalbard, and an increase in the interior of northern Norway and northern parts of Svalbard.

Pilot studies with the NorACIA-RCM led to the conclusion that the potential for Polar Lows off the coast of Norway will decrease.

A regional ocean model system has been used to simulate conditions in the Arctic Ocean and the Barents Sea. The control run for the present climate covered the period 1986-2000, while the scenario was taken from the period 2051-2065 using the A1B simulation. The control run gave good results in the western Barents Sea. In the east, however, the model suffered extensive heat loss to the atmosphere. The mean temperatures in September at a depth of 50 m increased by 0.9 °C in the area studied. The ice problem in the control run showed an unrealistic warming in the eastern part of the Barents Sea. In the western part, the warming was less than 1 °C. The downscaling shows a slight weakening of the Atlantic inflow to the Barents Sea with approximately the same heat transport.

The sea level is expected to rise during the 21st century, mainly due to the melting of glaciers and the thermal expansion of sea water. Changes in the circulation in the atmosphere and the ocean influence the mean sea level regionally. Recent estimates indicate a 10-20 cm rise in sea level along the coast of Troms and Finnmark towards 2050, and 50-70 cm towards 2100. These estimates are corrected for land uplift.

Downscaling has been performed to assess changes in the future wave climate. Areas that are now ice covered in winter and will be ice free in the future will experience a rougher wave climate. Otherwise, the changes are not significant. The storm surge climate does not show a significant change on a yearly basis, but there is a significant increase in autumn surge activity. However, combined with the mean sea level rise, the impact of the surges may become more severe.

It is important to bear in mind that the projections of local and regional changes in climate contain many uncertainties and shortcomings:
• Unpredictable internal natural variability (particularly large in the Nordic Arctic)
• Uncertainty of climate forcing mechanisms
• Imperfect climate models
• Weaknesses in downscaling techniques

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NORSK POLARINSTITUTT

Kim Holmén og Winfried Dallmann (red)

Fysiske og biogeokjemiske prosesser

Klimaendringer i norsk Arktis

NorACIA delutredning 2

NORSK POLARINSTITUTT/NORWEGIAN POLAR INSTITUTE, POLARMILJØSENTERET/POLAR ENVIRONMENTAL CENTRE, NO-9296 TROMSØ

Summary of the sub-report “Physical and biogeochemical processes. Climate changes in the Norwegian Arctic”

Physical feedbacks

Human-induced climate change will have more effect in the Arctic than elsewhere on the Earth. The main reason for this is a simple physical feedback: when snow or ice melts, the surface becomes darker and thus absorbs more sunlight, which leads to further warming and more melting.

Physical feedbacks play a major role in the Earth’s climate system. It is essential to understand them to be able to predict the future climate. Climate models take several of these processes into account, but many processes in real life are comparatively incompletely described. This is partly because of lack of knowledge, but also because many of the processes that are known take place on a scale which the models are unable to resolve. Simplified models are used to find the outer limit of what the future may hold.

A fully overarching physical feedback is how the large-scale circulation in the atmosphere and the ocean will change in the future. When the Arctic warms up more rapidly than the rest of the Northern Hemisphere, the difference in temperature between the Polar regions and the middle latitudes will decrease, thereby changing the premises for the entire wind system. It is absolutely essential to understand the changes on this scale to be able to discuss details in the changing of the processes on regional or local scales. NorACIA scenarios have only been worked out using a limited number of large-scale experiments and must therefore be interpreted with care, as studies of examples rather than illustrations of the entire span of a possible development. The NorACIA discussions must be viewed in the light of this limitation in our possibility to understand how the overarching physical feedbacks influence the changes in climate.

Important physical feedbacks which may significantly influence regional and local climates in the future are described and discussed here. Special attention is directed towards processes that are important for the Norwegian Arctic.

Oceans

Future changes in the Norwegian Arctic are especially linked to potential changes in the Barents Sea, which would give different premises for the formation of sea ice in the region and for the weather in northern Norway and Svalbard. The influx of relatively warm Atlantic Ocean water affects the entire Barents Sea and lays the premises for changes in the quantity of ice and, of course, for the vital necessities for many commercial species and the marine ecosystems. The water temperature in the Barents Sea is an important factor that controls wind patterns and weather in the area. The position of the Polar Front is decisive for where the bulk of the biological production takes place, and also for where the contrasts in temperature in the sea are. Its position in the western part of the Barents Sea seems to be strongly controlled by the seabed topography and is thus stable so far. Admittedly, we know too little about what is required to get the Polar Front to move away from these topographical barriers. At the same time, there is a threshold effect here, where sudden and major changes can take place if the warm water continues northwards past Bjørnøya. The Polar Front in the east is more variable and moves northwards when the climate is warmer, thus giving different conditions for ice and organisms.

Gaps in knowledge:

- Research on the stability of the Polar Front west and south of Spitsbergen is required to be able to say something about the possibly important threshold for conditions in Svalbard.

Atmospheric circulation

The air flows to the Norwegian Arctic are controlled by the large-scale circulation patterns. The North Atlantic Oscillation (NAO) and the Arctic Oscillation (AO) seem to be two different characteristics of an overarching change in the atmosphere. According to the models, these will be in a “positive” phase, carrying mild, moist air to Scandinavia and beyond to the Barents Sea. This has been observed in the atmosphere, but in the past ten years the circulation has diverged from the classic patterns to give a relatively neutral phase, but still with mild winds in the region.

Gaps in knowledge:

- Since the winds to a fairly large extent influence the transport of water to the Barents Sea and any changes in the Polar Front, research on and understanding of what controls the large-scale wind patterns in the region are absolutely fundamental if we are to determine what will take place. Detailed studies of local or small-scale changes in the climate give only added value if these large-scale changes are correctly reproduced in our models.

Clouds

The amount of cloud in the Arctic has probably increased due to less ice, because that gives more evaporation and thus more water vapour that can form clouds. The net effect of clouds for the radiation balance seems to be more warming than cooling. White clouds do not reduce the incoming radiation to the surface if the surface is already white (snow or ice), and clouds have no influence on the incoming solar energy during the polar night. As reflection of heat radiation is restrained by clouds irrespective of the season, a larger amount of cloud generally warms the Earth’s surface in the Arctic. Warming of the Arctic also increases the chance that the clouds will contain drops of water instead of ice crystals, which further boosts the warming effect. Observations indicate an increase in the amount of cloud in the Arctic, which is also consistent with the summer temperatures having risen.

Gaps in knowledge:

- A major gap in knowledge is our understanding of clouds in the Arctic and how they are changed by changes in moisture and temperature. The effect of particles on the formation of clouds is, moreover, still less well known, especially in the case of clouds in the Arctic.

Hydrology

Arctic hydrology is strongly influenced by frost in the ground and by permafrost. When snow melts earlier in spring, thawing of the ground will also start earlier and will reach deeper. This gives different premises for runoff of water and for the entire hydrology of the soil. More precipitation generally leads to increased runoff, and if the precipitation comes as rain on ice, the melting accelerates. The runoff is expected to increase in winter and decrease in summer in northern Norway. Enhanced runoff will influence the coastal oceanography and hence the ecosystems there.

Gaps in knowledge:

- Changes in hydrology depend greatly on local soil conditions and topography. Detailed hydrological studies are especially desirable, but will only be justified when good scenarios for the large-scale changes in precipitation and wind are available.

Sea level

The sea level has been rising for a long time, as has been confirmed by satellite data for the last 15 years. In Norway and the Norwegian Arctic, the relative rise in sea level (the rise seen when we stand on the shore) has been quite modest because it is counteracted by land uplift. The sea level changes when water from glaciers on land enters the sea (through melting or calving) and by the warming of the sea (the water expands). The supply of water to the sea from glaciers and icecaps has changed greatly in recent years and constitutes an element of uncertainty for the future. Regionally, the effects of changes in atmospheric pressure (controlled by temperature and wind patterns) and movements of ocean currents may give sea-level changes. There are expected to be large regional differences in how much the sea rises in Norway and the Norwegian Arctic.

Gaps in knowledge:

- Understanding the regional effects on the sea level demands especially good knowledge of the regional trend in temperatures in the sea and the large-scale changes in the air circulation (and thus the atmospheric pressure).

Sea ice

The sea ice has decreased in extent throughout the Arctic in summer. There has been less ice in all of the last five years (2005–2009) than in earlier years (since 1979 when data began to be collected). The ice has become thinner almost all over the Arctic and has generally become younger. Consequently, the Arctic is now covered by a layer of ice which can melt more rapidly than earlier since less warmth is required to melt thin than thick ice and thin ice can be more easily deformed and moved by the wind. Detailed studies in the Barents Sea show increased melting in summer everywhere. Sea ice still forms in the Arctic Ocean and the northern Barents Sea in winter. A decline in the extent of ice is, nevertheless, observed in winter further south in the Barents Sea (76-78 ºN), too, leading to changed prerequisites for heat exchange between the atmosphere and the sea, increased evaporation and more mixing in the sea through the influence of the wind.

Gaps in knowledge:

- The processes that control the melting of ice in the sea need to be better understood.
- The representation of sea ice processes in the climate models is perhaps one of the greatest weaknesses in the models and needs to be improved. This requires better understanding of the actual processes.
- More needs to be known about the effects of changed ice conditions (both

summer and winter) on the ecosystems.

Glaciers and snow

Glaciers in Norway and Svalbard are continuously decreasing in volume, with the exception of some coastal glaciers on the mainland. Most glaciers have retreated since 2000. The glacier snout is often used as an indicator of the trend of the glacier, but this can give a misleading impression because the snout may move through redistribution of the ice without a change in the total volume of ice (for example, a surge does not entail increased melting, just a movement of ice). Mass balance studies nevertheless show a reduction in the volume of ice, which is confirmed through a number of independent techniques. Nevertheless, the mass balance in Svalbard has been clearly negative in all glaciers experiencing a large loss of mass in the past ten years. The negative mass balance is first and foremost associated with melting in summer, whereas the winter balance has been relatively stable over the last 40 years. Several glaciers in Svalbard show increased melting in recent decades. The snow cover in southern Norway has become thinner and more short-lived. No trend in the thickness of the snow cover in northern Norway and Svalbard has been demonstrated.

Gaps in knowledge:

- The processes controlling melting and surging of Svalbard glaciers are still not clarified.
- The effect on the glaciers of changes in the amount of cloud is uncertain, but probably important.
- There is a great need for good data on snowfall, amounts of snow and distribution of snow in Svalbard.
- The influence of pollution on the melting of snow and ice must be verified and quantified.

Albedo

Feedback on albedo (the ability of a surface to reflect sunlight) exists on several scales. Melting of snow and ice exposes darker substrates which absorb more sunlight. This has been demonstrated particularly for sea ice in the Barents Sea and for southern Norway through earlier melting of snow, but there is little quantitative data for Svalbard, even though many indications point in the same direction. On a smaller scale, snow may be recrystallised into larger crystals which are somewhat darker coloured and thus absorb more light. This process probably increases in a warmer climate, but is not yet quantified in Svalbard. When melting takes place, running water may even collect on the surface of glaciers or sea ice, producing a darker area which therefore increases the melting. This phenomenon has recently been shown to be an important mechanism that helps to explain the observed melting of sea ice. Finally, contamination on the snow (especially soot, but also other substances, minerals and stones in the glacier) can be concentrated on the surface during melting and lead to reduced albedo and increased melting.

Gaps in knowledge:

- Albedo changes must be quantified and ranked in their impact to be able to identify which processes are actually of great significance in the Norwegian

Arctic. When the processes are better understood, the models can also be improved in this field.

Carbon cycle

Terrestrial systems at high latitudes are characterised by the fundamental fact that photosynthesis is less dependent on the temperature than the respiration. A certain amount of photosynthesis nevertheless takes place (in the Arctic, too), but organic material decays very slowly. The soil therefore contains carbon to a much greater degree as humus and other reducing forms of carbon than the living biomass above the surface. Climate change may give changes in growth, but changes in the soil can potentially result in large emissions of carbon dioxide, methane and nitrous oxide to the atmosphere. These emissions are regulated by many factors, like frost and moisture in the soil, access to nutrients and the type of carbon deposits in the soil. Higher temperature will probably result in increased emissions to the atmosphere, but studies that have been performed suggest a markedly patchy landscape where there will be large local variations in the net effect. The carbon store in the soil and wetland has been built up over a long time (since the last Ice Age) and is a huge, long-term reservoir. Studies of the net exchange to and from soil over a relatively short period (some tens of years) may therefore give unexpected results that are difficult to interpret. The reason is that emissions can be dominated by changes in the huge reservoir rather than being linked to the primary production at the site. Methane hydrate is an important factor in this context, but the hydrate reservoirs on land in the Norwegian Arctic are probably very limited.

The carbon cycle in the ocean is complex and depends on the temperature conditions, stratification in the ocean, ice conditions, ocean currents, supply of water from land, access to nutrients and biological production. More carbon dioxide in the atmosphere gives higher concentrations of dissolved organic carbon in the ocean (carbonic acid), which raises the acidity. Organisms which make calcium carbonate shells can find it difficult to do so in a more acidic ocean. This can lead to major changes in the mutual competitive relationships between species and, thus, changes in the ecosystems. The acidification effect is expected to be higher in the Barents Sea region than in other parts of the world's oceans.

A warmer ocean will result in major changes in the transport of carbon and in the ecosystems, but our level of knowledge is so limited that it is uncertain what the net effect on the carbon flow between the atmosphere and the ocean in the Norwegian Arctic can be. An important, but little discussed, threshold effect in the carbon cycle in the Norwegian Arctic is that if the ice-edge zone with its high productivity moves from the shallow Barents Sea to north of the continental shelf a drastic regime shift may take place, where the primary production – with bound up nutrients – is no longer limited downwards by conditions on the seabed, but disappears down into the deep ocean.

Methane hydrate has been found in sediments around Svalbard, and methane emissions have been recorded from sediments in the sea. Admittedly, it has not been shown that these emissions are a response to changes in temperature, but there may potentially be a methane reservoir which can be mobilised relatively rapidly.

The Norwegian Arctic is characterised by relatively limited areas of wetland (wetlands are being intensively studied in Siberia and Canada), but large areas of comparatively shallow sea where ice conditions are already changing rapidly. The

Barents Sea and the changes there stand out as an absolutely key part of the system, also with respect to the carbon cycle.

Gaps in knowledge:

- How will climate change alter the emissions of carbon dioxide, methane and nitrous oxide from the soil and tundra in the Norwegian Arctic?
- How will the carbon reservoirs in soil and ocean sediment be influenced by climate change?
- How will the ecosystem in the Barents Sea be altered by climate change and changes in the concentration of carbon dioxide?
- Are we close to a regime shift, where important parts of the primary production will move from the continental shelf to the deep ocean in the Arctic?

Atmospheric air pollution

In addition to the increase in greenhouse gases, people affect particles in the atmosphere, the amount of soot in the atmosphere and several other kinds of air pollution.

Particles (especially sulphate, which is formed by sulphur emissions from combustion) in the atmosphere are capable of influencing radiation and the formation of clouds. Larger amounts of particles probably give rise to clouds with more, but smaller, drops of water which have a somewhat higher albedo, and particles can spread and reflect light so that less sunlight reaches the ground. Both these effects may potentially reduce the warming. Particles in the Arctic in winter have a much longer conversion time in the air than at lower latitudes because the lack of sunlight means that few chemical conversions take place in the air, and because the small amount of precipitation gives little deposition of particles on the ground. The lack of sunlight in winter also means that the light scattering effect of the particles has little significance. The net effect of the particles on the arctic atmosphere therefore remains uncertain.

Soot may potentially give large changes in the albedo by being deposited on the snow or attaching to snowflakes falling through the atmosphere. This may increase melting in spring because soot absorbs a great deal of sunlight. It is potentially possible by relatively simple means to reduce the amount of soot in the atmosphere and thus counteract the warming for a period. It has also been claimed that large parts of the warming observed in recent years may be due to soot lying on snow and ice. Ice cores from Greenland (which mainly receives soot from North America) show a reduction in the amount of soot since the 1950s, which is consistent with the technological development related with the use of coal in industry. An increase in the amount of soot in the air has been observed locally on Zeppelinfjellet in the last three years.

Large quantities of ozone-depleting substances are still found in the atmosphere, and these result in the breakdown of stratospheric ozone. Changes in the quantities of ozone influence the amount of ultraviolet radiation reaching land and the ocean. Enhanced ultraviolet radiation on the ocean surface may cause species of plankton to die, thus producing changes in the ecosystem. Data gathered in Ny-Ålesund since 1980 show less UV radiation, which is explained by an increase in the cloud cover. Changes in the extent of sea ice are expected to have much more effect on the amount of UV radiation reaching plankton than changes in the amount of ozone in the atmosphere.

Several types of pollutants are transported to the Arctic by air and sea. Special attention has been directed at the persistent pollutants like PCB. Despite lower emissions, an increase in the concentration of certain substances has been observed at Zeppelinfjellet in recent years.

These increases seem to be associated with effects that are a consequence of warming. Substances that were formerly stored in the ocean or in the ice are liberated into the atmosphere when the sea becomes warmer. There are, moreover, changes in the circulation which carries air to Svalbard from lower latitudes. As mentioned earlier, there has also been some increase in soot in recent years, which is consistent with an interpretation that there is an increase in the transport from polluted areas to the Arctic.

Combustion of biomass and forest fires which liberate pollutants stored in the biological material are also factors which have had some important eruptions in recent years, and may help to explain the observed changes in the concentration. This is also consistent with the observations of soot. The mechanisms are still uncertain, but concentrations of several types of pollution are increasing in the Arctic owing to the rise in temperature.

Gaps in knowledge:

- The role of particles in the radiation balance in the Arctic, both directly and indirectly through changes in cloud formation.
- The special longevity of particles in the atmosphere in the Arctic.
- Quantification of the role of soot in the warming of the Arctic.
- Identification and quantification of processes which control the concentration of pollutants in the Arctic as a consequence of climate change.
- A complete system of observations for the Arctic which give a representative picture of what is actually taking place. Many of the conclusions and examples in this section are based on isolated observations from places that are not necessarily representative for the entire region. The SIOS initiative (part of the EU infrastructure programme, ESFRI) is envisaged to fill these weak points in our observations, which is absolutely essential if our level of knowledge is to be radically enhanced in the next few years.

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Harald Loeng, Geir Ottersen, Martin-A. Svenning, Audun Stien

Effekter på økosystemer og biologisk mangfold

Klimaendringer i norsk Arktis

NorACIA delutredning 3

NORSK POLARINSTITUTT/NORWEGIAN POLAR INSTITUTE, POLARMILJØSENTERET/POLAR ENVIRONMENTAL CENTRE, NO-9296 TROMSØ

Summary of the sub-report “Effects on ecosystems and biodiversity. Climate changes in the Norwegian Arctic”

Substantially greater changes in climate are expected in the Arctic than elsewhere on the Earth and, despite some uncertainties, climate experts have now formed quite a good impression of coming changes in the atmosphere in arctic regions, whereas it is less clear how the changes in climate will affect the oceans. The air temperature will rise in both summer and winter, and precipitation, probably mostly falling as snow, will also increase. Knowledge of climate change effects on the various ecological systems in the Arctic is, however, very meagre. This report describes the status in the marine, terrestrial and limnic ecosystems in the Arctic, and then tries to shed light on what are assumed to be the most important ecological effects the future changes in climate will inflict on these ecosystems.

Major biological changes in the *primary production and phytoplankton* of the marine ecosystem are not expected in the coming decades. A few species may, however, display concrete effects of acidification already in the course of a few decades, and these may be expected for one species after another further ahead in time. Large-scale changes in primary production and for zooplankton will change the availability of food for other species, including fish. In practice, this trend is impossible to reverse by taking actions in the short term. The *zooplankton* biomass may increase if the climate becomes warmer. Several species may extend their distribution, and the total production of zooplankton biomass may also change.

To be able to demonstrate changes in *demersal animals and macro-algae* during a chosen period, it is essential to know the distribution of the species at the outset of the period. In general, such knowledge is lacking for bottom-dwelling organisms in Norwegian waters. We can, nevertheless, suggest some consequences of a rise in temperature; for example, new species will move northwards. Generally speaking, species will move northwards and eastwards. The relative proportions of species in an area may also change.

As regards *fish*, higher sea temperatures have proved positive in the past for recruitment of cod, herring and haddock in northern waters. On the other hand, a warmer sea will also lead to fish becoming more widely dispersed and entering the north-western part of the Norwegian Sea and the north-eastern part of the Barents Sea, where the temperature is now lower and the distribution of prey differs, or prey are limited. Some species of *marine mammals* are strongly attached to ice habitats for reproduction or to seek food, whereas others seek food in frontal zones. In both these groups, changes in the area covered by ice, or in the location of fronts where production is high, may have significant effects on the population level. A northerly shift in the distribution of species that feed in the Norwegian Sea is expected, and some high-arctic species will therefore be displaced northwards and new, more warmth-loving species will enter from the south.

There is little doubt that a substantial change in the climate will have far-reaching consequences for the species of *seabirds* present here. The consequences need not be negative. A change in climate up to 2080 will probably have a positive effect on several species, but it must be emphasised that there is great uncertainty here.

Higher sea temperatures may make it simpler for *new species* coming from the south with the Norwegian Coastal Current or the Atlantic Ocean Current to become established in the Norwegian Sea and the Barents Sea. This applies both to species that have lived in the North Sea for a very long time and those that have been introduced more recently through human activity. The effects of climate change must also be considered across groups of organisms and biological systems. Knowledge of biodiversity, key species, distribution in time and space, production potential, ecosystem interactions and vulnerability is essential to be able to say something about integrated effects in the ecosystem.

A rise in temperature will result in many species in the terrestrial ecosystem extending their distribution northwards. Species that are now exclusively found further south will become established in northern Norway, Svalbard and Jan Mayen. This will give an increase in the diversity of species, but there is also a risk that a few of the present-day key species will disappear. Species that now occur in northern areas will extend their distribution to higher altitudes and colder, inland areas. In northern Norway, an increase in the extent of coniferous forest, in particular, will have significant repercussions on the ecosystems.

A rise in temperature will give *plant communities* an earlier start to their growing season, a longer growing season and higher primary production. The moss cover will be reduced and grasses and herbs, in particular, will increase their distribution and density in the Arctic and the mountains. Both coniferous forest and birch woodland will increase their distribution northwards and to higher altitudes. A few species, like bilberry, may respond negatively to more frequent periods of mild weather in winter.

An increase in the primary production and milder winters will give larger populations and a wider distribution of many *herbivores*. In particular, the species diversity and populations of insects and members of the deer family can be expected to rise. Reindeer may be facing a more insecure future.

Effects on *predator* populations will probably primarily be revealed by the way the climate affects the population size of their prey. In addition, species which are attached to woodland, like lynx, may increase their distribution and the size of their population. The expected discontinuation of peak years for lemmings will have great importance for the alpine ecosystem in northern Norway. The rise in temperature is expected to give an earlier spring peak for many species of insects that are important food for *birds* in the nesting period. The migrating and breeding periods of many species of birds are expected to shift to coincide with the spring peak of insects. The rise in temperature and the greater diversity of host species will give a higher diversity of *parasites*. Problems with mosquitoes, biting flies and ticks may increase.

Effects in the ecosystem perspective are difficult to predict. It is still difficult to construct quantitative models for the effect of climate change on the ecosystems because little quantitative information on the strength of the climatic effects on individual species and the ecosystem interactions is available.

The expected impacts on the limnic (fresh water) ecosystems as a consequence of higher temperature and precipitation are extremely complex, with a number of direct and indirect cause and effect relationships. The increases in temperature and precipitation will, for example, affect parameters like the water temperature, permafrost, ice thickness and quality, duration of the ice cover, runoff, impacts of flooding and glaciers, and supply of nutrients. The likeliest most important physical effects on limnic ecosystems will, nevertheless, be linked with the duration of the ice-free period. Thawing of the permafrost may also result in the disappearance of the shallow resources of fresh water in arctic areas (Svalbard). The impacts of climate change on *primary production, plankton and demersal animals* will probably differ in the freshwater ecosystems in northern Norway and Svalbard. In northern Norway, there will probably be a higher production of algae and phytoplankton, which, in turn, will favour the production of *zooplankton*. Studies in Svalbard, East Greenland and high mountainous areas on the mainland suggest that more precipitation in the form of snow compensates for rising air temperature and leads to shorter ice-free periods and lower production in lakes. If the climate gets warmer, *zooplankton* will probably increase the number of generations per year, and species that have a perennial lifecycle may evolve an annual one. All told, this will enhance the growth rate in the populations. In the most extreme high-arctic areas, such as Svalbard, a rise in precipitation in winter may, however, reverse the assumptions mentioned earlier.

Higher winter and summer temperatures give higher growth and production in the freshwater stage in arctic *fish populations*, whereas this may be strongly compensated for by increasing precipitation in the form of snow. Small changes in the air temperature and the precipitation have a great impact on the discharge in the rivers down which the anadromous Svalbard char reach the sea, and thus in the life history and survival of the char. A change in climate will alter the competition between species. Sea char, for example, have declined greatly in rivers in northern Norway over the past 10 years, whereas the quantity of sea trout has increased. Higher sea temperatures result in anadromous species of fish moving further northwards, thus increasing the probability of new species becoming established in lakes in Svalbard. One example is the stickleback, which has now been found in two rivers on Spitsbergen.

As we have seen, changes in climate may alter both the production and the array of species in the ecosystems. In addition to the long-term climate change that will come, there will be natural oscillations in the ecosystem because that is affected by annual variations in weather conditions and the balance between the plant and animal life. To be able to distinguish natural oscillations from changes in climate, and the resulting effects on the ecosystem, scientists within the disciplines of oceanography, sea-ice studies, meteorology, and biology and ecology need to work together. Specialists from the social sciences must also be involved to gain a deeper understanding of the consequences changes in the ecosystem may have for society and the development of business and industry.

A key question is whether changes in climate can bring about far-reaching changes in the northern areas. By ”far-reaching changes” we mean, here, that the structure of the ecosystem changes so that other groups become dominant. We also need to know more about how various kinds of human activity (for example, development of infrastructure, agriculture, forestry, fishery and petroleum activity) can alter the resilience of the ecosystem to withstand climate change. Ecosystem models must be extended and modified to include new processes and components as new knowledge becomes available. They must include synergistic effects of pH, pCO_2, climate and temperature. There is a great need for more quantitative knowledge on the effects of the direction, strength and variation of climate change on production and trophic interactions in the food chain (interactions between different levels in the chain).

Climate change may lead to changes in the timing of reproduction at different levels in the food chain. It is not clear whether the seasonal co-variation that has evolved between prey and plants, and predators and grazers, will continue and produce ecosystems with corresponding functions in the future. More needs to be learnt about this to gain a better understanding of how the ecosystem may react to changes in climate. Climate change may also lead to new infective organisms (viruses, bacteria, parasitic animals and plants) becoming established. More knowledge is required about which species of infective organisms this may concern and the effects they may have on populations, as well as how they influence interactions between species.

Species can be indirectly affected by changes in climate in that prey on which they live or species with which they compete are affected. The stronger such indirect effects are, the more difficult it may be to predict their total effects in the system. To be able to say something about the predictability of the ecosystems it is therefore necessary to know about the significance of such indirect effects of climate. Many arctic species have relatively small habitats and specific demands to their surroundings and food, and it is not known how these organisms will respond to increased competition from more opportunistic, boreal species.

Nearly all evaluation of the effect of UV radiation on algae is based on short-term studies. As long-term studies of radiation on both individuals and production in the marine ecosystem are lacking, there is a need for more effort to acquire such information. Most of the existing data on biological effects of acidification result from the demonstration of substantial changes in pH. Since more moderate changes in the pH in the sea and fresh water are expected in the coming 10-100 years, knowledge is needed about their biological effects. It is especially important to focus on the effects of moderate acidification on the species composition and succession patterns in phytoplankton, as well as on reproduction processes and survival of eggs and larvae in the large groups of animals in the food chain.

Little research has been performed that can help to predict how the toxicant load will change as a consequence of climate change. There is a great need to map how changes in atmospheric and ocean currents will affect the supply of pollution and how the composition of toxicants that impact on arctic ecosystems will change as a consequence of that. It is also important to learn how changes in the pollution load, temperature and other stress factors in aggregate influence species and ecosystems. Such knowledge is vital to be able to predict the effect of the changes and perhaps do something to counter the most damaging impacts.

Our understanding of ecology and the development of models lie far behind the climate models when it comes to detailed predictions in time and space. It appears as if the quality of future predictions for the development in the ecosystems in northern areas is chiefly limited by our knowledge of ecology and, hence, our ability to incorporate changes in climate in appropriate ecosystem models. More knowledge about which major changes can be expected in the ecosystems as a result of climate change must therefore come through better understanding of the effect of the climate on the species, their ability to adapt to, or compensate for, climatic change, and the interactions between the species in the ecosystems. Such studies should be combined with monitoring to have a possibility to become aware of major, undesirable changes at an early date and thus make it possible to introduce countermeasures at an early stage. With a view to such countermeasures, better knowledge should be acquired of how different nature management strategies influence the ecosystem. Such knowledge will make it feasible to evaluate possible countermeasures against particularly undesirable trends.

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Arild Buanes, Jan Åge Riseth og Eirik Mikkelsen

Effekter på folk og samfunn

Klimaendringer i norsk Arktis

NorACIA delutredning 4

NORSK POLARINSTITUTT/NORWEGIAN POLAR INSTITUTE, POLARMILJØSENTERET/POLAR ENVIRONMENTAL CENTRE, NO-9296 TROMSØ

Summary of the sub-report “Effects on people and society. Climate changes in the Norwegian Arctic”

This report seeks to take stock of the work done to evaluate the effects on, and vulnerability of, society for climate change in the northern parts of Norway (North Norway and Svalbard). How vulnerable a society is to climate change is an aggregate result of exposure, sensitivity and adaptability. Since adaptation and adaptability influence vulnerability, it is impossible to evaluate the vulnerability of societal systems to climate change based merely on a linear cause-and-effect relationship from changes in climate and climatic impacts on ecosystems to impacts on society. Adaptation and adaptability are dealt with in NorACIA’s sub-report no. 5; this sub-report concentrates on exposure and sensitivity to climate change and methods to evaluate the vulnerability of society from this perspective. The task of studying and assessing vulnerability to climate change has not been taking place for long in Norway. Some key themes are addressed in separate NorACIA sub-projects, but this report also draws on other works. Most investigations on this issue are general for the sector or field on which they focus, and often have limited evaluations of geographical variations between regions and parts of a country. This means that the thematic review in this report is correspondingly general for some sectors and fields. People and society are exposed to the impacts of climate change through changes in the weather (temperature, wind and precipitation), impacts on natural systems (including sea level, waves, erosion and biological and ecological changes) and impacts on such aspects as infrastructure and business sectors. For many players and sectors, the impacts of climate policy (like levies on greenhouse gas emissions) are noticed before, and to a greater extent than, the impacts of the climate change itself. However, this sub-report only looks at the direct and indirect impacts of climate change, not climate policy. It takes as its basis several recent contributions which seek to develop perspectives on vulnerability and adaptation to climate change accommodated to Norwegian conditions. Several of these have been developed under the NorACIA umbrella. They distinguish between three main types of vulnerability:

1. Natural vulnerability: processes in nature which are exposed to impacts of climate change; for example, landslides, floods and changes in biodiversity. This corresponds to exposure to climate change.

2. Socio-economic vulnerability: factors and processes in society which influence vulnerability to climate change. Examples are the proportion of employees in businesses that are vulnerable to climate change and the proportion of infrastructure and buildings that are located in areas exposed to landslides. This gives an impression of their sensitivity to climate change.

3. Institutional vulnerability: the capacity in different institutions to carry out measures to adapt to climate change; adaptability. Examples here are access to expertise and economic resources to implement measures for adaptation.

Both ”top-down” and ”bottom-up” methods of performing such vulnerability assessments have been tested within the framework of the NorACIA project. Using top-down methodology, the vulnerability of a region or sector is evaluated with the help of macro-economic data, surveys and/or other statistics. In bottom-up methodology, local inhabitants, users and others with special interests are involved in evaluating the vulnerability. The report reviews how climate change may affect infrastructure, occupations based on natural resources, health and environmental conservation. Special focus is also placed on groups and regions that are considered particularly vulnerable to climate change, including the use of methods to evaluate municipal vulnerability. The consequences of climate change for society may be reinforced or countered by other trends, such as migration pattern and choice of places to live. They can reduce or enhance the total requirement for new infrastructure as well as its location. Market trends in various branches of commerce will influence their profitability and thus have a bearing on how vulnerable they are to climate change.

Infrastructure

In the country as a whole, there is a strong probability that the temperature and sea level will rise and there will also be more precipitation along the entire coast. The direct weather-related challenges, particularly from wind and precipitation, are the most important climatic impacts for the transport sector through a greater risk of flooding, avalanches and scouring of fill. More frequent flooding due to increased temperature and precipitation will have a negative impact on roads. More frequent exposure to high water levels and stronger currents will weaken bridge foundations. Stretches of railway lines that cross mountainous areas (like the Nordland and Ofoten Lines within the NorACIA region) are expected to be especially affected by avalanches, rock falls and slides, but the scale of this problem cannot be particularly precisely specified.

Reduction of sea ice may encourage more ships to use the North-East Passage. Shorter sailing time and less fuel consumption as a consequence of this will give both economic and environmental returns, but more maritime transport in the Barents Sea may bring problems related to maritime law and where to place responsibility in the event of accidents, discharges and emissions, and not least the establishment and maintenance of an overall infrastructure for shipping, such as chart production, oil pollution contingency and new port facilities.

This also implies opportunities for local communities in northern Norway and Svalbard. The municipal network of water mains and sewers will be affected by increasing amounts of precipitation, rising sea level and higher storm surges. The impacts are related to the potential for reduced hygiene security, rising contents of natural organic material, algae, toxins and contamination hazards related to the rise in sea level. The risk and vulnerability analysis for Finnmark (Fylkesmannen i Finnmark 2008) also pointed out how impacts at one point in the infrastructure chain may be transmitted further; for example, that a failure in the electricity supply may have consequences for the water supply.

Both production and distribution of hydroelectric power may be affected by climate change. More precipitation per year gives a greater potential for production, but more variations in the frequency and extent of precipitation can be expected, which will have consequences for surface runoff and the extent to which reservoirs are filled. The transmission network may also suffer more faults and breakdowns due to more icing and wind.

Occupations based on natural resources

Farming is probably one of the occupations that are most sensitive to climate change. The climate now differs greatly from north to south and from the coast to the interior in northern Norway. The substantial differences in climate and farming practices make it difficult to give clear, all-embracing answers as to how climate change will affect farming in northern Norway.

A general increase in crop yield is expected in northern areas due to higher temperatures, a longer growing season and more CO_2 in the air. This may give a basis for cultivating more warmth-demanding and fewer winter-tolerant crops, but agriculture is expected to continue to be dominated by grass and livestock production. Higher temperatures and more precipitation in winter may lead to a reduced frequency of serious winter damage in some areas, but at the same time there may be great problems with ice in areas where there are none today. Better living conditions for fungi, insects and bacteria may give more frequent attacks by pests, including new ones.

Even though the situation regarding the impacts of climate change on forest and woodland is complicated, there is expected to be significantly more productive forest in Norway as a consequence of the change in climate. A rise in temperature of 2 °C may elevate the tree line by some 300 metres. This can substantially increase the productive area for forestry in Nordland and Troms, but Finnmark is, nevertheless, assumed to have the greatest potential. Frost damage in winter, drought stress, attacks by insects and other pests, and fungal damage may rise as a result of the change in climate, and the same applies to the risk of forest fires.

Reindeer husbandry is an industry that is particularly dependent on nature since it is based on the animals using natural grazing all the year round. The change in climate will influence grazing conditions in every season and will have both positive and negative effects, but the impact as a whole seems likely to be negative. Higher temperatures in summer, autumn and spring will lead to a reduction in both summer and winter grazing in areas like the Finnmarksvidda plateau, because open heathland will be overgrown and the tree line will be elevated. They will also extend the growing season, thus shifting the balance between the use of winter and snow-free grazing areas. In inland districts, higher winter temperatures will give more unreliable winters, primarily due to the probability of more frequent freezing-thawing cycles, leading to inaccessible grazing, whereas in coastal districts the average temperature will be above freezing for most of the winter, and ice and snow will thaw more rapidly. The effects may to some extent compensate one another. More trouble from insects and greater risks of parasite and other diseases are expected, and there is likely to be an increase in land-use conflicts with other interests.

The fisheries in the Norwegian Arctic are important for fishermen and local communities in northern Norway and Svalbard, and also elsewhere. Relevant climatic variables for marine ecosystems are temperature, precipitation, wind strength, wind direction, cloud cover, salinity (salt content), currents, ice conditions, sea level, waves, turbulence and light (dependent upon both ice and cloud conditions). Climate change influences the marine environment throughout the food chain and affects the size of fish stocks through impacts on recruitment and growth rates, and also the spatial distribution and migration patterns of the fish stocks. The ACIA report concluded that a moderate rise in temperature in Norwegian waters, together with less sea ice which is expected to give enhanced primary and secondary production, will probably be advantageous for commercially important species. Numerous factors complicate the situation, so that great uncertainty surrounds the impacts. If the impacts are moderate, we can experience changes in the distribution and size of valuable stocks, but the structure of the ecosystem will largely remain intact. If a serious mismatch arises in the food chain due to changes in the time and place of spawning and hatching, and/or the blooming of plankton, the structure of the ecosystem may change dramatically, giving extremely uncertain impacts owing to the complexity of the ecosystem. Changes in the geographical distribution of fish stocks may lead to stocks that are now shared between Norway and Russia being within the Russian zone to a much greater extent than before, with possible consequences for quota negotiations. The same may apply with regard to other nations with which we share stocks. It may also be a challenge for fisheries management if more cod congregate in the disputed area in the Barents Sea. The geographical distribution of vessels, fishermen and landing and processing plants means that climatic impacts on the fisheries will have different repercussions on different parts of the Norwegian Arctic.

Aquaculture is also important for northern Norway and for many local communities in the region. Warmer water will lead to more rapid growth in farmed fish, up to a certain limit. The water temperature in southern Norway may become too high for good productivity for salmon farming, whereas conditions can improve in northern Norway. Some studies suggest that the effect of this can be very significant for value creation and employment in aquaculture in northern Norway.

Climate change may transform the tourist industry in that changes in the weather may directly influence the choice of holiday destinations for tourists, and also because changes in the vegetation may influence the attractiveness of areas. Changes in the natural environment may be especially important for Norway, where nature and landscape are crucial reasons why tourists come here. Less snow cover and poorer, more instable snow conditions may result in ski tourism, viewed in isolation, being negatively affected. However, should our most important competitors experience greater reductions in snow cover, the tourist industry in northern Norway may, nevertheless, experience an enhanced demand. Tourism in Svalbard is expected to increase further, partly because less ice in the fjords on the northern and eastern coasts will increase accessibility. Less ice in the Barents Sea may lead to greater pressure to open the waters for exploration drilling and recovery of petroleum.

Health and environmental protection

Both gradual changes in temperature and precipitation and more frequent episodes of extreme weather (heat and cold waves, floods and avalanches) may affect health directly as well as indirectly. This typically takes place through influence on paths of infection and transmittance of diseases, and more long-term and indirect influences via effects on, for example, food production. Climate impacts on health are thus multi-faceted, but the greatest impact is, nevertheless, assumed to be an increased distribution of vector-transmitted diseases, that is diseases transferred by bearers such as mosquitoes and ticks. Whereas the global health situation is expected to be seriously affected by changes in climate, the situation is less dramatic in Norway.

A key part of nature conservation in Norway is the protection of areas under the terms of the Nature Conservation Act. The criteria for selecting areas for protection, such as representativeness and to protect species, was not designed with a view to the impacts climate change will have on the ecosystems. The changes in climate will lead to changes in the distribution ranges of species, with changes in species composition and ecosystems in the protected areas as consequences. To counteract this, nature management is focusing on minimising other stress factors, ensuring the protection of large areas of natural environment, securing corridors along which species can disperse, and adapting practices in relevant industries. It now transpires that brief climatic events, such as warm periods in winter, may also have significant consequences for individual species and ecosystems. More protection cannot halt the changes in climate, but protection of areas can help species and habitats to be less threatened by other disturbances. This may increase the chances for biodiversity to be safeguarded in the future, too.

Climate change may have consequences for cultural heritage sites on land in this region, and those in Svalbard may be particularly threatened by more rapid erosion, and indirectly by more wear and tear due to increasing numbers of visitors.

Particularly vulnerable regions and groups

It is an important task to identify groups, sectors or regions that are particularly vulnerable to climate change so that these may be given priority and accommodations can be put in place to moderate the effects of climate change. The NorACIA project has worked on indicator-based, top-down evaluations of climatic vulnerability on regional, and particularly municipal, levels on the basis of natural, socioeconomic and institutional vulnerability. This can be used to undertake an initial selection of boroughs for further vulnerability analysis. Top-down methods to assess climatic vulnerability should be supplemented with local evaluations. The scale for analysis of climatic vulnerability is important. Whereas none of the counties have individual industries that are sensitive to climate and have a proportion of employees that exceeds 7–8 %, the situation is completely different at the municipal level where some boroughs have a third of their workers employed in fishing and trapping.

The Sámi are exceptionally vulnerable to the impacts of climate change because they are in many ways already in a pressured, marginalised situation. Reindeer husbandry is an important industry for the Sámi and for Sámi identity, and is expected to experience substantial consequences of the change in climate. Other aspects of Sámi life are also under pressure, but their situation is more poorly investigated. The long experience Sámi have in reindeer husbandry, hunting and harvesting of natural resources under shifting climatic and weather conditions have given them a valuable foundation of experience and knowledge to tackle climate change, but the predicted changes in climate raise qualitatively new challenges. This is because the recorded and expected changes in climate are increasing in both extent and strength, and other social and economic processes are contributing to rising marginalisation.

Summary and gaps in knowledge

To be able to achieve a better analysis of the vulnerability for climate change, it is necessary to improve the methods for evaluating how impacts of climate change cooperate with other changes in society, which have other causes. This entails finding new and improved methods of constructing socioeconomic scenarios and being able to link these to downscaled climate scenarios. It can be useful in this context to perform regional perspective analyses and scenarios of communities rooted in individual industries or sectors. When vulnerability to climate is being evaluated, it is also important to make overall impact assessments, and this requires a multistressor or multifactor perspective on climate vulnerability.

The NorACIA subprojects which have assessed municipal climate vulnerability have helped to improve the selection of indicators relative to previous studies. New indicators have been chosen because of new knowledge on the link between climate and society, and also because of better knowledge of the data available for individual indicators. This demonstrates how the application of methodology for evaluating climate vulnerability also leads to an improvement of the methodology, as well as making contributions regarding which data should be collected in the future to be in a better position to evaluate vulnerability and impacts of climate change in the future. At the same time as methods for climate vulnerability evaluations are developed, they must be continuously used, tested and improved.

Spatially and contextually based vulnerability analyses can include documentation of local vulnerability factors, identification of how local communities are sensitive to impacts of changes in climate combined with changes in socioeconomic and biophysical conditions, analyses of how social, economic and biophysical conditions can be expected to change, and assessment of the adaptability of the local communities. The complexity attached to different factors and interactions locally between biophysical, social, economic, political, legal and institutional conditions should not be toned down, but we should rather aim to develop good methods for evaluating climate vulnerability which take such complexity into account.

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Klimaendringer i norsk Arktis

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Summary of the sub-report “Adaptation and mitigation. Climate changes in the Norwegian Arctic”

This sub-report seeks to take stock of the task of adapting some key themes and sectors to climate change in the Norwegian Arctic. It also takes up carbon binding in the Norwegian Arctic as a mitigating measure. In line with reports from the UN Climate Panel, adapting to the climate is regarded here as adjustment in natural or human systems as a response to actual or expected climatic stimuli, or their influences or impacts, and which reduces damage or exploits positive alternatives. Mitigation does not concern response to climate change, but is a generic term for deliberate intervention to either reduce greenhouse gas emissions or, for example, to bind CO_2 in forest. The objective of investigating adaptation to climate is to reduce the vulnerability of society to climate change and help to strengthen Norway’s ability to adapt. It also means that the generation of knowledge should be directed at identifying the mechanisms and processes which we can most easily influence.

The task of studying and assessing adaptation to climate change has not been taking place for long in Norway. Some aspects that are essential for adaptation to climate change are addressed in separate sub-projects under the NorACIA umbrella, but the challenges are so broad and complex that this report also draws on the other work. Most reports on this topic are general for the sector or field on which they focus and make little assessment of the importance of geographical variations within the sector. The thematic review in this sub-report is therefore correspondingly general in scope.

Vulnerability

The vulnerability of a system, a sector, a local community or an individual to climate change is understood as an expression of the degree to which it is sensitive (negative) to impacts of the change. There is a close relationship between adaptation and vulnerability. The vulnerability is generally seen as being determined by exposure, sensitivity and adaptability to the changes in climate. Adaptation is used here about actions that lead to reduction in vulnerability. In recent years, several papers have sought to develop perspectives on vulnerability and adaptation to climate change, notably for Norwegian conditions. They have distinguished between three main types of vulnerability:

1. Natural vulnerability: Processes in nature which are exposed to the influence of climate change. Examples are avalanches, erosion, floods and changes in biological diversity.

2. Socio-economic vulnerability: Social conditions and processes that influence the vulnerability to climate change. Examples are the proportion of people employed in occupations that are vulnerable to the climate and the proportion of infrastructure and buildings which are located in avalanche-prone areas.

3. Institutional vulnerability: Capacity of different institutions to implement measures to adapt to climate change. Examples are access to expertise and a financial fundament to implement measures for adaptation.

Adaptability

Institutional vulnerability does not concern whether institutions are vulnerable to climate change, but that limited institutional capacity contributes to the vulnerability to climate change. Institutional vulnerability and capacity must not be understood as being confined to public management institutions which have responsibility for climate-related problems. Both the marketplace and the civilian society (local communities) are social institutions with the resources and capacity to influence the vulnerability of society to climate.

It is important to recognise that adaptation takes place in complex situations where impacts that are a consequence of changes in climate are just one of many things people, industries, local communities and political administrative bodies have to take into account. A best possible overall understanding of their situation is therefore essential to be able to have a good and efficient adaptation to the changes in climate.

The changes in climate are expressed as both changes in the frequency of extreme events like storms, floods, precipitation and avalanches, and slow changes in physical factors and systems in nature, with effects on, for instance, growing conditions and distribution ranges for species. This means that there can be said to be two main types of effort to achieve adaptation. One is directed at crisis management and the other at long-term planning. A notable challenge for community planning is attached to how to tackle uncertainty. Uncertainty occurs in virtually every factor that is relevant for assessing climate change and efforts to adapt to it, and also on several levels.

General strategies and measures for adaptation

An overarching conclusion from this work is that there is a great need to acquire more knowledge about the effects of changes in climate, the vulnerability of society and adaptability in various sectors and at various levels of management. At this early stage in the effort to adapt, a great deal of focus is being placed precisely on strategies and measures that enhance adaptability. The question of knowledge is not merely a question of more research and expert knowledge about the scientific aspects of the changes in climate and their impacts. A general element in social science discussions is the need to identify parties that are affected and their need for data and knowledge. Knowledge about adaptation to climate must be obtained and developed in cooperation between experts and practitioners, users and inhabitants in the areas that are affected. It is particularly important to ensure that knowledge about specific local and sectorial aspects come out, even if these in themselves are not directly linked to climate change.

Mapping and monitoring of the changes in climate and their impacts on nature and society must be improved by developing methods, models and indicators, and by continuing and modifying established monitoring programmes and routines, and initiating new ones.

Viewed as a whole, the nature management sector is undertaking a significant amount of monitoring, but little of what is taking place on ecosystems in northern Norway is suitable for revealing any differences caused by climate change. It is therefore suggested that the monitoring should be strengthened by focusing on those parts of the ecosystems where substantial changes can be expected; on vulnerable and globally or nationally rare species or habitats.

In every aspect of the preparedness and rescue service there is a need for greater awareness of, and more knowledge about, changes in climate. Equipment and resources in the various agencies must be accommodated to the challenges which the changes in climate are expected to give. The Directorate for Civil Protection and Emergency Planning sees the need for the regional contingency authorities, the offices of the county governors of the three northernmost counties, to establish cooperation with relevant bodies in the region to carry out a regional and systematic survey of the contingency resources in the North.

More maritime activity as a consequence of less sea ice is expected along the Norwegian coast and off Svalbard. This concerns more transport of oil by ship from north-western Russia, more cruise traffic near Svalbard, and sailing in the North-East Passage and across the Arctic Ocean. Reduced sea ice and other effects of the changes in climate will probably also lead to more recovery of minerals and metals along the northern coasts of Russia and Canada, and their shipment will thus also further increase maritime transport in the North. All told, this will put greater demands on monitoring and preparedness with respect to both oil protection and maritime safety. Around Svalbard, there is a specific need to chart areas of sea that have become ice free due to the climate change, particularly with a view to the safety of cruise vessels.

The Planning and Building Act is an important instrument for tackling climate problems in the long term. The sector transcending character of its clauses concerning land-use planning makes it a particularly suitable agent where it is essential to view various sectors of society as an entity. It is most important that regards for the safety of society directed at climate change are incorporated into municipal land-use planning. To exercise their responsibility, local authorities must have access to up-to-date information on hazards facing potential development areas. A primary challenge is to make existing knowledge available in an appropriate way. The county governors will have a special task to pass on new knowledge to the local authorities and warn them when they have draft plans put before them which do not take adequate account of safety aspects. The county council, as the regional planning authority, also has an important task and key responsibility here.

Infrastructure

There is a need for a critical review of roads and power supply with a view to assessing their vulnerability in relation to the effects of climate change. A less vulnerable infrastructure will sometimes require new materials and designs. This also represents a positive opportunity for industry in the Norwegian Arctic to evolve cold-climate technology and technical solutions for some of the challenges presented by the climate, and these can subsequently be exported.

A special challenge in Svalbard is that all the buildings and infrastructure are built on permafrost. There will be very serious consequences in the settlements and elsewhere if the uppermost few metres of the permafrost thaw. Research is essential to find out how these problems can be tackled. Increased thawing will also lead to more solifluction and a greater danger of avalanches, as well as more meltwater in the mines.

Only 10 % of the extensive network of main roads in northern Norway holds a standard that is acceptable for present-day requirements. In response to the changed climatic conditions, the Norwegian Public Roads Administration is operating a 4-year project (2006-2010) called Climate and Transport whose purpose is to improve routines and regulations for planning, projecting, building and maintaining roads.

Several important preventative measures have been implemented to reduce maritime transport hazards in general, and several of them are particularly relevant for the northern regions. These include adjustments of the use of leads and separation of shipping according to type, so that loaded tankers sail further from land than previously. The traffic control system has also been improved, as, too, has cooperation with Russia.

As regards air travel, the subsoil conditions at Svalbard airport have been investigated with a view to possible impacts of climate change.

Whether the network of sewers and drains is up to scratch is decisive for whether it can adequately deal with the increasing amounts and intensity of precipitation. Separation of storm water and sewage became standard from the 1970s and 1980s, but has still not been fully implemented in all towns and built-up areas in northern Norway. The change in climate will increase the need to replace out-of-date pipes and will call for investments by local authorities which have not yet fully upgraded. Increasing intensity of precipitation and changes in the flood regime must be included in plans for dealing with surface water, dimensioning of pipes, and also drinking water supplies.

Production and supply of electric power faces substantial challenges in northern Norway today, and climate change will significantly intensify these problems. Most hydroelectric power stations in northern Norway were built with a view to meeting local needs and were thus dimensioned for dry years; that is, they have a substantial spillway. Increased amounts of precipitation mean more overflow, which both reduces the exploitation of the power potential and poses a risk of flood damage. It will be most important to investigate the likely extent of flooding. A simultaneous predicted rise in energy consumption will require that the power stations can be operated more efficiently with less overflow. The development of wind power and other renewable sources of energy will help to supplement hydroelectric power. This will require more capacity on the transmission network. Greater loads of snow combined with more variable temperatures around 0 °C (thawing and freezing periods), in addition to more wind, must be met by measures that give a more robust transmission network.

Occupations based on natural resources

The changes in climate may lead to more difficult conditions for arable farming in many parts of the world that are important for agriculture, whereas there may be better potential for production in the North, giving favourable opportunities for agriculture here. Even though agriculture will probably have better conditions for production, uncertainty surrounds the geographical distribution of the effects and of the aggregate effect of different factors such as the increased frequency and length of mild periods in combination with more snow. Together with altered conditions for growth and for the occurrence of harmful organisms, this means that more research is required on both the impact of climate change and adaptation to it. The latter will include breeding new strains of plants, fertilising and crop production, as well as plant conservation.

Forests and forest soils are valuable carbon stores. Growing forest absorbs CO_2, and active forest management may help to increase this. A rise in temperature, a longer growing season and increases in the CO_2 content and N fertilisation from the atmosphere are all factors that will help to raise the production of biomass. A warmer climate will, however, increase insect damage in forests.

Reindeer husbandry is one of the occupations in the Norwegian Arctic which has been most studied with respect to climate change. This sub-report discusses adaptations to changes in vegetation, changes in adaptation to winter grazing and the balance in the use of seasonal grazing, adaptations across national borders, in the structure of herds and in supplementary feeding.

Few studies have been undertaken that examine the implications of climate change on the design of policies in the fisheries sector. On a general level, it is nevertheless obvious that it is vital to have a fisheries management that helps to maintain robust fish stocks. Studies show that the choice of management regime will be more important than the impacts of climate change in the foreseeable future. Current management instruments are, however, inadequately dynamic to tackle the shifting environmental conditions and must therefore be improved.

The changes in climate will probably mean that the most suitable sites for aquaculture as regards traditional species will be further north than they are now. Re-localisation will be one type of adaptation. The industry may also be able to implement more proactive strategies like breeding and genetic modification, or develop new pen technology. More frequent episodes of extreme weather will call for more robust constructions and thus offer incentives to product development in the equipment industry.

Tourism must adapt to changed climatic conditions, including a shorter winter season and wetter, warmer summers. Destinations for winter tourism which are in the border zone for a reliable snow cover and have poor access by public transport may be regarded as doubly vulnerable to the climate, vulnerable to both climate change impacts (shorter snow season) and climate policy measures (higher levies on transport).

Health and the environment

The greatest danger to health in the event of global and local warming is considered to be a higher incidence of diseases transmitted by vectors, that is, a carrier like a mosquito or a tick. It is also most likely that hurricanes will cause more accidents and deaths in Norway. Key factors that will reduce vulnerability to health-related climate impacts are the general state of health and the sensitivity of the population, exposure to climate change, and a well-run public health service and home nursing care.

The Directorate for Nature Management has looked at how nature management should react to climate impacts and climate adaptation. Several kinds of measures are common for a number of the fields with which nature management is concerned, not least taking climate into account in overall ecosystem-based nature management, viewing climate change in the context of other factors that have significance for biological diversity and outdoor recreation, and using this knowledge in planning work.

Analysis of the consequences of, and adaptation to, climate change has not advanced as far in cultural heritage conservation as it has in nature conservation. In the case of Svalbard, it is clear that a warmer climate will lead to more rapid deterioration of protected buildings and objects, and that this will call for a new strategy in relation to the current practice in the present cold, dry climate. Nearly all cultural heritage sites in Svalbard are within or close to the shore zone, and erosion will increase there if the sea level rises and there are more frequent and more violent storms. More archaeological excavations as well as protection and/or moving of buildings and objects will probably be required. It is important to carefully monitor the effects of climate change in Svalbard so that the correct strategies for the protection work can be chosen as early as possible.

Particularly vulnerable regions or groups

The changes in climate pose a challenge to the flexibility and adaptability which, over many generations, has been the key to how indigenous peoples have tackled variations in their environment. Native communities are therefore faced with huge economic and cultural consequences of climate change. Studies point out that the capacity of small and vulnerable groups and communities to adapt should be viewed in the light of the situation that control and adaptation take place in multi-level systems where their possibilities for adaptation are in many cases limited by political decisions at regional, national and international levels. What remains of flexibility to adapt thus acquires extra significance, whereas transparency and communication may pave the way for institutional learning.

Some studies in NorACIA have sought to measure the institutional vulnerability of local authorities. Surveys have thus been performed on the basis of the following vulnerability topics: economic resources, expertise, proactive ability, reactive ability and “living local community”. These categories may be useful for identifying which areas local authorities should concentrate on to enhance their ability to adapt.

Conclusion

There is great variation between different themes and sectors regarding how far we have reached in the task of adapting to climate change. There is an obvious need to find better ways of uncovering vulnerability to climate change, and to develop possible measures for adaptation. This applies in local communities, business sectors and management. Uncertainty concerns several of the factors and conditions which should form the basis for selecting strategies and measures for adaptation. It is wise to concentrate more on developing methods to reduce the uncertainty. Given that there are limited funds to implement vulnerability assessments and set up strategies and measures for adaptation, methods should also be developed to prioritise between geographical areas, levels, sectors and themes.

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