AMAP 2017

ADAPTATION ACTIONS FOR A CHANGING ARCTIC

PERSPECTIVES FROM THE BARENTS AREA

AMAP

Arctic Monitoring and Assessment Programme (AMAP)

AMAP 2017

Adaptation Actions for a Changing Arctic: Perspectives from the Barents Area

AMAP

Arctic Monitoring and Assessment Programme (AMAP)
Oslo, 2017

AMAP 2017 Adaptation Actions for a Changing Arctic: Perspectives from the Barents Area

Citation
AMAP, 2017. Adaptation Actions for a Changing Arctic: Perspectives from the Barents Area. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. xiv + 267pp

ISBN –13 978-82-7971-102-5

Published by
Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. (www.amap.no)

Ordering
This report can be ordered from the AMAP Secretariat, Gaustadalléen 21, N-0349 Oslo, Norway
This report is also published as electronic documents, available from the AMAP website at www.amap.no

Production

Production management
Julia Tchernova and Jon L. Fuglestad (AMAP Secretariat)

Editing
Carolyn Symon (carolyn.symon@btinternet.com)

Technical production
Burnthebook, United Kingdom (www.burnthebook.co.uk)
Jane White and Simon Duckworth (Burnthebook)

Cover photograph
Mountains of Longyearbyen at sunset, Svalbard
ginger_polina_bublik/Shutterstock.com

Printing
Narayana Press, Gylling, DK-8300 Odder, Denmark (www.narayanapress.dk)

FSC www.fsc.org MIX Paper from responsible sources FSC™ C010651

AMAP Working Group (during period of preparation of this assessment)
Martin Forsius (Chair, Finland), Morten Olsen (Vice-Chair, Denmark), Sarah Kalhok (Canada), Mikala Klint (Denmark), Outi Mähönen (Finland), Helgi Jensson (Iceland), Marianne Kroglund (Vice-Chair, Norway), Tove Lundeberg (Sweden), Yuri Tsaturov (Vice-Chair, Russia), J. Michael Kuperberg (United States), Eva Krummel (Inuit Circumpolar Council), Jannie Staffansson (Saami Council), Bob van Dijken (Arctic Athabaskan Council)

AMAP Secretariat
Lars-Otto Reiersen, Simon Wilson, Jon L. Fuglestad, Julia Tchernova, Jan-Rene Larsen, Janet Pawlak, Inger Utne

Arctic Council Member States and Permanent Participants of the Council
Canada, Kingdom of Denmark, Denmark/Greenland/Faroe Islands, Finland, Iceland, Norway, Russia, Sweden, United States, Aleut International Association (AIA), Arctic Athabaskan Council (AAC), Gwitch'in Council International (GCI), Inuit Circumpolar Council (ICC), Russian Association of Indigenous Peoples of the North (RAIPON), Saami Council

Coordinating Lead Authors (see chapters for complete author overview)
Marianne Kroglund, Tove Lundeberg, Monica Tennberg, Anna Degteva, Helene Amundsen, Peter Arbo, Ingrid Bay-Larsen, Rasmus Benestad, Philip Burgess, Marcus Carson, Wenche Eide, Grete Kaare Hovelsrud, Vladimir Ivanov, E. Carina H. Keskitalo, Kit Kovacs, Svein Mathiesen, Annika E. Nilsson, Anders Oskal, Glen Peters, Martin Sommerkorn, Minna Turunen, Seija Tuulentie

Contents

Preface

This report presents the results of the 2017 AMAP Assessment of *Adaptation Actions for a Changing Arctic (AACA): Perspectives from the Barents Area*. This is one of the three pilot study regions included in the AACA project. AACA is the first AMAP assessment dealing with adaptation actions and how to meet possible Arctic futures in these times of rapid change.

There are two other pilot study areas included in the AACA-C project. The first is the Bering-Chukchi-Beaufort region, which includes the Chukotka Autonomous Okrug in Russia, northern parts of Alaska and western Canada and adjacent marine areas and the second is the Baffin Bay/Davis Strait region involving West Greenland, the eastern part of Nunavut in Canada and Baffin Bay/Davis Strait between these land masses.

These pilot studies are the Part C of the total AACA project. AACA-A involved an overview of Arctic Council working group reports which could be used as background information for adaptation work, while AACA-B involved an overview of already implemented adaptations in the Arctic Council member states.

The Arctic Monitoring and Assessment Programme (AMAP) is a working group under the Arctic Council. The Arctic Council Ministers have requested AMAP to:

- enable more informed, timely and responsive policy and decision making related to adaptation action in a rapidly changing Arctic
- produce information to assist local decision makers and stakeholders in three pilot regions in developing adaptation tools and strategies to better deal with climate change and other pertinent environmental stressors.

This report provides the accessible scientific basis and validation for the statements made in the *AACA Barents Area – Overview Report* that was delivered to the Arctic Council Ministers at their meeting in Fairbanks, Alaska, USA 11 May 2017. This science report includes extensive background data and references to the scientific literature and whereas the overview report contains statements about foundations for adaptations that focus mainly on policy-relevant actions concerned with options on how to adapt to projected Arctic futures, the conclusions and key messages presented in this report also cover issues of a more scientific nature.

This assessment of adaptation perspectives for the Barents area was conducted between 2013 and 2016 by an international group of experts. Coordinating lead authors were appointed following an open nomination process coordinated by AMAP. The peer-review process involving independent international experts was organized by the International Arctic Science Committee (IASC).

Information contained in this report is fully referenced and based first and foremost on peer-reviewed and published results of research and monitoring undertaken within the past decade. Care has been taken to ensure that no critical probability statements are based on non-peer-reviewed material.

Access to reliable and up-to-date information is essential for the development of science-based decision-making regarding ongoing changes in the Arctic and their global implications. Related assessment summary reports have therefore been developed specifically for decision makers, summarizing the main key messages from the Barents regional report. The assessment lead authors have confirmed that both this report and its derivative products accurately and fully reflect their scientific assessment. All AMAP assessment reports are freely available from the AMAP Secretariat and on the AMAP website (www.amap.no) and their use for educational purposes is encouraged.

AMAP would like to express its appreciation to all experts who have contributed their time, efforts and data, in particular the coordinating lead authors for each of the chapters in this report. Thanks are also due to the reviewers who contributed to the peer-review process and provided valuable comments that helped to ensure the quality of the report. A list of coordinating lead authors is included in the acknowledgements at the start of this report and all authors are identified at the start of each chapter. The acknowledgements list is not comprehensive. Specifically, it does not include the many national institutes and organizations, and their staff, which have been involved in the various countries. Apologies, and no lesser thanks are given to any individuals unintentionally omitted from the list.

The support from the Arctic countries and non-Arctic countries implementing research and monitoring in the Arctic is vital to the success of AMAP. The AMAP work is essentially based on ongoing activities within these countries, and the countries that provide the necessary support for most of the experts involved in the preparation of the AMAP assessments. In particular, AMAP would like to acknowledge Finland, Norway, Russia and Sweden for taking the lead country role in this assessment. AMAP would also like to thank the Norwegian Ministry of Foreign Affairs; the Government of Finland's analysis, assessment and research activities; the Ministry for Foreign Affairs of Finland; the Swedish Environmental Protection Agency; the Nordic Council of Ministers and the Norwegian Research Council for financial support to the assessment work. AMAP further acknowledge and appreciate the in-kind contribution to the project from the authors and their employers.

The AMAP Working Group is pleased to present its assessment to the Arctic Council and the international science community.

Marianne Kroglund (Assessment Co-chair, Norway)

Tove Lundeberg (Assessment Co-chair, Sweden)

Monica Tennberg (Assessment Co-chair, Finland)

Anna Degteva (Assessment Co-chair, Russia)

Martin Forsius (AMAP Chair, April 2017)

Lars-Otto Reiersen (AMAP Executive Secretary)

Oslo, September 2017

Executive Summary to the report on *Adaptation Actions for a Changing Arctic: Perspectives from the Barents Area*

The AACA project

In 2013, in recognition of the changes occurring in the Arctic and the need for Arctic communities and governments to respond to them, the Arctic Council launched the *Adaptation Actions for a Changing Arctic* (AACA) project. Its aim is to enable more informed, timely, and responsive decision-making at the local and regional level by integrating knowledge across different regions and fields of expertise.

The study focuses on the diverse challenges faced by residents, sectors and economies in the Arctic, and the adaptations that they have begun to plan and implement in response to the rapid changes taking place, as well as those expected in the future. It also provides key strategies and tools intended to inform decision-makers about possibilities for helping their communities adapt to future change.

The Barents area

The geographic study area includes the Barents Sea as well as the adjacent terrestrial areas, and Svalbard and Franz Josef Land. Thus, the study area is broader than the 'Barents Region' as defined by the Barents Euro-Arctic Council (BEAC; www.beac.st/en). This report sometimes also covers the neighboring regions of Yamalo-Nenets.

Climatically, the region is heavily influenced by its proximity to the sea and its high latitude. The North Atlantic Current (a northern branch of the Gulf Stream) makes the entire Barents area far warmer than comparable areas at similar latitudes, but parts of the region still possess glaciers, permafrost and environmental features typical of the Arctic. Ecologically, the Barents area largely comprises boreal forest, which makes up 54% of the mainland area, with alpine and Arctic tundra accounting for 20%. Glaciers constitute about 4% of the land area, and there are abundant and wide-ranging freshwater ecosystems and open wetlands. The Barents Sea hosts more than 200 species of fish and the most species-rich marine mammal community in the circumpolar Arctic, reflecting the rich seasonal productivity of the continental shelf. The area also supports some of the largest concentrations of seabirds in the world. The region is rich in renewable and non-renewable resources. These form the basis for forestry, fisheries, mining, agriculture and the hydrocarbon industry, as well as tourism and local and indigenous economic activities such as herding, hunting and gathering.

This highly varied region is inhabited by 5.5 million people, including indigenous peoples (Sámi, Nenets, and Veps) as well as many other groups. In terms of the primary sector, forestry is important in Sweden, Finland and northwestern Russia, while fishing and energy (mainly oil and gas) are important in northern Norway and northwestern Russia. The area is an important source of hydroelectricity, both for local use and for export outside the region. Mining is economically important in parts of each country. Tourism and reindeer husbandry are also important locally, although these are lesser activities. However, in some areas, such as northern Finland, tourism is an important source of employment, and its importance is growing in other parts of the region. The primary sector makes a relatively small contribution to employment, but represents an important contribution to GDP in the Barents Region. About 7% of the Barents Region's total work force is employed in agriculture, forestry, fishing and reindeer husbandry. Human activities in the Barents area have traditionally been directly coupled with resources provided by ecosystems. Today, many livelihoods entail a mix of market and non-market activities that provide material necessities and social, cultural and spiritual needs. While non-market aspects of Arctic livelihoods are typically closely integrated with nature and access to nature, many important market-oriented activities are also closely tied to nature.

The Barents area is experiencing environmental change driven by climate change and increasing human activity, in parallel with changes in socio-economic systems driven by a range of environmental, political, societal and cultural conditions. Some changes are easy to predict – some more difficult. Some changes are rapid and obvious, while others are slower and more subtle. The interlinkages within these wide-ranging environmental and societal changes are many and complex; and some combined effects are acting synergistically, enhancing the rate or magnitude of change.

Although environmental and societal changes are creating unprecedented challenges in the Barents area, opportunities for societies and their foundations are also emerging. While most adaptation takes place locally – where the changes are obvious – the regional, national and international contexts shape the configuration and opportunities for local adaption. The implications for policy and planning are substantial, and adaptation has thus become a major priority across the Barents area, in addition to the mitigation of greenhouse gas emissions and short-lived climate forcers. National adaptation policies in the region are increasingly linked with the development of international governance that articulates common goals such as sustainable development, human security, climate change mitigation, and indigenous peoples' rights. The Paris Agreement strengthens the policy commitments to adaptation action, and enhances the link between adaptation, mitigation and sustainable development.

Environmental and socio-economic changes and impacts

Social and economic trends, together with projected changes in average and extreme air temperature and precipitation, sea temperature, sea level and snow and ice cover on land and at sea, play essential roles in shaping the future. These trends affect terrestrial, freshwater and marine ecosystems, peoples and societies, and economic activities and opportunities in the

Barents area. There is a need for adaptation at both the local level (adaptation to direct and indirect impacts) and national level (governance for adaptation to complex issues), and at the international level (cooperation on common challenges).

Key environmental changes

A 'hot-spot' for warming

The Arctic is warming much faster than the global average, and the Barents area is a 'hot-spot' even within the Arctic context. Under a mid-range scenario for emission growth (RCP4.5), average winter temperatures are projected to rise by 3–10°C between 2010 and 2080, and by up to 20°C by the end of the century. Warming of the Arctic has already had direct impacts on terrestrial, freshwater and marine ecosystems in the Barents area. Increased frequency of natural hazards, such as storms, avalanches, extreme wave heights and icebergs are all linked with warming.

Sea ice decline will strongly impact ice-dependent species

Ice extent in the Barents Sea varies from year to year, but the main development has been a clear decline, and the Barents Sea is projected to become the first Arctic region free of ice all year round by mid-century. This single environmental change will have enormous consequences; especially for those species that depend on sea ice as habitat. Reduced sea ice in combination with sea-level rise and high winds can result in significantly higher waves and greater storm surges, which will be a challenge for coastal infrastructure. However, sea-level rise is expected to vary. For some areas the land is still rising following the disappearance of the Fennoscandian ice sheet at the end of the last period of glaciation. Along the Norwegian coast, for example, sea-level projections vary by as much as 0.5 m depending on local conditions. Impacts also depend on the local features of the coastline (low-lying, erosion prone versus steep and rocky).

Snow cover is changing

Seasonal snow cover in the Barents area plays a critical role in the hydrological regime and for plant and animal life. Currently, snow depth is decreasing in inland regions but increasing in coastal areas. Annual maximum snow depth has increased in colder regions such as Russia. Another trend is towards earlier snow-free dates in spring.

Permafrost in decline

A combination of rising temperatures and changing patterns of snowfall is leading to reductions in the extent and depth of permafrost over large areas.

More frequent rain-on-snow events

Changes in snow-pack and permafrost properties will have far-reaching implications for Arctic ecosystems and societies. Higher temperatures mean more precipitation is expected to fall as rain, among others increasing the risk of rain-on-snow events during winter. These cause ice layers within the snowpack that prevent animals from grazing.

Widespread change in ecosystems

In the marine environment, climate change brings warmer, less saline seawater, changes in sea-ice extent and thickness, and sea-level rise, while higher concentrations of carbon dioxide lead to ocean acidification. These physical and chemical changes affect biological systems, resulting in higher phytoplankton productivity in previously ice-covered waters as well as northward shifts in boreal zooplankton, fish, seabirds and marine mammals at the expense of Arctic species.

Critical ecosystem services are changing

Freshwaters and wetlands contain a multitude of habitats and species and provide a wide range of key ecosystem services, such as the maintenance of permafrost, water regulation and filtration, and the storage of vast amounts of greenhouse gases. Such regulating services are critical for human well-being at a local and regional scale, but are also important globally in terms of climate regulation and conservation of biodiversity. Snowmelt and spring flooding occur earlier in the season. The timing of ice formation on waterways is shifting, affecting the seasonal movements of reindeer as well as their migration routes.

In the Barents area, warming combined with changes in hydrology have already led to increased growth and spread of tall shrubs, while mosses and lichens are declining. Projections indicate gradual extension northwards and upwards (in mountain areas) of both pine and deciduous trees. Forest ecosystems are also increasingly affected by pest outbreaks and wildfires, with implications for forestry that require adaptive responses. Nutrient cycling is expected to accelerate. The shifts in the vegetation zones are causing wide-range impacts for ecosystem services and ecosystem-dependent livelihoods. As the treeline moves northward, so too do species such as heather and grasses. The spread of invasive species is expected to increase.

Diversity, range and distribution are already changing for many animal species. Growth seasons are shifting and extending, and primary production in both terrestrial and marine areas is changing. These ongoing changes are causing a decline in native species and an increase in invasive species. Measured over several decades, many commercial fish populations are currently at record high levels, while most endemic Arctic invertebrates, fish, birds and mammals are facing challenges of various types due to climate warming, particularly those with lifecycles associated with sea ice.

Key socio-economic changes

Global actors and demand for resources

Climate change is an important driver of societal change, but it is not the only important driver. The main non-climate global drivers of socio-economic change include increasing population, economic growth, technology development, increased demand for and use of natural resources and energy, and international cooperation. Megatrends and global actors from outside the Barents area are likely to play an ever more important role in the future, through migration, resource markets, investment, and government policies and commitments. For instance, the development of Arctic hydrocarbon and mineral resources will be influenced not only by global market forces, but also by international climate and adaptation policies. These prevailing socio-economic conditions interact with climate change impacts in complex ways that may exacerbate current community challenges. The opportunities and implications for the different sub-regions of the Barents area will depend on the availability of natural and human resources, institutional characteristics, and the policies adopted.

Economic development over the longer term will be increasingly linked to the extent of diversification of local economies and the capacity to facilitate innovation. For example, the declining sea ice will present both opportunities (due to the opening up of new areas for oil and gas exploration and better conditions for shipping) and challenges (more frequent storms and icing events will pose technical challenges, particularly to marine operations, and increase the risk of oil spills in sensitive areas). Economic development will also depend on global demand for the region's petroleum products, which may be influenced by competing energy sources, and climate policies. Renewable energy production is expected to become a more important energy source. Wind power is already expanding, and hydropower production is likely to benefit from increased precipitation.

Industries will be affected

The mining industry is vulnerable to climate change through the changes expected in hydrology and future water management. The mining sector is also very sensitive to non-climate related factors such as changing demand for raw materials and changes in global mineral and metal market prices. Shipping in the Kara and Pechora seas is expected to increase following the decline in ice cover. Svalbard and Franz Josef Land will become more accessible and their significance as a tourist destination is expected to continue to increase. Fishing in the Barents Sea will almost certainly continue to expand northward.

Tourism and primary industries will need to adapt

Tourist operators will need to adapt to the new climate and socio-economic conditions. Lack of snow would have negative consequences for traditional winter tourism, although longer summers would create more favorable conditions for summer tourism, including cruise-ship ventures.

Climate changes are likely to affect growth, productivity and distribution of forests through changes in temperature, rainfall, weather, and other factors. A warming climate can increase forest productivity, and can support forestry in areas where it is not currently possible. However, shorter and warmer winters would make harvesting more difficult. The warming climate might also increase the risk of forest damage by pests, diseases and wildfires.

Warmer and longer growing seasons are expected to result in higher agricultural productivity, but long warm autumns may weaken winter hardening and predispose grazing land to winter damage. In cases where local plant breeding does not include varieties suited to the change in conditions, decreased economic output is likely. Reindeer pastures are under increasing pressure from industrial and infrastructure development, urbanization, land fragmentation, regulations, and rising temperatures, among other factors. Pasture fragmentation reduces herders' ability to respond to the increasingly unstable and unpredictable weather conditions by moving their herds to other areas.

Service provision by local governments is under pressure

Infrastructure such as roads, harbors, electricity grids and pipelines is vulnerable due to higher precipitation, thawing permafrost, greater frequency of storm events, more frequent freeze-thaw cycles, and increased risk of floods and landslides. Higher waves and storm surges put coastal infrastructure at risk. All such phenomena can lead to road closures and the disruption of energy supply, goods and services. An ageing population in many areas of the region is also creating challenges for local governments. Employment reflects trends towards urbanization, with the secondary sector – processing, production and construction – accounting for a large part of the employment in Fennoscandia and some Russian areas.

The extreme and rapidly changing weather, environmental disasters, new diseases, loss of food, water and housing security, and wildfires and floods could increase negative impacts on human health and well-being.

Interlinkages and cumulative impacts

Multiple, interconnected factors associated with climate change are affecting local communities, ecosystems and the geophysical environment, with consequences for water and food security, infrastructure, and ecosystem goods and services. The magnitude of change depends on the development and interaction of social and environmental systems over time. What is new today is the scale, scope, intensity and speed of change.

Eroded ecosystem services

Environmental and social systems are interconnected. Changes such as rising temperatures, diminishing sea ice and ocean acidification interact with changes in the location and intensity of human activities such as fishing and transportation. The impacts manifest in changes in coastal and marine species, ecosystems and their services, and related livelihoods and economic activity. In terrestrial ecosystems, ongoing cryospheric and hydrological change are already having consequences. Harvesting, transport, and industrial activities are causing intensified and cumulative impacts on ecosystems, and subsequently on ecosystem services and ecosystem dependent livelihoods.

Marine mammals in the Barents area are being affected by changes in prey community composition. They are also sensitive to noise, chemical pollution and disturbance from human activities, all of which are increasing with the declining sea ice. Changes in the abundance and distribution of these animals have direct impacts on local economies, linked to the intensity of subsistence and commercial use of these animals.

Invasive species, pests and diseases are becoming more prevalent due to a combination of increased transport and tourism, higher temperatures, and a longer growing season. This is occurring at the expense of Arctic species. In some cases, shifts may negatively affect the structure and function of entire ecosystems.

Reduced resilience to change

Society's ability to respond to future change may diminish through the erosion of ecosystem services and societal resilience. The interacting changes may undermine the state's ability to provide the conditions necessary for critical infrastructure, resource management, management of land use conflict, and health care.

Plant and animal populations with limited options to shift geographically as the environment changes are very vulnerable. Changes in landscapes, ecosystems and species that represent natural resources may undermine livelihoods, compromise culture and identity, and increase the need for relocation. Indigenous peoples are especially exposed to the consequences of climate change due to their dependence on the environment for food, lifestyle, and culture.

Climate change is causing a northward spread of some serious human and animal diseases, and increased risk of remobilization of contaminants. This trend is likely to increase pressure on public health services and increase the need for disease prevention strategies and accessible health care and veterinary services across the Barents area.

Well-functioning and reliable connections to infrastructure have already become essential for the social and economic functioning of remote communities in the Barents area. Climate change may provide new opportunities for improving accessibility, within and to the region. However, more extreme weather conditions may disrupt existing infrastructure, putting livelihoods and economic activity at risk, and increasing the cost of maintaining the current level of economic activity, due to increased maintenance and rebuilding costs. Future development of natural resources in the Barents area will depend on major investment to ensure the resilience of existing and new infrastructure under climate change.

Adaptation is a response to multiple changes and drivers
Conflict over land use in the Barents area will continue; with growing demand to acquire land for activities such as wind farms and mining and hydrocarbon extraction occurring alongside the traditional needs of reindeer herding, farming, forestry and fisheries. Infrastructure development, land fragmentation and climate change are all interconnected drivers of change. Conflicting interests regarding land use rights and their effects on the livelihoods of indigenous peoples is a recurring theme throughout the Barents area.

Adaptive capacity in the region

Adaptation is both a new policy field and a normal part of everyday life for individuals, communities, corporate actors, and whole societies as they adjust their activities in relation to observed and anticipated changes. The capacity to adapt is inherently dependent on environmental and economic diversity, and on social and organizational networks and mobility.

'One size does not fit all'

Adaptation is already taking place in the Barents area, taking different forms depending on institutional capacity, access to knowledge, and human and economic resources. Potential strategies range from technical solutions (e.g. infrastructural reinforcements), regulatory actions (e.g. building codes, land use planning, regulation of access to natural resources, healthcare instructions), economic mechanisms (e.g. insurance policies, incentives, subsidies and taxes), innovation (e.g. diversification of tourism activities, crop varieties, aquaculture) to institutional structures (e.g. climate data provision, search and rescue, interagency coordination).

The Barents area has significant human, social, infrastructural, and biological resources to draw upon in responding to rapid change. However, there is variation in adaptive capacity within and between the countries in the region, particularly between growing urban centers and depopulating rural areas. In the primary industries, adaptation to climate change is predominantly reactive while adaptation by local governments is predominantly proactive, such as spatial planning and avalanche protection.

Processes that activate adaptation

Adaptation as a continuous social process
Responses to climate change impacts are shaped by and interact with political, cultural and socio-economic factors. The processes leading to the development and implementation of adaptation actions are highly significant and contribute to building adaptive capacity in the Barents area. Adaptation in the region should therefore be recognized as a continuous social process, rather than a project or a specific measure. This shifts attention towards the social actors and institutions that generate adaptation practices and actions, including their embedded knowledge, values, power relations, and resources.

Cooperation and coordination across governance levels are important for local capacity building, along with a clear distribution of responsibility. Approaches that may be used to produce knowledge about local and regional perspectives in the area include downscaled climate information, community studies, local and indigenous knowledge collection, and stakeholder engagement.

The process of adaptation starts with an acknowledgement that change is occurring and that adaptation is required in order to address both short- and long-term perspectives. Access to relevant knowledge and observations of real events such as floods, outmigration and unemployment, can affect the perceived need to adapt. Access to knowledge about the change, and to human and financial resources are critical dimensions for activating adaptation processes. With respect to climate change such information is generally produced at a national level, but often as part of larger international efforts. However, knowledge can only be used if it is available, understandable and relevant for local conditions and activities.

Access to and co-production of knowledge is critical
Many communities have called for specific tools and information to help them identify key challenges and effective adaptive measures. These need to go beyond providing information about the future climate and could, for example, include regional maps that visualize multiple changes and effects, cost-benefit analysis of adaptation options, and statistical data to assess the progress of implementation of adaptation strategies and to facilitate comparisons between different sub-regions.

The integration of traditional, local and scientific knowledge across various levels is required to ensure that adaptation decisions are robust. Knowledge is improved when conventional science and regular policy development is combined with traditional and local knowledge. Understanding cumulative impacts and future consequences of climate and socio-economic drivers provides essential information to assist local and regional decision-makers in planning future development and advancing adaptation strategies.

Development of adaptation strategies can be achieved through applying indicators and exploratory scenarios. Carefully constructed indicators may make information on complex issues more accessible to decision-makers and thereby support policy planning, prioritization of potential actions, reassessment and follow-up. Indicators can be used for establishing baselines and to assess the direction and speed of change. The report suggests a framework of resilience indicators based on five fundamental qualities of people-environment systems: assuming change, fostering diversity, ongoing learning and knowledge development, capacity for self-organization, and sustainable livelihoods.

Scenarios provide a tool for discussing the robustness of adaptation options in the face of potential futures. They are simplified descriptions of how the future may develop and can provide plausible information about how the climate may change based on different socio-economic forecasts. Applying participatory methods that use narratives as a communication interface can help overcome a potential 'disconnect' between experts and practitioners. Nesting local and regional narratives within global scenario perspectives increases the possibility for comparing prospects for mitigation, impact, adaptation, and vulnerabilities across different municipalities, regions and sectors.

Preparedness is essential. Some uncertainties and many specific risks related to impacts of climate change, such as increased extreme weather events, will remain difficult to predict. For risks that are difficult or very costly to avoid, adaptation action must include discussion about what level of risk is acceptable and how much to invest in buffering capacity or other types of insurance.

To this end, it is necessary to improve information sharing processes as well as potentially supporting funding measures across national, regional and local levels to support action and development.

Understanding barriers and limits

General adaptive capacity does not automatically translate into adaptation actions. Adaptation planning for the Barents area needs to include an understanding of the barriers and limits, and their root causes. Typical barriers in the region are related to demography, community resilience, conflicting interests, access to salient and relevant knowledge, the perceptions of uncertainty and adaptation needs, and the decision-making power and capacity.

The extent of local decision-making power is a concern. This relates to the relative power between national government, economic sectors and governments at the local or regional level, corporate versus local political power, as well as to local and indigenous rights and the extent to which they are respected, not least in relation to conflicts over land use. Municipalities and local businesses face trade-offs between adaptation concerns and more immediate needs. It is a challenge to balance different interests, which often make different value judgments about what constitutes inequality and fairness, and about the relative importance of economic benefits, biodiversity, and other desirable outcomes. The shortage of adequate funding and time for municipal employees to integrate attention to adaptation in their daily practices is a key limiting factor.

Adaptive measures and responses that span different sectors are often needed, but the responsibility for developing adaptation measures is often unclear and there are major challenges in translating national goals into local contexts, and in funding adaptation at various levels. While many adaptation decisions may need to be made at the local level, the Barents area is governed by the respective states, connected to the global economy and governance structures, and in the case of Sweden and Finland (Norway more indirectly), also subject to EU regulatory systems. Hence, many decisions affecting the Barents area are made outside the region. Furthermore, the increasing role of transnational corporations, particularly in the primary sectors, can weaken local power of decision with major local implications. At the same time, profits from industries such as those based on petroleum and minerals are often channeled out of the less diverse economies of the Barents area, affecting the financial capacity of regional and local governments.

How to prepare for future change?

Crucial changes with the strongest impact on nature and society in the near-term (present day to 2030) in the Barents area include: more rapid warming; a shift to seasonal ice cover and substantial reduction of sea ice cover in winter; increased frequency of natural hazards caused by the overall warming; and an intensification of trade and investment in transportation, fishery and natural resources extraction. For the near-to-mid future (2030 to 2080) a plausible picture will be: an ice-free sea all year round; a substantial increase in ocean acidification; change in ocean currents and hydrographic conditions; a substantial reduction in snow-cover season; a substantial degradation of permafrost; increasing urbanization; and increased pollution, degradation of ecosystems and irreversible loss of region-specific biodiversity.

The Arctic and the regions explored as part of the AACA project are complex systems undergoing rapid environmental and societal change. It is evident that climate change is an important driver of change, but it is not the only one. Adaptation strategies should therefore always reflect a broader context than climate change alone. AACA has broken new ground by integrating knowledge from many different fields of expertise, and across regions with large cultural diversity, multiple uses and users of local resources. A key message is that adaptation is a social process and that planning needs to be cross-sectoral. Adaptation must adopt a holistic approach.

Having considered environmental and socio-economic changes and their implications in the Barents area, the report outlines a number of key adaptation strategies and actions.

- **Adaptation is an ongoing process and a strategy, rather than an end in itself.** The complex interactions of social and environmental change make it necessary to assess and support the capacity for adaptation in ways that go beyond business-as-usual. There is a need for integrated processes and strategies, across different societal groups and scales, that can support proactive measures and build preparedness for further change. Reacting based on past experience and immediate threats will not be enough.

- **It is increasingly important to recognize the significance of natural capital and ecosystem services** in the context of governance and management, as well as in the context of economic decision-making and global stewardship. Sustainable management of critical ecosystems and landscapes is important for the practice of traditional and local livelihoods, but also for a range of other concerns such as water supply and flooding, and sustainable productivity in agriculture, forestry and fisheries.

- **Integrating local, traditional and scientific knowledge to support policy is vital.** Indigenous and local people, especially those active in renewable resource management, experience the effects of climatic changes first-hand owing to their close connection to the environment that provides food, livelihood and cultural and social identity. To ensure successful adaptation within the Barents area to current and expected changes, local, traditional and scientific knowledge must serve as the backdrop for understanding the challenges and for developing responses. Local and indigenous institutions should expect and thus prepare for new challenges to arrive with the changing Arctic. There is a need to integrate local and traditional knowledge into education.
- **Access to and co-production of knowledge is needed.** Improved monitoring systems and co-production of knowledge by fully integrating different groups in adaptation processes is key to maintaining and making use of the rich, varied and valuable body of knowledge held within the Barents area.
- **Strengthening the interactions between science and policy is necessary at all levels.** Comprehensive, relevant and usable knowledge is needed to support continuous social learning and the development of adaptation governance at multiple levels. Knowledge production and dissemination remains a key instrument in dealing with climate change. New networks and partnerships for knowledge production and communication are needed to advance social learning and adaptive measures. However, funding of adaptation development and clarification of responsibilities and authority remains a major task.
- **Resilience should be protected and strengthened.** Strengthened resilience improves the capacity to adapt to as yet unknown conditions. By assuming change in planning and managing, and by generating knowledge and capacity for ongoing learning, ecosystems and livelihoods are equipped with greater capacity to respond to disruptive developments or events. Diversity plays an important role by providing a wider range of options for the future. Resilience can be strengthened through safeguarding or incentivizing biodiversity and diversity in markets, cultures and knowledge and culture.
- **Cooperation together with mainstreaming and acknowledging complexity may capture adaptation opportunities.** There are no one-size fits all methods for conceptualizing, measuring and assessing adaptive capacity or resilience. There is a need for the research and policy communities to work together to develop new interactive tools that can be used in decision-making processes at different levels of governance, from local communities to the international level. Climate change adaptation should be integrated into existing policy and governance. Such mainstreaming may capture opportunities for adaptation that might not otherwise be identified. For effective governance to take place, a clear distribution of responsibility for adaptation at different levels is necessary. Conflict resolution mechanisms that can be used to negotiate among actors with diverging priorities are also important.
- **Uncertainty does not preclude action; it should inform action.** Although its exact form cannot be known, it is inevitable that the future will bring change. This highlights the importance of strengthening the capacity to develop the knowledge base and take action. Given the many uncertainties related to the direction, magnitude and consequences of change in environmental, political, societal, economic and culture conditions, there is a need to further develop approaches for assessing and managing uncertainty. Important considerations include developing an understanding of the complexity of governance required to mainstream climate change adaptation across different sectors and management levels.

Adaptation and mitigation processes must proceed in parallel

The Barents area is strongly integrated with the world economy and will thus be strongly influenced by global actors and megatrends, as well as by business and industrial activities in the area and beyond. The implications of environmental and socio-economic change in the Barents area will depend on the region's natural and human resources, their institutional characteristics and the policies adopted. The key strategies and tools described here can help inform decision-makers in government, civil society, business and academia as they prepare for the changes anticipated in the Arctic. It is important to note, however, that adaptation has its limits. Mitigation effort at the national and international level will improve the chances of successful adaptation at the local level, by decreasing the rate of change to which ecosystems and human systems must adapt, and eventually by limiting the amplitude of that change.

1. Introduction and framing issues

Authors: Marianne Kroglund, Tove Lundeberg

Key messages

- ***The Barents area is undergoing rapid environmental and societal change.*** *The implications of these changes require sound scientific knowledge as a basis for developing appropriate and effective policy responses. The earlier the capacity to adapt is integrated into planning and policy decisions, the better equipped society will be to cope with additional changes.*
- ***Challenges and opportunities have local and regional specificity.*** *By integrating knowledge from many different fields of expertise, and across regions with large cultural diversity, multiple uses and users of local resources, and ambitious development plans for the future, this report provides a sound basis for informed, timely and responsive decision-making in the Barents area.*
- ***Adaptation to change, and building adaptive capacity and resilience, is a dynamic process.*** *One that is constantly evolving in response to an increasing knowledge base as well as to the actual or expected effects of change. Building shared knowledge and understanding is key.*

1.1 What can be done to prepare for changes in the Arctic?

The coming decades will see many changes in the Arctic – changes in the economy, population, climate and environment. Factors driving these changes include growth in the world demand and use of energy and mineral resources, industrial and infrastructure development, and changes in demographic patterns and land use. Projected changes in average and extreme temperature and precipitation, warmer oceans, rising sea level and declining snow and ice cover on land and at sea, as well as the changes in social and economic development play an essential role in shaping the future. The implications of these changes require sound scientific knowledge as a basis for developing appropriate and effective policy responses.

In 2013, in recognition of the changes occurring in the Arctic and the need for Arctic communities and governments to respond to them, the Arctic Council requested the Arctic Monitoring and Assessment Programme (AMAP) to "*produce information to assist local decision-makers and stakeholders in three pilot regions in developing adaptation tools and strategies to better deal with climate change and other pertinent environmental stressors*". The project *Adaptation Actions for a Changing Arctic* (AACA) is the response to this request: an assessment of the key drivers of change, how these drivers are interacting, and how human and natural communities are responding to or could respond to these changes in the future.

To date, most Arctic Council assessments of Arctic change have focused on identifying and describing the science related to specific challenges and ongoing change within a given Arctic system. The AACA moves beyond assessing the state of science, and focuses on the question *What can be done to prepare for Arctic changes?* The project ultimately intends to enable more informed, timely and responsive decision-making in a rapidly changing Arctic – to aid decision-makers to respond to the challenges, while taking judicious advantage of the opportunities, now and in the future.

1.2 Need for local and regional perspectives and responses

The challenges and opportunities resulting from a rapidly changing Arctic have local, national and regional specificity, and vary depending on climatic, geographic, political and socio-economic conditions. AACA therefore explores three pilot regions; the Barents area, the Baffin Bay/Davis Strait region and the Bering/Chukchi/Beaufort region (Figure 1.1).

This report presents perspectives from the economically, socially and culturally diverse Barents area. This region is home to a number of indigenous peoples and contains unique ecosystems and biodiversity values. It is rich in renewable and non-renewable resources, which form the base for production in forestry, fisheries, mining, agriculture and the hydrocarbon industry, as well as tourism and local-scale economic activities such as herding, hunting and gathering. Broad socio-economic trends at the global as well as regional scale, will impact all these actors and sectors.

The Arctic is warming faster than the global average and this is expected to continue. In the Barents area, as in the Arctic as a whole, changes in precipitation and extreme weather events will affect offshore activities, transport and infrastructure. Changes in climate will have direct impacts on snow and ice, as well as on terrestrial, freshwater and marine ecosystems. In addition to climate change, the region's ecosystems are also influenced by several other impacts of human activities, such as chemical pollution, invasive species, and increased shipping and industrial developments. The end result is cumulative and cascading impacts on ecosystems and societies in the area. Local communities and indigenous peoples are among the first to face the direct consequences of change in the Arctic, owing to their dependence upon, and close relationship with the environment and its resources, not only for food and income but also, especially for indigenous peoples as the basis for their cultural and social identity.

Efforts to enhance adaptation, adaptive capacity and resilience are needed in order to lessen undesirable impacts of existing and future consequences of climatic, social and economic change. Furthermore, the earlier the capacity to adapt is integrated into planning and policy decisions, the better equipped society will be to cope with additional changes.

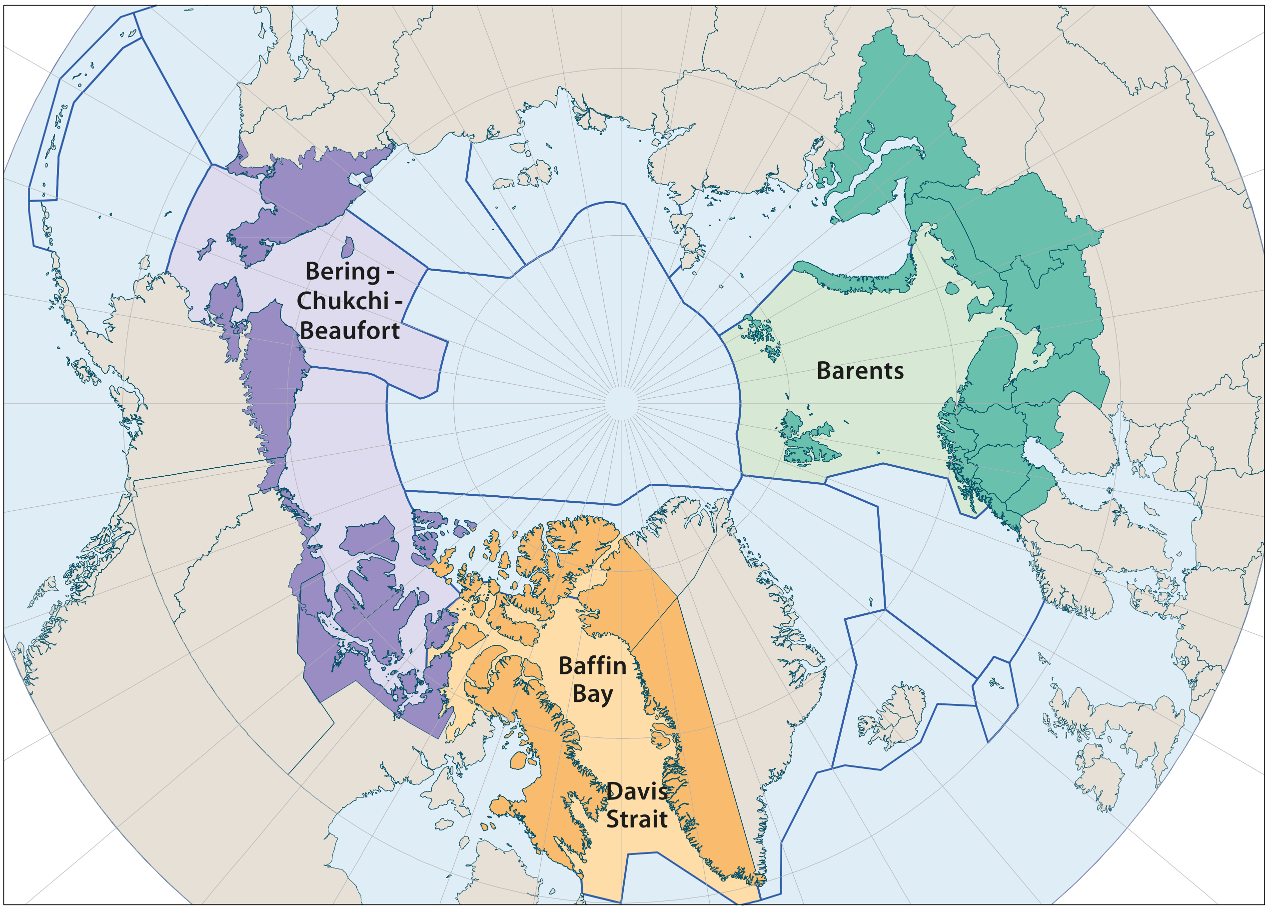


Figure 1.1 The three pilot regions for the project Adaptation Actions for a Changing Arctic. Blue lines delimit Large Marine Ecosystems (LMEs).

Owing to the social, economic and environmental diversity of the Barents area, there are different views, expectations and concerns about the future of the region, the changes expected and what can be done to prepare for and adapt to these changes. The capacity of the region to adapt depends on social and environmental contexts (e.g. demography and economic diversity), as well as on conflicting interests, decision-making power and capacity, and access to relevant knowledge.

This report provides a knowledge base for understanding Arctic change and its impacts upon communities and ecosystems in the Barents area, as well as tools for adaptation. It presents insights and perspectives that can help society become better equipped to cope with, and even thrive in a rapidly changing Arctic. Mitigation actions, including the essential mitigation of greenhouse gases, will increase the potential for successful adaption to Arctic change by local/regional actors, through decreasing the rate of change to which ecosystems and human systems must adapt, and over the long term through limiting the amplitude of that change. Adaptation and mitigation must therefore proceed in parallel.

1.3 Outline of the Barents area report

This report summarizes existing knowledge related to past, present and possible future changes within a section of the Arctic – in this case the Barents area (Figure 1.2). The geographic scope includes the Barents Sea as well as the adjacent terrestrial areas, and Svalbard and Franz Josef Land. Thus, the study area is broader than the 'Barents Region' as defined by the Barents Euro-Arctic Council (BEAC; www.beac.st/en). This report sometimes also covers the neighboring regions of Yamalo-Nenets. This reflects the social, economic and environmental continuity to these nearby regions for some issues. This broader area is referred to here as the 'Barents area' or the 'Barents study area'. The term 'Barents Region' is only used in the context of the defined BEAC area.

The assessment is based on peer-reviewed publications, indigenous and local knowledge, and other documented information and data. By applying a 'resilience and adaptation lens' to existing information and assessments, it has been possible to identify and highlight the key local and regional perspectives that will provide decision-makers with the information they need to prepare for and respond to the challenges, while taking well-judged advantage of the opportunities.

The report comprises ten chapters. Chapter 2 provides an overview of the *current status* of environmental and socio-economic conditions in the region, while Chapter 3 gives insights into *regional and local knowledge on adaptation*. Chapter 4 outlines *future socio-economic and climate changes* in the region based on observed trends and model projections. The construction of *future scenarios and narratives* based on stakeholder consultation is discussed in Chapter 5, as a tool for identifying adaptation needs and evaluating strategies. Additional analyses of *impacts from climatic, environmental and socio-economic drivers* and their interaction, and as well

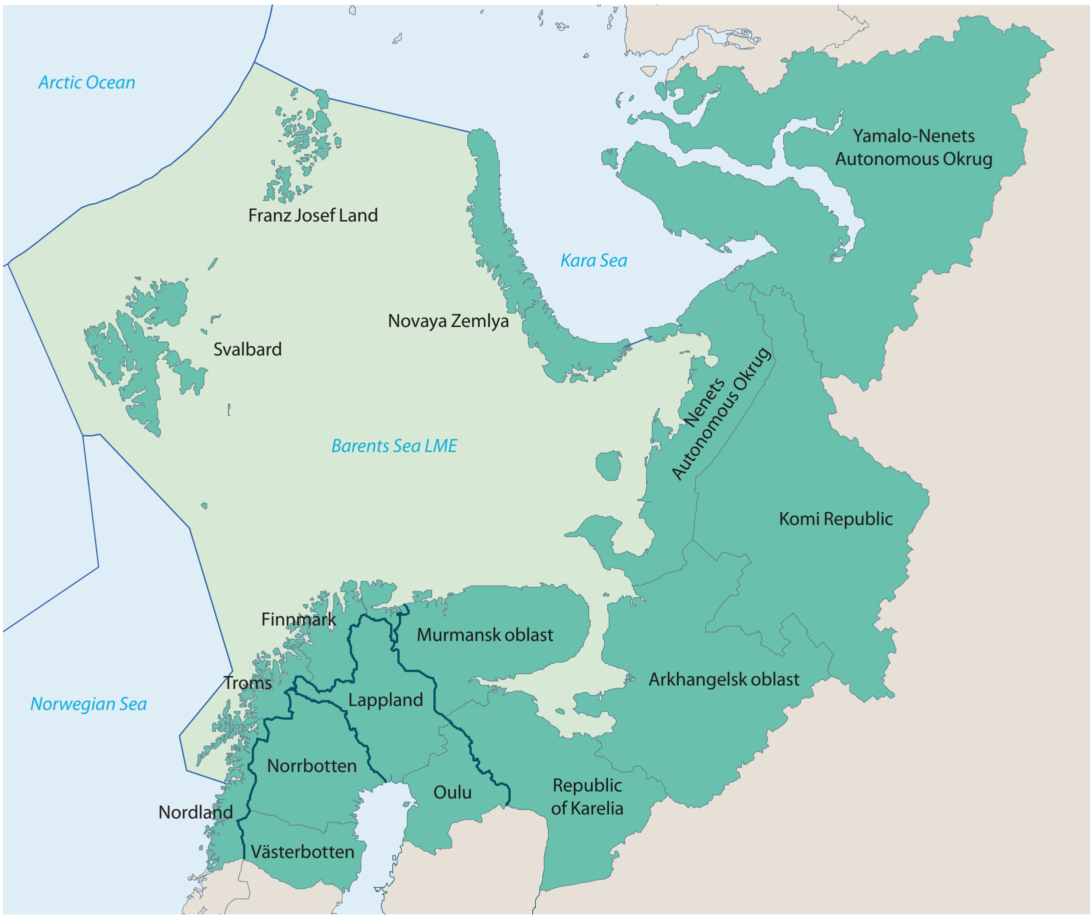


Figure 1.2 The Barents area, as defined in this pilot study. The terrestrial areas follow relevant administrative boundaries within the four countries. The marine area comprises the Barents Sea Large Marine Ecosystem (LME).

as key consequences of projected changes, are discussed in Chapter 6, with particular emphasis given to *indigenous peoples perspectives* in Chapter 7. A *resilience approach* to adaptation is introduced in Chapter 8, and applied to studies of several local contexts to test the utility of developing a framework of resilience indicators. Chapter 9 on *adaptation options* highlights the many changes that will need to be addressed within the Barents area in the context of multiple stressors (environmental and climatic, societal, institutional and governance, and political and economic). The chapter illustrates different adaptation processes, barriers and limits to adaptation, and governing tools. Chapter 10 – the *Synthesis* chapter – places adaptation within the context of broader policy goals related to sustainable development and highlights those social processes that will need strengthening in order to support long-term adaptation action to the multiple and interacting changes expected in the coming decades.

1.4 Way forward

The Arctic and the regions explored as part of the AACA project are complex systems undergoing rapid environmental and societal change. By integrating knowledge from many different fields of expertise, and across regions with large cultural diversity, multiple uses and users of local resources, and ambitious development plans for the future, AACA has broken new ground. Using a multidisciplinary approach, applying this across wide geographical and societal scales, and looking decades ahead has been a challenge. Nevertheless, building shared knowledge and understanding of cumulative and cascading impacts is key to developing effective policy responses, such as adaptation actions, enhancing resilience and implementing of mitigation measures. Adaptation to change, and building adaptive capacity and resilience, is an evolving and dynamic process, constantly responding to an increasing knowledge base as well as to the actual or expected effects of change. It is a learning process, in which the Arctic Council can also play a constructive role for many years to come.

2. Status of the natural and human environments

Coordinating lead authors: Wenche Eide, E. Carina H. Keskitalo, Kit M. Kovacs

Lead authors: Randi B. Ingvaldsen, Andrey N. Petrov, Maria Pettersson, Lovisa Solbär

Contributing authors: Natalia Anisimova, Peter Arbo, Dag Avango, Per Axelsson, Rasmus Benestad, Padmini Dalpadado, Andrey Dolgov, Niklas Eklund, Elena Eriksen, Martin Forsius, Anne Kirstine Frie, Antti Hannukkala, John Richard Hansen, Ketil Isaksen, Edda Johannnesen, Lis L. Jørgensen, Hossain Kamrul, Asta Kietäväinen, Tor Knutsen, Oleg Korneev, Dmitry Lajus, Kari Lehtonen, Pavel Ljubin, P. Lyubin, Michal Luszczuk, Dieter Müller, Emma Orlova†, Willy Østreng, Geir Ottersen, Stanislav Patin, Vladimir Pavlov, Örjan Pettersson, Øyvind Ravna, Peder Roberts, Hein Rune Skjoldal, Peter Sköld, Päivi Soppela, Adam Stepien, Olof Stjernström, Petteri Vihervaara, Bob van Oort, Cecilie von Quillfeldt, Paul Warde

Key messages

- ***The Barents area has significant human, social, infrastructural, and biological resources to draw upon in responding to climate change.*** *The region is rich in natural resources and has a well-developed system of infrastructure and a high standard of living. The Barents area is more densely populated than other Arctic regions, partly owing to its rich, coastal resources (fish and marine mammals) and its long historical development.*
- ***Climate change and globalization are important drivers of change within the region.*** *Both have been occurring for a very long time. Climate change impacts on flora and fauna are already notable and globalization is having strong impacts on local economies, trade patterns and governance. The economy at both local and regional levels is strongly integrated within global flows of resources, people and products.*
- ***The role of local and regional economies and governance within a multi-level governance context needs to be emphasized in the context of regional adaptation to climate change.*** *The multicultural, highly integrated Barents Region is part of several large states with relatively strong natural resource development, but with large distances to markets. The region is also strongly impacted by international and global changes. Maintaining service and infrastructure is crucial for maintaining the strong economic role and continued attractiveness and competitiveness of the region.*
- ***Invasive alien species are considered one of the major threats to native biodiversity in the Barents area.*** *They are a serious threat to resident species in both terrestrial and marine environments. Climate warming, in combination with globalization and growth in the volume of trade and tourism has provided species of plants, animals, fungi and microorganisms with a means to establish in areas outside their natural range. International cooperation must be a component in management plans to combat invasive species in the Barents area.*
- ***Maintaining the biodiversity of the Barents area is important for ecosystem resilience and related functions.*** *Conservation of rare as well as common species must be a priority when planning for the long-term maintenance of ecosystem functioning. Conservation of Arctic endemic populations in the Barents area is a global stewardship responsibility of the governing states in the region.*

2.1 Introduction

This chapter provides background information on 'status and trends' relevant to human adaptation in the face of climate change, within a geographical area – the Barents study area – as defined during the AACA process. This region includes the areas involved in the political Barents Region cooperation that has existed since 1993, and been extended over time. However, it also extends northward to include the Svalbard and Franz Josef Land archipelagos within the High Arctic, as well as eastward, incorporating the Yamalo-Nenets (Figure 2.1). There is thus both considerable overlap and some differences between the area commonly referred to as the Barents Region and the area treated in this assessment.

This geographical region is heavily influenced climatically and economically by its maritime areas, which include part of the Norwegian Sea, the Barents Sea, the White Sea and the Pechora and Kara Seas. These ocean areas are bordered to the south by the North Sea, to the west by the Greenland Sea, to the east by the Laptev Sea and to the North by the Arctic Ocean. Landmasses surrounding the northern Baltic Sea are also included within the area of concern for this assessment, but not the Baltic Sea marine environment. The Barents Region is the core area covered in the established socio-economic literature and is thus a major focus in this chapter. Over five million people are resident in this area alone, while the Arctic parts of the broader Barents area are sparsely populated (the entire circumpolar Arctic is thought to include only four million people; see Nordic Council of Ministers, 2015). Not surprisingly given its large size, the area is extremely diverse in terms of its cultural mix. As a part of the European North the area has been settled for a long time, with considerable blending and intermingling of population groups. Inhabitants of the area include Swedes, Finns, Norwegians, Russians, indigenous peoples of Saami, Nenets, and Vepsian origin as well as Kven and Torne Valley Finnish minority groups (BEAC, 2016). The area also includes the Fennoscandian countries (Norway, Sweden, Finland) and Russia; areas between which there are large historical differences. All of these areas are currently undergoing change as a result of broader globalization, migration and urbanization trends, which adds to the social complexity. The population is, on average, aging with older people often remaining in the countryside while younger people are moving to the larger urban areas for higher education and employment. This results in challenges for labor supply and maintaining the tax base for healthcare, housing, education and welfare services in rural areas (e.g. Johnsen and Perjo, 2014). Urbanization, "*the process through which society is*

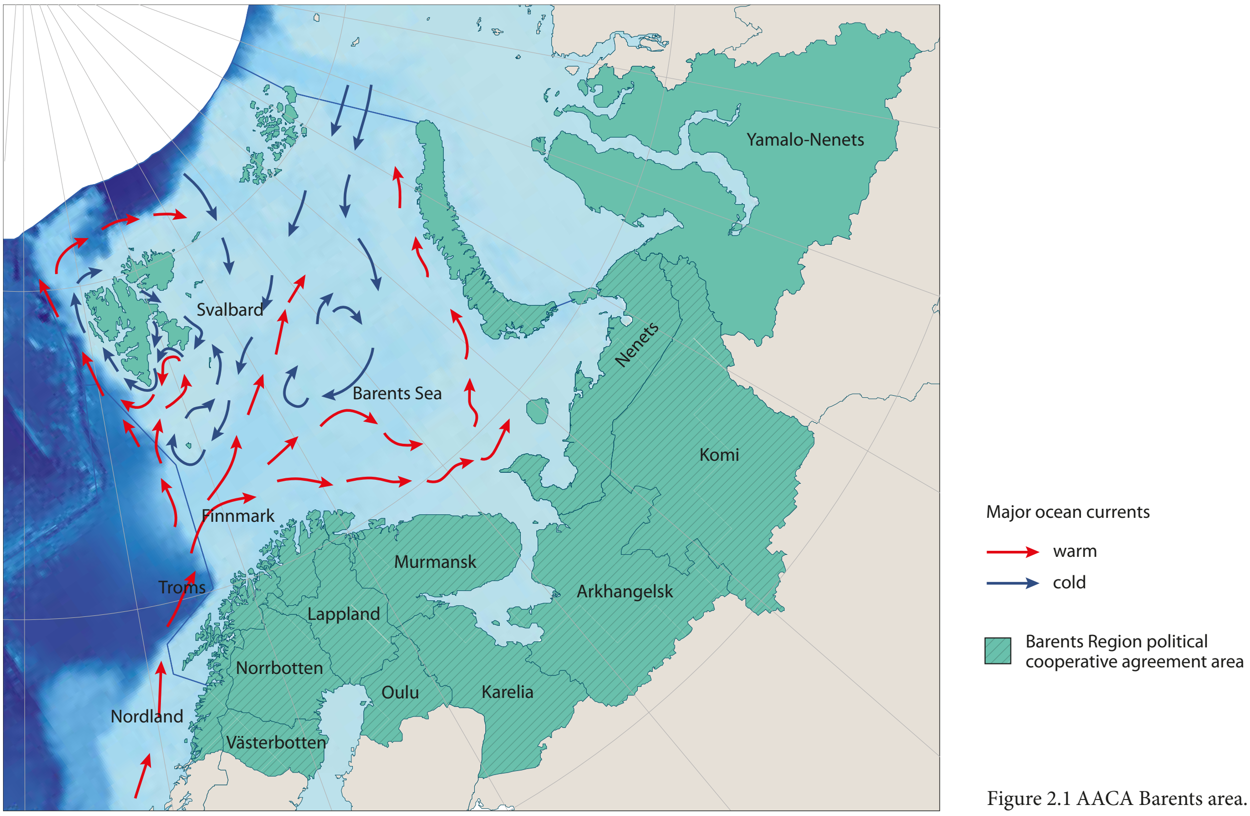


Figure 2.1 AACA Barents area.

transformed from one with predominantly rural characteristics in terms of economy, culture and lifestyle, to one which can be characterised as urban" (Nordic Council of Ministers, 2011) constitutes a strong trend in the region. The service sector is a large employer in the region, while employment in the secondary sector – processing, production, constructing – is dominant in some areas. Activities in the primary sector are of less importance in terms of employment but are of strong economic importance (Nordic Council of Ministers, 2011). The region thus has a mixture of industrial and post-industrial characteristics, with relatively well-developed services, infrastructure and administration throughout much of the region.

Svalbard and Franz Josef Land as well as Novaya Zemlya, differ from the Barents Region core areas in having a relatively High-Arctic character with very limited human populations. Yamal-Nenets, lying outside the Barents Region, is an important oil, gas and reindeer husbandry district. The marine areas covered in this chapter are mostly unproblematic in a jurisdictional sense, especially after the 2010 Russian-Norwegian agreement on delimitation of the exclusive economic zones (EEZs) and continental shelf regions within the Barents Sea (Byers, 2013).[1]

This chapter describes the natural terrestrial and marine environments of the area and then provides an overview of socio-economic and political structures, with a particular emphasis on environmentally-based sectors that are likely to be influenced by climate change. The focus is mainly on highlighting characteristics that are important for understanding the uniqueness of the area within the broader Arctic context and for placing it in an international context. It should be noted, however, that because much of the Barents Region is highly developed and heavily populated compared to other Arctic areas, a much wider range of topics than just natural systems and environment-based industries would be necessary to understand the many factors influencing adaptation even in this area. For instance, almost all the industries mentioned here form part of international flows of people, energy and resources, such that global economic changes, competition, energy prices, and changes in international (especially European Union) contexts, will influence the region and decisions made at any level within it.

2.2 Natural environment

2.2.1 Terrestrial and freshwater ecosystems

The terrestrial and freshwater ecosystems of the Barents area cover 1.8 million km^2, with about 75% of this in Russia. Using the Barents Protected Area Network (BPAN) categorization for terrestrial areas there are five main ecosystem types: glacier, freshwater, open wetland, alpine and lowland tundra, and forest.

---

[1] The Svalbard Archipelago is subject to a separate legal regime established by the 1920 Spitsbergen/Svalbard Treaty, which means that it constitutes a specific decision-making arrangement. The Treaty bestowed sovereignty over the islands to Norway, including responsibility for introducing non-discriminatory nature conservation measures, but at the same time it secured free commercial and scientific access for nationals and companies from other parties to the treaty. There is an ongoing disagreement between Norway and some parties over whether the commercial rights guaranteed to other contracting states' nationals on the basis of the Svalbard Treaty also apply to the EEZ on the continental shelf surrounding the islands. These latter concepts have arisen decades after the treaty was adopted. One of the consequences of this disagreement is that a Fisheries Protection Zone was established around Svalbard, rather than an EEZ, with consequences for fishing as well as potentially more broadly.

2.2.1.1 Climate

The natural landscape and species present in the Barents area of today result mainly from the present climatic conditions combined with past events. For the whole of the northern hemisphere, ice-sheet advances during the Last Glacial Maximum played a significant role in forming the present landscape. Even though the extent and thickness of the ice cap are a subject of scientific discussion (Kullman, 2002; Birks et al., 2005), the period undoubtedly affected the Barents area. The lake-rich postglacial terrain is perhaps the most dominant feature in mainland areas, presenting a landscape with a lake density (number of lakes per 1000 km^2) more than four times that of areas not previously covered by glaciers (Smith et al., 2007). The climate of the terrestrial areas within the Barents area is heavily influenced by proximity to the sea and its high latitude. The Gulf Stream also makes the entire region far warmer than comparable circumpolar areas at these latitudes, and mainland Norway, Sweden and Finland are regularly defined as sub-Arctic rather than Arctic. Present-day mean annual temperature (Figure 2.2), estimated for the period 1960–2015 (see Benestad et al., 2016 for data and gridding), ranges from about -18°C at Novaya Zemlya (Russia) to about 6°C on the west coast of Norway. Temperature is estimated to have increased by 1–2°C over the period 1954–2003, with warming strongest in winter (ACIA, 2004). See Chapter 4 for further discussion.

Present-day mean annual total precipitation (Figure 2.2) estimated for the period 1960–2015 (see Benestad et al., 2016 for data and gridding) also demonstrates a gradient, from about 1700 mm on the Norwegian west coast to about 100 mm on Svalbard and Novaya Zemlya (Russia). Precipitation is estimated to have increased by 8% over the last century (ACIA, 2004). See Chapter 4 for further discussion of changes in precipitation.

Changes in winter climate, in particular winter warming events affect snow property. If followed by freezing temperatures the snow pack will increase in density and can generate ice layers in the snow. Such ice layers may limit access to forage by reindeer (Vikhamar-Schuler et al., 2016) as well as shelter and access to food for small rodents living below the snow (Fuglei and Ims, 2008), thus affecting predators dependent on the rodents. See Chapter 4 for more discussion on snow.

2.2.1.2 Forest and tundra ecosystems

Forest/Taiga

The taiga (often referred to as boreal forest in the USA and Canada) constitutes the most widespread forest ecozone (Figure 2.3) in the Barents area, covering 54% of the land area on the mainland. It is bordered by Scandinavian coastal conifer forests (west), Scandinavian Montane birch forest and grasslands (northwest and upwards in the highlands and mountains), Kola Peninsula tundra (north), Northwest Russian-Novaya Zemlya tundra (northeast), Urals montane tundra and taiga (east) and Sarmatic mixed forests (south), and by the Baltic and White Seas.

The taiga summer is one to three months long with an average temperature of 10°C, although some areas, mainly in the west have a more humid continental climate with milder winters and longer summers. The mean annual temperature is generally between -5°C and 5°C, although actual temperatures may range from -54°C to 30°C. A typical winter day has a temperature of -20°C while a typical summer day has a temperature of 18°C. Precipitation is relatively low throughout the year, generally 200–750 mm, but can reach 1000 mm in some areas, occurring mainly as rain during summer months, but also as fog and snow.

The flora comprises coniferous forests dominated by pine (*Pinus sylvestris*) in drier locations, often with an understory of juniper (*Juniperus communis*), spruce (*Picea abies* and *P. obovata*) and a significant mixture of birch (*Betula pubescens* and *B. pendula*). Siberian larch (*Larix sibirica*) is characteristic of the eastern parts of the ecozone. Besides birch, broadleaf trees of aspen (*Populus tremula*), willow (*Salix* spp.), and rowan (*Sorbus aucuparia*) also occur. Many smaller herbaceous plants grow on the forest floor, such as ferns, as

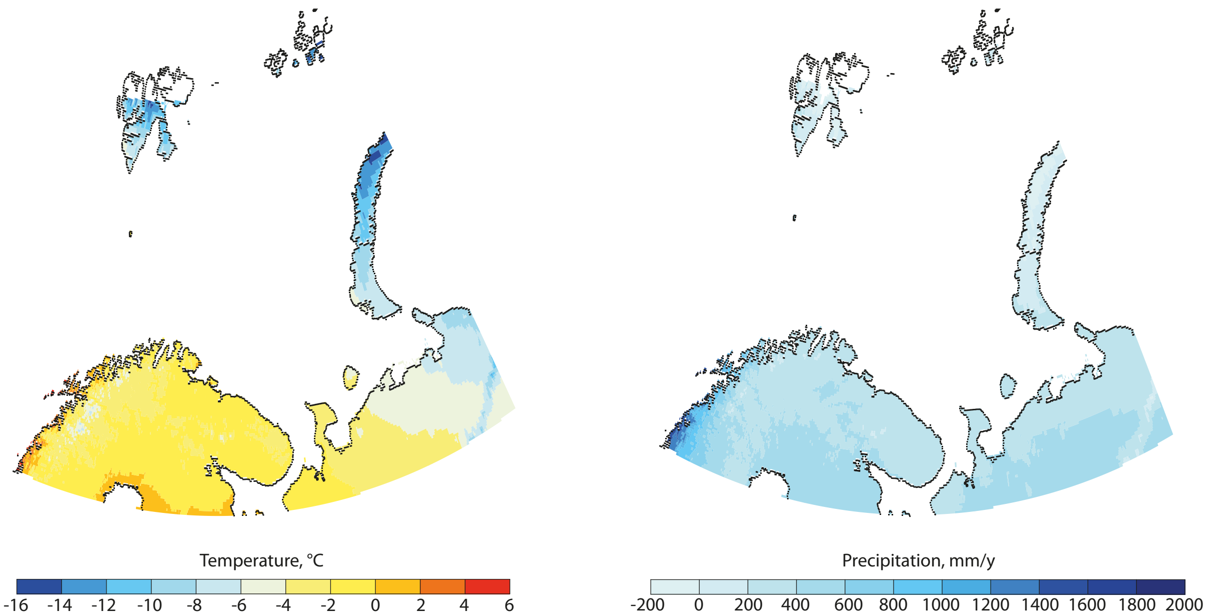


Figure 2.2 Present-day mean annual temperature (left) and mean annual total precipitation (right) estimated for the period 1960–2015. The data are based on station records from the European Climate Assessment & Dataset (ECA&D) project with methodology as per Benestad et al. (2016).

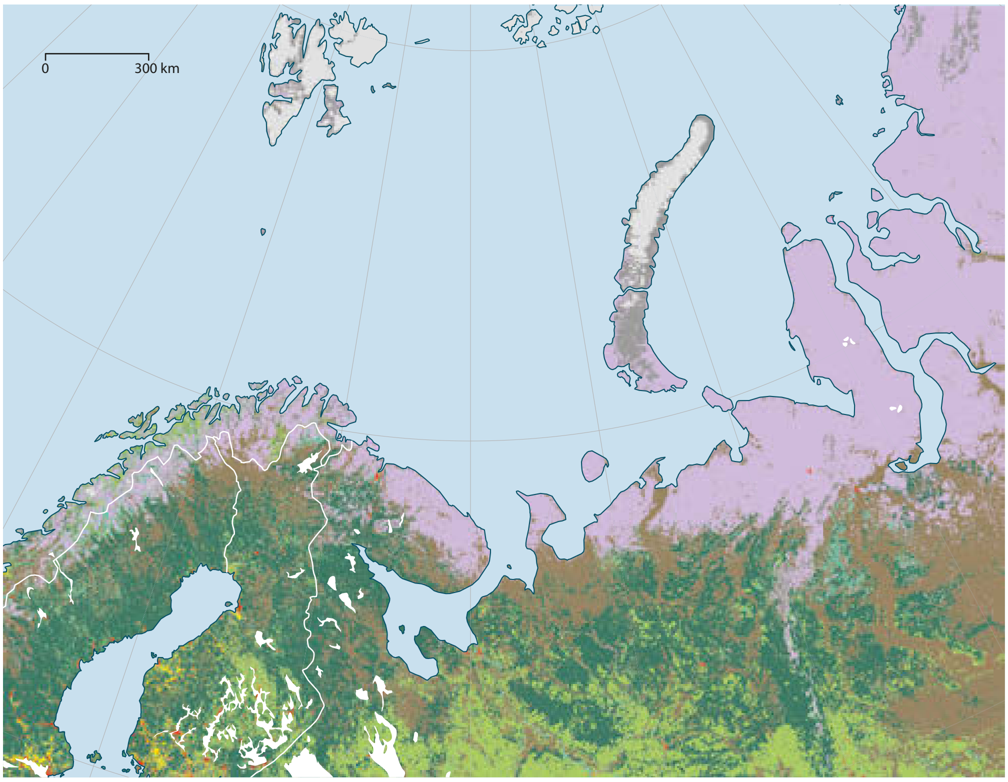


Figure 2.3 Distribution of forest types and ecozones in the Barents area.

well as many different types of berry, for example cranberry (*Vaccinium oxycoccus*), cloudberry (*Rubus chamaemorus*), blueberry (*V. myrtillus*) and cowberry (*V. vitis-idaea*), most of them surviving winter protected by the snow cover. Grasses grow wherever they can find a patch of sun, and mosses and lichens thrive on the ground and on the sides of tree trunks. Wildfire and windfalls are important factors in the dynamics of the forests (Angelstam, 1998), opening up the canopy and enabling regeneration. Mixed in among the forests are bogs, fens, marshes, shallow lakes, rivers and wetlands, all of which hold vast amounts of water. The flora listed here are based on Olson et al. (2001) and https://en.wikipedia.org/wiki/List_of_terrestrial_ecoregions (WWF), 'Scandinavian and Russian taiga'.

The fauna is relatively low in species richness, but many species consider the taiga home for all or part of the year. Large herbivorous mammals are represented by reindeer (*Rangifer tarandus*), moose (*Alces alces*), red deer (*Cervus elaphus*) and roe deer (*Capreolus capreolus*). Smaller mammals are represented by the mountain hare (*Lepus timidus*) and rodent species such as beaver (*Castor fiber*), squirrel (*Sciurus vulgaris*) and voles (Arvicolinae). Mammalian predators of the taiga include the (Eurasian) lynx (*Lynx lynx*), stoat (*Mustela erminea*), European otter (*Lutra lutra*), wolverine (*Gulo gulo*), gray wolf (*Canis lupus*), red fox (*Vulpes vulpes*), and brown bear (*Ursus arctos*). The fauna listed here are based on Hof et al. (2015), the Swedish Species Observation System (www.artportalen.se), and the Norwegian Species Observation Reporting System (www.artsobservasjoner.no).

The taiga has environmental conditions that are too harsh for most reptiles and amphibians. However, the common European adder (*Vipera berus*) survives winter by hibernating underground, and the European common frog (*Rana temporaria*) may survive for months under ice. Adaptations to cold water and the ability to survive under ice-covered water is a prerequisite for fish of the taiga. Examples of species that reside in the region are the northern pike (*Esox lucius*), grayling (*Thymallus thymallus*) and trout (e.g. *Salvelinus alpinus* and *Salmo trutta*). The largest animal group is the insects, which are important prey for mammals and birds and also function as pollinators and decomposers. The taiga is home to a few hundred bird species in summer, most of which take advantage of the long days and the abundance of insects. While many of these species leave as autumn arrives, carrion-feeders and large raptors such as the golden eagle (*Aquila chrysaetos*) and the raven (*Corvus corax*), stay behind in the southernmost parts of the taiga together with seed-eating birds such as ptarmigans (*Lagopus* spp.) and crossbills (*Loxia* spp.). About 1160 species of vascular plant, over 1000 lichens, 600 mosses, 36 mammals, 180 birds, and 19 different freshwater fish have been documented in this ecozone.

Tundra

Alpine and Arctic tundra covers almost 20% of the area and is mainly present in Norway and Russia, situated north of the taiga belt in coastal areas of the north and west and in the High-Arctic archipelagos of Svalbard and Franz Josef Land. The area corresponds well with the Circumpolar Arctic Vegetation Map's (CAVM Team, 2003) definition of the Arctic.

The tundra is often defined as a biome where tree growth is hindered by low temperatures and a short growing season. In this context the tundra is defined both from a latitudinal and an altitudinal perspective, both with the tree line as a border to other biomes further south or at lower altitudes. Nevertheless, scattered occurrences of trees can occur in tundra. Moderating ocean winds prevent temperatures from becoming as severe as interior regions of the Barents area tundra. However, it is still relatively cold throughout all months of the year, with summer temperatures rarely exceeding 7–10°C and average winter temperatures down to around -30°C. Mean annual precipitation ranges between 150 and 250 mm in mainland areas (Figure 2.2), but is lower in High-Arctic desert areas such as Svalbard and Novaya Zemlya. However, due to low rates of evaporation most tundra areas often appear wet. Permafrost prevents the shallow lakes and bogs from draining and these wetland areas are very important for insects as well as for providing food and water for many birds. In contrast, alpine tundra lacks permafrost and so has better-drained soil.

Tundra vegetation is dominated by perennial dwarf shrubs, sedges, grasses, bryophytes and lichens (Chernov and Matveyeva, 1997; Olson et al. 2001; Kobyakov and Jakovlev, 2013). Freeze-thaw activity, a thin active layer (in areas of permafrost), and soil slippage during the summer thaw contribute to strong controls on vegetation patterns and create a mosaic of microhabitats and plant communities. So even though many of the same plant species (at least for alpine tundra) occur in the taiga, the vegetation cover in the tundra looks different as it is often less continuous and the vascular plant species are shorter.

Animal species have evolved strategies to withstand the harsh environment (CAFF, 2013). Among resident mammals and birds, such as the Arctic hare (*Lepus arcticus*), Arctic fox (*Vulpes lagopus*) and ptarmigan (*Lagopus muta*), morphological adaptations expressed as a thick insulating cover of feathers or fur, and pelage and plumage that turn white in winter and brown in summer are among the adaptive suite of characters common to the terrestrial community. In addition, physiological adaptations such as the ability to accumulate thick deposits of fat during the short growing season, which then act as insulation and a store of energy for use during winter, are important characteristics of the animals of the northern Barents area. Other common species include lemming (*Lemmus* spp.) and reindeer (*Rangifer tarandus platyrhynchus*). For the High Arctic in particular, the resident terrestrial fauna of birds and mammals (Ims et al., 2014) has low species diversity, and this is especially true for Svalbard and Franz Josef Land in the northern reaches of the Barents area. Only the reindeer, Svalbard ptarmigan (*Lagopus mutus hyperboreus*) and Arctic fox reside on land year round. This is not too surprising given that over 60% of the land in Svalbard and 85% of the land in Franz Josef Land is glaciated. The reindeer in Svalbard is a unique subspecies compared to the mainland or to Greenland; its relationship to animals in Franz Josef Land is not known. The ptarmigan in Svalbard is likely to be the same subspecies as that in Franz Josef Land, based on morphology, so both terrestrial grazers have experienced island-endism phenomena. The Arctic fox travels widely across the sea ice between land masses and so populations are broadly spread and genetically open to other areas. Migratory species such as waterfowl, shorebirds and domesticated reindeer avoid the harsh winter by moving south into the boreal forest or even further south at the end of the growing season. In spring, they return to the tundra to breed and feed.

Many invertebrate species are endemic to the Arctic. Due to their small size and ability to move they can utilize the variety of microhabitats in the landscape, interacting with climatic differences and the contrasting biotic environment (Coulson, 2000). Common groups of invertebrate tundra species (CAFF, 2013), in terms of species density, include nematodes (Nematoda), springtails (Collembola), non-biting midges (Chironomidae), mosquitoes (Culicidae), flies (Diptera), mites (Arachnida), moths (Lepidoptera), tardigrades (Tardigrada) and small earthworms (Enchytraeidae).

The length of the growing season (seasonal spread of photosynthetic activity) in the Barents area has increased over the past 30 years, and plant flowering has advanced by up to 20 days during a single decade in some areas (Xu et al., 2013). Primary productivity and vascular plant biomass have increased rapidly in terrestrial communities – particularly in terms of increased growth and expansion of tall shrubs. However, plants in the lowest vegetation layers, such as mosses and lichens, are declining in terms of abundance (CAFF, 2013). See Chapter 6 for further discussion.

2.2.1.3 Glaciers, freshwater ecosystems, wetlands

Glaciers

Glaciers constitute about 4% of the area and are mainly present on Novaya Zemlya and the islands of Svalbard and Franz Josef Land, meaning they are well within the High Arctic as defined by the Arctic Council working group Conservation of Arctic Flora and Fauna (CAFF). Climatic conditions are harsh, with an average July temperature of 4–6°C and an average annual precipitation of less than 200 mm to just above 400 mm. The glaciers are classed into different types based on morphology. Most dominant by area are the large continuous ice masses – plateau glaciers – that are subdivided into individual ice streams by mountain ridges and nunataks (isolated peaks of rock projecting up through the ice). The presence of small animals during summer has probably been noted by most people walking on glaciers in summer. However, recognizing the existence of glacial ecosystems exploiting habitats such as wet snow, cryoconite holes, streams, ponds and moraines in the ice masses is relatively new (De Smet and van Rompu, 1994; Säwström et al., 2002). According to Hodson et al. (2008) there are two key glacial ecosystems, one inhabiting the glacier surface (the supraglacial system) and one at the ice-bed interface (the subglacial system). Life in the supraglacial ecosystem, with its snowpack, supraglacial streams and melt pools is characterized by bacteria, algae, phytoflagellates, fungi, viruses and occasional rotifers, tardigrades, and diatoms. The basal ice/till mixtures and subglacial lakes of the subglacial system are dominated by bacteria and probably viruses (Säwström et al., 2007). Despite differences between continental glaciers (decreasing) and oceanic glaciers (increasing), the overall trend is a major decline in glacier volume and area throughout the Barents area. See Chapter 4 for further discussion of changes in glaciers.

Freshwater ecosystems

The Barents area contains abundant and wide-ranging freshwater ecosystems, including lakes, ponds, rivers and streams and a complex array of wetlands and deltas. These contain habitats of varying ecological complexity that support a range of permanent and transitory species adapted to life in a highly variable and extreme environment (Vincent and Laybourn-Parry, 2008). They also serve as important ecological transition zones within and between terrestrial, freshwater and oceanic ecosystems. Freshwater ecosystems are undergoing rapid change in response to both environmental and anthropogenic drivers. Freshwater is found throughout the Barents area, covering about 5.5% of the area in total and reflecting the entire climatic gradient, with July temperatures ranging from 4°C to 15°C and precipitation of less than 200 mm (i.e. well within the definition of polar desert) to over 1700 mm along parts of the Norwegian coast.

Coastal freshwater fish communities in Norway are dominated by salmon (*Salmo salar*), and by trout and char (both members of the genus *Salvelinus*), all of which are cold-water species. High latitude lakes generally have low fish abundance and diversity. According to Sierszen et al. (2003), Arctic lakes typically have low productivity, supporting small fish populations with slow growth rates, such as Arctic char (*Salvelinus alpinus*), lake trout (*S. namaycush*), and lake whitefish (*Coregonus clupeaformis*), although biomass may be high (Power et al., 2008). Planktonic and benthic communities in Arctic lakes may be very productive (Vincent and Laybourn-Parry, 2008), although this decreases with increasing latitude. The number of species present ranges from 20 to 150 per lake, correlating with latitude, altitude, or water temperature, whereas species composition mainly follows water chemistry (Moore, 1979; Forsström et al., 2009). According to O'Brien et al. (2004), zooplankton density and biomass can be considerable, mainly limited by food availability and fish predation.

Inland waters show great variety in physical and chemical properties. They include glacier-fed rivers, snow-melt streams, cold oligotrophic lakes, and shallow temporary or permanent ponds. Running freshwaters receive large amounts of glacial meltwater, producing large braided river systems with high sediment loads and fluctuating flow (even no flow after the main snow-melt period) with low temperatures, also in summer. In coastal, glacier-free areas, the streams are snowmelt- and spring-fed and for these as well as for lake outflows (Füreder and Brittain, 2006), conditions can be more favorable for plants and animals, although many snowmelt streams dry up in summer. Temporary thaw ponds, permanent shallow ponds and small lakes are numerous and owing to their shallow depth (usually <2 m) or small catchments, will freeze to the bottom in winter and dry out in summer; both conditions limit permanent residence by biota. Abundant representatives of freshwater invertebrates are springtails (Collembola) and crane flies (Chironomidae) (CAFF, 2013).

The Pechora River is the largest river by volume in the Barents area, with a length of 1809 km and a drainage basin about the size of Finland. This mighty river flows north into the Arctic Ocean on the west side of the Ural Mountains. It lies mostly within the Komi Republic but the northernmost section crosses the Nenets Autonomous Okrug. The Pechora River has the second largest catchment area in the Barents area, exceeded only by the Northern Dvina River. The latter has a drainage basin that includes major parts of the Vologda and the Arkhangelsk Oblasts, as well as areas in the western part of the Komi Republic and the northern part of the Kirov Oblast, and small areas in the north of Yaroslavl and Kostroma Oblasts.

Wetlands

Wetlands occur throughout the Barents area (Figure 2.3) and are an important contributor to the mosaic nature of the landscape. Open wetlands cover 14% of the area, although this percentage increases if tree-covered wetlands are also included. In this context, wetlands are as defined by the National Wetlands Working Group (1988), as the area in the transition between land, in the conventional sense, and open water. Ecosystems are dominated by the constant presence of excess water. They are also characterized by a water table near the ground surface and so have poorly aerated soil requiring the dominant plants and other organisms to be adapted to wet and anoxic conditions. Wetlands comprise a mixture of habitats, shaped by past and present management in combination with the physical and biological conditions of each site.

Peatlands are a dominant wetland type within the Barents area; here defined as areas where the peat is at least 30 cm deep and often up to 40 cm deep (Joosten and Clarke, 2002). Plants, bacteria, and more than 500 species of fungi, liverwort, lichen and algae occur in peatlands. The most important groups, represented by several hundred species are the green algae (including desmids) and diatoms (for reviews see Hingley, 1993; Gilbert and Mitchell, 2006). Factors such as water chemistry, continuously open water and gradients of calcium and sediment iron-content are important for determining species groups and overall diversity (Rydin and Jeglum, 2013). Peat mosses dominate low-pH peatlands but as pH and nutrient levels increase, peat mosses are replaced by another ecological group, brown mosses. Vascular plants such as graminoids, herbs, shrubs and trees are also present in wetland areas.

Ecotone transitions are the most species-rich (see Box 2.1), such as occur between rich fen and calcareous meadow, and between swamp and upland forest. Mowing and cattle grazing are likely to increase diversity by holding back the tallest plants and possibly creating small patches of barren soil that provide habitat for less competitive species. Where species occur depends on their needs for water depth, with a gradient from species growing in waterlogged soil (e.g. *Myriophyllum*) to those partly or fully submerged in water (e.g. *Potamogeton*, *Nymphaea*). In dryer areas, such as wooded bogs and hummocky parts of open bogs, evergreen dwarf shrubs (*Erica*, *Calluna*, *Empetrum*, *Vaccinium*) are common. Peatland fauna covers a wide range of species from peatland specialists to generalists, such as mollusks (Mollusca), tardigrades (Tardigrada), annelids (Annelida), nematodes (Nematoda), flatworms (Platyhelminthes), and rotifers (Rotifera). Amphibians, such as frogs, toads (both *Anura*), and salamanders (Salamandridae), often depend on wet habitats but generally prefer wetlands other than peatlands. For large parts of the Barents area the climatic conditions are not suitable for amphibians; and summer is too short for most amphibian offspring to reach adulthood.

Wetlands are crucial for many types of bird, and species richness increases northward in open boreal mires probably due to the high productivity of insects (Järvinen and Väisänen, 1978) combined with long days for foraging during summer. Moving north, peatlands also become bigger offering a mosaic of habitats over large areas, which results in increased species diversity. High numbers of waders and passerine birds attract

Box 2.1 Ecological resilience

An important aspect of biodiversity is its role in ecological resilience. In this context, resilience is defined as the capacity of an ecosystem to resist disturbance and/or recover quickly from a perturbation (Ives and Carpenter, 2007). One commonly accepted hypothesis, the 'diversity–stability hypothesis' (McCann, 2000), states that higher species diversity within biological communities buffers the risk of ecological collapse. This does not necessarily mean that the diversity is driving the relationship. Rather, as a consequence of being diverse, communities contain important ecological mechanisms that provide resilience. One explanation for this is that in a species-rich ecosystem, niche-partitioning will be high leading to different responses (to environmental fluctuations, for example), with some species performing better than others (Ives and Carpenter, 2007). In addition, species-rich systems may also have more 'functional redundancy', meaning that if one species disappears, another will take its place providing the same or similar ecosystem functions and thereby providing stability (Walker, 1982). Previous studies have mostly focused on the number of species (α-diversity) in an area. However, a recent study by Mellin et al. (2014), looking at species turnover (β-diversity), demonstrated the potential to determine whether higher species diversity may buffer the risk of ecological collapse over time at the landscape level. As already mentioned, the Arctic is less species-rich than areas further south. Some of the species are unique to the region while others are not, and some are common while others are rare. Conserving all species is very costly, in every respect, particularly rare species. However, conservation of rare species offers more than taxonomic, aesthetic, cultural, or ethical value and must be a priority alongside common species when planning for the long-term maintenance of ecosystem function (Mouillot et al., 2013). Loss of response diversity may increase the vulnerability of specific functional groups, or even cause the loss of entire groups. This may in turn lead to social and economic vulnerability, to changes in nature's ability to supply essential ecosystem services, and ultimately to degraded socio-ecological systems (Elmqvist et al., 2003).

Box 2.2 Ecosystem services

Ecosystem services link ecosystems with society. They were described in detail in the Millennium Ecosystem Assessment (2003). Arctic ecosystems provide many unique services, such as the charismatic wildlife populations so important for tourism, and regulating services linked with snow, water cycling, phenology and culture of the high latitudes. The Economics of Ecosystems and Biodiversity Nordic study synthesized available knowledge on the socio-economic significance of biodiversity and ecosystem services in the Nordic countries (Kettunen et al., 2012), with the aim of making nature's values visible and helping bring them into decision-making. Findings include the importance of Nordic 'specialties' such as wood and other forest-based services such as berries, mushrooms and game, reindeer herding, recreation and tourism, and bio-innovations related to genetic diversity or for bio-economy. The report also noted the important role of regulating services such as carbon storage and sequestration, and water purification. Forest-related services are particularly important in Finland and Sweden, and fish/fishery-related services in Iceland and Norway. The report concluded that the Nordic countries are well placed in terms of economic resources to act as pioneers in promoting a green economy based on the sustainable use of ecosystem services.

Ecosystems are changing and as a consequence so are ecosystem services. Many key ecosystem services are influenced by climate change, emphasizing the need for adaptation action (Forsius et al., 2013; Fu et al., 2013). Jansson et al. (2015) examined the potential for changes in ecosystem services in the European north arising from climate change as well as societal and economic changes. They found (very) likely increases in wood production, summer outdoor recreation and species richness, and likely decreases in winter outdoor recreation and native Arctic species. The latter are of particular value as typical Nordic hunting species as well as having cultural and educational value. Many other changes are uncertain due to unknowns in species interactions, changes in land-use and future tourism behavior. The overall societal consequences of the 'likely' changes include more forest harvest and economic revenue, more intense forestry practices, more fragmented forests and a loss of biodiversity; longer summer (and shorter winter) tourist seasons resulting in more (and fewer) tourists; and potentially more goods and services as new species move into the region but a lower supply of traditional services and a loss of cultural and educational values. The projected changes in ecosystems and their services are likely to occur gradually, although rapidly emerging surprises associated with state changes are almost inevitable (Lindenmayer et al., 2010). Species distributions and vegetation composition are unlikely to be in equilibrium with climate at the end of the 21st century (Svenning and Sandel, 2013). The importance (and often unknown impacts) of ecosystems and ecosystem services on broader cultural and landscape values, indirect employment impacts, and human health and well-being are increasingly important issues that are not well covered (Kettunen et al., 2012). Communities, values, health and well-being are thus linked to climate and ecosystem change, but are also changing as a result of other drivers in the region.

Many key ecosystem services are influenced by the integrated impacts of climate change and other drivers, and this emphasizes the need for adaptation action. Remote sensing methodologies provide increasing possibilities for real-time monitoring and assessment of ecosystem services and changes in biodiversity. The vulnerability of ecosystem services in the Arctic to the developing bio-economy and to the increasing use of natural resources requires further investigation.

raptors and other birds that require large territories. Among the tree-covered areas, nutrient-rich deciduous forests offer more insects and tree holes for breeding birds than uplands forests, and so are more species-rich. Mammals are not represented in high species diversity or numbers in peatlands. Peat moss has a low energy content and small rodents, moose and reindeer tend to be found in wetland areas only in the nutrient-rich swamps and fen-forests. Beaver can inhabit peaty wetlands, depending on the availability of brooks and streams and proximity to food and lodge material such as aspen and birch. Wetlands provide a wide range of key ecosystem services: maintaining permafrost (in northern areas, see next section), regulating and filtering water and storing vast quantities of greenhouse gases, which is critical for global biodiversity. See Box 2.2 for further descriptions of ecosystem services.

2.2.1.4 Discontinuous and continuous permafrost

Permafrost (cryotic soils) is defined as soil(s) that remains at or below the freezing point of water for at least two consecutive years. Permafrost can only develop when the mean annual air temperature is low enough and snowfall in winter is limited, to allow heat flux from the ground. Permafrost is often divided into subgroups based on extent (Figure 2.4): continuous (90–100%), discontinuous (50–90%), sporadic (10–50%) and isolated patches (0–10%). On the mainland, continuous permafrost occurs mainly in Russia with extent increasing eastwards. Svalbard and Franz Josef Land have extensive permafrost zones.

Within the discontinuous permafrost areas thawing and freezing processes create frost heaves, and where there is a thick enough peat layer a peat hummock with a frozen core will rise above the surface of a mire (Seppälä, 1986). This is referred to as a 'pals'. Eventually the structure collapses exposing bare soil and often producing a small pond. This dynamic process creates a mosaic on the mire (Figure 2.5) which generates a heterogeneous environment (Luoto et al., 2004) potentially exploited by a range of species. This habitat is listed in the EU Habitats Directive (Council Directive 92/43/EEC) as important for biodiversity in Europe.

Permafrost temperature decreases with increasing latitude. In Scandinavia, Svalbard and northwestern Russia the permafrost is warmer than in other Arctic regions. This is due to the warming influence of ocean currents and prevailing winds on climate, while altitude is a modifying factor in the Nordic mountains (Romanovsky et al., 2010; Sato et al., 2014). Permafrost has been thawing since the 1990s (AMAP, 2017). The draining of lakes and wetlands converts aquatic and wetland areas into terrestrial ecosystems (Bring et al., 2016; Wrona et al., 2016). Peatlands in the permafrost zone are important reservoirs of soil organic carbon, particularly where permafrost is extensive and the peat is relatively thick. Disturbance of the peat surface layers in the tundra may lead to irreversible changes, transforming a carbon-sink ecosystem into a carbon-releasing system, either directly through emissions of greenhouse gases or through hydrological flows becoming a subsequent source of emissions (Degteva et al. 2015). For further implications of the ongoing climate change on permafrost see Chapter 4.

2.2.2 Marine ecosystems

The Barents Sea is a high-latitude Arctic shelf sea comprising 1.6 million km^2 (Carmack et al., 2006) with a mean depth of 230 m. It is one of two major shallow and highly productive Arctic seas, the other being the Bering Sea in the North Pacific Region. The Barents Sea is bordered by the northern Norwegian and Russian coasts and by the Novaya Zemlya Islands. The 500-m depth contour is often used to delimit the Barents Sea towards the Greenland Sea, Norwegian Sea, and Arctic Ocean (see Figure 2.1). Ocean circulation in this region is dominated by the Norwegian Atlantic Current, which brings warm saline Atlantic Water into the area from the south (e.g. Loeng, 1991). Atlantic Water extends throughout much of the western and central parts of the Barents

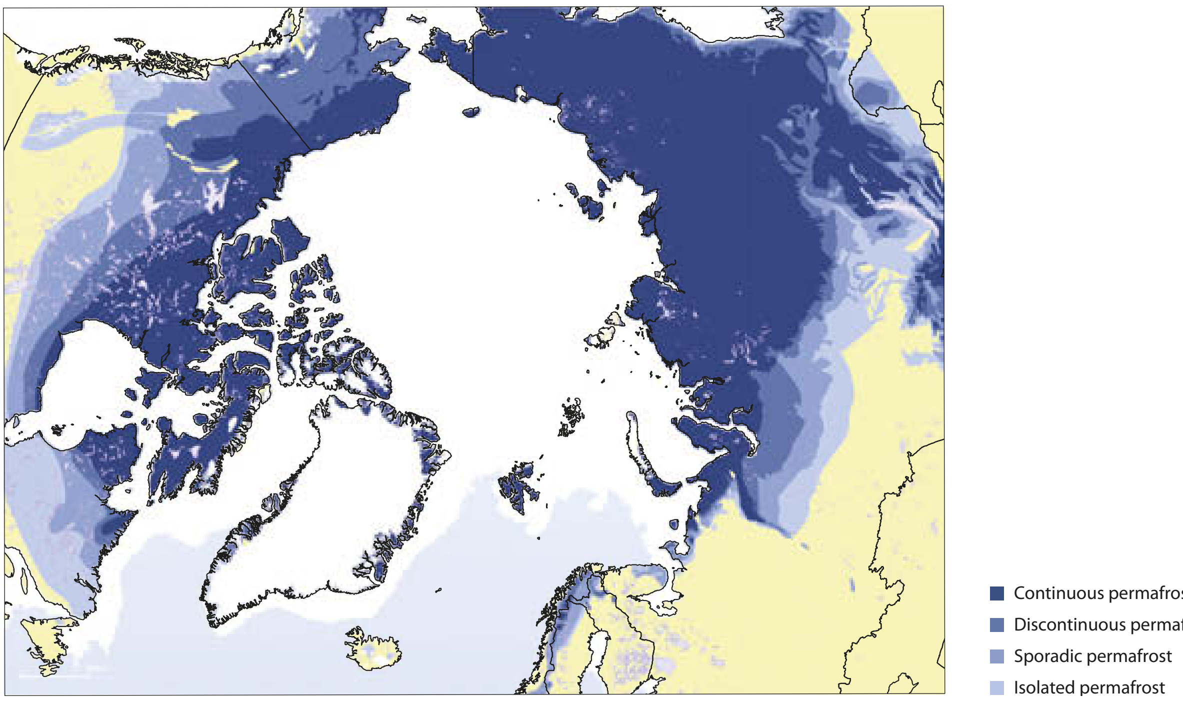


Figure 2.4 Distribution of permafrost in the circumpolar north (http://maps.grida.no/arctic/).

Figure 2.5 Mosaic of a Palsa mire (left), demonstrating a collapsing pals (right).

Sea whereas cold fresher Arctic Water dominates the surface layer in the northern sectors. Atlantic Water that travels north along the west coast of Svalbard (the West Spitsbergen Current) influences ice cover in the region (Ivanov et al., 2012); inducing open water areas at very high latitudes, even in winter, in places such as Whalers Bay. The boundary between the two main water masses (Arctic water and Atlantic water) is delineated by the Polar Front. There is also a coastal current running along the mainland shores carrying relatively warm and fresh water eastward. See Chapter 4 for further details.

Sea ice is one of the most important drivers of the Barents Sea system (see Chapter 4). The flow and interactions of the Atlantic Current in the south and the Arctic currents in the north have a significant impact on the distribution and extent of sea ice in the Barents Sea (e.g. Vinje, 2001; Årthun et al., 2012). Most of the sea ice in the Barents Sea is formed locally (Vinje and Kvambekk, 1991; Vinje, 2001) but a significant amount is imported from adjacent regions of the Arctic Basin through the straits between Svalbard and Novaya Zemlya (e.g. Pavlov and Pavlova, 2008; Kwok, 2009). Arctic sea ice also makes its way south along the east Greenland coast via southward flowing currents in Fram Strait. The Barents Sea ice cover has a strong seasonal variability. The spring melt stabilizes the upper water layers and is associated with a 'spring' plankton bloom that has traditionally followed the receding ice edge northward into the northern Barents Sea (Sakshaug and Skjoldal, 1989). A significant part of the southern Barents Sea is ice-free throughout the year. The decline in sea-ice volume and extent in the Arctic Ocean is widely documented (e.g. Parkinson and Cavalieri, 2008; Comiso, 2012) and many studies have shown that the most dramatic changes have taken place in the Russian sector of the Barents Sea. (e.g. Overland and Wang, 2007; Pavlov and Pavlova, 2008; Rodrigues, 2008; Smedsrud et al., 2013). An ecologically-focused study of seasonal changes in sea ice is provided by Laidre et al. (2015). This showed the Barents Sea region to have experienced four times the average rate of change in terms of seasonal sea-ice coverage compared to the Arctic in general, with a reduction of 20+ weeks in just the last few decades; these changes have already had impacts on the region's biota *(Figure 2.6)*. See Chapter 4 for more detail on sea-ice dynamics.

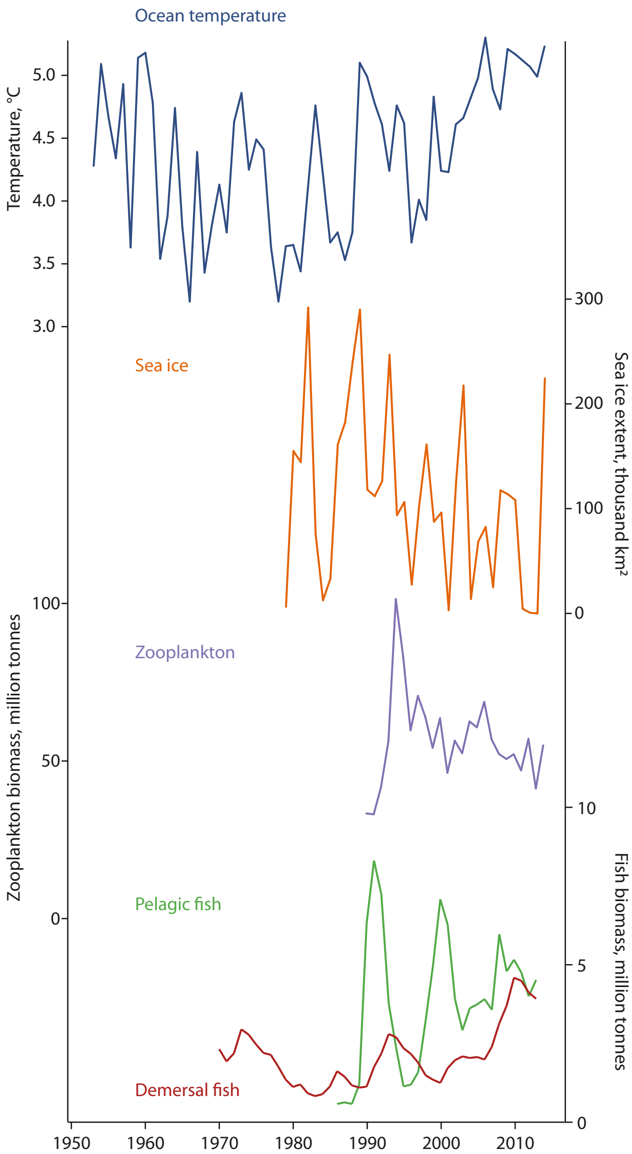


Figure 2.6 Temporal patterns in ocean temperature, sea-ice extent, zooplankton biomass and fish biomass in the Barents Sea. Ocean temperature (50–200 m in the Atlantic Water in the Vardø-North section in August–September), September sea-ice extent, August–September zooplankton biomass (wet weight), and August–September pelagic fish biomass (capelin, polar cod, herring) and demersal fish biomass (cod, haddock).

2.2.2.1 Phytoplankton and zooplankton

Primary production and phytoplankton growth rates in the Barents Sea region are highly seasonal due to the extreme variation in light levels and temperature across the annual cycle at this high-latitude location (Sakshaug, 2004; Sakshaug et al., 2009). The Barents Sea has two main domains of phytoplankton production – the open-water domain and the seasonally ice-covered domain. Total annual primary production in the Barents Sea is about 90 g C/m^2, with higher production in the open Atlantic water masses of the southern Barents Sea (100–150 g C/m^2) than in the seasonally ice-covered northern Barents Sea (<50–70 g C/m^2) (Sakshaug, 2004; Wassmann et al., 2006a,b; Hunt et al., 2013; Dalpadado et al., 2014). New production is typically about 50 g C/m^2 in the Atlantic Water and less in the colder, northern water masses. Despite the seasonally ice-covered areas having lower overall production rates, the relatively predictable location of the pronounced nature of the short-lived spring bloom of phytoplankton ('ice-edge bloom') that sweeps across the northern Barents Sea as a more or less distinct band following the seasonal retreat of the sea ice, is an important source of food for zooplankton and other fauna (Sakshaug and Skjoldal, 1989; Skjoldal and Rey, 1989). Studies in the 1980s revealed interannual variation of four to six weeks in the timing of the peak in the spring bloom in response to climatic variation between cold and warm years (Skjoldal et al., 1987; Skjoldal and Rey, 1989). Modelling studies and remote sensing data suggest the less extensive sea-ice coverage of recent decades is likely to have increased the total annual primary production for the Barents Sea substantially (Slagstad and Wassmann, 1996; Wassmann et al., 2006a,b; Dalpadado et al., 2014). Diatoms are the predominant phytoplankton group during spring blooms in the Barents Sea, while other microalgal groups comprising a wide range of systematically different flagellates are important in the region at different times of the year (Sakshaug et al., 2009).

The Barents Sea zooplankton community is diverse and comprises many species of various taxonomic and trophic groups (Eiane and Tande, 2009). Monitoring has shown that large interannual variability in the mesozooplankton biomass, largely due to varying levels of predation by fish, is a normal condition in this ecosystem (Dalpadado et al., 2012; Johannesen et al., 2012a; Stige et al., 2014). In addition to predation pressure from higher trophic levels, variable advective transport of plankton from the Norwegian Sea into the Barents Sea also contributes to biomass variability in the western/central Barents Sea (Skjoldal and Rey, 1989; Dalpadado et al., 2012; Orlova et al., 2014).

The zooplankton community can be broadly divided into a boreal group associated with the warmer Atlantic Water in the south and an Arctic group associated with the cold Arctic water in north. Herbivorous 'large' *Calanus* copepods are dominant species among the mesozooplankton (Melle and Skjoldal, 1998a; Falk-Petersen et al., 2007, 2009), while several species of krill (mainly herbivores) and pelagic amphipods (mainly carnivores) are dominant macrozooplankton (Dalpadado, 2002; Dalpadado et al., 2002, 2008; Zhukova et al., 2009; Orlova et al., 2015).

Arctic copepod species include *Calanus glacialis*, *C. hyperboreus*, *Metridia longa*, and *Pseudocalanus minutus*. One of the most important of these northern species is *C. glacialis*, which thrives in the northern Barents Sea (Tande, 1991; Melle and Skjoldal, 1998a). It is considered a shelf species adapted to living in the zone of seasonally ice-covered waters on the periphery of the central Arctic Ocean. It reproduces in spring or early summer with egg production fueled by the spring (ice-edge) phytoplankton bloom (Melle and Skjoldal, 1998b). *C. finmarchicus* is the dominant copepod in the Atlantic Water in the southern Barents Sea. Egg production in this species also depends on the spring phytoplankton bloom (Melle and Skjoldal, 1998a; Niehoff, 2004, 2007). The development time of the new generation increases with decreasing temperature, from about one month at 10°C to five months at 0°C (Campbell et al., 2001). Delayed and prolonged development limits the distribution of this species in more northerly waters within the Barents Sea (Melle and Skjoldal, 1998b); but its distribution has shifted northward over the last few decades (Skaret et al., 2014).

Euphausiids (krill) can be important components of the system at times. Four species of krill are regular inhabitants of the Barents Sea (*Thysanoessa inermis, T. raschii, T. longicaudata*, and *Megancytiphanes norvegica*; Drobysheva, 1994; Dalpadado and Skjoldal, 1996; Orlova et al., 2015). *T. raschii* is a neritic species found predominantly in the shallow waters of the southeastern Barents Sea, while the other three species are associated with inflowing Atlantic Water. Their long lifespan makes krill sensitive to predation pressure from fish and other consumers such as the large baleen whales.

Analysis of time series going back to the 1950s shows a negative trend, due to warming, on *T. raschii* and positive effects on the other three species (Zhukova et al., 2009; Eriksen and Dalpadado, 2011; Dalpadado et al., 2012; Orlova et al., 2015; Eriksen et al., 2016). Predation, particularly from capelin (*Mallotus villosus*), also has an influence on the standing stock as can be seen from the inverse relationship between *T. inermis* and the fluctuating capelin stock (Dalpadado and Skjoldal, 1991, 1996; Eriksen and Dalpadado, 2011). A krill index (based on an extensive joint Norwegian-Russian autumn survey) shows a marked increase in krill abundance after 2000, associated with the warming of the past few decades (Figure 2.7). The increase is associated with a northward expansion of krill in the northern Barents Sea, possibly augmented by increased transport onto the northern shelf via the West Spitsbergen Current (Eriksen et al., 2016).

Pelagic amphipods also play important roles in the food webs of the Barents Sea ecosystem and are represented by two dominant hyperiid amphipod species of the genus *Themisto*. *T. abyssorum* (~2 cm) is a boreal–Arctic species associated with the warmer Atlantic Water, while the larger *T. libellula* (~4.5 cm) is an Arctic species (Dalpadado, 2002; Dalpadado et al., 2002, 2008). The amphipods have shown declining trends over recent decades due to the reduction in Arctic Water within the region; the Arctic Water index explains 54% of the variation in amphipod abundance (Dalpadado et al., 2012, 2014).

Two species of scyphozoan jellyfish commonly occur in the Barents Sea: the lion's mane jelly (*Cyanea capillata*) and the moon jelly (*Aurelia aurita*). They are mainly boreal species found in the temperature range 1–10°C in the Barents Sea, with peak abundance at about 4–7°C (Russel, 1970; Eriksen et al., 2012). Over the last two decades, jellyfish have showed a northern shift in distribution, partially explained by an increase in water temperature and increased areas of Atlantic and mixed waters (Prokhorova, 2013; Eriksen et al., 2014, 2015).

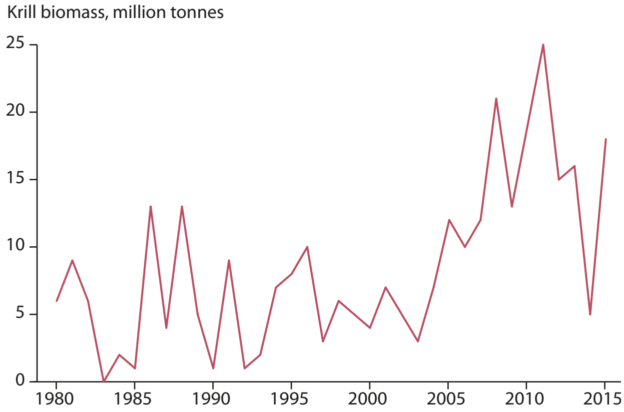


Figure 2.7 Mean biomass of krill recorded during joint Norwegian-Russian autumn surveys by trawl sampling in the upper 60 m of the Barents Sea. Based on Eriksen and Dalpadado (2011) with updates for 2010–2015 (Institute of Marine Research, Norway, unpubl. data).

2.2.2.2 Fish and other harvested resources

More than 200 species of fish have been registered in the Barents Sea, although less than half are caught regularly (Stiansen and Filin, 2008; Dolgov et al., 2011a; Wienerroither et al., 2011). Some species complete all phases of their lifecycle within the Barents Sea, while others feed in the Barents Sea but spawn elsewhere. Johannesen et al. (2012b) described six fish communities in the Barents Sea that were separated along depth and temperature gradients. Based on their geographical distribution and physiological adaptations, 166 of the fish species registered in the Barents Sea have been classified into zoogeographical groups (Andriashev and Chernova, 1995); 25% are Arctic or Arcto-boreal, half are boreal (or mainly boreal) and the rest are widely distributed or south-boreal species. However, shifts in distribution over recent decades and changing temperatures at depth are blurring the distinction among these assigned groupings. There has already been a marked 'borealization' of the fish community within the Barents Sea (Fossheim et al., 2015, see also Chapter 6).

From a trophic perspective there are three main groups of fish in the Barents Sea that each share fundamental life-history and habitat characteristics: species feeding on plankton, species feeding on benthos, and species feeding on other fish (Dolgov et al., 2011a). Planktivorous fish dominate in terms of biomass, but not in terms of the number of species (Dolgov et al., 2011b). Among the planktivorous species, capelin, polar cod (*Boreogadus saida*) and juvenile herring (*Clupea harengus*) are most abundant, although their biomass varies greatly from year to year. The three species have broadly divided the sea area among them with capelin in the north, herring in the south, and polar cod mainly in the east, although this species is also of key ecological importance within Svalbard. All three species are important to top trophic predators within their respective ranges. The events and conditions driving capelin cycles are clearly linked to climate variability but in a complex manner involving biological interactions with, for example, variable abundance of juvenile herring, zooplankton prey, and levels of cod predation. 0-group capelin are distributed further north in warm years (Eriksen et al., 2012). The distribution of immature capelin on their feeding migration in autumn is related to temperature conditions and this age group has a more northerly distribution in warm years (Gjøsæter et al., 1998; Carscadden et al., 2013; Ingvaldsen and Gjøsæter, 2013). However, the size of the stock also plays a role with a less northerly distribution being the norm when the stock is low, presumably because of lower food demand (Ingvaldsen and Gjøsæter, 2013).

Juvenile herring of strong year-classes of the Norwegian spring spawning herring stock grow up in the southern Barents Sea. They leave after three to four years to join the adult stock in the Norwegian Sea (Krysov and Røttingen, 2011).

Polar cod spawn in association with sea ice and young age classes of this small fish species tend to remain close to sea ice, often living in interstitial spaces within the ice, which provides some protection against predators. The polar cod stock has shown large fluctuations in abundance; from high levels during the early 1970s to a dramatic decline in the 1980s, followed by a recovery during the 1990s and then high levels in the early-mid 2000s. Since 2007, the stock size has again decreased, apparently driven by poor recruitment related to warming and associated reductions in sea ice and the area containing Arctic Water (ICES, 2014b; Eriksen et al., 2015). Expansion of Atlantic cod (*Gadus morhua*) into the northern Barents Sea has also played a role, leading to increased spatial overlap between the two species and increased predation pressure from Atlantic cod on polar cod.

All three planktivorous fishes are or have been harvested; capelin being the most important commercially (Figure 2.8). The harvest of Barents Sea polar cod has been very limited since the 1970s. The herring fishery targets adult fish, which are actually taken outside the Barents Sea.

The most important commercial species among the benthic-feeding and fish-feeding species include Atlantic cod, haddock (*Melanogrammus aeglefinus*), saithe (*Pollachius virens*) and Greenland halibut (*Reinhardtius hippoglossoides*). It is well established that climate variability is a major factor causing large variability in recruitment to the commercial fish stocks in the Barents Sea, expressed as alternating strong and weak year classes (Sætersdal and Loeng, 1987; Ottersen and Loeng, 2000). Strong and weak year classes drive fluctuations in the stocks, and strong year classes in particular have marked 'snowballing' effects as the cohort develops over time, with impacts on prey and predators throughout food webs.

Recruitment of Atlantic cod and haddock (as well as herring) is positively related to high inflows of Atlantic water and the accompanying higher temperatures in the Barents Sea (Sætersdal and Loeng, 1987; Ottersen and Loeng, 2000). During the last decade the cod stock has covered most of the Barents Sea shelf in autumn (August-September) and has also expanded northward during winter (Johansen et al., 2013; Prokhorova 2013; also see Figure 2.9). The cod distribution area increased from 2004 to 2013, expanding into the northern and northeastern part of the Barents Sea. In recent years a major part of the stock has been found on the northern shelf (north of 78°N) with some cod moving to the shelf edge at the rim of the Arctic Ocean at around 82°N. Increased temperature from sub-zero to positive may have removed a threshold barrier, now allowing cod to enter this northern area (Lind and Ingvaldsen, 2012). The northward expansion during the main feeding season in late summer

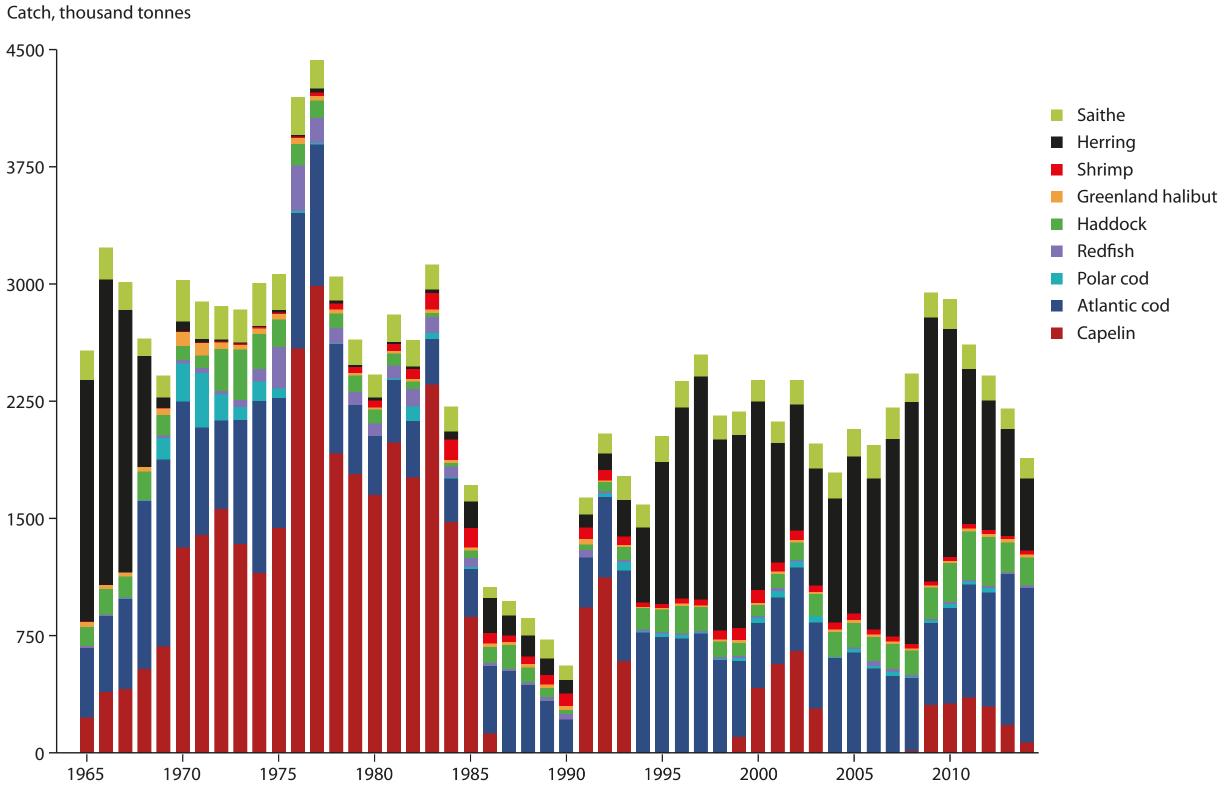


Figure 2.8 Total catches of the most important fish stocks in the Barents Sea since the mid-1960s. The data include catches in all ICES areas: I, IIb and IIa (i.e. along the Norwegian seas and the Norwegian coast south to 62°N). Redfish refers to *Sebastes mentella* (ICES, 2014a).

appears to be determined by more old and large cod in the stock and the northward shift in the distribution of capelin following its recovery to high abundance (2008–2013). Such trends have been seen in the past; both the cod and herring stocks increased significantly between 1920 and 1940 when water temperatures increased (Toresen and Østvedt, 2000; Hylen, 2002). This increase in stock size was probably an effect of enhanced recruitment, because catches also increased over this period. The northern expansion of cod is a prime example of the 'borealization' of the Barents Sea ecosystem.

Haddock has also recently reached a historic high in abundance and has increased its distribution range over the past few decades (1950–2013; Mehl et al., 2013; McBride et al., 2014). This is related to large stocks, an increasing proportion of large individuals in the stocks and higher water temperatures, similar to the situation for Atlantic cod.

2.2.2.3 Benthos

More than 90% of the invertebrates in the Arctic belong to the benthic community (Sirenko, 2001; Gradinger et al., 2010). Animals that live on (epifauna) or in (infauna) the sediments are collectively referred to as benthos. Most species of benthos are largely stationary. The composition of the bottom fauna of a region reflects prevailing environmental conditions including large-scale oceanography (Carroll et al., 2008; Cochrane et al., 2009, Jørgensen et al., 2015). For example, infauna (mostly worms and bivalves) density and species richness in the Barents Sea area are 86% and 44% greater at stations near the Polar Front than at stations in either Atlantic- or Arctic-dominated water masses (Carroll et al., 2008). In Arctic Water north of the Polar Front, sea ice suppresses water column productivity and infaunal abundances are significantly lower than in open-water areas south of the Polar Front, while the numbers of taxa present are similar (Cochrane et al., 2009). Epifauna biomass (mostly brittle stars, sponges, shrimps) is over five times greater in the north-eastern Barents Sea influenced by Arctic Water than at stations in Atlantic-Water influenced regions, with the exception of areas in the south-western Barents Sea where sponge fields dominated by a large biomass of Geodia-sponges prevail (Jørgensen et al., 2015). Areas in the southwest, the central Barents Sea and north of 80°N have a high biomass of species easily taken by bottom trawls (Jørgensen et al., 2016), including large-bodied Arctic species such as seapens and cephalopods, sponges and ophiuriods (Jørgensen et al., 2015).

In the Pechora Sea, despite its southerly location, Arctic species are common in its northern parts, which are influenced by cold-water currents. Boreal species predominate in areas of the Pechora Sea that are affected by warmer coastal waters, showing that this area functions as a transitional zone between the boreal and Arctic biogeographic regions (Denisenko et al., 2003).

Temperature (Lüning, 1990) and substrate characteristics (Saher et al., 2012) are important in the distribution of benthic algae, and areas exposed to the mechanical effects of sea ice or icebergs are generally devoid of macroalgae (Gutt, 2001; Wulff et al., 2011). Marked changes in surface salinity due to melting of sea ice and freshwater input from rivers have affected algae distribution, and an abrupt increase in macroalgal presence has been recorded in Arctic fjords together with changes in the abundance of benthos that are thought to be indicative of a climate-driven ecological regime shift (Kortsch et al., 2012).

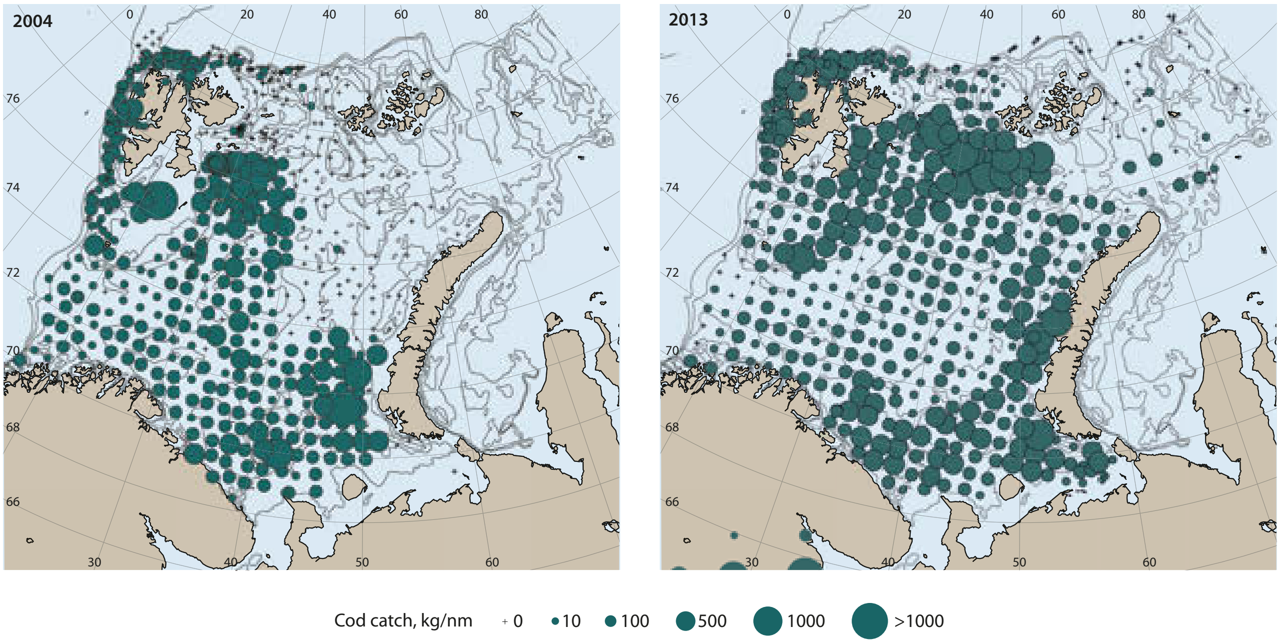


Figure 2.9. Distribution of Atlantic cod in 2004 and 2013 recorded in autumn during the joint IMR-PINRO ecosystem survey (Prozorkevich and Gjøsæter, 2013).

In coastal areas of Svalbard, recent warming with less sea ice has been associated with a two-fold increase in the number of species found intertidally on rocky shores, and a three-fold increase in macrophyte biomass. Subarctic boreal species occupied new areas, while Arctic species retreated (Weslawski et al., 2010). In Svalbard fjords, rapid and extensive structural changes in rocky-bottom communities have occurred along with an abrupt increase in macroalgal cover (Kortsch et al., 2012). Simultaneous changes in the abundance of benthic invertebrates suggest that macroalgae play a key role in structuring these communities.

Previous studies in the Barents Sea have shown that trawling activities are causing a reduction in the total biomass of benthic fauna, which can be as high as 70% (Denisenko, 2001; Wassmann et al., 2006a) and that the actual reductions are correlated with trawling intensity (Lyubin et al., 2011). Other factors influencing benthic community change include two introduced top-predator species, king crab (*Paralithodes camschaticus*) and snow crab (*Chionoecetes opilio*), both of which feed on benthos (Jørgensen and Primicerio, 2007; Agnalt et al., 2011) (for more details see Section 2.2.3).

2.2.2.4 Seabirds

The Barents Sea region supports some of the largest concentrations of seabirds in the world (Anker-Nilssen et al., 2000). About 20–25 million seabirds harvest approximately 1.2 million tons of prey biomass annually from the area (Barrett et al., 2002). A total of 33 seabird species breed regularly in the region and belong to five different systematic groups including Gaviiformes (divers), Procellariiformes (petrels and fulmars), Pelicaniformes (cormorants and gannets), Anseriformes (seaducks), and Charadriiformes (shorebirds, skuas, gulls, terns and alcids) (Strøm et al., 2009). Food preferences in the Barents Sea include meso-zooplankton (e.g. *Calanus* spp.), large crustaceans (e.g. krill and amphipods), juvenile fish (e.g. cod and herring), small pelagic fish (e.g. sand-eel *Ammodytes* spp., capelin, herring and polar cod) and cephalopods (Fauchald et al., 2011).

More than 50% of the Barents Sea is usually ice-covered in winter. Thus, most species breeding in the region are to some extent migratory. Although many populations leave the region during autumn and winter, they are replaced by other populations from breeding areas further to the east, to winter in the Barents Sea. Areas off Iceland, south-west Greenland and Newfoundland are important wintering areas for seabirds breeding in the region (Strøm et al., 2009; Fauchald et al., 2011).

The composition of seabird communities in the Barents Sea reflects the environmental gradient from the warm Atlantic water masses in the south to the cold ice-filled Arctic water masses in the North. Atlantic puffins (*Fratercula arctica*), black-legged kittiwakes (*Rissa tridactyla*) and common guillemots (*Uria aalge*) dominate the seabird communities south of the Polar Front while more-Arctic species such as Brünnich's guillemot (*U. lomvia*), little auk (*Alle alle*) and northern fulmar (*Fulmarus glacialis*) dominate in the north (Strøm et al., 2009). The diet of breeding seabirds also reflects the environmental gradient from Atlantic to Arctic water masses. The colonies of Atlantic puffin and common guillemot in the south feed on cod, haddock and herring larvae drifting from the spawning areas along the Norwegian coast and in to the Barents Sea. Pelagic fish such as young herring, sand-eel and capelin are important prey items in the southern colonies (Fauchald et al., 2011). North of the Polar Front, the colonies of little auk, fulmar and Brünnich's guillemot are closely linked to the marginal ice zone where they prey on polar cod and the energy-rich Arctic crustaceans (Mehlum et al., 1998).

The population status and trends for several species breeding in the western Barents Sea (i.e. Norwegian mainland and Svalbard) was recently assessed from monitoring and census data (Fauchald et al., 2015). This showed subarctic pelagic auk species (common guillemot, razorbill *Alca torda* and Atlantic puffin) to have increased while the Arctic sister species (Brünnich's guillemot breeding on Spitsbergen, large gull species, northern fulmar (on Bjørnøya), and kittiwakes in the Norwegian Sea and Barents Sea) have declined.

The reasons behind the recent changes in the Barents Sea seabird communities are not well known. However, several studies suggest that changes in food availability, triggered by changes in ocean climate are linked to the declines (Descamps et al., 2013; Erikstad et al., 2013; Myksvoll et al., 2013). Large variations in the preferred fish prey have been documented (Barrett, 2007). In addition to climate-related variations, the fishing industry might also have played a role by inducing predation pressure on pelagic fish species (Gjøsæter, 1995). For some populations, changed patterns of predation from mammalian and avian predators might also be important. For example, the increase in the population of white-tailed eagle (*Haliaeetus albicilla*) might have increased predation pressure on some avian species on the Norwegian mainland (Hipfner et al., 2012) and changed ice conditions in Spitsbergen fjords results in changes in the access of polar fox (*Alopex lagopus*) to islands with breeding colonies of common eider (Mehlum, 2012). For top predators and scavengers such as glaucous gull (*Larus hyperboreus*), bioaccumulation of organochlorine pollutants carried into the Arctic via long-range transport has been linked to population declines (Erikstad and Strøm, 2012). The present dynamics of several seabird populations on mainland Norway and Russia may still be influenced by the legacy of historical harvesting of eggs, chicks and adults from the breeding colonies (e.g. Fauchald et al., 2011).

2.2.2.5 Marine mammals

The Barents Sea region contains one of the most species-rich marine mammal communities in the circumpolar Arctic (Laidre et al., 2015), which reflects the high seasonal productivity of this shelf sea as well as the diversity of water masses present. Most marine mammals are high trophic level feeders, with large body sizes and large blubber reserves, which are important for insulation as well as for energy storage. These animals require food resources that are concentrated in time and space at least on a seasonal basis, making them particularly good ecosystem health indicators; they integrate signals of ecosystem change at lower trophic levels and hence are often referred to as ecosystem 'sentinels', thus warranting significant attention in climate change assessments. Twenty-one marine mammal species regularly reside in the Barents Sea, at least on a seasonal basis, and 13 of these are full-time residents that breed locally (Table 2.1). Three additional cetacean species are currently classified as vagrants, although these are increasingly regularly sighted within the region. Most of the marine mammals in the Barents Sea region have experienced high levels of past exploitation and some are still artificially depressed by these earlier excessive harvests, such that they are included on the International Union for Conservation of Nature (IUCN) Red List of Threatened Species and consequently protected. Currently, only harp seals (*Pagophilus groenlandicus*) and minke whales (*Balaenoptera acutorostrata*) are commercially harvested, both well within sustainable limits. A few marine mammal species are subject to sport hunting in Svalbard or along the mainland coast, and occasionally coastal seals are culled at the county level, owing to perceived conflicts with local fisheries. Non-exploitive 'use' of these species takes place via tourism, much of which is cruise-ship based both coastally and in Svalbard (see Section 2.3).

All of the circumpolar Arctic endemic marine mammal species are permanent residents in the Barents Sea Region, including the polar bear (*Ursus maritimus*), the three ice-affiliated cetaceans (bowhead *Balaena mysticetus*, narwhal *Monodon monoceros*, and white whale *Delphinapterus leucas*) and the three pinnipeds found throughout the Arctic (ringed seal *Pusa hispida*, bearded seal *Erignathus barbatus* and walrus *Odobenus rosmarus*). In addition, harp seals are closely associated with the marginal ice zone in the northern Barents Sea during summer and autumn. Breeding takes place in spring on the ice in the White Sea and in the West Ice (north of the island of Jan Mayen). Hooded seals (*Cystophora cristata*) also breed in the West Ice, but their foraging range extends from the Faroe Islands to the Arctic Ocean, with high occupancy in Fram Strait. White-beaked dolphins (*Lagenorhynchus albirostris*) are also resident throughout the year, and occur broadly spread through the area, from the northern coast of the mainland through to high latitudes during summer. Relatively little is known about their habitat requirements or even their basic biology, although there are thought to number almost 60,000 animals in this population (Øien, 1993). Similarly, little is known about pelagic killer whales (*Orcinus orca*), which occupy ice-edge areas in the Barents Sea from first light to last, but their residency status on a year-round basis is not known because they have never been tracked to determine whether they migrate out of the region in the period with limited light.

Ringed seals and bearded seals in Svalbard have experienced major reductions in available breeding habitat since 2006, when sea ice suddenly and unexpectedly declined markedly; the ice has not returned to earlier norms since that time and now rarely forms at all in most of the west coast fjords in winter. In addition to the basic need for land-fast ice for breeding, ringed seals have a unique requirement in their need for snow accumulation on the sea ice. This species constructs small caves (or lairs) in snow drifts associated with breathing holes in the ice, in which they give birth and rear their pups. Since 2006, virtually no ringed seal pupping has taken place in west coast fjords in Svalbard (Kovacs et al., 2011) and mortality of pups due to polar bear predation in areas with remaining ice has presumably increased (Freitas et al., 2012). In addition to loss of breeding habitat, recent satellite tracking studies have shown significant increases over the past 10 to 15 years in migration distances and changes in the activity budgets of subadult ringed seals during summer feeding excursions. Ringed seals must now travel further to reach summer foraging areas in the pack-ice and once there must spend more time travelling and diving and less time resting at the surface or on the ice. They also do less sympagic feeding and less area restricted searching, which implies that they are spending more energy finding food (Hamilton et al., 2015).

Other climate change signals that have been documented for the ice-affiliated species include dramatic declines in the abundance of the West Ice hooded seal population, in the order of 80% (Øigård et al., 2014). This major decline is undoubtedly linked to overharvesting in the past, but despite protection their decline has continued due to increased predation on pups from polar bears and killer whales because the whelping patch has

Table 2.1 Residency status, population trend, expected impacts of climate change, and hunting status for marine mammals in the Barents Sea region.

Species	Population trend	Cumulative climate change impact	Hunting status
Year-round resident, Arctic endemic			
Polar bear *Ursus maritimus*	Stable[a]	Negative	Protected
Walrus *Odobenus rosmarus*	Increasing	Negative	Protected
Ringed seal *Pusa hispida*	Decreasing	Negative	Sport hunting permitted
Bearded seal *Erignathus barbatus*	Decreasing	Negative	Sport hunting permitted
Bowhead whale *Balaena mysticetus*	Unknown	Negative	Protected
White whale (beluga) *Delphinapterus leucas*	Red Listed (Data deficient)	Negative	Protected
Narwhal *Monodon monoceros*	Red Listed (Data deficient)	Negative	Protected
Year-round resident, pack-ice breeder			
Harp seal *Pagophilus groenlandicus*	Increasing (due to reduced hunting pressure)	Negative	Commercially harvested
Hooded seal *Cystophora cristata*	Decreasing	Negative	Protected
Year-round resident, coastal breeder			
Grey seal *Halichoerus grypus*	Dependent on hunting pressure	Positive	Sport hunting permitted
Harbour seal *Phoca vitulina*	Dependent on hunting pressure on mainland Protected in Svalbard (Increasing)	Positive	Sport hunting permitted on mainland Protected
Year-round resident			
White-beaked dolphin *Lagenorhynchus albirostris*	Data deficient	-	Protected
Harbour porpoise *Phocoena phocoena*	(by-catch issue)	Positive	Protected
Seasonal migrant			
Blue whale *Balaenoptera musculus*	Increasing/northward distribution shift	Positive	Protected
Fin whale *Balaenoptera physalus*	Increasing/northward distribution shift	Positive	Protected
Humpback whale *Megaptera novaeangliae*	Increasing/northward distribution shift	Positive	Protected
Minke whale *Balaenoptera acutorostrata*	Increasing/northward distribution shift	Positive	Commercially harvested
Killer whale *Orcinus orca*	Data deficient	Positive	Protected
Northern bottlenose whale *Hyperoodon ampullatus*	Data deficient	Positive	Protected
Long-finned pilot whale *Globicephala melas*	Increasing/northward distribution shift	Positive	Protected
Sperm whale *Physeter macrocephalus*	Increasing/northward distribution shift	Positive	Protected
Seasonal migrant (still rare)			
Sei whale *Balaenoptera borealis*	Increasing/northward distribution shift	Positive	Protected
Summer vagrant			
Common dolphin *Delphinus delphis*	-	-	Protected
Bottlenose dolphin *Tursiops truncatus*	-	-	Protected
White-sided dolphin *Lagenorhynchus acutus*	-	-	Protected

[a]New data confirm that the Barents Sea polar bear population has remained stable over the past decade (Aass et al., 2017).

shifted closer to shore and sea ice is more fragmented. Harp seal pup production dropped by 50% between 2003 and 2005 in the White Sea, and was still at this low level during the last survey in 2013. The initial decline occurred during years of unusually bad ice conditions in the White Sea breeding areas, but subsequent ice conditions have generally been good within the White Sea. The decline also coincided with an increase in shipping activity in the White Sea, which may have affected the breeding areas directly during the first years (Zabavnikov et al., 2008) although no clear indications of significant shipping-related mortality were seen. Øigård et al. (2013) documented reduced body condition in molting Barents Sea harp seals caught in 2006 and 2011 compared to samples taken up to 2001. These authors suggested that recent low pup production in the White Sea may be due to reduced pregnancy rates caused by food shortage, mainly due to competition with the historically large cod stock (Bogstad et al., 2015). The recent declines in abundance and distribution of polar cod (Eriksen et al., 2014) are also likely to have played a role.

Declines in environmental carrying-capacity for some marine mammal species are probably being masked in this region because of the vast levels of overexploitation in the past. For example, the Svalbard walrus population is currently increasing at near maximum theoretical limits, although breeding sea-ice conditions are declining, and spring/early summer ice conditions are likely to be causing the animals to spend longer periods on shore (Kovacs et al., 2014, 2015), limiting their feeding range. Similarly, polar bears in Svalbard have shown high adult survival and stable body condition (males) and production of yearlings from 1995 to present (Fauchald et al., 2015), although their primary sea-ice hunting habitat has certainly declined. Changes are clearly occurring in this population; some previous denning areas have been fully or partially abandoned due to loss of contact with the sea ice in autumn when females move into dens (Andersen et al., 2012). But, the artificially low density of bears in the region is likely to be slowing responses to climate change that are taking place in other polar bear populations.

Migratory marine mammal species are important summer residents in the Barents Sea both because of the diversity of species in this community and their significant food requirements. Blue whale (*Balaenoptera musculus*), fin whale (*B. physalus*), humpback whale (*Megaptera novaeangliae*) and minke whales are regular seasonal occupants. The minke whale is the only commercially harvested cetacean species in the Barents Sea. Most of the other baleen whales have increased in abundance following the cessation of hunting for them a few decades ago; these species are certainly shifting their distributions northward as ice retreats and the open water season has extended (van der Meeren et al., 2014). A few toothed whale species are also seasonal migrants, including northern bottlenose whale (*Hyperoodon ampullatus*) and sperm whale (*Physeter macrocephalus*). Adult males of these two species regularly occupy high latitudes during summer, whereas females and young reside only in southern parts of the Barents Sea region (Christensen et al., 1975). Long-finned pilot whales (*Globicephala melas*) are particularly numerous and are important energetically because they feed on fish-eating squid; they occupy the southern parts of the region throughout the year, but extend as far north as Svalbard in summer.

The White Sea in Russia has breeding populations of several classically High-Arctic marine mammal species including white whales, harp, ringed and bearded seals. The harp seals are known to be a separate 'East Ice' population, which overlaps in range with animals breeding near Jan Mayen in the 'West Ice' when animals from both populations feed in the northern Barents Sea in summer. Walruses are also found in the southern parts of the Barents Sea region, in the Pechora and Kara Seas (Lydersen et al., 2012). Polar bears and walruses are known to be common biological populations across the north from Franz Josef Land to Svalbard (Paetkau et al., 1990; Andersen et al., 1998), but other species found in both Archipelagos such as bowhead whale, white whale and narwhal, as well as the more southerly stocks of white whale and walruses are currently of unknown genetic affinity compared to those in the north.

Grey seals (*Halichoerus grypus*) and harbour porpoises (*Phocoena phocoena*) are largely restricted to areas near the mainland coast, east across to the Pechora Sea in the case of grey seal. Harbour seals (*Phoca vitulina*) breed along the whole of the Norwegian coast across into Russia as far east as Murmansk. There is also an established population of some 2000 harbour seals in Svalbard, which is genetically distinct from neighboring populations (Andersen et al., 2011; Merkel et al., 2013).

Boreal-temperate species are already benefitting from climate change in northern areas of the Barents Sea. For example, harbour seals are increasing their distributional range in Svalbard and are also likely to be increasing in abundance (Merkel et al., 2013; Hamilton et al., 2014; Blanchet et al., 2015). Distributional changes in response to higher temperatures and less sea ice are already being documented routinely in the Barents Sea region for invertebrates, fish and top trophic animals including marine mammal species (Gilg et al., 2012). Additional examples of the latter include harbour porpoises being sighted in Svalbard in recent years, and sei whales (*Balaenoptera borealis*) becoming more routine at these high latitudes. Blue whales are now seen in the fjords of Svalbard from late spring well into autumn, extending their residency in the high north markedly in the last few years. However, competition from fish predators is thought to be limiting the abundance and distributional spread of some species such as minke whales (Bogstad et al., 2015).

2.2.3 Invasive alien species in terrestrial and marine environments

Globalization and growth in the volume of trade and tourism has provided some species with a solution for how to by-pass natural barriers such as ocean expanses, deserts, mountains and rivers. Some species of plants, animals, fungi and microorganisms have been transported across ecological barriers and become established in areas outside their natural range – these are defined as 'alien species'. Alien species that threaten ecosystems, habitats or resident species are defined as invasive alien species. These are considered one of the major threats to native biodiversity (UNEP, 2010) (see also Box 2.1). Within the Barents area, the first official effort to evaluate the risk posed by alien species and to document their impacts on the regions was the creation of the *Norwegian Black List* (2007), which assessed 217 species (Gederaas et al., 2007). A few years later, Gederaas and co-workers assessed all 1180 known reproducing alien species in Norway

(Gederaas et al., 2012). For Finnmark, Troms and Nordland, 25, 65, and 77 species, respectively, were assigned to the two highest impact categories – severe impact and high impact – indicating for which species actions were most needed. For the Norwegian part of the Barents Sea, the Atlantic snow crab and the Canada goose (*Branta canadensis*) were highlighted as species causing severe impacts. The assessment was based on ecological impact alone, no effects on human health or economy were taken into account. In 2013, a Svalbard-specific action plan was produced on how to deal with invasive alien species (SMS, 2013). At present, three species are actively removed from Svalbard: two mammals, the East European vole (*Microtus levis*) and the house mouse (*Mus musculus*), and the vascular plant cow parsley (*Anthriscus sylvestris*). The vole acts as an intermediate host for the tapeworm (*Echinococcus granulosa*), a lethal parasite for humans, which provided an added impetus for its extermination. Another 11 terrestrial vascular species are on a monitoring list, five of which are to be removed if found. Three marine species are being monitored: red king crab (*Paralihoides camtschatica*), Atlantic snow crab and pink salmon (*Oncorhynchus gorbuscha*).

The red king crab was introduced deliberately to the southern Barents Sea region in the 1960s and has become a valuable commercial species. It is currently distributed mainly along the Russian and Norwegian coasts of the southern Barents Sea but is dispersing northward (Figure 2.10). In the Russian sectors, the fjords are open and slope gradually toward the open ocean while in the Norwegian regions, the coast and fjords are steep and deep. As a result, the crabs are restricted to the coast in Norway where the migration for feeding (deep waters) and mating (shallow waters) take place close to land, while on the Russian side the crabs migrate northward over the shallow banks to reach foraging areas in deeper waters (Jørgensen and Nilssen, 2011*)*.

Snow crabs are a more recent addition to the region. How the introduction occurred is unclear, larvae were perhaps transported with ballast water, or changing environmental conditions promoted the migration of adults. But in any case, this species was first recorded outside the Pacific region by Kuzmin (2000) in 1996 close to northern Goose Bank, which appears to be a recruitment area (Agnalt et al., 2011). However, snow crab is a cold-water species and has spread rapidly into the eastern Barents Sea. It generally lives at depths of 20–700 m and at temperatures below 5–8°C (Elner and Beninger, 1992). Similar to king crab, snow crab preys on other species of benthic animals (Squires and Dawe, 2003).

In Sweden, Finland, and European parts of Russia, work on invasive alien species is progressing through The European Network on Invasive Alien Species (NOBANIS, www.nobanis.org). An open access portal has been developed to provide information about alien and invasive species in the region. This includes a central database with updated information from all countries participating in NOBANIS, factsheets for the most invasive species in the region, access to an identification key to marine invasive species, newsletters, an invasive species photo bank, and information about the national legislation on invasive alien species in the region. As well as providing general information, the system is intended to act as an early warning system, with a species alert function for new invasive species to the region, including information on how the species gets introduced, its current distribution in the region, likely habitats, potential ecological and socio-economic effects and references to relevant literature. The database was last updated in April 2015. However, commitments are needed from all countries involved to ensure that the information remains up-to-date and complete.

2.3 Socio-economic environment and resource use

In terms of the socio-economic environment and resource use, the Barents area represents a mosaic of highly varied conditions and challenges. Given its size, complexity and historical variation this is not one region but many and they are all undergoing change as a result of broader trends in globalization and urbanization. Globalization – a linked political, economic and socio-cultural phenomenon – is central to many of these changes, including changes in trade flow, shifting patterns of local industrial activity, and the potential impacts of climate change for the economy, environment, and security (Heininen and Southcott, 2010; Keskitalo and Southcott, 2015). This section provides background descriptions mainly focused on the Barents Region in comparison to other northern areas, including information on general population, employment, and infrastructure trends (Section 2.3.1). The latter parts focus on the resource-dependent sectors that are directly impacted by environmental change (Section 2.3.2). To provide some background information for addressing the issue of human adaptation to climate change this chapter broadens the political context of Arctic issues by including a focus on various human dimensions in the Barents Region. This includes some consideration of political and planning systems, the international economic context relevant to environment-based sectors, and demographic and institutional change.

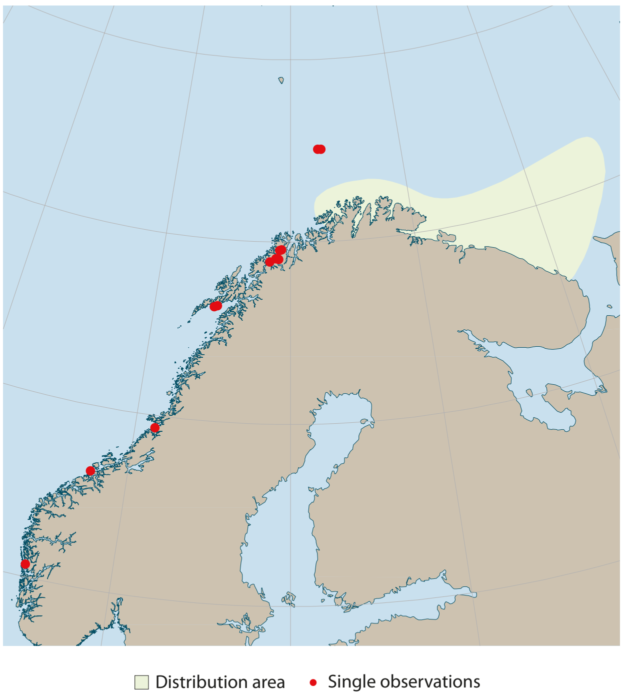


Figure 2.10 Distribution of red king crab in the Barents Sea (Norwegian Institute of Marine Research).

2.3.1 Population and employment

As a generalization, the Barents Region is characterized by established human environments and infrastructure, than for instance purely natural environments. It is large, equal in size to France, Spain, Germany, Italy and the Netherlands combined. Although population density is on average low (2.9 inhabitants/km^2) large population centers exist. These include, for example, Archangelsk (357,000 inhabitants) and Murmansk (300,000 inhabitants) in Russia, Oulu (196,000 inhabitants) in Finland, and Umeå (120,000 inhabitants) in Sweden (BEAC, 2016). Also the vast Yamal-Nenets Autonomous district grew strongly during the Soviet era, and despite a very low overall population density does include some cities with 100,000 inhabitants (Petrov, 2017). This stratification contrasts with the generally very low population densities found especially in the High Arctic areas (Box 2.3). The northern areas of mainland Norway, Sweden and Finland are relatively well integrated into the respective states. In addition, Sweden and Finland are directly subject to EU regulatory systems and part of an area of free trade and free movement of people. The result is that the Barents Region differs from much of the wider circumpolar Arctic in several ways: in being a region with a considerable intermingling of peoples with long-established local, indigenous and mixed groups, often with several or mixed identities; in having a relatively stratified population structure that includes large cities; and in having an infrastructurally developed character and an aging population. This means that reports that focus on describing the circumpolar Arctic as a single entity are often not applicable to the Barents Region. In fact, this applies to much of the Arctic Council's work, as this has tended to focus more on High Arctic and climatically as well as historically Arctic areas (see AHDR, 2004; ACIA, 2004; AMAP, 2012).

Compared to northern areas of North America, the Barents Region has been settled for a relatively long period, with much blending and intermingling of population groups having taken place (Keskitalo, 2004; BEAC, 2016; Nordic Council of Ministers, 2015). In comparison to other northern regions, the indigenous groups in the Barents Region today constitute small and relatively integrated minorities. During the nationalization periods of the 19th century, Saami as well as Kvens and Torne Valley Finns were limited in expressing their own languages and cultural traditions (e.g. Pietikäinen, 2003). Similarly, during the Soviet Era minorities were deprived of their social status. Since the 1970s, minority identities have been strengthened. For instance, the image of Sápmi as a cross-border geographical area and Saami homeland, together with a Saami flag, a National Day, and a national anthem, became potent symbols during the 1980s and 1990s as post-war Saami political mobilization intensified, as is now happening with other indigenous groups around the world (Pietikäinen, 2003). While the Saami are recognized as an indigenous people by Norway, Sweden, Finland, and Russia, differences exist in official attitudes to land claims and even international agreements. While all countries include recognition mechanisms for minority peoples, such as Kven and Torne Valley Finn, and Sámi parliaments as consultative elected bodies have been established in Norway, Sweden and Finland, Norway stands out as having ratified the ILO (International Labour Organization) Convention 169 on the rights of indigenous and tribal peoples, which includes provisions for lands and resources rights. Norway has also included a paragraph on Sámi rights in the Constitution, and further developed the 2003 Finnmark Act aimed at providing local people in general and Saami people in particular, with independent rights; however, the results of the process have been criticized (e.g. Ravna, 2013). In Russia, integration has been more limited and the Nenets reindeer herders represent one of the few cases of a successful mixed economy and stable population growth (Petrov, 2008). Nenets as well as Saami and Veps are recognized as 'small-numbered' indigenous groups by the Russian government with certain land use and economic rights afforded by legislation at the federal and regional level. However, some legislation lacks enforcement and implementation mechanisms (Murashko, 2008). Other groups, such as Komi, Komi-Izemtsy (Izhma Komi), and Karels, are not considered 'small-numbered indigenous people' and so are not granted these rights. However, Komi and Karels are the title ethnic groups in the two respective republics and are more numerous. Whether Komi-Izemtsy, a much smaller group, should be officially recognized as indigenous is currently being debated. In addition to these ethnicities, substantial groups of Ukrainians, Belorusians, Tartars and Mordvins also live in the region as a result of colonization during the

Box 2.3 Population in the High Arctic parts of the Barents study area

Human population numbers within the High Arctic areas of the Barents study area are low, historically depending on natural resource extraction as well as on the need to provide a state presence in certain areas. Changes on Svalbard and some other areas provide good illustrations of the importance of these drivers.

The population of Svalbard fell from around 3500 in the early 1990s to 2667 in mid-2005, largely due to major reductions in the Russian settlements following the ending of government subsidies for coal mining. In fact, mining at Pyramiden ceased altogether during this period and the town is now a small tourist base with just a handful of local inhabitants. The coal mines of Barentsburg are still operational, but the school and other infrastructure was reduced or lost and families returned to Russia. Inhabitants of Barentsburg are a mix of Russian and Ukrainian citizens. From 1990 to 2006 the number of people living in the Norwegian settlements (primarily Longyearbyen) increased steadily. Since then, numbers have stabilized at both the Russian and Norwegian settlements; but the foreign population in Longyearbyen has increased and now comprises 25% of the settlement. Franz Josef Land has no permanent inhabitants, but instead this Russian archipelago is occupied in summer by a small number of park staff. A military base, Nagurskoye, built to house around 150 people, was established on Alexandra Land, at the site of a former meteorological station; activity and residency levels are not known. Novaya Zemlya is also occupied only by military personnel.

19th and 20th centuries. In addition, ethnic diversity has increased further through a large influx both for work and as refugees in the countries. Large numbers of Polish workers have been involved in the construction of the *Snøhvit* gas platform in the Barents Sea and the *Ormen Lange* gas project in northwest Norway, and Thai immigration as well as guest workers and seasonal workers (such as for berry picking) exist in many northern regions (Nordic Council of Ministers, 2011; Keskitalo and Southcott, 2015). The ongoing crisis in the Middle East (Syria, Afghanistan and Iraq) has also resulted in a large inflow of immigrants to Fennoscandian countries.

Despite these shifts in population, the general trend remains one of an aging population, with northern parts of Norway, Sweden and Finland having as much as 25% of the population over 60 years old (double that for the Russian parts of the Barents Region). This also manifests in patterns of residency, with older people often remaining in the countryside while younger people move to urban centers (Nordic Council of Ministers, 2011). While an aging population generally has higher health concerns, according to Rautio et al. (2014) Nordic countries "*rank the highest in every health indicator, and there is generally little difference between north and south, or between Indigenous and non-Indigenous people*". Mortality and health rates differ, however, between northern Norway, Sweden and Finland (which have some of the lowest rates in the world) and northern Russia, where mortality rates are similar to those of less developed countries (Emelyanova and Rautio, 2012; Emelyanova 2015). Cardiovascular diseases are the leading cause of death in all these areas. However, in the most remote and depopulating areas, the possibilities for continuing to provide strong support to regional health systems and education services have recently come under discussion as continued outmigration challenges these systems (e.g. Johansson et al., 2011). In northwest Russia, where fertility and life expectancy are low and net out-migration has been higher than in the Nordic countries, there has been a rapid depopulation during the post-Soviet period (Heleniak, 1999, 2014). The exception is the relatively fast-growing Komi capital, although the resource extracting industries are increasingly based on temporary labor comprising long-distance commuters to the region and this provides challenges for labor supply and the tax base for healthcare, housing, education and welfare services (Johnsen and Perjo, 2014).

Employment in the Barents Region reflects the general pattern of urbanization, and labor market participation in the working age group is generally high, indicating the strong role of waged work (Nordic Council of Ministers, 2011; Larsen and Huskey, 2015). The Arkhangelsk Region (with Nenets Autonomous Area) and Komi Republic are the largest economies by total GRP (gross regional product), while the Swedish and Norwegian parts of the Barents Region are the largest economies in terms of GRP per capita (Huskey et al., 2014). The mining industry, metal industry and the processing of forestry products are the main industries in the Russian, Swedish, and Finnish parts of the Barents Region (Figure 2.11), although the service sector is currently the largest source of employment. For example, services currently represent 62% of GRP in northern Sweden. The primary and secondary industries of the economy, i.e.

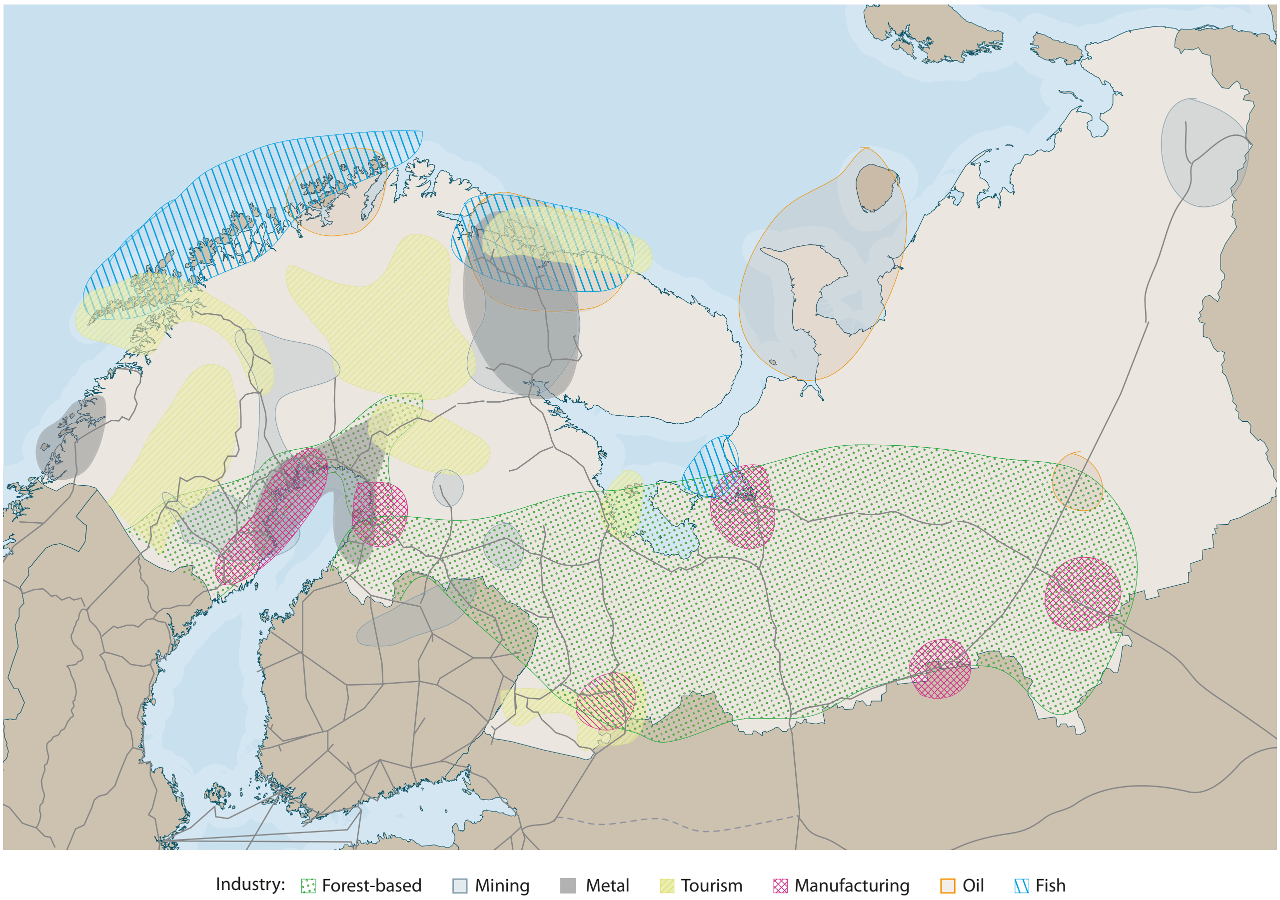


Figure 2.11 Overview of industries in the Barents area (based on ÅF-Infraplan, 2005).

Box 2.4 Differences between a Scandinavian and Russian model for societal organization

This box outlines some of the major differences between a Scandinavian (or more broadly Nordic) and Russian model for societal organization, as reproduced and revised from the ECONOR reports (Duhaime and Caron, 2009; Duhaime et al., 2017). Despite this situation being one of constant change, not least in Russia, the material presented here does provide some background to the varying political assumptions and development tracks that are resulting in large differences between these countries (and between these countries and other northern areas).

The 'Scandinavian model' as the redistribution mode of northern Europe, compared with the 'new Russia'

A comparison suggests distinct patterns of socio-economic differences between the Nordic countries and the Russian regions of the Barents area. Norwegian, Swedish and Finnish regions of the Barents area have among the longest life expectancy in the world and the proportion of females within the population is close to the global average. In contrast, several of the Russian regions show a very different situation with the female rate far below the global average, and low rates of economic dependency. Among the Russian regions, Yamal-Nenets and Khanty-Mansii have highly favorable social conditions. GDP per capita in Yamal-Nenets is the highest, and several other indicators are also very favorable. However, while the levels of disposable household income per capita and GDP per capita are similar in resource-rich Russian regions and Nordic regions, the socio-economic situation cannot be considered equivalent. Indeed, given the same income, the Nordic standard of living is higher, because it is supported by generous redistribution and social benefits general to the countries, which support health care, education and other public expenses to a level that is not found in the Russian regions.

According to two of the ECONOR authors (Duhaime and Caron, 2009:17/18), "*The Scandinavian model may be characterized by three distinct traits: a work-oriented approach for both men and women, universalism of social security benefits, and the importance of the State in the provision of social security and production of services, based on widespread redistribution of wealth through taxation*". They also noted that the "*diversity of the economy, social policies for the redistribution of wealth, the vitality of citizen associations' have made it possible to so far manage the impacts of global economic transformations and pressures*". In northern Norway, Sweden and Finland, "*push factors for outmigration of women are to some extent counterbalanced by strong pull factors*", such as employment opportunities for women in the public sector, and the fact that a more rural residence includes factors that are often perceived as part of "*a good life*". It is also perceived that "*regional centers and villages attract immigrants*", who do not perceive areas as "*remote*" in a negative sense, but rather "*appreciate the combination of beautiful landscapes, outdoor activities, and safety*" as well as existing urban elements. The ECONOR authors concluded that: "*These perceptions confirm the impression that northern or Arctic cities and villages in Nordic countries may have greater similarities with continental Europe than with North America or Russia*".

In contrast, the Russian transition after the end of the Cold War is described as characterized by large and overarching change including the extensive privatization of businesses and the creation of a powerful economic and political oligarchy. According to the same two authors (Duhaime and Caron, 2009:20), "*This adversely affected the economies and social conditions of rural and remote regions in several ways: by shrinking the social safety net, by territorial reorganization leading to marginalization of ethnic and indigenous minorities, through lower income and higher unemployment leading to higher infant mortality and reduced life expectancy*". This withdrawal of the government as a producer and organizer is seen to have shifted class boundaries and eroded the social safety net and employment structure. They also noted that "*Industrial complexes, which in the past ensured basic social services (health, school, day care) shed these responsibilities when they were privatized*", and regional and local authorities have been unable to replace them. The economic transition was thus accompanied by migration from northern to southern areas, where "[p]*overty has been particularly severe among single-parent families and large families, among individuals with little education and those living in rural areas*". Responses have included people increasingly cultivating land for self-sufficiency as well as the creation of small businesses to compensate for the withdrawal of the state. Thus, where Norway, Sweden and Finland express the mature Scandinavian welfare state (albeit under globalization), the Russian state has buffered the impacts of economic and other changes to a much lower level.

Understanding the graphics

Figure 2.12 depicts socio-economic consequences using a set of indicators. The economic indicators are disposable income for households per capita (i.e. income after tax) and GDP per capita for each region (both measured in 2010 US dollars converted to Purchasing Power Parities, in order to compare consumption baskets in different countries). These indicators are supplemented by social indicators: population growth, 'female rate' (i.e. proportion of women in the total population, replacement rate (i.e. proportion of women of reproductive age to children from 0–14 years; a proxy measure for total fertility rate), demographic dependency (i.e. proportion of children and elders to adults in the total population), life expectancy at birth, tertiary education level, and economic dependency (i.e. proportion of non-employed to employed persons in the total population). In addition, infant mortality was recorded in regions where data were available, however, this indicator is no longer registered for the Arctic regions in Finland and Sweden, and so is not included in the graphic.

To compare the indicators across regions, the indictors were scaled to a common format, presented as an index on a scale from 1 to 10: where 1 represents the least favorable condition and 10 the most favorable condition for human development. The scaling method reflects that for some indicators, high

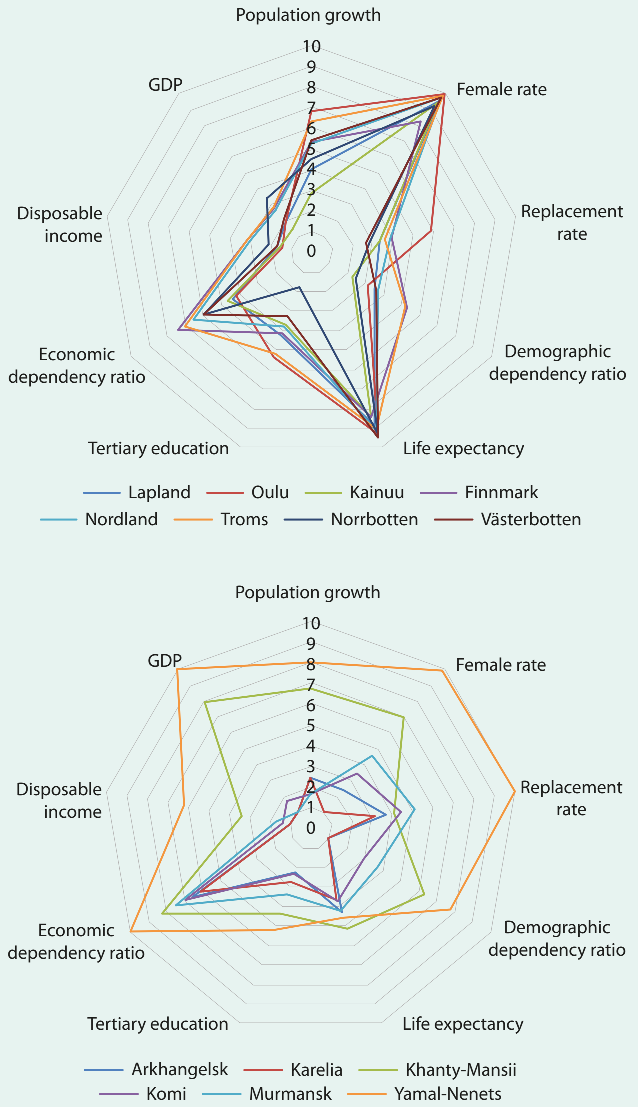


Figure 2.12 Main indices of economic and social condition in Nordic (upper) and Russian (lower) regions of the Barents area in 2012.

value is favorable, and for others, low value is favorable. For the indicators where 'more is better', the difference between the actual observation for each region and the lowest observation in the dataset was divided by the gap between the highest and lowest observation. The resulting ratios were multiplied by 10, to obtain indices expressed on a scale from 1 to 10. For the indicators infant mortality, economic dependency and demographic dependency, 'less is better', and the scaling was calculated in the opposite way: the observation for each region was subtracted from the highest observation, in order to express that low values of the indicators are beneficial for human development. In the case of the female rate, the observation for each region was subtracted from the global average, in order to express that a value close to the global average is beneficial. The results are displayed in the nine-point radar-shaped plots for the Nordic and Russian regions of the Barents area. The interpretation is that the more of the area that is covered by the radar-shaped figure for each region, the more favorable is the situation in that region in terms of human development.

natural resource based industries and manufacturing, account for 68% of GRP in the Russian sector, but only about 30-40% in the Nordic sector, with 29% in Norway, 38% in Sweden and 40% in Finland (Glomsrod et al., 2017). Primary resources, although of significant importance to GDP, account for a relatively small contribution to employment. Cohort replacement, by younger generations with more education and higher expectations, is another important factor. To use fisheries as an example, growing differences in education, capital, technology, and fishing capacity are driving a change from the formerly traditional small-boat sector to increasingly sophisticated fishing technology and more business-oriented fishermen (Nordic Council of Ministers, 2011).

While an increasingly urban population might imply a disconnect from natural resource use, evidence suggests that the rural-urban linkage remains relatively significant. In fact, the Fennoscandian part of the region stands out internationally in terms of large ownership and access to second homes or summer houses, which are often retained in places of origin (Müller, 2013), among other things providing a link to rural lifestyles. Thus, while components of rural livelihoods such as hunting, fishing, and berry and mushroom picking are often described as 'subsistence' in other Arctic areas (i.e. having an important and sometimes necessary economic role in the absence of or to supplement more limited economic income), the widespread practice of hunting, fishing and foraging among most Fennoscandian populations is better described as recreational and traditional (Vepsäläinen and Pitkänen, 2010). Thus, descriptions of northern areas in the Barents Region need to include both rural and urban lifestyles, as these are often interlinked in terms of practice and location.

The large differences that have resulted in these varying developments (e.g. regarding population and health) are difficult to summarize, but can be illustrated by comparing the differences between the Scandinavian and Russian regions, drawing on the ECONOR report (Box 2.4).

2.3.2 Multi-level regulation and planning

The primary sector makes a relatively small contribution to employment but continues to represent an important contribution to GDP in the Barents Region. Forestry is important in northern Sweden, Finland and northwest Russia, while fishing and energy (mainly oil and gas) are important in northern Norway and northwestern Russia. Mining is economically important in parts of each country. Tourism and reindeer husbandry are important locally, and in some cases for tourism regionally. About 7% of the total work force is employed in agriculture, forestry, fishing and reindeer husbandry (BEAC, 2016). Although resource development – often for an external market – has been important in the area, development within northern Fennoscandian welfare states has largely avoided the same boom and bust patterns and the limitations in local and regional infrastructure development (for instance road networks and integration into the states) that has been notable in circumpolar areas outside Fennoscandia. However, with shifts in the power of the state and organized capital through globalization, more short-term interests among developers originating in an international context have emerged, resulting in very quick developments as well as bankruptcies. In Russia, large-scale, long-term Soviet-era resource development projects have been partially abandoned in favor of more short-term piecemeal endeavors led by the state or resource extraction companies. However, in recent years, the Russian Government has approved plans for developing its northern areas through until 2020 (Pelyasov and Zamyatina, 2013), generally highlighting the effort to supplement resource-based industries services, transportation, manufacturing, and knowledge-based industries.

In the Fennoscandian countries, local resource use planning constitutes the fundamental system whereby infrastructure, economic development and resource access rights are coordinated, and thus constitutes the main mechanism whereby local populations can impact resource use. Norway, Sweden and Finland include relatively strong local level control via elected municipal governments, as legally binding plans are primarily adopted at the local level. Local level authorities also have the chief responsibility for producing the legally binding local/detail plans in all three countries. While the Finnish and Norwegian systems exhibit a more hierarchical structure than in Sweden, the similarities are greater than the differences. Exceptions to local planning rights include hydropower, nuclear power, minerals, and forests, which are administered at the national level by specific legal frameworks (Stjernström et al., 2013). These have regularly been subject to development by large state structures such as state-owned companies and with benefits to local employment (Roine and Spiro, 2013; Turi and Keskitalo, 2014). Today, however, as international private corporations become major mining interests, discussions over models for taxation, re-distribution and control of resources have increased, drawing comparisons with, for example, petroleum development in Norway where society receives a relatively large share of revenues. Among others, discussions have centered on modifications to environmental law and the social impacts of the mining activities (e.g. Suopajärvi et al., 2016). Municipal decision-making is also influenced by the territorial reform processes ongoing in all Nordic countries, and that could cause changes to the units responsible for planning. Finland and Sweden are both experimenting with regional self-government, and Sweden has discussed regional enlargement. In Norway, which already has a directly elected regional level of governance, discussions have focused on moving responsibilities from state to regional levels (Johansson et al., 2011). However, it is too early to define the effects of these processes.

In the Russian Federation, although the regions are granted substantial autonomy, the centralized system of administration and budget distribution limits the real power of local government (Kinossian, 2013). Municipal governments are present in all of the regions and do exercise some control over urban settlements and rural areas, although municipalities are typically fiscally and politically dependent on regional capitals. The planning system in Russia is still in transition following 74 years of centrally-controlled state planning, during which non-state land use needs were limited. While centrally-controlled state planning has been replaced by a modern legal framework based on democratic principles, the codes of conduct that typified the former system still characterize both application and practice, although there are examples of successfully implemented new practices (Zamyatina and Pilyasov, 2016). The main challenges are related to corruption, a lack of institutional capacity to manage the pursuit of a more market-oriented planning system and issues related to the design of both vertical and horizontal aspects of the planning system (Golubchikov, 2004). In recent years, the Russian government has passed several strategic planning programs designed to invest billions of dollars in northern infrastructure and economy (Pelyasov, 2011). The effectiveness of these measures is unclear, but some parts of the Russian Barents area have seen as influx of capital (e.g. Nenets Autonomous Area, Murmansk). However, this growth has been severely affected by the economic downturn in Russia since 2014 and low oil prices.

Substantial non-national legislation and regulation also influence the area. Sweden and Finland are members of the EU, and Norway is a member of the European Economic Area (EEA). Despite not being an EU member, Norwegian environmental policy and law are influenced by EU legislation via the EEA Agreement (Bugge, 2014). The regulatory framework of the EU and its influence on northern Fennoscandia are diverse and complex. EU legislation can be directly or indirectly applicable, and the division of competences between the EU's institutions and Member States depends on the policy field in question. EU competences may be exclusive, shared or complementary (Koivurova et al., 2012). EU policies particularly relevant to natural resource use include those concerning the environment, transport and energy. For instance, Natura 2000 (based on the EU Birds and Habitats Directives) protects species and habitats of high importance for European biodiversity, and roughly one-third of Finnish Lapland is covered by Natura 2000 areas, highlighting the significance of the framework for sectors such as reindeer herding, forestry, or planning for transport corridors. Various pieces of EU-legislation on mining waste, chemicals or air emissions are also relevant for mining and other industrial activities. EU action on climate includes incentives for renewable energy, which has contributed to the development of wind power throughout northern Fennoscandia. EU legislation on environmental and strategic impact assessment (Directive 85/337/EEC) has established a framework for national EIA regulations (Stepien et al., 2016), and various EU funding programs as well as regional planning are important for regional development funding and especially cross-border cooperation (Stepien et al., 2016). This indicates that adaptation to climate change in resource sectors must be seen in the context of planning frameworks and legislation that affects and guides adaptation.

2.3.3 Physical infrastructure and tourism

Infrastructure constitutes an important component in the use of natural resources and in adaptation. The Fennoscandian north is well integrated within the nation states of which it is part, as well as within larger organizations and company networks. The area is relatively technologically advanced, with internet access in northern Fennoscandia well developed. In Russian areas, on the other hand, there are wide variations with very limited internet and infrastructure access in some areas. As noted previously, health care and education are generally well developed in Nordic areas, with a network of large university hospitals and good education services from primary to higher education (universities). All areas include significant tertiary education (see Box 2.5).

Box 2.5 Tertiary education in Fennoscandia

University and college-level opportunities are substantial in northern Fennoscandia with many institutions, delivery sites and programs, including distance learning (Hirshberg and Petrov, 2014). This includes large universities as well as smaller university colleges. Northern Norway has two universities and four university colleges. The tendency has been consolidation towards larger entities with university colleges merging with the University of Tromsø. Northern Sweden and northern Finland both have two universities.

Umeå University, the University of Alaska system, Luleå University, University of Oulu, University of Iceland, Arctic University of Norway, and Murmansk State Technical University are the leading institutions in the area by enrollment. These are all associated with larger cities; although some have branch campuses in rural areas, these areas are served to a much lesser degree.

Figure 2.13 At-sea transport routes, major ports and land infrastructure (Nordic Council of Ministers, 2011) (map layout: José Sterling and Julien Grunfelder, Nordregio).

Fennoscandia also has a well-developed road system as well as an extensive air access network, in addition to large shipping and historical supply routes along the Norwegian coast. However, air and rail transport in the Barents area is oriented towards the respective national capitals, or otherwise organized from the national point of view, limiting intra-region connections (Regional Council of Lapland et al., 2007). The EU has supported establishment of trans-European transport networks and corridors, for instance supporting current developments of high-speed rail and cross-national ferry lines. The EU system also has implications for the structure, condition and costs of the different modes of transport. For example, the EU Directive on sulfur in marine fuels (2012/33/EU) imposes limits under the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) that influence transport modes for goods shipped into and out of northern Fennoscandia (see Figure 2.13 for road, rail and shipping routes) due to potentially higher maritime transport costs for vessels crossing the Baltic Sea (an internationally designated control area for sulfur emissions). Outside of its direct jurisdictional influence, EU regulations can influence Arctic maritime transport through flag state authority (for Arctic-going vessels flying flags of EU member states) or port state authorities (because many vessels crossing the Barents Sea call at EU ports).

The relatively extensive infrastructure network that does exist, especially regarding north-south travel, has enabled mass tourism in some areas, although there is wide regional variability and areas lacking major attractions for tourists struggle to establish employment opportunities within tourism (Müller and Brouder, 2014). Urban destinations are now important nodes for meetings and conventions, and good accessibility compared with other northern destinations has led to the successful development of various well-known mass tourism destinations, such as the North Cape in Norway, the Ice Hotel and the iron ore mine in Kiruna in Sweden, the Santa Park in Rovaniemi and the alpine resorts Levi and Ylläs in Finland (Müller, 2011). The Natura 2000–protected Tornio River that constitutes the border between Sweden and Finland and its tributaries, is also a popular recreational destination with rich migratory salmon and trout stocks; and the Norwegian coastal steamer has become a tourist attraction in its own right. Commodification of winter, snow and ice has been an important precondition for establishing winter as a major tourist season and attracting visitors from increasingly urbanized and industrialized areas on the European mainland or Asia. Nature tourism is also helped by the Right of Public Access, which grants the public at large the possibility to visit nature areas, even on private property (Müller, 2011; Sletvold, 2006).

The northern and eastern parts of the Russian Barents Region and Barents area are much less developed in terms of infrastructure than the western and southern areas. The double track high standard railway as well as roads between St Petersburg and Murmansk are important routes. Paanaiarvi national park and fishing rivers are popular destinations in Russia, alongside the Murmansk region, which is a known skiing destination, and Arkhangelsk region, which attracts tourists through its historical importance. The Republic of Karelia is a summer vacation destination for many St Petersburg residents. Increasing interest in international tourism is also evident in these areas, with angling tourism an exclusive international product and cruise tourism under development. However, high prices and visa requirements may limit further development (Stammler and Wilson, 2006; Pashkevich and Stjernström, 2014).

2.3.4 Energy

The Barents Region is a major importer of energy resources, and transportation and parts of the industrial sector are heavily dependent on imported fossil fuels. In northern Scandinavia, refined oil products (such as gasoline, diesel and heavy fuel oil) are entirely sourced from outside the region, while industrial centers such as Luleå consume large amounts of coal and coke. In Finland and Sweden, black liquor from wood pulping and other wood residues is also an important source of industrial bioenergy production (FAO, 2008). Hydroelectric power in northern Norway is consumed locally, and the region imports hydrocarbon products from the offshore gas sector (Statistics Norway, 2009). In contrast, northern Sweden is a net exporter of energy due to its large hydro-electric installations from which around two-thirds of electricity generated is surplus to local requirements. In 2008, the region exported about half as much energy (measured by heat content) as it consumed. Within the area, only about a fifth of gross energy consumed comes from electricity, with roughly equal shares coming from coal and coke, oil products, wood and biomass, and other sources such as waste heat (Statistics Sweden, 2008). In the Russian part of the Barents Region, Murmansk and Komi are energy abundant, while the Republic of Karelia and Arkhangelsk region are net energy importers (RIAReiting, 2015).

Nationally, hydrocarbon (oil and gas) development constitutes a large source of state revenue in Norway and Russia, while also posing environmental concerns. The geological potential of the region, relative ease of access and relatively convenient conditions for exploration and exploitation, as well as proactive policies and granting of new licenses, and the experienced and technologically advanced companies already operating in the region may constitute a basis for large development potential in Norway. However, in Russia, national legislation focused on including foreign investors within the Russian company structure may limit development of technological capability. Large oil and gas fields exist off the coasts of northernmost Norway and north-western Russia, where declining sea ice makes further offshore development more attractive and makes possible access to markets through the Northern Sea Route. However, the reduced sea ice coverage has also resulted in increased volatility in weather phenomena (such as low pressure storms) and volumes of free ice have increased operating safety risk. Nonetheless, interest in the Barents Sea deposits has brought large investment in the Russian coastal areas. Much of the offshore development that has taken place has been dependent on the global energy market and close technological collaboration with Western partners. Oil revenues also have local impacts, for instance contributing to considerably higher incomes in Yamal-Nenets and the Khanty-Mansii (the largest oil- and gas- producing regions) compared to other northern areas in Russia. Although the Russian government remains the owner of the resources, it can grant their usage to regional

Rajakoski hydroelectric station on the Pasvik River, northwestern Russia near the border tripoint with Norway and Finland

authorities. In 2012, the petroleum industry generated more than 50% of total GRP in Arctic Russia, with the Russian company Gazprom having a strong presence for example in the Yamal-Nenets region (Stammler and Wilson, 2006; Glomsrød et al., 2017; Petrov, 2017). Whether this increase in GRP brings real improvements in local living conditions, especially for the ethnic minorities in the area is unclear, despite the improvements shown by quantitative indicators such as worker income (Glomsrød et al., 2017).

Climate policy has increased the focus on alternative means of energy production. Expressed as a percentage of total domestic electricity generation, Norway leads with 95.7%, followed by Sweden at 48.3%, and Russia at 17.8% (IEA, 2011). Sweden and Norway have seen a recent expansion of electricity generation systems, although only on a relatively moderate scale and mainly through the development of small-scale facilities and increased capacity at existing plants. In Sweden, further expansion of hydropower on the major national rivers is prohibited by law, in order to protect ecosystems in the remaining unmanaged rivers. In terms of global installed renewable energy capacity, wind power currently ranks second to hydropower. Until recently, the development of wind power in the Barents Region was modest. However, the need to ensure a secure energy supply and to address environmental concerns, particularly concerning climate change, most states now have policy instruments to support the development of both onshore and offshore wind power, and installed capacity across the region is steadily increasing (Pettersson, 2013). Good wind resources are found, for example, in the mountain areas of Norway and Sweden, and northwest Russia, with estimates that fully developed wind power could contribute 10–20% of the total power capacity in the region, which could also be used off-grid (Pettersson, 2013), although this would involve trade-offs with alternative uses of the landscape and biodiversity.

2.3.5 Mining

In the Barents area, mining has long been a core industry with the actors, activities, and resources involved embedded in large socio-technical networks extending far beyond the region (Andrew, 2014). Today, mining in the Barents area is developed as a high technological industry. The Barents area constitutes a relatively mature mining region, with a strategic role to provide the European industry with minerals (European Commission, 2008; Ericsson, 2010; Haley et al., 2011). A substantial part of the mining activities within each country is concentrated in the Barents area (Nordregio, 2009). The mining industry, however, is affected by large fluctuations in the demand for minerals and metals (Ericsson, 2010) with the global demand for metals increasing dramatically, especially over the period 2003–2008, largely due to economic growth in China (Ericsson, 2010). This has resulted in major investments and exploration activities in order to open new mines, re-open closed mines and increase production in well-established operations such as those owned by Sweden's state-owned LKAB company (Nordregio, 2009; Ericsson, 2010; Knobblock and Pettersson, 2010; Haley et al., 2011). The starting point for the right to assimilate minerals from the sub-soil is essentially the same in Sweden, Finland and Norway, including Svalbard; the discoverer of a deposit has preferential rights to mine the deposit, *on condition* that the activity meets substantive legal requirements in the form of, for example, environmental considerations. The extent of social impact assessments varies: in Finland, they are carried out as a rule although they are not yet a statutory requirement, in Sweden, they are not required by law and are rare, but to some extent compensated by extensive and stringent environmental impact assessment requirements. Thus, the rising level of globalization in mining and minerals use, coupled with the recent high prices, has attracted investors with shorter-term horizons and other mining aims than those typical of the region, increasing discussion of potential boom-bust risk, fast track development of mines, and fly-in fly-out employment (not strong historically in Fennoscandia). Such fast-track developments may also challenge municipal planning, because municipalities may find it difficult to refuse projects with potential economic benefits to the area despite environmental risks; a risk national legislation may not yet have responded to sufficiently given the historically domestic mining development patterns (see Söderholm et al., 2015).

Even with the global financial crisis of 2008 having caused down-turns in the mining sector, interest in the region's mineral resources remains high and several mining projects have continued development activity (PwC, 2012; SGU, 2013) (Figure 2.14). Apart from traditional demand for iron ore, copper, nickel, zinc, and precious metals, there is growing interest in rare earth metals (Ericsson, 2010; Sarapää et al., 2013). In Svalbard, coal mining, which started in the 20th century, has been a mainstay of the region (Kovacs and Lydersen, 2006), although it has recently declined. Today, large development projects, as well as some bankruptcies among companies new to mining development, have led to increased local interest, for instance in the Pajala and Kolari areas (Nordic Council of Ministers, 2011). The Talvivaara copper-nickel mine accidents in Finland have also increased awareness about the environmental risks associated with mining (Wessman et al., 2014). There are similar examples in northern Sweden and Norway.

In Russia, rights to subsoil resources are allocated by a tendering procedure and verified by a permit. Formally, mining activities in Russia must comply with, for example, basic environmental requirements, but in practice more attention has been given to issues such as property rights, and it is difficult to assess the extent to which environmental and social impacts are considered. Examples include extensive discussions concerning pollution from the nickel mine and smelter in Nikel close to the Russian border with Norway and Finland, especially following the fall of the Soviet Union.

2.3.6 Multi-use areas: forestry, environmental protection and reindeer husbandry

Forestry constitutes a major land use in Sweden, Finland, and northwestern Russia (and to a lesser extent Norway). Forests are important from the perspective of biodiversity conservation, carbon sequestration, and bio-energy, as well as being a source of timber and pulp (Teräs et al., 2014). Forests are also valued as a source of wellbeing and nature experiences, and as a basis for local use and industry (for instance, recreational as well as industrial berry picking, tourism and hunting). The range of forest owners in the four countries is wide. Forest in Russia is typically state-owned but

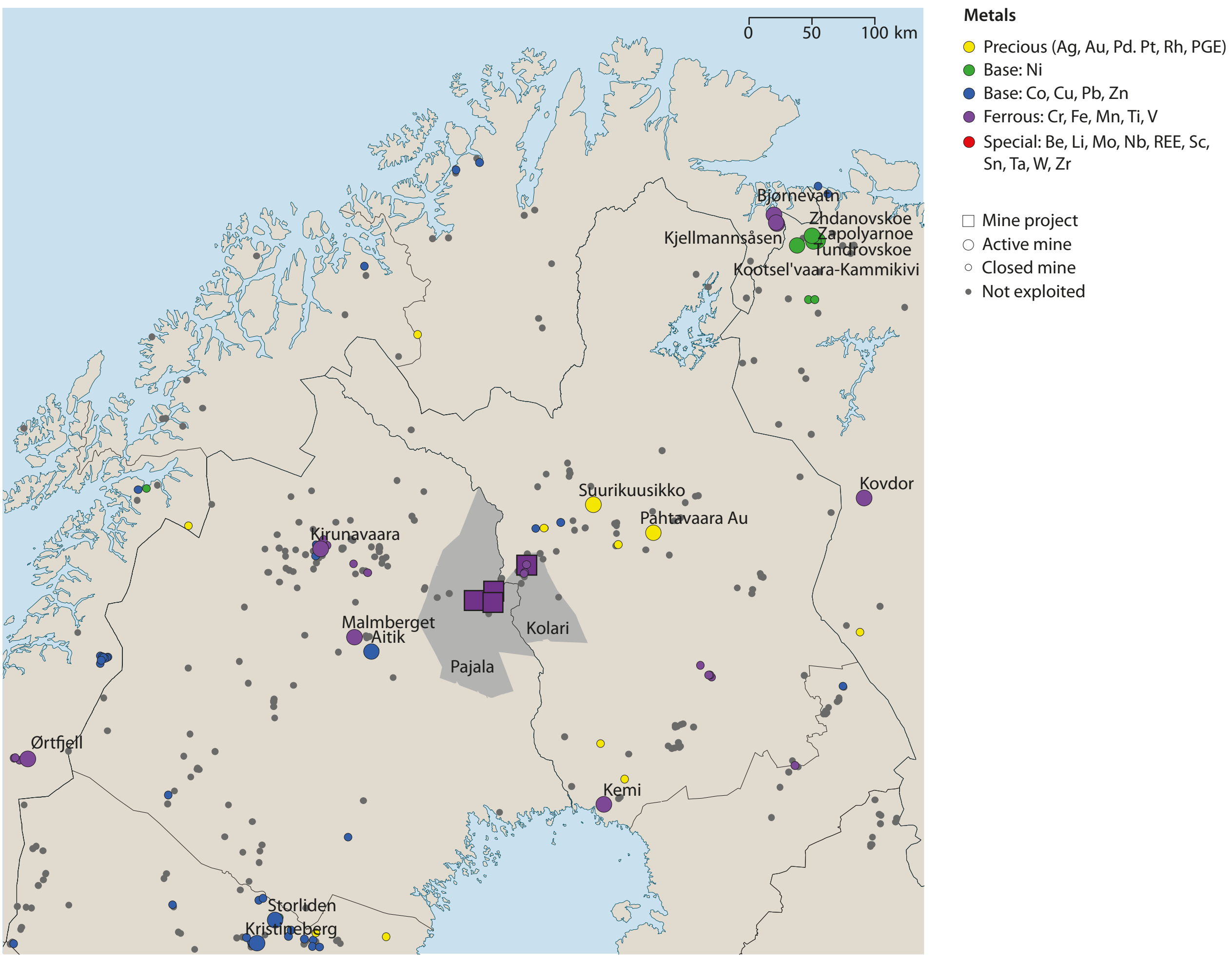


Figure 2.14 Mineral mines and deposits in northern Fennoscandia (Nordic Council of Ministers, 2011; map layout: Johanna Roto, Nordregio).

leased to large-scale forest industry, while forest in Norway, Sweden and Finland is owned by a mix of owners including state, church, municipalities, state-owned corporations, other large-scale forest companies and industry, and small-scale family forest owners often organized into forest owners cooperatives (especially in southern areas). Practitioners of reindeer husbandry typically possess parallel user rights on land, and the Right of Common Access provides access to resources such as berry picking free of charge – something that has recently come under discussion as it is now also used by berry picking industries bringing in emigrant workers (e.g. Thai seasonal workers) to harvest berries (Sténs and Sandström, 2013).

In forestry, the infrastructure necessary to conduct large-scale operations has evolved alongside the development of related, often vertically integrated industries such as saw-milling, paper, and pulp. Large-scale forest companies originating in the Nordic countries, such as SCA and Stora Enso, are thus largely globalizing corporations, owning both forest and large-scale sawmilling, pulp and paper plants. Owing to its importance to GDP and its export value, forestry has often been granted priority in land use and is now a highly intensive industry (with most forests planted from genetically selected plant material, fertilized, and cleaned and thinned prior to logging) in Sweden and Finland. In Finland and Russia, forestry companies hold specific rights that guarantee benefits to forestry compared to other land uses (such as reindeer husbandry), and in Sweden, forestry is defined in law as 'ongoing land use' in a separate Forest Act that makes forestry planning separate from municipal planning (e.g. Stjernström et al., 2013). While forestry has historically been strongly supported in local areas due to its role as a large employer, the local legitimacy of forestry land use has decreased as forestry has increasingly substituted employment for technology, for example replacing local harvesting teams with mobile entrepreneur units. This has resulted in discussions of how to develop land uses that provide local income, including an increasing focus on tourism as a partial substitute for employment in forestry (Keskitalo, 2008a,b). The decline in use of paper and print media through increasing digitalization has led to increased competition within the forest industry at an international level, and to a greater extent placed the focus on other options, such as forest-based bio-energy (FAO, 2008). Given the relatively high proportions of private small-scale family forest owners in the Nordic countries, coupled with high environmental protection demands, forestry actors, however, regularly note the relation between protection and production demands as a competition (Ambjörnsson et al., 2016). Environmental protection areas such as nature reserves are largest in the northern parts of the respective countries and are also influenced by EU and other international regulation (Keskitalo and Pettersson, 2012). Environmental protection may also support other industries. For instance, in Russia, the designation of a national park encompassing northern parts of Novaya Zemlya and Franz Josef Land with adjacent waters in 2009 is expected to encourage tourism in the area (Andrew, 2014).

The situation in forest use illustrates that developing trade-offs in forest use between different users is a highly complex issue. Beyond the conflict between forestry and environmental protection interests, one of the most long-standing issues concerns use-conflict between forestry and reindeer husbandry – or, especially in the Russian case, between different land uses such as reindeer husbandry and oil and gas exploration. While reindeer husbandry is an industry or use with few practitioners today, especially in Fennoscandia (with a small minority of Saami people, as well as Torne Valley Finns practicing in specific areas of Sweden, and Saami and Finns in Finland) it is one with a long history of traditional rights to land use and can be argued to hold a culture-carrying role. There are about 4700 reindeer herders in Sweden (Sametinget, 2015), 3100 in Norway (Reindriftsforvaltningen, 2015), 4500 in Finland, of which 1200 are Saami (Paliskuntain yhdistys, 2014) and about 20,000 in northwest Russia. The Nenets Autonomous area is home to about 41,000 indigenous Nenets, of which roughly 1500 are engaged in reindeer husbandry, mostly in the form of family-based enterprises or cooperatives (Kumpula et al., 2011; Forbes, 2013; ICR, 2016). Around 5000 Nenets are active in reindeer husbandry in the Yamal-Nenets area (Forbes et al., 2009). Reindeer husbandry thus provides an example of both traditional and local use. It also provides an example of the integration of reindeer husbandry as an economic sector in many of these cases: Saami may for instance own both forested land and reindeer, or work both in forestry and reindeer husbandry. The main income from reindeer husbandry in the Nordic areas results from the sale of meat, such as to regional slaughter houses and companies that then package it for further sale, through supermarkets (resulting in the broad availability of the meat) or directly to customers (which is different to indigenous subsistence focus in Arctic literature, see Keskitalo 2008a; Heikkinen et al. 2011). In the Nordic areas, as for other types of resource use, reindeer husbandry involves substantial use of technology, such as snowmobiles for regular monitoring in winter, helicopters if herds are dispersed, and trailer trucks to move reindeer between herding areas if natural paths are not available (Keskitalo, 2008a). However, the costs of motorization, supplementary winter feeding, fuel, and use of information and communication technology also place high demands on profitability in reindeer husbandry (Heikkinen et al., 2007, 2012; Turunen and Vuojala-Magga, 2014). Reindeer husbandry requires large areas for grazing and migration, areas which are increasingly fragmented due to urban growth, development of road and rail infrastructure, new extractive industries, power plants, increasing tourism and cabin developments, and predators; the accumulated impacts of which pose a large threat to continued reindeer husbandry. Recruitment problems are also arising as many young Saami from reindeer husbandry families are leaving for higher education and employment in urban areas. As a result, reindeer husbandry is sometimes combined with tourism or handicrafts or supplemented by other employment, and there is now a focus on increasing branding of reindeer meat products to increase market potential (Tyler et al., 2007; Keskitalo, 2008a; Rantamäki-Lahtinen, 2008). As a consequence, the compound economic impact of reindeer herding to the local and regional economy is likely to be much higher than the sole economic income of reindeer meat production.

In Russia, reindeer herding for instance in the Nenets Autonomous area has seen recent growth, partly due to support from the regional government that benefits from resource-related investments. In addition to federal laws, the traditional land use and reindeer herding activities of the Nenets are regulated by several regional legislative acts designed to support a mixed economy. Regional legislative efforts over the past decade have encouraged the formation of traditional forms of economic and social self-governance (*obschinas*) (Stammler and Wilson, 2006; Forbes et al., 2009; Kumpula et al., 2011; Forbes, 2013).

Conflicts between reindeer herding and other land-use interests are handled differently in each of the four countries. Under Norwegian law (Mining Act), due consideration is required to safeguard Saami culture. In Sweden, reindeer husbandry does not have a special position in terms of land-use assessment, except in the northernmost areas which are designated as Saami areas. In Finland, reindeer herding takes priority in 20 northernmost reindeer herding cooperatives of which 13 are Sámi cooperatives. In the area specifically intended for reindeer husbandry, state land should not be used in such a way that it causes harm to reindeer herding (Finnish Ministry of Agriculture and Forestry, 2000). The proportion of protected areas (e.g. national parks) in this region is large, allowing free grazing of reindeer but limiting other land use (e.g. forestry) (there are also no mines in this area). In other parts of the reindeer husbandry areas, reindeer herding is one of several land-use interests that must be considered in, for example, the licensing process for mining operations. Among the land-use interests to be considered under Swedish law (the Environmental Code), mining has one of the strongest positions (e.g. Pettersson et al., 2015). In Russia, reindeer husbandry is considered part of agriculture and is regulated as such, although special status may be granted following the declaration of reindeer herding as a traditional livelihood.

2.3.7 Agriculture

Agriculture (with the exception of reindeer herding where it is classified as such) currently constitutes a relatively small component of the nature-based sectors in the Barents area. Not least because agriculture has also been affected by the same trends in technological and other developments, further limiting the already low levels of employment in agriculture. Overall, only a small percentage of the total labor force is engaged in agriculture. About 15% of the total agricultural labor in Finland occurs in the northern part of Finland. In Karelia, agricultural land is 1.1% of total land area,[2] in Sweden the respective figure is less than 6% and in Norway about 10% (Wuori, 2013). Agriculture is mainly based on animal husbandry, especially dairy, beef, goat and sheep farming (Jordbruksverket, 2015; Luke statistics, 2015; Murmanskstat, 2015[3]; StatBank Norway, 2015). In Karelia, 16.2% of the total agricultural land was used for crop production in 2013 and basic agricultural production is concentrated mainly in the south (PwC, 2014; The Official Karelia 2014). In northern Fennoscandia, grassland and forage cropping dominate land under cultivation in order to sustain ruminant production systems such as dairy farming and cattle and sheep production, although potatoes, vegetables and berries are also cultivated. Timothy (*Phleum pretense*) and perennial ryegrass (*Lolium perenne*) are the most important forage grasses, and in cold and snow-rich regions, timothy out-competes perennial ryegrass due to better winter survival (Höglind et al., 2013). Altogether, the area of ley increases northward, for instance in Finland, the proportion of ley in terms of total field area was 40% in North Ostrobothnia in 2014, but 84% in Lapland province. Most of the Barents area is unfavorable for cereal production, although barley and oats are cultivated in the south, for example in North Ostrobothnia.

Structural change in farming has been rapid in northern Fennoscandia, among other reasons due to globalization and competition from dairy and food production in other areas. The changes are even more pronounced in agriculture than in the other resource sectors. Many young people are choosing not to follow their family into farming but to seek employment elsewhere, especially in regional centers (Wuori, 2013). While the total number of farms is declining, the average size of farms is increasing, shifting from the traditional multifunctional farm into more specialized and technologically-driven entrepreneurship (Jordbruksverket, 2015; Luke statistics, 2015; StatBank Norway, 2015). Nevertheless, northern agriculture especially in Norway is still a mixture of large-scale commercial and household production (Hovelsrud et al., 2011). Farms in the north of Russia are also still small, family-sized operations with an average of 30 hectares of land and 25 dairy cattle. This small-scale production may capitalize on trends for small-scale local food production, the importance of local cuisine for tourism, and potentially also local, regional and national food security in a changing world (e.g. Rikkonen et al., 2013).

2.3.8 Shipping, fisheries and aquaculture

Much of the shipping in the Barents area is related to fishing, which takes place year-round in the ice-free parts of the Barents Sea. Up to 1600 fishing vessels are involved each year (Arctic Council, 2009), with around 5000 ships in total operating within the Barents Sea (Arctic Council, 2009; Norwegian Ministry of Foreign Affairs, 2014; NNCA, 2015). In 2014, there were 3451 ship crossings of the delimitation line between Russia and Norway in the Barents Sea, similar to the number in 2012 (3823) and 2013 (3464). Shipping requiring pilotage to and from ports in the counties of Troms and Finnmark (9344 cases in 2014) and Nordland (8693 cases) (NNCA, 2015). The Barents Sea is important in connecting the Pacific and Atlantic Oceans, Siberia and continental Europe, and the landmasses between the big Siberian rivers that stretch more than 2000 km south from the Arctic coast to the Trans-Siberian railway. The Barents Sea is home to the Russian Northern Fleet, which uses the Barents area waters both as an operational area and as a transit area from its base on the Kola Peninsula to other oceans, ice-infested oceans as well as blue waters. The number of fishing-vessels-days in the Barents, White and Pechora Seas was estimated at 50,000 to 100,000 in 2004 (Arctic Council, 2009).

---

[2] http://vedlozero.ru/knowledge/karelia/economy/1191-agriculture.html/
[3] http://murmanskstat.gks.ru/wps/wcm/connect/rosstat_ts/murmanskstat/ru/municipal_statistics/main_indicators/

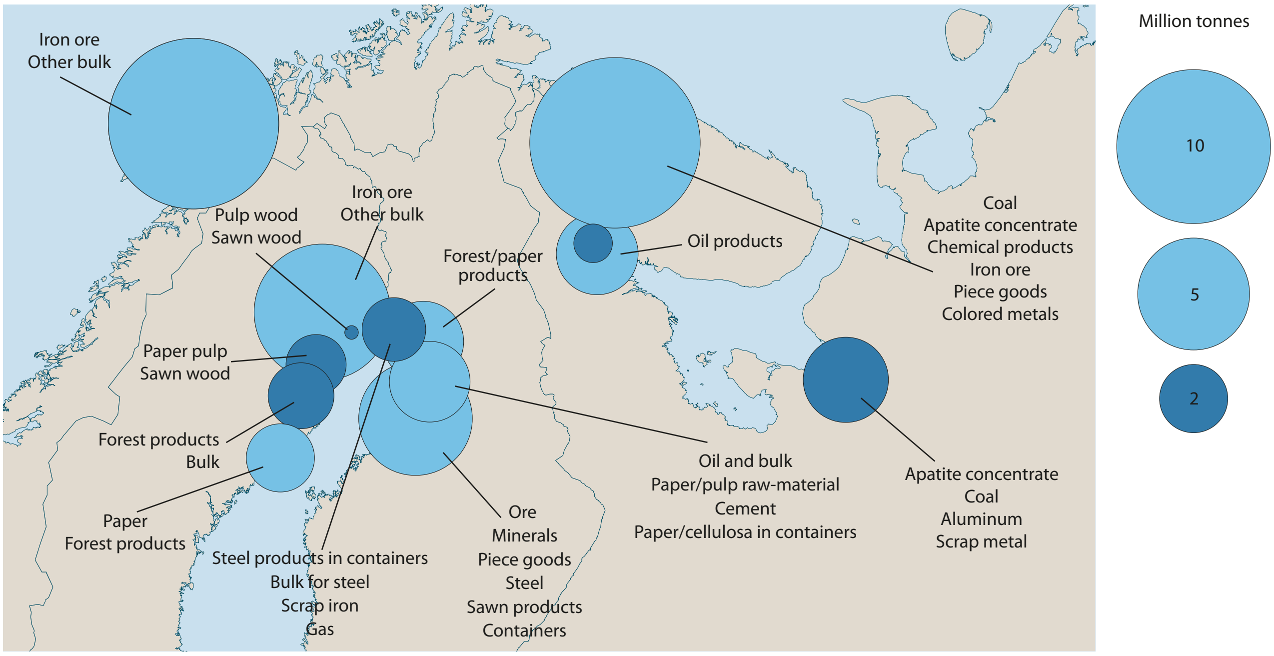


Figure 2.15 Industrial ports and shipped goods in the Barents area (ÅF-Infraplan, 2005).

Fisheries thus constitute a major economic sector in Norway and Russia, and much of its produce is for export (see Figure 2.15). The bulk of the Norwegian fish has been exported to countries such as France and Russia (Regional Council of Lapland et al., 2007, however, exports to Russia are currently limited by an export embargo). Internationally, the United Nations Convention on the Law of the Sea (UNCLOS; United Nations, 1982, 1995) establishes the basic legal framework for marine areas under which all sea fisheries must operate. This entails among other things, delimitation and constitution of maritime zones, including EEZs. To enhance the protection of common marine ecosystems, states throughout the world adopt regional seas agreements, also encouraged by UNCLOS. The Barents Sea, part of the Arctic Ocean and the North-East Atlantic are covered by the OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic. In addition, the 1992 Convention on Biological Diversity applies to both Barents marine and terrestrial ecosystems. Other prominent global conventions applicable to the marine area and shipping are the 1973 Convention on the Prevention of Pollution from Ships (MARPOL 73/78) and the 1974 International Convention on the Safety of Life at Sea. Straddling and highly migratory fish stocks are also covered by a dedicated UN Agreement (1995). In the field of fisheries management for shared living resources, states are encouraged to cooperate or even establish regional fisheries management organizations (RFMOs) for particular areas (primarily high seas) or fish stocks. In the North-East Atlantic and the Barents Sea the best example of an RFMO is the North-East Atlantic Fisheries Commission (NEAFC), which regulates fisheries in North Atlantic high seas and produces (upon state's request) recommendations for its parties' own EEZs. Since 1974/76, the Joint Russian-Norwegian Fisheries Commission has provided management advice on the most important fish stocks in the Barents and Norwegian seas, including quotas and minimum sizes for jointly managed live marine resources.

Unlike many marine fish stocks, the Barents Sea fish stocks are generally in good health. In Russia, the main goal of fisheries management, as defined by the Federal Fisheries Act, is the 'protection and rational use' of aquatic biological resources. The Russian system does not have an explicit environmental policy for the fisheries, but a number of Federal requirements apply to the protection of the environment. In the Barents Sea area, the Joint Norwegian-Russian Fishery Commission plays a key role in managing shared stocks. This commission coordinates a number of cooperative research projects, focused on enhancing understanding of the Barents Sea ecosystem and factors driving the dynamics of the most important commercial species. Total Allowable Catches (TACs) are based on recommendations by this commission. Management plans for ecosystem-based management of the Barents Sea also exist (e.g. Norwegian Ministry of the Environment 2001, 2006, 2011). These plans cover the Norwegian EEZ and the fisheries protection zone around Svalbard, and provide a framework for the sustainable use of natural resources and goods derived from the Barents Sea-Lofoten area, including the identification of valuable areas and setting of objectives for species management to be implemented through protected areas management. In spring 2014, a contract was signed by the Russian State Company Sevmorgeo ASA and the Russian Ministry of Natural Resources and Environment stipulating that Russian institutions, under the leadership of Sevmorgeo, must prepare an action plan for managing the resources in the Russian part of the Barents Sea, using an ecosystem-based approach (Bokhanov et al., 2013) (see Figure 2.16).

In Norway, it has been noted that more efficient harvesting and the development of more high-end products have increased the value of fish landed. Increasingly sophisticated fishing technology creates more business-oriented fishermen, and a younger generation with more education and higher expectations now constitute the primary cohort of fishers in Norway (Nordic Council of Ministers, 2011). However, there has

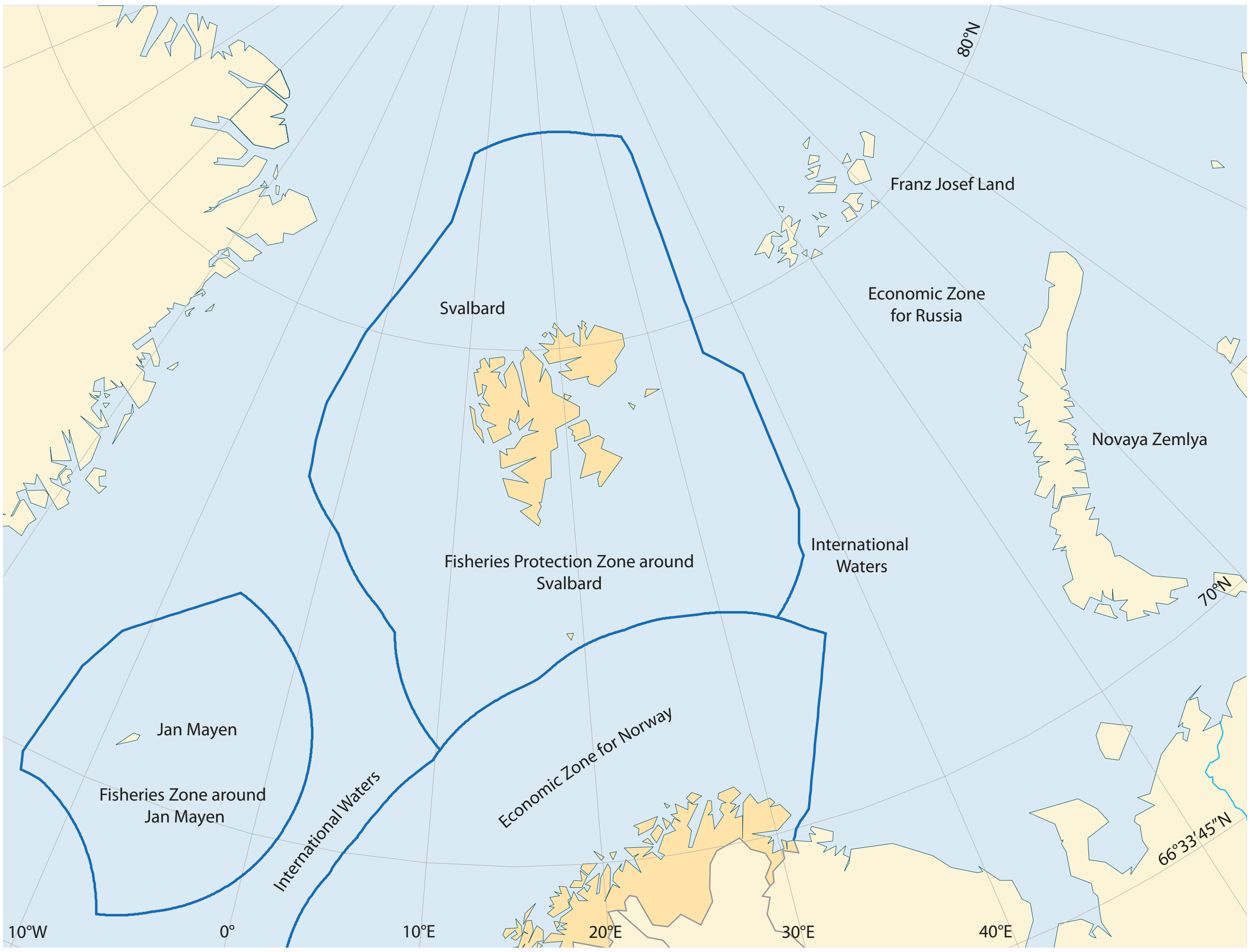


Figure 2.16 National jurisdictions in the Barents Sea, and the corresponding ICES fishery management areas (Norwegian Mapping Authority).

been a simultaneous decline in local fisheries with that described for forestry (Section 2.3.6): the small-scale coastal fishing pattern that was prevalent historically is increasingly being replaced by high technology, fewer fishers and larger companies and trawlers (Keskitalo, 2008a). Changes that could increase with climate change, such as the movement of cold-water fish northwards and a shift in fish species, are already exacerbating these trends, and different technologies such as ocean-going vessels and the need to possess quotas for other (more expensive) species may limit the extent to which local fishers can cope with changing circumstances (see Keskitalo, 2008a).

Fish farming has been driven by a growing international demand over the past few years. The main production takes place in Norwegian waters, where production of salmonids dominates and has become one of the country's leading export industries. The Norwegian share of Arctic aquaculture is currently 98% of total value (Hermansen and Troell, 2012), with Finland and Sweden producing small volumes of freshwater species and some production of Atlantic salmon (*Salmo salar*) in the Murmansk region. In the period 1998–2015 Norway's total fish farming production increased from about 0.4 million tons to 1.4 million tons. In 2015, the three northernmost counties (those included in the Barents Region) contributed almost 40% of Norway's aquaculture production. This is an increase from ~27% in 1998 (Norwegian Directorate of Fisheries, 2015). About 2000 people were employed in the Norwegian aquaculture industry in the three northernmost counties in 2015 (Norwegian Directorate of Fisheries, 2015). In Norway, disease, lice, and escape from sea cages are major challenges, and efforts are being made to solve these problems by using new technology and moving production offshore or onto land. Fish farming is a major source of nitrogen and phosphorus to Norwegian coastal waters. In 2013, discharges from fish-farming in Nordland, Troms and Finnmark counties accounted for about 85% (nitrogen) and 90% (phosphorus) of the total anthrophonic inputs of these substances to this coastline (Selvik and Høgåsen, 2014). However, the water bodies on this coastline are considered of good or high status according to the EU Water Framework Directive, and as a non-problem area for eutrophication according to the OSPAR screening procedure (Norderhaug et.al, 2016). Availability of marine foodstuffs is another challenge. The development of aquaculture into a large-scale industry with a high concentration of ownership creates further tensions with the local communities, which make space available for the industry but which may see few positive benefits of this activity. In Russia, aquaculture has decreased four-fold since 1990 leading to the development of the Federal law "On aquaculture (fish farming) and amendments to certain legislative acts of the Russian Federation". The sector is now under strong development in the Murmansk region, where the volume of raised commercial fish is now significantly higher; increasing from 440 tons in 2007 to 16,300 tons in 2012 (Strategy for development of the Murmansk region, 2013). Further development of this sector is planned, as it is expected that measures underway will drive an increase in the volume of fish farmed from 16,300 in 2012 to 98,900 by 2025 (a six-fold increase). However, aquaculture in northwestern Russia may be significantly affected, positively or negatively, by trade sanctions against the EU and Norway introduced by the Russian Federation in 2014.

2.4 Summary and conclusions

A northern branch of the Gulf Stream (the Atlantic Current) makes the entire Barents area far warmer than other areas at the same latitude. Nevertheless, part of the region still possesses glaciers, permafrost and environmental features typical of Arctic areas. This region is also warming faster than the global average and climate change impacts on flora and fauna of the region are already notable: growth seasons are shifting and extending; primary production in terrestrial and marine areas is changing; many commercial fish stocks are larger than they have been for decades; and ice-associated invertebrates, fish, birds and mammals are facing major challenges. Freshwaters and wetlands occur throughout the Barents area and these ecosystem-types contain a multitude of habitats and species and provide a wide range of key ecological services, which support important Ecosystem Services (see also Box 2.2). These include, for example, maintaining permafrost (in northern parts of the region), regulating and filtering water, and storing vast amounts of greenhouse gases, which is critical for global biodiversity. Peatlands in the permafrost zone are an important reservoir of soil organic carbon, especially in extensive permafrost areas where the peat is relatively thick. A damaged peat layer could result in irreversible changes, transforming a carbon-sink ecosystem into a carbon-emitting system, either directly through the release of greenhouse gases (especially methane) or through hydrological flows subsequently becoming a source of emissions. The Barents area is less species-rich than areas further south, although some of the species are unique to the region. Rare species are important for the long-term maintenance of ecosystem function, supporting sustainable use of the area and helping to maintain biodiversity. Globalization and growth in the volume of trade and tourism has provided some species with a solution for how to by-pass natural barriers such as oceans, mountains and rivers. Together with ongoing climate change, expressed as a longer growing season and higher temperatures (in air and water), species are able to establish and thrive in new areas. Invasive alien species are currently considered one of the major threats to native biodiversity and studies on invasive species are underway in all countries within the Barents area.

Socio-economically and politically, the Barents Region is a highly developed area that has relatively little in common with other Arctic areas in terms of development trajectories and overall societal integration. It is economically and socially diverse with limited risk of inter-state conflict that could affect regional security (e.g. Byers, 2013). Large variability exists within the Barents area, especially between the Fennoscandian countries and Russia. Internal variability also exists within in each country and sub-region, especially between the growing urban centers and de-populating rural areas. Areas are thus subject to the same globalization and urbanization pressures felt in many other areas of the world. Local employment has for many years been replaced by high technology solutions in all resource sectors covered by this assessment, something that may itself be contributing to increased urbanization, as reductions in the need for labor in rural areas may be driving youth to seek employment elsewhere. These changes in historical habitation and employment patterns result in many new challenges: for instance, a current trend is that of absent owners, who may retain ownership of the family property but no longer live in the area and may now use this mainly for recreation, for example as a summer cabin (e.g. Stjernström et al., 2013). Such changes imply shifts in who may be considered 'the locals', as land owners may increasingly live and work away from their areas of origin or family property. This also results in challenges for increasingly sparsely populated municipalities with regard to being able to assess resource use proposals such as mining within a strict environmental and social framework but with limited staff, and in maintaining services under decreasing local tax revenues. As the demographic shift has resulted in aging populations in many areas and related considerations around service maintenance and welfare state functions, particular challenges are thus being created for local government, which plays a significant role in the Nordic countries in relation to both local use and service provision. Local government responses to external developments may be increasingly shaped by perceptions of potential local employment, extent of local tax revenue, and related conflict among land-use sectors. The fact that the level of resource use has remained the same or increased while employment in natural resource-based sectors has fallen, also poses questions for how states might maintain a balanced economy with low unemployment rates while attempting to develop sustainable hydrocarbon use and address climate change, among other issues.

Taken together, the developments reported here demonstrate the importance of understanding historical patterns of resource exploitation and land use, the persistence of these trends into the present, and the relationship between technological and economic change and governance structures. This in turn demands a multi-level analysis of economic sectors and governance structures beyond the national level, placing the legislative and policy framework within historical as well as contemporary contexts in order to fully understand the conditions within which resource governance takes place, also under future change and potentially increased globalization. Because this chapter and the report as a whole focus on natural systems and environment-based industries, reference is brief to the complex decision-making systems and interests at the international, EU, national, regional and local level that are in a broader sense relevant to adaptation. For this, literature on the state system, governance and relation to the EU for each geographic area or case exists and is relevant. National literature on the issues addressed in this report (in national languages as well as more broadly) is substantial, and rather than attempting to identify specific gaps in knowledge it is more important to note that a chapter such as this on the whole of the Barents area can provide only a snapshot of the highly varied and complex nature of this region.

Acknowledgments

The participation of E. Carina H. Keskitalo, Peter Sköld, Dieter Müller, Niklas Eklund, Lovisa Solbär, Olof Stjernström, Örjan Pettersson, Dag Avango, Dmitry Lajus, Paul Warde, Maria Pettersson, Per Axelsson, and Peder Roberts was made possible through funding from the research programme Mistra Arctic Sustainable Development – New Governance for Sustainable Development in the European Arctic. The participation by Wenche Eide was funded by the Swedish Environmental Protection Agency. Norwegian authors were financed by the Norwegian Environment Agency, Norwegian Polar Institute and the Marine Research Institute.

References

Aass, J., T. Marques, K. Lone, M. Andersen, Ø. Wiig, I.M.B. Fløystad, S.B. Hagen and S.T. Buckland, 2017. The number and distribution of polar bears in the western Barents Sea. Polar Research.

ACIA, 2004. Arctic Climate Impact Assessment: Impacts of a Warming Arctic. Arctic Climate Impact Assessment (ACIA). Cambridge University Press.

AHDR, 2004. Arctic Human Development Report. Stefansson Arctic Institute, Akureyri.

ÅF-Infraplan, 2005. Barents Railway Network – Needs Study. Sustainable Transport in the Barents Region. STBR publications 5/2005.

Agnalt, A.L., V. Pavlov, K.E. Jørstad, E. Farestveit and J. Sundet, 2011. The snow crab, *Chionoecetes opilio* (Decapoda, Majoidea, Oregoniidae) in the Barents Sea. In: In the Wrong Place-Alien Marine Crustaceans: Distribution, Biology and Impacts. pp. 283-300. Springer.

AMAP, 2012. Arctic Climate Issues 2011: Changes in Arctic Snow, Water, Ice and Permafrost. Arctic Monitoring and Assessment Programme (AMAP), Oslo.

AMAP, 2017. Snow, Water, Ice and Permafrost in the Arctic (SWIPA) 2017. Arctic Monitoring and Assessment Programme (AMAP), Oslo.

Ambjörnsson, E., E.C.H. Keskitalo and S. Karlsson, 2016. Forest discourses and the role of planning-related perspectives: the case of Sweden. Scandinavian Journal of Forest Research, 31:111-118.

Andersen, L.W., E.W. Born, I. Gjert, Ø. Wiig, L.E. Holm and C. Bendixen, 1998. Population structure and gene flow of the Atlantic walrus (*Odobenus rosmarus rosmarus*) in the eastern Atlantic Arctic based on mitochondrial DNA and microsatellite variation. Molecular Ecology, 7:1323-1336.

Andersen, L.W., C. Lydersen, A.K. Frie, A. Rosing-Asvid, E. Hauksson and K.M. Kovacs, 2011. A population on the edge: genetic diversity and population structure of the world's northernmost harbour seals (*Phoca vitulina*). Biological Journal of the Linnaean Society, 102:420-439.

Andersen, M., A.E. Derocher, Ø. Wiig and J. Aars, 2012. Polar bear (*Ursus maritimus*) maternity den distribution in Svalbard, Norway. Polar Biology, 35:499-508.

Andrew, R., 2014. Socio-Economic Drivers of Change in the Arctic. AMAP Technical Report No. 9. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

Andriyashev, A.P. and N.V. Chernova, 1995. Annotated list of fishlike vertebrates and fish of the Arctic seas and adjacent waters. Journal of Ichthyology, 35:81-123.

Angelstam, P., 1998. Maintaining and restoring biodiversity in European boreal forests by developing natural disturbance regimes. Journal of Vegetation Science, 9:593-602.

Anker-Nilssen, T., V. Bakken, H. Strøm, A.N. Golovkin, V.V. Bianki and I.P. Tatarinkova, 2000. The Status of Marine Birds Breeding in the Barents Sea Region. Norwegian Polar Institute, Report No. 113.

Arctic Council, 2009. Arctic Marine Shipping Assessment 2009 Report. Arctic Council. Second printing.

Årthun, M., T. Eldevik, L.H. Smedsrud, Ø. Skagseth and R.B. Ingvaldsen, 2012. Quantifying the influence of Atlantic heat on Barents Sea ice variability and retreat. Journal of Climate, 25:4736-4743.

Barrett, R.T., 2002. Atlantic puffin *Fratercula arctica* and common guillemot *Uria aalge* chick diet and growth as indicators of fish stocks in the Barents Sea. Marine Ecology-Progress Series, 230:275-287.

Barrett, R.T., 2007. Food web interactions in the southwestern Barents Sea: black-legged kittiwakes *Rissa tridactyla* respond negatively to an increase in herring *Clupea harengus*. Marine Ecology Progress Series, 349:269-276.

BEAC, 2016. The Barents Region. Territory and population 2014. Barents Euro-Arctic Council (BEAC). www.beac.st/en/About/Barents-region/Regions#1. Accessed 31 May 2016.

Benestad, R.E., K.M. Parding, K. Isaksen and A. Mezghani, 2016. Climate change and projections for the Barents region: what is expected to change and what will stay the same? Environmental Research Letters, 11:054017, doi: http://dx.doi.org/10.1088/1748-9326/11/5/054017.

Birks, H.H., E. Larsen and H.J.B. Birks, 2005. Did tree-*Betula*, *Pinus* and *Picea* survive the last glaciation along the west coast of Norway? A review of the evidence, in light of Kullman (2002). Journal of Biogeography, 32:1461-1471.

Blanchet, M.A., C. Lydersen, R.A. Ims and K.M. Kovacs, 2015. Seasonal, oceanographic and atmospheric drivers of diving behaviour in a temperate seal species living in the High Arctic. PLoS ONE, 10: e0132686. doi: 10.1371/journal.pone.0132686

Bogstad, B, H. Gjøsæter, T. Haug and U. Lindstrøm, 2015. A review of the battle for food in the Barents Sea: cod vs. marine mammals. Frontiers in Ecology and Evolution, http://dx.doi.org/10.3389/fevo.2015.00029

Bokhanov, D.V., D.L. Lajus, A.P. Moiseev and K.M. Sokolov, 2013. Otsenka ugroz moskoi ekosisteme Arktiki, svaizannykh s pomyshlennym raybolvstvom, na primere Barentseva moria [Assessment of threats for Artic marine ecosystem, related to industrial fishing, exemplified by the Barents Sea)] Vsemirny fond dikoi prirody (WWF). Moscow. www.wwf.ru/data/publ/marine/arctic-ecosystems_fish.pdf

Bring, A., I. Fedorova, Y. Dibike, L. Hinzman, J. Mård, S.H. Mernild, T. Prowse, O. Semenova, S.L. Stuefer and M.-K. Woo, 2016. Arctic terrestrial hydrology: A synthesis of processes, regional effects and research challenges. Journal of Geophysical Research: Biogeosciences, 121:621-649.

Bugge, H.C., 2014. Environmental Law in Norway. 2nd Ed. Kluwer Law International.

Byers, M., 2013 International Law and the Arctic. Cambridge University Press.

CAFF, 2013. Arctic Biodiversity Assessment – Synthesis. Conservation of Arctic Flora and Fauna (CAFF), Arctic Council. Akureyri, Iceland.

Campbell, R.G., M.M. Wagner, G.J. Teegarden, C.A. Boudreau and E.G. Durbin, 2001. Growth and development rates of the copepod *Calanus finmarchicus* reared in the laboratory. Marine Ecology-Progress Series, 221:161-183.

Carmack, E., D. Barber, J. Christensen, R. Macdonald, B. Rudels and E. Sakshaug, 2006. Climate variability and physical forcing of the food webs and the carbon budget on panarctic shelves. Progress in Oceanography, 71:145-181.

Carroll, M.L., S.G. Denisenko, P.E. Renaud and W.G. Ambrose, 2008. Benthic infauna of the seasonally ice-covered western Barents Sea: patterns and relationships to environmental forcing. Deep Sea Research II, 55:2340-2351.

Carscadden, J.E., H. Gjøsæter and H. Vilhjalmsson, 2013. A comparison of recent changes in distribution of capelin (*Mallotus villosus*) in the Barents Sea, around Iceland and in the Northwest Atlantic. Progress in Oceanography, 114:64-83.

CAVM Team, 2003. Circumpolar Arctic Vegetation Map. Sale 1: 7,500,000. Conservation of the Arctic Flora and Fauna (CAFF). Map No. 1. U.S. Fish and Wildlife Service.

Chernov, Y.I. and N.V. Matveyeva, 1997. Arctic Ecosystems in Russia. In: Wielgolaski, F.E. (ed.). Polar and Alpine Tundra, pp. 361-507. Elsevier.

Christensen, I., T. Haug and N. Øien, 1992. Seasonal distribution, exploitation and present abundance of stocks of large baleen whales (Mysticeti) and sperm whales (*Physeter macrocephalus*) in Norwegian and adjacent waters. ICES Journal of Marine Science, 49:341-355.

Cochrane, S.K., S.G. Denisenko, P.E. Renaud, C.S. Emblow, W.G. Ambrose, I.H. Ellingsen and J. Skarðhamar, 2009. Benthic macrofauna and productivity regimes in the Barents Sea – ecological implications in a changing Arctic. Journal of Sea Research, 61:222-233.

Comiso, J.C., 2012. Large decadal decline of the Arctic multiyear ice cover. Journal of Climate, 25:1176-1193.

Coulson, S.J., 2000. A review of the terrestrial and freshwater invertebrate fauna of the High Arctic archipelago of Svalbard. Norwegian Journal of Entomology, 47:454-466.

Dalpadado, P., 2002. Inter-specific variations in distribution, abundance and possible life-cycle patterns of *Themisto* spp. (Amphipoda) in the Barents Sea. Polar Biology, 25:656-666.

Dalpadado, P. and H.R. Skjoldal, 1991. Distribution and life history of krill from the Barents Sea. In: Sakshaug, E., C.C.E. Hopkins and N.A. Øritsland (eds.), Proceedings of the Pro Mare Symposium on Polar Marine Ecology, pp. 442-460. Polar Research, 10.

Dalpadado, P. and H.R. Skjoldal, 1996. Abundance, maturity and growth of the krill species, *Thysanoessa inermis* and *T. longicaudata* in the Barents Sea. Marine Ecology-Progress Series, 144:175-183.

Dalpadado, P., B. Bogstad, H. Gjøsæter, S. Mehl and H.R. Skjoldal, 2002. Zooplankton–fish interactions in the Barents Sea. In: Sherman, K. and H.R. Skjoldal (eds.), Large Marine Ecosystems of the North Atlantic. pp. 269-291. Elsevier Science.

Dalpadado, P., A. Yamaguchi, B. Ellertsen and S. Johannessen, 2008. Trophic interactions of macro-zooplankton (krill and amphipods) in the Marginal Ice Zone of the Barents Sea. Deep Sea Research, 55:2266-2274.

Dalpadado, P., R.B. Ingvaldsen, L.C. Stige, B. Bogstad, K. Knutsen, G. Ottersen and B. Ellertsen, 2012. Climate effects on Barents Sea ecosystem dynamics. ICES Journal of Marine Science, 69:1303-1316.

Dalpadado, P., A.R. Arrigo, S. Hjøllo, F. Rey, R.B. Ingvaldsen, E. Sperfeld, G.L.V. Dijken, A. Olsen and G. Ottersen, 2014. Productivity in the Barents Sea - response to recent climate variability. PLoS ONE, 9:e95273 doi:10.1371/journal.pone.0095273

De Smet, R.W.H. and E.A. van Rompu, 1994. Rotifera and tardigrada in some cryonite holes on a Spitsbergen (Svalbard) glacier. Belgian Journal of Zoology, 124:27-37.

Degteva, S.V., V.I. Ponomarev, S.W. Eisenman and V. Dushenkov, 2015. Striking the balance: Challenges and perspectives for the protected areas network in northeastern European Russia. Ambio, 44:473-490.

Denisenko, S.G., 2001. Long-term changes of zoobenthos biomass in the Barents Sea. Proceedings of the Zoological Institute of the Russian Academy of Sciences, 289:59-66.

Denisenko, S., N. Denisenko, K.K. Lehtonen, A.-B. Andersin and A. Laine, 2003. Macrozoobenthos of the Pechora Sea (SE Barents Sea): community structure and spatial distribution in relation to environmental conditions. Marine Ecology-Progress Series, 258:109-123.

Descamps, S., H. Strøm and H. Steen, 2013. Decline of an arctic top predator: synchrony in colony size fluctuations, risk of extinction and the subpolar gyre. Oecologia, 173:1271-1282.

Dolgov, A., E. Johannesen and Å. Høines, 2011a. Fish: Main species and ecological importance. In: Jakobsen, T. and V.K. Ozhigin (eds.) The Barents Sea: Ecosystem, Resources, Management: Half a Century of Russian-Norwegian Cooperation. pp. 193-200. Tapir Academic Press.

Dolgov, A.V., E.L. Orlova, E. Johannesen, B. Bogstad, G.B. Rudneva et al. 2011b. Planktivorous fish. In: Jakobsen, T. and

V.K. Ozhigin (eds.), The Barents Sea: Ecosystem, Resources, Management: Half a Century of Russian-Norwegian Cooperation. pp. 438-454. Tapir Academic Press.

Drobysheva, S.S., 1994. Euphausiids of the Barents Sea and their role for productivity. Evfausiidy Barentseva moray i ikh rol' v formirovanii promyslovoy bioproduktsii. Izdatel'stvo. PINRO, Murmansk. (In Russian)

Duhaime, G. and A. Caron, 2009. Economic and social conditions of Arctic regions. In: Glomsrød, S. and I. Aslaksen (eds.), The Economy of the North 2008. pp. 11-23. Statistics Norway.

Duhaime, G., A. Caron, S. Lévesque, A. Lemelin, I.Mäenpää, O.Nigai and V. Robichaud, 2017. Social and economic inequalities in the circumpolar Arctic. In: Glomsrød, S., Duhaime, G and I. Aslaksen (eds.), The Economy of the North 2015. pp. 11-24. Statistics Norway.

Eiane, K. and K.S. Tande, 2009. Meso and macrozooplankton. In: Sakshaug, E., G. Johnsen and K. Kovacs (eds.), Ecosystem Barents Sea. pp 209-234. Tapir Academic Press.

Elmqvist, T., C. Folke, M. Nyström, G. Peterson, J. Bengtsson, B. Walker and J. Norberg, 2003. Response diversity, ecosystem change, and resilience. Frontiers in Ecology and the Environment, 1:488-494.

Elner, R.W. and P.G. Beninger, 1992. The reproductive biology of snow crab, *Chionoecetes opilio*: a synthesis of recent contributions. American Zoologist, 32:524-533.

Emelyanova, A., 2015. Cross-regional analysis of population aging in the Arctic. Doctoral thesis. Acta Universitatis Ouluensis D Medica 1326, Juvenes Print Tampere.

Emelyanova, A. and A. Rautio, 2012. Aging population of the Barents Euro-Arctic Region. European Geriatric Medicine, 3:167-173.

Ericsson, M., 2010. Global mining towards 2030. Food for thought for the Finnish mineral policy process 2010. Report of investigation 187. Geological Survey of Finland, Espoo.

Eriksen, E. and P. Dalpadado, 2011. Long-term changes in krill biomass and distribution in the Barents Sea: are the changes mainly related to capelin stock size and temperature conditions? Polar Biology, 34:1399-1409.

Eriksen, E., R. Ingvaldsen, J.E. Stiansen and G.O. Johansen, 2012. Thermal habitat for 0-group fishes in the Barents Sea; how climate variability impacts their density, length and geographical distribution. ICES Journal of Marine Science, 69:870-879.

Eriksen, E., C.M.F. Durif and D. Prozorkevich, 2014. Lumpfish (*Cyclopterus lumpus*) in the Barents Sea: development of biomass and abundance indices, and spatial distribution. ICES Journal of Marine Science, 71:2398-2402.

Eriksen, E., R.B. Ingvaldsen, K. Nedreaas and D. Prozorkevich, 2015. The effect of recent warming on polar cod and beaked redfish juveniles in the Barents Sea. Regional Studies in Marine Science, 2:105-112.

Eriksen, E., H.R. Skjoldal, A.V. Dolgov, P. Dalpadado, E.L. Orlova and D.V. Prozorkevich, 2016. The Barents Sea euphausiids: Methodological aspects of monitoring and estimation of abundance and biomass. ICES Journal of Marine Science, 73:1533-1544.

Erikstad, K.E. and H. Strøm, 2012. Effekter av miljøgifter på bestanden av polarmåke på Bjørnøya. Norwegian Polar Institute, Tromsø. Report No. 25.

Erikstad, K.E., T.K. Reiertsen, R.T. Barrett, F. Vikebø, H. Sandvik and F. Vikebo, 2013. Seabird-fish interactions: the fall and rise of a common guillemot *Uria aalge* population. Marine Ecology-Progress Series, 475, 267–276.

European Commission, 2008. The raw materials initiative – meeting our critical needs for growth and jobs in Europe. Communication from the Commission to the European Parliament and the Council. COM(2008) 699 final.

Falk-Petersen, S., S. Timofeev, V. Pavlov and J.R. Sargent, 2007. Climate variability and possible effect on arctic food chains. The role of *Calanus*. In: Orbaek, J.B., T. Tombre, R. Kallenborn, E. Hegseth, S. Falk-Petersen and A.H. Hoel (eds.), Arctic Alpine Ecosystems and People in a Changing Environment. pp. 147-166. Springer.

Falk-Petersen, S., P. Mayzaud, G. Kattner and J. Sargent, 2009. Lipids and life strategy of Arctic *Calanus*. Marine Biology Research, 5:18-39.

FAO, 2008, Forests and Energy. FAO Forestry Paper 154. UN Food and Agriculture Organization (FAO).

Fauchald, P., S.V. Ziryanov, H. Strøm and R.T. Barrett, 2011. Seabirds of the Barents Sea. In: Jakobsen, T. and V.K. Ozhigin (eds.), The Barents Sea. Ecosystem, Resources, Management. pp. 373-394. Tapir Academic Press.

Fauchald, P, T. Anker-Nilssen, R.T. Barrett, J.O. Bustnes, B.-J. Bårdsen, S. Christensen-Dalsgaard, S. Descamps, S. Engen, K.E. Erikstad, S.A. Hanssen, S.-H. Lorentsen, B. Moe, T.K. Reiertsen and H. Strøm and G.H. Systad, 2015. The status and trends of seabirds breeding in Norway and Svalbard. NINA Report 1151. Norwegian Institute for Nature Research (NINA).

Finnish Ministry of Agriculture and Forestry, 2000. Reindeer Husbandry Act (848/1990; amendments up to 54/2000 included).

Forbes, B.C., 2013. Cultural resilience of social-ecological systems in the Nenets and Yamal-Nenets Autonomous Okrugs, Russia: a focus on reindeer nomads of the tundra. Ecology and Society, 18: doi: 10.5751/ES-05791-180436

Forbes, B.C., F. Stammler, T. Kumpula, N. Meschtyb, A. Pajunen, E. Kaarlejärvi, 2009. High resilience in the Yamal-Nenets social-ecological system, West Siberian Arctic, Russia. Proceedings of the National Academy of Sciences of the USA, 106:22,041-22,048.

Forsius, M., S. Anttila, L. Arvola, I. Bergström, H. Hakola, H.I. Heikkinen, J. Helenius, M. Hyvärinen, K. Jylhä, J. Karjalainen. T. Keskinen, K. Laine, E. Nikinmaa, P. Peltonen-Sainio, K. Rankinen, M. Juhana Reinikainen, H. Martti Setälä and J. Vuorenmaa, 2013. Impacts and adaptation options of climate change on ecosystem services in Finland: a model based study. Current Opinion in Environmental Sustainability, 5:26-40.

Forsström, L. S. Sorvari and A. Korhola, 2009. Phytoplankton in subartic lakes of Finnish Lapland – implications for ecological lake classification. Advances in Limnology, 62:77-97.

Fossheim, M., R. Primicerio, E. Johannesen, R.B. Ingvaldsen, M.M. Aschan and A.V. Dolgov, 2015. Recent warming leads to a rapid borealization of fish communities in the Arctic. Nature Climate Change, 5:673-677.

Freitas, C., K.M. Kovacs, M. Andersen, J. Aars, S. Sandven, Skern-Mauritzen, O. Pavlova and C. Lydersen, 2012. Importance of fast ice and glacier fronts for female polar bears and their cubs during spring in Svalbard, Norway. Marine Ecology-Progress Series, 447:289-304.

Fu, B., M. Forsius and J. Liu, 2013. Ecosystem services: climate change and policy impacts. Editorial overview. Current Opinion in Environmental Sustainability, 5:1-3.

Fuglei, E. and R. Ims, 2008. Global warming and effects on the arctic fix. Science Progress, 91:175-191.

Füreder, L. and J.E. Brittain, 2006. High Arctic stream food webs - What remains at the limits of benthic life? Annual meeting North American Benthological Society, Anchorage, Alaska.

Gederaas, L., I. Salvesen and Å. Viken, 2007. Norsk svarteliste 2007 – Økologiske risikovurderinger av fremmede arter [2007 Norwegian Black List – Ecological Risk Analysis of Alien Species]. Artsdatabanken, Trondheim.

Gederaas, L., T.L. Moen, S. Skjelseth and L.-K. Larsen, 2012. Fremmede arter i Norge – med norsk svarteliste 2012. [Alien species in Norway – with Norwegian blacklist 2012] Artsdatabanken, Trondheim.

Gilbert, M. and E.A.D. Mitchell, 2006. Microbial diversity in *Sphagnum* peatlands. In: Martini, I.P., A., Martinez, Cortizas and W. Chesworth (eds.), Peatlands: Evolution and Records of Environmental and Climate Change. pp. 287-317. Elsevier.

Gilg, O., K.M. Kovacs, J. Aars, J. Fort, G. Gauthier, D. Gramillet, R.A. Ims, H. Meltofte, J. Moreau, E. Post, N.M. Schmidt, G. Yannic and L. Bollache, 2012. Climate change and the ecology and evolution of Arctic vertebrates. Annals of the New York Academy of Science, 1249:166-190.

Gjøsæter, H., 1995. Pelagic fish and the ecological impact of the modern fishing industry in the Barents Sea. Arctic, 48:267-278.

Gjøsæter, H., A. Dommasnes and B. Røttingen, 1998. The Barents Sea capelin stock 1972-1997. A synthesis of results from acoustic surveys. Sarsia, 83:497-510.

Glomsrød, S., G. Duhaime and I. Aslaksen (eds.), 2017. The Economy of the North 2015. Statistical Analyses 151. Statistics Norway, Oslo.

Golubchikov, O., 2004. Urban planning in Russia: towards the market. European Planning Studies, 12:229-247.

Gradinger, R., B.A. Bluhm, R.R. Hopcroft, A.V. Gebruk, K. Kosobokova, B. Sirenko and J.M. Wesławski, 2010. Marine life in the Arctic. In: McIntyre, A.D. (ed.), Life in the World's Oceans: Diversity, Distribution, and Abundance. pp. 183-202. Blackwell.

Gutt, J., 2001. On the direct impact of ice on marine benthic communities, a review. Polar Biology, 24:553-564.

Haley, S., M. Klick, N. Szymoniak and A. Crow, 2011. Observing trends and assessing data for Arctic mining. Polar Geography, 34:37-61.

Hamilton, C.D., C. Lydersen, R.A. Ims, and K.M. Kovacs, 2014. Haul-out behaviour of the world's northernmost population of harbour seals (*Phoca vitulina*) throughout the year. PLoS ONE, 9:e86055, doi:10.1371/journal.pone.0086055

Hamilton, C.D., C. Lydersen, R.A. Ims and K.M. Kovacs, 2015. Predictions replaced by facts in a changing Arctic: a keystone species' responses to declining sea ice. Biology Letters, 11:20150803, doi:10.1098/rsbl.2015.0803

Heikkinen, H.I., S. Lakomäki and J. Baldridge, 2007. The dimensions of sustainability and the neo-entrepreneurial adaptation strategies in reindeer herding in Finland. Journal of Ecological Anthropology, 11:25-42.

Heikkinen, H.I., O. Moilanen, M. Nuttall and S. Sarkki, 2011. Managing predators, managing reindeer: contested conceptions of predator policies in Finland's southeast reindeer herding area. Polar Record, 47:218-230.

Heikkinen, H.I., M. Kasanen and E. Lépy, 2012. Resilience, vulnerability and adaptation in reindeer herding communities in the Finnish-Swedish border area. Nordic Geographical Publications, 41:107-121.

Heininen, L. and C. Southcott (eds.), 2010. Globalization and the Circumpolar North. University of Alaska Press.

Heleniak, T., 1999. Out-migration and depopulation of the Russian North during the 1990s. Post-Soviet Geography and Economics, 40:155-205.

Heleniak, T., 2014. Arctic populations and migration. In: Arctic Human Development Report: Regional Processes and Global Linkages. pp. 53-104. Nordic Council of Ministers, Copenhagen.

Hermansen, Ø. and M. Troel, 2012. Aquaculture in the Arctic: A review. Report no. 36/2012, Nofima, Tromsø.

Hingley, M., 1993. Microscopic life in *Sphagnum*. Naturalists' Handbook 20. Richmond Publishing.

Hipfner, J.M., L.K. Blight, R.W. Lowe, S.I. Wilhelm, G.J. Robertson, R.T. Barrett, T. Anker-Nilssen and T.P. Good, 2012. Unintended consequences: how the recovery of sea eagle *Haliaeetus* spp. populations in the northern hemisphere is affecting seabirds. Marine Ornithology, 40:39-52.

Hirshberg, D. and A.N Petrov, 2014. Education and human capital. In: Arctic Human Development Report: Regional Processes and Global Linkages. pp. 347-395. Nordic Council of Ministers, Copenhagen.

Hodson, A., A.M. Anesio, M. Tranter, A. Fountain, M. Osborn, J. Priscu, J. Laybourn-Parry and B. Sattler, 2008. Glacial ecosystems. Ecological Monographs, 78:41-67.

Hof, A.R., R. Jansson and C. Nilsson, 2015. Future of biodiversity in the Barents region. TemaNord 2015:519.

Höglind, M., S.M. Thorsen and M.A. Semenov, 2013. Assessing uncertainties in impact of climate change on grass production in Northern Europe using ensembles of global climate models. Agricultural and Forest Meteorology, 170:103-113.

Hovelsrud, G.K., B. Poppel, B.E.H. van Oort and J. Reist, 2011. Arctic societies, cultures, and peoples in a changing cryosphere. In: Snow, Water, Ice and Permafrost in the Arctic (SWIPA): Climate Change and the Cryosphere. Arctic Monitoring and Assessment Programme (AMAP).

Hunt, G.L., A.L. Blanchard, P. Boveng, P. Dalpadado, K. Drinkwater, L. Eisner, R.R. Hopcroft, K.M. Kovacs, B.L. Norcross, P. Renaud, M. Reigstad, M. Renner, H.R. Skjoldal, A. Whitehouse and R.A. Woodgate, 2013. The Barents and Chukchi Seas: comparison of two Arctic shelf ecosystems. Journal of Marine Systems, 109/110:43-68.

Huskey, L, I. Maenpaa and A. Pelyasov, 2014. Economic systems. In: Larsen, J.N. and G. Fondahl (eds), Arctic Human Development Report: Regional Processes and Global Linkages. pp. 151-184. Nordic Council of Ministers.

Hylen, A., 2002. Fluctuations in the abundance of northeast Arctic cod during the 20th century. ICES Marine Science Symposia, 215:543-550.

ICES, 2014a. First Interim Report of the Working Group on Integrated Assessments of the Barents Sea (WGIBAR), 24-28 March 2014, Kirkenes, Norway. ICES CM 2014/SSGRSP:04.

ICES, 2014b. Report of the Arctic Fisheries Working Group (AFWG), Lisbon, Portugal. ICES CM 2014/ACOM:05.

ICR, 2016. Reindeer Herding: A virtual guide to the people that herd them - Nenets. International Centre for Reindeer Husbandry (ICR). http://reindeerherding.org/herders/nenets/

IEA, 2011. Key World Energy Statistics. International Energy Agency (IEA). Accessed 2 October 2012. See www.iea.org/textbase/nppdf/free/2011/key_world_energy_stats.pdf

Ims, R.A., I.G. Alsos, E. Fuglei, Å.Ø. Pedersen and N.G. Toccoz, 2014. An assessment of MOSJ – The state of the terrestrial environment in Svalbard. Report Series no. 144. Norwegian Polar Institute.

Ingvaldsen, R.B. and H. Gjøsæter, 2013. Responses in spatial distribution of Barents Sea capelin to changes in stock size, ocean temperature and ice cover. Marine Biology Research, 9:867-877.

Ivanov, V.V., V.A. Alexeev, I. Repina, N.V. Koldunov and A. Smirnov, 2012. Tracing Atlantic water signature in the Arctic sea ice cover east of Svalbard. Advances in Meteorology, No. 201818, doi:10.1.1155/2012/201818.

Ives, A.R. and S.R. Carpenter, 2007. Stability and diversity of ecosystems. Science, 317:58-62.

Jansson, R., C. Nilsson, E.C.H. Keskitalo, T. Vlasova, M.-L. Sutinen, J. Moen, F. Stuart Chapin III, K.A. Bråthen, M. Cabeza, T.V. Callaghan, B. van Oort, H. Dannevig, I.A. Bay-Larsen, R.A. Ims and P.E. Aspholm, 2015. Future changes in the supply of goods and services from natural ecosystems: Prospects for the European North. Ecology and Society, 20: doi:10.5751/ES-07607-200332.

Järvinen, O. and R.A. Väisänen, 1978. Ecological zoogeography of north European waders, or why do so many waders breed in the north? Oikos, 30:496-507.

Johannesen, E., R.B. Ingvaldsen B. Bogstad, P. Dalpadado, E. Eriksen, H. Gjøsæter, M. Skern-Mauritzen and T. Knutsen, 2012a. Changes in Barents Sea ecosystem state, 1970–2009: climate fluctuations, human impact, and trophic interactions. ICES Journal of Marine Science, 69:880-889.

Johannesen, E., Å.S. Høines, A.V. Dolgov and M. Fossheim, 2012b. Demersal fish assemblages and spatial diversity patterns in the Arctic-Atlantic Transition Zone in the Barents Sea. PLoS ONE, 7:e34924. doi:10.1371/journal.pone.0034924

Johansen, G.O, E. Johannesen, K. Michalsen, A. Aglen and Å. Fotland, 2013. Seasonal variation in geographic distribution of NEA cod - survey coverage in a warmer Barents Sea. Marine Biology Research, 9:908-919.

Johansson, M., L. Van Well, H. Eskelinen, M. Fritsch, T. Hirvonen, O. Foss, D. Juvkam and N. Boje Groth, 2011. Polycentricity and beyond in Nordic Regional Governance. Nordic Council of Ministers, Report 2009:9.

Johnsen, I.H.G. and L. Perjo, 2014. Local and regional approaches to demographic change in the Nordic countries. Nordregio Working Paper 2014:3. Nordregio, Stockholm.

Joosten, H. and D. Clarke, 2002. Wise Use of Mires and Peatlands. International Mire Conservation Group and International Peat Society, Jyskä, Finland.

Jordbruksverket, 2015. www.jordbruksverket.se

Jørgensen, L.L. and E. Nilssen, 2011. The invasive history, impact and management of the red king crab *Paralithodes camtschaticus* of the coast of Norway. In: Galil, B.S., P.F. Clark and J.T. Carlton (eds.), In the Wrong Place - Alien Marine Crustaceans: Distribution, Biology and Impacts. pp. 521-526. Springer.

Jørgensen, L.L. and R. Primicerio, 2007. Impact scenario for the invasive red king crab *Paralithodes camtschaticus* (Tilesius, 1815) (Reptantia, Lithodidae) on Norwegian, native, epibenthic prey. Hydrobiologia, 590:47-54.

Jørgensen, L.L., P. Ljubin, H.R. Skjoldal, R.B. Ingvaldsen, N. Anisimova and I. Manushin, 2015. Distribution of benthic megafauna in the Barents Sea: baseline for an ecosystem approach to management. ICES Journal of Marine Science, 72:595-613.

Jørgensen, L.L., B. Planque, T.H. Thangstad and G. Certain, 2016. Vulnerability of megabenthic species to trawling in the Barents Sea. ICES Journal of Marine Science, 73:84-97.

Keskitalo, E.C.H., 2004. Negotiating the Arctic. The Construction of an International Region. Routledge.

Keskitalo, E.C.H., 2008a. Climate Change and Globalization in the Arctic: An Integrated Approach to Vulnerability Assessment. Earthscan Publications.

Keskitalo, E.C.H., 2008b. Konflikter mellan rennäring och skogsbruk i Sverige. In: Sandström, C., S. Hovik and E.I. Falleth (eds.), Omstridd natur. Trender & utmaningar i nordisk naturförvaltning. pp. 248-268. Borea, Umeå.

Keskitalo, E.C.H. and M. Pettersson, 2012. Implementing multi-level governance? The legal basis and implementation of the EU Water Framework Directive for forestry in Sweden. Environmental Policy and Governance, 22:90-103.

Keskitalo, E.C.H. and C. Southcott, 2015. Globalization. In: Nymand Larsen, J. and G. Fondahl, (eds), Arctic Human Development Report. Regional Processes and Global Linkages. pp. 397-421. Nordic Council of Ministers, Copenhagen.

Kettunen, M., P. Vihervaara, S. Kinnunen, D. D'Amato, T. Badura, M. Argimon and P. ten Brink, 2012. Socio-economic importance of ecosystem services in the Nordic Countries – Synthesis in the context of The Economics of Ecosystems and Biodiversity (TEEB). Nordic Council of Ministers.

Kinossian, N., 2013. Stuck in transition: Russian regional planning policy between spatial polarization and equalization. Eurasian Geography and Economics, 54:611-629.

Knobblock, E. and Ö. Pettersson, 2010. Restructuring and risk-reduction in mining: employment implications for northern Sweden. Fennia, 188:61-75.

Kobyakov, K. and J. Jakovlev (eds.), 2013. Atlas of high conservation value areas, and analysis gaps and representativeness of the protected area network in northwest Russia: Arkangelsk, Vologda, Leningrad, and Murmansk Regions, Republic of Karelia, and City of St. Petersburg. Finnish Environment Institute, Helsinki.

Koivurova, T., K. Kokko, S. Duyck and A. Stepien, 2012. The present and future competence of the European Union in the Arctic. Polar Record, 48:361-371.

Kortsch, S., R. Primicerio, F. Beuchel, P.E. Renaud, J. Rodrigues, O.J. Lønne and B. Gulliksen, 2012. Climate-driven regime shifts in Arctic marine benthos. Proceedings of the National Academy of Sciences USA, 109:14052-14057.

Kovacs, K.M. and C. Lydersen (eds), 2006. Birds and mammals of Svalbard. Polarhåndbok No. 13, Norwegian Polar Institute, Tromsø.

Kovacs, K.M., S. Moore, J.E. Overland and C. Lydersen, 2011. Impacts of changing sea-ice conditions on Arctic marine mammals. Marine Biodiversity, 41:181-194.

Kovacs, K.M., J. Aars and C. Lydersen, 2014. Walruses recovering after 60+ years of protection at Svalbard, Norway. Polar Research, 33: 26034, doi.org/10.3402/polar.v.33.26034.

Kovacs, K.M., P. Lemons, J. McCracken and C. Lydersen, 2015. Walruses in a Time of Climate Change. Arctic Report Card. www.arctic.noaa.gov/reportcard/walruses.html

Krysov, A.I. and I. Røttingen, 2011. Herring. In: Jakobsen, T. and V.K. Ozhigin (eds.), The Barents Sea: Ecosystem, Resources, Management: Half a Century of Russian-Norwegian Cooperation. pp. 215-224. Tapir Academic Press.

Kullman, L., 2002. Boreal tree taxa in the central Scandes during the Late-Glacial: implications for Late-Quaternary forest history. Journal of Biogeography, 29:1117-1124.

Kumpula, T., A. Pajunen, E.M. Kaarlejärvi, B.C. Forbes and F. Stammler, 2011. Land use and land cover change in arctic Russia: ecological and social implications of industrial development. Global Environmental Change, 21:550-562.

Kuzmin, S.A., 2000. Spreading of snow crab *Chionoecete opilio* (Fabricus) in the Barents Sea. ICES. Theme session on marine biological invasions: Retrospectives for the 20th century – Prospectives. CM 2000/U:21.

Kwok, R., 2009. Outflow of Arctic Ocean sea ice into the Greenland and Barents Seas: 1979–2007. Journal of Climate, 22:2438-2457.

Laidre, K.L., H. Stern, K.M. Kovacs, L. Lowry, S.E. Moore, E.V. Regehr, S.H. Ferguson, Ø. Wiig, P. Boveng, R.P. Angliss, E.W. Born, D. Litovka, L. Quakenbush, C. Lydersen, D. Vongraven and F. Ugarte, 2015. Arctic marine mammal population status, sea ice habitat loss, and conservation recommendations for the 21st century. Conservation Biology, 29:724-737.

Larsen, J.N. and Huskey, L., 2015. The Arctic economy in a global context. In: The New Arctic. pp. 159-174. Springer.

Lind, S. and R.B. Ingvaldsen, 2012. Variability and impacts of Atlantic Water entering the Barents Sea from the north. Deep-Sea Research I, 62:70-88.

Lindenmayer, D.B., G.E. Likens, C.J. Krebs and R.J. Hobbs, 2010. Improved probability of detection of ecological "surprises." Proceedings of the National Academy of Sciences, 107:21957-21962.

Loeng, H., 1991. Features of the physical oceanographic conditions of the Barents Sea. Polar Research, 10:5-18.

Luke statistics, 2015. http://stat.luke.fi/en/uusi-etusivu

Lüning, K., 1990. Seaweeds. Their Environment, Biography, and Ecophysiology. John Wiley & Sons.

Luoto, M., R.K. Heikkinen and T.R. Carter, 2004. Loss of palsa mires in Europe and biological consequences. Environmental Conservation, 31:30-37.

Lydersen, C., V.I. Chernook, D.M. Glazov, I.S. Trukhanova and K.M. Kovacs, 2012. Aerial survey of Atlantic walruses (*Odobenus rosmarus rosmarus*) in the Pechora Sea, August 2011. Polar Biology, 35:1555-1562.

Lyubin, P.A., A.A. Anisimova and I.E. Manushin, 2011. Long-term effects on benthos of the use of bottom fishing gears. In: Jakobsen, T. and V.K. Ozhigin (eds.), The Barents Sea: Ecosystem, Resources, Management: Half a Century of Russian-Norwegian Cooperation. pp. 768-775. Tapir Academic Press.

Marine Stewardship Council, 2010.Sustainable fisheries certification. The Barents Sea Cod & Haddock Fisheries. Public Certification Report. Food certification international.

McBride, M.M., A. Filin, O. Titov and J.E. Stiansen (eds.), 2014. IMR/PINRO update of the 'Joint Norwegian-Russian environmental status report on the Barents Sea Ecosystem' giving the current situation for climate, phytoplankton, zooplankton, fish, and fisheries during 2012-13. IMR/PINRO Joint Report Series 2014(1).

McCann, K.S., 2000. The diversity-stability debate. Nature, 405:228-233.

Mehl, S., A. Aglen, D.I. Alexandrov, B. Bogstad, G.E. Dingsør, H. Gjøsæter, E. Johannesen, K. Korsbrekke, P.A. Murashko, D.V. Prozorkevich, O.V. Smirnov, A. Staby and T. Wenneck, de Lange, 2013. Fish investigations in the Barents Sea winter 2007-2012. IMR-Pinro Joint Report Series 1-2013.

Mehlum, F., 2012. Effects of sea ice on breeding numbers and clutch size of a high arctic population of the common eider *Somateria mollissima*. Polar Science, 6:143-153.

Mehlum, F., G.L. Hunt, M.B. Decker and N. Nordlund, 1998. Hydrographic features, cetaceans and the foraging of thick-billed murres and other marine birds in the northwestern Barents Sea. Arctic, 51:243-252.

Melle, W. and H.R. Skjoldal, 1998a. Distribution, life cycles and reproduction of *Calanus finmarchicus, C. glacialis* and *C. hyperboreus* in the Barents Sea. Manuscript in: Melle, W. 1998. PhD thesis, Department of Fisheries and Marine Biology, University of Bergen.

Melle, W. and H.R. Skjoldal, 1998b. Spawning and development of *Calanus* spp. in the Barents Sea. Marine Ecology-Progress Series, 169:211-228.

Mellin, C., C.J.A. Bradshaw, D.A. Fordham and M.J. Caley, 2014. Strong but opposing β-diversity-stability relationships in coral reef fish communities. Proceedings of the Royal Society B, 281:20131993.

Merkel, B., C. Lydersen, N.G. Yoccoz and K.M. Kovacs, 2013. The worlds's northernmost harbour seal population – How many are there? PLoS ONE, 8:e67576. doi:10.1371/journal.pone.0067576

Millennium Ecosystem Assessment, 2003. Ecosystems and Human Well-being: A Framework for Assessment. Millennium Ecosystem Assessment (MA). Island Press.

Moore, J.W., 1979. Factors influencing the diversity, species composition and abundance of phytoplankton in twenty one arctic and subarctic lakes. Internationale Revue der gesamten Hydrobiologie und Hydrographie, 64:485-499.

Mouillot, D, D.R. Bellwood, C. Baraloto, J.R. Chave, M. Galzin, Harmelin-Vivien, M. Kulbicki, S. Lavergne, S. Lavorel, N. Mouquet, C.E. Timothy Paine, J. Renaud and W. Thuiller, 2013. Rare species support vulnerable functions in high-diversity ecosystems. PLoS Biol, 11:e1001569. doi:10.1371/journal.pbio

Müller, D.K., 2011. Tourism development in Europe's 'last wilderness': an assessment of nature-based tourism in Swedish Lapland. In: Grenier, A.A. and D.K. Müller (eds.), Polar Tourism: A Tool for Regional Development. pp. 129-153. Presses de l'Université du Québec.

Müller, D.K., 2013. Progressing second home research: a Nordic perspective. Scandinavian Journal of Hospitality and Tourism, 13:273-280.

Müller, D.K. and Brouder, P., 2014. Dynamic development or destined to decline? The case of Arctic tourism businesses and local labor markets in Jokkmokk, Sweden. In: Viken, A. and B. Granås (eds.), Destination Development in Tourism: Turns and Tactics. pp. 227-244. Ashgate.

Murashko, O., 2008. Participation of Indigenous Numerically-Small Peoples of Russia in Natural Resource Management: Legal Foundations and Experience. RAIPON, Moscow. [In Russian]

Myksvoll, M.S., K.E. Erikstad, R.T. Barrett, H. Sandvik and F. Vikebø, 2013. Climate-driven ichthyoplankton drift model predicts growth of top predator young. PloS One, 8:e79225. doi:10.1371/journal.pone.0079225.

National Wetlands Working Group, 1988. Wetlands of Canada. Ecological Land Classification Series, No. 24. Environment Canada and Polyscience Publications.

Niehoff, B., 2004. The effect of food limitation on gonad development and egg production of the planktonic copepod *Calanus finmarchicus*. Journal of Experimental Marine Biology and Ecology, 307:237-259.

Niehoff, B., 2007. Life history strategies in zooplankton communities: The significance of female gonad morphology and maturation types for the reproductive biology of marine calanoid copepods. Progress in Oceanography, 74:1-47.

NNCA, 2015. Statistics. Norwegian National Coastal Association.

Norderhaug, K.M., H. Gundersen, T. Høgåsen, T.M. Johnsen, G. Severinsen, J. Vedal, K. Sørensen and M. Walday, 2016. Eutrophication Status for Norwegian waters: National report for the third application of OSPAR's Common Procedure.

Nordic Council of Ministers, 2011. Megatrends. TemaNord 2011:527. Nordic Council of Ministers, Copenhagen.

Nordic Council of Ministers, 2015. Arctic Human Development Report: Regional Processes and Global Linkages. Nordic Council of Ministers, Copenhagen.

Nordregio, 2009. Northern Norden: A new mining era. Journal of Nordregio, special issue, No. 3.

Norwegian Directorate of Fisheries, 2015. www.fiskeridir.no/English/Aquaculture/Statistics/Atlantic-salmon-and-rainbow-trout

Norwegian Ministry of Foreign Affairs, 2014. Norway's arctic policy: Creating value, managing resources, confronting climate change and fostering knowledge. Developments in the Arctic concern us all. Available at www.regjeringen.no/en/dokumenter/nordkloden/id2076193.

Norwegian Ministry of the Environment, 2001. Protecting the Riches of the Sea. Parliamentary White Paper No. 12 (2001-2002). Ministry of Environment, Oslo.

Norwegian Ministry of the Environment, 2006. Integrated Management of the Marine Environment of the Barents Sea and the Sea Areas off the Lofoten Islands. Parliamentary White Paper No. 8 (2005-2006). Ministry of Environment, Oslo.

Norwegian Ministry of the Environment, 2011. First update of the Integrated Management Plan for the Marine Environment of the Barents Sea–Lofoten Area. Parliamentary White Paper No. 10 (2010–2011). Ministry of Environment, Oslo.

O'Brien, W.J., M.D. Barfeld, N.D. Bettez, G.M. Gettel, A.E. Hershey, M.E. McDonald, M.C. Miller, H. Mooers, J. Pastor, C. Richards and J. Schuldt, 2004. Physical, chemical and biotic effects on arctic zooplankton communities and diversity. Limnology and Oceanography, 49:1250-1261.

Øien, N., 1993. *Lagenorhynchus* species in Norwegian waters as revealed from incidental observations and recent sighting surveys. Paper SC/48/SM15 to the IWC Scientific Committee, Aberdeen.

Øigård, T.A., U. Lindstrom, T. Haug, K.T. Nilssen and S. Smout, 2013. Functional relationship between harp seal body condition and available prey in the Barents Sea. Marine Ecology-Progress Series, 484:287-301.

Øigård, T.A., T. Haug and K.T. Nilssen, 2014. Current status of hooded seals in the Greenland Sea. Victims of climate change and predation? Biological Conservation, 172:29-36.

Olson, D.M., E. Dinerstein, E.D. Wikramanayake, N.D. Burgess, G.V.N. Powell, E.C. Underwood, J.A. D'Amico, I. Itoua, H.E. Strand, J.C. Morrison, C.J. Loucks, T.F. Allnutt, T.H. Ricketts, Y. Kura, J.F. Lamoreux, W.W. Wettengel, P. Hedao and K.R. Kassem, 2001. Terrestrial ecoregions of the world: a new map of life on Earth. Biosciences 51:933-938.

Orlova E., T. Knutsen, P. Dalpadado, V. Nesterova and I. Prokopchuk, 2014. Zooplankton. In: McBride M. M., Filin, A., Titov O. and Stiansen J.E. (eds.), IMR/PINRO update of the 'Joint Norwegian-Russian environmental status report on the Barents Sea Ecosystem' giving the current situation for climate, phytoplankton, zooplankton, fish, and fisheries during 2012-13. pp. 25-35. IMR/PINRO Joint Report Series 2014(1).

Orlova, E.L., A.V. Dolgov, P.E. Renaud, M. Greenacre, C. Halsband and V.A. Ivshin, 2015. Climatic and ecological drivers of euphausiid community structure vary spatially in the Barents Sea: relationships from a long time series (1952-2009). Frontiers in Marine Science, doi:10.3389/fmars.2014.00074

Ottersen, G. and H. Loeng, 2000. Covariability in early growth and year-class strength of Barents Sea cod, haddock and herring: The environmental link. ICES Journal of Marine Science, 57:339-348.

Overland, J.E. and M. Wang, 2007. Future regional Arctic sea ice declines. Geophysical Research Letters, 34:L17705, doi:10.1029/2007GL030808

Paetkau, D., S.C. Amstrup, E.W. Born, W. Calvert, A.E. Derocher, G.W. Garner, F. Messier, I. Stirling, M.K. Taylor, Ø. Wiig and C. Strobeck, 1999. Genetic structure of the world's polar bear populations. Molecular Ecology, 8:1571-1584.

Paliskuntain yhdistys [Reindeer Herders Association], 2014. Statistics of total number of reindeer owners, live reindeer and highest allowed number of reindeer in the reindeer herding area between the reindeer herding years 1978/79- 2013/14. Reindeer Herders' Association, Rovaniemi, Finland.

Parkinson, C.L. and D.J. Cavalieri, 2008. Arctic sea ice variability and trends, 1979–2006. Journal of Geophysical Research, 113:C07003, doi:10.1029/2007JC004558

Pashkevich, A. and O. Stjernström, 2014. Making Russian Arctic accessible for tourists: analysis of the institutional barriers. Polar Geography, 37:137-156.

Pavlov, V.K. and O.A. Pavlova, 2008. Sea ice drifts in the Arctic Ocean. Seasonal variability and long-term changes. In: Tewles, K.B. (ed.), Pacific and Arctic Oceans: New Oceanographic Research. NOVA Science Publishers.

Pavlova, O., V. Pavlov and S. Gerland, 2014. The impact of winds and sea surface temperatures on the Barents Sea ice extent, a statistical approach. Journal of Marine Systems, 130:248-255.

Pelyasov, A., 2011. The contours of the strategy for developing the Arctic Zone of Russia. Arctic. Ecology and Economy, 1:38-47. (In Russian)

Pelyasov, A. and N. Zamyatina, 2013. How institutional factors influence economic diversification of the Russian Arctic monoprofile towns (the case of two monoprofile cities in Yamal). In ERSA conference papers (No. ersa13p368). European Regional Science Association.

Pettersson, M., 2013. Renewable energy in the Arctic: Regulatory frameworks. In: Loukacheva, N. (ed.), Polar Law Textbook II. TemaNord 2013:535.

Pettersson, M., A. Oksanen, T. Mingaleva, V. Petrov and V. Masloboev, 2015. License to mine: A comparison of the scope of the environmental assessment in Sweden, Finland and Russia. Natural Resources, 6:237-255.

Petrov, A.N., 2008. Lost generations? Indigenous population of the Russian North in the post-Soviet era. Canadian Studies in Population, 35:269-290.

Petrov, N., 2017. Depopulation of Russia's Arctic North and local political development. In: Laruelle, M. (ed.), New Mobilities and Social Changes in Russia's Arctic Regions. Routledge.

Pietikäinen, S., 2003. Indigenous identity in print: Representations of the Sami in news discourse. Discourse and Society, 14:581-609.

Power, M., J.D. Reist and J.B. Dempson, 2008. Fish in high latitude Arctic lakes. In: Vincent, W.F. and J. Laybourn-Parry (eds.), Polar Lakes and Rivers, pp. 249-268. Oxford University Press.

Prokhorova, T. (ed.), 2013. Survey report from the joint Norwegian/Russian ecosystem survey in the Barents Sea August-October 2013. IMR/PINRO Joint Report Series, No. 4/2013.

Prozorkevich, D. and H. Gjøsæter, 2013. Fish community. In: Prokhorova, T. (Ed.) Survey report from the joint Norwegian/Russian ecosystem survey in the Barents Sea August-October 2013. IMR/PINRO Joint Report Series, No. 4/2013.

PwC, 2012. The Finnish Mining Industry. An overview 2012. PricewaterhouseCoopers (PwC).

PwC, 2014. Guide to Investment: Republic of Karelia. PricewaterhouseCoopers (PwC).

Rantamäki-Lahtinen, L. (ed.), 2008. Porotalouden taloudelliset menestystekijät [Reindeer management's economic success factors] MTT:n selvityksiä 156. www.mtt.fi/mtts/pdf/mtts156.pdf

Rautio, A., B. Poppel and K. Young, 2014. Human health and well-being. In: Arctic Human Development Report: Regional Processes and Global Linkages. pp. 297-346. Nordic Council of Ministers, Copenhagen.

Ravna, Ø., 2013. The First Investigation Report of the Norwegian Finnmark Commission. International Journal on Minority and Group Rights, 20:443-457.

Regional Council of Lapland, Road district of Lapland, State Traffic agency, Northern region and Road Agency [Lapin liitto, Lapin tiepiiri, Statens vägvesen, region nord and Vägverket, region norr], 2007. Pohjois-Kalotin itä-länsisuuntaisen poikittaisyhteyden tarveselvitys [The need for East-West connections in North Calotte. Liidea]. Liidea, Helsinki.

Reindriftsforvaltningen, 2015. Ressursregnskap for reindriftsnaeringe [Resource account for the reindeer husbandry industry] 2013-2014. Report, Landbruksdirektoratet. www.reindrift.no

RIAreiting, 2015. Rating of the Regions by the Level of Energy Self-Sufficiency in 2015. Accessed from http://vid1.rian.ru/ig/ratings/energodeficit012016.pdf on 18 August 2016.

Rikkonen, P., J. Kotro, K. Koistinen, K. Penttilä and H. Kauriinoja, 2013. Opportunities for local food suppliers to use locality as a competitive advantage – a mixed survey methods approach. Acta Agriculturae Scandinavica B, 63:29-37.

Rodrigues, J., 2008. The rapid decline of the sea ice in the Russian Arctic. Cold Regions Science and Technology, 54:124-142.

Roine, J. and D. Spiro, 2013. Utvinning för allmän vinning – en ESO-rapport om svenska mineralinkomster [Resource development for the common good – an ESO report about Swedish mineral revenue]. Rapport till Expertgruppen för studier i offentlig ekonomi 2013:9, Regeringskansliet Finansdepartementet, Stockholm.

Romanovsky, V.E., S.L. Smith and H.H. Christiansen, 2010. Permafrost thermal state in the polar Northern Hemisphere during the International Polar Year 2007-2009: a synthesis. Permafrost and Periglacial Processes, 21:106-116.

Russell, F.S., 1970. The medusae of the British Isles II. Pelagic Scyphozoa with a supplement to the first volume on hydromedusae. Cambridge University Press.

Rydin, H. and J.K. Jeglum, 2013. The Biology of Peatlands. Oxford University Press.

Sætersdal, G. and H. Loeng, 1987. Ecological adaptation of reproduction in northeast Arctic cod. Fisheries Research, 5:253-270.

Saher, M., D.K. Kristensen, M. Hald, O. Pavlova and L.L. Jørgensen, 2012. Changes in distribution of calcareous benthic foraminifera in the central Barents Sea between the periods 1965-1992 and 2005-2006. Global and Planetary Change, 98–99:81-96.

Sakshaug, E., 2004. Primary and secondary production in the Arctic Seas. In: Stein, R. and R.M. Macdonald, (eds.), The Organic Carbon Cycle in the Arctic Ocean. pp. 57-81. Springer.

Sakshaug, E. and H.R. Skjoldal, 1989. Life at the ice edge. Ambio, 18:60-67.

Sakshaug, E., G. Johnsen, S. Kristiansen, C. von Quillfeldt, F. Rey, D. Slagstad and F. Thingstad, 2009. Phytoplankton and primary production. In: Sakshaug, E., G. Johnsen and K.M. Kovacs, (eds.), Ecosystem Barents Sea. pp. 167-207. Tapir Academic Press.

Sametinget, 2015. Statistik Rennäring. www.sametinget.se/statistik_rennaring

Sarapää, O., T. Al Ani, S.I. Lahti, L. Lauri, P. Sarala, A. Torppa and A. Kontinen, 2013. Rare earth exploration potential in Finland. Journal of Geochemical Exploration, 133:25-41.

Sato, K., J. Inoue and M. Watanabe, 2014. Influence of the Gulf Stream on the Barents Sea ice retreat and Eurasian coldness during early winter. Environment Research Letters, 9:084009, doi:10.1088/1748-9326/9/8/084009.

Säwström, C., P.N. Mumford, W. Marshall, A. Hodson and J. Laybourn-Parry, 2002. The microbial communities and primary productivity of cryoconite holes in an Arctic glacier (Svalbard 79°N). Polar Biology, 25:591-596.

Säwström, C., J. Laybourn-Parry, W. Granélim and A.M. Anesio, 2007. Resource and temperature control of bacterioplankton and virioplankton dynamics in the Arctic freshwater environments. Polar Biology, 30:1407-1415.

Selvik, J.R. and T. Høgåsen, 2014. Source Apportioned Inputs of Nutrients to Norwegian Coastal Areas in 2013. Norwegian Institute for Water Research, Report no. 6753-2014.

Seppälä, M., 1986. The origin of palsas. Geografiska annaler, A68:141-147.

SGU, 2013. Bergverksstatistik 2012: Statistics of the Swedish Mining Industry 2012. Periodiska publikationer 2013:2. Geological Survey of Sweden (SGU), Uppsala.

Sierszen, M.E., M.E. McDonald and D.A. Jensen, 2003. Benthos as the basis food for arctic lake food webs. Aquatic Ecology, 37:437-445.

Sirenko, B.I. (ed.), 2001. List of species of free-living invertebrates of Eurasian Arctic seas and adjacent deep waters. Russian Academy of Science, Zoological Institute.

Skaret, G., P. Dalpadado, S.S. Hjøllo, M.D. Skogen and E. Strand, 2014. *Calanus finmarchicus* abundance, production and population dynamics in the Barents Sea in a future climate. Progress in Oceanography, 125:26-39.

Skjoldal, H.R. and F. Rey, 1989. Pelagic production and variability of the Barents Sea ecosystem. In: Sherman, K. and L.M. Alexander (eds.), Biomass and Geography of Large Marine Ecosystems. pp. 241-286. AAAS Selected Symposium 111, American Association for the Advancement of Science.

Skjoldal, H.R., A. Hassel, F. Rey and H. Loeng, 1987. Spring phytoplankton development and zooplankton reproduction in the central Barents Sea in the period 1979–1984. In: Loeng, H. (ed.), The Effect of Oceanographic Conditions on Distribution and Population Dynamics of Commercial Fish Stocks in the Barents Sea. pp. 59-89. Proceedings of the Third Soviet–Norwegian Symposium, Murmansk, 26-28 May 1986.

Slagstad, D. and P. Wassmann, 1996. Climate change and carbon flux in the Barents Sea: 3-D simulations of ice-distribution, primary production and vertical export of particulate organic matter. Memoirs of National Institute of Polar Research, 51:119-141.

Sletvold, O., 2006. The Norwegian Coastal Express: moving towards cruise tourism? In: Dowling, R.K. (ed.), Cruise Ship Tourism, pp. 223-231. CABI, Wallingford, UK.

Smedsrud, L.H., I. Esau, R.B. Ingvaldsen, T. Eldevik, P.M. Haugan, C. Li, V.S. Lien, A. Olsen, A.M. Omar, O.H. Otterå, B. Risebrobakken, A.B. Sandø, V.A. Semenov and S.A. Sorokina,

2013. The role of the Barents Sea in the Arctic climate system. Reviews of Geophysics, 51. http://dx.doi.org/10.1002/rog.20017.

Smith, L.C., Y. Sheng and G.M. MacDonald, 2007. A first pan-Arctic assessment of the influence of glaciation, permafrost, topography and peatlands on northern hemisphere lake distribution. Permafrost and Periglacial Processes, 18:201-208.

SMS, 2013. Handlingsplan mot skadelige fremmede arter pa Svalbard [Management plan against damaging, introduced species on Svalbard]. Office of the Governor of Svalbard.

Söderholm, K., P. Söderholm, H. Helenius, M. Pettersson, R. Viklund, V. Masloboev, T. Mingaleva and V. Petrov, 2015. Environmental regulation and competitiveness in the mining industry: Permitting processes with special focus on Finland, Sweden and Russia. Resources Policy, 43:130-142.

Squires, H.J. and E.G. Dawe, 2003. Stomach contents of snow crab (*Chionoecetes opilio*, Decapoda, Brachyura) from the Northeast Newfoundland Shelf. Journal of Northwest Atlantic Fishery Science, 32:27-38.

Stammler, F. and E. Wilson, 2006. Dialogue for development: An exploration of relations between oil and gas companies, communities, and the state. Sibirica, 5:1-42.

StatBank Norway, 2015. www.ssb.no/en/statistikkbanken

Statistics Norway, 2009. Last available energy use on a municipal basis from 2008-9. http://www.ssb.no/en/energi-og-industri

Statistics Sweden, 2008. Last available energy use on a municipal basis from 2007-8. http://www.statistikdatabasen.scb.se/pxweb/sv/ssd/START__EN__EN0203

Sténs, A. and C. Sandström, 2013. Divergent interests and ideas around property rights: The case of berry harvesting in Sweden. Forest Policy and Economics, 33:56-62.

Stepien, A., T. Koivurova and P. Kankaanpää, 2016. Changing Arctic and the European Union. Brill/Nijhoff.

Stiansen, J.A. and A. Filin, (eds.), 2008. Joint IMR/PINRO report on the state of the Barents Sea Ecosystem in 2007. IMR/PINRO Joint Report Series 2008(1).

Stige, L.C., P. Dalpadado, E. Orlova, A.C. Boulay, J. Durant, G. Ottersen and N.C. Stenseth, 2014. Spatio-temporal statistical analyses reveal predator-driven zooplankton fluctuations in the Barents Sea. Progress in Oceanography, 120:243-253.

Stjernström, O., S. Karlsson and Ö. Pettersson, 2013. Skogen och den kommunala planeringen. [The forest and municipal planning]. Plan, 1:42-45.

Strøm, H., M.V. Gavrilo, J.V. Krasnov and G.H. Systad, 2009. Seabirds. In: Stiansen, J.E., O. Korneev, O. Titov and P. Arneberg (eds.), Joint Norwegian-Russian environmental status 2008. Report on the Barents Sea Ecosystem. Part II – Complete report. pp. 67-73. IMR/PINRO Joint Report Series.

Suopajärvi, L., G.A. Poelzer, T. Ejdemo, E. Klyuchnikova, E. Korchak and V. Nygaard, 2016. Social sustainability in northern mining communities: A study of the European North and Northwest Russia. Resources Policy, 47:61-68.

Svenning, J.-C. and B. Sandel, 2013. Disequilibrium vegetation dynamics under future climate change. American Journal of Botany, 100:1266-1286.

Tande, K., 1991. *Calanus* in North Norwegian fjords and in the Barents Sea. Polar Research, 10:389-408.

Teräs, J., G. Lindberg, I.H.G. Johnsen, L. Perjo and A. Giacometti, 2014. Bioeconomy in the Nordic Region: Regional Case Studies. Nordregio Working Paper 2014:4.

The Official Karelia, 2014. The Republic of Karelia (brief information). The Official Web Portal of the Republic of Karelia. http://gov.karelia.ru/Different/karelia3_e.html. Last updated: 16 July 2014.

Toresen, R. and O.J. Østvedt, 2000. Variations in abundance of Norwegian spring-spawning herring (*Clupea harengus* L.) throughout the 20th century and the influence of climatic fluctuations. Fish and Fisheries, 1:231-256.

Turi, E.I. and E.C.H. Keskitalo, 2014. Governing reindeer husbandry in western Finnmark: barriers for incorporating traditional knowledge in local-level policy implementation. Polar Geography, 37:234-251.

Turunen, M. and T. Vuojala-Magga, 2014. Past and present winter feeding of reindeer in Finland: Herders' adaptive learning of feeding practices. Arctic, 67:173-188.

Tyler, N.J.C., J.M. Turi, M.A. Sundset, K. Strøm Bull, M.N. Sara, E. Reinert, N. Oskal, C. Nellemann, J.J. McCarthy, S.D. Mathiesen, M.L. Martello, O.H. Magga, G.K. Hovelsrud, I. Hanssen-Bauer, N.I. Eira, I.M.G. Eira and R.M. Corell, 2007. Saami reindeer pastoralism under climate change: Applying a generalized framework for vulnerability studies to a sub-arctic social-ecological system. Global Environmental Change, 17:191-206.

UNEP, 2002. Global Environmental Outlook 3: Past, present and future perspectives. Earthscan Publications.

UNEP, 2010. Convention on Biological Diversity. http://www.cbd.int/doc/decisions/cop-10/cop-10-dec-02-en.pdf

United Nations, 1982. United Nations Convention on the Law of the Sea of 10 December 1982. www.un.org/Depts/los/convention_agreements/convention_overview_convention.htm

United Nations, 1995. The United Nations Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (adopted 4 August 1995, in force as from 11 December 2001).

Van der Meeren, G.I., G. Skotte, G. Ottersen, S. Franzen, N.M. Jørgensen, A.K. Frie, S.H. Lorentsen, I. Selvik and H.I. Svensen, 2014. Barents Sea management plan – monitoring group report. Fisken og havet, No 1b-2014. (In Norwegian)

Vepsäläinen, M. and K. Pitkänen, 2010. Second home countryside. Representations of the rural in Finnish popular discourses. Journal of Rural Studies, 26:194-204.

Vikhamar-Schuler, D., K. Isaksen, J.E. Haugen, H. Tømmervik, B. Luks, T. Vikhamar Schuler and J.W. Bjerke, 2016. Changes in winter warming events in the Nordic Arctic region. Journal of Climate, 29:6201-6221.

Vincent, W.F. and J. Laybourn-Parry, 2008. Polar Lakes and Rivers: Limnology of Arctic and Antarctic Ecosystems. Oxford University Press.

Vinje, T., 2001. Anomalies and trends of sea-ice extent and atmospheric circulation in the Nordic Seas during the period 1864–1998. Journal of Climate, 14:255-267.

Vinje, T. and A.S. Kvambekk, 1991. Barents Sea drift ice characteristics. Polar Research, 10:59-68.

Walker, B.H., 1992. Biodiversity and ecological redundancy. Conservational Biology, 6:18-23.

Wassmann, P., M. Reigstad, T. Haug, B. Rudels, M.L. Carroll, H. Hop and O. Pavlova, 2006a. Food webs and carbon flux in the Barents Sea. Progress in Oceanography, 71:232-287.

Wassmann, P., D. Slagstad, C. Wexels Riser and M. Reigstad, 2006b. Modeling the ecosystem dynamics of the marginal ice zone and central Barents Sea. II. Carbon flux and climate variability. Journal of Marine Systems, 59:1-24.

Weslawski, J.M., J. Wiktor Jr. and L. Kotwicki, 2010. Increase in biodiversity in the arctic rocky littoral, Sorkappland, Svalbard, after 20 years of climate warming. Marine Biodiversity, 40:123-130.

Wessman, H., O. Salmi, J. Kohl, P. Kinnunen, E. Saarivuori and U.M. Mroueh, 2014. Water and society: mutual challenges for eco-efficient and socially acceptable mining in Finland. Journal of Cleaner Production, 84:289-298.

Wienerroither, R., E. Johannesen, A. Dolgov, I. Byrkjedal, O. Bjelland, K. Drevetnyak, K.B. Eriksen, Å. Høines, G. Langhelle, H. Langøy, T. Prokhorova, D. Prozorkevich and T. Wenneck, 2011. Atlas of the Barents Sea Fishes. IMR/PINRO Joint Report Series 1-2011.

Wrona, F.J., M. Johansson, J.M. Culp, A. Jenkins, J. Mard, I.H. Myers-Smith, T.D. Prowse, W.F. Vincent and P.A. Wookey, 2016. Transitions in Arctic ecosystems: ecological implications of a changing hydrological regime. Journal of Geophysical Research: Biogeosciences, 121:650-674.

Wulff, A., K. Iken, L.M. Quartino, A. Al-Handal, C. Wiencke and M.N. Clayton, 2011, Biodiversity, biography and zonation of marine benthic micro- and macroalgae in the Arctic and the Antarctic. In: Wiencke, C. (ed.), Biology of Polar Benthic Algae. pp. 23-52. De Gruyter, Berlin.

Wuori, O., 2013. Socioeconomic development of the Finnish countryside. In: Jyrki, N. and J. Ahlstedt (eds), Finnish Agriculture and Rural Industries. pp. 78-87. MTT Economic Research, Agrifood Research Finland.

Xu, L., R.B. Myneni, F.S. Chapin III, T.V. Callaghan, J.E. Pinzon, C.J. Tucker and J.C. Stroeve, 2013. Temperature and vegetation seasonality diminishment over northern lands. Nature Climate Change, 3:581-586.

Zabavnikov, V.B., S.A. Egorov, S.V. Zyryanov and I.N. Shafikov, 2008. About current situation with harp seal White Sea population (*Phoca groenlandica*): scientific based, complex, system. Marine Mammals of the Holarctic, 14-18 October, Odessa, Ukraine. pp. 606-609.

Zamyatina, N. and A. Pilyasov, 2016. Single-industry towns of Russia: Lock-in and drivers of innovative search. Foresight-Russia, 10:53-64.

Zhukova, N.G., V.N. Nesterova, I.P. Prokopchuk and G.B. Rudneva, 2009. Winter distribution of euphausiids (Euphausiacea) in the Barents Sea (2000–2005). Deep Sea Research II, 56:1959-1967.

3. Local and regional perspectives on adaptation

Coordinating lead author: Monica Tennberg
Lead authors: Brigt Dale, Elena Klyuchnikova, Annette Löf, Vladimir Masloboev, Annette Scheepstra
Contributing authors: Asta Kietäväinen, Päivi Naskali, Arja Rautio

Key messages

- ***Owing to its complexity it is a challenge to represent the many diverse local and regional perspectives on issues, opportunities and concerns about change in the Barents area****. Rather than generating a simple, coherent overview, examples are used to illustrate the range of perspectives present.*
- ***Research on local and regional perspectives takes three forms: community studies, indigenous knowledge and stakeholder approaches****. The current state of knowledge in and about the region is mostly based on information from particular economic sectors, nationally-organized research, and economically-defined stakeholders. There is a lack of region-specific information on adaptation issues for different age groups, for gender and for other social groupings, including those in non-traditional, urban contexts.*
- ***Community-based studies in the Nordic countries have identified a widespread lack of engagement in the development of adaptation governance, for climate change as well as for other long-term concerns****. For many stakeholders, this is partly due to a lack of capacity to participate in and influence adaptation discussions. Stakeholder research currently focuses on extractive industries, and on traditional and industrial land-use practices with a bias towards male-dominated livelihoods.*
- ***There is currently no regionally-constructed knowledge base for adaptation in the Barents area****. Framing issues in regional terms is difficult. Developing new types of partnership and network would help in the development of regionally-based knowledge. The present assessment is a step in this direction.*
- ***Establishing region-specific 'communities of practice' involving many types of knowledge producer, user and keeper, is a more interactional approach to adaptation governance than the traditional, informative and consultative approaches used to date****. Incorporating Russian actors in these networks will ensure better coverage of sub-regions and bring in new, so far mostly neglected stakeholders.*

3.1 Introduction

Comprehensive, relevant and usable knowledge is a basic requirement for the development of adaptation actions. For the Barents area (see Chapter 1 for a definition of 'Barents area'), the main issue is not a lack of knowledge, because there is a vast amount of knowledge on the changes, impacts, and adaptation needs in the region, despite considerable uncertainties (see Chapters 4 and 6). The problem is that the knowledge may be limited in terms of issues and areas covered, and may be difficult to compare and use. This chapter focuses on two issues: how much is known about local and regional perspectives on adaptation issues, and how to enhance knowledge production and better communicate existing knowledge. Knowledge, as expressed here, is based on ideas typical in social sciences: that knowledge is socially constructed, that it is situated in time and space, and that it is developed for a specific purpose. Based on a pragmatist view of knowledge, everyone has knowledge about changes and their impacts in terms of facts, values, meanings, skills, and practical and technical knowledge. But to create effective, timely and responsible adaptation governance requires co-production of knowledge in which different knowledge producers, keepers and users communicate with each other (see Chapter 9). In the Barents area, such processes are only just starting. After a brief introduction, this chapter discusses co-production of knowledge and its challenges at the local level (Section 3.2) and regional level (Section 3.3), followed by observations on the science-policy interface (Section 3.4) and gaps in knowledge (Section 3.5).

Although the focus of this chapter is local and regional perspectives of change, impacts and adaptation in the Barents area in general, many of the examples used here concern climate change adaptation. This reflects current trends in research. According to Ford and Furgal (2009), research has only recently begun to conceptualize the complexities of the human–environment interactions that shape vulnerability to a changing climate. The starting point for this chapter is the idea that knowledge is essential for the governance of adaptation: it frames the issues, relations and agencies to be governed. Production of knowledge through projects, assessments, workshops and panels is an important feature of adaptation governance (Bauer et al., 2011). Governance incorporates *vertical* interplay between levels (e.g. municipal, county, national) as well as *horizontal* interplay between different hierarchies, networks and markets. Non-state actors who often have valuable knowledge of local or sectoral issues, may play a crucial role in implementing adaptation policies and measures (Bauer et al., 2011).

In addition to adaptation strategies, plans and programs at the national level, adaptation may be advanced locally by municipalities and other non-state actors, as well as at the county/regional level in cross-border cooperation. The role of researchers, decision-makers and stakeholders may be informative, consultative or interactional. Knowledge and power are closely connected in adaptation governance, but as concluded by Vink et al. (2013) in a review of literature concerning knowledge and power in climate-related adaptation governance, the form of these connections is not yet clear ("*ambiguously understood*"). Adaptation is seen mainly as a complex system of regulatory frameworks and technical knowledge with the general assumption that these governance systems can easily adopt and use new knowledge. To date, studies have paid little attention to fluid/non-organized forms of power (i.e. negotiations and learning) and so have largely neglected the interplay between knowledge and power in adaptation governance (Vink et al., 2013).

This chapter introduces some of the major issues concerning knowledge production to support adaptation and presents examples from different parts of the Barents area (mostly Norway, Sweden and Finland) and for some of the main types of economic activity (fisheries, forestry, tourism, and reindeer herding). This approach reflects the fragmented nature of the adaptation-related knowledge base in the Barents area: it is sectoral, mostly nationally-based, and focuses on certain economically significant activities and local community concerns. Current approaches for studying local and regional perspectives comprise community studies (see also Chapter 8), indigenous knowledge (see also Chapter 7) and stakeholder perspectives (see also Chapter 5).

3.2 Local perspectives on adaptation

Although much adaptation takes place locally within the context of normal everyday activities, these are still taking place under a broader administrative, legal, political and economic framework. This makes research on connections between global and local concerns central to adaptation studies. It is addressed here from three perspectives: community-based studies (Section 3.2.1; see also Chapter 8), indigenous knowledge (Section 3.2.2; see also Chapter 7) and stakeholder perspectives (Section 3.2.3; see also Chapter 5). Participation and influence in adaptation debates is also addressed (Section 3.2.4).

3.2.1 Community-based studies

There is a long-tradition of community studies in the Arctic (Rasmussen et al., 2015), such as those based on communities relying on reindeer husbandry, fisheries or forestry. The result is a growing knowledge base in the Arctic on indigenous peoples and their communities, particularly those in North America, and to a lesser extent Russia and the Nordic countries, mostly in rural contexts and in relation to land-based and resource-dependent activities (Ford et al., 2015). However, community studies in the Arctic are challenging for several reasons: identifying the focus of the research is difficult because the community is itself a contested concept; communities show high diversity in terms of economic, political and administrative structures; and communities vary widely in how they cope with internal and external processes (Rasmussen et al., 2015).

One of the main findings of community-based studies in the Nordic countries is the 'laissez-faire' attitude to climate change issues. Studies on adaptation, especially in relation to climate change, show local actors find it extremely difficult to reach consensus on how to move forward (Ronkainen, 2008; Storbjörk, 2007, 2010; Hovelsrud et al., 2013; Wamsler and Brink, 2014; EVA national Survey, 2015). This is partly because many people perceive themselves as resilient and able to adapt to challenges they are faced with, mainly because they always have (see Chapter 8 for discussion on resilience). These perceptions of individual and local resilience are closely linked to high natural variability in the resource base and to climatic and societal conditions. Although this perceived resilience can advance a community's ability to adjust available resources within a community (one dimension of community resilience), it may also cause complacency and a system in an undesirable state (Hovelsrud et al., 2015). Another explanation for the complacent attitude is the urgency of other issues. In Norway, new and more urgent responsibilities for municipalities over the past few years has meant that efforts to curb the consequences of climate change – still not perceived as pressing and immediate – are postponed (Dannevig et al., 2013). This is also the case on the Kola Peninsula in Russia: climate change and the measurable effects of rising temperatures in the Arctic appear to be taking second place to the challenges of population decline, declining labor needs, and an aging infrastructure (Johansen and Skryzhevska, 2013). Municipalities are responsible for developing their own adaptation measures. Planning departments responsible for adaptation in smaller municipalities generally concentrate their efforts on mandatory commitments; such that if there is no regulatory requirement for adaptation then it receives a lower priority than tasks that *must* be achieved. It also matters that locally, climate change issues are often identified as 'environmental issues' and thus the responsibility of environmental authorities, when in fact many of the issues are more effectively handled by departments responsible for municipal infrastructure, technology and maintenance. Other factors are also important for adaptation governance at the local level: enough resources, capacity to seek external expertise, involvement in municipal networks related to climate change issues, and engaged individuals with dedicated positions to deal with such issues (Dannevig et al., 2013).

3.2.2 Indigenous knowledge

The role of local and indigenous experts and their knowledge (perceptions, skills and practical knowledge), is widely recognized in the Arctic but still the debate continues in terms of finding the means and tools to support their participation and representation in adaptation research. National decision-makers are often considered 'out of touch' with local reality and have little knowledge of local conditions, while indigenous communities and livelihoods are highly exposed to ongoing and anticipated changes, and so their active involvement is essential for understanding and addressing local challenges (Riseth et al., 2011; Löf et al., 2012; Löf, 2013; Rosqvist and Inga, 2015). In fact, indigenous peoples facing unprecedented impacts on their traditional lifestyles primarily through climate change and resource development (oil and gas, mining, forestry, hydropower, tourism, etc.), are already implementing creative ways of adapting (Cruikshank et al., 2001; Oskal, 2008; see also Aleynikov et al., 2014).

Raising the importance of indigenous knowledge will in itself emphasize its importance to government decision-makers, while also identifying constraints owing to the asymmetrical power relations as in, for example, reindeer management systems (Turi and Keskitalo, 2014). Collaboration between researchers and practitioners in reindeer research goes back to late 1990s (e.g. Müller-Wille and Hukkinen, 1999; Forbes et al., 2006; Smit and Wandel, 2006; Ensor and Berger, 2009; Vuojala-Magga et al.,

Philip Burgess

Inside the Lavvu, Finnmark county, Norway

2011; Turunen et al., 2016), especially indigenous knowledge keepers and communities (Tyler et al., 2007; Eira et al., 2008; Oskal et al., 2009; Ford et al., 2012; Nakashima et al., 2012; Löf, 2014). For reindeer herders, it is not the *direct* effects of climate change that are the main problem, since herders have always adapted to a changing environment and are masters of living with uncertainty; a capacity made possible through inherent flexibility and diversity of pastures, landscapes, economy, and herding practices; social and organizational networks; and mobility (Tyler et al., 2007; Vuojala-Magga et al., 2011; Löf et al., 2012; Horstkotte, 2013; Brännlund, 2015). Rather, the problem lies in the restricted opportunities for adaptation, socio-economic challenges, and the cumulative impacts of multiple drivers. These include loss of land and forage to other land uses, increasing predation, rising costs, poorly recognized indigenous land rights, and limited influence over other land uses and in governance systems (Forbes et al., 2006; Tyler et al., 2007; Rees et al., 2008; Oskal et al., 2009; Furberg et al., 2011; Klokov, 2012; Pape and Löffler, 2012; Arctic Council, 2013; Löf, 2013, 2014; Reinert and Benjaminsen, 2015). Being able to adapt is thus not just a desirable and historically defining trait of reindeer herding; it is also an illustration of how power is currently dispersed among different actors (Löf, 2013, 2014) and that in many instances, national priorities reflected in new legislation and administrative practices seem to take precedence over indigenous rights. This was certainly the case in several mining development cases over the past decade (Herrmann et al., 2014; Stefansdottir, 2014; Tuusjärvi et al., 2014; Nygaard, 2016).

3.2.3 Stakeholder perspectives

Another popular approach developed in recent years is research on stakeholder perspectives in different economic sectors (Stępień et al., 2016). In terms of the forestry sector in Sweden, the industry itself is diverse and is characterized by multiple stakeholders and users. The strategies used for addressing the direct and indirect impacts of climate change differ widely. For example, some strategies focus on how forests can sequester carbon and replace fossil fuels as a source of energy, whereas others focus on concerns about increasing competition for land and matters regarding multiple land use, justice and rights (Beland Lindahl and Westholm, 2011). An awareness of the need to integrate adaptation is slowly awakening within the industry, and although many report a lack of knowledge and information on how to adjust forest management practices, preliminary results indicate a high degree of willingness to adapt among forest owners (Andersson et al., 2015; Ulmanen et al., 2015). The role of markets, and regulatory and governance systems has been emphasized both by forestry and reindeer husbandry actors (Keskitalo, 2008).

An example of one such processes is the *Future Forests* research program (2009–2016), under which several visionary workshops were held with different stakeholder groups (nature conservation, recreation and local development, forestry and energy, and Sami industries) about future developments in Swedish forestry. Although an analysis has not yet been published, reports from the workshops are available. Forestry and energy stakeholders envisioned forestry as a continued foundation for the Swedish economy where market-based certification systems were adapted to allow a more flexible and diverse forestry sector that accommodates different stakeholder interests and public values. Emphasis was placed on technological development in both information tools and fast-growing tree species that could benefit from warmer conditions (Mossberg Sonnek et al., 2014). Other stakeholders emphasized the need for increased local influence over forestry practices and better opportunities for dialogue and collaboration, as well as more diversified forestry and forests. Forest management would ideally occur at the landscape level and there would be a ban on introducing non-native species. Sami representatives envisioned a future where Sami indigenous rights are protected, recognized and safeguarded and where Sami influence over forestry was increased considerably and was based on the principle of free prior and informed consent (Räty et al., 2014). The Swedish forestry case illustrates a dichotomy between increased production (mitigation and adaptation) and a balancing of multiple uses. In a preparatory study for the development of a new national forest program, key forestry stakeholders identified the need for a more coherent policy coordination (see also Wyser and Jonsson, 2014; and Nilsson et al., 2012 for a general discussion) and the development of more holistic perspectives; achieved by including more stakeholders and interests, and so increasing participation from different levels. How to enhance dialogue, collaboration and conflict management is thus a key priority (Skogsstyrelsen, 2013; see also Sandström and Widmark, 2007).

3.2.4 Power and participation

The lack of engagement noted at the local level (see Section 3.2.1) is not only a question of perceived adaptive capacity and resilience, but also a question of participation and influence in adaptation debates. Decision-making processes involve a range of issues (e.g. representation of stakeholders and rights holders, scientific knowledge, traditional knowledge, and organizational structures): who will be among those whose concerns are heard in the decision-making? In the case of new mining activities in northern Norway, local inhabitants participate in a hearing process, the results of which are then added to the knowledge base that underlies the decision-making process. This aims to ensure that the decision-making is democratic and representative; for legitimization purposes it is important that the process is inclusive. However, it has been argued that, in practice, many local and regional stakeholders are prevented from taking part by the time-frames, the disclosure and publication of deadlines, and the need for a specific level of technical skills and scientific knowledge. As noted by Dale (2016), "*…the focus on scientifically based knowledge and logics necessarily excludes groups, viewpoints and types of knowledge deemed 'unscientific' or 'based on emotions or idealism*'". Individuals that are unable to understand the language of techno-scientific reasoning will also be excluded (Dale, 2016:12).

Similar concerns have been raised in Russia regarding the participation of indigenous peoples on the Kola Peninsula in decision-making associated with energy-related industrial development. Although formal procedures for environmental impact assessment exist, which include ways to incorporate the views of the indigenous population (such as public hearings), how these are implemented seems to vary on a case-by-case basis (Vinogradova and Masloboev, 2015; See also Koivurova et al., 2015). The Norwegian state and the petroleum industry have attempted to include as many stakeholders and views as possible in discussions concerning petroleum-driven development and its local impacts (Knol, 2010; Dale, 2011), in line with the ideal of participatory governance. However, at the same time, they state that certain overarching goals and definitions are 'non-negotiable' with the consequence that particular values and knowledge cannot be supported. This happens through processes where pre-defined assumptions about development and sustainability are reproduced, for instance in the form of a 'fairytale' about petroleum development in Norway (Kristoffersen and Dale, 2014). Another strategy for restricting discussion is to repeat that certain goals and processes are 'beyond debate' (Dale, 2016), obtainable precisely because of the development of the petroleum industry; the securing of "*… a qualitatively improved society (… based on …) equality and welfare, frugality and austerity*" (Thesen and Leknes, 2010:54 our translation). A lack of attention to climate change in these energy-related debates is striking, given international commitments to stabilize atmospheric greenhouse gas concentrations and so prevent dangerous human-induced interference with the climate system (UNFCCC, 2015). In fact, Norwegian High North policies do not acknowledge a connection between human-induced climatic changes having opened up the Arctic for petroleum development, and increased greenhouse gas emissions as a result of this development (Jensen, 2012; Kristoffersen, 2014).

Stakeholder research largely focuses attention on extractive industries, and traditional and industrial land-use practices with a bias towards male-dominated livelihoods. However, in principle, the concept of 'economic stakeholder' includes a wide range of different actors, with different aims, scopes and interests – some vested in a particular community or region, others less so. They hold practical as well as technical knowledge relevant for adaptation, and represent various types of resource (e.g. skills, manpower, finances), power and capacity to deal with adaptation. Stakeholders in the Barents area include: political leaders; authorities from different levels of administration; representatives of governmental and non-governmental bodies, and indigenous peoples; small and large businesses inside and outside the region (including practitioners of natural resource based industries such as reindeer herding, fisheries and farming); educators and researchers; and many others, including individual citizens, the youth, the elderly and women, and urban inhabitants in general. There is thus a need to better define who stakeholders in adaptation are, as well as to examine the ways in which their perspectives can be better incorporated into adaptation studies. While the importance of including local, indigenous and regional perspectives has been increasingly recognized, public participation has been sometimes poor. This was the case for the project *Integrated Climate Change Strategies for Sustainable Development of Russia's Arctic Regions: Case Study for Murmansk Oblast* (Berdin et al., 2009). The report was prepared by experts from the United Nations Development Programme (UNDP) without having had any consultation with regional stakeholders, and with only one of the experts a regional representative working out of the Kola Science Center.

A potential area for consideration in the new regional partnerships between research, stakeholders and decision-makers is human health and gender studies. According to the

Nordic Council of Ministers (2015), men, women and different age groups (the youth and the elderly), are not affected equally by the changes taking place in the Arctic. In the Barents Region, human-health experts and stakeholders have collaborated since the early 1990s to exchange information and experiences, develop research projects and build competence in the public sector working with health, youth and gender issues. This has taken place under, for example, the Barents Working Group on Health and the EU Northern Dimension Partnership in Public Health and Social Well-being (NDPHS). Gender studies have also had a long tradition in the Barents Region, starting from the Nordic-Russian Femina Borealis network in the early 1990s and then projects on crisis centers in the Barents Region (Saarinen). Gender research cooperation has been included within the TUARK-network (*Tromsö-Umeå-Archangelsk-Rovaniemi-Kingston Network on Gender Equality in the Arctic*). Research on the wellbeing of elderly people was addressed in the project *Arctic Change and Elderly Exclusion: A gender-based perspective* (Naskali et al., 2016). This cooperation continues within the project *Advancing Elderly People's Agency and Inclusion in the Changing Arctic and Nordic Welfare System*.

3.3 Regional perspectives on adaptation

This section examines regional perspectives on adaptation, including the lack of a regionally-constructed knowledge base for adaptation, the difficulty of framing issues in regional terms, and the need to develop new types of partnerships and networks to develop regionally-based knowledge. As noted by Ford et al. (2015), "*Although these local responses represent important developments, adapting to future change will require broader-level action to address both generic and specific capacities to adapt in the context of ongoing social, economic, political, demographic and environmental change. There is evidence of this happening in some locations, although a coherent vision and framework for approaching adaptation is largely absent.*" The present assessment is a step in this direction.

There have been some previous efforts to produce a regional approach to adaptation issues in the Barents Region. The need for science to communicate with stakeholders was recognized at an early stage in regional climate change research (Lange and BASIS consortium, 2003; Lange et al., 2008). As part of the BALANCE project, Keskitalo (2008) held extensive interviews with stakeholders and knowledge keepers (reindeer herders, forestry professionals, fishers) to identify their concerns about climate change and globalization. The EU has encouraged the involvement of stakeholders in research.

Change in the Barents area has also been assessed within several EU projects, including an assessment of the EU's current and future footprint on the Arctic environment (Cavalieri et al., 2010) and an assessment of EU development in the Arctic (Stępień et al., 2014). Several knowledge and communication needs were identified in this process (Tedsen et al., 2014).

In 2015, the EU initiated EU-PolarNet. Among other things this project aims to establish an ongoing dialog between policy-makers, business and industry leaders, local communities and scientists to increase mutual understanding and identify new ways of working that will deliver economic and societal benefits. The outcome of this dialog will be brought together in a plan for an Integrated European Research Programme that will be co-designed by all relevant stakeholders. That the EU has a strong focus on stakeholder engagement in the Arctic is also evident from their new integrated policy for the Arctic (European Commission, 2016). Further development of EU Arctic policy will focus on three key areas: supporting research and channeling knowledge to address environmental and climate change in the Arctic; acting responsibly to ensure economic development in the Arctic is based on sustainable use of resources and environmental expertise; and strengthening engagement and dialog with Arctic states, indigenous peoples and other partners (Stępień and Raspotnik, 2016).

3.3.1 Adaptation in the Barents study area

The Barents Region formally began in 1993 with the establishment of the Barents Euro-Arctic Council (BEAC) and the Barents Regional Council. The BEAC is the forum for intergovernmental cooperation on issues such as security and sustainable development in northern Europe. Knowledge production is an essential element of this development (Tunander, 2008). However, there appears to have been a marked dichotomy in developing Barents-specific information for decision-makers. Regionally-based knowledge has mainly served projects on specific topics such as human health, transport and environmental hotspots, establishing short-term collaboration among knowledge producers and focusing more on some sub-regions than others. This is very different to the Arctic Council process. Since the early 1990s, the Arctic knowledge base has been developed through assessments aimed at identifying common concerns for cooperation, and through networks and partnerships formed to support regional knowledge production within the framework of the Arctic Council and other outside bodies, such as the University of the Arctic network (Tennberg, 1998; Keskitalo, 2004; Nilsson, 2007).

Although the BEAC region is part of the Arctic area of cooperation, many of the Arctic Council assessments do not follow a regional logic, but instead pursue particular themes concerning *Arctic* development. Without a specific regionally-focused approach to producing targeted knowledge, effective action is difficult. The BEAC region does not, for instance, appear as a unit of analysis or description in recent assessments of Arctic change (Statistics Norway, 2006, 2009; Aslaksen et al., 2010; Nordic Council of Ministers, 2011, 2015), while the Arctic Climate Impact Assessment (ACIA, 2005) and the Arctic Marine Shipping Assessment (Arctic Council, 2009) did adopt a regional approach. Table 3.1 compares differences in knowledge production within the Arctic Council and BEAC.

Climate change emerged on the BEAC agenda in the early 2000s, expanding the agenda to cover region-wide issues instead of Russian only concerns. According to Sreejith (2009), there have been two main approaches in terms of Barents cooperation on climate change: to raise 'impact awareness' through identification of threats and risks; and 'a solution approach' referring mostly to mitigation action. More specific issues for regional cooperation on climate change have now been identified, such as water resources, human health, transport, and nomadic reindeer herding. The need to increase understanding of climate change issues and for further regional adaptation

Table 3.1 Knowledge production in the Arctic Council and the Barents Euro-Arctic Council (BEAC).

	Arctic Council	BEAC
Role of knowledge	Identifying common issues for regional cooperation through knowledge-building	Specific issues of concern, especially related to Russia: development of transport network, tourism and dealing with environmental hotspots
Networks and partnerships	Continuous processes of scientific assessment, establishing networks and partnerships between different knowledge producers	No long-term networks and partnerships for knowledge production – short-term, project-based cooperation on certain issues
Rationale in knowledge production	Defining the object, relations and agencies in collaboration	Identifying practical action and funding needs
Regional focus	In most cases the entire circumpolar region, with some local and regional examples	Focus on Russian part of the Barents study area

measures was reflected in *An Action Plan on Climate Change in the Barents Region* adopted by BEAC in 2013. The Action Plan contains a number of different projects under the headings *Mitigation, Adaptation, Research, observation, monitoring and modelling and Outreach* and its aim is to learn from county-level climate strategy processes in different parts of the region, and to support regional climate-strategy making in the Russian part of the Barents study area. The expectation is that the action plan "*may contribute positively to national goals*" (Norwegian Ministry of the Environment, 2013). In the Barents Program (2014-2018) (Barentsinfo, 2013), multiple connections of change are identified – both climatic and socio-economic – in regional development and cooperation.

Approaches in adaptation governance differ across the Barents area. Municipalities in Sweden and Norway have a responsibility for adaptation while the approach in Finland and Russia is more regional (see Chapter 9). In the Nordic countries, the work on county-level climate strategies began in the late 2000s while this type of strategy work is still at an early stage in the Russian parts of the Barents area. According to an analysis by Sorvali (2015) based on information available from different countries, mitigation dominates over adaptation in their strategies and action plans. In the Nordic countries, regional strategies are mostly in place, but recent information on progress with implementation is lacking. Adaptation strategies also differ in their approaches at the regional and local level. The Nordic experience is that when a sub-regional climate strategy exists, climate change issues are incorporated into other policy documents and some implementation processes then follows. But it is often the case that vulnerability assessment or adaptive measures are either not included or are at very early stages of development, and the assessments are developed at a national level and mainly concern economic sectors.

There are many lessons to be learned from these county-level processes in terms of knowledge provision for adaptation. According to Sorvali (2015) and Himanen et al. (2012), regional and local level strategy work is often supported by national policies and coordination. In many cases, outside funding (for example from EU programs) supports regional climate strategy work in its early stages, but proves an obstacle in the implementation phase if there is a lack of funding for implementation. Another issue is that the strategy work is led by experts and consultants without ownership and commitment from the municipal or regional body responsible for the issue once the funding ends. The local and regional politicians concerned should be considered an important stakeholder group, as should the institutions responsible for securing the involvement of indigenous groups. A particularly challenging group to bring into regional climate strategy processes are businesses. This is due to their difficulty in seeing how meeting climate challenges could concern their own everyday work and because their attention is often fully engaged with more immediate matters. Despite all this, those that have taken part in regional climate strategy processes, have said that they found them a good learning experience, even though time-consuming. International cooperation (especially for Russian regions) has also proved important.

The BEAC working group that developed the climate action plan (Tennberg, 2015, 2016), found the most useful way to disseminate climate information was using maps. Regional and local decisions-makers also need economic analyses of costs and benefits of adaptation measures as well as statistical information with which to assess progress between the sub-regions on their implementation of climate strategies; better access is also needed to Russian information on various issues. Information needs to become more available and more accessible (see also Chapter 10). One example of how this could happen is a website developed by research institutes in Finland (www.climateguide.fi). This pools information in a uniform format at a single site, on mitigation as well as adaptation, and provides municipalities with concrete examples of appropriate measures in an interactive way. Such a tool would also be useful on a regional basis.

3.3.2 Framing issues regionally

The challenge of developing a region-specific knowledge base is twofold: Adaptation is a complex issue and the Barents area is a complex region. The scale of the complexity became clear at the stakeholder event organized by the AACA Barents project team on 12 March 2015 in Rovaniemi, Finland. The event was part of a series of four stakeholder meetings in Finland to discuss AACA topics – drivers of change, their impacts, and adaptation – involving local, regional and national stakeholders. Two events took place in Rovaniemi (March and November 2015) and two in Helsinki (February and December 2016). The events were organized to support the drafting of a national report on adaptation for the AACA process (Tennberg et al., 2017) (stakeholder activities within the AACA process are also discussed in Chapter 5).

One of the Finnish stakeholder meetings was held in association with the Arctic Business Forum with the aim of reaching

Table 3.2 Stakeholder views on adaptation as a complex issue (Nikula et al., 2015).

	Discussion points
Nature of change	Many changes including changing climatic conditions for winter tourism, dependence on seasons and client expectation
	Large-scale industrialization affects local companies and communities in different ways. More resources are needed for development of infrastructure and services
	Concerns about the future of local cultures and community viability
	Access and ownership to natural resources remains a highly debated issue in the region
	For business actors, participatory management, corporate social responsibility, increased transparency of corporations and digital economy and infrastructure are important
Impacts of change	Climate change was seen as a long-term driver of change, including changes in snow and ice cover as well as in growth seasons, permafrost thaw and extreme weather events, such as storms and floods
	Climate change also affects global political and economic structures; political and legal developments; demographic changes, increasing global resource demand, population growth, decrease in traditional resource based industries and growth of new industries, accessibility to the region, including virtual and physical access and development of infrastructure
Agency and responsibility	Most participants recognized that they were already undertaking some adaptation themselves, especially in relation to economic development and employment, and knew of some adaptation policies and their effects on their activities or in their sector
	Adaptation was seen by many as a shared and negotiated responsibility to which everyone needs to participate but the role of the government, business and extractive industries was stressed
	It was pointed out that small companies have to adapt to changing conditions all the time: it is necessary for their survival. Adaptation is based both on a need and a responsibility to adapt

business stakeholders. The Arctic Business Forum is an annual event organized by the Lapland chamber of commerce to discuss economic development and opportunities in the region among business actors. Owing to the small number of participants representing this stakeholder group – only seven of 20 participants in total, and mostly representing small and medium-sized enterprises (SMEs) – the discussions became more general. The 13 non-business participants were students from the University of Lapland, Arctic Centre staff members and AACA researchers. It is notable, however, that many of the researchers had some practical, small-scale business experience. Table 3.2 presents the main discussion points, together with a condensed summary of the opinions expressed during the event. Before the discussion with stakeholders took place, participants were provided with an overview of the AACA project and the changes expected, as well as likely impacts and adaptation concerns. Participants were also given plenty of opportunity to discuss their own concerns.

The central lesson from the stakeholder event was that stakeholders interpret adaptation concerns and needs in very different ways; reflecting their background, education and professional expertise. The event identified a broad range of adaptation-related concerns as well as different ideas of how to tackle them. For participants, the Barents area was only one of the possible spatial references; they also referred to Lapland, Finland, the European Arctic or the Arctic in general. The other three stakeholder events in Finland had more-or-less the same outcome. Thinking in terms of specific time frames, such as 2030 (to represent the short term) and 2080 (to represent the long term) proved difficult; most participants found it easier to think in terms of one or two generations into the future.

Some common issues are difficult to define for a regionally-constructed knowledge base, primarily because issues are complicated and often connected to broader political and economic considerations beyond the region itself. For example, ecological shifts within the Barents Sea have various biological causes, such as changes in fish reproduction, distribution, and movements (see Chapter 6). These changes may be of economic significance: How much fish will be caught? In which country will the fish be landed? How will commercially important stocks be distributed within the waters of two or more states? As a result, these changes could affect relations between states within the context of the economic, legal and political settings of the fisheries (e.g. for marine transportation, and offshore oil and gas development). Thus, assessment of adaptation practices in the fishery sector is also linked to the planning of resource use, market and trading mechanisms, emergency preparedness, insurance and social safety schemes, infrastructure capacity and flexibility, and food security (Stammler-Gossmann, 2013).

The nature of a change and its direction are also important, but may be interpreted differently by different stakeholders. For example, regional and local stakeholders may interpret the same change as positive or negative depending on the time perspective. This is the case for tourism in the Barents area (Brouder and Lundmark, 2011; Kelman et al., 2012). In Finland, to continue winter activities in the face of ever shorter winters and later snow cover, require adjustments by the tourism industry, for example storing snow or creating artificial snow. Although such responses might be appropriate in the short term, they are questionable from the perspective of long-term and sustainable adaptation (Kietäväinen and Tuulentie, 2013). In Norway, cruise tourism in Lofoten is seen by many as an integral part of the local economy. The question here is how to deal with the complex challenges posed by the growing number of tourists and their impacts on the fragile Arctic environment. The question is how to achieve a sustainable use of the natural landscape over time and so provide a sustainable basis for community development.

Some issues are governable from a regional perspective and some are not. For example, as global markets fluctuate, communities, livelihoods and even countries relying on natural resources are vulnerable to changes beyond their control. Until recently, projections of the future were typically based on scenarios built using development trends of the past few years (e.g. Bjørnsen and Johansen, 2012). The situation now is very different and one where the recent past may tell very little about what the future will bring. The boom-and-bust scenarios feed into concerns across the region about the extent to which communities should rely on the extractive industries for their long-term sustainability, or whether these should be supplemented by others to form a more versatile and adaptable economy (Dale et al., in press). The same concerns affect those actors whose financial capital is tied to the production facilities; put simply, if investments fail to raise the expected surplus, global actors may consider relocating to other geographical locations. Challenges relating to what might happen when a resource is exhausted or revenues dry up can be seen in Longyearbyen on Svalbard; a town now totally dependent on the operation of a (state-subsidized) coal mine. As prices – and political popularity – plummet, the community finds itself in need of a new basis upon which to secure its future; hence, initiatives to spur new developments, such as in tourism and research. Although the Norwegian state has again guaranteed a certain level of activity in the mines, the future of the extractive industry in Svalbard is uncertain; coal is very likely to become a stranded asset owing to international climate commitments. The local community – traditionally a mining community – will need to engage in this transition if they are to ensure a sustainable future; for a mining community to build a truly sustainable post-carbon future will represent an enormous challenge (Regjeringen, 2009, 2016).

3.4 Science-policy interface

Joint problem-solving processes, including new networks and partnerships (Wenger, 1999) between knowledge producers and keepers and 'knowledge brokers' (Nilsson, 2007), are needed to advance social learning and action. The idea of creating long-term participation partnerships is an example of the trend towards a stronger participatory component than has been the case with traditional informative or consultative approaches. In 'communities of participation' or 'communities of practice', stakeholders from the most powerful to the marginalized can enter into dialog with policy-makers, experts and each other (World Bank, 2005).

From a science-policy interface perspective, knowledge is socially constructed, situated in time and place, and created in a range of forms. Comprehensive, relevant and usable knowledge is needed at all levels of adaptation action in the Barents area – local, county, national and regional – to frame adaptation as a salient issue for decision-makers and stakeholders. Regional adaptation governance is still in the early stages of development and to construct a regionally-focused knowledge base requires *communities of practice*, incorporating researchers, decision-makers and stakeholders. To enable knowledge sharing within these communities requires user-friendly tools, databases, maps, and statistics. The next step, transforming knowledge into action, is not straightforward. Adaptation is a social process in which knowledge is communicated and negotiated through various media and used in different ways in complex unpredictable political processes, taking place within the context of ever changing political and economic situations, constraints and opportunities. Issues of power are also at play: As well as taking part in governance process it is important to ensure that stakeholders are able to influence the knowledge base upon which political decisions affecting their and their communities' future are to be made (Dale, 2016).

Knowledge production and communication can be supported by: developing better ways to integrate (or interact with) local knowledge into research and decision-making, including by establishing and/or strengthening communities of practice; furthering the development of region-specific activities and organizations, including knowledge brokers; better communicating existing information in more user-friendly and usable forms; accepting that a simple but all-encompassing knowledge-policy interface is not available; and adopting specific approaches to engage the most vulnerable, underrepresented and marginalized groups.

3.5 Summary and concluding comments

This chapter examines current approaches for studying local and regional perspectives of change and implications for regional knowledge production, such as this assessment of the Barents area. There are three main approaches: community studies, indigenous knowledge and stakeholder approaches. These show a strong focus on economically important, gendered, industrial and rural activities, nationally-based research and emphasis on policy relevance and development. However, adaptation is a broad social process covering societies, activities and local actors beyond male-dominated, industrial, rural or indigenous communities (see Ford et al., 2012, 2015). This indicates the need for a broad understanding of the cumulative nature of changes and their impacts, balancing short- and long-term sustainability considerations, and issues of governability and agency. To capture the complex nature of changes, impacts and adaptation needs, this chapter concludes by proposing that the way forward is to develop an interactional model for science-policy interface that builds on 'communities of practice' as multidisciplinary networks and partnerships between knowledge producers, keepers and users, as well as 'knowledge brokers' to translate knowledge between different fields of society. To support the implementation of adaptation plans, strategies and programs at municipal, county, national and regional level, knowledge is required in a unified, usable and relevant form. This could take the form of indicators (see resilience indicators in Chapter 8), comparable statistics, maps (see GLOBIO maps in Chapter 7), and various other tools, such as internet portals for knowledge sharing, presenting and discussing best practice, and supporting the development of adaptation governance.

The diversity of livelihoods, peoples and activities in the Barents area make it difficult to represent the concerns, expectations and views of stakeholders in a simple, coherent and unified view. The perceptions of changes and their impacts, and the possibilities for adaptation, are all equally real to those experiencing them. The importance of involving a range of stakeholders in research projects, planning processes and strategy development is therefore clear. Local and regional stakeholders are both knowledge providers, producing information in different forms (facts, values, perceptions and interpretations), and important as co-producers and users of knowledge within communities of practice.

Several factors currently limit an understanding of local and regional perceptions of changes and adaptation needs in the

Barents area: (1) a lack of good data collection and research methods; (2) the diversity of perspectives across the region and within groups and sectors, makes it virtually impossible to develop a single view of changes and adaptation needs; (3) ambiguity in the adaptation problems; (4) interpreting changes and assessing adaptation needs is often challenging for local and regional actors; (5) multiple – and not well understood – global and regional drivers of change; (6) ambiguity and uncertainty regarding economic trends and the effects of globalization in the Arctic; (7) governance systems are complex, with many decisions beyond the control of single actors; (8) existing participatory governance frameworks lack credibility; and (9) differences in power, in terms of resources and capacity to participate and influence social process of adaptation.

References

ACIA, 2005. Arctic Climate Impact Assessment. Cambridge University Press.

Aleynikov, A.A., A.M. Aleynikova, M.V. Bocharnikov, P.M. Glazov, P.P. Golovlev, V.O. Golovleva, G.V. Gruza, K.O. Dobrolyubova, A.I. Evina, P.I. Zhbanova, D.G. Zamolodchikov, E.A. Zenin, Y.A. Kalashnikova, M.N. Kozhin, A.O. Kokorin, I.V. Krylenko, I.N. Krylenko, Y.V. Kushcheva, O.N. Lipka, I.A. Miklyaev, I.M. Miklyaeva, V.V. Nikiforov, A.D. Pavlova, A.I. Postnova, M.A. Puhova, E.Y. Ran'kova, M.S. Stishov, O.K. Sutkajtis, S.A. Uvarov, S.Y. Fomin and S.F. Hohlov, 2014. Vaigach Island: Nature, Climate and People. Lipka O.N. (ed.). WWF-Russia. (In Russian). www.wwf.ru/resources/publ/book/964

Andersson, L., A. Bohman, L. van Well, A. Jonsson, G. Persson and J. Farelius, 2015. Underlag till kontrollstation 2015 för anpassning till ett förändrat klimat. [Supporting documents to the inspection post 2015 for adaptation to a changing climate] Swedish Meteorological and Hydrological Institute. SMHI Klimatologi No. 12. [In Swedish with English summary]

Arctic Council, 2009. Arctic Marine Shipping Assessment 2009 Report.

Arctic Council, 2013. Arctic Resilience Interim report 2013. Stockholm Environment Institute and Stockholm Resilience Centre.

Aslaksen, I., A. Caron, G. Duhaime, S. Glomsröd, J. Haukur Ingimundarson, I. Jonsson, J. Kruse, J. Nymand Larsen, S. Mathiesen, A. Ingeborg Myhr, B. Poppel, R. Ole Rasmussen, H. Reinert, E. Reinert, C. Southcott, G. Winther, L. Zalkind and H. Aage, 2010. The Political Economy of Northern Regional Development. TemaNord 2010:521. Nordic Council of Ministers, Copenhagen.

Barentsinfo, 2013. The Barents Programme 2014-2018. www.barentsinfo.fi/beac/docs/Barents_Programme_2014_2018_adopted_2_June_2013.pdf

Bauer, A., J. Feichtinger and R. Steurer, 2011. The governance of climate change adaptation in ten OECD countries: Challenges and approaches. Institute of Forest, Environmental, and Nature Resource Policy. Discussion Paper 1-2011. www.wiso.boku.ac.at/fileadmin/data/H03000/H73000/H73200/InFER_Discussion_Papers/InFER_DP_11_1__The_Governance_02.pdf

Beland Lindahl, K. and E. Westholm, 2011. Food, paper, wood, or energy? Global trends and future Swedish forest use. Forests, 2:51-65.

Berdin, V.H., D.A. Gershinkova, Y.S. Dobrolyubova and V.A. Masloboev, 2009. Kompleksnye klimaticheskie strategii dlja ustojchivogo razvitija regionov rossijskoj Arktiki v uslovijakh izmenenija klimata: model'nyj primer Murmanskoj oblasti [Integrated Climate Change Strategies for Sustainable Development of Russia's Arctic Regions Case Study for Murmansk oblast]. United Nations Development Programme & Russian Regional Environmental Centre, Moscow.

Bjørnsen, H.M. and S. Johansen, 2012. Samfunns- og næringsanalyser for Svalbard 2012. NIBR-rapport 2012:24.

Brännlund, I., 2015. Histories of reindeer husbandry resilience: Land use and social networks of reindeer husbandry in Swedish Sápmi 1740-1920. Doctoral Thesis, Centre for Sami Research. Umeå University, Sweden.

Brouder, P. and L. Lundmark, 2011. Climate change in northern Sweden: intra-regional perceptions of vulnerability among winter-oriented tourism businesses. Journal of Sustainable Tourism, 19:919-933.

Cavalieri, S., E. McGlynn, S. Stoessel, F. Stuke, M. Bruckner, C. Polzin, T. Koivurova, N. Sellheim, A. Stepien, K. Hossain, S. Duyck and A.E. Nilsson, 2010. EU Arctic Footprint and Policy Assessment. Ecologic Institute, Berlin.

Cruikshank, J., 2001. Glaciers and climate change: perspectives from oral tradition. Arctic, 54:377-393.

Dale, B., 2011. Securing a contingent future: How threats, risks and identity matter in the debate over petroleum development in Lofoten, Norway. PhD thesis. Department of Sociology, Political Science and Community Planning, University of Tromsø, Norway.

Dale, B., 2016. Governing resources, governing mentalities. Petroleum and the Norwegian integrated ecosystem-based management plan for the Barents and Lofoten seas in 2011. The Extractive Industries and Society, 3:9-16.

Dale, B., I. Bay-Larsen and B. Skorstad (eds.), in press. The Will to Drill - Mining and Arctic Communities. Springer.

Dannevig, H., G.K. Hovelsrud and I.A. Husabø, 2013. Driving the agenda for climate change adaptation in Norwegian municipalities. Environment and Planning C: Government and Policy, 31:490-505.

Eira, I.M.G., O.H. Magga, M.P. Bongo, M.N. Sara, S.D. Mathiesen and A. Oskal, 2008. The challenges of Arctic reindeer herding: The interface between reindeer herders' traditional knowledge and modern understanding of the ecology, economy, sociology and management of Sámi reindeer herding. http://library.arcticportal.org/550/1/Eira_127801.pdf

Ensor, J. and R. Berger, 2009. Community-based adaptation and culture in theory and practice. In: Adger, W.N., I. Lorenzoni and K.L. O'Brien (eds.), Adapting to Climate Change: Thresholds, Values, Governance. pp. 227-239. Cambridge University Press.

European Commission, 2016. An integrated European Union policy for the Arctic. http://eeas.europa.eu/arctic_region/

docs/160427_joint-communication-an-integrated-european-union-policy-for-the-arctic_en.pdf

EVA National Attitude Survey, 2015. www.eva.fi/arvopankki/perusnakyma.php?q=8

Forbes, B.C., M. Bölter, L. Müller-Wille, J. Hukkinen, F. Müller, N. Gunslay and Y. Konstantinov (eds.), 2006. Reindeer Management in Northernmost Europe: Linking practical and scientific knowledge in social-ecological systems. Ecological Studies 184. Springer.

Ford, J.D. and C. Furgal, 2009. Foreword to the special issue: climate change impacts, adaptation and vulnerability in the Arctic. Polar Research, 28:1-9.

Ford, J.D., K. Bolton, J. Shirley, T. Pearce, M. Tremblay and M. Westlake, 2012. Mapping human dimensions of climate change research in the Canadian Arctic. Ambio, 41:808-822.

Ford, J.D., G. McDowell and T. Pearce, 2015. The adaptation challenge in the Arctic. Nature Climate Change, 5:1046-1053.

Furberg, M., B. Evengård and M. Nilsson, 2011. Facing the limit of resilience: perceptions of climate change among reindeer herding Sami in Sweden. Global Health Action, 4: doi:10.3402/gha.v4i0.8417.

Herrmann, T.M., P. Sandström, K. Granqvist, N. D'Astrous, J. Vannar, H. Asselin, N. Saganash, J. Mameamskum, G. Guanish, J.-B. Loon and R. Cuciurean, 2014. Effects of mining on reindeer/caribou populations and indigenous livelihoods: community-based monitoring by Sami reindeer herders in Sweden and First Nations in Canada. The Polar Journal, 4:28-51.

Himanen, S., J. Inkeröinen, K. Latola, T. Väisänen and E. Alasaarela, 2012. Analysis of Regional Climate Strategies in the Barents Region. Ministry of the Environment, Helsinki, Finland

Horstkotte, T., 2013. Contested landscapes: Social-ecological interactions between forestry and reindeer husbandry. Doctoral thesis. Department of Ecology and Environmental Sciences. Umeå University, Sweden.

Hovelsrud, G.K., J. West and H. Dannevig, 2013. Fisheries, resource management and climate change: Local perspectives of change in coastal communities in Northern Norway. In: Sygna, L., K. O'Brian and J. Wolf (eds.), A Changing Environment for Human Security: Transformative Approaches to Research, Policy and Action. pp. 135-146. Routledge.

Hovelsrud, G.K., J. West and H. Dannevig, 2015. Exploring vulnerability and adaptation narratives among fishers, farmers and municipal planners in Northern Norway. In: O'Brien, K. and E. Selboe (eds.), The Adaptive Challenge of Climate Change, pp. 194-212. Cambridge University Press.

Jensen, L.C., 2012. Norwegian petroleum extraction in Arctic waters to save the environment: introducing 'discourse co-optation' as a new analytical term. Critical Discourse Studies, 9:29-38.

Johansen, H. and Y. Skryzhevska, 2013. Adaptation priorities on Russia's Kola Peninsula: climate change vs. post-Soviet transition. Polar Geography, 36:271-290.

Kelman, I., T. Rauken and G. Hovelsrud, 2012. Local business perceptions of weather impacts on tourism in Svalbard, Norway. The Northern Review, 35:96-124.

Keskitalo, E.C.H., 2004. Negotiating the Arctic: The construction of an international region. Routledge.

Keskitalo, E.C.H., 2008. Climate change and globalization in the Arctic: an integrated approach to vulnerability assessment. Earthscan publications, London.

Kietäväinen, A. and S. Tuulentie, 2013. Tourism strategies and climate change: rhetoric at both strategic and grassroots levels about growth and sustainable development in Finland. Journal of Sustainable Tourism, 6:845-861.

Klokov, K.B., 2012. Changes in reindeer population numbers in Russia: an effect of the political context or of climate? Rangifer, 32:19-33.

Knol, M., 2010. Scientific advice in integrated ocean management: The process towards the Barents Sea plan. Marine Policy, 34:252-260.

Koivurova, T., V. Masloboev, K. Hossain, V. Nygaard, A. Petrétei and S. Vinogradova, 2015. Legal protection of Sami traditional livelihoods from the adverse impacts of mining: A comparison of the level of protection enjoyed by Sami in their four home states. Arctic Review on Law and Politics, 6:11-51.

Kristoffersen, B., 2014. Drilling oil into Arctic minds? State security, industry consensus and local contestation. PhD thesis. Faculty of Humanities, Social Science and Education, UiT, The Arctic University of Norway.

Kristoffersen, B. and B. Dale, 2014. Post-petroleum security in Lofoten: How identity matters. Arctic Review on Law and Politics, 5:201-226.

Lange, M.A. and the BASIS consortium, 2003. The Barents Sea impact study (BASIS): methodology and first result. Continental Shelf Research, 23:1673-1694.

Lange, M.A., H. Roderfeld and R. Leemans, 2008. BALANCE: an attempt to assess climate change impacts in the Barents Sea Region. Climatic Change, 87:1-6.

Löf, A., 2013. Examining limits and barriers to climate change adaptation in an indigenous reindeer herding community. Climate and Development, 5:328-339.

Löf, A., 2014. Challenging Adaptability: Analysing the governance of reindeer husbandry in Sweden. Department of Political Science, Umeå University, Sweden.

Löf, A., P. Sandström, K. Baer, M. Stinnerbom and C. Sandström, 2012. Renskötsel och klimatförändring: Risker, sårbarhet och anpassningsmöjligheter i Vilhelmina norra sameby [Reindeer herding and climate change: Risks, vulnerability and adaptation options in Vilhelmina North RHC]. Department of Political Science, Research Report 2012:4, Umeå University, Sweden

Mossberg Sonnek, K., A. Carlsson Kanyama, E.-M.a Nordström and R. Räty, 2014. Den önskvärda skogen om 40 år: Visioner framtagna med fokus på skogsbruk och energi. FOI Memo 5011. Stockholm: Totalförsvarets forskningsinstitut.

Müller-Wille, L. and J. Hukkinen, 1999. Human environmental interactions in upper Lapland, Finland: Development of participatory research strategies. Acta Borealia, 16:43-61.

Nakashima, D.J., K. Galloway McLean, H.D. Thulstrup, A. Ramos Castillo and J.T. Rubis, 2012. Weathering Uncertainty: Traditional Knowledge for Climate Change Assessment and Adaptation. United Nations Educational, Scientific and Cultural Organization (UNESCO) and United Nations University (UNU).

Naskali, P., M. Seppänen and S. Begum (eds.), 2016. Ageing, Wellbeing and Climate Change in the Arctic. Routledge.

Nikula, I., M. Turunen, P. Soppela and M. Tennberg, 2015. Memo from a stakeholder event. An AACA BRIT stakeholder event in connection to the Arctic Business Forum held at the Arctic Centre, University of Lapland 12.3.2015. (In Finnish)

Nilsson, A.E., 2007. A Changing Arctic Climate. Science and policy in the Arctic climate impact assessment. Dissertation. Linköping University, Sweden.

Nilsson, A.E., Å. Gerger Swartling and K. Eckerberg, 2012. Knowledge for local climate change adaptation in Sweden: challenges of multilevel governance. Local Environment, 17:751-767.

Nordic Council of Ministers, 2011. Megatrends. TemaNord 2011:527. Nordic Council of Ministers, Copengagen.

Nordic Council of Ministers, 2015. Arctic Human Development Report: Regional Processes and Global Linkages. Nordic Council of Ministers, Copenhagen.

Norwegian Ministry of the Environment, 2013. Action Plan on Climate Change for the Barents Cooperation. Prepared by Carbon Limits, commissioned by the Norwegian Ministry of the Environment, based on input from the Barents Euro-Arctic Council working groups. www.barentsinfo.fi/beac/docs/Environment_Ministers_Meeting_4_5_Nov_2013_Inari_Action_Plan_Climate_Change_ENG.pdf

Nygaard, V., 2016. Do indigenous interests have a say in planning of new mining projects? Experiences from Finnmark, Norway. The Extractive Industries and Society, 3:17-24.

Oskal, A., 2008. Old livelihoods in new weather: Arctic indigenous reindeer herders face the challenges of climate change. Development Outreach, 10:22-25.

Oskal, A., J.M. Turi, S.D. Mathiesen and P. Burgess (eds.), 2009. EALÁT Reindeer herders' voice: Reindeer herding, traditional knowledge and adaptation to climate change and loss of grazing land. Arctic Council.

Pape, R. and J. Löffler, 2012. Climate change, land use conflicts, predation and ecological degradation as challenges for reindeer husbandry in Northern Europe: What do we really know after half a century of research? Ambio, 41:421-434.

Rasmussen, R.O., G.K. Hovelsrud, S. Gearheard, H. Amundsen, M. Berman, B. Dale, K.G. Hansen, L. Howe, H. Huntington, N. Johnson, J. Olsen, J. Roto and L. Sloan, 2015. Community viability and adaptation. In: Arctic Human Development Report: Regional Processes and Global Linkages. pp. 424-473. Nordic Council of Ministers.

Räty, R., A. Carlsson Kanyama, K. Mossberg Sonnek and E.-M. Nordström, 2014. Den önskvärda skogen om 40 år: Visioner framtagna med fokus på samiska verksamheter. [The desired future forest for 40 years: Visions focusing on Sami livelihoods] FOI Memo 5050. Swedish Defence Research Agency, Stockholm.

Rees, W.G., F.M. Stammler, F.S. Danks and P. Vitebsky, 2008. Vulnerability of European reindeer husbandry to global change. Climatic Change, 87:199-217.

Regjeringen, 2009. Svalbard. Recommendation by the Ministry of Justice and the Police of 17 April 2009, approved in the Council of State on the same date. (Stoltenberg II Government). Report No. 22 (2008–2009) to the Storting. www.regjeringen.no/no/dokumenter/stmeld-nr-22-2008-2009-/id554877/?ch=1&q=

Regjeringen, 2016. White Paper on the Future of Svalbard. Press release by Government of Norway. www.regjeringen.no/en/aktuelt/white-paper-on-the-future-of-svalbard/id2500474/

Reinert, H. and T.A. Benjaminsen, 2015. Conceptualising resilience in Norwegian Sámi reindeer pastoralism. Resilience: International Policies, Practices and Discourses, 3:95-112.

Riseth, J.Å., H. Tømmervik, E. Helander-Renvall, N. Labba, C. Johansson, E. Malnes, J.W. Bjerke, C. Jonsson, V. Pohjola and L.-E. Sarri, 2011. Sámi traditional ecological knowledge as a guide to science: snow, ice and reindeer pasture facing climate change. Polar Record, 47:202-217.

Ronkainen, S. (ed.), 2008. Ilmastonmuutoksen ennakointi ja vaikutusten arviointi Lapissa [Climate change forcing and impacts assessment in Lapland]. Lapin yliopiston menetelmätieteiden laitoksen tutkimuksia 2 e. www.ulapland.fi/loader.aspx?id=8f1c62d7-0823-4a24-98c5-1c34b8dccbc6

Rosqvist, G. and N. Inga, 2015. Effects of changing snow conditions on reindeer husbandry in Arctic, Sweden. International Conference on Arctic Research Planning (ICARP) III: Changes in Arctic snow cover and their consequences. Arctic Science Summit Week 2015.

Sandström, P. and C. Widmark, 2007. Stakeholders' perceptions of consultations as tools for co-management: A case study of the forestry and reindeer herding sectors in northern Sweden. Forest Policy and Economics, 10:25-35.

Skogsstyrelsen, 2013. Förstudie om ett nationellt skogsprogram för Sverige - omvärldsanalys. [Feasibility study of national forest programs for Sweden-macro analysis]. Meddelande 6. Skogsstyrelsen, Sweden.

Smit, B. and J. Wandel, 2006. Adaptation, adaptive capacity and vulnerability. Global Environmental Change, 16:282-292.

Sorvali, J., 2015. Climate Strategy Work in the Barents Region. www.climatesmart.fi/work

Sreejith, S.G., 2009. Subjective environmentalism: The Barents Euro-Arctic Council and its climate change policy. In: Koivurova, T., E.C.H. Keskitalo and N. Bankes (eds.), Climate Governance in the Arctic, pp. 383-402. Springer.

Stammler-Gossmann, A., 2013. Changing Barents Sea and coastal communities: Expedition to the High Arctic. Arctic Climate Change Economy and Society Newsletter, 5:15-16.

Statistics Norway, 2006. The Economy of the North. Glomsrød, S. and I. Aslaksen (eds.). Statistics Norway.

Statistics Norway, 2009. The Economy of the North 2008. Glomsrød, S. and I. Aslaksen (eds.). Statistics Norway.

Stefansdottir, M.M., 2014. Large scale projects in the Arctic: Socio-economic impacts of mining in Greenland. Msc thesis, University of Akureyri, Iceland.

Stępień, A. and A. Raspotnik, 2016. The EU's New Arctic Communication: No-So-Integrated, Not-So-Disappointing? ArCticles.

Stępień, A., T. Koivurova and P. Kankaanpää (eds.), 2014. Strategic Assessment of Development in the Arctic. Assessment conducted for the EU. Arctic Centre, University of Lapland.

Stępień, A., P. Kankaanpää and T. Koivurova, 2016. Introduction: Understanding Arctic change through assessments and stakeholder engagements. In: Stepien, A., T. Koivurova and P. Kankaanpää (eds.), The Changing Arctic and the European Union. pp. 1-19. Brill/Nijhoff.

Storbjörk, S., 2007. Governing climate adaptation in the local Arena: Challenges of risk-management and planning in Sweden. Local Environment, 12:457-469.

Storbjörk, S., 2010. 'It takes more to get a ship to change course'. Barriers for organizational learning and local climate adaptation in Sweden. Journal of Environmental Policy and Planning, 12:235-254.

Tedsen, E., A. Riedel, K. Weingartner, R. Azzolini, F. Guillon, S. Longo, C. Leone, O. Paadar and A. Leonenko, 2014. Gap Analysis Report. Preparatory Action, Strategic Environmental Impact Assessment of development of the Arctic. Arctic Centre, University of Lapland.

Tennberg, M., 1998. The Arctic Council. A Study in Governmentality. Acat Universitatis Lapponiensis 19. Thesis. University of Lapland, Finland.

Tennberg, M., 2015. Discussion with BEAC environmental group on 26 November 2015 in Rovaniemi, Finland. Personal communication.

Tennberg, M., 2016. Presentation and discussion at the BEAC environmental group meeting on 15 March 2016 in Svanhovd, Norway. Personal communication.

Tennberg, M., A. Emelyanova, H. Eriksen, J. Haapala, A. Hannukkala, J. Jaakkola, T. Jouttijarvi, K. Jylha, S. Kauppi, A. Kietavainen, H. Korhonen, M. Korhonen, A. Luomaranta, R. Magga, I. Mettiainen, K. Nakkalajarvi, K. Pilli-Sihvola, A. Rautio, P. Rautio, K. Silvo, P. Soppela, M. Turunen, S. Tuulentie and T. Vihma, 2017. Barentsin alue muuttuu - miten Suomi sopeutuu? Valtioneuvoston tutkimusja selvitystoiminnan julkaisusarja [The Barents area changes – How will Finland adapt?] 31/2017.

Thesen, G. and E. Leknes, 2010. Nord-Norge i norsk petroleumspolitikk - narrativer og politisk endring. [Northern Norway in Norwegian petropolitics - narratives and political change] In: Arbo, P. and B. Hersoug (eds.), Oljevirksomhetens inntog i nord: Næringsutvikling, politikk og samfunn. Gyldendal Akademisk.

Tunander, O., 2008. Geopolitics of the North: Geopolitik of the weak. A Post-Cold War return to Rudolf Kjellén. Cooperation and Conflict, 43:164-184.

Turi, E.I. and E.C.H Keskitalo, 2014. Governing reindeer husbandry in western Finnmark: barriers for incorporating traditional knowledge in local-level policy implementation. Polar Geography, 37:234-251.

Turunen, M.T., S. Rasmus, M. Bavay, K. Ruosteenoja and J. Heiskanen, 2016. Coping with difficult weather and snow conditions: Reindeer herders' views on climate change impacts and coping strategies. Climate Risk Management, 11:15-36.

Tuusjärvi, M., I. Mäenpää, S. Vuori, P. Eilu and S. Kihlman, 2014. Mining industry in Finland - development scenarios to 2030. Journal of Cleaner Production, 84:271-280.

Tyler, N.J.C., J.M. Turi, M.A. Sundset, K. Strøm Bull, M.N. Sara, E. Reinert, N. Oskal, C. Nellemann, J.J. McCarthy, S.D. Mathiesen, M.L. Martello, O.H. Magga, G.K. Hovelsrud, I. Hanssen-Bauer, N.I. Eira, I.M.G. Eira and R.W. Corell, 2007. Saami reindeer pastoralism under climate change: Applying a generalized framework for vulnerability studies to a sub-arctic social-ecological system. Global Environmental Change, 17:191-206.

Ulmanen, J., Å. Gerger Swartling and O. Wallgren, 2015. Climate adaptation in Swedish forestry: Exploring the debate and policy process, 1990–2012. Forests, 6:708-733.

UNFCCC, 2015. The Paris climate agreement (2015). https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf

Vink, M.J., A. Dewulf and C. Termeer, 2013. The role of knowledge and power in climate change adaptation governance: a systematic literature review. Ecology and Society, 18:46. http://dx.doi.org/10.5751/ES-05897-180446

Vinogradova, S.N. and V.A. Masloboev, 2015. Mining in the traditional territories of indigenous peoples of the North: features, problems and regulatory mechanisms. Arctic: Ecology and Economy, 2:96-103. (In Russian)

Vuojala-Magga, T., M. Turunen, T. Ryyppö and M. Tennberg, 2011. Resonance strategies of Sámi reindeer herders in Northernmost Finland during climatically extreme years. Arctic, 64:227-241.

Wamsler, C. and E. Brink, 2014. Planning for climatic extremes and variability: A Review of Swedish municipalities' adaptation responses. Sustainability, 6:1359-1385.

Wenger, E., 1999. Communities of Practice: Learning, Meaning and Identity. Cambridge University Press.

World Bank, 2005. Integrating Environmental Considerations in Policy Formulation: Lessons from Policy-Based SEA Experience. Report No. 32783.

Wyser, C. and A. Jonsson, 2014. Rapportering av näringslivsdialog klimatanpassning: Ett uppdrag om kartläggning genom Dialog kring behov av och möjligheter till klimatanpassning hos aktörer inom svenskt näringsliv för SMHI [Report on climate adaptation dialogue with industry. A mission to map through dialogue the needs and opportunities for climate adaptation among actors in the Swedish industries]. Pussel klimatkonsult och Catalysator Report 67.

4. Physical and socio-economic environment

Coordinating Lead Authors: Rasmus Benestad, Vladimir Ivanov, Peter Arbo, Glen Peters

Lead Authors: Maria Ananicheva, Andreas Dobler, Ralf Döscher, Igor Ezau, Randi Ingvaldsen, Ketil Isaksen, Christian Jaedicke, Zbigniew Klimont, Torben Koenigk, Meri Korhonen, Kaarle Kupiainen, Anna Luomaranta, Arne Melsom, Geir Moholdt, Jan Even Nilsen, Gunnar Noer, Kajsa Parding, Ville-Veikko Paunu, Anette Rinke, Anne Britt Sandø, Dagrun Vikhamar Schuler, Igor Shkolnik, Morten Skogen, Michael Tjernstrøm, Ari Venäläinen, Timo Vihma

Key messages

- ***The Barents Sea plays an integral role in the atmospheric and oceanic circulations, water masses and marine ecosystems of the Arctic.*** *Many drivers and impacts are interconnected and feedbacks are a source of considerable uncertainty. The Arctic is warming faster than the global average, and projections suggest an increase of 3–10°C in winter between 2015 and 2080 for the RCP4.5 scenario. Winter warming under RCP8.5 may be up to 20°C. More precipitation is expected to fall as rain in the future, amplified by the sea-ice retreat and increasing the probability of rain-on-snow events. Natural hazards include synoptic storms, avalanches, and extreme wave heights, but current projections are unable to provide robust indications of change other than a poleward shift in storm tracks. The risk of polar lows is projected to decrease in future as conditions become less favorable for their occurrence.*
- ***The Barents Sea is expected to become the first Arctic region that is ice-free all year round.*** *The business-as-usual emissions scenario (RCP8.5) implies a 94% reduction in September sea-ice extent. Sea ice influences the connection between ocean and the atmosphere, planetary energy flow, weather phenomena, and marine life, and so a decrease in its extent and volume could have profound effects on the future Barents area. Icebergs represent a major hazard to marine activity in the Barents Sea and the number fluctuates from year to year. There is some indication of increased numbers extending further south associated with warming, but the long-term statistics on icebergs in the Barents Sea are incomplete.*
- ***Major changes are expected in snow cover and permafrost properties within the Barents area.*** *Snow cover extent and snow season duration have decreased most at high latitudes (60–70°N), and the decline in snow cover in Eurasia over the period 2007–2014 has accelerated compared to earlier periods. The melt onset date in spring advanced by about 1–2 weeks in the 1979–2012 period, and the duration of snow cover in 2050 is projected to be about 30-40% shorter than in 2011. There has been an observed change in the timing of spring flood associated with changes in the timing of snowmelt, and the dates for ice formation on waterways has shifted to later in the season. Annual maximum snow depth has increased in colder regions such as Russia but has decreased in warmer locations, and future projections suggest a continued increase in some places. Observations suggest an increase in hard snow layers from 1961 to 2009, with harder snow in early winter, 'wetter' snow during spring, and future warming may bring more rain-on-snow events. Black carbon enhances snow melt through reduced albedo and also has negative impacts on human health. However, there is potential for reducing black carbon emissions by up to three-quarters by 2030. The permafrost is thawing, and the projected warming and increases in snow thickness will result in near-surface permafrost degradation over large geographic areas.*
- ***The Barents area is strongly affected by global social, economic, political and cultural changes, which interact with climate change and can make people and societies more or less vulnerable and able to adapt.*** *The main non-climate drivers at a global scale include population growth, urbanization, economic growth, technology development, demand for natural resources and energy, and the level of international cooperation. The Barents area will be influenced by external megatrends through migration, trade, investments, government policies and laws, but the implications for the different subregions will depend on their natural and human resources, their institutional characteristics, and the policies adopted.*

4.1 Introduction

This chapter provides a quantitative (where possible) description of what will shape the future Barents area in terms of its regional climate, and its physical and socio-economic environment. This includes a detailed description of these changes with respect to specific components of the climate system: the atmosphere (Section 4.2), ocean (Section 4.3) and land (Section 4.4), as well as socio-economic conditions (Section 4.5). This overview is based on scientific knowledge from multiple sources, including modelling studies and observations (Box 4.1). The main emphasis of this chapter is on those drivers and trends that originate outside the region. Later chapters address potential interactions and the consequences of these changes. The chapter concludes with a discussion that draws together the major findings reported here (Section 4.6).

Ongoing and future environmental change within Barents area will have significant for consequences for the people living and working there, as well as for the many sectors and activities within the region. This chapter presents a plausible future picture, based on past observations as well as downscaled results from global climate models (GCMs) and recent assessments

Box 4.1 Where does our knowledge come from?

Atmospheric models and downscaling

There are multiple sources for our knowledge of the Arctic climate, including past observations, model results, analysis, and experience. Observations are necessary for empirical analysis as well as for model validation. Although the long-term ground-based observational network is sparse in the Arctic, the World Meteorological Organization (WMO) Polar Prediction Project (PPP) has made some progress in connecting models and observations (Jung et al., 2016). Inoue et al. (2015) proposed a cost-benefit observing frequency of Arctic radiosonde observations. Observations derived from instruments on satellites provide better spatial coverage than the land-based network of in-situ measurements, but do not provide long-term records since many satellite missions are recent. Historic data provide information about climate phenomena, how they are connected, and their sensitivity to changing conditions (Benestad et al., 2016).

A rough view of possible future climates is provided by the range of global climate models (GCMs), but these model results must be seen in the context of empirical data such as observations. The GCMs do not provide local and regional detail, and their results must be downscaled to provide a more detailed view of regional and local climate. There are two main downscaling approaches, each with different strengths and weaknesses (Takayabu et al., 2016). The first involves regional climate models (RCMs) with around 10–50 km resolution runs. The higher resolution and adapted physics of RCMs, which includes coupling between the atmosphere, sea ice and ocean, is suitable for studying regional Arctic change and related processes. The Arctic RCMs intercomparison project (Arctic CORDEX) aims to provide high resolution projections and to quantify their uncertainty. However, a large RCM ensemble with forcing from many GCMs must be used to achieve robust conclusions with uncertainty estimates. The other approach, empirical-statistical downscaling (ESD) requires little computer power but needs long historical records for model training. One problem with ESD is that there are few long data records available from the Arctic. While ESD can only provide a similar type of information to that provided by data sampled historically, it does facilitate a means for downscaling a large ensemble of different GCMs, and so can capture the range of natural variation. ESD also makes use of information from different sources to that of RCMs: professional experience, GCMs, empirical data/observations, and statistical theory.

Ocean models and downscaling

Downscaling two different GCMs for the present climate (20C3M) brings the results closer to observations than the ocean components of global models. The results obtained and compared include sea ice, salinity, temperature, ocean volume and heat transport. These findings were made in the NorClim and RegScen projects regarding high-resolution regional downscaling experiments for the Barents Sea, based on two CMIP3 global models (GISS-AOM, NCAR-CCSM). Scenarios were downscaled using a 'delta-change' type approach (whereby changes simulated by models are added to the observed state and where the models do not necessarily correctly represent the present state, but despite systematic biases it is assumed that the simulated change is nevertheless plausible). The Norwegian Institute for Marine Research has also conducted new simulations for the CMIP5 experiment following RCP4.5 based on the NorESM model. A Russian-Norwegian project 'Isfjord' (Gjelten et al., 2016) will focus on coastal aspects.

iStock.com/3DSculptor

B&C Alexander / ArcticPhoto

Olaf Doering / Alamy Stock Photo

such as the SWIPA assessment (AMAP, 2012), the Arctic Climate Impact Assessment (ACIA, 2004, 2005), the fifth assessment of the Intergovernmental Panel on Climate Change (IPCC, 2014), the NordAdapt project (The Research Council of Norway, 2008), and a recent assessment of climate change for the Baltic Sea Basin (The BACCII Author Team, 2015) with some results that are relevant to the Arctic. The projections and scenarios involve foresight based on empirical information, known behavior, and interaction between drivers and impacts, but exclude unknowns and are limited by incomplete knowledge. For example, there are real risks of abrupt change or the crossing of tipping points, but it is extremely challenging (if not impossible) to identify the exact threshold for their trigger action. Relevant tipping points include cessation of the World Ocean Thermohaline Circulation, methane release, disintegration of the Greenland ice sheet and irreversible loss of biodiversity (ACIA 2004; Arctic Council, 2013). The future may also bring surprises because there is still much to be understood about drivers and feedbacks, and there may be many unknown unknowns (see Appendix 4.1).

4.2 Changes in the atmosphere

The Arctic region was long expected to warm at a faster rate than global mean temperature due to 'polar amplification' (Manabe and Stouffer, 1980). This has now been observed (Kattsov et al., 2011; Rutgersson et al., 2015) and is expected to continue (Kirtman et al., 2013; Collins et al., 2013). Several conditions associated with global warming are likely to have important consequences for the Arctic environment and Arctic societies (see Appendix 4.2). The rise in temperature is associated with ice and snow melt (Callaghan et al., 2011; Liston and Hiemstra, 2011; Roshydromet, 2014, 2016) as well as changes in the vegetation. Changes in ice, snow, and vegetation will in turn influence albedo and surface fluxes, while melting land ice contributes to rising sea level and changes in ocean salinity that may drive changes in the global thermohaline circulation. Higher temperatures also affect permafrost (Isaksen et al., 2007a,b; Etzelmüller et al., 2011; Koven et al., 2013; Roshydromet, 2014), causing an increase in active layer depth, permafrost degradation and a northward shift in the southern limit of the permafrost. Changes in permafrost have consequences for infrastructure and the built environment. Changes in temperature also affect the relative proportions of precipitation falling as snow and rain (Hansen et al., 2014; Roshydromet, 2014). There have been more frequent occurrences of rain-on-snow (ROS) and winter warming events (Vikhamar-Schuler et al., 2016), with an average increase of 0.2 to 2.5 events per winter per 1°C temperature rise in the Barents area according to Rasmus et al. (2015). Higher temperatures also increase the moisture-holding capacity of the atmosphere, and Rinke et al. (2011) projected significant changes in temperature, precipitation and snow indices over the 21st century. The observed rise in precipitable water over recent decades has been greatest in summer and early autumn and over the northern North Atlantic, including the Norwegian and Barents seas (Serreze et al., 2012). Added to this, a declining sea-ice cover favors increased evaporation from the Arctic seas and in turn influences the weather (Vihma, 2014). Other aspects, such as changes in storm statistics and frontal activity, present a challenge to communities and have a strong effect on sectors such as tourism, fishing, offshore, and shipping. These phenomena are associated with strong winds and high waves, and recent reports suggest a connection between cyclones (i.e. storms) and ROS events (Hansen et al., 2014; Roshydromet, 2014). Heavy snowfall can result in snow-induced forest damage, and in the period 1961–2000 the maximum number of heavy snow-load events occurred in 1994 in northern Finland (Rasmus et al., 2015). Stratospheric temperatures may influence ground conditions through indirect effects on circulation patterns (such as the NAO/AO, jet streams, and storm tracks) or volcanic eruptions (Baldwin and Dunkerton, 2001; Thompson et al., 2002; Bhend, 2015; Kidston et al, 2015). Ozone concentrations in the stratosphere affect the amount of solar radiation reaching the Earth's surface, and so control the intensity of the short-wave ultraviolet radiation that may harm living organisms and affect human health. Manney et al. (2011) reported unprecedented chemical ozone destruction over the Arctic in early 2011 that was comparable to that in the 'Antarctic ozone hole'.

4.2.1 Warming

Annual average temperature in the Barents area increased by 1–2°C over the period 1954–2003, with warming strongest in winter (Callaghan et al., 2005). The observed rate of increase in Ny Ålesund (Svalbard) for the period 1994–2013 was 1.3°C per decade (Maturilli et al., 2014), again with the increase greatest in winter (3°C per decade).

A new set of temperature and precipitation projections has been generated for the Barents area by empirical-statistical downscaling of results from the CMIP5 ensembles of General Circulation Models (GCMs) driven by the RCP2.6, RCP4.5 and RCP8.5 emission scenarios (Benestad et. al., 2016). Large ensembles are likely to capture the effect of natural variations (Deser et al., 2012) and by comparing the downscaled results and observations it is clear that the range in model results is similar to that for the observed interannual variability (Figure 4.1). The downscaled data indicate that the warmest (95th percentile) winter temperatures over the land-area surrounding the Barents Sea are likely to

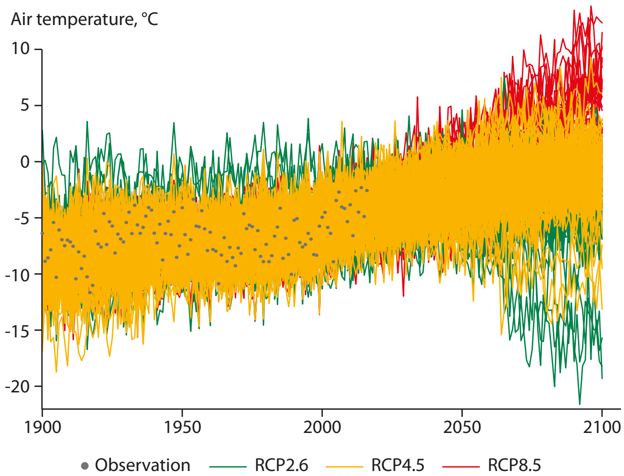


Figure 4.1 Comparison of observed temperature and computed winter-mean temperature for the period 1900–2100 at Svalbard airport for the RCP2.6, RCP4.5, and RCP8.5 emission scenarios (Benestad et al., 2016).

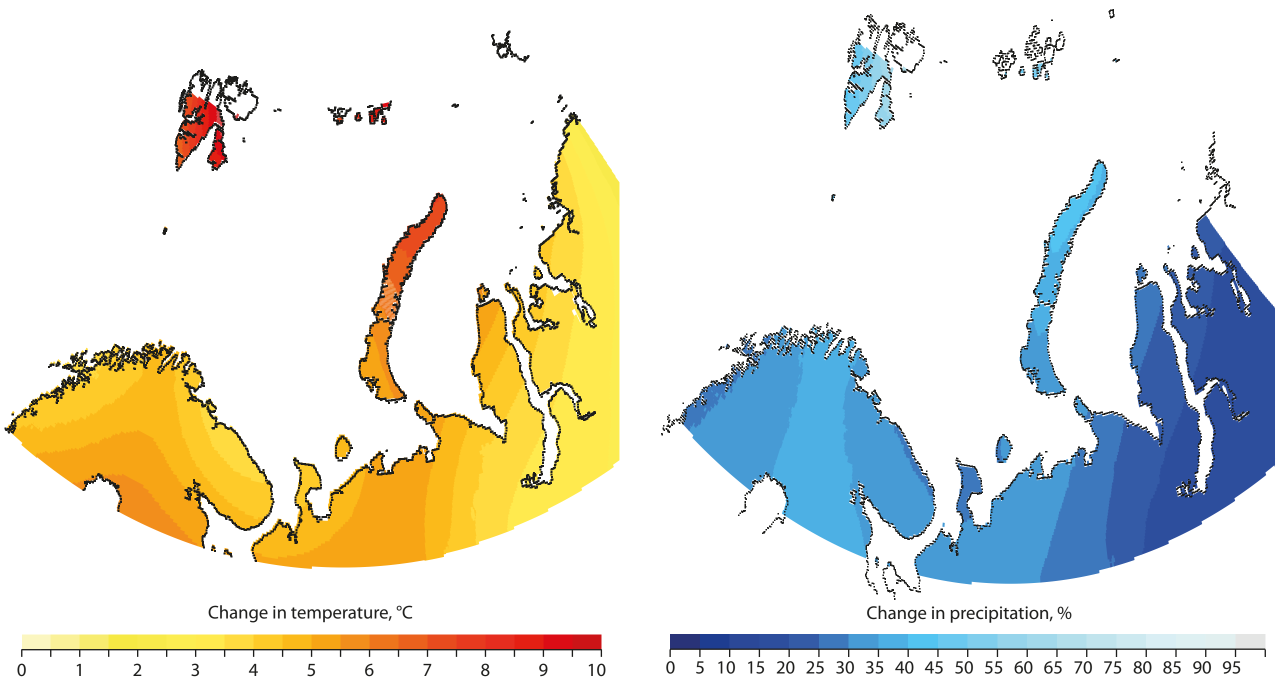


Figure 4.2 Projected change in a typical warm winter mean temperature (DJF; left) and annual total precipitation (right) for a typical wet year between 2015 and 2080 based on empirical-statistical downscaling of the 95-percentile of CMIP5 ensemble following the RCP4.5 emissions scenario. The results are based on Benestad et al. (2016).

increase by 3–10°C over the period 2015–2080 under the RCP4.5 scenario (Figure 4.2). The warming shows regional variability, with the greatest warming expected to occur over Svalbard and the High Arctic. Temperatures are projected to be even higher under a regional climate model (RCM) that downscaled data from four GCMs (CMIP5) and the RCP8.5 scenario (Koenigk et al., 2015). According to these results, warming over the Barents Sea may be 8–15°C by mid-century and up to 20°C by the end of the century in winter, largely driven by the disappearance of sea ice from the Baltic Sea. Warming over the Barents Sea in summer is projected to be 3–4°C by mid-century and 6–8°C by the end of the century under RCP8.5, with a warming over the adjacent land of 4–6°C by the end of the century. The drawback to this study is the small number of GCM simulations on which the regional data are based. However, these data are comparable with an atlas based on 81 RCP8.5 simulations, and corresponding results from empirical-statistical downscaling of larger ensembles indicates a similar range, albeit with strongest warming in the western part of the Barents area (Benestad et al., 2016). Recent analysis of projections from another RCM (COSMO-CLM, Steppeler et al., 2003), downscaling RCP2.6, RCP4.5 and RCP8.5 scenario runs from the Earth System Model MPI-ESM-LR to a resolution of about 25 km in the Barents and Scandinavian region, are in agreement with results reported by Koenigk et al. (2015) (Figure 4.3).

There was little difference between the projected summer temperatures for the different emission scenarios (i.e. the patterns were similar), although a temperature increase of several degrees is expected to bring the winter conditions closer to freezing over the Nordic countries, where winter temperatures already are moderate. Present winters are extremely cold in northern Russia and are expected to remain well below freezing even by the end of the century (Benestad, 2011). Future winters on Svalbard, however, are more likely to rise above freezing, and extreme high winter temperatures in the future are expected to have a range of effects with consequences for other parts of the cryosphere (Førland et al., 2011; Hansen et al., 2014; Vikhamar-Schuler et al., 2016). Winter warming may increase the risk of ROS events.

Projections for future warming in the Arctic were also generated for the fifth assessment of the Intergovernmental Panel on Climate Change (IPCC AR5), with the extent of warming dependent on time horizon and emission scenario. Changes in temperature are projected with higher confidence than for many other aspects of the climate system (such as precipitation and wind), even at high latitudes. However, the IPCC AR5 also pointed to the increased spread in model projections for temperature in the polar regions. "*The zonal means ... show good agreement of models and scenarios over low and mid-latitudes for temperature, but higher spread across models and especially across scenarios for the areas subject to polar amplification...*" (Collins et al., 2013). This increased spread in model results for high latitudes may be a bit deceptive, as explained by Benestad (2005), because the polar regions involve smaller surface areas with different geometry to the latitude bands at lower latitudes, and so represent a smaller statistical sample and fewer real degrees of freedom. Projections of future temperature suggest that model spread does not change much over time (Hansen et al., 2014). On the other hand, the presence of additional factors in the Arctic (such as sea ice) and different representation in the models, also gives rise to a wider range of results (Stramler et al., 2011).

It is important to note that pronounced natural variations, associated with shifts in ocean currents, sea ice, storm tracks, and wind can diminish or amplify the estimates of future temperature by roughly 5°C (Benestad et al., 2016). The Arctic climate responds to changes in ice and snow, heat transport through ocean currents and storms, and heat loss to space, but is also characterized by its marine environment; especially the strong Coriolis effect, frontal systems, energy and moisture

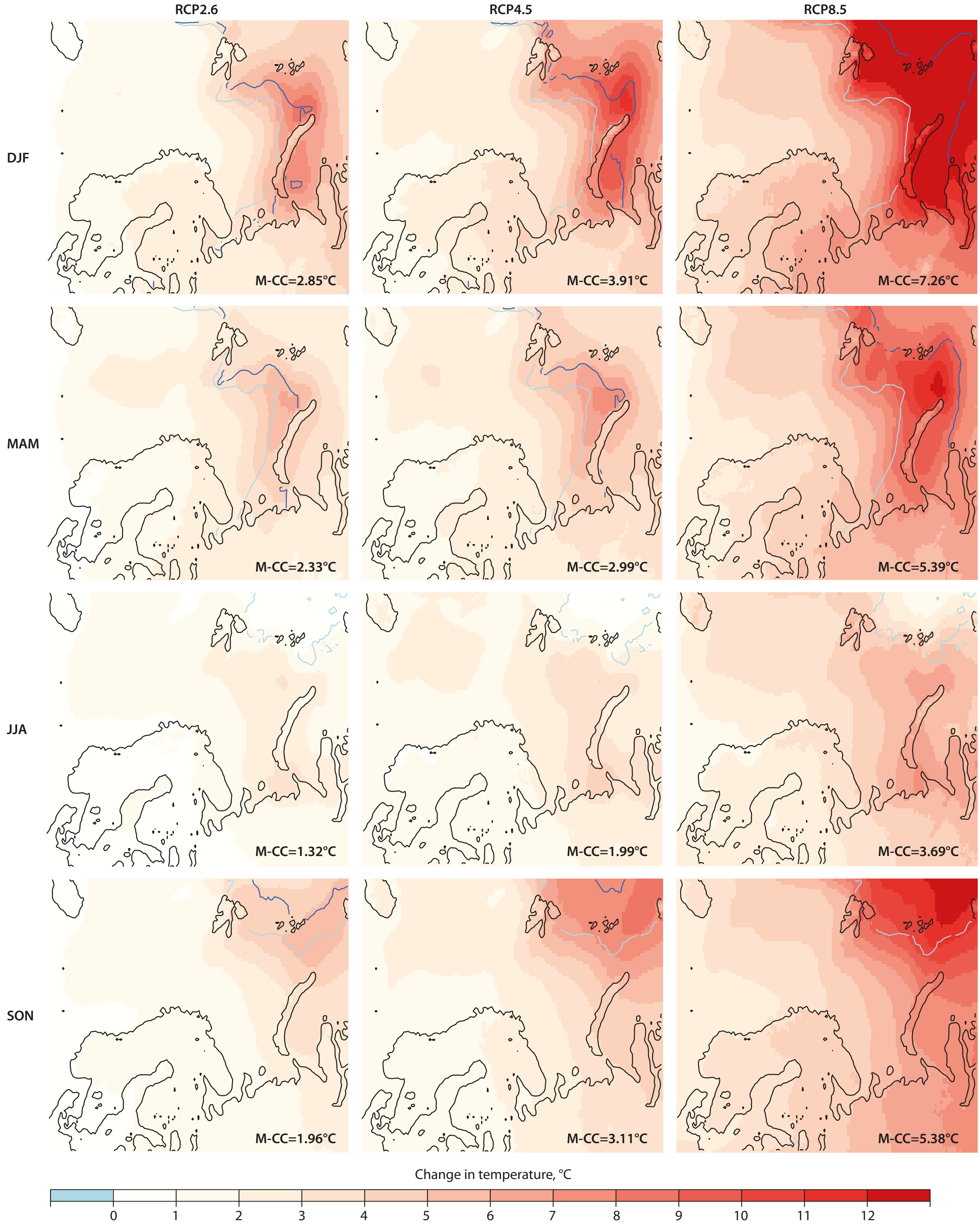


Figure 4.3 Projected change in seasonal temperature across the Barents and Scandinavian region using the regional climate model COSMO-CLM driven by the global MPI-ESM-LR Earth System Model under three emission scenarios. RCP2.6 (left), RCP4.5 (middle) and RCP8.5 (right) for the period 2071–2100 relative to 1971–2000. The dark and light blue lines indicate the northern extent of an ice-free sea for at least 20% of the time in the future and historical period, respectively. The biggest temperature changes occur between the two lines, i.e. where the sea ice is retreating regularly. Numbers at the lower right of each plot give the mean climate change signal over the domain shown (Dobler et al., 2016).

exchange between surface and the atmosphere, and near-surface processes. For instance, Woods and Caballero (2016) suggested that an increase in intense moisture injections across 70°N may explain a substantial fraction of the trends in winter temperature and sea ice over the past two decades. Recent studies have also examined the magnitude of day-to-day variation and the persistence (one-day auto-correlation) of the temperature, and found some support for reduced day-to-day variation in temperature in a warmer world, but little change in persistence in terms of day-to-day autocorrelation (Benestad et al., 2016).

4.2.2 Precipitation

Extreme precipitation can have major impacts on Arctic communities, especially when it falls as rain on snow and then freezes to form ice (Hansen et al., 2014). Changes in precipitation are expected to include greater amounts, changes in the frequency of occurrence, and a shift in the relative proportions falling as rain and snow (Førland and Hanssen-Bauer, 2003). There have been various efforts to project future precipitation since the previous IPCC assessment (AR4), and there are indications that the maximum increase in marine precipitation may take place over the Barents and Kara seas (Overland et al., 2011). Previous projections for these two areas suggested an increase in precipitation of 9–39% between 1980–1999 and 2080–2099, under the SRES A1B scenario (IPCC, 2000). However, more recent projections suggest much stronger increases, of the order of 50% in the Arctic region, which is among the highest globally (Bintanja and Selten, 2014). This corresponds to an increase of 2–10 mm per month, and

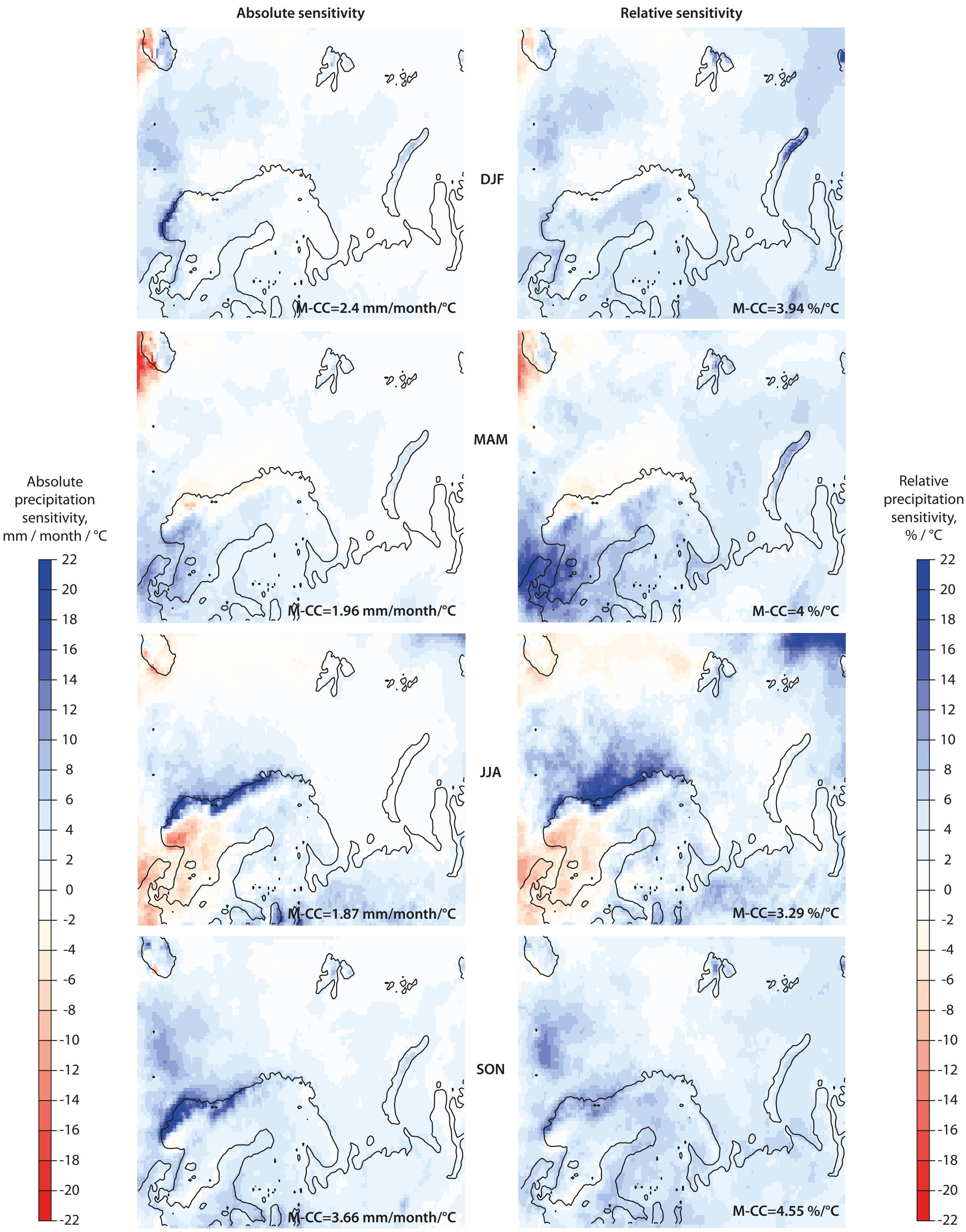


Figure 4.4 Calculated seasonal precipitation sensitivity over the Barents and Scandinavian region using the regional climate model COSMO-CLM driven by the global MPI-ESM-LR Earth System Model. Absolute (left) and relative (right) sensitivities following the RCP8.5 scenario for the period 2071–2100 relative to 1971–2000. Numbers at the lower right of each plot give the mean precipitation sensitivity over the domain shown (Dobler et al., 2016).

substantially more for the Barents Sea (up to 50 mm per month) by mid-century, and the increase is expected to continue until the end of the century (Koenigk et al., 2015). The projected increase is strongest in late autumn and winter and primarily attributed to increased evaporation from the local surface, with poleward moisture transport from lower latitudes a secondary factor. The increased surface evaporation associated with declining sea ice can be described as an amplifier for the Arctic hydrological cycle, and the Barents Sea region has been identified as an important source region where summer sea-ice anomalies feed back strongly to the atmosphere in autumn and winter (Rinke et al., 2013). Other researchers have also suggested a link between sea-ice decline and precipitation increase in summer, autumn and winter (e.g. Vihma, 2014). The increase in Arctic mean annual-average precipitation sensitivity has been estimated at 4.5% per 1°C temperature rise, compared to a global average of 1.6–1.9% per 1°C temperature rise (Bintanja and Selten, 2014). This global estimate was based on many GCM runs, whereas Koenigk et al. (2015) used a single RCM driven by four GCMs to compute climate change over the Arctic. They found different precipitation sensitivity in winter (0.8 mm per month per 1°C temperature rise) and summer (2 mm per month per 1°C temperature rise) and more pronounced summer precipitation changes in the regional model than the global models. The study by Dobler et al. (2016) using a single RCM and GCM provides further support for high precipitation sensitivity for the projected temperature changes in the area (Figure 4.4). Relative and absolute sensitivities following the RCP8.5 scenario show the biggest increases along the Norwegian west coast in summer and autumn. Relative sensitivity is about 4% per 1°C temperature rise in the Barents area and a large increase can be found in summer in the more Arctic parts of the domain. However, it should be noted that Koenigk et al. (2015) used a far larger Arctic area to calculate precipitation sensitivity than Dobler et al. (2016).

Stroeve et al. (2011) found a trend for increasing cyclone activity in the Atlantic sector of the Arctic, based on reanalysis data, and showed there is more precipitation associated with autumn cyclone activity and column water vapor during low ice-cover years than high ice-cover years. This has been supported by statistically significant responses in climate models (e.g. Strey et al., 2010; Porter et al., 2012; Rinke et al., 2013; Screen et al., 2014). Wegmann et al. (2015) presented observational evidence for increased snowfall over parts of Eurasia due to moisture transport in years of anomalous low sea-ice cover in the Barents/Kara seas region. Kusunoki et al. (2015) used a high-resolution global atmosphere model to project future changes in precipitation intensity over the Arctic. They reported a monotonic increase in annual mean precipitation, daily precipitation intensity, and the maximum 5-day precipitation total towards the end of the century, taking the average over the Arctic. The increases were partly attributed to an increase in water vapor connected with rising temperatures, but also to stronger horizontal transport of water vapor from low to high latitudes associated with transient cyclones.

More recent projections for precipitation intensity suggest up to a 70% increase for the wettest years in the annual totals between 2015 and 2080 under the RCP4.5 scenario (Figure 4.2). These estimates were derived based on projected temperature increases and a comparison between past trends in the *wet-day mean precipitation* and temperatures over the Barents area, which suggested an annual mean rate of 8.75% per 1°C temperature rise (Benestad et al., 2016). This estimate is not necessarily inconsistent with the value of 4.5% per 1°C temperature rise for *total precipitation*. Changes in large-scale circulation are expected to influence the frequency of wet days, but a shift in the storm track implies precipitation may increase in some regions and decrease in others. There was little indication that mean wet or dry spell lengths (number of consecutive wet or dry days) will change dramatically.

The Arctic Climate Impact Assessment reported that total precipitation had increased by 8% through the 20th century and gave a projected increase of 20% for 2100 (1981–2000 baseline to 2090; Juday et al., 2005). While increasing precipitation in the Arctic is consistent with model results and past observations, there is conflicting evidence about its cause. Førland and Hanssen-Bauer (2003) found an increase of more than 2.5% per decade in the historical annual precipitation measured in the Svalbard region and at Jan Mayen over the 20th century. They observed that the annual fraction of solid precipitation decreased at all sites with precipitation measurement during recent decades at the Arctic islands monitored by the Norwegian Meteorological Institute. This was suggested to have affected the total precipitation value through a reduction in undercatch at the precipitation gauges, and thus a larger fraction of 'true' precipitation being caught by the gauges. Which means much of the 'increase' may actually be due to more precipitation falling as rain.

4.2.3 Natural variability

Ecosystems and society are both exposed to a combination of natural variability and anthropogenic change. Arctic climate and weather exhibit considerable temporal variability, often associated with changes in mean sea-level pressure, sea-ice cover, wind patterns, and the distribution of air masses and temperature. The natural variations are associated with different weather phenomena and are linked to the position and strength of the polar jet (polar vortex), storm tracks, the Arctic Oscillation (AO), and ocean currents (especially the Atlantic Meridional Overturning Circulation). Some of these phenomena are expected to change over the coming decades and in so doing affect the nature of the short-term fluctuations, but how they are likely to change under a warmer climate is currently unclear. This is examined in the following sections.

4.2.3.1 Feedback mechanisms

The various components of the climate system interact in different ways, often with a change in one causing a change in another, which then leads back to cause additional change in the first. This is known as a feedback, and it is these *feedback mechanisms* that are responsible for natural variability in the climate system and make predictions so challenging. Although many feedbacks are well understood, the possibility of additional feedback mechanisms that are currently unknown cannot be excluded. One type of inter-connection is between sea-ice or snow and temperature, through their reflecting properties and the ability of the surface to absorb sunlight (the *albedo effect*). Clouds and atmospheric humidity also play a role by influencing the way light and heat are transferred. Air temperature itself also involves feedbacks to heat loss.

Pithan and Mauritsen (2014) analyzed results from state-of-the-art GCM simulations (CMIP5) and found the largest contribution to Arctic amplification was made by temperature feedbacks. Their reasoning was that more energy is radiated back to space at lower latitudes than higher latitudes when the surface warms. They concluded that the surface albedo feedback was the second largest contributor to Arctic amplification. Graversen et al. (2014) found changes in the mean vertical temperature profile associated with a stronger greenhouse effect (the *lapse-rate feedback*) to make a significant contribution to the polar amplification, and their analysis showed this to account for 15% of the amplification in the Arctic. In comparison, they found melting snow and ice to account for 40% of the Arctic amplification. Another type of feedback involves changes in the vertical temperature profile, and Woods and Caballero (2016) suggested that this may be connected with southerly moisture injections as these may influence both temperature and sea ice.

Other phenomena and processes which link different parts of the Arctic climate system include storm tracks and ocean currents and their importance for moving heat around. Left to their own devices, these interconnections, which allow changes in some aspects of the climate to feed back to others, sometimes even in circles, lead to natural variability. The question as to how these different feedback processes may change in the future can be rephrased to ask more specifically: How will the character of these important natural phenomena be affected by continued global warming?

4.2.3.2 Natural hazards

Natural hazards in the Arctic result from weather phenomena such as storms (strong winds, high waves), avalanches, rockslides, floods, wildfires, and harmful effects of freezing rain and rain-on-snow events. The hazards presented here are connected with physical phenomena and processes in the atmosphere, ocean and land. Many of these phenomena may have some connection with low-pressure systems and storm tracks. The risk associated with these events for society and ecosystems can be determined from a climatological description of a region, because climate is based on weather statistics and describes the probabilities connected to the weather events. The following sections examine the different types of hazard in the context of these extreme weather phenomena.

Synoptic activity and storm tracks

Mid-latitude storms, also referred to as *synoptic storms*, are associated with low surface pressure, high winds, and ocean surface waves. They may also generate heavy precipitation, and are considered weather hazards in relation to health, offshore activities, transport and infrastructure (avalanches and rockslides; Hov et al., 2013). In 2012, parts of Svalbard were covered in ice after a rain-on-snow event (Hansen et al., 2014), with severe implications for wildlife and tourism. The event itself was associated with a low-pressure system moving northwards that brought a combination of extreme warm spells and heavy precipitation, followed by sub-zero temperatures. The incident increased permafrost temperature, triggered slush avalanches, and left a significant ground-ice cover. Rain-on-snow events may become more frequent with higher temperatures in the future, which would have far-reaching implications for Arctic ecosystems and societies through the associated changes in snow-pack and permafrost properties.

On 19 December 2015, an avalanche responsible for two fatalities and the destruction of ten houses in Longyearbyen was triggered by a blizzard on the previous day with strong easterly winds that had generated a pile-up of snow on the hillside. This was connected to a low-pressure system from the Norwegian Sea, south of Iceland, that moved northeastward and combined with a temporarily stationary low-pressure system southwest of Svalbard (Figure 4.5 and 4.6). Fast icing at sea, caused by sea spray in sub-zero conditions is another winter

Christian Jaedicke

Figure 4.5 Avalanche in Longyearbyen, Svalbard on 19 December 2015.

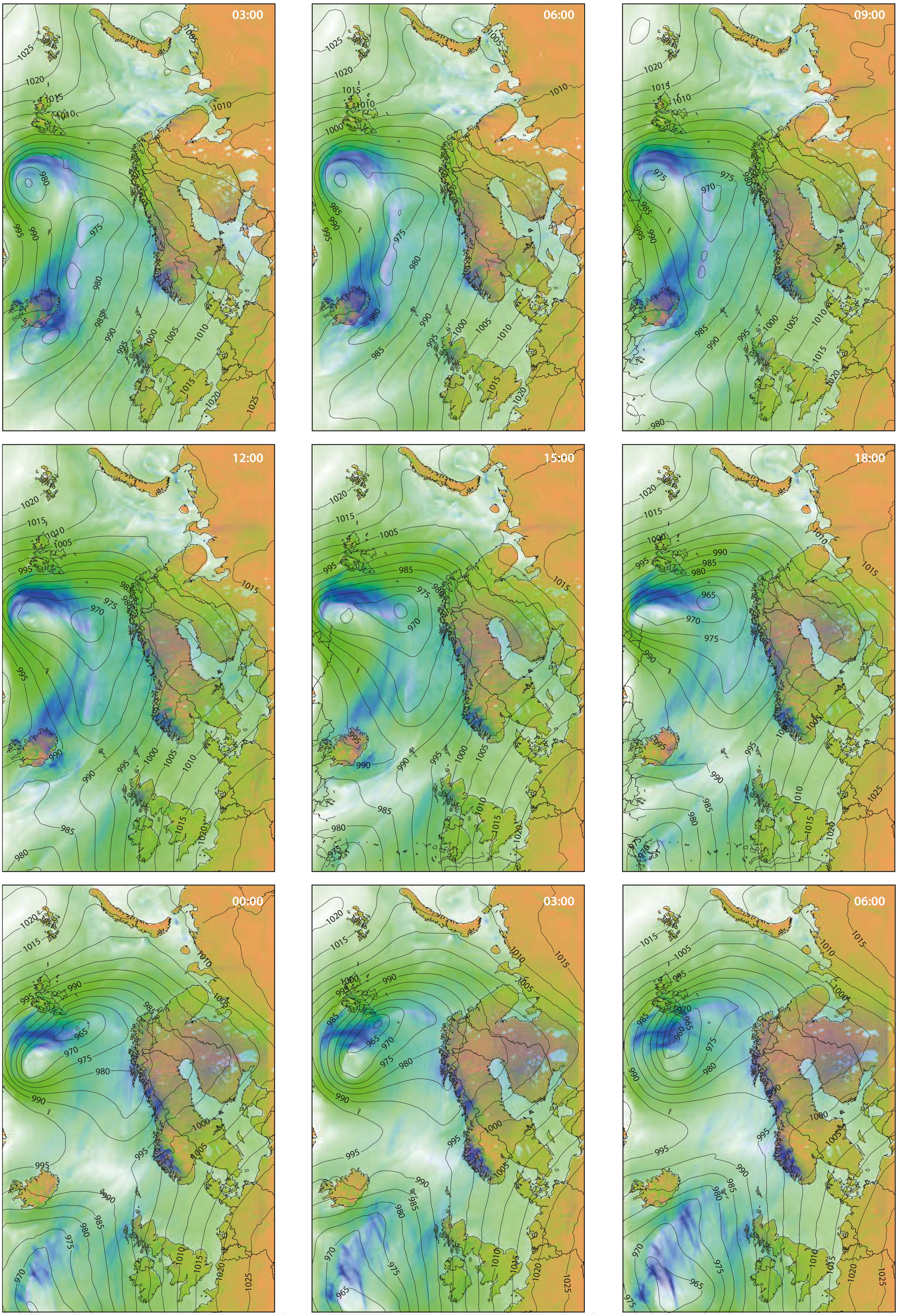


Figure 4.6 Development of the synoptic storm on 18 and 19 December 2015 responsible for two fatalities and considerable damage to buildings near Longyearbyen, Svalbard. The plots show archived forecasts from HIRLAM8 (Met Norway). Contours show mean sea-level pressure, green shading indicates wind gusts, and blue areas show the regions in which precipitation fell for a period of 24 hours.

phenomenon considered a hazard (Loeng, 2008). It becomes more severe with strong wind and higher waves, and is therefore also connected to storminess.

To know whether such storms will become more common or more severe in the Arctic in future is important for adaptation planning. However, it is difficult to predict the atmospheric circulation response to global warming owing to natural climate variability, in space and time. This natural variability generates substantial uncertainty in the model projections of future atmospheric circulation patterns, especially for the next 30 to 50 years. It should also be noted that most GCMs simulate storm tracks that are too weak and display equatorward biases in their latitude (Zappa et al., 2014), and these biases also affect their projections. At present, there is no clear signal for future changes in storm statistics.

Chang et al. (2012) analyzed a proxy for storm activity and found a reduction over the Barents area in the future for the CMIP5 results but little change using the CMIP3 results. Other model projections have also shown a decrease in cyclones over the Norwegian, Barents and Greenland seas during the cold season (Ulbrich et al., 2013; Roshydromet, 2014; Akperov et al., 2015). Projections of North Atlantic and European cyclones from multi-model studies (CMIP5 RCP4.5 and RCP8.5) indicate a tripole pattern with decreasing cyclones in the Norwegian Sea in winter and in summer with fewer and weaker cyclones along the southern flank of the North Atlantic storm track (Zappa et al., 2013). Catto et al. (2014) analyzed climate projections based on a multi-model ensemble (CMIP5 RCP8.5) and found overall decreases in future weather front frequency, but a poleward shift in maximum frequency. Another study of extreme Arctic cyclones based on a multi-model ensemble (CMIP5 historical period) found a modest historic increase in storminess in some regions (including southeast of Iceland) compared to future projections (Vavrus, 2013). Catto et al. (2014) suggested that future changes in frontal disturbances were likely to be associated with storm tracks, and that front strength could decrease at higher latitudes due to amplified surface warming in the Arctic and a reduced temperature gradient. They found little change in storm frequency for the Barents area, but strong indications that storm intensity will decrease. The simulated storm tracks were linked to sea ice is such a way that they both influenced and were influenced by the sea ice. According to Bengtsson et al. (2009), most models agree that a poleward shift in storm tracks is inevitable over the long-term under a warming climate, along with a general weakening of the global cyclonic activity.

In contrast, a recent study which used the dependency of storm track statistics on mean sea-level pressure to show a slight increase in the frequency of deep cyclones over the Barents Sea under a warming scenario (Benestad et al., 2016). This finding is consistent with an analysis of past trends, which suggests there has been a northward shift in the storm tracks as well as increased cyclonic activity in the Arctic in recent decades (e.g. Zhang et al., 2004; Inoue et al., 2012; Sato et al., 2014; Rutgersson et al., 2015). Recent RCM data project an increase in the maximum daily wind speed (Figure 4.7), especially in winter, in the northeastern part of the Barents Sea including the northeastern coast of Svalbard (Dobler et al., 2016). The projections show increases in wind speed of more than 3 m/s in winter between the two blue lines on the graphic (i.e. the

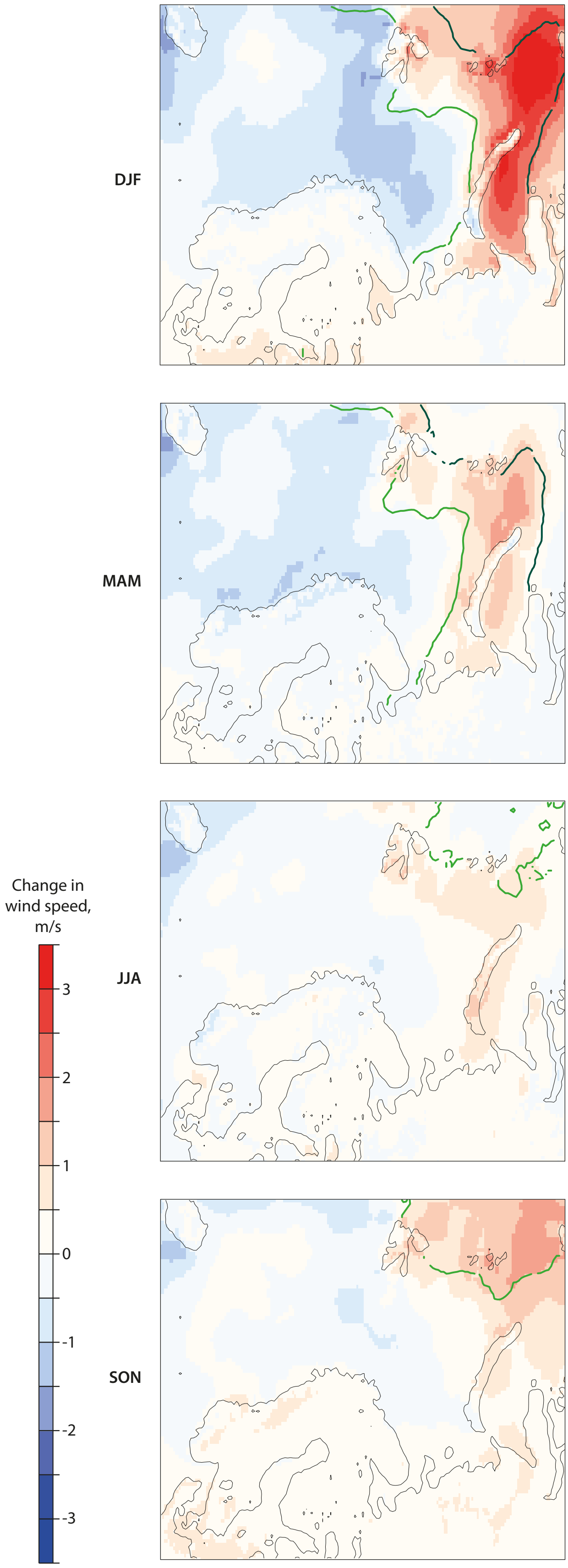


Figure 4.7 Projected seasonal change in daily maximum 10-m wind speed over the Barents and Scandinavian region using the regional climate model COSMO-CLM driven by the global MPI-ESM-LR earth system model under the RCP8.5 scenario for the period 2071–2100 against a 1971–2000 baseline. The green lines indicate the northern extent of an area that is ice-free sea for at least 20% of the time in the future (dark green) and historical period (light green) (Dobler et al., 2016).

Figure 4.8 Polar low off the Finnmark coast, 23 March 2011 (MET Norway / NOAA).

area where sea ice shows the strongest seasonal variations). For the areas of maximum change, north and northeast of Novaya Zemlya this corresponds to a relative increase in maximum wind speed of 40%.

Polar lows

Polar lows are small (~100 km) maritime vortices with a short lifetime (several hours), accompanied by extreme weather conditions in the lower troposphere and so represent a threat to human life, coastal infrastructure and offshore activities (Figure 4.8). There are on average 13 polar low events per year in the Norwegian and Barents seas, mainly during the cold season (October to April), with a high number of events in March (Figure 4.9). The seasonal dependency of polar lows was first shown in a study at MET Norway in Tromsø from 1982 to 1985 (Lystad et al., 1986), and the same seasonality was confirmed in a more recent study for 2000 to 2009 (Noer and Lien, 2010). Polar lows develop when cold air from the polar ice cap is forced out over the warmer waters of the North Atlantic Current such that the air is heated from below, which generates convective systems that bring storm force winds and heavy snowfall.

Polar lows pose a serious risk to shipping owing to the rapid onset of storm force winds. They are associated with weather conditions that are well outside the operating limits for aircraft and for oil and gas drilling operations. Due to their limited predictability and the rapid onset of extreme weather conditions, polar lows are a priority concern for shipping and oil exploration. A study by Zahn and von Storch (2008) using NCEP/NCAR re-analysis data shows there was little change in polar low frequency between 1948 and 2005. A mapping study by Kvammen (2014) of the actual trajectories (Rojo et al., 2015) of the polar lows recorded at MET Norway from 1999 to 2013 also shows little change in their spatial distribution

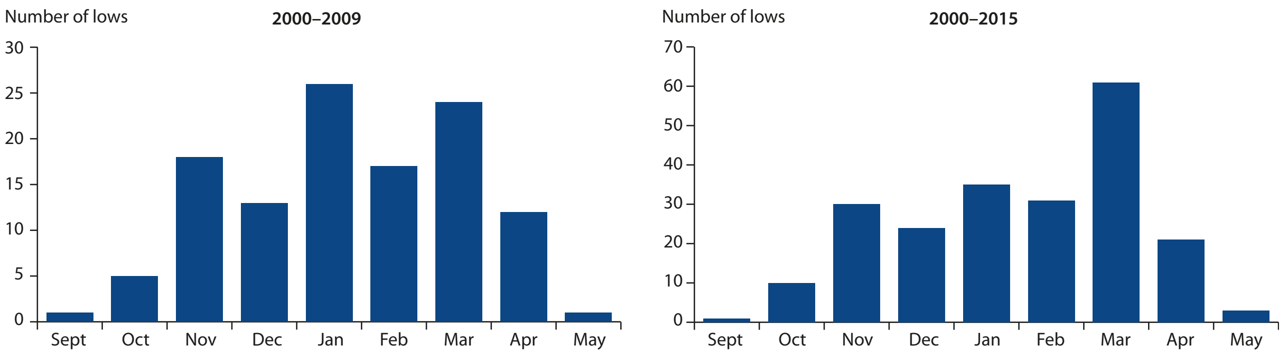


Figure 4.9 Seasonal distribution of polar lows recorded at MET Norway for the first two decades of the 21st century (note different scales on axes) (MET Norway).

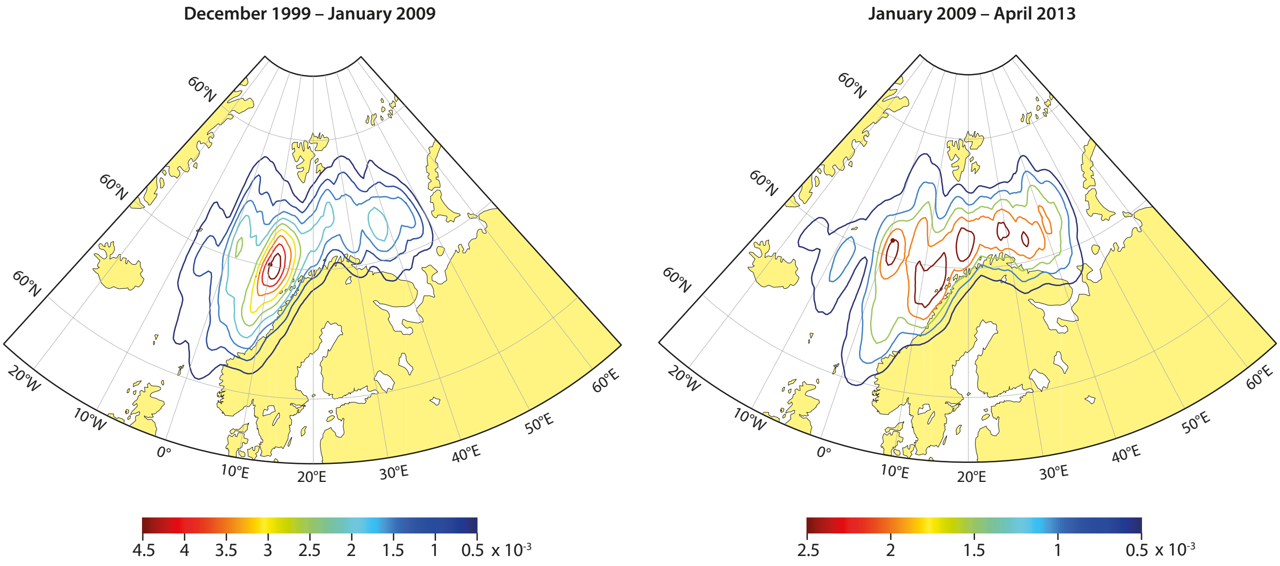


Figure 4.10 Kernel density estimates for two equally sized intervals of the data set. (Kvammen, 2014; Rojo et al., 2015).

prior to 2009, with peak activity off the coast of Lofoten and Vesterålen, but a recent shift eastward with more occurrences in the central Barents Sea (Figure 4.10).

According to the IPCC scenarios, the troposphere in Arctic regions is likely to warm faster than the global average, whereas sea-surface temperatures in the Arctic will rise more slowly, consistent with the concept of a shorter response time for the troposphere. The result will be reduced convective instability, which will lead to fewer polar lows in the future (Zahn and von Storch, 2010). The source area is also likely to shift slightly northward (Zahn and von Storch, 2010). This may lead to fewer polar lows affecting Norwegian coastal waters, but more in the northern and central Barents area. Observational data for the Norwegian and Barents seas show RCMs are able to reproduce the climatology of polar lows and associated extreme events reasonably well in this area (Shkolnik and Efimov, 2013). For future projections of polar low occurrence, the most useful parameters are sea-surface temperature and temperature in the mid-troposphere, since these determine the static stability, which is key to the development of polar lows. The regional flow pattern as represented by the North Atlantic Oscillation (NAO) or other similar indices can be a useful tool. There is also a connection to the planetary boundary layer (i.e. the lower part of the atmosphere between the surface and the upper layers where the air is free to flow, unrestricted by friction from the surface), because this determines the properties of the cold air outbreaks needed for polar low formation. Hence, good knowledge of ice and snow coverage in the Arctic and neighboring areas is essential for understanding polar lows.

Planetary boundary layer

The atmospheric boundary layer is a region characterized by turbulence and shallow convection, and is influenced by clouds, oceans, and the presence of sea ice. It is the medium through which the atmosphere is coupled to the oceans and a region dominated by a vertical flow of heat and moisture. Despite an increase in the frequency of convective clouds over past decades, a shallow stably stratified boundary layers is still thought to remain frequent over the continents and northern islands in the Barents area. Through turbulent convection over the Barents Sea, heat and moisture from the ocean are mixed throughout the low- and mid-troposphere from where they are transferred via the large-scale circulation across the wider Arctic region, causing a rise in temperature and precipitation along the Arctic rim. However, the large-scale circulation is extremely sensitive to perturbations (Rossby waves) within the circulation itself. It is now recognized that warming of the Barents Sea blocks heat transport into the Eurasian continent causing widespread winter cooling (Outten et al., 2013). The most visible and important impact of the convection is connected to increasing atmospheric moisture and developing of convective clouds.

The planetary boundary layer plays a strong role in the Arctic. A shallow planetary boundary layer is powerful magnifier of any climate forcing perturbations and anthropogenic pollution hazards. Under conditions with a shallow boundary layer, anthropogenic heat pollution (e.g. urban heat island effects) is significantly enhanced (up to 2°C in Longyearbyen, 6°C in Barrow, and 12°C in Murmansk), with potentially profound environmental implications. Theoretical studies suggest polar low events are initiated by developing boundary layer convection (Økland, 1987; van Delden et al., 2003).

Cloudiness and humidity

Clouds are associated with weather fronts, synoptic storms, sea ice and planetary boundary layer processes. Clouds are likely to be important for Arctic tourism, as is precipitation. Fog may present challenges in terms of navigation and transport, especially if the droplets are supercooled and freeze on contact with solid surfaces. The intense convection associated with some clouds may generate strong wind gusts, icing and rough surface waves. To date, there is little reliable information concerning past and future trends in cloudiness.

The combination of relatively high sea surface temperature and low air temperatures drives strong vertical convection in both the lower atmosphere and upper ocean. Vertical heat flux reaches an annual average of ~80 W/m^2, and in winter may exceed 200 W/m^2 over the open water in sea areas representative of conditions in the Barents area (Smedsrud et al., 2013). Frequent winter storms regularly increase the heat flux to 500 W/m^2 or more (Ivanov et al., 2003), which is higher than observed at tropical latitudes. Clouds require cloud condensation nuclei (aerosols) for droplets to form, and data from Arctic field studies suggest aerosol concentrations may be higher over the open sea and the ice-edge than over sea ice-covered regions (Leck and Svensson, 2015). Leck et al. (2002) identified two local aerosol sources: bubble bursting and oxidation products of dimethyl sulfide. As the Arctic climate warms, intensive convection follows the advance of open water, initiating regional and larger hemispheric impacts through teleconnections (Inoue et al., 2012; Smedsrud et al., 2013; Mori et al., 2014; Sato et al., 2014). There are some indications of more frequent convective cloud types over the past three decades (Esau and Chernokulsky, 2015), but strong interannual variability in winter cloudiness makes it difficult to identify trends (Stramler et al., 2011). Clouds are one of the most uncertain aspects of climate models (Boucher et al., 2013), and so projections are not yet possible.

Esau and Chernokulsky (2015) analyzed cloud observations recorded at stations since 1880 and found a steady increase in the frequency of convective cloud types over the past three decades. Local vertical convection with latent heat release in convective clouds is critical to the observed increase in moisture content in the mid-troposphere (2–6 km) and precipitation/snowfall in the surrounding regions (Bulygina et al., 2011; Boisvert et al., 2013; Bintanja and Selten, 2014). These processes cannot be linearly extrapolated following the prescribed scenario of Arctic warming and sea-ice retreat. Esau and Chernokulsky (2015) argued that convection over the Barents Sea develops spatially in the form of convective fields, based on the analysis of Bruemmer and Pohlman (2000), and thus is controlled by the frequency of cold air outbreak events and the size of the open water area. As both factors are constrained, it is reasonable to suggest that the observed intensification of extreme winds and related dangerous events will peak and then decline through the 21st century. Such a reduction is seen in the regional climate projections according to the analysis of polar lows by Zahn and von Storch (2010). It should be noted that the convective fields, cold air outbreaks, and polar lows indicate a shift in extreme weather phenomena to the eastern Barents Sea where observations show they have previously been rare or absent.

The question about cloud cover changes is not clear. On the one hand, Screen and Simmonds (2010) argued that past Arctic warming is mainly due to the decline in sea-ice extent with cloud cover playing a lesser role. However, changes in humidity may also have had some effect, and the decline in sea-ice extent is linked to the increase in humidity through the increase in open water area, and thus increased evaporation. On the other hand, higher water vapor concentrations may have enhanced the warming observed in the lower atmosphere during summer and early autumn. Variability in cloud cover has been linked to sea-ice variability near the ice margin (Schweiger et al., 2008) and retreating sea ice may be associated with a response governed by several factors, with a decrease in low-level cloud amount and an increase in mid-level clouds (Sato et al., 2012). Stramler et al. (2011) found conditions such as overcast or cloudless skies had a strong effect on the Arctic atmosphere and on phenomena such as storms at the surface. Extensive cloud cover prevents surface heat loss and so reinforces warming for sea ice and snow, in contrast clear skies allow heat to be lost back to space, thus cooling the surface. These effects are particularly strong in the Arctic, because cold air holds less water vapor and thus absorbs less heat energy. Although frequent transitions between clear and cloudy states in winter have been associated with pronounced swings between warm and cold sea-ice temperatures, there seems to be no clear upward or downward trend in the past observations (Stramler et al., 2011). When seasonal cloudy skies begin to dominate in spring, temperatures begin to rise and the sea ice is brought closer to its melting temperature, even before the heating effect of increased sunlight takes effect. Hence, springtime clouds may bring forward the date for melt onset, and thus more frequent Arctic clouds under a warmer climate could accelerate sea-ice decline. Dobler et al. (2016) analyzed cloud characteristics in a set of projections and found a decrease in winter mean cloud cover over the Barents Sea and an increase over the nearby land area, dominated by changes in low-level clouds. They observed an increase in the convective cloud fraction over the Barents Sea as well as increased convective and total precipitation. Although these model results were derived using a single RCM, Koenigk et al. (2015) found a similar decline in cloudiness with a different RCM.

There are natural hazards for which there is little published scientific literature, such as thick fog. There are few systematic observations of fog in the Arctic and it is difficult to model. It is mostly mentioned in connection with field trips and wildlife observation. Arctic fog appears to be more frequent in summer, and according to a Norwegian report (Loeng, 2008), is often caused by cold air extending over open sea during high pressure systems. The frequency of fog events is expected to fall in the central Barents Sea during mid-summer because the ice edge has receded. However, more fog is expected in other seasons when more sea ice is present with more polynyas (areas of persistent open water that are usually ice-covered).

That GCMs are poor at simulating seasonal variation in Arctic cloudiness (Inoue et al., 2006) is a concern and may result in inaccurate predictions for sea-ice onset and duration (Stramler et al., 2011). Sea ice and cloudiness are mutually interdependent through a feedback, which makes it difficult to determine cause and response. Nevertheless, such shortcomings may help explain the spread in model projections and their underestimate of sea-ice decline in recent decades. Furthermore, even if GCMs can reproduce average conditions in the Arctic, it may be for the wrong reason if they do not capture sea-ice onset and duration.

4.2.4 Air pollution and black carbon

The adverse effects of fine atmospheric particulates on human health have been well documented, with no evidence of a safe level of exposure or threshold below which no effects occur (WHO, 2013). Black carbon (BC) appears to be a better proxy for harmful combustion-related particulate species than the undifferentiated particle mass. Thus reductions in human BC exposure should lead to a reduction in health effects associated with fine suspended matter (WHO, 2012). Visible light is strongly absorbed by BC, and the result is atmospheric warming (Bond et al., 2013). BC is formed during incomplete combustion and can be distinguished from other carbonaceous species in the atmosphere because it is formed in flames, is refractory, and is insoluble in water and common organic solvents (Bond et al., 2013). It also has a short atmospheric lifetime (about a week) and is removed via wet and dry deposition processes. As a result, emission reductions can drive rapid change in atmospheric concentration.

Highly reflective surfaces, such as snow and ice in the Arctic increase light absorption by BC particles in the atmosphere. BC also absorbs light after deposition onto (and then into) snow and ice, where it accelerates the melt process (Pedersen et al., 2015). BC has made an important contribution to the observed rise in Arctic surface temperature through the 20th century (although carbon dioxide is still the major factor driving the rise in Arctic temperature) (Quinn et al., 2008; Koch et al., 2011; AMAP, 2015a). It may be technically possible to reduce global anthropogenic BC emissions by up to 75% by 2030 (Shindell et al., 2012; AMAP, 2015a; Stohl et al., 2015). As well as helping to slow warming, BC emission reductions would also have significant health benefits (Anenberg et al., 2012; Shindell et al., 2012).

Local emissions currently represent only a small fraction of the BC found in the Arctic, much of it having been transported into the Arctic via long-range transport from lower latitudes. However, higher latitude emissions are more likely to end up on the Arctic surface. In relative terms, emissions close to and within the Arctic region have a larger impact per unit of emission than those at more distant sites (AMAP 2015b). According to AMAP (2015a), the eight Arctic nations are responsible for about 30% of the Arctic warming due to BC. Thus emission reductions within the Arctic Council member countries could help reduce warming and lead to related health benefits, especially within the Arctic.

The Barents area has relatively high BC emissions compared to other regions at the same latitudes. Anthropogenic BC emissions in the region were estimated at 40 kt in 2010, which is 9% and 0.6% of Arctic and global anthropogenic emissions, respectively. Hegg et al. (2011) reported significantly higher washout ratios for BC than previously measured, and suggested that the increase can be explained by snow riming within the accretion zone. Hirdman et al. (2010) reported a general downward trend in measured BC concentrations at the Zeppelin station on Svalbard, with a decrease of 1.4±0.8 ng/m^3 per year (2002–2009). Forsström et al. (2013) measured BC concentrations in snow samples collected in the period 2007–2009 and found 11–14 ng/g on Svalbard. Air originating from the eastern sector appeared to contain BC levels more than 2.5 times higher than air arriving from south to west (Forsström et al., 2009), and may reflect the combined effect of the atmospheric concentration gradient, orographic effects of the archipelago, and efficient scavenging of carbonaceous particles through precipitation. In the Barents area, flaring associated with gas extraction is the most important source, responsible for ~90% of anthropogenic emissions. Flaring refers to the practice, mainly used within the oil industry, whereby a large proportion of the associated gas is burned at the production site. However, estimates are based on very few measurements (Stohl et al., 2013) and BC emission estimates are relatively uncertain (Bond et al., 2013). Other important BC sources are transport (mainly diesel engines; see Evans et al., 2015) and residential heating, both estimated to make roughly equal contributions to the emission balance. These emissions are usually concentrated in population centers, visible on a map of the region (Figure 4.11).

The high share of flaring in the emission balance is because the Barents area overlaps large parts of the Russian production fields in western Siberia (shown in the eastern part of the Barents area in Figure 4.11), that account for most past and current oil production in Russia (Carbon Limits, 2013). There is a general lack of data for the Russian part of the Barents area (and Russia in general), and very little local and regional information available to date for constructing emission inventories. However, ongoing efforts (atmospheric modelling, regional inventories, measurements) are expected to improve the situation in the near future. There are some data for the Nordic countries – Norway, Sweden (Swedish Environmental Protection Agency, 2015) and Finland – but further work is encouraged on improving the basis for activity level data, spatial representation of emission information, and emission factors for major emission sectors, especially residential combustion (ACAP, 2014). Some regional assessments have recently been conducted. For example, Evans et al. (2015) estimated BC emissions from diesel sources in the Murmansk district

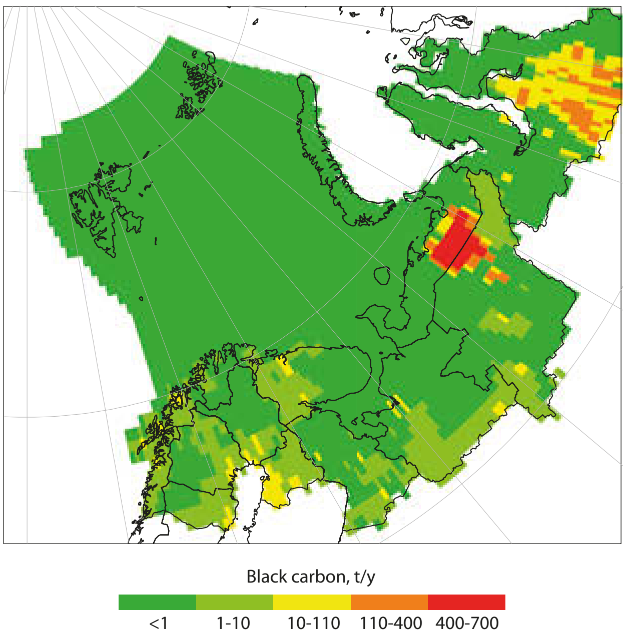


Figure 4.11 Black carbon emissions in the Barents area (excluding wildfires). Graphic based on the global emission dataset (IIASA-GAINS, ECLIPSE v5) used in the most recent AMAP assessment on black carbon and tropospheric ozone (AMAP 2015a,b) and the ECLIPSE project (Stohl et al., 2015; Klimont et al., 2017).

(including the city of Murmansk) at 0.4 kt in 2012. The most important sources were diesel trucks and machinery in the mining industry, followed by on-road transport.

There are also other atmospheric pollutants such as mercury, but they are not necessarily connected to climate change other than through an indirect connection with coal burning (AMAP, 2011).

4.3 Changes in the ocean and sea ice

4.3.1 Importance of the Barents Sea

The Barents Sea constitutes about 10% of the Arctic Ocean by area and has a mean depth of only 230 m. Despite this limited volume it influences a much larger region. It is favorably located for exchanges of heat between the ocean and atmosphere because it occupies a key position in one of the main gateways to the Arctic Ocean. The Barents Sea dominates the Arctic heat budget and has the strongest ocean-air heat exchanges in the Arctic (Häkakinen and Cavalieri, 1989). It is an important production area for dense water (Ivanov et al., 2004), which leaves the Barents Sea through relatively deep channels and sinks into the Arctic Ocean, thus contributing to the global thermohaline circulation. The sea ice cover is seasonal over the major part of the Barents Sea; in summer the area is ice free except for the very northern margin, whereas in winter, the marginal ice zone (the transition zone between open water and consolidated ice cover) is located north of the polar front (Smedsrud et al., 2013).

The state of the upper ocean is crucially important for weather and climate in the surrounding area. The ocean and atmosphere are continuously interacting, through the exchange of momentum, moisture and heat (Bintanja and Selten, 2014). Surface waves are the most visible effect of this interaction in the ocean. The properties of the upper mixed layer are a less visible but no less important an outcome since they determine the marine biota. Changes in sea water temperature are reflected in air temperature (for example, the warming effect of the ocean elevates mean winter temperature on Spitsbergen by about 10°C relative to the zonal average at the same latitude), cloudiness and precipitation.

In the Arctic, the ocean-atmosphere interaction is strongly mediated by sea ice, where sea ice properties (concentration and thickness) determine the strength of energy fluxes. In winter, the upward heat flux from the open ocean is about two orders of magnitude higher than through the pack ice (Smith et al., 1990). The area of open water determines fetch length and wave height. Sea ice also influences the underlying water column. In spring and summer, sea ice controls the amount of solar radiation absorbed, thus limiting warming in ice-covered areas, and ice melt contributes to the freshwater balance. Occasional opening of polynyas (compact ice-free zones in consolidated ice cover) in winter may trigger instant convective mixing of the water column to substantial depths (or cascading of dense water from the shelf) leading to ventilation of deep layers and upwelling of nutrients to surface waters (Marshall and Schott, 1999; Ivanov et al., 2004). Sea ice also provides a habitat for various Arctic species, including plankton, seals, and polar bears among others, and in the Barents Sea forms an important element of the marine ecosystem. Water temperature and salinity (basic seawater properties) affect the functioning of ecosystems, directly or indirectly through secondary effects such as density stratification and light transmission. Ocean waters are in constant motion, due to winds and tides. This motion drives constant renewal of the water at any given location. Any change in currents or tidal features may in turn affect water properties and nutrient transport, with potential for impacts on the marine ecosystem.

The Barents Sea supports various industrial sectors, including those important for local communities as well as those important for the wider Barents area (such as international shipping routes connecting Europe and Asia, see Danilov et al., 2014). Changes in oceanic and ice conditions in the Barents Sea are likely to have socio-economic consequences, locally and in distant regions. Projections for the future include continued warming and declining sea ice. Less sea ice leads to greater heat release to the atmosphere and reduced vertical stability, as well as a shift in the large-scale atmospheric circulation pattern over Europe in winter (Christensen et al., 2015). Models suggest further reductions in sea ice in the Barents and Kara seas may bring colder winter temperatures in Europe. Recent model simulations suggest that the North Atlantic Oscillation (NAO; the dominant mode of near-surface pressure variability over the North Atlantic and neighboring land masses) is highly sensitive to the location of sea ice loss, and that its northern center of action shifts westward or eastward depending on whether the sea ice loss occurs in the Atlantic or Pacific sectors of the Arctic (Pedersen et al., 2016).

4.3.2 Past trends and future projections

The Barents Sea is one of the Arctic regions with the greatest sea ice variations (Deser et al., 2000; Francis and Hunter, 2007). About 50% of the Barents Sea is ice-covered in winter, but most of it is open sea during summer. Daily to annual sea ice variations are mainly caused by variations in wind strength and direction (Kimura and Wakatsuchi, 2001; Kwok et al., 2005; Koenigk et al., 2009). Anomalously northerly winds transport more and thicker ice from the central Arctic into the Barents Sea and further south, mainly through the section between Svalbard and Franz Josef Land. In contrast, southerly winds prevent ice transport southward while simultaneously moving warmer air and water masses from the Atlantic into the Barents Sea, preventing sea ice formation (Sandø et al., 2014b; Sato et al., 2014). The Arctic sea ice cover is influenced by the northward ocean heat transport in the Norwegian Sea (e.g. Sandø et al., 2010; Smedsrud et al., 2010), and the ocean heat transport through Fram Strait and the Barents Sea Opening plays an important role in sea ice variability in the Barents Sea over annual time scales (Schlichtholz, 2011; Årthun et al., 2012; Nakanowatari et al., 2014; Ivanov et al., 2016) and longer (Koenigk et al., 2009; Alekseev et al., 2015). The observed sea ice decline in the Barents Sea has occurred at the same time as an observed increase in Atlantic heat transport due to both strengthening and warming of the inflow (Årthun et al., 2012). During winter, the ice margin has shifted towards the north and east (Årthun and Schrum, 2010). Autumn sea ice variations and reductions in the Barents Sea have been linked to the North Atlantic Circulation in the following winter, and to

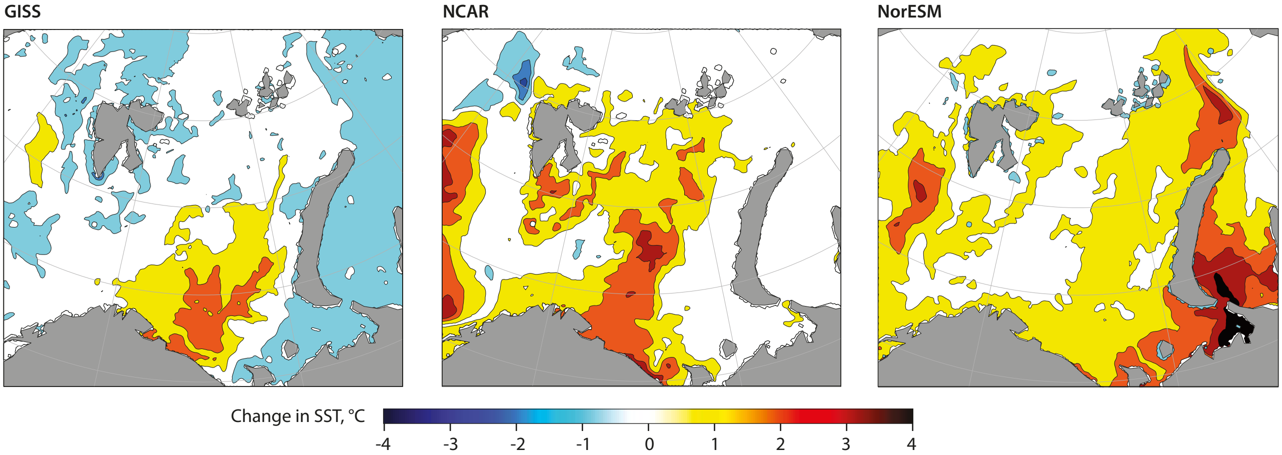


Figure 4.12 Change in sea surface temperature in March for downscaled GISS (left), NCAR (middle) and NorESM (right). The left and middle plots are from Sandø et al. (2014a) and show change between present (1981–2000, data from the 20C3M control run) and future (2046–2065, A1B scenario). The right plots shows change between 2010–2019 and 2060–2069 using the RCP4.5 scenario (Bentsen et al., 2013).

temperature and snowfall extremes over parts of Europe and Asia (Petoukhov and Semenov, 2010; Hopsch et al., 2012; Yang and Christensen, 2012; Liptak and Strong, 2014; Mori et al., 2014).

Observations provide clear evidence of change in Arctic sea ice. First-year sea ice extent decreased by 3.5–4.1% per decade over the period 1979–2012, with the most pronounced reduction occurring during summer at 9.4–13.6% per decade (equivalent to a loss of 0.73–1.07 million km^2 per decade), and was 11–16% per decade for multi-year sea ice (Vaughan et al., 2013). In the Barents Sea, observations reveal that ice extent in the 'cold' 1965–1975 period reached on average 180,000 km^2 in August, while in the 'warm' 2001–2012 period ice extent was considerably less at 46,000 km^2 (Roshydromet, 2014).

The monthly ice cover anomaly in the Barents Sea reveals a linear decrease of ~7% per decade over the period 1979–2007, but significant interannual variability (Comiso and Nishio, 2008). Submarine data and satellite measurements show mean Arctic sea ice thickness decreased from 3.64 to 1.89 m over the period 1980–2008 (Rothrock et al., 2008; Kwok and Rothrock, 2009). Observations over recent decades show a strong reduction in sea ice volume in the Arctic (Döscher and Vihma, 2014), attributed to increased greenhouse gas concentrations and increased northward ocean heat transport into the Barents Sea (Skagseth et al., 2008; Levitus et al., 2009).

Sea-ice loss has many consequences in the underlying ocean and the overlaying atmosphere. For example, ice decline in winter increases the exposure of relatively warm open water to cold air outbreaks, which in turn leads to stronger turbulent convection in the atmospheric boundary layer. Sea ice may provide a link between changes in the ocean and in atmospheric circulation (Nakanowatari et al., 2014; Sato et al., 2014), and stronger convection will increase boundary layer thickness and cloudiness, which may generate extreme snowfall and unusually strong winds (Tetzlaff et al., 2014).

The physical environment of the Barents Sea is influenced by climate change in terms of changes in sea level, salinity, temperature, and thereby also changes in sea-ice extent and thickness. Changes in temperature and salinity are likely to cause changes in vertical stratification, which has implications for vertical exchange, water chemistry and the biota. Oceanographic conditions are strongly determined by advection (horizontal movement of mass, heat and salt) and by exchange with the atmosphere (precipitation, evaporation, air-ocean energy fluxes).

Observed trends are likely to continue or strengthen in the future, and recent climate model simulations (CMIP5; IPCC, 2013) suggest the Barents Sea will be the first Arctic region ice-free all year round. An evaluation of how well the most recent GCMs capture past trends suggests there is a tendency for models to slightly overestimate sea-ice extent in the Arctic (by about 10%) in winter and spring (Flato et al., 2013). Projections indicate that surface air temperature in the Barents Sea and Arctic Ocean will increase by about twice as much as the global mean, with accompanying decreases in sea-ice extent (IPCC, 2013). The air-ocean heat fluxes will thus show considerable change, principally in response to a warmer ocean due to increased uptake of solar heat following the decline in ice cover and increased heat transport into the region. The Barents Sea will be ice-free all year round by mid-century according to many climate models, and recent analyses of future projections suggest that increased oceanic heat transport will be a major contributory factor to sea-ice decline in this area (Koenigk and Brodeau, 2014).

The latest assessment by the Intergovernmental Panel on Climate Change (AR5) confirms the findings of its previous assessment (IPCC, 2007) in terms of change in Arctic sea-ice extent to the end of the century, despite a wide spread in model results. The rate of decrease in mean sea-ice cover is greatest in September, but there are major differences in the multi-model averages depending on RCP used. The projected decline in sea-ice extent ranges from 8% (RCP2.6) to 34% (RCP8.5) in February and 43% (RCP2.6) to 94% (RCP8.5) in September (Collins et al., 2013). Due to a substantial reduction in sea-ice thickness, the corresponding losses in sea ice volume are expected to be much higher.

Regional effects of climate change can be heavily modulated by internal variability and may either mitigate or worsen the impacts of global warming. Interannual variability in sea-ice extent is largely determined by the inflow of relatively warm Atlantic Water through the Barents Sea Opening (Sandø et al., 2010; Årthun et al., 2012, Smedsrud et al., 2013, Nakanowatari et al.,

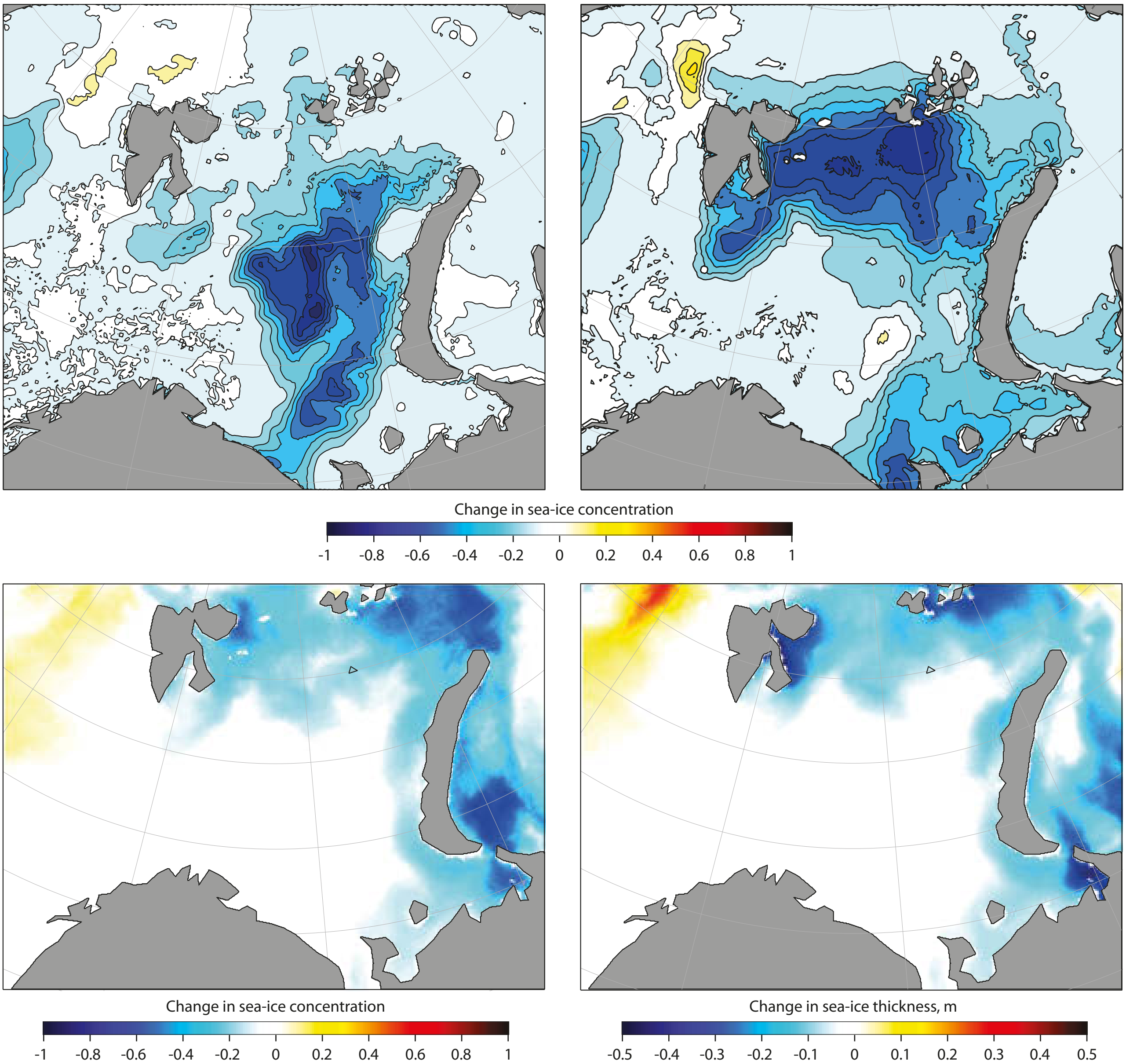


Figure 4.13 Change in sea ice concentration and thickness in March. Downscaled GISS sea ice concentration (upper left), NCAR sea ice concentration (upper right), NorESM sea ice concentration (lower left), and NorESM sea ice thickness (lower right). The upper plots are from Sandø et al. (2014a) and show change between present (1981–2000, data from the 20C3M control run) and future (2046–2065, A1B scenario). In the lower plots, change is between 2010–2019 and 2060–2069 using the RCP4.5 scenario (Bentsen et al., 2013).

2014; Sandø et al., 2014a,b), but observations show none of the CMIP5 GCMs are able to simulate sufficient inflow of heat through this region (Sandø et al., 2014a). Results from ocean-downscaling of two CMIP3 control climate simulations (20C3M) were analyzed by Melsom et al. (2009) and Sandø et al. (2014a). They found that sea ice and hydrographic conditions in the Barents Sea are reproduced well in the downscaling experiments, despite large regional biases in the GCMs used for boundary conditions. This improvement is attributed to a more realistic ocean circulation and inflow of Atlantic Water in the Barents Sea Opening due to higher resolution in the regional models.

Can similar improvements be expected if the future scenarios from the GCMs are downscaled? Comparing the downscaled CMIP3 GCMs for the A1B scenario shows relatively good agreement for future temperature rise, but large differences for future salinity (Sandø et al., 2014a). These differences were attributed to deviations in the GCMs that were transferred to the regional models through initial and boundary conditions. Differences in the representation of the hydrological cycle in the GCM simulations lead to large differences in the ocean salt budget that regional downscaling cannot change much. The ocean is too inert and the impact of the GCM results from the initial and boundary conditions is too large. So, despite improvements due to increased resolution in regional models, unrealistic biases in the global model projections will influence the final regional results. Figure 4.12 shows the projected change in sea-surface temperature from the downscaled NorESM4.5 model. The downscaled RCP4.5 results from GISS-AOM, NCAR-CCSM, and NorESM show the greatest temperature increase in the Barents Sea will occur in March, which differs from the rest of the Arctic Ocean. Like the two downscaling studies reported by Sandø et al. (2014a), this model also shows a warming of 1–2°C for March in most of the Barents Sea. This warming is reflected in the sea-ice extent data shown in Figure 4.13, where reductions relative to the present ice concentration can be seen in the central and northern parts of the Barents Sea. These results support the idea of oceanic heat transport having a critical role in sea-ice decay in this region. The decreasing trend in average sea-ice thickness for the 50-year period 2010–2070 (Figure 4.13) is less than observed from 1980 to 2008. This may be due to natural variability, which is typically stronger on a decadal scale than a multi-decadal scale.

4.3.3 Water temperature and salinity

A continued northward shift in the ice edge in the Barents Sea will affect thermohaline properties in the upper mixed layer. Prolonged exposure of the open sea surface to the atmosphere will lead to a substantial increase in the uptake of short-wave solar radiation and consequent warming of surface waters (Sandø et al., 2010). Together with reduced surface salinity, as indicated by the downscaled NorESM results the warming strengthens density stratification over most of the Barents Sea (Figure 4.14). The excess freshwater input at the surface is due to increased high latitude precipitation, as projected in almost all CMIP5 models (Collins et al., 2013).

The significance of the large-scale inflow of warm and saline Atlantic-origin water in shaping thermohaline conditions in the Barents Sea is well-established (Smedsrud et al., 2013; Sandø et al., 2014b). Under conditions of gradually shrinking ice cover, the effect of Atlantic-origin water inflow is expected to strengthen and extend further east, since cooling and freshening of the Atlantic-origin water en route will slow, as there will be less ice to melt. Signs to support this idea have recently been reported (Årthun et al., 2012; Dmitrenko et al., 2015). Warmer and saltier Atlantic-origin water further to the north-east in the ice-free Barents Sea will provide more heat for release to the atmosphere in winter, and the associated heat loss will increase water density and favor the development of deeper convection. This phenomenon results in the formation of a well-ventilated water column and enhances nutrient transport to the surface waters.

In shallow waters, convection may extend to the seabed, providing the prerequisite conditions for cascading (down-slope gravity-driven current), which transports dense water from the shelf to the deep ocean (Shapiro et al., 2003). Dense water formation on the shallow banks of the Barents Sea and western shelf of Novaya Zemlya Archipelago is well-documented (Midttun, 1985; Ivanov et al., 2004). As long as ice forms on the shallow shelves in winter, dense water formation will continue and may even increase (Bitz et al., 2006; Ivanov and Watanabe, 2013; Moat et al., 2014). One of the reasons for this is effective salinization of cold shallow water near the marginal ice zone, as described by Ivanov and Shapiro (2005). Later, however, together with declining sea ice formation in winter, bottom water formation in the Barents Sea is expected to slow, both in terms of open ocean convection and cascading (e.g. Årthun and Schrum, 2010). Recent (2008) measurements confirm that the density of Atlantic-origin water in the Barents Sea and bottom water in St Anna Trough (through which dense water enters Nansen Basin) have remained higher than those measured in the 1990s (Lien and Trofimov, 2013), potentially indicating greater dense water formation in the ice-depleted conditions of the 2000s.

The existence of large-scale open water area in winter caused by increased influx of Atlantic-origin water, might also impact on the atmosphere both locally and remotely. For the hypothetical case of a totally ice-free Arctic Ocean in winter, simple calculations by Newson (1973) suggest that weakening of the meridional temperature gradient would lead to a weakening of westerly winds, atmospheric blocking and general cooling in the mid-latitudes. The veracity of this foresight was recently confirmed by more sophisticated model studies (Petoukhov and Semenov, 2010; Hopsch et al., 2012; Yang and Christensen, 2012; Liptak and Strong, 2014; Mori et al., 2014).

4.3.4 Sea level and surface waves

Sea level is the combined result of many factors and local sea level will be affected differently depending on location. These factors include melting ice over land (but not melting sea ice), thermal expansion as water warms, prevailing winds, distribution of land and ice masses, and the shape of the ocean basin. Land rebound following the disappearance of the Fennoscandian ice sheet is

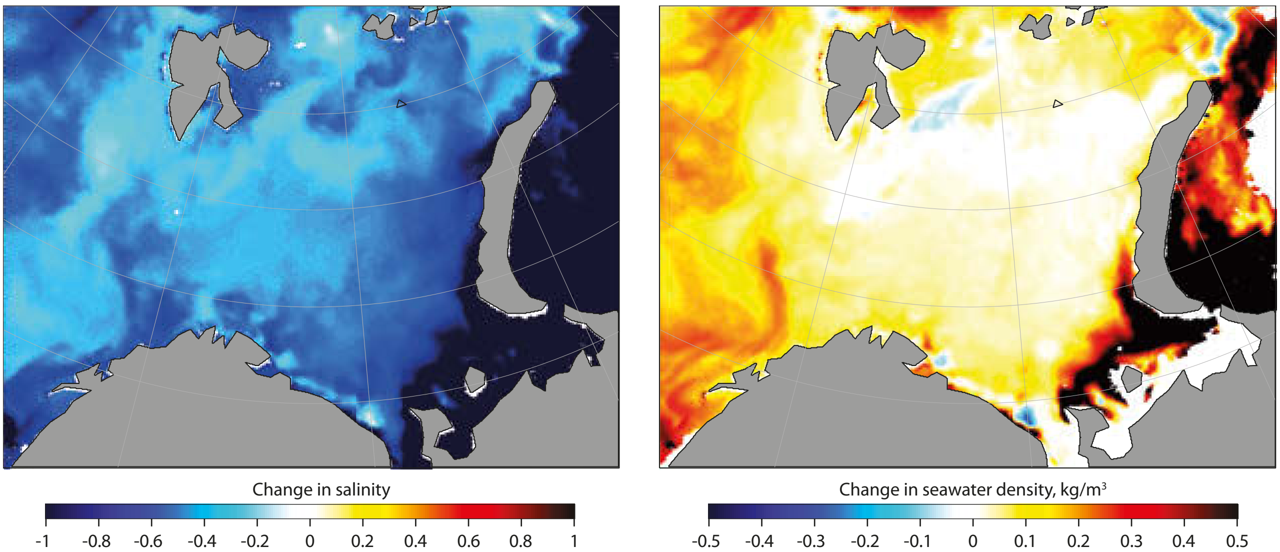


Figure 4.14 Change in salinity (left) and stratification (right) in the upper 50 m in March based on downscaled NorESM data. Present (2010-2019) and future (2060-2069) using the RCP4.5 scenario.

also a major factor in the Baltic Sea region. Simpson et al. (2015) observed that relative sea level projections can differ by as much as 0.50 m from place to place depending on vertical uplift rates. Analysis of changes in local sea level must take into account the glacial isostatic effect. The adjustment-corrected rate from Arctic tide gauges for the period 1993–2014 varies along the Norwegian mainland: Vardø (2.7±1.6 mm/y), Honningsvåg (2.9±1.6 mm/y), Hammerfest (3.8±1.7 mm/y), Tromsø (3.7±1.8 mm/y), Andenes (3.7±1.7 mm/y), Harstad (3.4±1.7 mm/y), Kabelvåg (4.0±1.8 mm/y), and Bodø (3.3±2.0 mm/y).

Future wave conditions in the Barents Sea will depend on surface wind and ice conditions, and the open sea is subject to strong wind fetch (Lynch et al., 2008). Based on model simulations for the 21st century, Khon et al. (2014) reported a significant increase in wave height across the Arctic due to reduced sea-ice cover and stronger regional winds. An opposite tendency, a slight reduction in wave height, may appear over the Atlantic sector and Barents Sea. Rutgersson et al. (2015) found no trend in wind statistics, but pronounced decadal variations.

An important implication of stronger wave-induced vertical mixing under ice-free conditions is a deepening of the upper mixed layer and a rise in salinity due to the influx of deeper more-saline water (Kraus and Turner, 1967). This additional salt flux from below may partly compensate for the additional freshwater input through increased precipitation. This could result in a spatially intermittent weakening of vertical density stratification accompanied by localized winter convection rather than massive overturning events.

4.3.5 Ocean acidification

Many marine species incorporate calcium carbonates into their body armor (shells, exoskeletons, claws). Ocean acidification leads to less favorable conditions for the formation of these mineral-based features. Currently, surface waters are generally supersaturated with respect to calcium carbonates, but saturation state decreases when more CO_2 is dissolved in the water. Understanding how saturation state could change with respect to these minerals is therefore important for understanding how ocean acidification might impact future ecosystems.

The average pH of surface waters in the global oceans has decreased from about 8.2 before the onset of the industrial revolution to a present-day average of about 8.1 (Caldeira and Wickett, 2003; Orr et al., 2005). This ocean acidification (i.e. fall in pH) is due to the dissolution of CO_2, and corresponds to about one third of the CO_2 released to the atmosphere from fossil fuel combustion, cement production, and changes in land use (Canadell et al., 2007). Oceanic uptake of atmospheric CO_2 is influenced by ice cover, biological productivity, surface water temperature and ocean circulation. A longer ice-free period and a decrease in ice extent will increase the air-sea carbon flux, especially through increased biological productivity (Sakshaug, 2004; Wassmann et al., 2006). However, warming of surface waters also decreases CO_2 solubility (e.g. Kaltin et al., 2002) and reduced deep water formation will slow the transport of CO_2 into the deeper ocean.

Surface water from the North Atlantic entering the Nordic Seas is presently equilibrated with respect to atmospheric CO_2 and carries a small or zero capacity for further uptake (Olsen et al., 2006). A timeline of carbon chemistry from Ocean Weather Station Mike (66°N 2°E) reveals an annual change in pH of -0.001 pH-units per year in surface water between 2001 and 2005 (Skjelvan et al., 2008). In this respect, it is important to remember that the pH scale is logarithmic.

The surface waters of the Arctic Ocean, with low temperature and high natural concentrations of inorganic carbon are expected to become under-saturated with respect to aragonite (a common form of calcium carbonate) within a few decades (Steinacher et al., 2009). In fact, Arctic surface waters are already under-saturated in some areas for parts of the year, especially over the continental shelves (Chierici and Franson, 2009; Steinacher et al., 2009). Models have become an important tool for investigating the effect of further increase in atmospheric CO_2 in a future climate. Using downscaled physics from a GCM to force an ecosystem model, Skogen et al. (2014) compared the simulated carbonate system in 2000 and 2065 under the A1B scenario in the Nordic and Barents seas. They found the aragonite saturation state of seawater would evolve, with under-saturated bottom waters shoaling by about 1200 m in the Nordic Seas (from 3000 m to 1800 m) and a large increase in the areal extent of under-saturated surface waters. Surface water pH fell by 0.19 pH-units between 2000 and 2065, while the model showed the annual CO_2 air–sea flux in the Barents Sea almost doubled over this period, from 23 to 37 gC/m^2.

4.3.6 Icebergs

Sea ice and icebergs are two distinctive ice forms at high latitudes. While sea ice forms under cold conditions when the upper layer freezes, icebergs are generated when glaciers calve and disintegrate, often associated with warming episodes, and may represent a hazard to shipping and offshore activities (Sharp et al., 2011). See Section 4.4.3 and CliC/AMAP/IASC (2016) for more information concerning glaciers. The main sources of Barents Sea icebergs are glaciers on Svalbard, Franz Josef Land, and Novaya Zemlya and some other Arctic islands (Ushakov and Victoria) (Walsh et al., 2005; Kubyshkin et al., 2006). Iceberg calving accounts for 30% of glacier reduction on Franz Josef Land (Koryakin, 1988). There is limited information on icebergs, because there is no universal model for predicting their presence, and climate change projections do not include icebergs calved from glaciers. The number of icebergs varies from year to year, and Abramov (1992) found a correlation between the southern limit of the sea ice and the southward extension of the icebergs in the Barents Sea, based on navigation and aircraft monitoring of icebergs between 1933 and 1990. The southward movement in both ice forms may be explained by a predominance of northerly and northeasterly winds. Abramov also found an increase in the number of iceberg reaching further south over the 57-year study period. Kubyshkin et al. (2006) attributed a big tabular iceberg detected in the Shtokman Gas Condensed Field in 2003 to outlet glaciers on Franz-Josef Land.

The number of icebergs observed in the Barents Sea between 1928 and 2007 showed pronounced year-to-year variability (Zubakin et al., 2007), with fewer icebergs observed before 1950 (less than ~50) than between 1950 and 1955 (~400), followed by a period with variations in the range 200–1400 per year. They also mapped the location of icebergs, their debris, and pieces discovered in the Barents Sea in April–May, and compared this with the number found in September over the period 1928–2007. This showed stronger southerly movement during April–May and that icebergs have extended further south over time.

The present-day upstream glacier retreat and increased iceberg calving rates are expected to fall when glaciers attain new stable states relative to air temperature (CliC/AMAP/IASC, 2016). Rignot et al. (2011) and Enderlin et al. (2014) have produced the most complete annual iceberg discharge time-series to date. This indicates an average loss of 501±52 Gt/y for the 15-year observation period beginning in 1992.

4.4 Changes in terrestrial conditions

4.4.1 Snow

Snow is an important element of the global climate system and serves as an reflective cover over Arctic land areas and ice surfaces. It has particular importance for the Barents area (see Chapter 2) where the different economic sectors (transportation, infrastructure, tourism/recreation, hydropower production, agriculture) are affected differently by snow. Snow structure (especially internal ice layers) may affect the Arctic ecosystem and reindeer herding through changes in the nature of the habitat and in access to food for grazing animals. Reindeer grazing affects low vegetation and its effect on snow melt, and there is a link to permafrost, heat fluxes, soil moisture, and run-off. Extreme cold outbreaks usually take place in the presence of snow cover, and there have been suggestions of associations with the northern hemisphere winter circulation (Rutgersson et al., 2015). The snow cover reflects much of the incoming solar radiation and so cools the overlying air, but also acts as an insulator by protecting vegetation from frost-damage. Snow is also a heat sink during snow melt, keeping ground temperature near zero, and on the tundra determining whether vegetation is visible. Snow on the ground is also an important reservoir for some pollutants, and is affected by snowfall, temperature and wind. It has socio-economic implications through hazards in terms of avalanches.

4.4.1.1 Snowfall

Key elements determining snowfall and snow accumulation at any place on land are elevation, latitude and proximity to moisture sources. Moisture access is determined by the general atmospheric and oceanic circulation, as well as local factors (e.g. mountains, lakes, and distance from the coast). Substantial Arctic warming has been observed since the mid-20th century (Bindoff et al., 2013), with a temperature increase of 0.5°C per decade and a 2% increase in precipitation per decade over the past 30 years in the Arctic (Karl et al., 2015). Declining sea ice and increased evaporation are contributing to an increase in atmospheric moisture and thereby to increased Arctic precipitation (Bintanja and Selten, 2014). Screen and Simmonds (2012) found a pronounced decline in historic summer snowfall over the Arctic Ocean and Canadian Arctic Archipelago in the ERA-Interim reanalysis dataset, due to an increase in the proportion of precipitation falling as rain rather than snow, but little change in total precipitation. They connected the loss of snow on ice to a decrease in surface albedo over the Arctic Ocean, which they found to be comparable to the reduction in albedo associated with the decline in sea ice. The decline in summer snowfall may also explain the thinning of sea ice over recent decades and provides support for the existence of an amplifying feedback associated with warming-induced reductions in summer snowfall.

Local climatic conditions affect precipitation phase, leading to different trends for snowfall (and rain) across the Arctic. Regions with warmer winter climates, such as Scandinavia and the Baltic Sea Basin, have seen declining snowfall trends (Irannezhad et al., 2016), whereas increasing trends have been reported for regions with colder winter climates, such as Canada and Siberia (Kononova, 2012; Vincent et al., 2015).

Räisänen (2016) used data from 12 RCMs (SRES A1B scenario) from the ENSEMBLES project to project changes in snowfall in northern Europe through the 21st century. Results indicate a decrease in total winter snowfall across almost all of northern Europe by 2069–2099. In contrast, snowfall in the middle of winter is projected to increase in the coldest areas: northern Finland, northern Sweden, northern Norway and the Kola Peninsula. But even in these areas, results indicate a general decline in total annual snowfall. This is due to a decline in the number of snowfall days. By 2100, the number of snowfall days may be 10–20% lower in northern Fennoscandia, and 20–50% lower in coastal areas. However, there may be a slight increase (0–10%) in average snowfall intensity during snowfall days. Rutgersson et al. (2015) associated higher snowfall in the Arctic with excess moisture due to warm conditions in the preceding summer and autumn.

4.4.1.2 Snow cover extent

Historical and projected changes in Arctic snow-cover extent (SCE) are reported in the SWIPA update (Brown and Schuler et al., 2017). Changes in spatial, temporal and seasonal SCE reflect changes in drivers such as Arctic warming, Arctic moistening and Arctic greening, and interaction between these drivers and feedback mechanisms. Since 1980 there have been widespread decreases in Eurasian SCE, especially over northern Scandinavia. The ACIA assessment reported a 10% decline in SCE over 30 years, with increasingly shorter snow seasons (ACIA, 2004) associated with increased rates of freezing and thawing. The reinforcing snow albedo feedback has played a key role in the poleward retreat of spring and early summer SCE, and the most pronounced decline in SCE has occurred at high latitudes (60°–70°N) where the potential impacts of snow albedo feedback are greatest. The decline in SCE accelerated between 2007 and 2014, especially in Eurasia where the trend over 1971–2014 was amplified compared 1972–2006. This amplification was mainly due to the stronger decline in SCE over 1971–2014 in spring and early summer (Hernández-Henríquez et al., 2015).

4.4.1.3 Snow cover duration

Over the past 30 to 40 years, snow-cover duration (SCD) has declined by 2 to 5 days per decade in the Arctic, including the Baltic area, mostly due to earlier melt onset in spring (Brown and Schuler, 2017). Across much of the northern hemisphere, the date of melt onset advanced by about 1–2 weeks over the period 1979–2012 (Mioduszewski et al., 2014). The strongest trends in SCD occurred in northern and western Eurasia. Arctic coastal and island areas experienced a statistically significant decline in SCD over the period 1978–2007 (Callaghan et al., 2011). There was a statistically significant decline in SCD of about 3 days per decade in Fennoscandia over the period 1951–2007. For the period 1978–2007, there was a statistically significant decline in SCD of 7.3 days per decade over the Fennoscandian sector and 6.3 days per decade over the Barents Sea sector. Rasmus et al. (2014a,b) found the snow season had shortened over the past 30 to 50 years at several observation sites in the reindeer management area of Finnish Lapland. Between 1979 and 2007, melt onset near Sodankylä in northern Finland advanced by 3.4 days per decade, and over northern Fennoscandia, SCD was projected to decrease by 10–15 days under 1°C warming, 15–25 days under 2°C warming, 20–35 days under 3°C warming, and 25–45 days under 4°C warming (Lehtonen et al., 2013). In the Atlantic areas of Russia, Bulygina et al. (2011) found the number of days with snow covering more than 50% of the area surrounding a meteorological station decreased by 1.4% per decade between 1966 and 2010. Callaghan et al. (2011) found SCD over northern Europe and Siberia has decreased since 1980.

The decline in SCD is projected to be greatest over northern Scandinavia. SCD in 2050 is projected to be 30-40% shorter than in 2011 (Brown and Schuler, 2017), and the expected fall in the annual number of snow cover days in northern Fennoscandia is projected to be greater in coastal regions than mountainous areas (Lehtonen et al., 2013). The main reason for the decline in SCD appears to be earlier melt onset in spring and later freeze-up in autumn. When compared to the mean length of the snow season for 1981–2010, the decrease is expected to vary from 10 to 40 days with a rise in temperature of 1–4°C. Annual SCD is projected to decrease by 10–20% over most of the Arctic by 2055 under the RCP8.5 emissions scenario (Brown and Schuler, 2017) but with much larger decreases (>30%) over the European sector and western Alaska. However, the magnitude and temporal evolution of the projected changes in SCD averaged over the Arctic are strongly dependent on the emission scenario used as the basis for the projected changes in climate.

4.4.1.4 Snow depth and snow water equivalence

Although SCD has broadly decreased across the Arctic, snow depth (SD) and snow-water equivalent (SWE) (mean and maximum values) have shown wide regional variations with both increasing and decreasing trends observed. According to Rasmus et al. (2015), there has been a long-term increase in SD and SCD over most of northern Eurasia. Although *maximum* SD showed little change in northern Sweden over the period 1905–2003, there has been an increase in *mean* winter SD of about 2 cm (5%) per decade since 1913 and 10% since 1930–1940 (Rasmus et al., 2015). The duration and maximum thickness of the basal ice layer has decreased in the European part of Russia since 1966. SD over Eurasia increased over the period 1966–2010 over Eurasia (Bulygina et al., 2011).

In Finland and Russia, there have been reports of greater SD but shorter SCD, and SCD is more sensitive to climate change. Recent updates (Brown and Schuler, 2017) show significant trends for the period 1966–2014 in maximum annual SD in two Russian Arctic regions: the Atlantic Arctic (1.4% per decade) and eastern Siberia (2.4% per decade). This tendency contrasts with that observed in regions with warmer winter climates (e.g. Scandinavia and the Baltic Sea Basin), where the sign and magnitude of the trends in SWE and maximum SD can vary significantly with elevation and distance to the coast.

There are three possible explanations for the recent increase in SD across most of northern Eurasia. First, loss of Arctic sea ice at the start of the cold season has enabled additional water vapor influx into the dry Arctic atmosphere, leading to greater snowfall further south. Second, changes in atmospheric conditions through more intensive cyclonic circulation and more frequent storms have contributed to increased snowfall (Callaghan et al., 2011). Finally, increased precipitation (see Section 4.2.2)

Maximum SD is projected to increase over many areas by 2050, however, the snow season is expected to continue shortening due to the earlier onset of spring melt (Brown and Schuler, 2017). As part of the ENSEMBLES project, Räisänen and Eklund (2012) used regional climate model simulations based on the SRES A1B scenario to project future changes in SWE in northern Europe. They found a general decline in snow amount over the 21st century, but high regional and interannual variability. Individual snow-rich winters may still occur in future decades despite a long-term decline in mean SWE. Climate models project greater changes in future SCD than SWE in the Arctic (Brown and Schuler, 2017). Snow cover in the warmer coastal regions of the Arctic (such as in Alaska and Scandinavia) shows the strongest sensitivities to the warming projected. Only northern Siberia and the Canadian Arctic are projected to see an increase in maximum SD. This contrasting pattern of projected change in maximum SWE is a consequence of the impact of non-linear interactions between rising temperature and increasing precipitation, on snowfall, the snow accumulation period and winter melt events (Räisänen, 2008).

4.4.1.5 Snow quality

Changes in winter climate and especially the frequency and intensity of winter warming events (with or without rain) affect snow properties such as albedo, temperature, density, snow grain size distribution, and ice layers. An observational study by Johansson et al. (2011) of 49 years of snow profile stratigraphy data from Abisko (Sweden), showed an increase in very hard snow layers between 1961 and 2009, with harder snow in early winter and more moist snow during spring. Towards the end of the observation period the number of occasions with very hard snow layers in the snow-pack had more than doubled. Temperature and precipitation both increased over this period, with the increase in air temperature particularly strong at the start and end of the snow season. Warming events followed by low temperatures increase snow-pack density and can generate ice layers in the snow. These ice layers can impede access to forage for caribou, musk-ox and reindeer (Forchhammer et al., 1993; Hansen et al., 2014; Vikhamar-Schuler et al., 2016) as well as for small rodents living below the snow (Kausrud et al., 2008). Soil temperature and thus permafrost are also affected by rain-on-snow induced changes in snow properties (Westermann et al., 2011). There are indications that ground ice formation has become more common at the lichen layer in Finland (Rasmus et al., 2015). Using climate model results (2081–2090 and RCP8.5), English et al. (2015) estimated that future net downward short-wave radiation at the top of the atmosphere may increase by 8 W/m^2 over the Arctic basin due to a decline in surface albedo resulting from a decline in snow and ice cover.

Examples of ecological and societal consequences of rain-on-snow events were reported from Svalbard during and after an extreme event in February 2012 (Hansen et al., 2014). This resulted in a thick ice layer on the ground, increased permafrost temperatures to 5 m depth, and triggered slush avalanches with major impacts on infrastructure (airport closure, restricted traveling in the terrain, closed roads) and wildlife (reindeer starved because they could not access forage). Future warming may bring more frequent rain-on-snow events (Hansen et al., 2014). The processes leading to hard layers or ground-ice layers occur on daily rather than monthly timescales, and whether specific conditions are problematic depends on the general conditions during winter, not just those on particular days.

4.4.2 Permafrost

The changes taking place in permafrost areas under a warming climate are having various impacts. Thawing permafrost has major consequences for buildings, infrastructure and transport networks designed to be supported by frozen ground. For example, roads can be badly damaged when ice within the soil melts and the land subsides. Another effect of thawing permafrost is the release of methane and the reinforcement of the global greenhouse effect. Thawing permafrost can also increase the risk of erosion and landslides if the frozen water in the soil has been acting as a glue. More details about the present state of the permafrost and its effect on hydrology and vegetation can be found in Chapters 2 and 6. According to the recent SWIPA update, the combination of climate-cryospheric-hydrologic change and multiple ecological feedback processes may cause unpredictable reorganization of ecosystem structure and function, and hence trigger ecosystem shifts or give rise to novel ecosystems (Romanovsky et al., 2017). This tendency has already been observed with vegetation shifts and conversions between terrestrial and aquatic ecosystems. For example, thermokarst lakes and wetlands in ice-rich permafrost environments may drain as the permafrost thaws, resulting in their conversion from aquatic to terrestrial ecosystems (Wrona et al., 2016). Projecting the geographic extent and magnitude of such shifts carries great uncertainty, however. According to Bring et al. (2016) and Wrona et al. (2016), the aquatic and terrestrial landscapes of the Arctic have experienced many changes in successional patterns and the spatial extent of biomes where tundra has become shrubland and forest. These changes have largely been driven by climate change and changes in hydrology, especially in relation to permafrost thaw and related flow pathways. Such changes are important in terms of key climate-related fluxes of carbon dioxide, methane, energy, and water (Wrona et al., 2016), and there is an emerging need to establish the spatial extent of ecosystem transformations. Palsas are frost heaves that contain permanently frozen ice lenses. Norway started monitoring palsa peatlands in 2004 (Hofgaard and Myklebost, 2015), in response to concerns about the consequences of reduced palsas on the ecosystem.

The permafrost is thawing because the Arctic is warming, and is expected to continue to thaw under the projected increases in future temperature. Long-term records at a selection of sites providing good spatial coverage across the Barents area show the permafrost has warmed since the 1990s (Romanovsky et al., 2017). The greatest warming has occurred in the cold permafrost of Svalbard and Russia (Figure 4.15). In northern Russia and in the western Siberian Arctic, temperatures at 10 m depth at cold permafrost sites have increased by ~0.4–0.6°C per decade since the late 1980s, with less warming at warmer permafrost sites (Figure 4.15). The European permafrost is thawing and there has been a northward retreat of the southern boundary of near-surface permafrost in European Russia (Rasmus et al., 2015). Records from Abisko in northern Sweden show the period over which the ground remains frozen each year is decreasing, driven by later freeze-up and earlier spring thaw. Mean monthly air temperature is highly correlated with ground temperature to 100 cm depth, and the warming is correlated with soil surface movement due to freezing and thawing. Rasmus et al. (2015) found the southern limit of patchy near-surface permafrost retreated northward by 20–50 km in European Russia between 1974 and 2008.

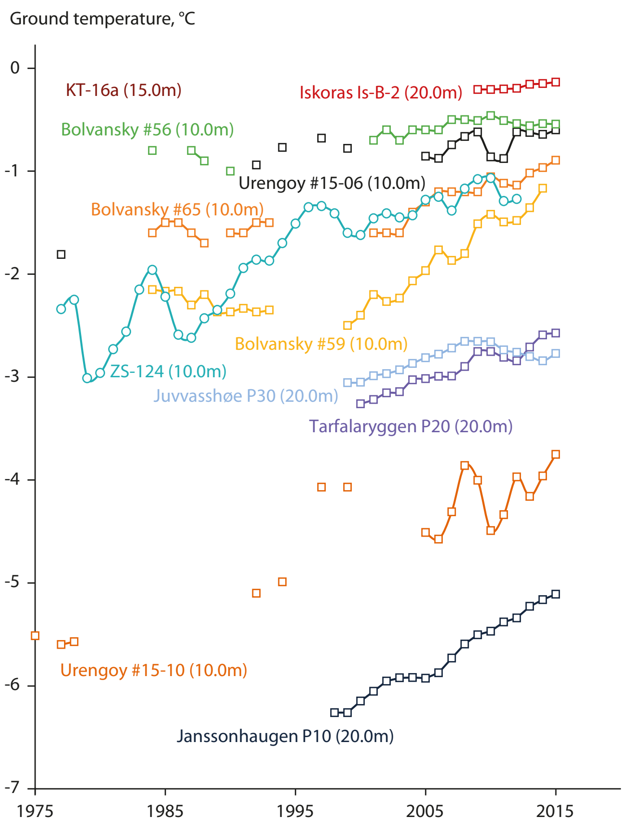


Figure 4.15 Time series of ground temperature at depths of 10 to 20 m below the surface at selected measurement sites that fall roughly within the continuous to discontinuous and warm permafrost zones in the Barents area, including Scandinavia, Svalbard, and Russia. Data updated from Christiansen et al. (2010) and Romanovsky et al. (2014, 2015).

Although there is a general decrease in permafrost temperature with increasing latitude, this relationship varies between regions. Permafrost is warmer in Scandinavia, Svalbard and northwestern Russia than in other Arctic regions, due to the influence of warm ocean currents and prevailing winds on climate, while elevation is a modifying factor in the Nordic countries (Romanovsky et al., 2010; Sato et al., 2014).

Temporal trends in historical permafrost temperature below the depth of seasonal variation (the top layer of soil that thaws during summer and refreezes in autumn, known as the 'active layer) in Svalbard and Scandinavia were analyzed by Isaksen et al. (2007b). Updated records from the Nordic monitoring sites show ground temperature at 20 m depth to have increased by 0.3–0.7°C per decade since the late 1990s at the colder mountain permafrost sites (Figure 4.15). A significant temperature increase is measurable to at least 80 m depth, reflecting multi-decadal warming of the permafrost surface. The high rate of warming on Svalbard since 1998 coincided with a period of higher air temperature. In addition, several extreme and long-lasting warm spells were superimposed on a significant warming trend (Isaksen et al., 2007a; Hansen et al., 2014). Less warming has been observed at warm permafrost sites that have been affected by latent heat exchange close to 0°C. Ground temperature observations at some Nordic sites also confirm permafrost degradation over this period: 1999–2009 (Isaksen et al., 2011) and 2002–2012 (Farbrot et al., 2013).

Active layer thickness (ALT) is more sensitive to short-term variations in climate than deeper ground. ALT records thus exhibit greater interannual variability, mainly in response to variations in summer temperature (e.g. Smith et al., 2009). Most regions where long-term ALT observations are available show an increase over the past five years (Romanovsky et al., 2015). The Russian European North has been characterized by almost monotonic thickening of the active layer over the past 15 years, reaching a maximum in 2012, but decreasing between 2012 and 2014. In the Nordic countries, records (1996–2013) indicate a general increase in ALT since 1999. Summer 2014 was particularly warm in the Nordic countries and contributed to the deepest active layer measured to date at some sites (Romanovsky et al., 2017).

McGuire et al. (2016) analyzed uncertainties in the permafrost response to climate change within the permafrost region since 1960 for 15 model simulations. Although all models showed a loss in permafrost area (ALT <3 m) from 1960 to 2009 over the study area (Romanovsky et al., 2017), there were large differences in loss rates among the models. Slater and Lawrence (2013) and Koven et al. (2013) analyzed Earth System Model projections of soil temperature from the CMIP5 database to assess the models' representation of current-climate soil thermal dynamics. Despite large differences in the extent and rate of change in the permafrost, all models agree that the projected warming and increased snow thickness will result in near-surface permafrost degradation over large areas. In the northern hemisphere, the sensitivity of permafrost to climate change is 0.8–2.3 million km^2 per 1°C of warming. This range in sensitivity results in a wide range of projections for permafrost loss: 15–87% under the RCP4.5 scenario and 30–99% under RCP8.5. Collectively, the CMIP5 models project that permafrost will have largely disappeared from the present-day discontinuous zone by 2100 under RCP4.5.

4.4.3 Land ice

Whereas tundra dominates the northern Siberian mainland, glaciers and ice caps are mainly located on the Arctic archipelagos of the Barents and Kara Seas (Figure 4.16). Some of the world's largest continuous icefields are found there (see Chapter 2), and nowhere else in the Arctic does so much of the coastline constitute of ice-cliffed glacier fronts. These marine glaciers are almost entirely grounded on the sea floor, with only a few examples of floating tongues or ice shelves, mainly on Franz Josef Land (Dowdeswell et al., 1994). Most glacier cover occurs on the Svalbard archipelago (33,800 km^2), followed by Novaya Zemlya (22,100 km^2), Severnaya Zemlya (16,700 km^2), and Franz Josef Land (12,700 km^2). Glaciers on the mainland are limited to a few mountain areas in northern Scandinavia (Lyngen and Øksfjord region, 230 km^2; Sweden/Sarek, 240 km^2) and Siberia (Polar Urals, 15 km^2; Putorana, 9 km^2; Taymir, 35 km^2) (Pfeffer et al., 2014; Arendt et al., 2015).

Most glaciers in the region have been in retreat since the end of the Little Ice Age about 100 years ago (Vaughan et al., 2013). The longest observational record of surface mass balance is from two small mountain glaciers near Ny-Ålesund (Svalbard), and this shows a relatively stable trend of glacier wastage over the last half century (Hagen et al., 2003). Shorter-term records from the larger glaciers and ice caps on Svalbard and the Russian archipelagos show these ice masses are shrinking more slowly, which has also been confirmed by satellite remote sensing over the past decade (Moholdt et al., 2010, 2012b). The first reliable estimates of regional mass balance were obtained from satellite altimetry and gravimetry, and show a negative mass balance of 5–10 Gt/y for Svalbard and about 10 Gt/y for the Russian archipelagos (Gardner et al., 2013). This is unlikely to differ much from the longer-term trend, which contrasts with the situation in the Canadian Arctic and Greenland where glacier mass losses over the past decade have been much larger than in previous decades (Gardner et al., 2011; Kjeldsen et al., 2015). Climate reanalysis and modelling indicate that these regional patterns could change in the future, and surface melting is predicted to increase substantially this century under current climate scenarios (Lang et al., 2015).

The effects of oceanic and climatic change on glacier dynamics are unclear. Two of the largest ice caps in the region, Austfonna on Svalbard and the Academy of Sciences ice cap on Severnaya Zemlya are currently experiencing surging or accelerated glacier flow in several drainage basins, causing rapid dynamic thinning and increased ice discharge into the ocean (Moholdt et al., 2012a; Dunse et al., 2015; see also icebergs in Section 4.3.6). Although these are cyclical or transient effects, they do have a large impact on the regional mass balance and the frequency and size of such events might change under a future climate. No widespread changes in ice flow have been observed, but the retreat of marine glaciers on Novaya Zemlya has increased substantially since about 2000 (Carr et al., 2014) and this might affect their future flow rates. The largest ice shelf in the region (the Matusevich Ice Shelf on Severnaya Zemlya) collapsed in summer 2012 and satellites have observed accelerated flow and increased thinning in the tributary glacier basins in response to the reduced buttressing (Willis et al., 2015).

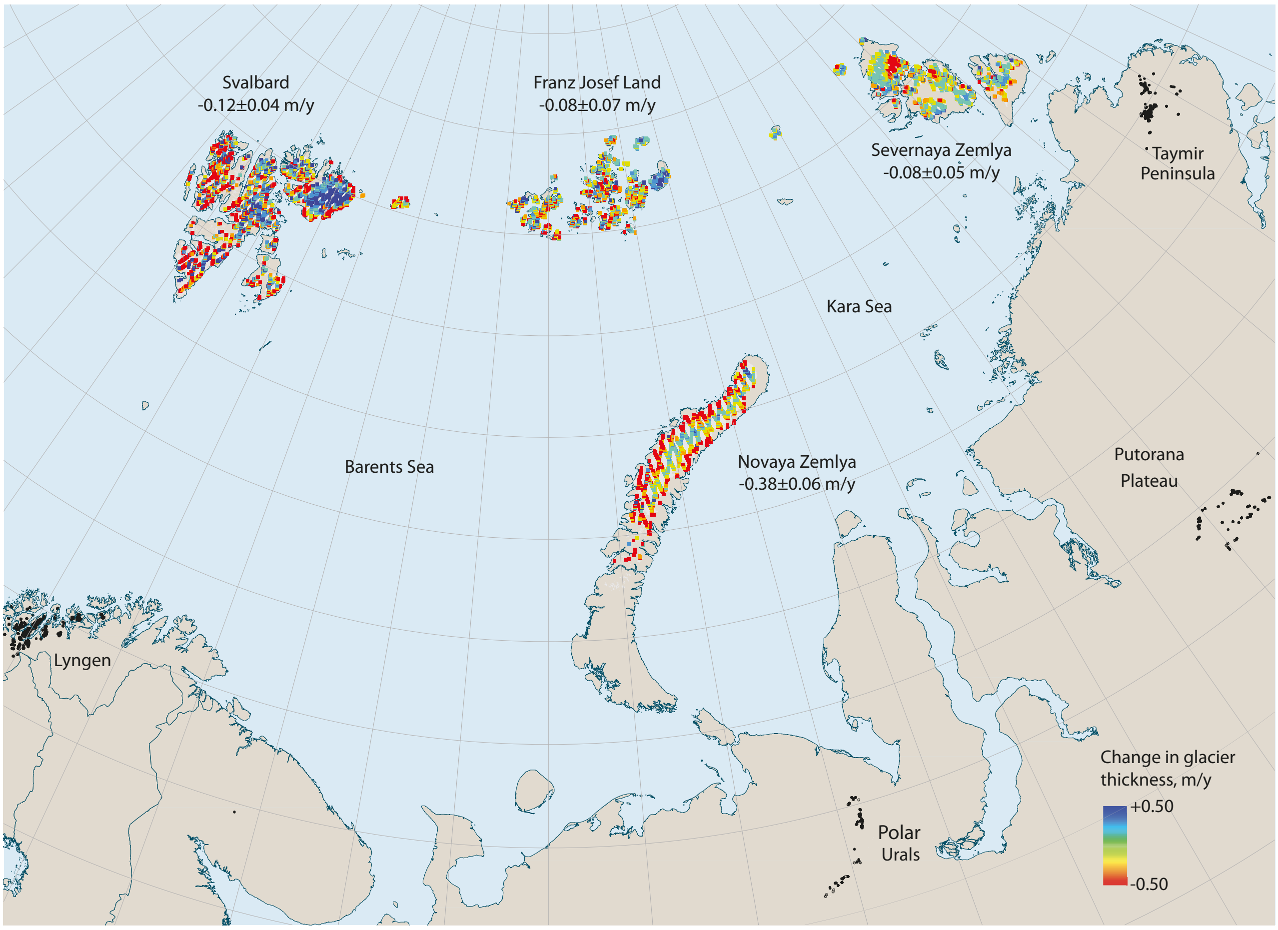


Figure 4.16 Distribution and recent change in thickness for glaciers in the Barents-Kara Sea region. Colors indicate rate of change in thickness based on ICESat laser altimetry for the period 2003–2009. Glaciers on the Eurasian continent are shown in black, with exaggerated extent for better visibility.

Mountain glaciers on the Eurasian mainland are in rapid decline, and the recent thinning of Langfjordjøkulen near the Barents coast of Norway is stronger than observed for any other glacier in Scandinavia. The Siberian glaciers have few direct observations, but satellite imagery shows considerable glacier area losses over the past decade (Khromova et al., 2014). These mass losses are likely to increase in the future and many of the smaller Russian glaciers are in danger of disappearing completely.

Storglaciären in northern Sweden has lost mass since 1992 (Rasmus et al., 2015). The Swedish glaciers respond strongly to changes in climate. Two glacier inventories from northern Scandinavia show a large reduction in ice area between 1973 (321.8 km^2) and 2001 (264.5 km^2) (Rasmus et al., 2015). More details about climate impacts on land ice are reported in the latest SWIPA assessment (Box and Sharp, 2017).

4.4.4 Fresh water and river ice

There has been an observed change in the timing of spring flood associated with changes in the timing of snowmelt (Käyhkö et al., 2015), and ice on waterways is forming later in the season. Earlier break-up dates and shorter periods of ice cover have also been reported. There has been a trend for increased annual river discharge over the period 1961–2000. Over the period 1912–2004, winter and spring discharge in Finland increased most in the north, while summer discharge decreased in the south (Käyhkö et al., 2015). While winter and spring discharge have increased in most rivers, there are some indications in northern Lapland that the long-term winter discharge has decreased. One explanation is that the presence of snow is latitude-dependent, but river regulation complicates any interpretation of these trends. Changes in the prevailing air flow over the 20th century has led to changes in river run-off characteristics in the Baltic States (some which overlap with the Barents study area), with increased winter discharge and decreased spring floods. The situation in the Baltic States contrasts with that of the Nordic countries where changes in winter snow melt are not yet apparent (Rasmus et al., 2015). However, future warming is expected to lead to similar cases further north in the Baltic area. An assessment of Norwegian rivers draining into the Barents Sea (Finnmark county), suggest little change over the past 90 years (Hanssen-Bauer et al., 2015). Lotsari et al. (2010) analyzed climate projections and concluded that the flood discharge in the Tana river (average discharge: 203 m^3/s) draining into the Barents Sea may decline, with spring floods occurring earlier. They also projected that autumnal floods will become more frequent in the future and as a result that their role in sediment transport may also increase. Dankers (2003) suggested that annual discharge from the Tana river may increase by almost 40% under local warming of ~5°C. The Alta river (average discharge: 90 m^3/s) and Pasvik river (average discharge: 175 m^3/s) also drain into the Barents Sea, although both are regulated by dams which means discharge is not only affected by changes in climate. More details concerning rivers and runoff are reported in the SWIPA update (Prowse et al., 2017) and Chapter 2.

4.4.5 Avalanches

Avalanches are a common phenomenon in all areas with steep mountainsides and a seasonal snow cover, and this includes the Barents area where such events occur mainly in Norway. They also occur in Sweden, Finland and Russia. In the High Arctic, on Svalbard and in Franz Josef Land, there are numerous events every year. Avalanches are classified by the water content of the snow during an event. Dry snow avalanches occur where cold winter snow prevails, usually in a continental climate. Wet snow avalanches and slush flows occur in a coastal maritime climate or during spring melt in the Arctic. In Norway, three to four avalanche fatalities are reported each year on average, many in the northern regions of Finnmark and Troms, as well as Spitsbergen.

Rising temperatures and increasing precipitation are changing the types and abundance of avalanches. While wet snow avalanches and slush flows were previously known only around the spring melt in Spitsbergen, events in recent years have occurred around mid-winter in February and March. These resulted from intense rain and unusually high temperatures (Hansen et al., 2014). This indicates a shift from dry cold winters (continental climate) to a more maritime coastal climate, even in the High Arctic. If this trend continues, avalanche types and return periods known from southwestern Norway will be seen more frequently in the coastal continental areas of the Barents area, while the Arctic islands will experience avalanches of the type currently common along the coast of Troms and Finnmark. Hazard zoning based on avalanche frequency analysis for data from previous decades (1961–1990) will thus need to be revised to reflect the changes taking place under Arctic warming.

4.5 Socio-economic drivers: global megatrends and multiple exposure

A general description of the Barents area, including information on the population, employment, main industries, living conditions and systems of governance is given in Chapter 2. Current and projected changes in regional climate and the physical environment are addressed in Sections 4.2 to 4.4. These changes in climatological and meteorological variables (temperature, precipitation, snow, wind, waves, ice, icebergs) are affecting the region's ecosystems, and general conditions for human development. This is addressed in Chapter 6. However, climate change is but one of several factors that will change the current characteristics of the region; it is exposed to multiple other challenges, and climate change interacts with these social, economic and political drivers in complex ways. The focus of this section is on the key socio-economic drivers that will shape the future of this region and affect the ability of its communities to deal with climate change. The drivers are summarized in terms of six megatrends based on the key global drivers in the ~1200 scenarios assessed during the latest assessment of the Intergovernmental Panel on Climate Change (IPCC AR5), as well as on other future studies recently undertaken by national and international institutions.

The Barents area has never been insulated from the external world. Since ancient times, people living in the region have been involved in long-distance trade and exchanges, and over the past 1000 years the vast territories and natural resources of the North have gradually been unlocked. First, the region was made the object of taxation, colonization, and Christianization. With the rise of territorial states, contested boundaries were drawn and the divided areas were integrated into the nation states that emerged in northern Europe after the French Revolution. Exploration and conquest of the Arctic became important tasks for the new nation states, and through waves of industrialization, starting in the late 19th century, the economies of the North were totally transformed. During the Second World War and the Cold War, the Barents area was a focal point in the rivalry between the superpowers. Thus, the region has always been shaped by developments and events originating outside the region. What is new today is the scale, scope and intensity of the external linkages and interactions. The Barents area has become increasingly interconnected with social, economic, political, and cultural processes and changes worldwide. This includes the flow of trade and investment, migration, governance systems, and the spread of knowledge and ideas.

These non-climate-related drivers are of great importance both for the transformation of the region and for the ability to cope with global warming. The consequences of climate change will always depend on societies' vulnerability and adaptive capacity, which are largely determined by human and economic resources, institutions and policies. As pointed out in the last Arctic Human Development Report, "*While the climate in the Arctic is changing, in a number of studies of communities in the region, the impact of climate change on adaptation of communities to change is rather minimal compared to many other factors*" (Heleniak, 2014: 91). This is captured in the notion of 'multiple exposure', which points to the many-faceted threats and hazards that local communities typically face (Kelman et al., 2015).

Climate scenarios are also based on socio-economic assumptions (Andrew, 2014). The IPCC's latest climate change projections are based on selected time- and space-dependent trajectories of concentrations of greenhouse gases and pollutants resulting from human activities. These are known as Representative Concentration Pathways (RCPs) and are commonly known as RCP2.6, RCP4.5, RCP6.0, and RCP8.5, with the number representing the radiative forcing level in 2100. A broader range of socio-economic assumptions can be explored using a more expansive set of socio-economic scenarios assessed by the IPCC (Clarke et al., 2014; Krey et al., 2014). Figure 4.17 shows the key socio-economic drivers (population, economic activity, energy consumption) and the associated global average temperatures as reported by the IPCC (Krey et al., 2014).

Rapid global change makes the future of the Barents area increasingly uncertain and thus more difficult to predict. To date the approach has largely been to extrapolate current trends

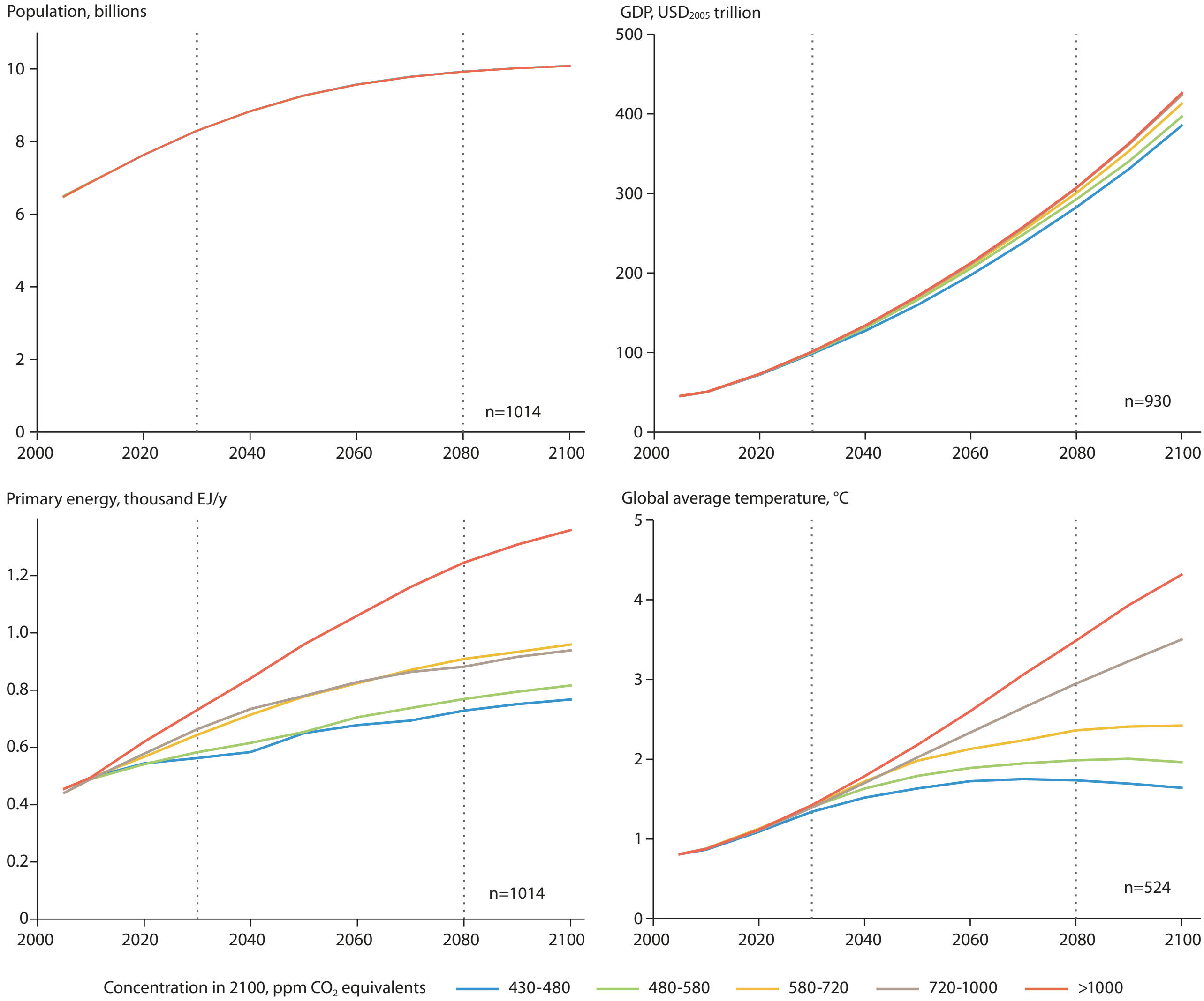


Figure 4.17 Key global drivers in the ~1200 scenarios assessed during the latest IPCC assessment. To enhance clarity, only the median is shown within each scenario category. The dotted lines at 2030 and 2080 are to help highlight the increase in uncertainty with time horizon. The number of scenarios used to generate each plot is shown at the bottom right. Based on the IPCC scenario database (Krey et al., 2014).

and assume that existing patterns will continue. Knowledge is limited however, and the only certainty is that unpredictable events with major global consequence are inevitable. For example, neither the collapse of the Soviet Union nor the terrorist attacks on the World Trade Centre in September 2001 could be predicted but both have changed the course of history. This illustrates the importance of identifying those drivers and megatrends that could have significant impacts on economies and societies worldwide.

A number of studies have attempted to identify these drivers and megatrends, also with a view to the Arctic (Arctic Council, 2009; EEA, 2011, 2015; Nordic Council of Ministers, 2011; Smith, 2011; FNI and DNV, 2012; Lloyd's, 2012; Gore, 2013; Andrew, 2014; Stępień et al., 2015; Haavisto et al., 2016; see also Arbo et al., 2013). However, because most of these studies took place during a period of high commodity prices and before the Russian annexation of Crimea and the introduction of sanctions, they are already out-of-date in several respects. This highlights the uncertainty associated with all projections of future conditions. Moreover, the studies generally address overall trends, but how these trends manifest within different parts of the Arctic is rarely addressed. This gap in knowledge for the Barents area is considered in the following sections. These outline six megatrends and examine how they may affect the Barents area over the mid- to long term. Although most projections extend to 2050, it should be noted that socio-economic projections extending beyond the next 15 to 25 years are usually highly uncertain.

4.5.1 Divergent world population trends

Population is an important driver at the global level and demography is easier to forecast than most other factors. The reason is that the number of people born in a certain period cannot increase during the lifetime of that generation. Population growth is linked to births, deaths and migrations rates, which normally change slowly. As countries develop economically, they tend go through a demographic transition from a fairly stable population, followed by rapid population growth, before reaching a stable or stagnant population. The main element that can modify this demographic transition is net migration. According to the latest UN projections, world population will continue to grow from around 7.3 billion at present to 9.7 billion by 2050 (UNDESA, 2015a). By 2100, the medium projection is 11.2 billion, which is slightly higher than earlier estimates. Growth will be very unevenly distributed; more than 90% of world population growth between now and 2050 is expected to occur in developing countries in Africa and Asia. This may exacerbate existing problems of poverty, inequality, and competition for resources, and thus trigger social unrest and migration. Due to declining fertility, the world population is currently growing more slowly than in the recent past. At the same time, life expectancy at birth is increasing. All over the world the population is therefore ageing.

Europe today has the oldest population, with a median age of 42 years, while the world average is 29.6 years. The fertility rate is now below the replacement rate in all European countries and in the medium UN projection, Europe will have a smaller population in 2050 than in 2015. Deaths are estimated to exceed births by 63 million, but this reduction will be partly offset by international migration. Europe has net immigration, and in recent years some countries have received a large number of refugees and asylum seekers.

In the UN projections, Sweden will see its population grow from 9.8 million at present to 11.9 million in 2050. Similarly, the population of Norway will grow from 5.2 million to 6.7 million. However, population growth in Finland will be lower, from 5.5 million to 5.8 million, while population in the Russian Federation will fall from around 143.5 million at present to 128.6 million in 2050. Although fertility and life expectancy are projected to increase in all four countries, levels are lower in Russia than the Nordic countries. The main uncertainty factor is future migration. Among the Nordic countries, Sweden has received many immigrants and the latest forecasts from Statistics Sweden suggest the Swedish population will reach 12 million by 2040 (Statistics Sweden, 2015). The immigrant population will account for a large share of the population growth (Raneke, 2015). Rosstat, the Russian Federal State Statistics Service, has also produced three population projections to 2051, based on different migration assumptions (Rosstat, 2015). The medium scenario, taking into account socio-economic programs that are already underway, suggests population will remain at the current level. In the low projection, with a continuation of current trends, population will shrink by 20% over the next 35 years, and in the high projection population will increase by 15%. In the latter scenario it is assumed that annual immigration will increase rapidly from about 270,000 people at present, to half a million by 2022, and then to 550,000 after 2030. Although much evidence suggests the Russian Federation is unlikely to receive such a high inflow of migrants (Aleksashenko, 2015), future immigration policies will be important in all four countries.

The Barents area, as defined in this assessment, covers a vast geographic area but contains a relatively small proportion of the total population of each of the four constituent countries. The northernmost parts of Sweden, Norway and Finland have 5.2%, 9.2% and 12.1% of the national populations, respectively, while Northwest Russia, including the Yamalo-Nenets Autonomous Okrug (AO) has less than 3% of the total Russian population. These shares have been decreasing over recent decades. In Russia, several of the indigenous populations are at an earlier stage of demographic transition than the majority population, and have high rates of fertility. In contrast, fertility rates in the Nordic countries have decreased since the 1970s and are now similarly low in rural and urban areas. Future development of the population in the Barents area will therefore be largely driven by migration rather than fertility.

General ageing of the populations implies an increasing dependency ratio. There will be relatively fewer people of working age to support the youngest and oldest parts of the population. The age composition of the population and the ability to integrate immigrants will thus have large consequences for the economy, government expenditure and many aspects of social life.

4.5.2 Urbanization

Globally, there are migration flows between countries and continents, but the largest movements take place within each country. Since 1950, there has been a major shift as people have moved from the countryside to urban areas to seek employment, education, and better life chances. Today, more than half the global population is urban, and by 2050 two-thirds are expected to live in cities and towns (UNDESA, 2015b). By 2030, the world is projected to have 41 mega-cities with more than 10 million inhabitants. The fastest-growing urban agglomerations are located in Asia and Africa.

In the four countries of the Barents area, a large proportion of the population already lives in urban areas. In 2014, the share was 86% in Sweden, 84% in Finland, 80% in Norway, and 74% in the Russian Federation (UNDESA, 2015b). By 2050, these shares are projected to be higher. The urbanization process in the Nordic countries is no longer based on a large number of people moving from rural to urban areas (Svanström, 2015). Rural areas are still losing young people, especially women, but due to lower fertility rates and an ageing population there are no large cohorts of young people in the rural areas anymore. However, looking behind the net figures, it is clear that people are moving in both directions. Many are now moving out of the biggest cities and settling in the peri-urban areas. They live in smaller communities and commute to work in urban centers. Urban growth is mainly an effect of the long-term inflow of young people over several decades, which means urban areas on average have a younger population and more births than rural areas. The urban centers also attract more immigrants. Thus, the rural areas are not drained and depopulated on a massive scale. Instead, the population is slowly ageing and thinning out. The challenges associated with a declining number of working-age people are therefore particularly salient in rural areas, where the maintenance of infrastructure, health and social services will become more challenging.

Settlement patterns in the Barents area reflect the economic base and the historical modes of development. They comprise dispersed settlements, based on local and decentralized harvesting of natural resources; company towns, centered around large-scale companies that are the major local employers; and diversified cities, which are centers of public services, trade, and transport hubs. Demographic development and shifts in settlement structure reflect a number of factors, such as economic disparities, reorganization of industries, people's aspirations and preferences, and public efforts to maintain settlement in the North.

All population forecasts for the northernmost parts of Sweden, Norway and Finland show a continuing depopulation of rural areas. Statistics Sweden only publishes national figures, but the latest available regional forecasts indicate a slight population increase in both Norrbotten and Västerbotten over the next 20 to 25 years (Lindblad et al., 2015; NSD, 2015; Svenskt Näringsliv, 2016). Growth will mainly take place in and around Umeå and Luleå. In northern Finland, Statistics Finland (2015) projects a population decline in Lapland and Kainuu to 2040, but growth in North Ostrobothnia, concentrated in the Oulo region. Under the main alternative presented by Statistics Norway (2016), the counties of Finnmark, Troms and Nordland will all increase their population until 2040, but the rate of growth will only be half the national average. Tromsø and Bodø are the main centers of growth.

Northwest Russia has seen a different development. In this region the population is mainly located in scattered mining and industrial centers with few physical connections between them. In general, Russian cities in the Barents area have larger populations than the cities in northern Sweden, Norway and Finland. The former Soviet Union attempted to equalize income among regions through centrally administered prices, wages and subsidies (Heleniak, 2016). In the North, people enjoyed a number of benefits. After the collapse of the Soviet Union, living in the northern parts of the country became more expensive and difficult and over 20% of the population moved out, mainly toward the bigger cities in central Russia (Sievert et al., 2011). Between 1989 and 2015, the population of Murmansk declined from 480,020 to 305,236, and in Arkhangelsk from 415,921 to 350,982.[4] The only exceptions to this trend were the capital cities of Karelia and Komi (Petrozavodsk and Syktyvkar, respectively) and a few of the booming oil and gas centers further east, such as Novyj Urengoi and Naryan-Mar. In the three Rosstat regional population projections (high scenario, balanced scenario, low scenario), both the balanced scenario and the low scenario (based on a continuation of the current trend) indicate further population decline in the Russian part of the Barents area to 2031. The only administrative unit for which population is projected to increase is the Yamalo-Nenets AO.[5]

4.5.3 Uneven economic growth

The world economy has been projected to grow at around 3% per year over the next 40 to 50 years (OECD, 2012a; PwC, 2015). With this growth rate, the world economy will double in size by 2037 and almost triple by 2050, measured in terms of world gross domestic product (GDP) based on purchasing power parity (PPP). Growth is expected to decelerate in many countries as they become more prosperous (EEA, 2015), and recent forecasts have also lowered the growth rate until 2050 due to the slowdown in China's economy, declining commodity prices, reduced capital flows to emerging markets, and increasing financial market volatility (EIU, 2015; OECD, 2016a). However, global growth is not expected to weaken dramatically. In some countries, economic growth will be largely due to population growth, but rising productivity is generally the most important factor.

Real growth in GDP will vary widely between countries and regions. In the mid- to long-term there is expected to be a major shift in global economic power away from the leading countries in North America, Western Europe, and Japan and towards Asia and a group of fast-growing emerging economies. Economic growth will bring substantial improvements in living standards and make resources available for development of public infrastructure and services. By 2050, the top three world economies will be China, the USA and India, and each will be richer than the next five (Indonesia, Germany, Japan, Brazil, and the UK) in total (EIU, 2015). Based on PPP valuation of country GDP, China surpassed the USA as the world's largest economy in 2014[6], but today's most advanced economies will still continue to have the highest income per capita in 2050.

According to OECD projections, Sweden, Norway, Finland, and Russia will see economic growth rates well below the world average.[7] All four countries will roughly double their economies between 2015 and 2050, with the highest real GDP growth in Sweden (110%) and the lowest in Russia (93%). The Barents area may develop in line with these trends or display a different pattern. In Sweden, Norway, and Finland, the northern regions have traditionally lagged behind the rest of the country economically. Compared to the more centrally located regions in each country, their industrial base is less versatile and labor market participation is lower. A significant proportion of the regional value creation also occurs in large companies, which tend to channel much of their earnings out of the region (Huskey et al., 2014). Despite government policies and transfers aimed at reducing regional disparities, the northern parts of Sweden, Norway and Finland are thus characterized by a lower GDP per inhabitant than the national averages.[8] In the Russian Federation the situation is different, with the resource-rich regions in the North, together with the capital region, having the highest GDP per inhabitant. Future economic growth in the Barents area will to a large extent depend on development of the extractive industries and on the government expenditure allocated to the region. Some places may experience boom (or bust) related to oil and gas activities, mining, seafood production, renewable energy, tourism, and shipping, but the most diversified centers, which are able to attract skilled people and facilitate innovation have the largest growth potential.

---

4 City Population, http://www.citypopulation.de/Russia.html (accessed 17 January 2016)

5 Knoema, http://goo.gl/jMCiBG (accessed 17 January 2016)

6 www.imf.org/external/pubs/ft/weo/2014/02/weodata/weoselco.aspx?g=2001&sg=All+countries

7 https://data.oecd.org/gdp/gdp-long-term-forecast.htm (accessed 19 January 2016)

8 http://ec.europa.eu/eurostat/statistics-explained/index.php/GDP_at_regional_level and www.ssb.no/nasjonalregnskap-og-konjunkturer/statistikker/fnr/aar/2015-10-20?fane=tabell&sort=nummer&tabell=243268 (accessed 19 January 2016)

4.5.4 Accelerating technological change and worldwide interconnectedness

Technological change is a major driver of economic growth and societal transformation. The globalization processes have been spurred on by new technology and have themselves increased the pace of technological change, which is currently at an unprecedented level. New advances and convergence in the fields of microelectronics, biotechnology, nanotechnology, sophisticated production methods and software are accelerating the rate of change and disruption. In the future, 'smart' sensors and actuators, 'big data', intelligent robots, unmanned vehicles, 3D printing, and advanced materials will play an ever greater role. Devices and systems will be connected in the 'Internet of things', enabling a range of objects to collect and exchange data (DASTI, 2016; OECD, 2016b). Digitalization and automation will remove the need for many jobs. At the same time, new jobs will be created. Technological change will give rise to new business models, including the sharing of access to goods and services, and will transform health, education, communication, and ways of living.

Technological change will also increase worldwide interconnectedness and interdependence. As networks and interactions become more extensive and intensive, time and space are compressed and the world shrinks (Harvey, 1989). This implies that events in one part of the world can create large and unintentional consequences for people in many other areas of the globe. The global financial markets are already strongly integrated. More and more challenges will become boundary-spanning and require coordinated efforts and joint, international solutions.

Technological change will continue to alter the spatial organization of activities. Over recent decades, there has been a rapid development of global production networks and value chains. Stages within production processes have been unbundled, outsourced, and located in places that can offer special advantages. With the help of new technology, it is expected that some production, which until now has been transferred to low-wage countries, can be relocated to today's advanced economies (Brynjolfsson and McAfee, 2014). But new centers of innovation and technology are also developing in the fast-growing countries of Asia and Latin America. As a consequence, product cycles are shortening and competition is increasing.

The small, open Nordic economies have historically been quick to adapt to new economic and technological conditions. This has been possible due to a well-educated workforce, constant upgrading of infrastructure, traditions of co-determination, a high level of trust, and advanced social security systems. These countries are thus assumed to be well positioned to meet future technological changes and the challenges associated with the globalizing knowledge economy. They will attempt to remain in the high-technology and high value-added end of the value chains and maintain their welfare states and an inclusive working life with a high level of employment. However, there is concern about an increasing polarization of labor markets (Autor, 2010; Goos et al., 2010). A sharing economy may provide new opportunities, but when routine tasks and low-skilled jobs disappear this can lead to greater income disparity. The Russian Federation follows another model and will probably face far greater challenges in modernizing its economy and governance systems.

Accelerating technological change may have different effects in the Barents area. On the one hand, an increasing number of activities are becoming less dependent on distance. Accessibility is increasing and new businesses can be established in remote areas, provided the Internet services are of sufficient quality. On the other hand, new technology also enables a higher level of automation and enhanced steering at distance. New mega-projects do not necessarily mean increased settlement in the region. Instead, workers may be flown in and out for a limited construction and operation period. This model already characterizes several of the oil and gas projects in the Yamalo-Nenets AO.

iStock.com/windjunkie

Unmanned aircraft systems ('drones') are used to support environmental monitoring in the Arctic

4.5.5 Increasing demand for energy and natural resources

A growing world population and economy will demand more energy. In the New Policies Scenario of the International Energy Agency (IEA, 2015), which takes account of broad policy commitments and agreed national plans, including national pledges to reduce greenhouse gas (GHG) emissions and plans to phase out fossil-energy subsidies, global energy demand is expected to grow by a third between 2013 and 2040. All the net growth will come from non-OECD countries. The links between global economic growth, energy demand and energy-related emissions will weaken, but unless urgent action is taken to curb GHG emissions, fossil fuels will still account for almost three-quarters of primary energy supply in 2040. Until now, renewable energy sources have mainly been added to the energy mix without replacing fossil fuels (York, 2012). In the New Policies Scenario, energy-related carbon dioxide (CO_2) emissions will be 16% higher in 2040 than in 2013.

The IPCC AR5 scenarios (Clarke et al., 2014) show that scenarios following a baseline have slightly higher economic activity than scenarios that keep global average temperatures below 2°C. This suggests that climate policy will have limited impact on economic activity, but that climate and other policies will have significant impact on resource consumption per economic activity. In general, all scenarios assume that primary energy consumption will grow more slowly than economic activity due to continued improvement in energy efficiency. The assumed efficiency improvements are much greater for mitigation scenarios than for baseline scenarios. Importantly, the source of primary energy consumption (e.g. fossil fuel versus renewable energy) varies in different scenarios, such that a given energy consumption can lead to much lower levels of climate change. Energy consumption ultimately leads to GHG emissions dependent on the underlying energy mix. Hence, it will lead to further global warming of a magnitude that depends on the character of the energy consumption. A baseline scenario of energy consumption may lead to global average temperatures approaching 5°C towards the end of the century, with much larger variation in some regions (perhaps double this in the Arctic). A mitigation scenario may keep global average temperatures below 2°C over the century (again, roughly double this in the Arctic). Another important feature of the climate system is that it takes time for a given GHG emission to lead to maximum temperature change (a decade or so). As a consequence, temperatures in 2030 are already set by past activities, with society having an opportunity to alter temperature trajectories only towards the end of the century (Clarke et al., 2014).

The OECD Environmental Outlook to 2050, which demonstrates the consequences of no new policies and continuing socio-economic trends, projects that world energy use in 2050 will be 80% higher than today, while the share of fossil-fuel based energy in the global energy mix will be about 85% (OECD, 2012b). By 2050, the world is also set to consume three times more natural resources (UNEP, 2011). There will be an increasing dematerialization and decoupling between economic growth and use of resources, but freshwater, food, fossil fuels, and many minerals and metals will become scarcer.

The current path of socio-economic development has significant environmental consequences. Rapid population growth and carbon-powered economic growth lead to climate change, increasing levels of pollution, degradation of ecosystems, and irreversible biodiversity loss. The basic life-sustaining processes of the planet are clearly at risk (IPCC, 2014) and the ability of ecosystems to provide services and sustain future generations cannot be assumed (Millennium Ecosystem Assessment, 2005). Even with a growing awareness of the environmental and climate challenges, the effects of global warming will be unevenly distributed. Vulnerable poor societies and communities that have contributed the least to the problem are likely to suffer the most.

Ole Martin Nilsen/OMN foto

Abandoned coal mine, Svalbard

The Barents Region countries vary in terms of energy production and consumption, energy efficiency, resource use, and environmental conservation. Before the 2015 Paris Climate Conference (COP 21), all four countries submitted their intended nationally determined contributions (INDCs) to GHG reduction. However, all four have also been eager to exploit the natural resources of the Arctic. Although their Arctic strategies and policy statements emphasize that this must take place in a sustainable manner, their visions include large-scale oil and gas development, new mining, and the promotion of the Northern Sea Route (the sea lane between the ports of Dudinka and Murmansk) as a major transcontinental shipping lane. The importance of the Arctic for Russia's economic development is underlined in several strategic communications. According to the *Foundation of the State Policy of the Russian Federation in the Arctic up to and beyond 2020*, the main objective is to transform the Arctic into Russia's 'foremost strategic base for natural resources'. The *Russian Energy Strategy up to 2030* (signed in 2009) defines the Arctic region as one of the key areas for future extraction of oil and gas, and in the *Russian Energy Strategy up to 2035* (signed 2014) it is stated that by 2035, Arctic offshore resources should account for 5% of total oil production and 10% of total gas production in the Russian Federation. Similarly, the Norwegian government expects the Barents Sea - Lofoten area to hold the largest undiscovered reserves of oil and gas on the Norwegian Continental Shelf. Over recent years, several new licenses have been awarded on both sides of the maritime boundary established in 2010 between Norway and Russia in the Barents Sea and Arctic Ocean.

Future development of mineral and hydrocarbon extraction in the North will largely depend on world market prices and general resource demand, which will be affected by the underlying energy mix. New technology renders exploitation possible in previously inaccessible areas, and strategic considerations with regard to energy security, state revenue and employment always play an important role. The Barents area becomes relatively more attractive if alternative reserves are geographically concentrated in politically unstable regions and there is uncertainty regarding access to essential raw materials. Some technologies, such as carbon capture and storage (CCS), may allow significant resource exploitation while maintaining lower global temperature change. However, prices must be high enough to justify huge investments in a region with a harsh climate, lack of infrastructure, and large distances to market (Harsem et al., 2011; Lindholt and Glomsrød, 2012). The US shale production boom, the weakening of OPEC, and the end of the great commodities boom that prevailed from 2000 to 2014, driven by rising demand from China, has changed the outlook. China is now shifting to a growth model more driven by services and domestic consumption, and this will make the economy less dependent on energy and raw materials. Studies also indicate that in the coming decades, the Northern Sea Route will hardly be able to compete with the Suez Canal Route due to its short and unpredictable navigation season, particularly for container shipment. Internal and destinational traffic will still dominate Arctic shipping (Buixadé Farré et al., 2014; Ørts Hansen et al., 2016; Sander et al., 2016).

4.5.6 A more multipolar world with complex systems of governance

The catch-up process among the developing nations alters the patterns of global integration and political influence. Throughout history, political and military power has always been linked to economic power, and there will be a power shift as countries such as China and India increase their share of global economic output, trade and investment, combined with a rapid increase in educational achievement. The USA will still be a superpower but the country will be challenged by more actors. No single country or region will dominate world affairs. Multinational companies and other non-government organizations will also play a more prominent role. The global arena is shaped by issues, actor constellations, resources and definitions of interests, and the governance system comprises nested sets of institutions. Within this framework there will be shifting alliances and lines of conflict. The growing number and diversity of participants will make it harder to coordinate global activities and respond to complex challenges (EEA, 2015).

During the Cold War, the geopolitical landscape in the Arctic was shaped by the rivalry between the USA and Russia. This relationship remains important. However, the rules of the game are largely defined by international law. The UN Convention on the Law of the Sea (UNCLOS) provides the basic legal framework for managing all marine activities in the Arctic. Several other international treaties and conventions also apply to the Arctic, from those concerning international trade and polar shipping to the rights of indigenous peoples (see Bankes and Koivurova, 2014). In the years ahead, a salient issue will be the commitments made under the UN Framework Convention on Climate Change (UNFCCC) to reduce GHG emissions and the steps taken to limit global temperature increase. Since the end of the Cold War, the Arctic states have been eager to promote peace, stability and socio-economic development in the Arctic region. New regional governance frameworks have been introduced such as the Arctic Council, the Barents Euro-Arctic Council and the EU's Northern Dimension, and international law has been supplemented by bilateral and multilateral regional agreements.

The Barents area is currently witnessing a more strained East-West relationship. Several factors may undermine the close cooperation established by the Arctic states in recent decades. There are fears that greater marine access could trigger a race for resources and shipping routes, that China's increasing financial and physical presence in the region could create new tensions, and that there could be a spillover from geopolitical changes beyond the Arctic, with consequences for the stability and prosperity of the Barents area. With heightened tension and an increased lack of trust, security issues and military priorities tend to dominate, whereas less tension and a higher level of trust mean more resources and efforts can be directed to industrial development, trade, resource management, and social welfare. Despite concern, the countries in the Barents Region have demonstrated their willingness to shield Arctic cooperation, to abide by international legal frameworks and to develop new joint rules and regulations. In the Ilulissat Declaration (2008),

Tankers in convoy behind icebreaker

the Arctic coastal states declared that UNCLOS should form the basis for Arctic Ocean governance. There are still some disputes regarding the legal status of the shipping lanes along the coasts of Canada and Russia, and some maritime borders are not clarified, but all the main resources in the Arctic are already under clear national jurisdiction and the delimitation of the outer continental shelves beyond the 200-nm exclusive economic zones proceeds according to the rules laid down under UNCLOS. The Arctic states have also recently adopted legally binding agreements on cooperation in maritime and aeronautical search and rescue and on cooperation in oil spill response, and have agreed on conservation measures for fisheries in the central Arctic Ocean. To retain their governance prerogatives, the Arctic states are obliged to cooperate.

The level of international cooperation is important for the future of the Barents area. For the people living in the region, national policies are even more important. The countries differ in terms of legal-institutional frameworks, sets of collective actors, and decision-making processes. While Russia is a federal state with weak democratic traditions, the Nordic countries are unitary states with strong democratic traditions. The countries' overall economic policies and welfare systems affect all aspects of human development. Another key element is the strategies adopted to develop the northern regions, which will be determined by economic prospects, security and geopolitical considerations, and the willingness and ability of governments to support the peripheral areas relative to the central parts of the countries. In each country, the institutional context and historical legacies tend to create a path-dependent pattern of development.

4.6 Discussion

This section summarizes the key findings arising from this quantitative (where possible) description of what is likely to shape the future Barents area in terms of its regional climate, and the physical and socio-economic environment. The aim is to provide a starting point for the following chapters on resilience and adaptation actions. This summary highlights (1) those changes of greatest relevance for ecosystems and society, (2) positive and negative impacts on environmental and socio-economic conditions, (3) possible feedbacks between environmental and socio-economic processes, and (4) knowledge gaps (uncertainties).

Strongest impacts. Those changes in the Barents area likely to have the strongest impacts on ecosystems and society include:

- *Present day to 2030*: faster warming at higher latitudes; a shift to seasonal sea-ice cover and a substantial reduction in sea-ice cover in winter; increased frequency of natural hazards, linked with overall warming: polar lows, storms, rain-on-snow events, avalanches, extreme wave heights, and icebergs; and stronger trade and investment in transportation, fisheries and natural resource extraction.
- *Near to mid-term (2030–2080)*: a plausible picture will be an ice-free sea all year round; a substantial increase in ocean acidification; different ocean currents and hydrographic conditions; a substantially shorter snow season; substantial degradation of permafrost; increased urbanization; and increasing risk of pollution, degradation of ecosystems and irreversible biodiversity loss.

Positive/negative effects of change. With respect to environmental and socio-economic conditions, many of the impacts of the continued warming projected for the Barents area can be considered simultaneously positive and negative. For example, a steady increase in surface air temperature, especially in winter would make the climate milder and thus more comfortable for living, but would also enhance permafrost degradation with serious consequences for infrastructure (roads, buildings etc.). However, things are not always as clear cut as they appear. Although more comfortable living conditions seems unquestionably positive and damage to infrastructure seems unquestionably negative, it is also the case that improved living conditions at a time of fast growth in world population could also increase the attractiveness of the region for migrants, with as yet unknown consequences for local communities and the environment. Whether, in reality, the consequences are mostly positive (economic growth, increased living standards, more openness to the wider world) or mostly negative (increased social tension, more unemployment) is an open question, one that could to some extent be resolved through adaptation policy. The same could be said for permafrost thaw and damage to infrastructure. Anticipating the problems that thaw could bring would foster the development of new technologies in the construction sector, providing new jobs and eventual improvement in living conditions through good business planning and implementation. Again, this is a matter of timely and correctly implemented adaptation actions and rational regional governance. Thus it is clear that the key findings of this chapter should be used with great care and should be thoroughly considered in relation to their mixed (and sometimes opposing) impacts on the environment and society. It must be stressed that the changes expected in the Barents area will be multifaceted, and future warming (as the major global driver) cannot be considered in isolation from changes in precipitation patterns, declining snow and ice, thawing permafrost, shifts in the storm tracks, waves, ocean currents, and impacts on ecosystems and socio-economic conditions. These changes are all interconnected, and their combined impacts may be substantially greater than the sum of their parts. Two incidents on Svalbard serve to illustrate this point. Both the rain-on-snow event of 2012 and the avalanche of December 2015 (Section 4.2.3.2) were the compound outcome of several elements. Such possibilities must be considered when planning adaptive actions.

Feedbacks between environmental and socio-economic processes. The various elements of the climate system interact in a nonlinear and mutually interdependent manner. These interactions, known as feedbacks, can generate cyclical variations or shift the whole system to some new thermodynamic state (reinforcing feedback). The possibility of feedbacks occurring increases with growth in the amplitude of internal or externally-forced oscillations within the system, and makes predictions extremely challenging. In terms of entire 'environment-socio-economic' systems, formulating reasonable predictions of their behavior under the influence of direct forcing and possible feedbacks is even more challenging. In a very general sense, an increase in atmospheric levels of human-produced carbon may be considered a direct impact of the global economy on the environment and Earth climate. This 'external' condition to the climate system forcing may interact in some unknown way with natural (internal) climate oscillations. In all long-term predictions it is taken for granted that anthropogenic forcing is strong enough to substantially affect the climate system; namely that it either dominates over natural variability or acts in phase with it. By default this thesis accepts the notion that interaction between the anthropogenic forcing and natural modes of climate variability is linear and that their combined effect may be calculated in terms of simple superposition without any significant feedbacks. This simplistic concept is not challenged here, because no better substantiated theory exists and such exercise is beyond the scope of this chapter. Instead, the message conveyed here is that if it can be accepted that from the latter half of the last century the anthropogenic forcing on climate and the environment became strong enough to substantially warm the planet, then it must also be accepted that at a certain point the climate system and its natural phenomena may change character. The problem is that when, and in what form this feedback will occur is not known. In downscaling this general speculation to the Arctic (and in particular the Barents area), it is important to highlight that this is a region with an extremely vulnerable environment, one which often responds in an exaggerated manner to any atypical external forcing. The often-used example is catastrophic pollution following an oil spill at a production platform or during transport. The Arctic environment is particularly vulnerable owing to the extremely cold conditions and to the ice-snow cover,

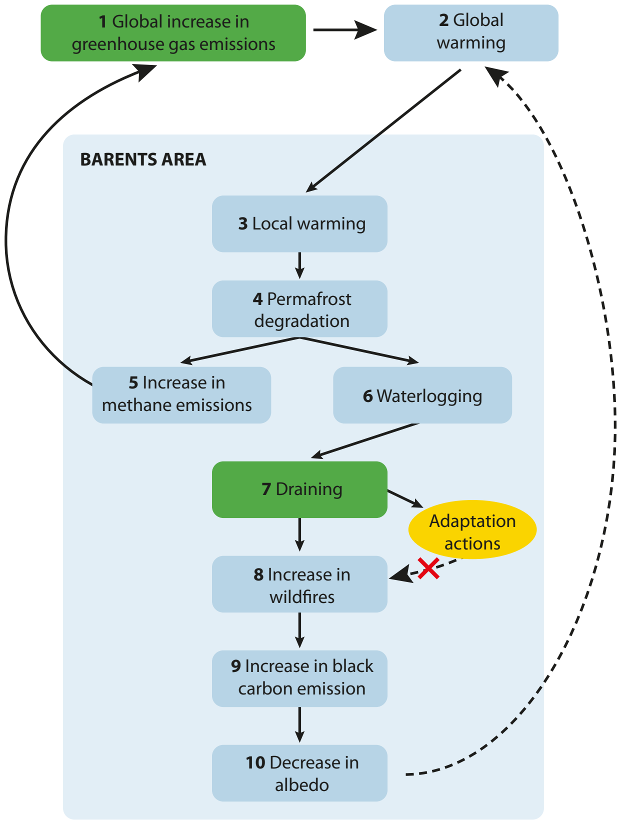


Figure 4.18 Example of positive feedbacks in the 'environment-socio-economic' system with possible intervention via adaptation actions. Human actions (green and yellow boxes), environmental responses (blue boxes).

which suppress the natural restoration of the environment. To some extent this speculation might also be applied to pollutants; for which the amount and type found might also increase with population and economic growth in the region. In contrast to feedbacks, which occur in the climate system and may be predicted (at best) but not changed, those in the joint 'environment-socio-economic' system could theoretically be affected in advance, in order to reduce any negative effect. This is conceptualized in Figure 4.18 where human actions are shown in green and yellow boxes and environmental responses in blue boxes. The sequence of environmental responses in the Barents area is shown in boxes 3 to 6 and 8 to 10. The pure environmental feedback from box 5 to box 1 is probably an inevitable outcome of permafrost thaw. The other feedback (box 10 to box 2) is triggered by human activities aimed at draining waterlogged areas (7). The negative result of this action (more wildfires) could be mitigated by adaptation actions, thus eliminating the entire chain (boxes 7 to 10) and the corresponding feedback. Similar chains of actions, responses and feedbacks could be also constructed for the other drivers discussed in this chapter. A detailed analysis of whether these possible feedbacks are realistic and what adaptation actions could be used to avoid/enhance their negative/positive consequences, is beyond the scope of this chapter.

References

Abramov, V.A., 1992. Russian iceberg observations in the Barents Sea 1933-1990. Polar Research, 11:93-97.

ACAP, 2014. Reduction of Black Carbon Emissions from Residential Wood Combustion in the Arctic: Black carbon inventory, abatement instruments and measures. Arctic Contaminants Action Program (ACAP).

ACIA, 2004. Impacts of a Warming Arctic. Arctic Climate Impact Assessment (ACIA). Cambridge University Press.

ACIA, 2005. Arctic Climate Impact Assessment. Cambridge University Press.

Akperov, M., I. Mokhov, A. Rinke, K. Dethloff and H. Matthes, Cyclones and their possible changes in the Arctic by the end of the twenty-first century from regional climate model simulations. Theoretical and Applied Climatology, 122:85-96.

Aleksashenko, S., 2015. The Russian economy in 2050: Heading for labor-based stagnation. Brookings Up Front. www.brookings.edu/blogs/up-front/posts/2015/04/02-russia-economy-labor-based-stagnation-aleksashenko

Alekseev, G.V., E.I. Aleksandrov, N.I. Glok, N.E. Ivanov, V.M. Smolyanitskij, N.E. Kharlanenkova and Ulin, 2015. Evolution of the area of a sea ice cover of Arctic regions in conditions of modern changes of a climate. Research of the Earth from Space. 2015. No. 2. pp. 5-19. (In Russian)

AMAP, 2011. AMAP Assessment 2011: Mercury in the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

AMAP, 2012. Arctic Climate Issues 2011: Changes in Arctic Snow, Water, Ice and Permafrost. SWIPA 2011 Overview Report. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

AMAP, 2015a. Summary for Policy-makers: Arctic Climate Issues 2015. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

AMAP, 2015b. AMAP Assessment 2015: Black Carbon and Ozone as Arctic Climate Forcers. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

AMAP, 2017. Snow, Water, Ice and permafrost in the Arctic (SWIPA). Arctic Monitoring an Assessment Programme (AMAP), Oslo, Norway.

Andrew, R., 2014. Socio-Economic Drivers of Change in the Arctic (SEDoCA). Center for International Climate and Environmental Research (CICERO),Oslo.

Anenberg, S.C., J.D. Schwartz, D. Shindell, M. Amann, G. Faluvegi, Z. Klimont, G. Janssens-Maenhout, L. Pozzoli, R. Van Dingenen, E. Vignati, L. Emberson, N.Z. Muller, J.J. West, M. Williams, V. Demkine, W.K. Hicks, J. Kuylenstierna, F. Raes and V. Ramanathan, 2012. Global air quality and health co-benefits of mitigating near-term climate change through methane and black carbon controls. Environmental Health Perspectives, 120:831-839.

Arbo, P., A. Iversen, M. Knol, T. Ringholm and G. Sander, 2013. Arctic futures: conceptualizations and images of a changing Arctic. Polar Geography, 36:163-182.

Arctic Council, 2009. Arctic Marine Shipping Assessment 2009 Report. Protection of the Arctic Marine Environment Working Group (PAME), Akureyri.

Arctic Council, 2013. Arctic Resilience Interim Report 2013. Stockholm Environment Institute and Stockholm Resilience Centre, Stockholm.

Arendt, A., A. Bliss, T. Bolch, J.G. Cogley, A.S. Gardner, J.-O. Hagen, R. Hock, M. Huss, G. Kaser, C. Kienholz, W.T. Pfeffer, G. Moholdt, F. Paul, V. Radić, L. Andreassen, S. Bajracharya, N.E. Barrand, M. Beedle, E. Berthier, R. Bhambri, I. Brown, E. Burgess, D. Burgess, F. Cawkwell, T. Chinn, L. Copland, B. Davies, H. De Angelis, E. Dolgova, L. Earl, K. Filbert, R. Forester, A.G. Fountain, H. Frey, B. Giffen, N. Glasser, W.Q. Guo, S. Gurney, W. Hagg, D. Hall, U.K. Haritashya, G. Hartmann, C. Helm, S. Herreid, I. Howat, G. Kapustin, T. Khromova, M. König, J. Kohler, D. Kriegel, S. Kutuzov, I. Lavrentiev, R. LeBris, S.Y. Liu, J. Lund, W. Manley, R. Marti, C. Mayer, E.S. Miles, X. Li, B. Menounos, A. Mercer, N. Mölg, P. Mool, G. Nosenko, A. Negrete, T. Nuimura, C. Nuth, R. Pettersson, A. Racoviteanu, R. Ranzi, P. Rastner, F. Rau, B. Raup, J. Rich, H. Rott, A. Sakai, C. Schneider, Y. Seliverstov, M. Sharp, O. Sigurðsson, C. Stokes, R.G. Way, R. Wheate, S. Winsvold, G. Wolken, F. Wyatt and N. Zheltyhina, 2015. Randolph Glacier Inventory – A Dataset of Global Glacier Outlines: Version 5.0, Global Land Ice Measurements from Space, Boulder, Colorado. Digital Media.

Årthun, M. and C. Schrum, 2010. Ocean surface heat flux variability in the Barents Sea. Journal of Marine Systems, 83:88-98.

Årthun, M., T. Eldevik, L.H. Smedsrud, Ø. Skagseth and R.B. Ingvaldsen, 2012. Quantifying the influence of Atlantic heat on Barents Sea ice variability and retreat. Journal of Climate, 23:4376-4743.

Autor, D., 2010. The polarization of job opportunities in the U.S. labor market. Implications for employment and earnings. Center for American Progress and the Hamilton Project.

Baldwin, M.P. and T.J. Dunkerton, 2001. Stratospheric harbingers of anomalous weather regimes. Science, 294:581-584.

Bankes, N. and T. Koivurova, 2014. Legal systems. In: Larsen, J.N. and G. Fondahl (eds.), Arctic Human Development Report: Regional Processes and Global Linkages, pp. 223-254. Nordic Council of Ministers.

Benestad, R.E., 2005. On latitudinal profiles of zonal means. Geophysical Research Letters, 32:L19713, doi:10.1029/2005GL023652

Benestad, R.E., 2011. A new global set of downscaled temperature scenarios. Journal of Climate, 24:2080-2098.

Benestad, R.E., D. Chen, A. Mezghani, L. Fan and K. Parding, 2015. On using principal components to represent stations in empirical–statistical downscaling. Tellus A, 67:28326, doi:10.3402/tellusa.v67.28326

Benestad, R.E., K.M. Parding, K. Isaksen and A. Mezghani, 2016. Climate change and projections for the Barents region: what is expected to change and what will stay the same? Environmental Research Letters, 11:054017.

Bengtsson, L., K.I. Hodges and N. Keenlyside, 2009. Will extratropical storms intensify in a warmer climate? Journal of Climate, 22:2276-2301.

Bentsen, M., I. Bethke, J.B. Debernard, T. Iversen, A. Jirkevag, Ø. Seland, H. Drange, C. Roelandt, I.A. Seierstad, c. Hoose and J.E. kristjansson, 2013. The Norwegian Earth System Model, NorESM1-M Part 1: description and basic evaluation of the physical climate. Geoscientific Model Development, 6:687-720.

Bhend, J., 2015. Regional evidence of global warming. In: Second Assessment of Climate Change for the Baltic Sea Basin. pp. 427-439. Regional Climate Studies. Springer.

Bindoff, N.L., P.A. Stott, K.M. AchutaRao, M.R. Allen, N. Gillett, D. Gutzler, K. Hansingo, G. Hegerl, Y. Hu, S. Jain, I.I. Mokhov, J. Overland, J. Perlwitz, R. Sebbari and X. Zhang, 2013. Detection and attribution of climate change: from global to regional. In: Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Bintanja, R. and F.M. Selten, 2014. Future increases in Arctic precipitation linked to local evaporation and sea-ice retreat. Nature, 509:479-482.

Bitz, C.M., P.R. Gent, R.A. Woodgate, M.M. Holland and R. Lindsay, 2006. The influence of sea ice on ocean heat uptake in response to increasing CO_2. Journal of Climate, 19:2437-2450.

Boisvert, L.N., T. Markus and T. Vihma, 2013. Moisture flux changes and trends for the entire Arctic in 2003–2011 derived from EOS Aqua data. Journal of Geophysical Research: Oceans, 118:5829-5843.

Bond, T.C., S.J. Doherty, D.W. Fahey, P.M. Forster, T. Berntsen, B.J. Deangelo, M.G. Flanner, S. Ghan, B. Kärcher, D. Koch, S. Kinne, Y. Kondo, P.K. Quinn, M.C. Sarofim, M.G. Schultz, M. Schulz, C. Venkataraman, H. Zhang, S. Zhang, N. Bellouin, S.K. Guttikunda, P.K. Hopke, M.Z. Jacobson, J.W. Kaiser, Z. Klimont, U. Lohmann, J.P. Schwarz, D. Shindell, T. Storelvmo, S.G. Warren and C.S. Zender, 2013. Bounding the role of black carbon in the climate system: A scientific assessment. Journal of Geophysical Research: Atmospheres, 118:5380-5552.

Boucher, O., D. Randall, P. Artaxo, C. Bretherton, G. Feingold, P. Forster, V.-M. Kerminen, Y. Kondo, H. Liao, U. Lohmann, P. Rasch, S.K. Satheesh, S. Sherwood, B. Stevens and X.Y. Zhang, 2013. Clouds and Aerosols. In: Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Box, J.E., and M. Sharp, 2017. Land ice. In: Snow, Water, Ice and Permafrost in the Arctic (SWIPA) 2017. Arctic Monitoring and Assessment Programme (AMAP), Oslo.

Bring, A., I. Fedorova, Y. Dibike, L. Hinzman, J. Mård, S. H. Mernild, T. Prowse, O. Semenova, S. L. Stuefer, M.-K. Woo, 2016. Arctic terrestrial hydrology: A synthesis of processes, regional effects and research challenges. Journal of Geophysical Research: Biogeosciences, 121:621-649.

Brown, R., D. Vikhamar Schuler, O. Bulygina, C. Derksen, K. Luojus, L. Mudryk, L. Wang and D. Yang, 2017. Arctic terrestrial snow cover. In: Snow, Water, Ice and Permafrost in the Arctic (SWIPA) 2017. Arctic Monitoring and Assessment Programme (AMAP), Oslo.

Bruemmer, B. and S. Pohlman, 2000. Wintertime roll and cell convection over Greenland and Barents Sea regions: A climatology. Journal of Geophysical Research: Atmospheres, 105:15559-15566.

Brynjolfsson, E. and A. McAfee, 2014. The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies. Norton & Co.

Buixadé Farré, A., S.R. Stephenson, L. Chen, M. Czub, Y. Dai, D. Demchev, Y. Efimov, P. Graczyk, H. Grythe, K. Keil, N. Kivekäs, N. Kumar, N. Liu, I. Matelenok, M. Myksvoll, D. O'Leary, J. Olsen, S. Pavithran, E. Petersen, A. Raspotnik, I. Ryzhov, J. Solski, L. Suo, C. Troein, V. Valeeva, J. van Rijckevorsel and J. Wighting, 2014. Commercial Arctic shipping through the Northeast Passage: routes, resources, governance, technology, and infrastructure. Polar Geography, 37:298-324.

Bulygina, O.N., P. Ya. Groisman, V.N. Razuvaev and N. N. Korshunova, 2011. Changes in snow cover characteristics over Northern Eurasia since 1966. Environmental Research Letters, 6:045204, doi:10.1088/1748-9326/6/4/045204

Caldeira, K. and M. Wickett, 2003. Anthropogenic carbon and ocean ph. Nature, 425:365.

Callaghan, T.V., M. Johansson, R.D. Brown, P.Ya. Groisman, N. Labba, RG. Barry, O.N. Bulygina, R.L.H. Essery, D.M. Frolov, V.N. Golubev, T.C. Grenfell, M.N. Petrushina, VN. Razuvaev, D.A. Robinson, P. Romanov, D. Shindell, A.B. Shmakin, S.A. Sokratov, S. Warren, D. Yang, 2011. The changing face of arctic snow cover: A synthesis of observed and projected changes. Ambio, 4:17-31.

Callaghan, T.V., L.O Björn, F.S. Chapin III, Y. Chernov, T.R. Christense, B. Huntley, R. Ims, M. Johansson, D.J. Riedlinger, S. Jonasson, N. Matveyeva, W. Oechel, N. Panikov and G. Shaver, 2005. Arctic tundra and polar desert ecosystems. In: ACIA, 2005. Arctic Climate Impact Assessment. pp. 243-352. Cambridge University Press.

Canadell, J., C. Le Quere, M. Raupach, C. Field, E. Buitenhuis, P. Ciais, T. Conway, N. Gillett, R. Houghton and G. Marland, 2007. Contributions to accelerating atmospheric CO_2 growth from economic activity, carbon intensity, and efficiency of natural sinks. Proceedings of the National Academy of Sciences USA, 104:18866-18870.

Carbon Limits, 2013. Associated Petroleum Gas Flaring Study for Russia, Kazakhstan, Turkmenistan and Azerbaijan. Final report. Carbon Limits, Norway.

Carr, J.R., C. Stokes and A. Vieli, 2014. Recent retreat of major outlet glaciers on Novaya Zemlya, Russian Arctic, influenced by fjord geometry and sea-ice conditions. Journal of Glaciology, 60:155-170.

Catto, J.L., N. Nicholls, C. Jakob and K.L. Shelton, 2014. Atmospheric fronts in current and future climates. Geophysical Research Letters, 41:7642-7650.

Chang, E.K.M., Y. Guo and X. Xia, 2012. CMIP5 Multimodel ensemble projection of storm track change under global warming. Journal of Geophysical Research: Atmospheres: 117, doi:10.1029/2012JD018578

Chierici, M. and A. Franson, 2009. Calcium carbonate saturation in the surface water of the Arctic Ocean: undersaturation in freshwater influenced shelves. Biogeosciences, 6:2421-2432.

Christiansen, H.H., B. Etzelmüller, K. Isaksen, H. Juliussen, H. Farbrot, O. Humlum, M. Johansson, T. Ingeman-Nielsen, L. Kristensen, J. Hjort, P. Holmlund, A.B.K. Sannel, C. Sigsgaard, H.J. Åkerman, N. Foged, L.H. Blikra, M.A. Pernosky and R. Ødegård, 2010. The thermal state of permafrost in the Nordic area during the International Polar Year. Permafrost and Periglacial Processes, 21:156-181.

Christensen, O.B., E. Kjellström and E. Zorita, 2015. Projected change – atmosphere. In: Second Assessment of Climate Change for the Baltic Sea Basin. Regional Climate Studies. pp. 217-233. Springer.

Clarke, L., K. Jiang, K. Akimoto, M. Babiker, G. Blanford, K. Fisher-Vanden, J.-C. Hourcade, V. Krey, E. Kriegler, A. Löschel,D. McCollum, S. Paltsev, S. Rose, P.R. Shukla, M. Tavoni, B.C.C. van der Zwaan and D.P. van Vuuren, 2014. Assessing, transformation pathways. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

CliC/AMAP/IASC, 2016. The Arctic Freshwater System in a Changing Climate. WCRP Climate and Cryosphere (CliC) Project, Arctic Monitoring and Assessment Programme (AMAP), International Arctic Science Committee (IASC).

Collins, M., R. Knutti, J. Arblaster, J.-L. Dufresne, T. Fichefet, P. Friedlingstein, X. Gao, W.J. Gutowski, T. Johns, G. Krinner, M. Shongwe, C. Tebaldi, A.J. Weaver and M. Wehner, 2013. Long-term climate change: projections, commitments and irreversibility. In: Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Comiso, J.C. and F. Nishio, 2008. Trends in the sea ice cover using enhanced and compatible AMSR-E, SSM/I, and SMMR data. Journal of Geophysical Research: Oceans, 113:C02S07, doi:10.1029/2007JC004257

Danilov, A.I., G.V. Alekseev and A.V. Klepikov, 2014. [The effects of climate change on maritime activities in the Arctic]. Ice and snow. 54:91-99. doi:10.15356/2076-6734-2014-3-91-99 (In Russian)

Dankers, R., 2003. Sub-arctic hydrology and climate change: a case study of the Tana River Basin in Northern Fennoscandia. Dissertation, Utrecht University. http://dspace.library.uu.nl/handle/1874/557

DASTI, 2016. An OECD horizon scan of megatrends and technology trends in the context of future research policy. Danish Agency for Science, Technology and Innovation (DASTI).

Deser, C, J. Walsh and M. Timlin, 2000. Arctic sea ice variability in the context of recent atmospheric circulation trends. Journal of Climate, 13:607-633.

Deser, C., R. Knutti, S. Solomon and A.S. Phillips, 2012. Communication of the role of natural variability in future North American climate. Nature Climate Change, 2:775-779.

Dmitrenko, I.A., B. Rudels, S.A. Kirillov, Y.O. Aksenov, V.S. Lien, V.V. Ivanov, U. Schauer, I.V. Polyakov, A. Coward and D.G. Barber, 2015 Atlantic water flow into the Arctic Ocean through the St. Anna Trough in the northern Kara Sea. Journal of Geophysical Research: Oceans, 120: 5158-5178.

Dobler, A., J.E. Haugen and R. Benestad, 2016. Regional climate change projections for the Barents region. Earth System Dynamics discussion paper, esd-2016-27

Döscher, R. and T. Vihma, 2014. Recent advances in understanding the Arctic climate system state and change from a sea ice perspective: a review. Atmospheric Chemistry and Physics, 14:13571-13600.

Dowdeswell, J.A., M.R. Gorman, A.F. Glazovsky and Y.Y. Macheret, 1994. Evidence for floating ice shelves in Franz Josef Land, Russian High Arctic. Arctic and Alpine Research, 26:86-92.

Dunse, T., T. Schellenberger, J.O. Hagen, A. Kääb, T.V. Schuler and C.H. Reijmer, 2015. Glacier-surge mechanisms promoted by a hydro-thermodynamic feedback to summer melt. Cryosphere, 9:197-215.

EEA, 2011. The European Environment – State and Outlook 2010: Assessment of global megatrends. European Environment Agency (EEA), Copenhagen.

EEA, 2015. The European Environment – State and Outlook 2015: Assessment of global megatrends. European Environment Agency (EEA), Copenhagen.

EIU, 2015. Long-term macroeconomic forecasts. Key trends to 2050. The Economist Intelligence Unit, London.

Enderlin, E.M. and G.S. Hamilton, 2014. Estimates of iceberg submarine melting from high-resolution digital elevation models: Applications to Sermilik Fjord, East Greenland. Journal of Glaciology, 60: doi:10.3189/2014JoG14J085.

English, J.M., A. Gettelman and G.R. Henderson, 2015. Arctic radiative fluxes: Present-day biases and future projections in CMIP5 Models. Journal of Climate, 28:6019-6038.

Esau, I. and A. Chernokulsky, 2015. Convective cloud fields in the Atlantic sector of the Arctic: Satellite and ground-based observations. Remote Study of Arctic Atmospheric Process, 51:1007-1020.

Etzelmüller, B., T.V. Schuler, K. Isaksen, H.H. Christiansen, H. Farbrot and R. Benestad, 2011. Modeling the temperature evolution of Svalbard permafrost during the 20th and 21st century. The Cryosphere, 5:67-79.

Evans, M., N. Kholod, V. Malyshev, S. Tretyakova, E. Gusev, S. Yu and A. Barinov, 2015. Black carbon emissions from Russian diesel sources: case study of Murmansk. Atmospheric Chemistry and Physics Discussions, 15:3257-3284.

Farbrot, H., K. Isaksen, B. Etzelmüller and K. Gisnås, 2013. Ground thermal regime and permafrost distribution under a changing climate in northern Norway. Permafrost and Periglacial Processes, 24:20-38.

Flato, G., J. Marotzke, B. Abiodun, P. Braconnot, S.C. Chou, W. Collins, P. Cox, F. Driouech, S. Emori, V. Eyring, C. Forest, P. Gleckler, E. Guilyardi, C. Jakob, V. Kattsov, C. Reason and M. Rummukainen, 2013. Evaluation of climate models. In: Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

FNI and DNV, 2012. Arctic resource development: Risks and responsible management. Fridtjof Nansens Institutt and DNV, Oslo. www.fni.no/pdf/ONS-Arctic-summary.pdf

Forchhammer, M.C. and D. Boertmann, 1993. The muskoxen *Ovibos moschatus* in north and north-east Greenland: population trends and the influence of abiotic parameters on population dynamics. Ecography, 16:299-308.

Førland, E.J. and I. Hanssen-Bauer, 2003. Climate variations and implications for precipitation types in the Norwegian Arctic. Norwegian Meteorological institute. Report No. 24/02 KLIMA

Førland, E., R.E. Benestad, I. Hanssen-Bauer, J.E. Haugen and T. Engen Skaugen, 2011. Temperature and precipitation development at Svalbard 1900-2100. Advances in Meteorology, Article ID 893790, doi:10.1155/2011/893790

Forsström, S., J. Ström, C.A. Pedersen, E. Isaksson and S. Gerland, 2009. Elemental carbon distribution in Svalbard snow. Journal of Geophysical Research, 114:D19112, doi:10.1029/2008JD011480

Forsström, S., E. Isaksson, R.B. Skeie, J. Ström, C.A. Pedersen, T.K. Berntsen, H. Lihavainen, F. Godtliebsen and S. Gerland, 2013. Elemental carbon measurements in Arctic snow packs. Journal of Geophysical Research: Atmosphere, 118:13,614-13,627

Francis, J.A. and E. Hunter, 2007. Drivers of declining sea ice in the Arctic winter: a tale of two seas. Geophysical Research Letters, 34:L17503, doi:10.1029/2007GL030995

Gardner, A.S., G. Moholdt, B. Wouters, G.J. Wolken, D.O. Burgess, M.J. Sharp, J.G. Cogley, C. Braun and C. Labine, 2011. Sharply increased mass loss from glaciers and ice caps in the Canadian Arctic Archipelago. Nature, 473:357-360.

Gardner, A.S., G. Moholdt, J.G. Cogley, B. Wouters, A.A. Arendt, J. Wahr, E. Berthier, R. Hock, W.T. Pfeffer, G. Kaser, S.R.M. Ligtenberg, T. Bolch, M.J. Sharp, J.O. Hagen, M.R. van den Broeke and F. Paul, 2013. A reconciled estimate of glacier contributions to sea level rise: 2003 to 2009. Science, 340:852-857.

Gjelten, H.M., Ø. Nordli, K. Isaksen, E.J. Førland, P.N. Sviashchennikov, P. Wyszynski, U.V. Prokhorova, R. Przybylak, B.V. Ivanov and A.V. Urazgildeeva, 2016. Air temperature variations and gradients along the coast and fjords of western Spitsbergen. Polar Research, 35:29878.

Goos, M., A. Manning and A. Salomons, 2010. Explaining job polarization in Europe. The roles of technology, globalization and institutions. CEP Discussion Paper No 1026. Centre of Economic Performance, London School of Economics and Political Science.

Gore, A., 2013. The Future: Six Drivers of Global Change. Random House.

Graversen, R.G., P.L. Langen and T. Mauritsen, 2014. Polar amplification in CCSM4: Contributions from the lapse rate and surface albedo feedbacks. Journal of Climate, 27:4433-4450.

Haavisto, R., K. Pilli-Sihvola, A. Harjanne and A. Perrels, 2016. Socio-economic scenarios for the Eurasian Arctic by 2040. Finnish Meteorological Institute, Report No. 2016:1.

Hagen, J.O., J. Kohler, K. Melvold and J.G. Winther, 2003. Glaciers in Svalbard: mass balance, runoff and freshwater flux. Polar Research, 22:145-159.

Häkkinen, S. and D.J. Cavalieri, 1989. A study of ocean surface heat fluxes in the Greenland, Norwegian and Barents Seas. Journal of Geophysical Research, 94:6145-6157.

Hansen, B., K. Isaksen, R. Benestad, J. Kohler, Å. Pedersen, L. Loe, S. Coulson, J. Larsen and Ø. Varpe, 2014. Warmer and wetter winters: characteristics and implications of an extreme weather event in the High Arctic. Environmental Research Letters, 9:114021, doi:10.1088/1748-9326/9/11/114021

Hanssen-Bauer, I., E.J. Førland, I. Haddeland, H. Hisdal, S. Mayer, A. Nesje, J.E.Ø. Nilsen, S. Sandven, A.B. Sandø, A. Sorteberg and B. Ådlandsvik, 2015. Klima i Norge 2100: Kunnskapsgrunnlag for klimatilpasning oppdatert i 2015 [Climate in Norway 2100: Knowledge Basis for Climate Change Adaptation Updated in 2015]. Norsk klimasenter, NCCS report no. 2/2015.

Harsem, Ø., A. Eide and K. Heen, 2011. Factors influencing future oil and gas prospects in the Arctic. Energy Policy, 39:8037-8045.

Harvey, D., 1989. The Conditions of Postmodernity: An Enquiry into the Origins of Cultural Change. Blackwell.

Heleniak, T., 2014. Arctic populations and migration. In: Larsen, J.N. and G. Fondahl (eds.), Arctic Human Development Report: Regional Processes and Global Linkages, pp. 53-104. Nordic Council of Ministers.

Heleniak, T., 2016. Population trends. In: Wegren, S.K. (ed.), Putin's Russia: Past Imperfect, Future Uncertain. pp. 153-176. Sixth Edition. Rowman & Littlefield.

Hegg, D.A., A.D. Clarke, S.J. Doherty and J. StröM, 2011. Measurements of black carbon aerosol washout ratio on Svalbard. Tellus B, 63:891-900.

Hernández-Henríquez, M.A., S.J. Déry and C. Derksen, 2015. Polar amplification and elevation-dependence in trends of Northern Hemisphere snow cover extent, 1971–2014. Environmental Research Letters, 10:44010, doi:10.1088/1748-9326/10/4/044010.

Hirdman, D., J.F. Burkhart, H. Sodemann, S. Eckhardt, A. Jefferson, P.K. Quinn, S. Sharma, J. Ström and A. Stohl, 2010. Long-term trends of black carbon and sulphate aerosol in the Arctic: changes in atmospheric transport and source region emissions. Atmospheric Chemistry and Physics, 10:935193-68.

Hofgaard, A. and H.E. Myklebost, 2015. Overvåking av palsmyr. Andre gjenanalyse i Ostojeaggi, Troms. Endringer fra 2004 til 2014 [Monitoring of Palsyr. Second reanalysis in Ostojeaggi, Troms. Changes from 2004–2014]. Norwegian Institute for Nature Research (NINA), NINA Rapport 1164. (In Norwegian)

Hopsch, S., J. Cohen and K. Dethloff, 2012. Analysis of a link between fall Arctic sea ice concentration and atmospheric patterns in the following winter. Tellus A, 64:18264, http://dx.doi.org/10.3402/tellusa.v64i0.18264

Hov, Ø., U. Cubasch, E. Fischer, P. Höppe, T. Iversen, N. Gunnar Kvamstø, Z.W. Kundzewicz, D. Rezacova, D. Rios, F. Duarte Santos, B. Schädler, O. Veisz, C. Zerefos, R. Benestad, J. Murlis, M. Donat, G.C. Leckebusch and U. Ulbrich, 2013. Extreme Weather Events in Europe: preparing for climate change adaptation. Norwegian Meteorological Institute.

Huskey, L., I. Mäenpää and A. Pelyasov, 2014. Economic systems. In: Larsen, J.N. and G. Fondahl (eds.), Arctic Human Development Report: Regional Processes and Global Linkages, pp. 151-182. Nordic Council of Ministers.

IEA, 2015. World Energy Outlook 2015. International Energy Agency (IEA), Paris.

Inoue, J., J. Liu, J.O. Pinto and J.A. Curry, 2006. Intercomparison of Arctic regional climate models: Modeling clouds and radiation for SHEBA in May 1998. Journal of Climate, 19:4167-4178.

Inoue, J., M.E. Hori and K. Takaya, 2012. The role of Barents Sea ice in the wintertime cyclone track and emergence of a warm-Arctic cold-Siberian anomaly. Journal of Climate, 25:2561-2568.

Inoue, J., A. Yamazaki, J. Ono, K. Dethloff, M. Maturilli, R. Neuber, P. Edwards and H. Yamaguchi, 2015. Additional Arctic observations improve weather and sea-ice forecasts for the Northern Sea Route. Scientific Reports, 5:16868, doi:1038/srep16868.

IPCC, 2000. Emissions Scenarios. Nakicenovic, N. and R. Swart (eds.). Cambridge University Press.

IPCC, 2007. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.).

IPCC, 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.). Cambridge University Press.

IPCC, 2014. Climate Change 2014 – Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), Geneva.

Irannezhad, M., A.-K. Ronkanen and B. Kløve, 2016. Wintertime climate factors controlling snow resource decline in Finland. International Journal of Climatology, 36:110-131.

Isaksen, K., R.E. Benestad, C. Harris and J.L. Sollid, 2007a. Recent extreme near-surface permafrost temperatures on Svalbard in relation to future climate scenarios. Geophysical Research Letters, 34:L17502, doi:10.1029/2007GL031002

Isaksen, K., J.L. Sollid, P. Holmlund and C. Harris, 2007b. Recent warming of mountain permafrost in Svalbard and Scandinavia. Journal of Geophysical Research, 112:F02S04, doi:10.1029/2006JF000522

Isaksen, K., R.S. Ødegård, B. Etzelmüller, C. Hilbich, C. Hauck, H. Farbrot, T. Eiken, H.O. Hygen and T.F. Hipp, 2011. Degrading mountain permafrost in southern Norway - spatial and temporal variability of mean ground temperatures 1999-2009. Permafrost and Periglacial Processes, 22:361-377.

Ivanov, V.V. and G.I. Shapiro, 2005. Formation of dense water cascade in the marginal ice zone in the Barents Sea. Deep Sea Research I, 52:1699-1717.

Ivanov, V.V. and E. Watanabe, 2013. Does Arctic sea ice reduction foster shelf–basin exchange? Ecological Applications, 23:1765-1777.

Ivanov, B.V., S. Gerland, J.-G. Winther and H. Goodwin, 2003. Energy exchange processes in the marginal ice zone of the Barents Sea, Arctic Ocean, during spring 1999. Journal of Glaciology, 49:415-419.

Ivanov, V.V., G.I. Shapiro, J.M. Huthnance, D.M. Aleynik and P.N. Golovin, 2004. Cascades of dense water around the World Ocean. Progress in Oceanography, 60:47-98.

Ivanov, V., V. Alexeev, N.V. Koldunov, I.A. Repina, A.B. Sandoe, L.H. Smedsrud and A. Smirnov, 2016. Arctic Ocean heat impact on regional ice decay: A suggested positive feedback. Journal of Physical Oceanography, 46:1437-1456.

Johansson, C., V.A. Pohjola, C. Jonasson and T.V. Callaghan, 2011. Multi-decadal changes in snow characteristics in sub-Arctic Sweden. Ambio, 40:566-574.

Juday, G.P., V. Barber, P. Duffy, H. Linderholm, S. Rupp, S. Sparrow, E. Vaganov and J. Yarir, 2005. Forests, land management, and agriculture. In: ACIA, 2005. Arctic Climate Impact Assessment. pp. 781-862. Cambridge University Press.

Jung, T., N.D. Gordon, P. Bauer, D.H. Bromwich, M. Chevallier, J.J. Day, J. Dawson, F. Doblas-Reyes, C. Fairall, Goessling, H.F., M. Holland, J. Inoue, T. Iversen, S. Klebe, P. Lemke, M. Losch, A. Makshtas, B. Mills, P. Nurmi, D. Perovich, P. Reid, I.A. Renfrew, G. Smith, G. Svensson, M. Tolstykh and Q. Yang, 2016. Advancing polar prediction capabilities on daily to seasonal time scales. Bulletin of the American Meteorological Society, 97:1631-1647.

Kaltin, S., L.G. Anderson, K. Olsson, A. Fransson and M. Chierici, 2002. Uptake of atmospheric carbon dioxide in the Barents Sea. Journal of Marine Systems, 38:31-45.

Karl, T.R., A. Arguez, B. Huang, J.H. Lawrimore, J.R. McMahon, M.J. Menne, T.C. Peterson, R.S. Vose and H.-M. Zhang, 2015. Possible artifacts of data biases in the recent global surface warming hiatus. Science, 348:1469-1472.

Kattsov, V.M., V.E. Ryabinin, J.E. Overland, M.C. Serreze, M. Visbeck, J.E. Walsh, W. Meier and X. Zhang, 2011. Arctic sea-ice change: A grand challenge of climate science. Journal of Glaciology, 56:1115-1121.

Kausrud, K.L., A. Mysterud, H. Steen, J.O. Vik, E. Østbye, B. Cazelles, E. Framstad, A.M. Eikeset, I. Mysterud, T. Solhøy and N.C. Stenseth, 2008. Linking climate change to lemming cycles. Nature, 456:93-97.

Käyhkö, J., E. Apsite, A. Bolek, N. Filatov, S. Kondratyev, J. Korhonen, J. Kriaučiūnienė, G. Lindström and M. Sztobryn, 2015. Recent change – River run-off and ice cover. In: Second Assessment of Climate Change for the Baltic Sea Basin. pp. 99-116. Regional Climate Studies. Springer.

Kelman, I., J.C. Gaillard and J. Mercer, 2015. Climate change's role in disaster risk reduction's future: beyond vulnerability and resilience. International Journal of Disaster Risk Science, 6:21-27.

Khon, V.C., I.I. Mokhov, F.A. Pogarskiy, A. Babanin, K. Dethloff, A. Rinke and H. Matthes, 2014. Wave heights in the 21st century Arctic Ocean simulated with a regional climate model. Geophysical Research Letters, 41:2956-2961.

Khromova, T., G. Nosenko, S. Kutuzov, V. Muraviev and L. Chernova, 2014. Glacier area changes in Northern Eurasia. Environmental Research Letters, 9:015003.

Kidston, J., A.A. Scaife, S.C. Hardiman, D.M. Mitchell, N. Butchart, M.P. Baldwin and L.J. Gray, 2015. Stratospheric influence on tropospheric jet streams, storm tracks and surface weather. Nature Geoscience, 8:433-440.

Kimura, N. and M. Wakatsuchi, 2001. Mechanisms for the variation of sea ice extent in the Northern Hemisphere. Journal of Geophysical Research: Oceans, 106:31319-31331.

Kirtman, B., S.B. Power, J.A. Adedoyin, G.J. Boer, R. Bojariu, I. Camilloni, F.J. Doblas-Reyes, A.M. Fiore, M. Kimoto, G.A. Meehl, M. Prather, A. Sarr, C. Schär, R. Sutton, G.J. van Oldenborgh, G. Vecchi and H.J. Wang, 2013. Near-term climate change: projections and predictability. In: Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Kjeldsen, K.K., N.J. Korsgaard, A.A. Bjørk, S.A. Khan, J.E. Box, S. Funder, N.K. Larsen, J.L. Bamber, W. Colgan, M. van den Broeke, M.-L. Siggaard-Andersen, C. Nuth, A. Schomacker, C.S. Andresen, E. Willerslev and K.H. Kjær, 2015. Spatial and temporal distribution of mass loss from the Greenland Ice Sheet since AD 1900. Nature, 528:396-400.

Klimont, Z., K. Kupiainen, C. Heyes, P. Purohit, J. Cofala, P. Rafaj, J. Borken-Kleefeld and W. Schöpp, 2017. Global anthropogenic emissions of particulate matter including black carbon. Atmospheric Chemistry and Physics, 17:8681-8723.

Koch, D., S.E. Bauer, A. Del Genio, G. Faluvegi, J.R. McConnell, S. Menon, R.L. Miller, D. Rind, R. Ruedy, G.A. Schmidt and D. Shindell, 2011. Coupled aerosol-chemistry-climate twentieth-century transient model investigation: Trends in short-lived species and climate responses. Journal of Climate, 24:2693-2714.

Koenigk, T. and L. Brodeau, 2014. Ocean heat transport into the Arctic in the 20th and 21st century in EC-Earth. Climate Dynamics, 42:3101-3120.

Koenigk, T., U. Mikolajewicz, J.H. Jungclaus and A. Kroll, 2009. Sea ice in the Barents Sea: seasonal to interannual variability and climate feedbacks in a global coupled model. Climate Dynamics, 32:1119-1138.

Koenigk, T., P. Berg and R. Döscher, 2015. Arctic climate change in an ensemble of regional CORDEX simulations. Polar Research, 34:24603, http://dx.doi.org/10.3402/polar.v34.24603.

Kononova, N.K., 2012. The influence of atmospheric circulation on the formation of snow cover on the north eastern Siberia. Ice and Snow, 1:38-53. (In Russian, English summary).

Koryakin, V.S., 1988. The Arctic Glaciers. NAUK, Moscow.

Koven, C.D., W.J. Riley and A. Stern, 2013. Analysis of permafrost thermal dynamics and response to climate change in the CMIP5 Earth System Models. Journal of Climate, 26:1877-1900.

Kraus, E.B. and J.S. Turner, 1967. A one-dimensional model of the seasonal thermocline II. The general theory and its consequences. Tellus, 19:98-106.

Krey, V., O. Masera, G. Blanford, T. Bruckner, R. Cooke, K. Fisher-Vanden, H. Haberl, E. Hertwich, E. Kriegler, D. Mueller, S. Paltsev, L. Price, S. Schlomer, D. Urge-Vorsatz, D. van Vuuren and T. Zwickel, 2014. Annex II: Metrics & Methodology. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Kubyshkin, N.V., I.V. Buzin, A.F. Glazovsky and A.A. Skutin, 2006. Determination of the area of generation of big icebergs in the Barents Sea – temperature distribution analysis. Proceedings of the Sixteenth, International Offshore and Polar Engineering Conference.

Kusunoki, S., R. Mizuta and M. Hosaka, 2015. Future changes in precipitation intensity over the Arctic projected by a global atmospheric model with a 60-km grid size. Polar Science, 9:277-292.

Kvammen, Y., 2014. Polar low trajectories in the Nordic Seas 1999-2013: A statistical analysis using kernel density methods. Master's Thesis in Energy, Climate and Environment, Department of Physics and Technology, UiT – The Arctic University of Norway. EOM-3901.

Kwok, R. and D.A. Rothrock, 2009, Decline in Arctic sea ice thickness from submarine and ICESat records: 1958–2008. Geophysical Research Letters, 36:L15501, doi:10.1029/2009GL039035

Kwok, R., W. Maslowski and S.W. Laxon, 2005. On large outflows of Arctic sea ice into the Barents Sea. Geophysical Research Letters, 32:L22503, doi:10.1029/2005GL024485

Lang, C., X. Fettweis and M. Erpicum, 2015. Future climate and surface mass balance of Svalbard glaciers in an RCP8.5 climate scenario: a study with the regional climate model MAR forced by MIROC5. Cryosphere, 9:945-956.

Leck, C. and E. Svensson, 2015. Importance of aerosol composition and mixing state for cloud droplet activation over the Arctic pack ice in summer. Atmospheric Chemistry and Physics, 15:2545-2468.

Leck, C., M. Norman, E.K. Bigg and R. Hillamo, 2002. Chemical composition and sources of the High Arctic aerosol relevant for cloud formation. Journal of Geophysical Research: Atmospheres, 107:AAC1-1-AAC1-17.

Lehtonen, I., A. Venäläinen, J. Ikonen, N. Puttonen and H. Gregow, 2013. Some features of winter climate in northern Fennoscandia. Finnish Meteorological Institute, Report No. 2013:3.

Levitus, S., J.I. Antonov, T.P. Boyer, R.A. Locarnini, H.E. Garcia and A.V. Mishonov, 2009. Global ocean heat content 1955-2008 in light of recently revealed instrumentation problems. Geophysical Research Letters, 36: L07608, doi:10.1029/2008GL037155.

Lien, V.S. and A.G. Trofimov, 2013. Formation of Barents Sea Branch Water in the north-eastern Barents Sea. Polar Research, 32:18905, doi:10.3402/polar.v32i0.18905

Lindblad, S., U. Tynelius, T. Danell, W. Pichler and C. Anderstig, 2015. Demografins regionala utmaningar: Bilaga 7 til Långtidsutredningen 2015 [The Regional Demographic Challenges: Appendix 7 to the Long-term Assessment]. Finansdepartementet, Stockholm. (In Swedish)

Lindholt, L. and S. Glomsrød, 2012. The Arctic: no big bonanza for the global petroleum industry. Energy Economics, 34:1465-1474.

Liptak, J. and C. Strong, 2014. The winter atmospheric response to sea ice anomalies in the Barents Sea. Journal of Climate, 27:914-924.

Liston, G.E. and C.A. Hiemstra, 2011. The changing cryosphere: pan-Arctic snow trends (1979–2009). Journal of Climate, 24:5691-5712.

Lloyd's, 2012. Arctic Opening: Opportunity and risk in the High North. Chatham House, London.

Loeng, H., 2008. Klimaendringer i Barentshavet - Konsekvenser av økte CO_2-nivåer i atmosfæren og havet [Climate Change in the Barents Sea - Consequences of Increased CO_2-concentrations in the Atmosphere and Ocean]. Norwegian Polar Institute, Report No. 126.

Lotsari, E., N. Veijalainen, P. Alho and J. Käyhkö, 2010. Impact of climate change on future discharges and flow characteristics of the Tana River, sub-Arctic northern Fennoscandia. Geografiska Annaler A, 92:263-284.

Lynch, A.H., L.R. Lestak, P. Uotila, E.N. Cassano and L. Xie, 2008. A factorial analysis of storm surge flooding in Barrow, Alaska. Monthly Weather Review, 136:898-912.

Lystad, M., (ed.), 1986. Polar Lows in the Norwegian, Greenland and Barents Sea. Final report, Met-Norway.

Manabe, S. and R.J. Stouffer, 1980. Sensitivity of a global climate model to an increase of CO_2 concentration in the atmosphere. Journal of Geophysical Research, 85:5529-5554.

Manney, G.L., M.L. Santee, M. Rex, N.J. Livesey, M.C. Pitts, P. Veefkind, E.R. Nash, I. Wohltmann, R. Lehmann, L. Froidevaux, L.R. Poole, M.R. Schoeberl, D.P. Haffner, J.Davies, V.Dorokhov, H. Gernandt, B. Johnson, R. Kivi, E. Kyrö, N. Larsen, P.F. Levelt, A. Makshtas, C.T. McElroy, H. Nakajima, M. Concepción Parrondo, D.W. Tarasick, P. von der Gathen, K.A. Walker and N.S. Zinoviev, 2011. Unprecedented Arctic ozone loss in 2011. Nature, 478:469-475.

Marshall, J. and F. Schott, 1999. Open-ocean convection observations, theory and models. Reviews of Geophysics, 37:1-64.

Maturilli, M., A. Herber and G. König-Langlo, 2014. Basic and other measurements of radiation from the baseline surface radiation network (BSRN) station Ny-Ålesund in the years 1992 to 2013. Reference list of 253 datasets. Supplement to:

Maturilli, M., A. Herber and G. König-Langlo, 2014. Surface radiation climatology for Ny-Ålesund, Svalbard (78.9°N). Basic observations for trend detection. Theoretical and Applied Climatology, 120:331-339.

McGuire, A.D., D. Lawrence, E. Burke, X. Chen, C. Delire, C. Koven, A. MacDougall, S. Peng, A. Rinke, K. Saito, W. Zhang, R. Alkama, T.J. Bohn, P. Ciais, B. Decharme, I. Gouttevin, T. Hajima, D. Ji, G. Krinner, D.P. Lettenmaier, P.A. Miller, J.C. Moore, B. Smith and T. Sueyoshi, 2016. A retrospective assessment of the vulnerability of permafrost and carbon in the earth system: Comparison of dynamics among process-based models. Global Biogeochemical Cycles, in press.

Melsom, A., V.S. Lien and W.P. Budgell, 2009. Using the Regional Ocean Modeling System (ROMS) to improve the ocean circulation from a GCM 20th century simulation. Ocean Dynamics, 59:969-981.

Midttun, L., 1985. Formation of dense bottom water in the Barents Sea. Deep Sea Research, 32:1233-1241.

Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being: Synthesis. Island Press.

Mioduszewski, J.R., A.K. Rennermaim, D.A. Robinson and L. Wang, 2014. Controls on spatial and temporal variability in northern hemisphere terrestrial snow melt timing, 1979-2012. Journal of Climate, 28:2136-2153.

Moat, B.I., S.A. Josey and B. Sinha, 2014. Impact of Barents Sea winter air-sea exchanges on Fram Strait dense water transport. Journal of Geophysical Research: Oceans, 119:1009-1021.

Moholdt, G., C. Nuth, J.O. Hagen and J. Kohler, 2010. Recent elevation changes of Svalbard glaciers derived from ICESat laser altimetry. Remote Sensing Environment, 114:2756-2767.

Moholdt, G., T. Heid, T. Benham and J.A. Dowdeswell, 2012a. Dynamic instability of marine glacier basins of Academy of Sciences Ice Cap, Russian High Arctic. Annals of Glaciology, 53:193-201.

Moholdt, G., B. Wouters and A.S. Gardner, 2012b. Recent mass changes of glaciers in the Russian High Arctic, Geophysical Research Letters, 39, doi:10.1029/2012GL051466.

Mori, M., M. Watanabe, H. Shiogama, J. Inoue and M. Kimoto, 2014. Robust Arctic sea-ice influence on the frequent Eurasian cold winters in past decades. Nature Geoscience, 7:869-873.

Nakanowatari, T., K. Sato and J. Inoue, 2014. Predictability of the Barents Sea ice in early winter: remote effects of oceanic and atmospheric thermal conditions from the North Atlantic. Journal of Climate, 27:8884-8901.

Newson, R.L., 1973. Response of general circulation model of the atmosphere to removal of the Arctic ice cap. Nature, 241:39-40.

Noer, G. and T. Lien, 2010. Dates and positions of polar lows over the Nordic Seas between 2000 and 2010. Norwegian Meteorological Institute, Report No. 16/2010.

Nordic Council of Ministers, 2011. Megatrends. R.O. Rasmussen (ed.). Nordic Council of Ministers, Copenhagen.

NSD, 2015. SCB: Länets glesbygd dör ut [The Sparsely Populated Regions of the County are Losing Population]. www.nsd.se/nyheter/lulea/scb-lanets-glesbygd-dor-ut-9002579.aspx (accessed 22 June 2016).

OECD, 2012a. Looking to 2060: A Global Vision of Long-Term Growth. Economic Department Policy Note No. 15. Organisation for Economic Co-operation and Development (OECD).

OECD, 2012b. The OECD Environment Outlook to 2050: The Consequences of Inaction. Organisation for Economic Co-operation and Development (OECD).

OECD, 2016a. OECD Economic Outlook, Volume 2016, Issue 2. Organisation for Economic Co-operation and Development (OECD).

OECD, 2016b. OECD Science, Technology and Innovation Outlook 2016. Organisation for Economic Co-operation and Development (OECD).

Økland, H., 1987. Heating by organized convection as a source of polar low intensification. Tellus A, 39:397-407.

Olsen, A., A. Omar, R. Bellerby, T. Johannessen, U. Ninnemann, K. Brown, K. Olsson, J. Olafsson, G. Nondal, C. Kivimäe, S. Kringstad, C. Neill and S. Olafsdottir, 2006. Magnitude and origin of the anthropogenic CO_2 increase and ^{13}C Suess effect in the Nordic seas since 1981. Global Biogeochemical Cycles, 20:GB3027, doi:10.1029/2005GB002669

O'Neill, B.C., E. Kriegler, K. Riahi, K.L. Ebi, S. Hallegatte, T.R. Carter, R. Mathur and D.P. van Vuuren, 2014. A new scenario framework for climate change research: the concept of shared socioeconomic pathways. Climate Change, 122:387-400.

Orr, J., V. Fabry, O. Aumont, L. Bopp, S. Doney, R.A.G. Feely, N. Gruber, A. Ishida, F. Joos, R. Key, K. Lindsay, E. Maier-Reimer, R. Matear, P. Monfray, A. Mouchet, R. Najjar, G.-K. Plattner, K. Rodgers, C.L. Sabine, J. Sarmiento, R. Schlitzer, R. Slater, I. Totterdell, M.-F. Weirig, Y. Yamanaka and A. Yool, 2005. Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. Nature, 437:681-686.

Ørts Hansen, C., P. Grønsedt, C. Lindstrøm Graversen and C. Hendriksen, 2016. Arctic Shipping - Commercial Opportunities and Challenges. CBS Maritime, Copenhagen.

Outten, S., R. Davy and I. Esau, 2013. Eurasian winter cooling: Intercomparison of Reanalyses and CMIP5 data sets. Atmospheric and Oceanic Science Letters, 6:324-331.

Overland, J.E., K.R. Wood and M. Wang, 2011. Warm Arctic – cold continents: Climate impacts of the newly open Arctic sea. Polar Research, 30:15787, doi:10.3402/polar.v30i0.15787.

Pedersen, C.A., J.-C. Gallet, J. Ström, S. Gerland, S.R. Hudson, S. Forsström, E. Isaksson and T.K. Berntsen, 2015. In situ observations of black carbon in snow and the corresponding spectral surface albedo reduction. Journal of Geophysical Research: Atmosphere, 120:1476-1489.

Pedersen, R.A., I. Cvijanovic, P.L. Langen and B.M. Vinther, 2016. The impact of regional Arctic sea ice loss on atmospheric circulation and the NAO. Journal of Climate, 29:889-902.

Petoukhov, V. and V.A. Semenov, 2010. A link between reduced Barents-Kara sea ice and cold winter extremes over northern continents. Journal of Geophysical Research, 115:doi.10.1029/2009JD013568

Pfeffer, W.T., A.A. Arendt, A. Bliss, T. Bolch, J.G. Cogley, A.S. Gardner, J.-O. Hagen, R. Hock, G. Kaser, C. Kienholz, E.S. Miles, G. Moholdt, N. Mölg, F. Paul, V. Radić, P. Rastner, B.H. Raup, J. Rich and M.J. Sharp, 2014. The Randolph Glacier Inventory: a globally complete inventory of glaciers. Journal of Glaciology, 60:537-552.

Pielke Sr., R.A. and R. L. Wilby, 2012. Regional climate downscaling - what's the point? Eos, 93:52-53.

Pithan, F., and T. Mauritsen, 2014. Arctic amplification dominated by temperature feedbacks in contemporary climate models. Nature Geoscience, 7:181-184.

Porter, D.F., J.J. Cassano and M.C. Serreze, 2012. Local and large-scale atmospheric responses to reduced Arctic sea ice and ocean warming in the WRF Model. Journal of Geophysical Research: Atmospheres, 117:D11115, doi:10.1029/2011JD016969.

Prowse, T.D., A. Bring, E.C. Carmack, M.M. Holland, A. Instanes, J. Mård, T. Vihma and F.J. Wrona, 2017. Freshwater. In: Snow, Water, Ice and Permafrost in the Arctic (SWIPA) 2017. Arctic Monitoring and Assessment Programme (AMAP), Oslo.

PwC, 2015. The World in 2050: Will the shift in global economic power continue? PricewaterhouseCoopers, London.

Quinn, P.K., T.S. Bates, E. Baum, N. Doubleday, A.M. Fiore, M. Flanner, A. Fridlind, T.J. Garrett, D. Koch, S. Menon, D. Shindell, A. Stohl and S.G. Warren, 2008. Short-lived pollutants in the Arctic: their climate impact and possible mitigation strategies. Atmospheric Chemistry and Physics, 8:1723-1735.

Räisänen, J., 2008. Warmer climate: less or more snow? Climate Dynamics, 30:307-319.

Räisänen, J., 2016. Twentyfirst century changes in snowfall climate in Northern Europe in ENSEMBLES regional climate models. Climate Dynamics, 46:339-353.

Räisänen, J. and J. Eklund, 2012. 21st century changes in snow climate in northern Europe – a high-resolution view from ENSMBLES regional climate models. Climate Dynamics, 38:2575-2591.

Raneke, A., 2015. Invandring avgörande för framtidens befolkning. [Immigration vital to future population]. Statistics Sweden. (In Swedish)

Rasmus, S., J. Kumpula and K. Jylhä, 2014a. Suomen poronhoitoalueen muuttuvat talviset sää- ja lumiolosuhteet [The changing winter weather and snow conditions in Finnish reindeer husbandry area]. Terra 126:4 [In Finnish, English abstract]. www.helsinki.fi/maantiede/geofi/terra/pdf/Terra_4_2014.pdf

Rasmus, S., J. Kumpula and J. Siitari, 2014b. Can a snow structure model estimate snow characteristics relevant to reindeer husbandry? Rangifer, 34:37-56.

Rasmus, S., J. Boelhouwers, A. Briede, I.A. Brown, M. Falarz, S. Ingvander, J. Jaagus, L. Kitaev, A. Mercer and E. Rimkus, 2015. Recent change – terrestrial cryosphere. In: Second Assessment of Climate Change for the Baltic Sea Basin. pp. 117-129. Regional Climate Studies. Springer.

Rignot, E., I. Velicogna, M.R. van den Broeke, A. Monaghan and J.T.M. Lenaerts, 2011. Acceleration of the contribution of the Greenland and Antarctic ice sheets to sea level rise. Geophysical Research Letters, 38:L05503, doi:10.1029/2011GL046583.

Rinke, A., K. Dethloff, W. Dorn, D. Handorf and J.C. Moore, 2013. Simulated Arctic atmospheric feedbacks associated with late summer sea ice anomalies. Journal of Geophysical Research: Atmospheres, 118:7698-7714.

Rojo, M., C. Claud, P.-E. Mallet, G. Noer, A.M. Carleton and M. Vicomte, 2015. Polar low tracks over the Nordic Seas: A 14-winter climatic analysis. Tellus A, 67:24660, http://dx.doi.org/10.3402/tellusa.v67.24660

Romanovsky, V.E., S.L. Smith and H.H. Christiansen, 2010. Permafrost thermal state in the polar Northern Hemisphere during the International Polar Year 2007-2009: a synthesis. Permafrost and Periglacial Processes, 21:106-116.

Romanovsky, V.E., A.L. Kholodov, S.L. Smith, H.H. Christiansen, N.I. Shiklomanov, D.S. Drozdov, G.V. Malkova, N.G. Oberman and S.S. Marchenko, 2014. [The Arctic] Terrestrial permafrost ["State of the Climate in 2013"]. Bulletin of the American Meteorological Society, 95:S139-S141.

Romanovsky, V.E., S.L. Smith, H.H. Christiansen, N.I. Shiklomanov, D.A. Streletskiy, D.S. Drozdov, G.V. Malkova, N.G. Oberman, A.L. Kholodov and S.S. Marchenko, 2015 [The Arctic] Terrestrial permafrost ["State of the Climate in 2014"]. Bulletin of the American Meteorological Society, 96:S139-S141.

Romanovsky, V., K. Isaksen, D. Drozdov, O. Anisimov, A. Instanes, M. Leibman, A.D. McGuire, N. Shiklomanov, S. Smith and D. Walker, 2017. Changing permafrost and its impacts. In: Snow, Water, Ice and Permafrost in the Arctic (SWIPA) 2017. Arctic Monitoring and Assessment Programme (AMAP), Oslo.

Roshydromet, 2014. Second Roshydromet Assessment Report on Climate Change and its Consequences in Russian Federation, Roshydromet, Moscow (In Russian, English summary). http://downloads.igce.ru/publications/OD_2_2014/v2014/htm/

Roshydromet, 2016. A Report on Climate Change on the Territory of the Russian Federation in 2015. Roshydromet, Moscow. (In Russian).

Rosstat, 2015. Демографический ежегодник России - 2015 г. Federal State Statistics Service, Russian Federation. www.gks.ru/bgd/regl/B15_16/Main.htm (accessed 21 June 2016).

Rothrock, D.A., D B. Percival and M. Wensnahan, 2008. The decline in arctic sea-ice thickness: Separating the spatial, annual, and interannual variability in a quarter century of submarine data. Geophysical Research Letters, 113: C05003, doi:10.1029/2007JC004252

Rutgersson, A., J. Jaagus, F. Schenk, M. Stendel, L. Bärring, A. Briede, B. Claremar, I. Hansson-Baur, J. Holopainen, A. Moberg, Ø. Nordi, E. Rimkus and J.Wibig, 2015. Recent change – Atmosphere. In: Second Assessment of Climate

Change for the Baltic Sea Basin. pp. 69-97. Regional Climate Studies. Springer.

Sakshaug, E., 2004. Primary and secondary production in the Arctic Seas. In: Stein, R. and R.M. Macdonald (eds.), The Organic Carbon Cycle in the Arctic Ocean. pp. 57-81. Springer.

Sander, G., J. Gille, A. Stępień, T. Koivurova, J. Thomas, J.-C. Gascard and D. Justus, 2016. Changes in Arctic maritime transport. In: Stępień, A., T. Koivurova and T, Kankaanpää (eds.), The Changing Arctic and the European Union. pp. 81-114. Brill Nijhoff.

Sandø, A.B., J.E. Nilsen, Y. Gao and K. Lohmann, 2010. Importance of heat transport and local air-sea heat fluxes for Barents Sea climate variability. Journal of Geophysical Research, 115:C07013, doi:10.1029/2009JC005884

Sandø, A.B., Y.A. Melsom and W.P. Budgell, 2014a. Downscaling IPCC control run and future scenario with focus on the Barents Sea. Ocean Dynamics, 64:927-949.

Sandø, A.B., Y. Gao and H.R. Langehaug, 2014b. Relation between ocean heat transports, sea ice processes and Arctic sea ice variability in NorESM1-M simulations. Journal of Geophysical Research: Oceans, 119:2095-2108.

Sato, K., J. Inoue, Y.-M. Kodama and J.E. Overland, 2012. Impact of Arctic sea-ice retreat on the recent change in cloud-base height during autumn. Geophysical Research Letters, 39:L10503, doi:10.1029/2012GL051850

Sato, K., J. Inoue and M. Watanabe, 2014. Influence of the Gulf Stream on the Barents Sea ice retreat and Eurasian coldness during early winter. Environmental Research Letters, 9:101003.

Schlichtholz, P., 2011. Influence of oceanic heat variability on sea ice anomalies in the Nordic Seas. Geophysical Research Letters, 38:L05705, doi:10.1029/2010GL045894

Schweiger, A.J., R.W. Lindsay, S. Vavrus and J.A. Francis, 2008. Relationships between arctic sea ice and clouds during autumn. Journal of Climate, 21:4799-4810.

Screen, J.A. and I. Simmonds, 2010. The central role of diminishing sea ice in recent arctic temperature amplification. Nature, 464:1334-1337.

Screen, J.A. and I. Simmonds, 2012. Declining summer snowfall in the Arctic: causes, impacts and feedbacks. Climate Dynamics, 38:2243-2256.

Screen, J.A., C. Deser, I. Simmonds and R. Tomas, 2014. Atmospheric impacts of Arctic sea-ice loss, 1979–2009: Separating forced change from atmospheric internal variability. Climate Dynamics, 43:333-344.

Serreze, M.C., A.P. Barrett and J. Stroeve, 2012. Recent changes in tropospheric water vapor over the Arctic as assessed from radiosondes and atmospheric reanalyses. Journal of Geophysical Research: Atmospheres, 117:D10104, doi:10.1029/2011JD017421.

Shapiro, G.I., J.M. Huthnance and V.V. Ivanov, 2003. Dense water cascading off the continental shelf. Journal of Geophysical Research, 108:3390, doi:10.1029/2002JC001610, C12.

Sharp, M., M. Ananicheva, A. Areendt, J.-O. Hagen, R. Hock, E. Josberger, R.D. Moore, W.T. Pfeffer and G.J. Wolken, 2011. Mountain glaciers and ice caps. In: Snow, Water, Ice and Permafrost in the Arctic (SWIPA): Climate Change and the Cryosphere. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway

Shindell, D., J.C.I. Kuylenstierna, E. Vignati, R. van Dingenen, M. Amann, Z. Klimont, S.C. Anenberg, N. Muller, G. Janssens-Maenhaut, F. Raes, J. Schwartz, G. Faluvegi, L. Pozzoli, K. Kupiainen, L. Höglund-Isaksson, L. Emberson, D. Streets, V. Ramanathan, K. Hicks, N.T. Kim Oanh, G. Milly, M. Williams, W. Demkine and D. Fowler, 2012. Simultaneously mitigating near-term climate change and improving human health and food security. Science, 335:183-189.

Shkolnik, I.M. and S.V. Efimov, 2013. Cyclonic activity in high latitudes as simulated by a regional atmospheric climate model: added value and uncertainties. Environmental Research Letters, 8:45007, doi:10.1088/1748-9326/8/4/045007.

Sievert, S., S. Zhakarov and R. Klingholz, 2011. The Waning World Power: The Demographic Future of Russia and the other Soviet Successor States. Berlin Institute for Population and Development.

Simpson, M.J.R., J.E.Ø. Nilsen, O.R. Ravndal, K. Breili, H. Sande, H.P. Kierulf, H. Steffen, E. Jansen, M. Carson and O. Vestøl, 2015. Sea Level Change for Norway: Past and Present Observations and Projections to 2100. Norwegian Centre for Climate Services (NCCS), NCCS Report No. 1/2015.

Skagseth, Ǿ., T. Furevik, R. Ingvaldsen, H. Loeng, K.A. Mork, K.A. Orvik and V. Ozhigin, 2008. Volume and heat transports to the Arctic Ocean via the Norwegian and Barents Seas. In: Dickson, B., J. Meincke and P. Rhines (eds.), Arctic-Subarctic ocean fluxes: defining the role of Nordic Seas in climate. Springer.

Skjelvan, I., E. Falck, F. Rey and S. Kringstad, 2008. Inorganic carbon time series at Ocean Weather Station M in the Norwegian Sea. Biogeosciences, 5:549-560.

Skogen, M.D., A. Olsen, K.Y. Børsheim, A.B. Sandø and I. Skjelvan, 2014. Modelling ocean acidification in the Nordic and Barents Seas in present and future climate. Journal of Marine Systems, 131:10-20.

Slater, A.G. and D.M. Lawrence, 2013. Diagnosing present and future permafrost from climate models. Journal of Climate, 26:5608-5623.

Smedsrud, L.H., R. Ingvaldsen, J.E.Ø. Nilsen and Ø. Skagseth, 2010. Heat in the Barents Sea: transport, storage, and surface fluxes. Ocean Science, 6:219-234.

Smedsrud, L.H., I.N. Esau, R.B. Ingvaldsen, T. Eldevik, P.M. Haugan, C. Li, V. Lien, A. Omar, O.H. Otterå, B. Risebrobakken, A.B. Sandø, V. Semenov and S.A. Sorokina, 2013. The role of the Barents Sea in the Arctic climate system. Reviews of Geophysics, 51:415-449.

Smith, L.C. 2011. The New North: The World in 2050. London: Profile Books.

Smith, S.D., R.D. Muench and C.H. Pease, 1990. Polynyas and leads: an overview of physical processes and environment. Journal of Geophysical Research: Oceans, 95:9461-9479.

Smith, S.L., S.A. Wolfe, D.W. Riseborough and F.M. Nixon, 2009. Active-layer characteristics and summer climatic indices, Mackenzie Valley, Northwest Territories, Canada. Permafrost and Periglacial Processes, 20: 201-220.

Statistics Finland, 2015. Population projections 2015. http://pxnet2.stat.fi/PXWeb/pxweb/en/StatFin/StatFin__vrm__vaenn/020_vaenn_tau_102.px/?rxid=75e2585c-56aa-45cb-8b9f-42ce173cea0a (accessed 21 June 2016).

Statistics Norway, 2016. Population projections, 2016-2100. www.ssb.no/en/befolkning/statistikker/folkfram/aar/2016-06-21 (accessed 21 June 2016).

Statistics Sweden, 2015. Sveriges framtida befolkning 2016-2060. Sveriges oficiella statistik [The Future Population in Sweden 2016-2060]. Statistiska meddelanden BE 18 SM 1601.

Steinacher, M., F. Joos, T. Frölicher, G.-K. Plattner and S. Doney, 2009. Imminent ocean acidification in the Arctic projected with NCAR global coupled carbon cycle climate model. Biogeosciences, 6:515-533.

Stępień, A., T. Koivuova and P. Kankaanpää, 2015. The Changing Arctic and the European Union. Brill Nijhoff.

Steppeler, J., G. Doms, U. Schättler, H.W. Bitzer, A. Gassmann, U. Damrath and G. Gregoric, 2003. Meso-gamma scale forecasts using the nonhydrostatic model LM. Meteorology and Atmospheric Physics, 82:75-96.

Stohl, A., Z. Klimont, S. Eckhardt, K. Kupiainen, V.P. Shevchenko, V.M. Kopeikin and A.N. Novigatsky, 2013. Black carbon in the Arctic: the underestimated role of gas flaring and residential combustion emissions. Atmospheric Chemistry and Physics, 13:8833-8855.

Stohl, A., B. Aamaas, M. Amann, L.H. Baker, N. Bellouin, T.K. Berntsen, O. Boucher, R. Cherian, W. Collins, N. Daskalakis, M. Dusinska, S. Eckhardt, J.S. Fuglestvedt, M. Harju, C. Heyes, Ø. Hodnebrog, J. Hao, U. Im, M. Kanakidou, Z. Klimont, K. Kupiainen, K.S. Law, M.T. Lund, R. Maas, C.R. MacIntosh, G. Myhre, S. Myriokefalitakis, D. Olivié, J. Quaas, B. Quennehen, J.-C. Raut, S.T. Rumbold, B.H. Samset, M. Schulz, Ø. Seland, K.P. Shine, R.B. Skeie, S. Wang, K.E. Yttri and T. Zhu, 2015. Evaluating the climate and air quality impacts of short-lived pollutants. Atmospheric Chemistry and Physics Discussions, 15:15155-15241.

Stramler, K., A.D. Del Genio and W.B. Rossow, 2011. Synoptically driven Arctic winter states. Journal of Climate, 24:1747-1762.

Strey, S.T., W.L. Chapman and J.E. Walsh, 2010. The 2007 sea ice minimum: impacts on the northern hemisphere atmosphere in late autumn and early winter. Journal of Geophysical Research: Atmospheres, 115:D23103, doi:10.1029/2009JD013294.

Stroeve, J.C., M.C. Serreze, A. Barrett and D.N. Kindig, 2011. Attribution of recent changes in autumn cyclone associated precipitation in the Arctic. Tellus, 63:653-663.

Svanström, S., 2015. Dagens urbanisering – inte på landsbygdens bekostnad. [Today's urbanization – not at the expense of rural areas] Välferd 2/2015.

Svenskt Näringsliv, 2016. En framtidsrapport för Västerbottens län. Förutsättningar för företagande, jobb och tillväxt [A Future Outlook for Västerbottens Municipality. Conditions for Businesses, Jobs, and Growth]. Svenskt Näringsliv, Stockholm.

Swedish Environmental Protection Agency, 2015. Air & Environment 2015: Arctic. Swedish Environmental Protection Agency.

Takayabu, I., H. Kanamaru, K. Dairaku, R. Benestad, H. von Storch and J.H. Christensen, 2016. Reconsidering the quality and utility of downscaling. Journal of the Meteorological Society of Japan, 94A:31-45.

Tetzlaff, A., C. Lüpkes, G. Birnbaum, J. Hartmann, T. Nygård and T. Vihma, 2014. Brief Communication: Trends in sea ice extent north of Svalbard and its impact on cold air outbreaks as observed in spring 2013. The Cryosphere, 8:1757-1762.

The BACC II Author Team, 2015. Second Assessment of Climate Change for the Baltic Sea Basin. Regional Climate Studies. Springer.

The Research Council of Norway, 2008. Climate change and impacts in Norway (NORKLIMA). Annual Report 2008. (In Norwegian)

Thompson, D.W.J., M.P. Baldwin and J.M. Wallace, 2002. Stratospheric connection to northern hemisphere wintertime weather: Implications for prediction. Journal of Climate, 15:1421-1428.

Ulbrich, U., G.C. Leckebusch, J. Grieger, M. Schuster, M. Akperov, M.Y. Bardin, Y. Feng, S. Gulev, M. Inatsu, K. Keay, S.F. Kew, M.L. Liberato, P. Lionello, I. Mokhov, U. Neu, J.G. Pino, C.C. Raible, M. Reale, I. Rudeva, I. Simmonds, N.D. Tilinina, I.F. TrigoS. Ulbrich, X.L. Wang and H. Wernli, 2013. Are greenhouse gas signals of northern hemisphere winter extra-tropical cyclone activity dependent on the identification and tracking algorithm? Meteorologische Zeitschrift, 22:61-68.

UNDESA, 2015a. World Population Prospects: The 2015 revision, Key findings and advance tables. United Nations, Department of Economic and Social Affairs.

UNDESA, 2015b. World Urbanization Prospects: The 2014 revision, Key findings and advance tables. United Nations, Department of Economic and Social Affairs

UNEP, 2011. Decoupling Natural Resource Use and Environmental Impacts from Economic Growth. A Report of the Working Group on Decoupling to the International Resource Panel. United Nations Environment Programme (UNEP).

Uusitalo, L., A. Lehikoinen, I. Helle and K. Myrberg, 2015. An overview of methods to evaluate uncertainty of deterministic models in decision support. Environmental Modelling and Software, 63:24-31.

van Delden, A., E.A. Rasmussen, J. Turner and B. R¢sting; Theoretical investigations. In: Rasmussen, E.A. and J. Turner (eds.), 2003. Polar Lows: Mesoscale Weather Systems in the Polar Regions. Cambridge University Press.

Vaughan, D.G., J.C. Comiso, I. Allison, J. Carrasco, G. Kaser, R. Kwok, P. Mote, T. Murray, F. Paul, J. Ren, E. Rignot, O. Solomina, K. Steffen and T. Zhang, 2013. Observations: cryosphere. In: Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Vavrus, S.J., 2013. Extreme Arctic Cyclones in CMIP5 Historical Simulations. Geophysical Research Letters, 40:6208-6212.

Vihma, T., 2014. Effects of arctic sea-ice decline on weather and climate: A review. Surveys in Geophysics, 35:1175, doi:10.1007/s10712-014-9284-0.

Vikhamar-Schuler, D., K. Isaksen, J.E. Haugen, H. Tømmervik, B. Luks, T.V. Schuler and J.W. Bjerke, 2016. Changes in winter warming events in the Nordic Arctic Region. Journal of Climate, 29:6223-6244.

Vincent, L.A., X. Zhang, R.D. Brown, Y. Feng, E. Mekis, E.J. Milewska, H. Wan and X.L. Wang, 2015. Observed trends in Canada's climate and influence of low-frequency variability modes. Journal of Climate, 28:4545-4560.

Walsh, J.E., O. Anisimov, J.O.M. Hagen, T. Jakobsson, J. Oerlemans, T.D. Prowse, V. Romanovsky, N. Savelieva, M. Serreze, A. Shiklomanov, I. Shiklomanov and S. Solomon, 2005. Cryosphere and hydrology. In: Arctic Climate Impact Assessment. pp. 183-242. Cambridge University Press.

Wassmann, P., M. Reigstad, T. Haug, B. Rudels, M.L. Carroll, H. Hop, G.W. Gabrielsen, S. Falk-Petersen, S.G. Denisenko, E. Arashkevich, D. Slagstad and O. Pavlova, 2006. Food webs and carbon flux in the Barents Sea. Progress in Oceanography, 71:232-287.

Wegmann, M., Y. Orsolini, M. Vázquez, L. Gimeno, R. Nieto, O. Bulygina, R. Jaiser, D. Handorf, A. Rinke, K. Dethloff, A. Sterin and S. Brönnimann, 2015. Arctic moisture source for Eurasian snow cover variations in autumn. Environmental Research Letters, 10:054015, doi:10.1088/1748-9326/10/5/054015.

Westermann, S., J. Boike, M. Langer, T.V. Schuler and B. Etzelmüller, 2011. Modeling the impact of wintertime rain events on the thermal regime of permafrost. The Cryosphere, 5:945-959.

WHO, 2012. Health Effects of Black Carbon. World Health Organization (WHO), WHO Regional Office for Europe.

WHO, 2013. Review of evidence on health aspects of air pollution – REVIHAAP Project. Final technical report. World Health Organization (WHO), WHO Regional Office for Europe.

Willis, M.J., A K. Melkonian and M.E. Pritchard, 2015. Outlet glacier response to the 2012 collapse of the Matusevich Ice Shelf, Severnaya Zemlya, Russian Arctic. Journal of Geophysical Research: Earth Surface, 120:2040-2055.

Woods, C. and R. Caballero, 2016. The role of moist intrusions in winter arctic warming and sea ice decline. Journal of Climate, 29:4473-4485.

Wrona, F.J., M. Johansson, J.M. Culp, A. Jenkins, J. Mård, I.H. Myers-Smith, T.D. Prowse, W.F. Vincent and P. A. Wookey, 2016. Transitions in Arctic ecosystems: Ecological implications of a changing hydrological regime. Journal of Geophysical Research: Biogeosciences, 121:650-674.

Yang, S. and J. Christensen, 2012. Arctic sea ice reduction and European cold winters in CMIP5 climate change experiments. Geophysical Research Letters, 39:L20707, doi:10.1029/2012GL053338

York, R., 2012. Do alternative energy sources displace fossil fuels? Nature Climate Change 2:441-443.

Zahn, M. and H. von Storch, 2008. A long-term climatology of North Atlantic polar lows. Geophysical Research Letters, 35:L22702: doi:10.1029/2008GL035769.

Zahn, M. and H. von Storch, 2010. Decreased frequency of North Atlantic polar lows associated with future climate warming. Nature, 467:309-312.

Zappa, G., L.C. Shaffrey, K.I. Hodges, P.G. Sansom and D.B. Stephenson, 2013. A multimodel assessment of future projections of North Atlantic and European extratropical cyclones in the CMIP5 climate models. Journal of Climate, 26:5846-5862.

Zappa, G., G. Masato, L. Shaffrey, T. Woollings and K. Hodges, 2014. Linking northern hemisphere blocking and storm track biases in the CMIP5 climate models. Geophysical Research Letters, 41:135-139.

Zhang, X., J. Walsh, J. Zhang, U.S. Bhatt and M. Ikeda, 2004. Climatology and interannual variability of arctic cyclone activity: 1948-2002. Journal of Climate, 17:2300-2317.

Zubakin, G.K., Yu.P. Gudoshnikov, A.K. Naumov, A.F. Glazovsky, N.V. Kubyshkin, I.V. Buzin, V.V. Borodulin and E.A. Skutina, 2007. Results of investigations of icebergs, glaciers and their frontal zones in the northeastern part of the Barents Sea. Proceedings of the 19th International Conference on Port and Ocean Engineering, Dalian, China, 27-30 June 2007. pp. 548-564.

Appendix 4.1 Knowledge, information and uncertainties

Everybody deals with some degree of uncertainty every day, as nobody knows how the day will pan out when they get out of bed in the morning. The term "uncertainty" is also commonly used, e.g. in the assessment reports of the IPCC, however, its exact definition is not always clear. It may mean different things to different people. Within the scientific community, it may embody aspects such as model shortcomings, known unknowns, unknown unknowns, lack of information, lack of knowledge, lack of understanding, lack of precision, probabilities, error bars, and errors. Uusitalo et al., (2015) list a number of approaches for dealing with uncertainties: (i) expert assessment, (ii) model sensitivity analysis, (iii) model emulation, (iv) variability, (v) multiple models, and (vi) data based approaches. Several of these approaches are present in this chapter: The contribution from a number of different experiments brings in the first approach, and the use of different emission scenarios (global drivers, socio-economic futures), large ensembles, and different downscaling strategies (ESD and RCMs) introduce both a kind of sensitivity analysis (ii) and make use of multiple models (v). The comparison with past trends also serves to address uncertainty, e.g. in terms of variability (iv) and data based approaches (vi). A key issue concerning uncertainty is a proper validation of the models being used to address some question, and this is part of some of the projections presented in this chapter.

The discussion of uncertainty often implies the presence of some information, e.g. about the limitation of our ability to predict or the characteristics of the probability distribution function. The character of the type of uncertainty connected to some question is furthermore contextual, and it is difficult to put all in one basket (Uusitalo et al., 2015). In many cases, much of the uncertainty concerns aspects which are not crucial, and we may arrive at an answer by starting with the information that is available, and apply known constraints to infer a range of possibilities (elimination). Furthermore, the picture of the situation about which we wish to study may become more complete by bringing together information from different and independent sources and applying proper statistics. This also includes studying data from different sites across regions, e.g. at different sides of national borders. Some of the analysis presented in this report builds on multiple lines of evidence from a set of independent station observations. The ESD presented here made use of a group of station within the Barents region and combined the information from all these to improve the quality and reduce the effect of errors (Benestad et al., 2015).

The degree of confidence and the uncertainty often has to be explained in even simpler terms to stakeholders, while being based on the principles above, and some sketchy ideas could be based on a table of possible outcomes where the likelihood for each is assessed, based on scientific results and findings. This is essentially similar to a simple risk analysis or risk management that makes use of a contingency table. This type of presentation may provide a common format across a range of situations, both where the information is quantitative and qualitative. Such tables may provide a more intuitive description than the description provided in the IPCC reports by also including a description of alternative outcomes and the likelihood associated with each. For a quantitative statement (e.g. temperature or precipitation), a small set of categories can cover all possibilities: a reduction, no change, or increase. The number of categories reflects the confidence and the amount of details that can be provided. Unlike quantitative forecasts, it is likely that a range of qualitative scenarios do not cover all possible futures (unknown unknowns). In this case, the stakeholder needs to ask 'what can happen?' and assess which conditions are important and which are not by applying a sensitivity test for impact models in a "bottom-up approach" (Pielke Sr. and Wilby, 2012). Such a sensitivity test needs to go hand-in-hand with an uncertainty analysis, and can be carried out in terms of downscaling applied to large ensembles of GCM runs (different emission scenarios, models, and initial conditions) in addition to testing impact models with a range of different inputs. The results of such a sensitivity test can be used to create a risk contingency table and guide contingency plans, but experience has shown that they may not always be complete (e.g. the tsunami that hit Fukishima in 2011).

Uncertain outcome can also be stated as risk analysis based on statistical estimation of probabilities. The risk-based approach can include alternative conditions as well as a combination of events (a "perfect storm"), providing information about what can happen and what is likely. Most of this report has dealt with the respective drivers without much emphasis on the fact that many are likely to take place in combination with others. This is known to be true with respect to temperature, precipitation, permafrost, and ice, although ecological response and socio-economic pressures will also be part of this mix. Because of this complex nature, confidence statements as presented in the IPCC reports, which are also useful for describing the degree of belief in a statement, do not necessarily provide information about alternative types of outcomes in terms of more complex situations. Confidence intervals (statements) for each factoid can even be estimated objectively through statistical estimation of confidence intervals, however, they are not so easy to combine for a complex mix of conditions which may reinforce or weaken the effect of each other. There are also likely surprises which by definition are difficult to anticipate, partly due to non-linear and convoluted interactions between different drivers. They may also involve tipping points or unknown unknowns.

There are different parallel sources of information available for assessing different questions. For instance, there are few known laws of nature when it comes to socio-economic questions, as opposed to scientific disciplines such as physics and chemistry. Nevertheless, demography is fairly straightforward in terms of births and deaths, although migration patterns is a major unknown. Both socio-economic and physics-related assessments can involve statistics and empirical evidence, however, an additional unknown is that there is no immediate and direct links between a changing climate and societal changes. Furthermore, there is an increasingly faster pace of change in the Arctic and in the rest of the world, in terms of politics, economy, climate change, and with many intertwined ties between these. This makes it tricky to rely on experience and empirical information, however, we can still count on an uneven development within the Arctic in the future. The regional details and differences make the picture both more complicated and more uncertain. There is also limited knowledge concerning global megatrends, and it is expected that there will be unanticipated shifts, ruptures (e.g. 'Brexit') and surprises (unknown unknowns).

One way to deal with uncertainties associated with a complex situation that involves many entangled dimensions is to address 'what-if' questions and explore the range of plausible outcomes, perhaps through simulations and gaming technology. For instance, it is possible to explore different effects of the urbanization process, which may involve both a scenario where people move from rural to urban areas as well as in the other direction. Furthermore, it is possible to consider how age and employment may affect society and its institutions. The professional structure in a community may also change as many routine tasks and low-skilled jobs disappear contributing to greater income disparities. Hence, it is plausible with an increasing polarization of the labor markets. The emergence of sharing and circular economy ("green shift") may also provide new opportunities and challenges.

Other known unknowns may be that the economic growth differs regionally and most likely will depend on leading technology which has not yet been invented. Furthermore, the future economic growth, energy demand, and energy mix depend on a number of factors, such as the global political, economic and ecological stability and progress. If fusion energy[9] succeeds, then the picture will be radically changed, and the current power structure will probably change in its wake. Moreover, the consequences of technological progress will generate new opportunities and challenges, in terms of politics, culture, livelihood, economy, and environment. The geopolitical climate will also likely depend on individual people as well as the public opinion, political decisions, economy, technology, environment, and corporations. Will the UNFCCC commitment be respected, or will the greenhouse gas concentrations continue to grow as it has done since Kyoto 1997? This source of uncertainty can be illustrated with the case where member countries of the Arctic council pledge to CO_2 reduction yet simultaneously push for a continued fossil fuel exploitation in the Arctic. A society with global connection is also likely to feel the geographical diversity in the effect of climate change, which at the present is poorly known, and where people and economies in some regions can expect to feel the effects more adversely. For example, drought, heat, and ocean inundation may trigger economic recession, conflicts and mass migration, and drought in some region may affect the import and export needs of agricultural products. The availability of climate information varies from place to place due to national data policies and investment in early warning systems and climate services[10], all of which provide a basis for risk analysis and management. One consequence may be that future businesses will seek locations where they are less exposed and the climate related risks are well documented when climate extremes are getting more severe. In many places, there will be little information. The danger of major accidents or oil spills associated with activities in the Arctic as well as elsewhere also represents a substantial source of uncertainty, and the risk is affected by climate change.

Research gaps

There are several research gaps which need further research, such monitoring, simulation, and downscaling of precipitation, wind, storm tracks, snow, ice, natural variability, and tipping points. The connection between climate change and socio-economic impacts needs to be elucidated, and there is lack of understanding of sources of uncertainties and how they interact.

---

9 https://www.iter.org/

10 https://www.wmo.int/pages/themes/climate/climate_services.php

Appendix 4.2

A small survey among lead authors of the other chapters in this report that tried to identify what climate information was being used to connect climate to various sectors. In many cases, the established knowledge is based on experience and tacit knowledge, but seems not always to explicitly include state-of-the-art climate data, partly because there may be no direct observations available[11]. There is also a more comprehensive table in chapter 6 in addition to a simpler table on biophysical systems.

Sector or theme	Relevant climatological or meteorological variables	How is the weather or climate affecting the sector?
Agriculture	temperature, precipitation, snow	Air temperature and precipitation affect vegetation species, period of growth and land productivity
Environment & ecosystems	temperature, precipitation, snow, wind, ice	High temperatures melt the permafrost and cause the ground to subside; in dry areas permafrost is forcing the water to stay, but when this melts, lakes may drain and wetlands may dry out affecting plant and animal living there (will also affect the local climate and eventually possibly affecting the area even more, perhaps resulting in irreversible conditions); Species established in new places may outcompete some of the existing species (in particular alien invasive species and diseases are important) which in the end may create less resilient ecosystems (perhaps even resulting in irreversible situations);
Fisheries	wind, ice, waves	Wind, waves and ice conditions influence effectiveness of navigation in coastal and deep waters
Fishing/ hunting/ gathering		Forests: potential increased risk for pests and fire Tourism: snow condition; changes in bird populations making certain areas less attractive for tourism Reindeer herding: grazing conditions, infrastructure impacts that affect getting reindeer to slaughtering and markets, changes in timing om migration
Forestry	temperature, precipitation, snow	Temperature and precipitation determine vegetation species. Snow cover prevents ground species from frost byte.
Forestry	temperature, precipitation, snow	Length of growing season and/or effective (>+5C degree) temperature sum affect the tree growth. Changes in the wintertime conditions can have adverse effect on the survival of trees (especially seedlings).
Mining	temperature, precipitation, snow	Seepage and flooding spread pollutants
Oil & gas	wind, ice, waves, icebergs	Safety of oil and gas extraction from underwater resources is affected by weather conditions (wind) and state of sea surface (waves ice)
Reindeer husbandry	temperature, precipitation, snow, ice	Changes in areas with good quality for grazers (ie reindeer follow snow beds, reduced area and longevity will force them to eat less favourable food) will influence the reindeer population (health conditions become worse, more of them will die), More costly to move the animals from one area to another ie during spring earlier onset of thawing of lakes and rivers, forces them to choose different routes or ways of transport. Icing events lead to difficulties of reaching down to the food affecting reindeer health, increase in precipitation (when coming as snow) makes it more difficult to find food and more energy demanding to move.
Shipping	wind, ice, waves	Wind, waves and ice conditions influence effectiveness of navigation

[11] https://docs.google.com/spreadsheets/d/16NwPbcr8ZfnrIV828-rnqUryWyrPHkp--q8vZmpwM1Y/edit?usp=sharing

What climate information has been used for identifying a link between climate and the sector?	How has climate data been used to establish links with climate?
General knowledge from agricultural meteorology	Statistical modeling
Snowbeds are becoming smaller (direct effect of temperature and precipitation as snow), reindeer movements change (or additional fodder has been needed); warm water species are expanding, lowland species are mowing upwards/northwards (longer growing season allows them to finish their cycle even at higher altitudes/latitudes); icing events can be linked to problems for small mammals living in the subnival (the space between the ground and snow) zone;	Vegetational modeling; reindeer statistics (weight of the reindeer, number of calves born...); small mammals statistics; changes in vegetation, both changes in type of dominating vegetation (i.e.shrubs are increasing at the expense of herbs and grasses) as well as percentage cover (denser vegetation at higher altitudes and latitudes) has been demonstrated. Ecosystem modelling to project how different trophic levels in the marine ecosystem will be affected.
Knowledge on vessels limitations on weather and ice conditions	Climate modelling
Based on qualitative comments and speculations during scenario workshop	No specific data used.
General knowledge from biology	Statistical modeling, numerical modeling, GLOBIO
Length of growing season and/or effective (>+5°C) temperature sum. To lesser extent the amount of precipitation.	Most models making predictions of forest productivity in the future use the length of growing season and/or effective (>+5°C) temperature sum as a climate variable. What is not used, but can very important e.g. for the survival of the seedlings, is the frequency of warm spells during the winter (that can lead to ice layers on the soil surface or in the snow).
Daily observations for temperature, precipitation and snow depth over at least 25 years.	Anecdotal evidence
Established limitations of oil and gas platforms to weather conditions	Climate modeling
Clear patterns have been demonstrated linking causes and effects: Temperature and date of thawing of lakes, temperature fluctuations and icing events,changes in temperature and precipitation leads to less/smaller snow beds and so on	Vegetational modeling, reindeer statistics (weight of the reindeer, number of calves born...),...
Joint analyses of climate data and shipping routes properties	Climate modeling

5. Future narratives

Coordinating lead authors: Annika E Nilsson, Ingrid Bay-Larsen

Lead authors: Henrik Carlsen, Kirsti Jylhä, Lize-Marie van der Watt, Bob van Oort

Contributing authors: Maiken Bjørkan, Anatoli Bourmistrov, Niklas Eklund, Ludmila Isaeva, Ludmila Ivanova, Galina Kharitanova, Elena Klyuchnikova, Vladimir Masloboev, Karoliina Pilli-Sihvola

Key messages

- ***National adaptation programs and research projects in the Barents area increasingly use regionally adapted scenarios.*** *These are based on down-scaled results from climate models and sometimes also socio-economic factors. In some cases narratives about potential futures are used.*
- ***Participatory methods that use narratives as a communication interface can help overcome an observed 'disconnect' between the experts and practitioners.*** *Narratives are especially relevant for 'translating' complex scientific data to a more understandable form and for combining insights from diverse perspectives, scales and streams of knowledge. Narratives of possible futures highlight the perception and saliency of current trends but nevertheless have major implications for decisions related to adaptation.*
- ***Local mitigation and adaptation challenges are closely linked to global developments not only regarding climate change but also in relation to resource markets, international security, values and norms, and technology development.*** *This conclusion is based on results from four scenario workshops with local and regional actors. In a time perspective of 30 to 50 years, the uncertainties related to social factors may for the Barents area be greater than any uncertainties related to the direct impacts of climate change.*
- ***Challenges to mitigation and adaptation can vary greatly depending on the local and/or regional economic structures, resource base and demography.*** *This conclusion is based on results from four scenario workshops in different locations. The diversity of contexts within the Barents area makes it difficult to draw regional-level conclusions about adaptation challenges.*
- ***Nesting local and regional narratives with global scenario narratives increases the potential for comparing prospects for mitigation, impact, adaptation, and vulnerabilities across different municipalities, regions and sectors.*** *The pilot workshops conducted for the AACA shows that such an approach is useful for gathering insights from local and regional actors but also that further work is needed to engage with a broader group of people.*

5.1 Introduction

What will the Barents area look like in the future? How will the regional development path relate to the rest of the world? While some overarching trends are certain to continue because of the inherent inertia in geophysical and societal systems, the details of the future are inherently uncertain. Trajectories that we take for granted will change direction, and surprises will occur due to unexpected events or because different drivers of change interact in ways that we do not fully understand. Just like extreme weather events, there are likely to be societal and economic events beyond what is normally expected. Unusual events often catch society by surprise and are therefore much more likely to strain society's immediate capacities than slower and more foreseeable changes or events with recent parallels that may have already initiated some changes in response strategies. There is also the potential for major shifts in the structure of ecosystems and how they relate to social structures, so-called regime shifts (Arctic Council, 2013). Regardless of how much we try to forecast the future, we will encounter developments that are beyond the consideration of various planning processes, and indeed beyond the imagination of most people. We nevertheless plan for the future. Individuals might save money, make investments and choose education because of specific expectations for the future. Moreover, in formal planning processes related to, for instance, land use or public investments, assumptions about the future are inevitable.

While rapid environmental and social changes make planning for the future more challenging, the policy goal of sustainable development entails a responsibility towards *future generations and therefore* an imperative to both think ahead and to find ways for navigating the increased space of uncertainty. Uncertainty – in the broad generic sense – can be met in many ways, including investment in increased knowledge and by various forms of insurances and general capacity building. An important complementary strategy is to use narration to see how current development paths and scenarios might change according to values, scales and multiple end-user perspectives (for better or for worse). Such scenario-inspired narratives can serve as backdrops for decisions that are likely to have long-term consequences, including decisions about adaptation actions.

The aim of this chapter is to provide a structured approach for thinking about the future in the Barents area and to provide narratives about potential futures to facilitate discussions about adaptation actions and other long-term planning in the region. The focus is not on forecasting but on sketching a broad range of explorative scenarios to highlight some of the inevitable uncertainty that we have to live with and which should ideally be considered in today's decision making. The chapter builds on the premise that developments in the Barents area will be increasingly linked to global processes – both social and environmental – but also that these linkages will play out differently in different places across the Barents area and that understanding local impacts requires engaging in a co-production of knowledge with local and regional actors.

5.2 Scenarios as tools for understanding possible futures

5.2.1 What are scenarios?

Scenarios can be defined as "… *plausible and often simplified descriptions of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces and relationships*" (Ash et al., 2010). Scenarios are extensively used as tools for defining potential futures that need to be taken into account in decision-making in, for example, long-term business planning, defense planning, and in many other public policy areas, including environmental assessments. Scenarios come in many different forms and the literature contains a large number of different definitions and frameworks aimed at organizing the plethora of methodologies. One useful way to conceptualize the field is based on the principal questions an actor may want to pose about the future: What will happen? What can happen? How can a specific target be reached? (Börjeson et al., 2006). These three questions can be linked to three different types of scenario: predictive scenarios (sometimes referred to as forecasting or trend analysis), explorative scenarios, and normative scenarios.

When working with longer time-horizons, predictive scenarios are not of much use; system dynamics are usually so complex that predictions are unviable at those time-scales. Normative scenarios, which can be used for both shorter and longer time-scales, are targeted towards a desirable future and investigate possible pathways to such futures. Policy scenarios are often normative. Exploratory scenarios usually cover longer time-frames, sometimes up to 100 years. They are constructed for exploring plausible alternative development pathways that allow for assessment over a range of future conditions, and are thus found to be particularly relevant for the purpose of the Arctic Council assessment *Adaptation Actions for a Changing Arctic* (AACA). Scenarios may be targeted towards a vast range of drivers of change, including economic, ecological, geopolitical, and cultural factors. Since climate change in the Arctic is expected to be rapid and cascading, scenarios that include attention to climate change are seen as particularly salient for this assessment.

Box 5.1 Global futures: Shared Socioeconomic Pathways

The new global scenario framework for assessing challenges related to adaptation and mitigation of climate change includes a set of Shared Socioeconomic Pathways (SSPs) with different assumptions of global development pathways (O'Neill et al., 2014, 2017). The purpose of the SSPs is to highlight the uncertainty space of adaptation and mitigation challenges and to provide a framework for regional, local and sectoral analysis of impacts and response strategies (see Figure 5.1). SSPs are based on different trajectories of change within six broad categories: policies and institutions, human development, demography, technology, and environment and natural resources. Table 5.1 provides some examples of key assumptions for four SSPs. A fifth SSP (not shown in the table) is a middle-of-the road development path in relation to these four. The assumptions have been used as a basis for developing the storylines of different global futures, which served as boundary conditions for the discussion during the scenario workshops conducted for this assessment (see Section 5.4).

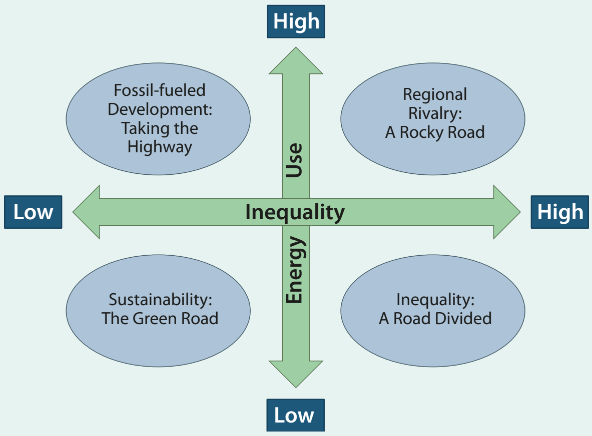


Figure 5.1 The SSPs were developed to cover different challenges in relation to adaptation and mitigation (based on O'Neill et al., 2017).

5.2.2 Global scenario framework

Within the climate change research community, global explorative scenarios have been developed to provide plausible information about how the climate might change based on different assumptions of global socio-economic developments and corresponding scenarios for emissions and concentrations of greenhouse gases (e.g., the 'SRES report', IPCC, 2000). Moreover, local scenarios have been used for assessing impacts of future climate change (Berkhout et al., 2002) as well as for climate adaptation planning (Kok et al., 2007; Baard et al., 2012; Carlsen et al., 2012).

The climate change community recently developed a new global scenario framework (Moss et al., 2010; O'Neill et al., 2014 and references therein). This includes attention to socio-economic development independent of climate change, which is illustrated by a set of shared socio-economic pathways, the so-called SSPs (see Box 5.1). Climate change as such is captured by another component of the framework: global forcing projections, the so-called Representative Concentration Pathways (RCPs) (van Vuuren et al., 2011), as described in more detail in Chapter 4. The third component of this framework is Shared Policy Assumptions (SPAs) (Kriegler et al., 2014).

The new scenario framework is aimed at facilitating analyses of the pros and cons of impacts and adaptation strategies under common assumptions about future socio-economic development. The initial SSP narratives focus on developments at the global scale, which cannot be translated directly to the regional or local scale, as discussed further in Section 5.4. However, they are useful as common boundary conditions for creating 'extended SSPs' for regional or local scales. If used consistently, they can also facilitate comparability between different studies across regions and across sectors.

Table 5.1 Selected key assumptions in four of the global SSPs (based on O'Neill et al., 2017).

Selection of SSP elements	Fossil-fueled Development: Taking the Highway	Sustainability: The Green Road	Regional Rivalry: A Rocky Road	Inequality: A Road Divided
Policies and institutions				
Environmental policies	Focus on local environment and benefits to well-being, little concern with global issues	Improved management; strong regulations	Low priority for environmental issues	Focus on local environment in middle and high-income countries; no attention to vulnerable areas or global issues
Policy orientation	Towards development and human capital with free markets	Towards sustainable development	Towards security	Towards benefit of the political and business elite
Institutions	Increasingly effective, fostering competitive markets	Effective	Weak global; national governments dominate societal decision-making	Effective for elite, not for rest of society
Human development				
Education	High	High	Low	Very low to medium, unequal
Social cohesion and equity	High	High	Low	Low, stratified with medium equity
Health investments	High	High	Low	Unequal within regions, lower in low-income countries
Economy and lifestyle				
Economic inequality	Strongly reduced, especially across countries	Reduced across and within countries	High, especially across countries	High, especially within countries
Globalization	Strongly globalized and increasingly connected markets	Connected markets, regional production	De-globalizing; regional security	Globally connected elite
Consumption and diet	Materialism, status consumption, tourism, mobility, meat-rich diets	Low growth in material consumption, low meat diets, first in high-income countries	Material intensive consumption	Elites: high consumption lifestyle; Rest: low consumption and mobility
Demography				
Population growth	Relatively low	Relatively low	Low in OECD; High in high-fertility countries	Low in OECD, relatively high elsewhere
Technology				
Technology development and transfer	Rapid	Rapid	Slow	Rapid in high-tech economies and sectors; slow in others. Little transfer within countries to poorer populations
Carbon (energy) intensity	High	Low	High (especially in regions with domestic fossil fuel resources)	Low/medium
Environment and natural resources				
Environmental status	Highly engineered approaches, successful management of local issues	Improving conditions	Serious degradation	Highly managed and improved near high-income areas, degraded otherwise

5.2.3 Barents scenario work

Scenarios are generally developed to inform decision makers within a certain sector, region or country. This section provides examples of typical approaches employed in the different countries of the Barents area, with a focus on methodology, inclusion of climate and socio-economic scenarios, and the level of local or regional actor participation in the scenario-building process.

5.2.3.1 Scenarios primarily based on climate information

In Norway, scenario development is connected to the national level (Miljøverndepartementet, 2010), but also serves as a resource for planning and climate adaptation at the municipal and sectoral level (e.g., Meteorologisk institutt et al., 2009). Local and sectoral work is driven in part by research projects and in part by the national requirement for all municipalities to perform a risk and vulnerability (ROS) analysis in the context of areal planning and civil protection, where the Norwegian Directorate for Civil Protection (DSB) provided guidelines with regard to methodology and analysis. The ROS reports include impact assessments as well as maps of risk and frequency of incidents such as avalanches or floods.

In Sweden, the Swedish Meteorological and Hydrographical Institute (SMHI) generated climate scenarios to inform the 2007 national benchmark report on climate change, vulnerability and adaptation (Swedish Commission on Climate and Vulnerability, 2007), as well as subsequent regional reports (e.g., Norrbotten County Administrative Board, 2009). These county-level reports have formed the basis for issue-specific reports relating, for example, to areal planning, in some cases down to the individual municipal level (Länsstyrelsen Norrbotten, 2012, 2015). The Swedish national and county-based reports are all expert-based, involving either county advisors or consultants, with climate input from SMHI. The 2007 national report was followed up in 2015 by a comprehensive review of future risks and consequences of climate change that involved broad consultation with government agencies, municipalities, researchers and business organizations (Andersson et al., 2015). Moreover, SMHI released new reports for all Swedish counties based on data from regional climate models, statistically downscaled to provide geographically detailed information about climate trends in Sweden. The material is available via an interactive website (SMHI, 2015).

In Finland, climate projections and climate impact projections have been developed by the FINADAPT project (Assessing the adaptive capacity of the Finnish environment and society under a changing climate) (Carter et al., 2005), in the National Climate Change Adaptation Research Programme (ISTO) (Ruuhela, 2012) and in the Finnish Research Programme on Climate Change (FICCA). The climate projections were used in national reports, including Finland's National Strategy for Adaptation to Climate Change (Marttila et al., 2005), Finland's Sixth National Communication under the Framework Convention on Climate Change (Monni, 2013), and Finland's National Climate Change Adaptation Plan 2022 (Ministry of Agriculture and Forestry, 2014). Partially through the web portal climateguide.fi, they also informed regional scenarios used in Northern Ostrobothnia (the Oulu Region), Lapland and Kainuu, where different economic sectors and key civil organizations were involved in the final stages of the scenario development process (e.g., Himanen et al., 2012).

In the Russian Federation, scenarios for the Arctic have usually been commissioned by federal policy-makers responsible for regional development and then developed in academic settings. Recent scenarios were mainly based on an official federal report that assessed the macroeconomic consequences of climate change projections in the Russian Federation (Katsov and Porfiryev, 2010; Frolov, 2014; Roshydromet, 2014). Scenario methodology is usually combined with SWOT analysis (strengths, weaknesses, opportunities and threats) and with different types of system analysis. The scenarios are usually either normative (asking how a specific future can be reached) or predictive (when related to climate change as such), and focus mostly on climate change. However, some scenarios have also elaborated on projected socio-economic changes in terms of climate impacts.

Climate change and impact scenarios have also been developed in relation to specific sectors, such as health (e.g., AMAP, 2014), agriculture (e.g., Hanssen-Bauer et al., 2010; Rønning, 2011), forestry, and tourism (Hille et al., 2011). In the case of agriculture, and typical of scenarios for the sector, impact analyses were made in relation to climate change, which were then analyzed in the context of *today's* agriculture- and climate policy. As such, these scenarios relate not so much to different or trending socio-economic futures, but rather to those challenges that exist for the sector given *future* climatic but *current* political constrictions.

5.2.3.2 Scenarios with a substantial input of socio-economic information

Scenarios focusing on the regional to local and sectoral level often use one or more socio-economic narratives to explore a range of futures, in addition to information about climate change impacts. One example is the ArcRisk project (AMAP, 2014), which developed different pollution and health scenarios for the Arctic (including the Barents area) that included scenarios showing how different policy options could lead to alternative pathways for the future chemical contamination levels in the environment. Health impact analyses for Norway and Sweden were based on assumptions of a high level of adaptation and an aging population in the North.

Another example concerns the scenarios developed by the Swedish Civil Contingencies Agency (MSB) for a mapping of adaptation action across Sweden, which include attention to national security and migration issues (Andersson et al., 2015). The mapping covers several sectors and draws on inputs from a wide range of experts, from the private and public sectors, as well as input from selected government agencies.

Several research projects cover climate and socio-economic change in municipalities in the Barents area (e.g., Groven et al., 2008; CAVIAR, 2009; NORADAPT, 2011). In these cases, socio-economic scenarios typically focus on more near term-futures (2040 and 2025), and are based on current trends and 'business as usual' scenarios *without* adaptation measures. Another example of a research-driven process is the Climatools project, which focused on tailoring scenario methodology to the needs of local and municipal stakeholders. One of the case studies aimed at testing the method, involved the local planning body of Umeå in Västerbotten county (Carlsen et al., 2012). The researchers developed socio-economic scenarios starting from the needs of the end-users, without linking local to global socio-economic scenarios.

The TWASE project (Haavisto et al., 2016) has developed six socio-economic scenarios for 2040 for the Eurasian Arctic, presented as narratives. The primary focus is on the development of shipping, resource extraction and tourism industries. The main input to the scenarios was obtained through an expert workshop and the resulting scenario for 2040 was presented along the three dimensions: open–closed, public–private and dirty–clean. The main conclusion is that environmental changes, political shifts and technological development all have the potential to cause drastic new developments in the region.

The MERMAID–project has developed socio-economic scenarios to identify risks and opportunities for Arctic marine transport and tourism from the Finnish perspective. Using participatory workshop methods, three scenario narratives were developed with the conclusion that the role of Finland will depend heavily on the economic development of the Arctic region as a whole, particularly in the maritime sector. Climate change can create possibilities for the tourism sector, but to harness the benefits, improved risk assessment, management and marketing is needed (Pilli-Sihvola et al., 2016).

Research-driven scenarios development projects typically include a mix of researchers and local actors and/or municipal and sectoral representatives working together in the scenario development process using participatory methods, such as workshops and iterative processes where scenarios are developed with inputs from actors or scientists. An alternative approach was applied in the tourism sector project Sustainable Destination Norway 2025. Models for future tourism in the Norwegian Barents area were fed with varying socio-economic parameters (such as global scenarios for population, economic growth, qualitative and quantitative aspects of tourism development, and technological developments and national policy scenarios). While the models were developed with top-down input climate models contributing to Intergovernmental Panel on Climate Change (IPCC) work and regional statistical data, the scenarios also included user-controlled inputs about socio-economic futures (Hille et al., 2011).

Some of the best known sectoral scenarios in the region come from the shipping industry, and especially from the Arctic Marine Shipping Assessment (AMSA) scenario workshops (Arctic Council, 2009). With nearly 120 identified factors that could shape the future of Arctic marine activity by 2050, climate change was seen as far from the only driver of change. The scenarios were developed by experts and actors in the field, and also included the views of indigenous and non-Arctic actors.

The oil and gas sector is a large player in the region, and Bourmistrov et al. (2015) developed three future scenarios on international petroleum cooperation in the Barents area, with the aim to increase understanding of the challenges and opportunities for Arctic petroleum resource development and for future international cooperation. Taking the Murmansk Treaty signed in 2010 by Norway and Russia as the point of departure, the scenarios included both climate and socio-economic factors, addressing uncertainties in future prices of oil and gas; amount of oil and gas found; future of the Asian population and economic growth; spread of unconventional energy use outside the USA; global climate policy; development of the Lofoten area and its infrastructure; speed and level of Arctic petroleum technology development; development of Russian-Western (and Norwegian) relations; and the extent of Russian orientation towards Asia.

5.2.4 Lessons learned

Scenarios have most often been developed by scientific experts or in a process including both scientists and local actors. They have typically been developed at the request of municipal or national policy-makers, industry strategists, or following research calls requesting scenario-work tailored to a region or sector. Depending on the nature of the call or request, experts then disseminated the scenarios to policy-makers, while more localized or sector-specific information was conveyed directly to relevant decision-makers (see, for example, Pilli-Sihvola et al., 2015). Some scenarios were more specifically sector- or industry-driven, and did not directly involve scientific experts or policy-makers as such.

Looking at the diversity of scenario processes, three dimensions are particularly relevant for further discussion: the degree to which they include both climate-related and social development, the degree of user participation, and the geographic scale.

B&C Alexander / ArcticPhoto

Nenets herder and his children in front of a gas rig on the Arctic tundra near Bovanenko, Yamal, western Siberia, Russia

5.2.4.1 Climate scenarios vs. socio-economic scenarios

Scenarios based on climate change only (under current or desired emission trends) are most typical at the national level, often to serve as general information to national decision-makers and sometimes to support transitions to a desired future (through emission regulations etc.). Scenarios based on climate change are also used by specific sectors and municipal planning processes, where the main interest concerns avoiding climate- or weather-related risks, such as in the placement of structures (to adapt to increased avalanche risks or sea-level rise) or dimensioning drainage pipes to handle increased surface water flow. In cases where climate-related factors are the main challenge the current level of detail in climate scenarios gives sufficient input to develop solutions.

While climate scenarios provide a fair amount of agreement about future development, socio-economic scenarios are often very place-dependent, as well as linked to issues that are context-specific. Linking climate scenarios to socio-economic trends or to a variety of socio-economic scenarios has therefore been most typical at the sector, municipal, or regional level. Visions regarding economic development in the Barents area vary across the different scenarios: ranging from 'ideals' of shipping and tourism blooming with the opening of the Northern Sea Route, to a focus on lacking infrastructure, costs and competition. Some smaller municipalities have highlighted ageing populations and out-migration, while others have focused on new opportunities in agriculture, mining, fishing or other activities. Much depended on local entrepreneurship, and the involvement of the municipal/sectoral institutions in identifying vulnerability, adaptive capacity and future potentials.

Research-project based scenarios may include analyses of climate and mitigation options (e.g., 'Framtidens byer' [cities of the future]), climate scenarios only (e.g., CIVILCLIM, Rambøll Management Consulting, 2015) or both climate and socio-economic scenarios (e.g., Groven et al., 2008; AREALCLIM, CAVIAR 2009; NORADAPT, 2011). Only a few multidisciplinary projects have coupled climate and socio-economic scenarios in ways that combine top-down and bottom-up knowledge input (e.g., NORADAPT, 2011). The combination of climate and social scenarios in Norway indicates that local climate vulnerability is often a product of natural-, socio-economic and institutional vulnerability. Increased focus on combining detailed climate scenarios with socio-economic scenarios is therefore important for supporting decision-making and local adaptation action.

5.2.4.2 Scale effects on methodology

Development of nationally-initiated scenarios, often financed through national climate change adaptation programs, includes various mixes of scientists, policy-makers and industry. Such scenarios typically involve large infrastructures with the capacity to execute sophisticated modeling, especially using climate models. Typical examples are national reports on climate change and impact from the Nordic countries, produced since the early 2000s and involving scientists and national meteorological institutes. Regional (such as is typical for Russia) and sectoral-level scenarios differ widely in scope and scale, depending on the purpose of the scenario and the regionally contingent variables. They often depend on climate scenarios built at national level for baseline input. While tailored to local or specific sectoral conditions and needs, sectoral scenarios tend to be strongly influenced by national or even global events.

The regionally contingent variables make comparisons and generalizations from national to regional level difficult. There is thus a need to develop scenarios at the regional scale, which could inform work at the municipal level. Municipal scenarios are even more locally relevant, but also less transferable than regional scenarios. They are also more challenging to systematically develop because of the large number of municipalities and resource limitations. Sector-initiated scenarios often have a more narrowly defined purpose, such as improving yield or mapping risk.

5.2.4.3 User participation

There is a clear trend over time from focusing only on climate to increasingly addressing impacts, and in recent years also recognizing the importance of including multiple actors, disciplines and perspectives in the scenario process. User participation was typically found at the lower scales of governance: local and municipal, while national and regional level scenarios typically included less local actor inputs. That local engagement can encourage inclusion of local values is, for example, reflected in the CLIM-atic project with comments such as "*the snow-scooter season will be shorter*" (Abbing, 2009).

It is increasingly understood that climate change will have extensive impacts on all sectors of society, sometimes as a consequence of highly complex chains of causal relationships and interdependencies. This has accentuated the need for a broader range of expertise including more extensive user involvement to ensure inclusion of practitioners' expertise.

5.3 Bringing in local and regional voices

In climate research there has often been a 'disconnect' between the experts who use models to better understand climate change and its direct impacts and the practitioners who need to deal with expected changes in their everyday planning (Pilli-Sihvola et al., 2015). With a need to better handle real world problems, improved communication across the science/policy/practitioner communities becomes essential (e.g., Pohl, 2011; see also Chapter 3). One way to better connect practitioners and experts and so create a mutual understanding of what is needed in terms of adaptation action is to use participatory methods that bring local and regional voices into the process of constructing scenarios.

Such approaches also provide a way to take into account the complex local or regional social context, where many factors other than climate may be perceived as critically important (Hovelsrud and Smit, 2010; IPCC, 2014). Many non-climate factors are also changing, partly because of global processes but also because of specific local and regional dynamics. In a time perspective of the next 30 to 50 years, the uncertainties related to societal factors may in fact be greater than any uncertainties related to the direct impacts of climate change. Assessing these uncertainties requires a great range of expertise, and the assessment benefits from knowledge about each specific local context.

Participatory scenario exercises can be described as a way of creating boundary spaces between science and practice that hopefully play a similar role to boundary organizations, which have been effective nodes for communication between different expert communities (Guston, 2001). Participatory methodologies often focus more on qualitative than quantitative information. Narratives play a particularly important role, and this section provides background on the use of narratives for exploring potential futures.

5.3.1 Narratives as communication: social learning and knowing in action

In the process of learning, communicating and making decisions, people do not add new information at random to a loose conglomeration of earlier knowledge, instead they construct mental models that help make sense of observations (Kempton et al., 1996). These mental models are simplified representations of the world and exhibit story-like properties (Bruner, 1991). Stories and story-telling can therefore help translate complex scientific data into a more comprehensible format by presenting them in a way that relates more to everyday life (Paschen and Ison, 2014). The use of narratives can therefore serve as a communication device. Moreover, it can help bring information to the table that is initially not framed in scientific language, including the expertise and experience of local and regional actors, and can facilitate the translation of local knowledge into policy-relevant data.

As discussed in Chapter 3, the creation of dynamic social arenas where researchers participate alongside other actors, places focus on dialogue and a mutual construction of meaning (Ison and Russell, 2007). Such dialogue and *knowing-in-action* (Ison et al., 2011), where reframing of challenges is facilitated, contributes to integrating knowledge-making with decision-making on the ground (Leach et al., 2010).

5.3.2 What are narratives and how do they evolve?

In the context of scenarios, narratives, or storylines, are internally consistent qualitative descriptions of how the future might develop. Narrations of future physical and human geographies thus describe possible scenarios of change. Narratives can be articulated in many ways, both by experts, plotting a narrative onto communities, or by communities, constructing a narrative to inform perceptions of past and future possibilities (Daniels and Endfield, 2009; McIntosh et al., 2000). Narratives about Arctic futures have a long history that has often been linked to political ambitions for the region. They have often followed plotlines of either opportunity or decline. With climate change, there has been a recent surge in the production of Arctic futures (Arbo et al., 2013).

Paschen and Ison (2014) identified two dimensions of narratives that are particularly relevant for discussing adaptation. First, they point to how we 'story' the environment, and how our stories determine our understanding and adaptation in practice; how risks are defined, who is authorized as actors in the change debate, and the range of policy options considered. Second, they claim that, beyond producing data on local knowledge and on the socio-cultural and affective-emotive factors influencing adaptive capacity, narrative research can significantly inform public engagement, deliberation and learning strategies.

Narratives often play "*a rhetorical role in producing futures*" (Avango et al., 2013) and this rhetorical role warrants some reflection on what we do when using and producing scenario narratives. For example, we need to pay attention to the fact that scenarios are reflections of contemporary knowledge, discourses, ambitions, and power relations. This raises questions about who has power to partake in producing scenarios. It also highlights the need for researchers and practitioners to reflect on how language, social roles and relationships influence the communicative situations within which scenarios are constructed, and how the situations ultimately enable or inhibit agency.

The constructed nature of narratives means that *different* plotlines can be drawn from the same facts and that they often include underlying assumptions that are not always transparent. Examples include Arctic narratives about how rapid climate change is associated with multiple risks and opportunities, which in turn create a need for adaptation. Such claims provide information/knowledge about a particular situation and at the same time frame the problem and solution in a certain way. Another narrative based on the same facts might frame the solution not in terms of trying to adapt within the current system logic but in terms of a need for a radical transformation of the system itself.

Narratives come into existence through social networks across different institutional, cultural, and geographical scales. The specific perceptions of problems and solutions provided in a narrative are the result of societal processes where some worldviews (values and perceptions) appear as more legitimate than others. One can think of these processes as random without a specific goal or ambition, but in practice they may be facilitated by particular interest groups or power networks and emerge as a 'group story' that gains hegemony over narratives told by less dominant actors (Paschen and Ison, 2014). Scholars warn against crisis narratives as dominant climate-change narratives about the Arctic, constituted by researchers or experts that emphasize the power of global climate systems to threaten northern communities by situating them as being intrinsically at risk. This can drown out alternative narratives of civic participation, including northern communities as actors in decision-making (Bravo, 2009). This is why a deliberative approach is vital in the process of framing and narrating futures.

The way that time is constructed in climate-change narratives may affect imaginations of the future (Brace and Geoghegan, 2011). Climate-change scenarios tend to focus on specific end points, for example 2050 or 2100. This organizes data in ways that are 'inconceivably distant' for most people, not least when there is a need to make decisions now (Hulme, 2009; Brace and Geoghegan, 2011). In climate-change adaptation narratives, it is therefore important to be cognizant of the relations between global, sometimes long-term, narratives of climate and more local, sometimes episodic and anecdotal narratives of weather (Daniels and Endfield, 2009). Situating climate change in timescales that are useful for decision-making can serve as a way to challenge the determinism that often appears in discussions of climate change, and thus highlight the role of agency and choice. While attention to chance, openness and unpredictability might cultivate apathy and indecision (Brace and Geoghegan, 2011), the use of participative future scenarios, grounded locally, offers a way to create openness to the fact that the decision we make now will also affect the future.

Box 5.2. Methodology for generating extended Shared Socioeconomic Pathways (SSPs)

The design of the scenario-building process is based on two premises. First, that the future development of the region will become increasingly interconnected with global development pathways. Second, that local actor involvement is necessary in order to comprehend the dynamics of future developments and for anchoring the scenarios in the local reality. A combined top-down/bottom-up process was therefore designed with the aim of producing local scenarios embedded in the global pathways as described by the SSP storylines (see Box 5.1), hence producing the so-called 'extended SSPs' (Figure 5.2). This is one of the first projects to use this combined approach. Another early example was given by Absar and Preston (2015), who developed sub-national and sectoral extensions of the global SSP storylines in order to identify future socio-economic challenges for adaptation for the U.S. Southeast.

The specific methodology made use of highly interactive workshops to facilitate a process that fostered inclusion of local and regional voices. The focus question for the workshops was: What future changes may influence this region economically, environmentally and socially within the perspective of one to two generations? The time perspective was thus longer than the time horizon for most policy-related planning processes, such as spatial planning, but still relevant and useful in relation to needs for dealing with uncertainty in decision-making. The geographic perspective, or focal spatial scale, was on the local and county levels for each of the specific settings.

All workshops started with presentations from local participants aimed at familiarizing everyone with local challenges and to give these perspectives a priority in issue framing. The workshops also included some presentations on different topics that were deemed relevant by the workshop organizers. Topics included climate change, aquaculture, and geopolitics.

Locally-relevant drivers of change were identified by asking participants to write down the two most relevant drivers in relation to factors that would be most pertinent for answering the focus question. These were then placed on a wall, creating a shared work-think space for the exercise. Ideas that had similarities with notes that had been posted earlier were placed in the vicinity of the first note, which provided some initial clustering. The organizers later arranged these initial clusters into a number of distinct categories that were given cluster names.

To prioritize clusters that would be used for developing extended SSPs, the participants 'voted' for the most important cluster and the ones with most associated uncertainty, using colored sticky 'dots'. The clusters were ranked by adding the number of votes on importance, with a separate ranking for the number of votes on uncertainty. Those scoring highly on both parameters were selected as the major topics for the group discussion that followed.

To discuss how the prioritized clusters of drivers might play out at a specific scale or in a specific sector, the workshop participants were divided into groups, with each group given the task of talking about what the prioritized clusters might entail at the local and regional level given a specific set of boundary conditions. These boundary conditions were given by the global SSPs described in Box 5.1: Fossil-fueled Development, Sustainability, Regional Rivalry, or Inequality. The group discussions generated a very rich material, which was narrated by the workshop organizers based on notes taken during the group discussions and reports from the subsequent plenary session. The results are summarized in Section 5.4.1.

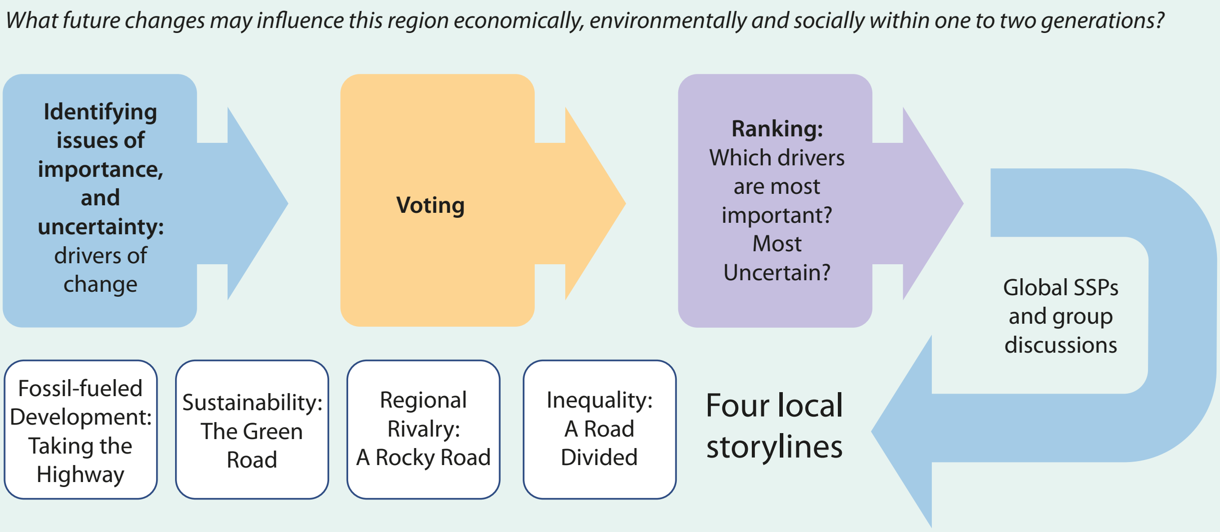


Figure 5.2 Methodology for producing an extended Shared Socioeconomic Pathway (SSP).

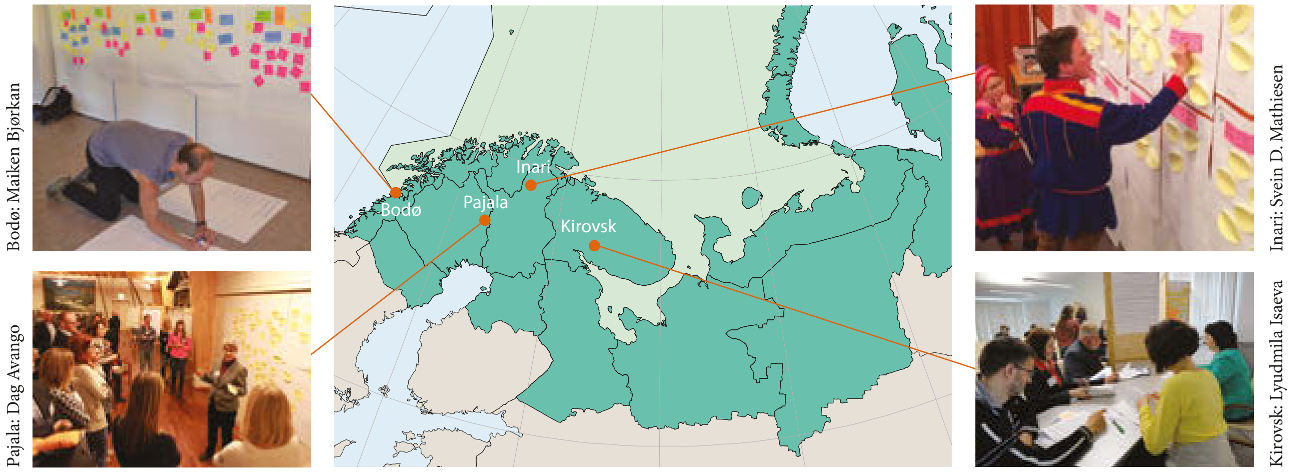


Figure 5.3 Locations of scenario workshops conducted for the Barents area pilot studies.

5.4 Future narratives in the Barents area

To obtain a better understanding of future adaptation challenges in the Barents area, three workshops took place aimed at developing locally and regionally relevant narratives of potential futures (Figure 5.3). The methodology took advantage of the newly developed global scenario framework described in Section 5.2 while also including participatory approaches to produce so-called extended SSPs. The methodology is described in Box 5.2 and by Nilsson et al. (2015).

The workshop participants were local and regional actors with various backgrounds, such as planners, public servants, sector representatives, and other experts, including researchers. The workshops took place in Pajala in Norrbotten County of Sweden, Kirovsk in the Murmansk region of Russia, and Bodø in Nordland County of Norway. A similar exercise also took place at a gathering in Inari, Finland, of reindeer herding youth from across the Eurasian North – *Gávnnadeapmi 2015* (subsequently referred to in this chapter as the Gávnnadeapmi workshop). The results are summarized in Section 5.4.1.4. Further details, including more elaborated narratives of potential futures based on the group discussion, are available for Pajala (Nilsson et al., 2015), Kirovsk, and Bodø (van Oort et al., 2015).

5.4.1 Workshop results

5.4.1.1 Pajala workshop

Pajala is a municipality in the Torne Valley in Norrbotten County, Sweden. Historically, forestry has been the dominant industry but there are now fewer job opportunities in forestry than in the past. Mining is a major issue in discussions about the future: a new mine opened in 2012 but was declared bankrupt in 2014. The municipality includes spring-winter lands for reindeer herding. The municipality has 6300 inhabitants spread over more than 80 smaller villages and hamlets. The Pajala workshop participants included roughly equal numbers of researchers and local/regional participants. The workshop was held in March 2015.

The workshop highlighted climate change and power relations between the national and local level as particularly relevant drivers from a local/regional perspective. Participants perceived issues related to international security as the most uncertain, together with the impacts of climate change (Figure 5.4).

The narratives

Fossil-fueled Development globally entails increasing investment in industrial development in Pajala, with new job opportunities. Reindeer herding declines. Demands on education are high and people move into the region. Risks relate to security, terrorism, and to competitiveness on the international resource market.

Sustainability: With the green road, forestry becomes a major industry in the Pajala region, both as an energy resource (biofuel production) but also to sequester carbon. The social focus shifts towards highly self-sufficient livelihoods, favoring rural areas that can supply locally produced food and energy. The rate of urbanization in the region slows. Knowledge becomes a premium resource as the basis of the green economy, especially in technological innovation and operation.

Regional Rivalry: While the global security situation worsens, community life and decision-making in Pajala continues far-removed from such global changes. The state withdraws from

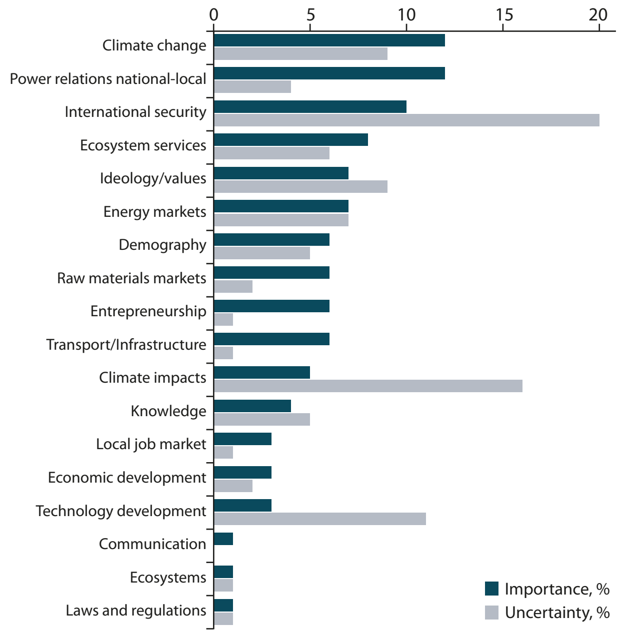


Figure 5.4 Pajala workshop: results of brainstorming and 'voting' in response to the question: *What future changes may influence this region economically, environmentally and socially within one to two generations?* (Nilsson et al., 2015).

a variety of public sectors, gradually pushing the responsibility for welfare state functions over to municipalities, which results in a more local focus. Mining creates some jobs but there is also a growing service sector in which a large immigrant population is active. In this world, social tensions present a major risk.

Inequality: In the divided world, Pajala attracts refugees and other immigrants. Risks include social tensions between a large and growing group of low-income households and a rich elite coming to the region for recreational or entrepreneurial purposes. Local resources are important for low-income groups. Local influence on important decisions declines and with a loss of trust in formal forms of collective decision-making, people increasingly rely on informal social networks in all aspects of life. A major uncertainty is the regional security situation.

5.4.1.2 Kirovsk workshop

Kirovsk is a municipality located in the Murmansk region, Russia. Mining is the dominant industry. Winter tourism, developed in the Soviet era, is increasing due to the new regional development strategy. There are 29,000 inhabitants in the municipality, including Koashva village. The Kirovsk workshop participants were mostly regional representatives of industry, small and medium-sized enterprises (SMEs), non-governmental organizations and academia. The workshop was held in June 2015.

Discussions about locally and regionally relevant drivers highlighted the development of technologies and changing environmental conditions as particularly important. Participants perceived issues related to the impacts of climate change as the most uncertain, together with the changes in mineral resource markets (Figure 5.5).

The narratives

Fossil-fueled Development globally entails demand for advanced mining technologies, which for the Murmansk region leads to fewer job opportunities and an outflow of population. High demands on qualification of labor force drive increasing investment to education and human capital. Risks relate to fluctuation of international mineral markets. People that come to the Murmansk region lack affinity to the region and leave when job opportunities end. International cooperation plays a significant role.

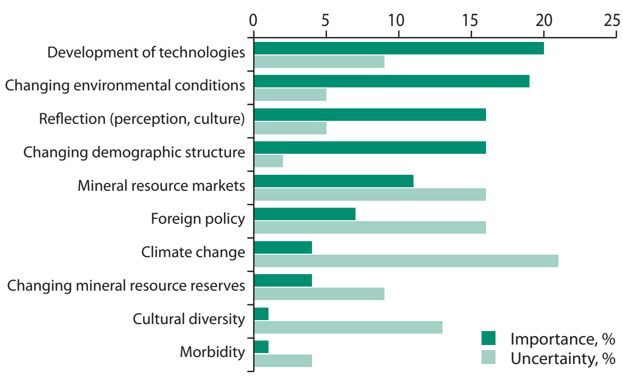


Figure 5.5 Kirovsk workshop: results of brainstorming and 'voting' in response to the question: *What future changes may influence this region economically, environmentally and socially within one to two generations?* (van Oort et al., 2015).

Sustainability: In this world, technologies for environmentally-friendly mining and waste treatment are important for development in the Murmansk region. Demands for environmentally-friendly solutions to development problems force a transfer of decision-making to the local level, and a transition towards participatory regional governance. The political focus is on welfare and well-being of society as a whole, resulting in rising birth rates. Climate change requires increased investments for infrastructure.

Regional Rivalry: While the global security situation worsens, the Russian federal center amasses administrative powers and develops the Murmansk region into an Arctic military outpost of Russia. The area also becomes a point on the Northern Sea Route that links the Arctic region to the rest of the Russian Federation. Mining remains the basis of economic development. Risks relate to reduced environmental protection caused by efforts to cut costs for products and services.

Inequality: In the divided world, the Murmansk region is completely transformed into a raw materials appendage of the central regions of the Russian Federation. Intense development of new mineral deposits reduces the areas available for traditional nature use (reindeer herding, mushroom and berry picking, fishing) and also creates difficulties with access for public recreation. The risks are related to a divided society and the emergence of nationalist political parties.

5.4.1.3 Bodø workshop

Bodø is a municipality in the county of Nordland, Norway, and is also the county administrative center. Bodø is located in the middle of the county and, importantly, at the coast. Historically, Bodø has thrived as an important trade center for fish. Fisheries remains a key industry today, while economic activities related to trade, finance and administrative tasks are also significant. The Bodø region, which includes three municipalities, has 53,257 inhabitants and Bodø city has 39,384 inhabitants.

The Bodø workshop participants represented local, regional and sector-specific perspectives, and included both practitioners and researchers. The participants identified energy/petroleum, climate, and demography as the most important drivers of change from a local/regional perspective, while local politics, global economy, and international security were ranked as the three most uncertain (Figure 5.6). The workshop was held in August 2015.

The narratives

Fossil-fueled Development globally translates to 'full speed ahead' for Nordland, with Bodø acting as a hub for the region's oil and gas resources. New technologies, with demand for high competence and global capital, emerge across multiple economic sectors. The political landscape is more polarized with a greater focus on regional than local issues.

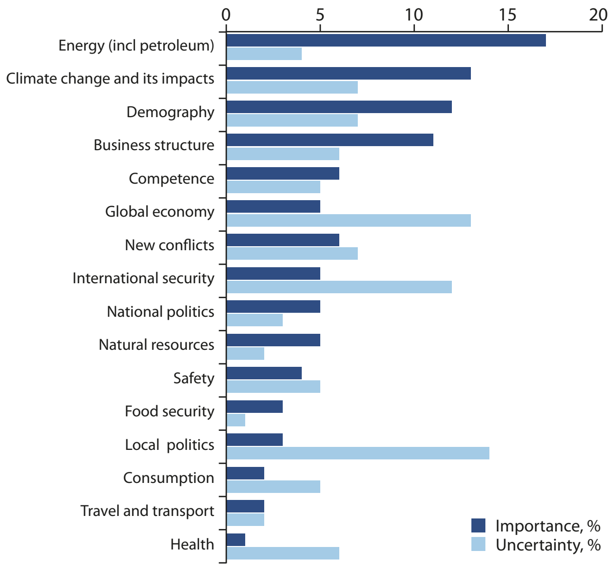


Figure 5.6 Bodø workshop: results of brainstorming and 'voting' in response to the question: *What future changes may influence this region economically, environmentally and socially within one to two generations?* (van Oort et al., 2015).

Sustainability: The world is ever more connected, and despite an increased green focus in all sectors and more climate-friendly energy use, there is a continued need for energy. In Nordland, climate change allows an increase in aquaculture, including production of algae or algae based-products, while coastal fish stocks are migrating north and new stocks and species are moving into the region. Bodø grows as a knowledge center. There is an increased focus on tourism, and the local military is downsized.

Regional Rivalry: There is little development in Nordland and people focus on making ends meet, while environmental issues are disregarded. There is little international cooperation. A new knowledge structure develops around an increased focus on the primary sector. People feel disempowered but there is still local activism.

Inequality: In a divided world, Nordland is a society with large differences, where a political and economic elite control energy production, prices and distribution patterns. While there are few investments from the national level, Nordland does well since it is a region rich in natural resources. The return to the 'old ways' with an elite controlling politics and resources gives rise to conflicts with and among the rest of the population.

5.4.1.4 **Gávnnadeapmi workshop**

Reindeer herding is practiced throughout the Eurasian Arctic by a range of indigenous peoples. At the reindeer herding youth gathering *Gávnnadeapmi 2015*, 30 young reindeer herders discussed current and future challenges for this livelihood. The participants were mostly Saami from Finland, Norway and Sweden, but also Nenets, Even and Evenki from Russia. Exercises similar to those in the workshops were carried out at the gathering, which also included presentations about issues in different localities and the adoption of the Gávnnadeapmi Declaration (http://reindeerherding.org/tag/gavnnadeapmi/).

The participants identified indigenous rights and traditional knowledge as the most important issues for understanding adaptation challenges for their livelihood, followed by industrial economic development and climate change (Figure 5.7). The workshop was held in September 2015.

The narratives

Fossil-fueled Development globally would mean that everybody is equal without any special attention given to indigenous rights. The focus on developing oil and gas thus pays no attention to indigenous land rights. In-migration leads to pressure on land. Indigenous youth often pursue science and technology careers rather than continue with reindeer herding and there is a loss in traditional knowledge and languages. Reindeer are genetically engineered and herding gives way to reindeer farming. Climate change creates more demand for grazing land and exacerbates land-use conflicts. Reindeer herding becomes even more challenging when reindeer 'get confused' because of environmental changes.

Sustainability: Indigenous rights are strong in this world and traditional knowledge is included in decision-making as well as in a unique education system for reindeer herding. The era of extractive industries in the north is of the past and economic development focuses on agriculture and small-scale businesses. The region attracts new people. Impacts of climate change are reduced owing to many opportunities for adaptation. Wealth is more equally distributed between center and periphery.

Regional Rivalry: In this 'gray' world, industry is prioritized. Little attention is given to the values that nature provides, such as clean water and food. State control is strong and indigenous rights are weak. Priority to military demands drives increasing competition for land. International cooperation declines which also affects cooperation among indigenous peoples and mobility across borders for reindeer herders. Fewer resources are given to education, which especially affects indigenous education. Progressive people leave the region and there is an influx of cheap labor. Food production is intensified as countries need to be self-sufficient.

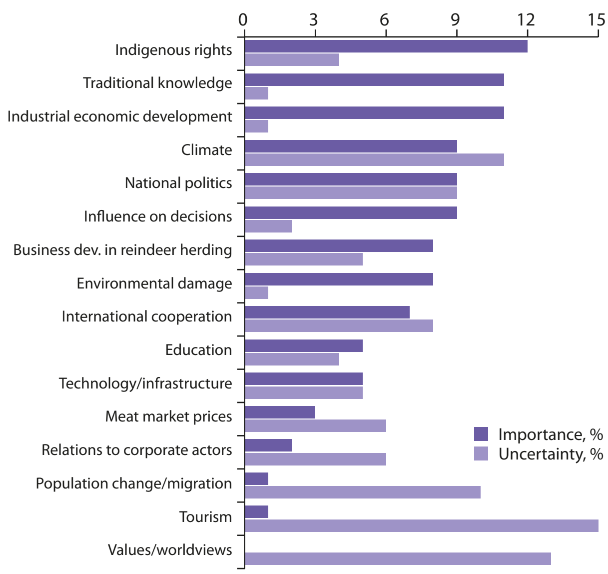


Figure 5.7 Gávnnadeapmi workshop: results of brainstorming and 'voting' in response to the question: *What future changes may influence this region economically, environmentally and socially within one to two generations?*

Inequality: In the unequal world, the elite live in a protected paradise, where nature is unharmed and industrial pollution is unseen. Many people live in 'normal' areas, neither paradise nor destroyed. Minorities live next to industrial areas. Reindeer herders live in industrial areas. Herders cannot live only on reindeer herding, but need additional income to survive. Traditional knowledge and language are lost. It is a fully class-based society.

5.4.2 Recurring themes

Owing to the diversity of workshop settings and because these contexts are not representative for all local settings in the region, the workshop results cannot be used as a basis for constructing overarching future narratives for the Barents area. However, many issues were raised that were relevant across the workshops. This section highlights the most prominent cross-cutting themes.

5.4.2.1 Demography

Demography was a major theme at the Pajala, Kirovsk and Bodø workshops, rated as both an important and an uncertain driver of change, which means it is difficult to project what the future will entail. For the Torne Valley and the Murmansk region, with a recent history of out-migration, keeping people in the region was a major concern. Rural areas of Nordland were also thought more likely to see out-migration in some of the future global developments, while the population of Bodø, a larger town, could increase as investments and access to education and jobs become centralized. In global scenarios that emphasize slow economic growth and 'greening' of the economy (i.e., Green Road and Inequality), this urbanization trend was not as apparent. Out-migration was also a major issue in local/regional scenarios developed in the workshops, in which extractive industries rely heavily on a fly-in-fly-out workforce.

Some of the local scenarios based on global development paths with rapid climate change and/or heightened conflicts and inequity, highlight an influx of refugees and migrants from other parts of the world, potentially off-setting some of the expected out-migration. In one narrative, this was portrayed as a way to build more creative communities where the diversity of human capacities served as a resource for meeting other challenges. However, depending on world views and ideologies, it could also lead to increasing social tensions, and in some discussions (based on the Inequity and Regional Rivalry scenarios), xenophobia was part of the future. In the Regional Rivalry scenarios from the Gávnnadeapmi workshop, an outflow of people with progressive values was highlighted.

Demography is thus a salient factor to consider in making decisions about adaptation actions. It is also a factor in which global developments intersect with local and regional population changes, such as the trend for increasing urbanization in the Barents area. Population changes were portrayed both as a consequence of ongoing major trends with certain built-in inertia and linked to decisions about how work is organized, to local economic structures, and to world views and ideologies. Demographic changes can have major impacts on local communities as people bring human capital as well as much needed municipal tax income.

5.4.2.2 Climate change and its impacts

Climate change and its impacts on the environment and ecosystems was a major issue in all workshops. Climate change was identified as one of the most important drivers of change at the Pajala and Bodø workshops and the most uncertain at Kirovsk. Observations of ongoing climate and related ecosystem changes affecting livelihoods were reported in the workshops, such as the appearance of mass numbers of jelly fish getting caught in shrimp fishing equipment and replacing shrimp (Bodø), a need to move reindeer to the mountain earlier in the season (Pajala), and a need to find new slaughtering routines due to difficulties of moving reindeer on the tundra (Kirovsk). In the longer time perspective, workshop participants discussed further climate change impacts in their future narratives, regardless of global scenario. These included major changes in hydrology affecting water quality and access to water (Murmansk region), forestation of the Nordland archipelago due to a combination of climate change and lessened grazing pressure, and the appearance of new species while other species move northward.

The ecosystem changes are expected to affect tourism (bird tourism in Nordland), forestry (with increased uncertainty and risk related to pest species), fisheries (major changes in the marine ecosystem including species composition), and reindeer herding (new diseases, and a need for larger grazing areas). In the Torne valley, a need to foster entrepreneurship to capture new opportunities for tourism was identified. Several local/regional future narratives included increased flood risk with an associated need for adaption measures. For example, in a fossil-fueled future for Nordland, major investments would be needed for adaptation.

5.4.2.3 Global markets and their intersection with local economies and power structures

The current economic structures of Norrbotten, the Murmansk regions, and Nordland are all linked to the extraction of natural resources that depend on global markets. As a consequence, global resource markets were seen as important and posed uncertainty about the future. The envisioned impacts on demography are especially striking, as in- or out-migration was seen as following gains or losses in job opportunities. The specifics depend on the resource, with a focus on hydrocarbons in Nordland, and mineral resources in Pajala and surrounding areas and in the Murmansk region.

The relevance of global markets differed across the global SSPs as well as between local narratives. For example, in Nordland, the diversity of energy resources in the region was seen as making the region less dependent on a fossil-fuel economy than might be expected. However, a global future built on fossil fuel was seen as having major impacts on how the region develops in relation to urbanization, power issues, and competition for space with other activities. Industrial activities leading to competition for land was also a major concern at the Gávnnadeapmi workshop, where issues related to land rights and indigenous rights were seen as *the* most important driver of change. The workshop participants saw major differences in how indigenous rights are recognized and respected in the different future worlds with make-or-break impacts on reindeer herding as an economically viable activity, due to differences in competition for land.

Locally in Pajala municipality, workshop participants highlighted that it would make a large difference socially and environmentally whether the iron mine was reopened or whether the focus shifted to renewable resources where the forests were seen as a local asset. For the Murmansk region, some narratives included a diversification of the economy (as a result of lower demand and new technologies) while futures with intensified resource extraction highlighted a deterioration of the local environment. Concentration of power to companies and a demography dominated by fly-in-fly-out labor were seen as exacerbating such a development.

On the basis of the workshop outcomes, global markets and their intersection with local economic structures is an area of high importance and high uncertainty for local futures. There is thus a need for further discussion about how this should be taken into account in decisions about adaptation. The intersection with power issues, including land rights, also makes it a focus area where local and indigenous voices and perspectives are needed to complement national and international discussions.

5.4.2.4 The environment and ecosystem services

Environment and ecosystem services capture the emphasis on how societies depend on their physical and ecological surroundings. Again, the specifics differ between contexts and what the global future may look like. For the Murmansk region, pollution was an important theme where some narratives were seen as leading to deteriorating environmental conditions with impacts on access to clean water and health. In the workshop results, there is a strong link to issues of power/ownership and to what affinity people have to the place they live. For the Torne Valley and Nordland, some global futures were seen as leading to an increasing focus on the economic value of the environment, either as a site for food production (agriculture and aquaculture), material and energy (forestry products), or as part of making a place attractive for tourists or for attracting people to settle there. The significance of environmental conditions thus ranges from serving basic human security needs to being an important base for economic development.

5.4.2.5 Technology, know-how, and culture

Development of new technologies was an important feature of many of the narratives. At the Kirovsk workshop, it was rated as the most important factor. In general, new energy-related technologies (or more widespread use of existing ones) were seen as an opportunity to develop local and regional energy independence. Other technologies appeared as factors in realizing the economic value of rich local and regional natural resources (linking the theme to ecosystem services). Specifics ranged from new forms of aquaculture to energy-saving buildings and getting higher value products from forests. The focus on technology was also linked to a need for know-how and high competence among local people. In some narratives, this competence was very focused on the need of specific sectors such as the fossil-fuel sector in Nordland, whereas other narratives included attention to a more diversified set of competences. For example, for the Torne Valley 'entrepreneurship' was highlighted as crucial for meeting challenges ahead. The need for knowledge and competence in the workforce also has implications for demography, for example if there are attractive jobs for people with different profiles, which is likely to affect whether women and youth stay or leave. Moreover, the need for competence can either be met by local people who have had access to relevant education or by workers coming only for short periods of time, with different implications for the social development in the local setting, as well as for cultural diversity, and sense of place.

Annika E. Nilsson

Kiruna City and the iron ore mine

The themes of technology and know-how are also closely related to larger issues of how the cultural environment develops. At the Gávnnadeapmi workshop, traditional knowledge was highlighted as one of the key issues for understanding the future, with major differences on how it would be valued in the different global futures. For example, the Fossil-fueled Development pathway with its emphasis on rapid technological development included possibilities of a high-tech intensive reindeer industry based on genetically engineered animals. This was accompanied by a loss in indigenous languages but also by an increasing number of highly educated reindeer herders. By contrast, the Green Road pathway implied integration of traditional knowledge to decision-making at all levels, new unique education systems, and nomadic livelihoods being highly esteemed.

5.4.2.6 International security and cooperation

A theme that appeared in some form in all workshops was international security and cooperation. Military activities were generally seen as less likely to have local impacts, despite the strong military presence in the region and historic experiences of direct impacts of war. However, a development towards international insecurity and conflicts was identified as a key issue with other potential impacts. Arctic locations remote from conflict areas have already seen an increasing number of refugees, which is a development that some scenario narratives highlighted. Moreover, impacts of increasing international tensions and conflicts may be felt via market forces. For example, increasing pressure on resources that are available in the region or changes in food markets may affect demand for reindeer meat. Some specific issues that were raised by workshop participants point to potential for both increasing and decreasing tensions at the regional level. In Bodø, discussions included how increasing tensions could come from increasing international fisheries leading to pressures on the current legal framework for ocean governance, while declining sea ice could lead to decreased potential for conflict between Norway and Russia because Russia would have its own open water harbors in the Arctic. The narratives from the Murmansk region and from the Gávnnadeapmi workshop highlight the role of regional cooperation, such as the Barents regional cooperation and cross-border indigenous cooperation. In one of the Nordland narratives, regional cooperation becomes more focused on joint economic interests as a result of increasing international insecurity.

5.4.2.7 Fate control, sense of place and cultural diversity

Power to make decisions about local development was an important theme (see also Section 5.4.2.3). At the Pajala workshop, power relations between the local and national level featured very high on the list of critical drivers of change, while the issue of fate control was more interconnected with other issues at the workshop in Bodø. A major issue here was power relationships between global companies and local municipalities. At the Gávnnadeapmi workshop, power issues became explicit in relation to a very strong focus on the role of indigenous rights as well as highlighting how dependent future development is on national policies. In the Murmansk narratives, power relations were not discussed explicitly but several of the narratives from the workshop highlight how affinity to the local context would favor decisions to protect the local environment in contrast to decisions taken elsewhere leading to more pollution.

Sense of place is sometimes used as a way to capture the complex processes that make people identify their relation to a particular locality. While sense of place in the Arctic has historically been linked to local contexts, culture and knowledge, this was not necessarily the case in the narratives about possible futures. Several feature an influx of people from elsewhere, as either a workforce or as refugees. Sense of place then becomes part of incorporating this new diversity in a way that ensures that newcomers start to care for the local context, environmentally and socially. In the circumpolar North, international cooperation has extended the sense of place, as was evident in shared experiences among reindeer herding youth from across the Eurasian Arctic at the Gávnnadeapmi workshop. In the future, 'sense of place' may thus not only relate to the local context but also to how global development influences international security, global markets, and knowledge in its broadest sense.

5.4.3 Reflections on workshop outcomes

The workshop participants clearly saw their local context as part of a global world and that their future will be affected by global development, not only regarding climatic and other environmental changes but also related to energy and resource markets and international security developments that lead to migration. The local and regional impacts identified in the workshops were seen to depend on a combination of the extent to which local actors have decision making power and 'soft' features such as world views, values, sense of place, and entrepreneurship.

Many of the global trends are likely to affect whether people stay or leave the places that are now populated. Population trends can thus be seen as a key outcome of global drivers of change. However, regional population trends are also drivers of change. Together with know-how, entrepreneurship, and values, demography shapes the capacity of societies to meet challenges ahead, regardless of what the global future may look like.

The futures that people envision are very context- and time dependent, where current local concerns have impacts on what issues workshop participants deem important or uncertain. Similarly, the envisioned future developments were affected to a large degree by how participants saw the role of local actors in relation to the global drivers, as active or passive in shaping the local future. Because of this context dependency, narratives will be different each time a workshop is convened. The advantage is that narratives generated from workshop discussions add to the range of potential futures in discussions about adaptation actions and give an indication of the uncertainty space that society has to navigate.

Challenges with the participatory methodology are associated with finding local and regional actors that are willing to spend one or two days in the workshop. Moreover, most stakeholders participating (with very few exemptions) were engaged only during the workshop event itself, despite interaction being sought both in advance (preparations) and after the meeting (quality check of constructed narratives).


Carl-Johan Utsi

5.5 Summary and discussion

All countries in the Barents area have well-developed climate change scenarios for their northern areas. A major challenge is to understand how climate change scenarios are used by decision-makers in different contexts at any level. Many of the nationally developed scenarios do not involve much local knowledge (Pilli-Sihvola et al., 2015), but it is becoming more common to include practitioners and users in scenario building, especially at the local level and in relation to specific sectors. Participatory workshops that combine scenarios and local narratives provide a method for engaging local and regional actors in the process of producing knowledge relevant for future planning. The new global scenario framework that has been developed – the global SSPs in particular – provides a useful context for co-constructing local and regional narratives that link to both global development and local contexts.

While the approach of producing narratives based on input from local workshops is similar to methods used in NORADAPT, the work on producing extended SSPs for this chapter provides a more systematic link to global development paths. Lessons learned from projects with strong user involvement suggest that in addition to involving multiple disciplines, the most important aspect is finding methods that ensure engagement in the process (see, for example, Dannevig et al., 2012; Jönsson and Gerger Swartling, 2014). To develop tools that are useful for adaptation action, it is thus relevant to evaluate how different scenario approaches manage to engage practitioners in different contexts and so help construct shared worldviews.

An overarching conclusion from the four scenario exercises is that local adaptation challenges are closely linked to global developments, not only regarding climate change but also in relation to resource markets, international security, values and norms, and technology development. For several of these issues, the future is highly uncertain, creating a range of potential global futures with a corresponding range of potential local and regional futures. Some of these issues may also be linked to climate change outside the region, highlighting the need to include attention to indirect impacts of climate change. The space of uncertainty created by the potential for very different global trajectories of social, economic and political developments at the global level needs to be integrated into current decision-making processes relating to adaptation and into strategic planning.

5.5.1 Knowledge gaps and ways forward

The strong focus on the role of values and 'soft' qualities in the local narratives about the future highlights a need for better knowledge of social trends that are difficult to quantify. Other factors identified as relevant for future challenges lend themselves to further studies with quantitative methods. This might be especially relevant for demographic dynamics.

There is also a need for methods to integrate qualitative assessment of social trends within frameworks that focus on quantitative analysis. An important component of such development is to find ways to systematically review the quality of the information available. For the global scenarios, there is a vision to develop integrated assessment models. While this may be more challenging at the local level, due to the resources needed for such work, a focus for future research could be to develop methods that better integrate narrative and quantitative scenario approaches at the regional scale. An additional line of further research is to link the future-oriented scenarios with studies of the history of the region. This could become a powerful way to better understand path dependencies and trigger points for change in development direction.

The work on which this chapter is based provides a few snapshots of how actors in the region see future possibilities and challenges. The future looks different depending on where you are and who you are. There is thus a need for organizing workshops in a broader range of settings and involving a more diverse set of actors. Especially relevant is to engage with young people who have a direct stake in how the future develops. A possible future activity would be to conduct similar workshops aimed at teenagers in schools at the junior high and high school level. Another potential group is families with young children. Further attention also needs to be placed on gender perspectives and on capturing the knowledge and thoughts of people that have come to the region very recently, including people from other parts of the world. These are just some examples to highlight the need to think about diversity issues when undertaking this type of exercise.

While scenarios are used extensively for analyzing potential impacts of climate change and adaptation challenges, there appears to be a lack of explicit reflection on their advantages and disadvantages, as well as on joint method development across different communities of practice. A priority follow-up activity could thus be to create networks that facilitate cross-study comparisons of scenario methodologies and approaches. Such networks may focus on the Barents area but also be circumpolar and/or closely linked to the global scenario research community.

Acknowledgments

We would like to acknowledge the substantial contribution made to this chapter by participants at the scenario workshops in Pajala, Kirovsk and Bodø, and at Gávnnadeapmi 2015. Work on this chapter by Annika E Nilsson and Lize-Marié van der Watt was funded by the research program Mistra Arctic Sustainable Development – New Governance, which also funded the Pajala workshop. Additional funding for Nilsson and for Henrik Carlsen's participation was provided by the Swedish Environmental Protection Agency. Ingrid Bay-Larsen, Bob van Oort and Maiken Bjørkan were funded by the Norwegian Research Council, which also supported the Bodø and Kirovsk workshops.

References

Abbing, K., 2009. Illustration av kommande klimatförändringar i Lycksele Kommun - Delrapport inom projektet Clim-ATIC [Illustration of Future Climate Change in Lycksele Municipality – Subreport within the project Clim-Atic]. www.lycksele.se/templates/DepartmentPage.aspx?id=19602

Absar, S.M. and B.L. Preston, 2015. Extending the shared socioeconomic pathways for sub-national impacts, adaptation, and vulnerability studies. Global Environmental Change, 33:83-96.

AMAP, 2014. ArcRisk (Arctic Health Risks: Impacts on Health in the Arctic and Europe Owing to Climate-Induced Changes in Contaminant Cycling) Results Overview. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

Andersson, L., A. Bohman, L. van Well, A. Jonsson, G. Persson and J. Farelius, 2015. Underlag till kontrollstation 2015 för anpassning till ett förändrat klimat [Supporting Report for Checkpoint 2015 for Adaptation to a Changing Climate]. Swedish Meteorological and Hydrological Institute (SMHI) Klimatologi No 12.

Arbo, P., A. Iversen, M. Knol, T. Ringholm and G. Sander, 2013. Arctic futures: conceptualizations and images of a changing Arctic. Polar Geography, 36:163-182.

Arctic Council, 2009. Arctic Marine Shipping Assessment 2009 Report. Arctic Council, second printing.

Arctic Council, 2013. Arctic Resilience Interim Report 2013. Stockholm Environment Institute and Stockholm Resilience Centre, Stockholm, Sweden.

Ash, N., H. Blanco, C. Brown, K. Garcia, T. Henrichs, N. Lucas, C. Ruadsepp-Heane, R.D. Simpson, R. Scholes, T.Tomich, B. Vira and M. Zurek (eds.), 2010. Ecosystems and Human Well-Being: A Manual for Assessment Practitioners. Island Press.

Avango, D., A.E. Nilsson and P. Roberts, 2013. Assessing arctic futures: voices, resources and governance. The Polar Journal, 3:431-446.

Baard, P., M. Vredin Johansson, H. Carlsen and K. Edvardsson Björnberg, 2012. Scenarios and sustainability: tools for alleviating the gap between municipal means and responsibilities in adaptation planning. Local Environment, 17:641-662.

Berkhout, F., J. Hertin and A. Jordan, 2002. Socio-economic futures in climate change impact assessment: using scenarios as 'learning machines.' Global Environmental Change, 12:83-95.

Börjeson, L., M. Höjer, K.-H. Dreborg, T. Ekvall and G. Finnveden, 2006. Scenario types and techniques: towards a user's guide. Futures, 38:723-739.

Bourmistrov, A. (ed.), 2015. International Arctic Petroleum Cooperation: Barents Sea Scenarios. Routledge Studies in Environmental Policy. Routledge.

Brace, C., and H. Geoghegan, 2011. Human geographies of climate change: landscape, temporality, and lay knowledges. Progress in Human Geography, 35:284-302.

Bravo, M.T., 2009. Voices from the sea ice: the reception of climate impact narratives. Journal of Historical Geography, 35:256-278.

Bruner, J., 1991. The narrative construction of reality. Critical Inquiry, 18:1-20.

Carlsen, H., K.H. Dreborg and P. Wikman-Svahn, 2012. Tailor-made scenario planning for local adaptation to climate change. Mitigation and Adaptation Strategies for Global Change, 18:1239-1255.

Carter, T.R., K. Jylhä, A. Perrels, S. Fronzek and P. Kankaanpää, 2005. FINADAPT scenarios for the 21st century: Alternative futures for considering adaptation to climate change in Finland. FINADAPT Working Paper 2. Mimeograph 332. Finnish Environment Institute, Helsinki, Finland.

CAVIAR, 2009. Community Adaptation and Vulnerability in Arctic Regions (CAVIAR). IPY Project, 2007-2009. www.ipy.org/images/uploads/CAVIAR.pdf

Daniels, S. and G.H. Endfield, 2009. Narratives of climate change: Introduction. Journal of Historical Geography, 35:215-222.

Dannevig, H., T. Rauken and G. Hovelsrud, 2012. Implementing adaptation to climate change at the local level. Local Environment, 17:597-611.

Frolov, A.V. (ed.), 2014. Vtoroĭ Ot͡senochnyĭ Doklad Rosgidrometa Ob Izmeneniiakh Klimata I Ikh Posledstviiakh Na Territorii Rossiĭskoĭ Federat͡sii: Obshchee Rezi͡ume [The second report of Roshydromet on climate change and their impact on the territory of the Russian Federation: general summary] Federal Service for Hydrometeorology and Environmental Monitoring, Moscow. (In Russian) http://voeikovmgo.ru/download/2014/od/od2.pdf

Groven, K., H. Høyer Leivestad, C. Aall, T. Selstad, Ø. Armand Høydal, A. Solveig Nilsen and S. Serigstad, 2008. Naturskade I kommunene. Sluttrapport fra prosjekt for KS [Natural damage in municipalities. Final project report for KS (Norwegian Association of Local and Regional Authorities)]. Vestlandsforsking-rapport no. 4/2008.

Guston, D.H., 2001. Boundary organizations in environmental policy and science: An introduction. Science, Technology and Human Values, 26:399-408.

Haavisto, R., K. Pilli-Sihvola, A. Harjanne and A. Perrels, 2016. Socio-economic scenarios for the Eurasian Arctic by 2040. Finnish Meteorological Institute, Report, No. 2016:1.

Hanssen-Bauer, I., H. Hygen and T. Engen Skaugen, 2010. Climatic basis for vulnerability studies of the agricultural sector in selected municipalities in northern Norway. Norwegian Meteorological Institute, Report No. 19/2010.

Hille, J., M. Lange Vik and P. Peeters, 2011. Background for scenario making. Sustainable destination Norway 2025. 1/2011. Western Norway Research Institute, Report No. 1/2011. www.vestforsk.no/filearchive/notat1-2011-background-for-scenario-making.pdf

Himanen, S., J. Inkeröinen, K. Latola, T. Väisänen and S. Alasaarela, 2012. Analysis of Regional Climate Strategies in the Barents Region. Reports of the Ministry of the Environment, No. 23. Finland.

Hovelsrud, G.K. and B. Smit (eds.), 2010. Community Adaptation and Vulnerability in Arctic Regions. Springer.

Hulme, M., 2009. Why We Disagree about Climate Change: Understanding Controversy, Inaction and Opportunity. Cambridge University Press.

IPCC, 2000. Emissions Scenarios. Nakicenovic, N. and R. Swart (eds.). Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press.

IPCC, 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press.

Ison, R. and D. Russell (eds.), 2007. Agricultural Extension and Rural Development: Breaking out of Knowledge Transfer Traditions. Cambridge University Press.

Ison, R., K. Collins, J. Colvin, J. Jiggins, P. Paolo Roggero, G. Seddaiu, P. Steyaert, M. Toderi and C. Zanolla, 2011. Sustainable catchment managing in a climate changing world: New integrative modalities for connecting policy makers, scientists and other stakeholders. Water Resources Management, 25:3977-3992.

Jönsson, A.M. and Å. Gerger Swartling, 2014. Reflections on science–stakeholder interactions in climate change adaptation research within Swedish forestry. Society and Natural Resources, 27:1130-1144.

Katsov, V.M. and B.N. Porfiryev, 2010. Evaluation of macroeconomic impact of climate change on the territory of the Russian Federation for the period up to 2030 and beyond. Glavnaya geofizicheskaya observatoriya Publ.

Kempton, W., J.S. Boster and J.A. Hartley, 1996. Environmental Values in American Culture. MIT Press.

Kok, K., R. Biggs and M. Zurek, 2007. Methods for developing multiscale participatory scenarios: insights from southern Africa and Europe. Ecology and Society 13:8 [online] www.ecologyandsociety.org/vol12/iss1/art8

Kriegler, E., J. Edmonds, S. Hallegatte, K.L. Ebi, T. Kram, K. Riahi, H. Winkler and D.P. van Vuuren, 2014. A new scenario framework for climate change research: the concept of shared climate policy assumptions. Climatic Change, 122:401-414.

Länsstyrelsen Norrbotten, 2012. Klimatförändringar i Norrbottens Län - Konsekvenser och anpassning [Climate change in Norrbotten County – Consequences and Adaptation]. 2/2012. Länsstyrelsens Rapportserie. Länsstyrelsen i Norrbottenslän, Luleå.

Länsstyrelsen Norrbotten, 2015. Naturmiljö och klimatförändringar i Norrbotten - Konsekvenser och anpassning [Nature and Climate Change in Norrbotten County – Consequences and Adaptation]. 14/2015. Länsstyrelsens Rapportserie. Länsstyrelsen i Norrbottenslän, Luleå.

Leach, M., I. Scoones and A. Stirling, 2010. Governing epidemics in an age of complexity: narratives, politics and pathways to sustainability. Global Environmental Change, 20:369-377.

Marttila, V., H. Granholm, J. Laanikari, T. Yrjölä, A. Aalto, P. Heikinheimo, J. Honkatuki, H. Järvinen, J. Liski, R. Merivirta and M. Paunio, 2005. Finland's National Strategy for Adaptation to Climate Change. Publication of the Ministry of Agriculture and Forestry 1a/2005, Finland.

McIntosh, R.J., J.A. Tainter and S. Keech McIntosh (eds.), 2000. The Way the Wind Blows: Climate, History, and Human Action. Columbia University Press.

Meteorologisk institutt, Bjerknessenteret, Nansensenteret, Havforskningsinstituttet, and NVE, 2009. Klima i Norge 2100. [The Climate in Norway 2100] Meteorologisk institutt – Bjerknessenteret – Nansensenteret – Havforskningsinstituttet and NVE. Updated 2015 report: www.miljodirektoratet.no/Documents/publikasjoner/M406/M406.pdf

Miljøverndepartementet, 2010. Tilpassing til eit klima i endring — Samfunnet si sårbarheit og behov for tilpassing til konsekvensar av klimaendringane [Adaptation to a Changing Climate – Society's Vulnerability and Need for Adaptation to Consequences of Climate Change]. Noregs offentlege utgreiingar, Report No. 2010:10. https://www.regjeringen.no/no/dokumenter/nou-2010-10/id624355/?ch=1&q=

Ministry of Agriculture and Forestry, 2014. Finland's National Climate Change Adaptation Plan 2022. Government Resolution 20 November 2014. Publication of the Ministry of Agriculture and Forestry 5b/2014, Finland.

Monni, S. (ed.), 2013. Finland's Sixth National Communication under the United Nations Framework Convention on Climate Change. Ministry of the Environment and Statistics Finland, Helsinki.

Moss, R.H., J.A. Edmonds, K.A. Hibbard, M.R. Manning, S.K. Rose, D.P. van Vuuren, T. R, Carter, S. Emori, M. Kainuma, T. Kram, G.A. Meehl, J.F.B. Mitchell, N. Nakicenovic, K. Raihi, S.J. Smith, R.J. Stouffer, A.M. Thomson, J.P. Weyant and T.J. Wilbanks, 2010. The next generation of scenarios for climate change research and assessment. Nature, 463:747-756.

Nilsson, A.E., H. Carlsen and L.-M. van der Watt, 2015. Uncertain futures: The changing global context of the European Arctic. Report from a Scenario Workshop in Pajala, Sweden, 9-10 March 2015. SEI Working Paper 2015-12. Stockholm Environment Institute.

NORADAPT, 2011. Community Adaptation and Vulnerability in Norway (NORADAPT). http://climate-adapt.eea.europa.eu/projects1?ace_project_id=504

Norrbotten County Administrative Board, 2009. Climate Change in Norrbotten County - Consequences and Adaptation. Country Administrative Board, Report No. 13/2009.

O'Neill, B.C., E. Kriegler, K. Riahi, K.L. Ebi, S. Hallegatte, T.R. Carter, R. Mathur and D.P. van Vuuren, 2014. A new scenario framework for climate change research: The concept of shared socioeconomic pathways. Climatic Change, 122:387-400.

O'Neill, B.C., E. Kriegler, K.L. Ebi, E. Kemp-Benedict, K. Riahi, D.S. Rothman, B.J. van Ruijven, D.P. van Vuuren, J. Birkmann, K. Kok, M. Levy and W. Solecki, 2017. The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. Global Environmental Change, 42:169-180.

Paschen, J.-A. and R. Ison, 2014. Narrative research in climate change adaptation – exploring a complementary paradigm for research and governance. Research Policy, 43:1083-1092.

Pilli-Sihvola, K., B. van Oort, I. Hanssen-Bauer, M. Ollikainen, M. Rummukainen and H. Tuomenvirta, 2015. Communication and use of climate scenarios for climate change adaptation in Finland, Sweden and Norway. Local Environment, 20:510-524.

Pilli-Sihvola, K., D. Gritsenko, R. Haavisto, A. Harjanne, P. Iivari, S. Kyyrä, R. Pöntynen, S. Repka, A. Suominen, H. Virta, V.-P. Tynkkynen and A. Perrels, 2016. Finland's journey toward the Forefront of Responsible Arctic Development – Suggestions for General Development, Maritime Cluster and Tourism Measures by 2035. Publications of the Government's analysis, assessment and research activities 10/2016. (In Finnish, English and Swedish Abstract). http://tietokayttoon.fi/julkaisu?pubid=10101

Pohl, C., 2011. What is progress in transdisciplinary research? Futures, 43:618-626.

Rambøll Management Consulting, 2015. Følgeevaluering Av Framtidens Byer. Sluttrapport [Evaluation of Future Cities. Final report]. Kommunal- og moderniseringsdepartementet, Oslo. www.regjeringen.no/contentassets/d0a2bc3aeec44ce8bf642eab6daea28d/sluttrapport_evaluering_framtidens_byer.pdf

Rønning, L., 2011. Klimatisering Av Landbrukspolitikken [Climatization of Norwegian Agricultural policy]. Notat 1009/2011. Nordlandsforskning, Bodø.

Roshydromet, 2014. Second Roshydromet Assessment Report on Climate Change and its Consequences in Russian Federation. Roshydromet, Moscow, Russia. (In Russian, English Summary). http://downloads.igce.ru/publications/OD_2_2014/v2014/htm/

Ruuhela, R., 2012. Miten väistämättömään ilmastonmuutokseen voidaan sopeutua? Yhteenveto suomalaisesta sopeutumistutkimuksesta eri toimialoilla [How to adapt to inevitable climate change? - A synthesis of Finnish research on adaptation in different sectors]. Publication of the Ministry of Agriculture and Forestry 6/2011, Finland. (In Finnish)

SMHI, 2015. Framtidens klimat [Climate in the future]. SMHI website for climate scenarios for Sweden. Swedish Meteorological and Hydrological Institute (SMHI). www.smhi.se/klimat/framtidens-klimat/klimatscenarier

Swedish Commission on Climate and Vulnerability, 2007. Sweden Facing Climate Change – Threats and Opportunities. Swedish Government Official Report, No. 2007:60. Stockholm. www.government.se/sb/d/574/a/96002

van Oort, B., M. Bjørkan and E.M. Klyuchnikova, 2015. Future Narratives for Two Locations in the Barents Region. Center for International Climate and Environmental Research (CICERO), Report No. 2015:06. Oslo.

van Vuuren, D.P., J. Edmonds, M. Kainuma, K. Riahi, A. Thomson, K. Hibbard, G.C. Hurtt, T. Kram, V. Krey, J.-F. Lamarque, T. Masui, M. Meinshausen, N. Nakicenovic, S.J. Smith and S.K. Rose, 2011. The representative concentration pathways: An overview. Climatic Change, 109:5-31.

6. Impact analysis and consequences of change

Coordinating lead authors: Minna Turunen, Anna Degteva, Seija Tuulentie

Lead authors: Anatoli Bourmistrov, Robert Corell, Edward Dunlea, Grete Hovelsrud, Timo Jouttijärvi, Sari Kauppi, Nancy Maynard, Bob van Oort, Arja Rautio, Hein Rune Skjoldal

Contributing authors: Natalia Anisimova, Valery Chaschin, Dmitrii Denisov, Anastasia Emelyanova, Elena Eriksen, Jaakko Erkinaro, Jon L Fuglestad, Geir Wing Gabrielsen, Ludmila Maria Granberg, Leena Grandell, Andrei Gudkov, Ingeborg G Hallanger, Antti Hannukkala, Petri Heinimaa, Boris Ivanov, Edda Johannesen, Lis Jørgensen, Timo Jouttijärvi, Panu Juntunen, Sari Kauppi, Carina Keskitalo, Asta Kietäväinen, Juha Kiviluoma, Oleg Korneev, Kari Lehtonen, Lars Lindholt, Pavel Lyubin, Frode Nilssen, Teuvo Niva, Jon Øyvind Odland, Julia Olsen, Willy Østreng, Riku Pasonen, Stanislav Patin, Andrey Petrov, Pasi Rautio, Kimmo Silvo, Laura Sokka, Julia Tchernova, Seppo Vuori

Key messages

- ***The warming climate will cause many boreal species to shift northwards over the next few decades and within the Arctic some species will retreat or decrease in number.*** *The incidence of invasive species, pests and diseases will increase. Impacts of increased anthropogenic activity and related emissions in and outside the Barents area are very likely to intensify towards 2030 and beyond.*
- ***The warming and expansion of Atlantic Water that has occurred over recent decades will continue, and winter sea ice and the marginal ice zone will decrease to a small area in the northern Barents Sea.*** *The warming climate will increase phytoplankton primary production. Ice-associated species will be negatively affected by the loss of sea ice, while open water species may benefit from the warming The cumulative impacts of human activities can have serious long-term consequences for coastal and marine ecosystems and marine-based food production from the Barents Sea.*
- ***The consequences of climate change for human health and wellbeing are expected to increase,*** *due to extreme and rapidly changing weather, environmental disasters, new diseases and societal changes. Indigenous peoples are especially vulnerable due to their close dependence on the environment for food, way of life, and culture.*
- ***Communities, both rural and urban, are affected by interacting socio-economic and environmental changes and are dependent on sufficient human and economic resources.*** *The consequences of multiple stressors on key economic sectors and services can be considered as risks for business-as-usual, but can also represent new economic opportunities.*
- ***Forestry and agriculture can benefit from a longer growing season while negative impacts for traditional livelihoods such as reindeer herding may exceed benefits.*** *Cumulative impacts from global resource demand, climate change and other drivers will threaten traditional and recreational activities and lifestyles. Shorter and warmer winters and increased pests and diseases may increase risk for agriculture and forestry.*
- ***The potential for new industrial livelihoods may grow due to the economic changes and better accessibility but these also face adverse impacts.*** *Melting sea ice will lead to increased shipping and cruise tourism through to better accessibility. Winter tourism may suffer from a lack of snow. Fishing will shift north in the Barents Sea. Favorable geopolitical circumstances may have positive impacts on oil and gas resources. Alternative energy sources are expected to become increasingly important. Mining is strongly sensitive to global demand, and also vulnerable to climate change impacts.*
- ***Depending on the geographical scale and sector, some drivers of change are more important than others and their importance changes over time.*** *A step-by-step analysis is used to study the cumulative consequences of various drivers and impacts on forestry as an example.*

6.1 Introduction

Climatic and environmental change, globalization, geopolitical shifts, increased industrial, shipping and tourism activities, and other socio-economic, cultural and political conditions all interact to create complex and cumulative impacts in all communities: indigenous, non-indigenous, rural and urban. These impacts will have consequences that will lead both to challenges and opportunities.

The viability of communities is shaped by the degree to which their response to pressures and opportunities is sustainable (e.g. Larsen and Fondahl, 2014). In turn, this is linked to institutional flexibility and to collaborative policies for reducing the impacts of man-made and environmental disasters. Pelagic fisheries, for example, are reliant on international cooperation and adherence to existing agreements in order to be successful when ocean warming causes fish stocks to migrate to new waters and new fish stocks to appear. Recent institutional changes in some parts of the Barents area, such as the Finnmark Act in Norway, have led to consequences for both local communities and resource developers because the communities have gained more control and ownership over natural resources.

In addition to changing environmental and climatic conditions, major societal trends in the Barents area include: increasing demographic shifts into urban centers and proportionally higher outmigration by women than men; increasing mobility, of both people and ideas within and between communities and to and from the region; increased import of foodstuffs as well as increased interest in locally produced foods; and increasing globalization with impacts on community connections (Larsen and Fondahl, 2014) (see also Section 4.5).

Against the backdrop of this complex picture of climatic, environmental, and socio-economic change, this chapter highlights the current impacts of specific drivers of change and their interactions and points to projected key consequences relevant for future planning and adaptation actions in the Barents area. The emphasis is on regionally identified priorities and the material draws on recent peer-reviewed publications. The key consequences are described in three sections; the first two address impacts and consequences for the biophysical, social, and economic domains of the area (Sections 6.2 and 6.3) while the third presents a methodology for understanding the cumulative impacts and future consequences of these multiple drivers of change (Section 6.4).

The analysis in this chapter represents what is known about drivers, impacts, and consequences before any adaptation actions are implemented for building resilience. Communities and nations have the ability to lessen the impacts and consequences of change through adaptation measures. Thus, this chapter provides the foundations of key consequences to inform the discussions on adaptation actions in Chapter 9 that can, in turn, design adaptation planning strategies, useful mechanisms and adaptation tools to assist the people of the Barents area to better adapt for and live in the Arctic of the future.

6.2 Impacts on ecosystem and human health

6.2.1 Terrestrial and freshwater ecosystems

There is a close coupling between human systems and natural ecosystems in the Arctic (see Section 8.2.2). The terrestrial parts of the Barents area include five main ecosystem types: glacier, freshwater, open wetland, alpine and lowland tundra, and forest (Section 2.2.1). These Arctic ecosystems are vulnerable to climate change (Legagneux et al., 2014) owing to the dependence of several key species on snow and ice and 'edge effects' (i.e. species invasions from sub-Arctic ecosystems). Arctic ecosystems are complex and interlinked by nutrient cycling between the terrestrial, freshwater, and marine components. Current understanding of Arctic ecosystems is based mostly on limited time series of single species observations. Ecosystem impacts are thus mostly based on inferences, and projecting the type and timing of consequences is inherently difficult.

6.2.1.1 Impacts on hydrology, freshwater ecosystems and vegetation

Groundwater levels are expected to change significantly as a result of climate-related changes, especially warming (Section 4.2.1), changes in precipitation, snowfall and the snowpack (Sections 4.2.2 and 4.4.1), declining meltwater from glaciers (Section 4.4.3), and vegetation shifts (Haldorsen and Heim, 1999). Permafrost thaw also plays an important role in hydrological change across most of the Arctic, but the Barents area has relatively little permafrost (Section 4.4.2). Soil type is a defining factor in such change. The largest non-climatic impact on tundra hydrology is due to vegetation change, with increased shrub growth and a shift from boreal evergreen trees to deciduous vegetation (Post et al., 2009). Such a shift will lead to complex changes including changed albedo, increased warming (and thus melting), and further change in hydrology through increased evapotranspiration, and potentially increased cloudiness and precipitation (Swann et al., 2010). There are only a few (and uncertain) direct anthropogenic hydrological changes. Increased industrial development and traffic in the Arctic and more frequent and larger forest fires in Europe (Camia et al., 2008) as well as the Barents area, will result in higher black carbon emissions and other particle contamination. These exacerbate melt of snow and ice and have associated follow-on effects for hydrology and vegetation (Degteva et al., 2015; see also Chapter 4). Water diversions for mining or hydroelectric purposes and intensive or unsustainable land- or water use may also affect the hydrological balance.

As discussed by Bring et al. (2016), snow-cover extent and duration is generally decreasing on a pan-Arctic scale, but snow depth is likely to increase in the Arctic tundra. Evapotranspiration is likely to increase overall, but as it is coupled to shifts in landscape characteristics, regional changes are uncertain and may vary over time. Streamflow will generally increase with increasing precipitation, but high and low flows may decrease in some regions.

Arctic freshwater ecology is strongly influenced by the duration of snow- and ice-cover (Sections 4.4.1.3 and 4.4.4), water temperature and nutrient concentrations, and inputs from the catchments and surrounding terrestrial ecosystem (Wrona et al., 2006). A warming climate will continue to reduce seasonal ice cover in Arctic rivers, lakes and ponds, which will in turn increase water temperature and both shift and increase the length of the growing season (Prowse et al., 2006). Ecosystem productivity will increase across the system, from algal growth to invertebrate emergence, to fish development (Wrona et al., 2013). Climate-induced changes will cause reductions in the populations of cold-water fishes, especially salmonids (Wrona et al., 2013), including their associated parasites which are important for overall ecosystem stability and resilience (Lafferty et al., 2008). Many warm-water fishes on the other hand will expand their current range into northern habitats (Wrona et al., 2006), taking with them their parasites (Marcogliese, 2001). Increased growth and use of freshwater bodies by fish and wildlife, but also the continued pollution and contamination, such as atmospheric deposition of nitrate (a plant nutrient) transported to the Arctic from southern sources, may increase the eutrophication of freshwater ecosystems (Prowse et al., 2006). Of perhaps even greater impact in freshwater ecosystems are not the changes taking place within the systems, but the appearance or disappearance of the systems themselves. For example, while Arctic lakes are rapidly draining and disappearing following the loss of permafrost and increased evaporation due to higher air temperatures, it is also the case that increased snow and ice melt and thawing permafrost may increase the formation of swamps and new lakes (Arctic Council, 2013 and references therein). All such changes have implications for hydrology at large, the surrounding vegetation, and the animals depending on this (Post et al., 2009), as well as for livelihoods. See Section 6.3.1.5 for discussion on the impacts of climate change on freshwater fisheries.

Direct climate- and cryospheric changes, the related indirect changes in hydrology, and grazing pressure are expected to have the greatest impacts on vegetation in the Barents area, although land-use change may become almost as important in the boreal biome (Elmhagen et al., 2015). The formation and draining of lakes may also cause large shifts in vegetation and species balance with consequences for pastures and livelihoods. Such changes in hydrology and as a consequence vegetation may take place over very short time scales, from as little as three to five years to ten or more years. One example is the shift from tundra to boreal plant vegetation over a period of ten years in an alpine area of northern Swedish Lapland. This shift has had major consequences for grazing reindeer (*Rangifer tarandus*) as the grazing-important cotton grass (*Eriophorum vaginatum*) disappeared in favor of non-grazing important lingonberry (*Vaccinium vitis-idaea*) (Molau, 2010). Section 6.3.1.1 and Chapters 7 and 9 discuss the consequences of changes in temperature and precipitation for pastures and reindeer husbandry.

Projections of vegetation change for the Barents area indicate gradual extensions northward and upward in mountain areas of both pine- and deciduous trees over the next 100 years (Wolf et al., 2007; Post et al., 2009), as temperatures and soil moisture increase especially during the first half of the century (Roderfeld et al., 2008). Open ground vegetation will largely disappear and be replaced by shrubs, which will decrease in extent and be gradually replaced by taller vegetation (Arctic Council, 2013). Trampling and grazing by reindeer and migrating bird populations can in some places affect vegetation composition and limit forest expansion (Ims et al., 2013), with consequences for hydrology. While growing season duration may decrease due to hydrological changes and decreasing summer air temperatures in the short term (Bhatt et al., 2013), long-term projected changes include earlier spring greening and increased biomass and primary production (Swann et al., 2010).

The current average browning trend of the tundra in Eurasia, indicating a long-term decrease in growing season, may be attributed to permafrost degradation and subsequent hydrological changes (Jorgenson et al., 2001; Frost and Epstein, 2014) and also to decreasing summer air temperatures (Bhatt et al., 2013). As vegetation and climate continue to change, browning may turn to a greening in some areas, depending on the hydrological (drying) effects of deciduous vegetation (Swann et al., 2010).

Climate and vegetation changes may lead to more pest outbreaks, which in recent years have led to historically low vegetation productivity in the European North (Epstein et al., 2014). Climate induced vegetation changes may also increase potential for carbon sequestration (Chapter 4) but this effect may be masked by changes in albedo due to vegetation change (Swann et al., 2010).

Overall, the potential consequences of these changes in climate, hydrology and vegetation, especially for the forestry sector, are serious and potentially rapid. These consequences are discussed further in Sections 6.3.1.3, 6.4.3 and Chapter 9.

6.2.1.2 Impacts on microorganisms, invertebrates, birds and mammals

Many elements across the hydrological and social-ecological systems are interconnected. Fluxes and connections vary in strength through the seasons, and may change completely as the climate changes, and as impacts associated with human activities and the presence of invasive species increase (Figure 6.1).

Continued warming and increasing soil moisture will increase microorganism activity in the near and far term, increasing

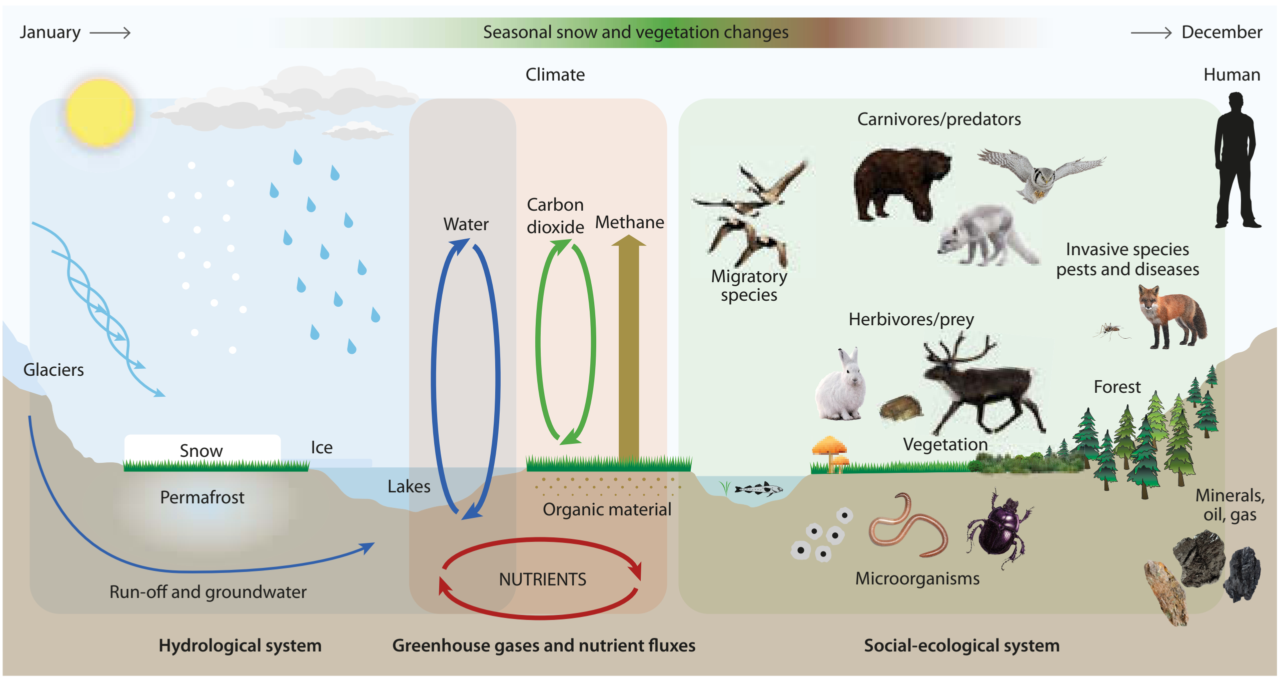


Figure 6.1 Important elements in the Arctic terrestrial and freshwater ecosystems (Bob van Oort, Cicero).

decomposition, nutrient cycling, and vegetation productivity, which will in turn increase greenhouse gas emissions and carbon uptake. Invertebrate activity will also increase, which is important because invertebrates play a crucial role in the pollination of many Arctic plants and are the major food source for many breeding birds and freshwater fish species. An increase in invertebrate activity and diversity may further promote dispersal of vegetation and increase populations of both Arctic and invasive species of birds and fish. Importantly for reindeer herding, the seasonal pattern of occurrence and abundance of biting flies and mosquitos is increasing in some places (CAFF, 2013a,b).

Similar to today, harvest, disturbance, and habitat loss outside the Arctic are expected to influence the population trends of many Arctic (including migratory) birds in the future. The consequences of changing climatic and vegetation conditions on Barents area bird populations are difficult to project, but are expected to be a gradual and continuous process, rather than a 'sudden' tipping point change (Lenton, 2012). Changing bird populations may have consequences for society via their impacts on vegetation (through grazing) and on eutrophication of lakes and as hunting species. Some grouse species, important for hunting and seed dispersal, may be affected more immediately by disappearing snowbeds (which provide cover) and changes in insect abundance (Arctic Council, 2013 and references therein). For overwintering small rodents and for reindeer, decreasing snow cover may be critical as snowbeds provide cover (from mosquitos) and temperature relief in summer, and their gradual melt through the season improves pasture quality for reindeer (Lenton, 2012). Thus, decline in snow cover may decrease pasture quality and have consequences for reindeer health and reproduction (Callaghan et al., 2011). Further effects of changes in snow abundance and quality as well as trends in industrial development and fragmentation are discussed in Section 6.3.1.1 and Chapter 7 and in other sections on reindeer herding. Otherwise, climate change and a continued northward expansion of the boreal forest may allow moose (*Alces alces*) (an important hunting species) and southern generalist species to spread further north (Elmhagen et al., 2015).

The ultimate impact of climate change, increasingly pronounced interannual variability and increasing impacts of human activities depend on the complex interactions between the different drivers and species (Arbo et al., 2012). The combined changes will have consequences for society especially through their effects on ecosystem services (Jansson et al., 2015 and Chapter 2). Main research needs include more monitoring to better understand species interactions, biome shifts and future land-use changes (including forestry, farming and recreation), as well as better understanding of ecosystem service use in the Barents area, including Russia.

6.2.2 Marine and coastal ecosystems

The Barents Sea is a flow-through system with Atlantic Water entering from the Norwegian Sea in the southwest and leaving between Novaya Zemlya and Franz Josef Land in the northeast (see Chapter 2). This sets the stage for the Barents Sea being a biogeographical transition zone between a warmer boreal region in the southern part and an Arctic region in the north. The Barents Sea has been monitored and investigated for more than 50 years in a collaborative effort between Norway and Russia. This has provided an extensive knowledge base for this sea area (Sakshaug et al., 2009; Jakobsen and Ozhigin, 2011).

6.2.2.1 Impacts of climate variability and change

Large climate and ecological variability is a key feature of the Barents Sea marine ecosystem. Climate variability is expressed on different time scales including multi-decadal and interannual fluctuations. The observed responses to climate variability of ecosystem components including plankton, fish, benthos, birds and marine mammals form a basis of reference for assessing the likely impacts of future climate change. With the warming over recent decades there has been a general increase in the overall abundance and spread of boreal species, and a decline and retreat of Arctic species. This 'borealization' with a northward shift in distribution is likely to continue under the warming projected for the next 50 years (Fossheim et al., 2015).

The cold waters of the Arctic Ocean are particularly vulnerable to the rapid and progressive process of ocean acidification (AMAP, 2014b and references therein). The pH of surface waters in the Norwegian Sea has decreased significantly over the past 30 years (Skjelvan et al., 2014). While not uniform across the area and demonstrating seasonal and interannual variability, ocean acidification has direct and indirect effects on Arctic marine life (Orr et al., 2005; AMAP, 2014b). While impacts vary significantly for different organisms (Secretariat of the Convention on Biological Diversity, 2014), they are likely to lead to significant changes in marine ecosystems, such as changes in species composition, leading to potential impacts on Arctic fisheries and economic and social impacts on livelihoods (AMAP, 2014b).

Continued decline in winter sea ice in the Barents Sea (see Chapter 4) is expected to lead to increased primary production by phytoplankton (Ellingsen et al., 2008; Skaret et al., 2014) and decreased primary production by ice algae. But because the contribution of ice algae to the total primary production in the Barents Sea has been low in recent years (<5%) despite extensive ice cover (Hegseth, 1998; Wassmann et al., 2006; von Quillfeldt et al., 2009), the effect on total production is low and compensated for by increased production by phytoplankton. However, less ice algae as well as reduced occurrence of other ice biota represents a major qualitative change in the ecosystem in the northern Barents Sea.

Increased warming and little or no ice in the Barents Sea by 2070 (see Chapter 4), is expected to result in an expansion of boreal zooplankton and a reduction in Arctic zooplankton. With warming there is an extension of the reproductive habitat for the dominant copepod *Calanus finmarchicus* in the southern and central Barents Sea, and increased production due to a greater role for a second generation of the copepods in the warmer Atlantic Water (Melle and Skjoldal, 1998; Skaret et al., 2014). However, this species is expected to continue to be expatriated and not able to occupy the still cold waters of the northern Barents Sea for its breeding habitat. For the closely related Arctic species *C. glacialis*, the impact of warming and little or no sea ice is unclear. It is possible that the overall effect of warming and less ice may be favorable for *C. glacialis*, allowing it to sustain higher predation pressure from pelagic fish such as capelin (*Mallotus villosus*) and polar cod (*Boreogadus saida*).

With continued warming, krill are expected to expand their distribution and increase in the Barents Sea. The spawning habitat of *Thysanoessa intermis* may expand east and north with the warmer Atlantic Water in a similar manner as for *C. finmarchicus*, while the southwestern Barents Sea may become a regular part of the habitat for *Meganyctiphanes norvegica*. Predation from pelagic fish and other consumers will continue to be important, and the interaction between climate and predation will determine how the abundance and roles of the various krill species will develop in a future warmer climate (Eriksen and Dalpadado, 2011; ICES, 2015a).

It is expected that the Arctic *Themisto libellula* (Dalpadado, 2002; Dalpadado et al., 2002, 2008), which is one of the dominant hyperiid amphipod species of the genus *Themisto*, will be negatively impacted by warming, and its future role in the northern part of the Barents Sea ecosystem will diminish.

Jellyfish populations share the pelagic environment with many small planktivorous fishes (Brodeur et al., 2008; Eriksen, 2016), and further warming is likely to increase overlap and strengthen species interactions.

Climate may affect marine fish populations through many different pathways, operating at a range of temporal and spatial scales. Climate impacts may affect fish directly, or indirectly through bottom-up or top-down processes within the food web. These direct and indirect effects can act simultaneously but with complex patterns involving non-linearity and time lags, and are not mutually exclusive (Rijnsdorp et al., 2009). The many drivers and pathways through which climate affects marine fish stocks can often make it difficult to establish unequivocal connections between climate forcing and the ecological responses of fish populations, let alone quantify them (Ottersen et al., 2004, 2010; Vilhjálmsson and Hoel, 2005). This is even more the case for exploited fish populations where the effects of fishery exploitation interact with effects of climate forcing and the two can be difficult to separate (Skjoldal, 2004; Perry et al., 2010; Planque et al., 2010).

What will happen to three species of plankton-feeding fish: capelin, herring (*Clupea harengus*) and polar cod with continued warming is a key issue due to their importance in the ecosystem (see Chapter 2). The complex biological interactions involved make it difficult to develop predictions. Occupation of new spawning grounds on banks off Novaya Zemlya is a possibility that may shift the spatial distribution and ecological role of capelin in the Barents Sea ecosystem under a warmer climate (Huse and Ellingsen, 2008). Norwegian spring spawning herring is expected to continue to thrive under the warming projected for the next 50 years, but with fluctuations driven by fluctuations in the future climate. The loss of sea ice may have led to a loss of spawning habitat and thus have contributed to the dramatic recent recruitment failures and stock decline. Further, the expansion of Atlantic cod (*Gadus morhua*) into the northern Barents Sea has led to increased spatial overlap between the two species and increased predation pressure from Atlantic cod on polar cod. The decline in the polar cod stock may cause structural reorganization of the Arctic food web in the future (Hop and Gjøsæter, 2013). The projected warming may lead to a permanently reduced polar cod stock in the Barents Sea with consequences for the ecology of the northern and southeastern Barents Sea.

With further warming, the Barents Sea will continue to be a favorable habitat for commercially important cod (see Chapter 2; Fossheim et al., 2015). The stock will probably not be able to increase further due to restrictions in space and productivity. It is likely that there will continue to be large fluctuations in the ecosystem, as is now being seen with the ongoing collapse of the capelin stock and which is likely to affect the cod stock as well as other species in the ecosystem. How the ecosystem dynamics will develop is difficult to predict, however, due to the complexity of climate forcing and food web interactions. The northern expansion of cod is a prime example of the borealization of the Barents Sea ecosystem under warming (Fossheim et al., 2015) (see also Box 6.1).

As is the case for the fish communities (Fossheim et al., 2015), continued warming is expected to lead to a further borealization of megabenthos (and probably also benthic infauna) with an increase in boreal species and a decrease in Arctic species along the southwest-northeast axis. The ecological processes thought to drive the observed changes are likely to promote the borealization of Arctic marine communities in the coming years (Kortsch et al., 2012).

Climate change is expected to affect all marine mammal species (see Table 2.1 for an overview) in the Barents Sea through impacts on the productivity of plankton, benthos and fish. The ice-associated species are very likely to be negatively affected by the loss of sea ice (Laidre et al., 2015), while open water species such as the large baleen whales are very likely to benefit from the warming trend. Ringed seal (*Pusa hispida*), harp seal (*Pagophilus groenlandicus*), hooded seal (*Cystophora cristata*) and bearded seal (*Erignathus barbatus*) depend on ice as a substrate for breeding, lactation, molting and resting, and are therefore particularly vulnerable to the decline in Arctic sea ice (Laidre et al., 2015). Some bearded seals follow the marginal ice zone and may therefore be negatively affected by increased migration distances and possible changes in prey composition and availability. If sea ice retreats to deep water north of Svalbard, it can no longer serve as a feeding platform for bearded seal. Reduced availability of ice habitat over the continental shelf is therefore a concern for this species (Kovacs et al., 2011). A general concern with respect to Arctic warming is the replacement of Arctic species of zooplankton and fish by less energy-rich southern species. These species may not allow sufficient accumulation of body reserves for capital breeding animals like seals (Grebmeier et al., 2006; Dalpadado et al., 2012).

Owing to low abundance, crowding in haul-out areas or food limitation close to haul-outs do not currently appear to be a problem for walrus (*Odobenus rosmarus*) in the Barents Sea area in contrast to large parts of the Pacific Arctic (Laidre et al., 2008). However, continued sea-ice retreat may become a problem for Barents Sea walrus over the long term.

Continued retraction of the sea ice will almost certainly lead to large reductions in the abundance of all ice breeding seals and thereby to a reduction in the prey base for polar bears (*Ursus maritimus*) (Wiig et al., 2008; Kovacs et al., 2011;

Box 6.1 Observed changes in Barents Sea fish and benthic species

The Barents Sea is home to roughly 100 species of fish that are regularly recorded during surveys (Bogstad et al., 2008; Wienerroither et al., 2011). Of these, just over half are considered boreal species while about one third are Arctic species (Andriyashev and Chernova, 1995; Bogstad et al., 2008, 2014). The species are distributed in patterns of fish communities that shift in composition and distribution with changing climatic conditions (Fossheim et al., 2006; Johannesen et al., 2012; Aschan et al., 2013). The general increase in overall abundance and expansion of boreal species that has accompanied the warming of the past few decades, referred to as 'borealization' (Figure 6.2), is likely to continue under the projected warming over the next 50 years (Fossheim et al., 2015).

A decrease in total benthic biomass between surveys in 1924–1935 and 1968–1970 through almost the entire Barents Sea (Figure 6.3) has been attributed to climate change by many researchers. However, this situation changed in the period 1991-1994 with biomass shifting and showing a considerable increase in the central region. The mechanisms underlying the changes in biomass are not clear. Some studies have suggested that this was due to a change in faunal distribution during the cold period between the 1960s and 1980s (Bochkov and Kudlo, 1973; Bryazgin, 1973; Antipova, 1975), while others have invoked declining biomass of resident boreal-Arctic species during the warm period from the 1930s to the 1960s (Galkin, 1987; Kiyko and Pogrebov, 1997, 1998). The dominant boreal-Arctic species have an optimum temperature range that is positioned within the long-term mean temperature measured for the region. According to the latter theory, any deviations from the long-term mean have negative impacts on the reproduction, abundance, and biomass of boreal-Arctic species (Anisimova et al., 2011 and references therein).

Monitoring of benthos at the Kola transect, which was started in 1994 by the Murmansk Marine Biological Institute, revealed an increase in the relative number of boreal species following the historical maximum temperature anomaly recorded in 2006. Benthic biomass increased through the entire 17-year monitoring period and peaked in 2010. This is believed to have been caused by the long period of warming and abnormally high bottom temperatures between 2006 and 2012 (Olga Ljubina, Murmansk Marine Biological Institute, pers. comm.).

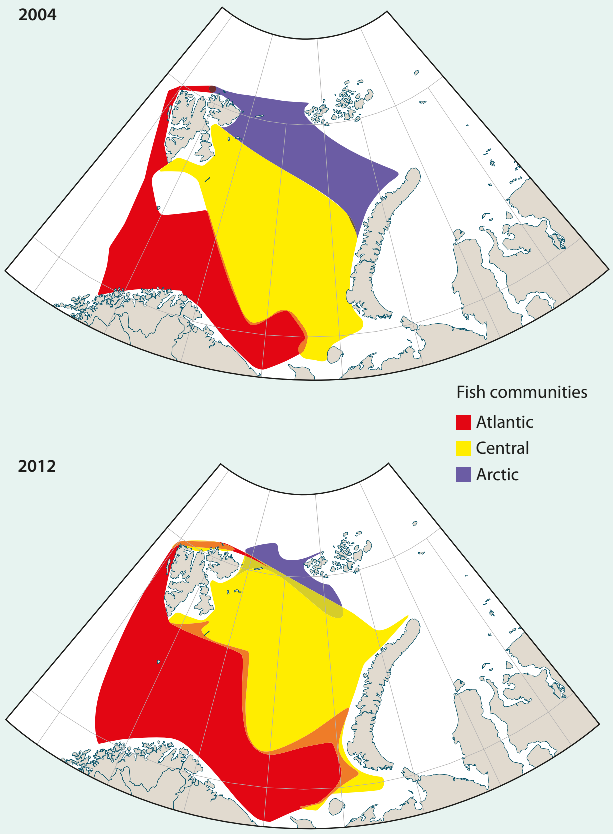


Figure 6.2 Comparison of the abundance of fish communities in the Barents Sea between 2004 and 2012 (Fossheim et al., 2015).

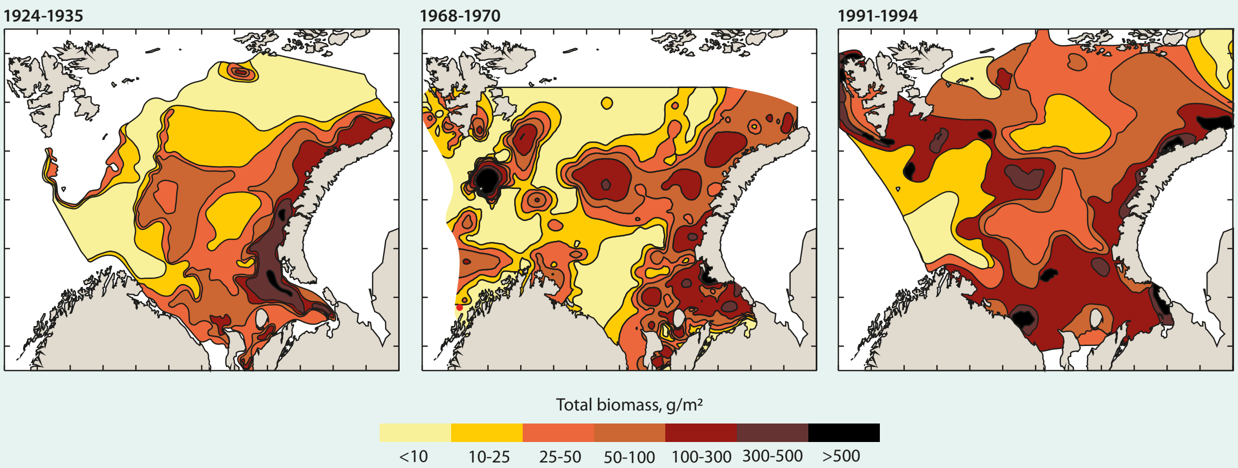


Figure 6.3 Distribution of benthic biomass in the Barents Sea for three survey periods (after Brotskaya and Zenkevich, 1939; Antipova, 1975; Kiyko and Pogrebov, 1997) (Institute of Marine Research).

Box 6.2 Cumulative impacts and consequences for seabird populations

Many seabird populations in the Barents area have shown a significant and steady decline (see Chapter 2). Studies have been attributing this not just to one factor (such as loss of prey base due to human influence or natural variation, disease, or increase in contaminant loads), but rather to a cumulative effect of multiple stressors.

The breeding population of glaucous gull (*Larus hyperboreus*) at Bjørnøya, which is home to the largest colony in the Barents area, has drastically declined; by 65% over a 30-year period. Autopsy and chemical analyses of dead and dying birds showed very high levels of chlorinated pollutants in their brain and liver (Sagerup et al., 2009). The elevated chlorinated pollutant levels are likely to have affected the gulls directly (physiological) or indirectly (suppression of condition) (Sagerup et al., 2009) and could be one of the main causes of mortality in glaucous gull.

According to Erikstad et al. (2013), the Bjørnøya glaucous gull population is currently declining at 8% per year. This indicates a median time to quasi-extinction of 19 years for this species. However, a third of the population decline is estimated to be due to the effect of pollutants in the adult population. In the absence of pollution, median time to population quasi-extinction is 50 years (Erikstad et al., 2013). See also Figure 6.4. In 1980 and 2006, total counts indicated population sizes of 2000 and 650 breeding pairs, respectively.

Temporal trend assessment suggests that although several organochlorines are declining in Svalbard glaucous gull samples (Verreault et al., 2010), environmental factors such as atmospheric variability may modulate the influx and thus the food chain transfer of these compounds in the Arctic ecosystem (Verreault et al., 2010). The effects of pollutants are more severe in years when the environmental conditions are worse (Bustnes et al., 2006). Even low levels of pollution in combination with other stress factors, such as food shortage or increased competition for nesting sites, can be critical (Erikstad et al., 2013).

As well as pollution, other explanations for the decline in the breeding population of glaucous gull include reduced prey availability, increasing predation from Arctic foxes (*Vulpes lagopus*) and competition from a growing number of great skua (*Stercorarius skua*) (Erikstad et al., 2013). There is agreement that climate change may result in reduced food availability and in an increase in adverse weather events. The effects of these factors on the glaucous gull population, in combination with pollutants, are not yet clear.

All monitored colonies of Brünnich's guillemot (*Uria lomvia*) at Bjørnøya and Svalbard (Descamps et al., 2013; Fauchald et al., 2014) began to decline during the same period (1994–1998). The annual rate of decline has since varied from 2–5%, and during the past decade Brünnich's guillemot colonies have decreased by about 15-45%. If this trend continues at the same rate, the Svalbard population has an almost one in two chance (43%) of becoming quasi-extinct within the next 50 years and extinct in the next 100 years (Descamps et al., 2013). Further, because there is high synchrony between colonies at west Svalbard, the risk of extinction increases as all of these colonies may crash concurrently (Heino et al., 1997). This decline in population has coincided with a major shift in oceanographic conditions (Descamps et al., 2013). The 1995 shift in the sub-polar gyre and consequent changes in the subarctic waters of the North Atlantic are very likely to have played an important role (Descamps et al., 2013).

Brünnich's guillemots may be vulnerable to pollution and to human impact on the availability of their prey through climate change and overfishing (Fauchald et al., 2014). Since the mid-1980s, levels of polychlorinated biphenyls (PCBs) have been reported for Brünnich's guillemot from Svalbard (Norheim and Kjoshanssen, 1984; Mehlum and Daelemans, 1995). Levels correspond to those for other auk species and are lower than for glaucous gull (Norheim and Kjoshanssen, 1984; Mehlum and Daelemans, 1995; Borgå et al., 2005; Letcher et al., 2010; Verreault et al., 2010). Although lower pollutant concentrations have been measured in Brünnich's guillemot, negative effects on vitamin status have been observed (Murvoll et al., 2007). However, taken in context the findings for glaucous gull indicate that pollutants, even at low levels, act as a stressor enhancing the negative effect of other stressors (Bustnes et al., 2006). It is possible that pollutants are playing a role in the decline of the Brünnich's guillemot population, or are making these birds more vulnerable to other changes related to climate and food availability.

Ivory gull (*Pagophila eburnea*) is the least studied species in the Arctic, with an estimated global population of 14,000 pairs (de Wit et al., 2003). This species has a strong and year-round association with pack ice and its scavenging habits, and thus is vulnerable to changes in sea ice cover and exposure and the accumulation of high levels of organic pollutants, including mercury (Braune et al., 2006, 2007; Miljeteig et al., 2009; Lucia et al., 2015). Global warming and pollution have been identified as the major threats to ivory gull and how this species will progress in the future is unknown.

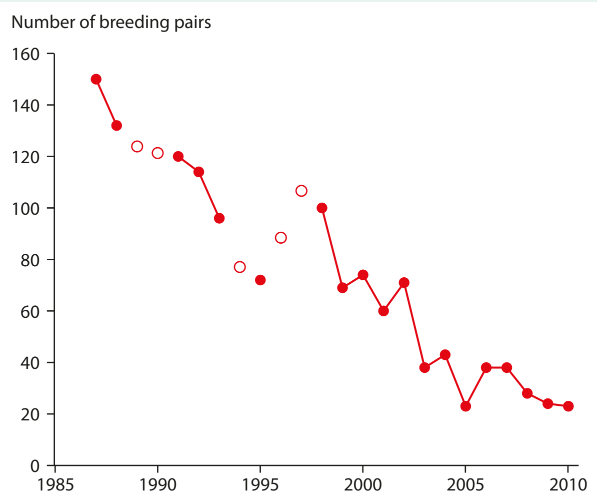


Figure 6.4. Nests occupied by glaucous gull at Bjørnøya between 1987 and 2010 at a study plot. No monitoring was undertaken in 1989, 1990, 1994, 1996 and 1997. Open symbols indicate explorations based on the PROC EXPAND procedure which is a tool to work with time series. Erikstad et al. (2013).

McKinney et al., 2013). Following the seasonally retreating ice edge with much open water north of Svalbard may also be associated with increased mortality, particularly of young cubs that are less able to endure long swims in cold water (Aars and Plumb, 2010; Pagano et al., 2012).

Finally, most seabird species (see Chapter 2) are susceptible to changes in the marine ecosystem, including changes in prey availability related to ocean climate change, and it is likely that these changes will be even more significant in the future. An increase in boreal species and a decrease in Arctic and subarctic species in Norwegian waters are anticipated. According to Fauchald et al. (2015), ecosystem specific changes, possibly initiated by past and present fisheries in combination with climate change, are the major indirect drivers of the observed seabird declines. While human impacts cannot alone explain the recent population declines, they are an important contributor to declining and threatened seabird populations and are therefore especially important to control (Box 6.2).

Patterns of species change in the marine ecosystem are complex because different species are affected differently by warming waters and decreasing ice cover. It is expected that the marine ecosystem of the Barents Sea will exhibit borealization with northward shifts in species over the next few decades. These changes are overlaid by impacts from the oil and gas industry, shipping, and fisheries with further consequences for the fisheries and aquaculture sectors (Sections 6.3.1.4 and 6.3.1.6).

6.2.2.2 Impacts of non-climatic factors

A wide range of industrial sectors are represented in the Barents Sea region, including fisheries, oil and gas production, mining, and shipping (see Chapters 2 and 4, and Section 6.3). Fish products are a major source of animal protein for a significant fraction of the world's population, and large-scale oil and gas development, new mining, and the promotion of the Northern Sea Route as a major transcontinental shipping lane reflect the growing needs of a rising world population and increased energy requirements. The Barents Sea ecosystem has been strongly influenced by fishing (Figure 6.5) and the hunting of marine mammals. More recent human activities include transportation of goods, oil and gas, tourism, and aquaculture. Interest is currently focused on the likely response of the Barents Sea

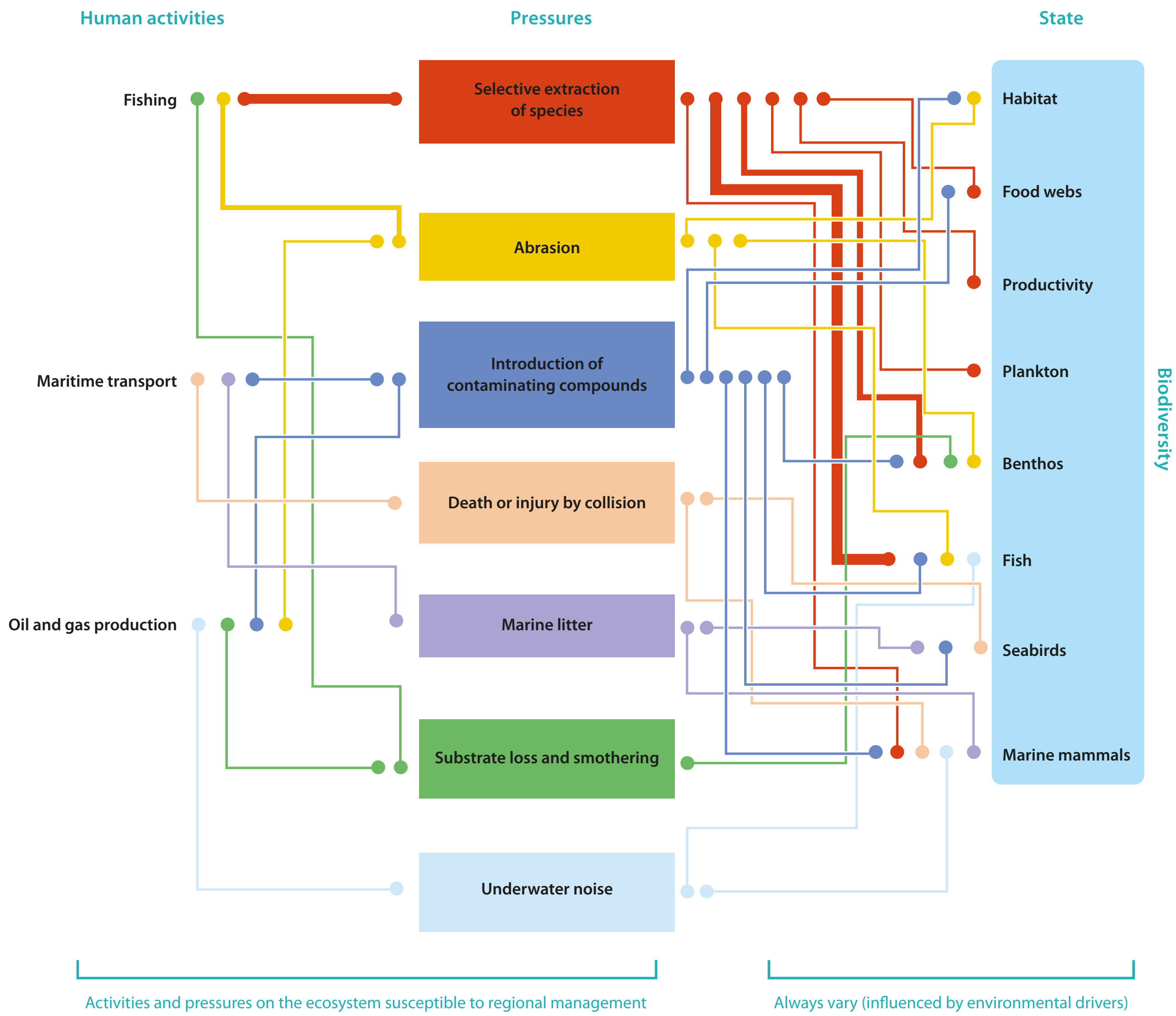


Figure 6.5 Overview of the major regional pressures, human activities, and state of the ecosystem within the Barents Sea. Line width indicates the relative importance of individual links (ICES, 2015b).

ecosystem to future climate change and ocean acidification (Section 6.2.2.1). Non-climatic impacts can be physical (e.g. construction, dredging), chemical (e.g. direct waste discharges, oil spills) or biological (e.g. invasions of non-indigenous species, reef effect around platforms and pipelines). The greatest human impact on the Barents Sea fish stocks, and thus on the functioning of the ecosystem as a whole is from commercial fisheries. Fishing occurs in most of the Barents Sea except the far north. Declining sea ice is opening new grounds for trawling and for transport routes, with potential for impacts (see also Section 6.3.1.4; ICES, 2016).

The influence of land-based industrial activities and river outflow within the Barents area are greatest in the coastal zone. Coastal areas of Russia in the Barents Sea are sub-divided into 16 impact zones and 'hot spots' with elevated levels of environmental risk due to river runoff, air pollution and economic activities in the coastal zone (Evseev et al., 2000).

There is extensive international cooperation on protecting the marine environment and managing maritime activity, including maritime transport, and the use of living resources and petroleum resources. The management regimes, technologies and standards are constantly being developed, to ensure integrated, ecosystem-based management, reduced pollution risk and protection of biodiversity. Overfishing (i.e. removal of commercial species above allowable limits) results not only in unstable fish populations and a corresponding fall in catches, but also in a change in trophic structure at the sub-regional and regional level. Under the current ecosystem-based management regime most commercial stocks are in good shape and fished sustainably, although there are some examples of overfishing from the past in the Barents and Norwegian Seas (Matishov, 2007; WWF, 2007; McBride et al., 2014).

Despite national and international regulations, the discard of non-target species is widespread in many marine areas and can account for as much as 20–80% of the total catch. It is estimated that discard of the main commercial species in the Barents Sea can represent 10–30% of catches (UNEP, 2004; WWF, 2005). Discards may lead to local organic pollution and can affect the natural balance of the marine food web. Concern also extends to non-commercial and protected species, when bycatch endangers those with vulnerable life histories and protected species at low population levels. Even low levels of bycatch mortality may pose a threat to Red List species such as common guillemot (*Uria aalge*), white-billed diver (*Gavia adamsii*), and Steller's eider (*Polysticta stelleri*). There is particular concern about the skates of the Arctic and northern European seas, as their abundance has declined dramatically through incidental by-catch over the past 100 years (Kaiser and de Groot, 2000).

The destructive impact of bottom trawling operations on benthic habitats and communities is a particular concern (see Figure 6.6). In areas of traditional trawl fishing, including the Barents Sea, such operations can cover up to half the sea area and can result in the death of 20–40% of benthic organisms. Trawling impacts are greatest on hard bottom habitat dominated by large sessile fauna (Jørgensen et al., 2015). Direct visual observations in the Barents Sea show vast areas of the seabed exhibit traces of trawling in the form of a trench 2.3 m wide and 0.8 m deep, where the benthic fauna has been virtually eliminated (Aibulatov, 2005). The most vulnerable species include corals, sponges and other components of benthic communities. Such species can take tens to hundreds of years to recover from trawling pressure. The long-term impacts of bottom trawling are now the focus of detailed studies in relation to the development of 'sustainable fisheries' (Lyubin et al., 2011; WWF, 2013).

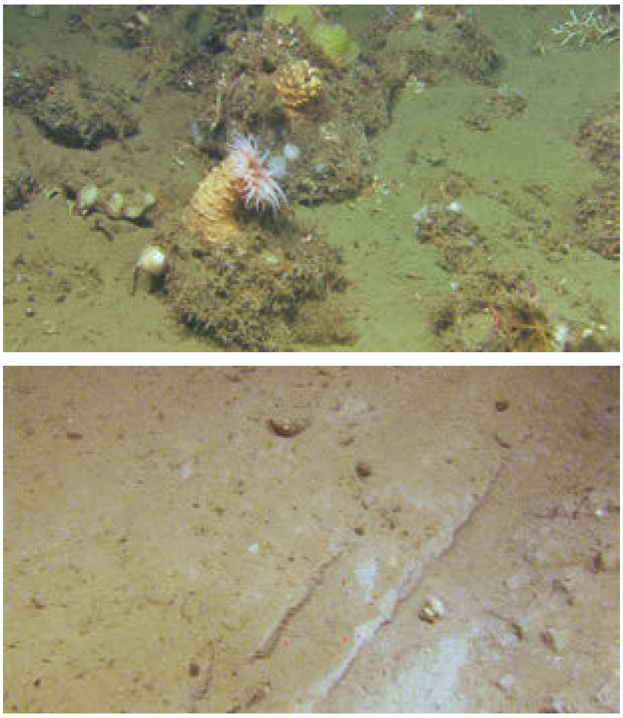


Figure 6.6 Impact of bottom trawling on the benthic community in the Barents Sea: before trawling (upper) and after trawling (lower) (photos Mareano/Institute of Marine Research, Norway).

Aquaculture is increasing along the coasts and in the fjords of northern Norway and Russia, with several commercial fish farms producing salmonids (salmon *Salmo salar*, trout *Oncorhynchus mykiss*) and shellfish. Red king crabs (*Paralithodes camtschaticus*) were released in the past to provide a resource for fishing, but these releases are now regarded as the introduction of an invasive species and the long-term effects on the ecosystem are unknown (ICES, 2016).

Oil and gas activities affect large areas of the sea, the seabed and land (see Figure 6.7). They affect the environment through emissions to air, noise from seismic surveys, and their physical footprint on the seabed. Further development of oil and gas activity will depend on market prices and climate policy, where reductions in oil and gas activity may play a major role in countries' mitigation commitments (see Sections 6.3.3.1 and 6.3.3.2 and Box 6.3).

The biological effects of impulsive noise from seismic surveys on fish and other marine organisms may vary widely – from effects on the orientation and food searching systems (eyesight, hearing, olfaction) to physical damage of organs and tissues, and ultimately death. Zooplankton and fish at early life stages (larvae, fry, and possibly eggs) are particularly vulnerable. Mortality in

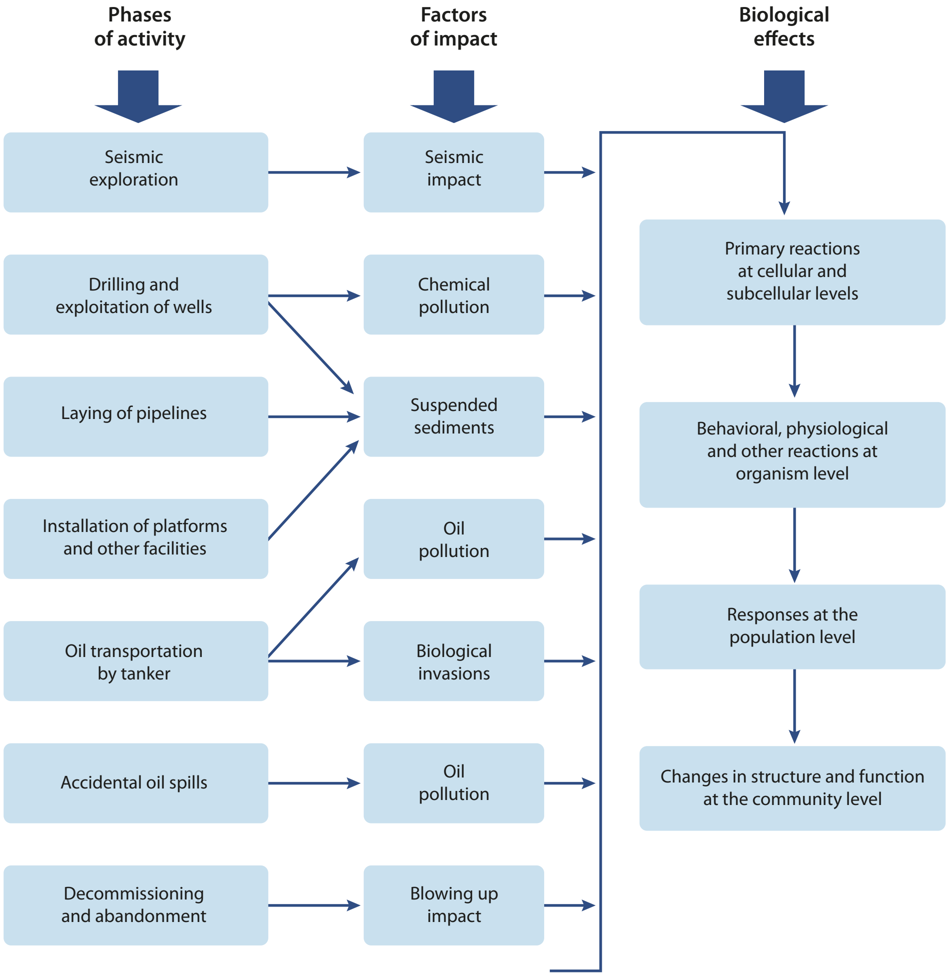


Figure 6.7 Sources of impact and biological responses in marine ecosystems associated with the offshore oil and gas sector.

Box 6.3 Oil spills in the Arctic marine environment

Despite a clear decline in the frequency and volume of oil spills in the marine environment in recent decades, spills continue to accompany offshore activities and to present a serious threat to the marine ecosystem (AMAP, 2007). Analysis of global statistics and a wide range of peer-reviewed literature indicates that:

- Spills during tanker transport represent about 80% of accidental losses
- Small spills, and operational and illegal discharges are the most common sources of long-term oil contamination
- The number of large spills (thousands of tonnes of oil, and with catastrophic consequences) ranges from none to several incidents per year
- There is no correlation between the amount of oil spilled and the level of ecological threat
- The consequences of any one spill depend on the type and properties of the oil released, the nature of the receiving environment and the specific circumstances of the accident.

A recent assessment of oil and gas activity in the Arctic (AMAP, 2010) shows that these global statements would also apply in the Barents area. However, to date, there have been no large oil spills within the marine Arctic. This is mainly due to the still limited extent of offshore operations in the Arctic. Meanwhile, the transportation of oil by tanker through the Barents Sea is increasing rapidly, such that this should now be considered a major potential source of accidental oil spills. In the case that possible Russian offshore oil and gas projects in the Barents Sea are realized, the overall input of oil to marine environment (through accidental and operational losses) could reach 100,000 tons by 2030 (Patin, 2008). Harsh environmental conditions and the presence of sea ice make operations in the Arctic much riskier than further south.

The adverse impacts of oil spills on fisheries fall into two main groups: injury to commercial species and marine living resources, and economic losses. To date, there has been no direct evidence of any detectable impact of oil spills on the stock and biomass of commercial species at population level. Estimates suggest that even for the most pessimistic oil spill scenarios, losses of commercial species do not exceed hundreds/thousands tonnes of biomass and so cannot be reliably identified against the backdrop of very high population variability due to environmental change, natural mortality, and fishing (Patin, 2008).

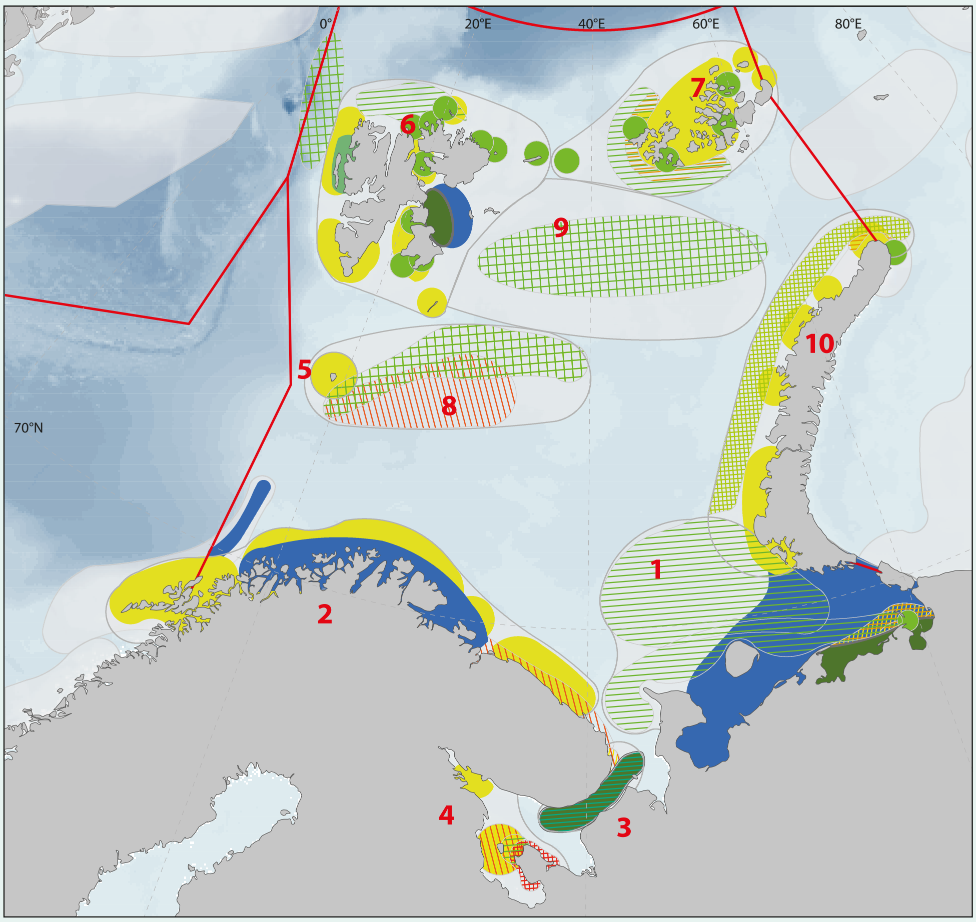
Box 6.4 Areas of heightened ecological and cultural significance

Oil spills are considered to represent the main threat to the marine environment, both from oil and gas activities and marine shipping (AMAP, 2007, 2010; AMAP/CAFF/SDWG, 2013). Tourism and transport represent additional threats. Ecologically important areas that are particularly vulnerable to oil spills and disturbance were identified in the recent Arctic Marine Shipping Assessment (AMAP/CAFF/SDWG, 2013).

Ten areas of heightened ecological significance and sensitivity were defined in the Barents Sea (Figure 6.8). These areas comprised a total of 43 subareas. The subareas were identified based on review and evaluation of data mainly for higher trophic levels (fish, birds, marine mammals). They include areas where large numbers of individuals from one or several species aggregate during migrations or during certain times of the year for purposes such as breeding, spawning, feeding, staging, molting and are thus vulnerable to the impacts of shipping and traffic (oil spills, noise, physical disturbance).

Use of such areas by animals is characterized by a strong seasonality. Sensitivity and increased ecological importance often occur during only one to two months of the year. Sensitivity to oil spills and disturbance from ship traffic varies widely between areas, depending on the density and distribution of the animals. Because ice availability is often the most significant determinant for the presence and high density of animals, the physical boundaries for some areas vary from year-to-year depending on weather and ice conditions. The location of particular areas may also shift in response to climate change.

Owing to expanding marine traffic, knowledge of areas of increased ecological sensitivity must be taken into account in planning for shipping routes as well as other types of transport and for oil and gas development projects. Such information would also be useful in responding to extreme events such as oil spills.



Barents Sea

Mammals:
- Breeding
- Feeding
- Migration
- Molting
- Wintering
- Seal habitat
- Haul-out

Birds:
- Wintering
- Feeding
- Migration
- Molting
- Staging
- Breeding colonies

Fish:
- Spawning

LME (AMSA IIc)

Figure 6.8 Ten areas of heightened ecological significance in the Barents Sea LME (AMAP/CAFF/SDWG, 2013).

the zone of direct seismic impact (up to 5 m from the source) could reach 1% of the local population. Low-frequency seismic impulses travel easily through seawater and can exceed the acoustic background level at a distance tens of kilometers from the source. Due to their reliance on long distance acoustic communication, bowhead whales (*Balaena mysticetus*) are potentially vulnerable to increased levels of ocean noise from ship traffic and oil and gas activity (Reeves et al., 2014). In combination with other sources of anthropogenic sound in the Barents area (especially shipping), seismic surveys could have cumulative effects in marine ecosystems. Acoustic pollution is considered a serious ecological threat in the marine environment at the regional and global level (IWC, 2006; OSPAR, 2009).

The most significant threat to the marine environment from shipping is the accidental or illegal discharge of oil (AMAP, 2007; AMAP/CAFF/SDWG, 2013) (see Boxes 6.3 and 6.4, and Section 6.3.5). Longer navigation seasons (as sea ice declines) could have several consequences for the marine environment, including increased risk of introducing non-indigenous

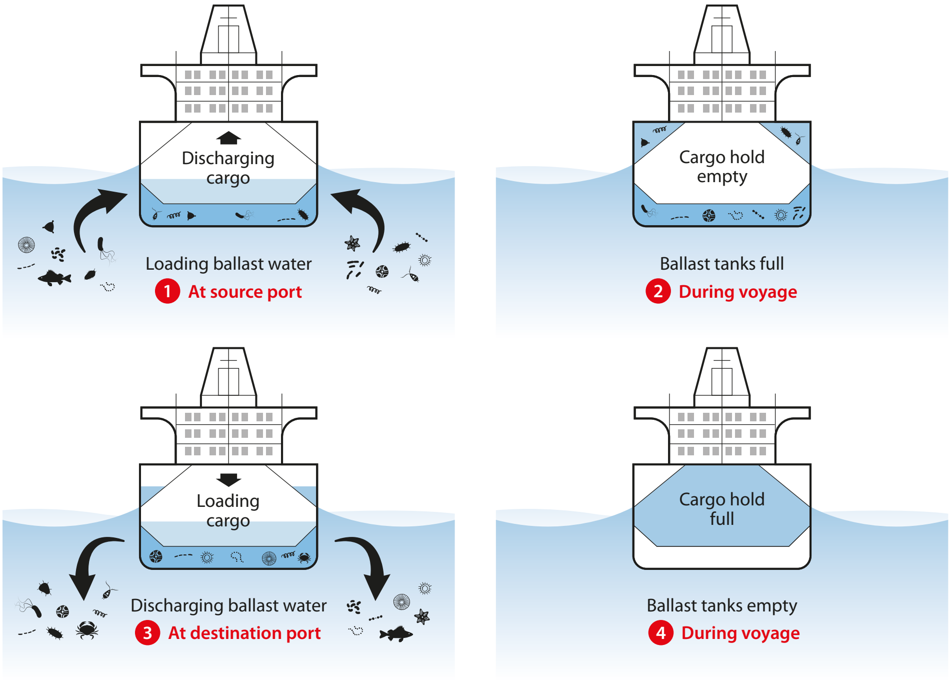


Figure 6.9 The ballast water cycle (International Maritime Organization).

species through ballast waters (Korneev et al., 2015), noise pollution, more ship strikes of marine mammals, disruption of their migratory patterns (AMAP/CAFF/SDWG, 2013) and their potential displacement from preferred habitat. Shipping is a significant source of black carbon emissions in the Barents area (which may help accelerate ice melt) and emissions of sulfur oxides and nitrogen oxides (AMAP/CAFF/SDWG, 2013).

It is likely that Arctic tourism will continue to grow and expand (see Section 6.3.2) in part due to technical advances that overcome constraints imposed by the challenging logistics, remoteness and environmental conditions. However, growth in the tourism sector will remain tied to tourists' financial capacity and general economic situation. More people are likely to spend more time in more locations, leading to increased environmental impact in more areas (AMAP/CAFF/SDWG, 2013). Some of the main impacts – for marine and terrestrial ecosystems – are environmental degradation, damage to ground cover through trampling, disturbance of wildlife, introduction of non-indigenous species and pollution (from visitors themselves as well as from cruise ships) (Norwegian Polar Institute, 2016).

In addition to deliberately introduced species, the Barents area may be subject to unintended bio-invasions due to the transfer of non-indigenous species (mainly as larvae, eggs, and other planktonic forms) with ballast water (see Figure 6.9). Species invasions are related to the volume of ballast water discharged, the frequency of ship visits and the environmental match of the donor and recipient region of the ballast water. Taking into account the increase in shipping through the Barents area, particularly oil transport by tankers (Dalsoren et al., 2007; AMAP, 2010), 'biological pollution' is an increasingly serious threat in the Barents area. Globally, ballast water transfers and invasive species are possibly the greatest environmental challenge facing the shipping industry this century (Raaymakers, 2003).

There are relatively few major sources of contaminants in the Barents area. Industrial point sources mainly result in local pollution. These local point sources include mining, smelters and petroleum activities. Many contaminants undergo long-range atmospheric transport from their sources at southerly latitudes and are deposited in the Arctic (AMAP, 2004). Other transport routes to the Arctic include ocean currents, rivers and biotic transport. Prevailing wind directions and ocean currents transport contaminants to the Barents area from sources in Europe, Asia and North America.

Some of the most widely distributed pollutants in the Barents area are heavy metals, oil, persistent organic pollutants (POPs) and artificial radionuclides. The coastal ecosystems of the Barents Sea are particularly exposed to contaminants. However, even in coastal areas, the levels of chemical pollutants are generally lower than environmental quality standards and lower than in other parts of the Russian or European seas (UNEP, 2004; Matishov, 2007). 'Hot spots', where ecological impacts are most severe, are usually located in coastal areas with a high degree of economic activity. In terms of marine (pelagic) ecosystems, there is no reason to suppose negative effects in open waters due to their low background contamination. Pollutants have been observed to affect seabird populations (see Box 6.2).

There are few trend monitoring stations for POPs and heavy metals in the Barents area. Atmospheric monitoring since the 1990s at the Zeppelin station (Ny-Ålesund, Svalbard) and Pallas station (northern Finland) show declining trends for most legacy POPs (AMAP, 2014a). As an example, although the levels of PCBs have declined at both monitoring stations since the 1990s, the rate of decline appears to have slowed in recent years as the concentrations have become lower (AMAP, 2014a). Concentrations are expected to continue to decline, but sea-ice retreat may result in the re-emission of PCBs previously deposited on sea ice, for example for lighter congeners. Concentrations of polybrominated diphenyl ethers (PBDEs; brominated flame retardants) have also declined (2006–2012) at Zeppelin and Pallas (AMAP, 2014a). PCBs and

PBDEs are both listed under the Stockholm Convention and so concentrations should continue to decline.

Of the heavy metals, mercury has received most attention in the Arctic. Over the past 150 years, mercury levels in the Arctic have increased roughly ten-fold. Most mercury in biota is now of human origin (AMAP, 2011). Most of the time series showing increased concentrations are for marine species, with no significant recent increases detected in terrestrial animals (AMAP, 2011). For example, total mercury showed no significant trend in reindeer from Abisko (northern Sweden) over the period 1980–2005 (AMAP, 2011).

Organic contaminants bind to fat and Arctic species typically build fat reserves to protect them from the cold and provide a source of energy when food is scarce. When the fat is consumed, the pollutants are released into their blood stream, perhaps having damaging effects even though the air and the water are cleaner in the Arctic than further south.

Future trends of mercury in Arctic biota, at least from the medium term onwards will depend on the implementation of the Minamata Convention and thus on global emissions. Emissions scenarios project that if currently available emission reduction measures are implemented globally, then mercury deposition in the Arctic could decrease by 20% by 2020 relative to 2005 levels (AMAP, 2011).

The limited amount of human development in the Arctic has traditionally meant that local sources of chemical pollution were low. However, many new chemicals are found in consumer products such as electronics, clothing, furniture and building materials, as well as personal care products and pharmaceuticals. These chemicals of emerging Arctic concern include siloxanes, parabens, flame retardants, and per- and polyfluoroalkyl substances (PFASs). Thus, their existence in the Arctic may be due not only to transport from long-range sources, but also to local sources such as community waste sites and sewage outflows (AMAP, 2017).

Levels of anthropogenic radioactivity in the Arctic attributable to previously identified releases are low and generally declining (AMAP, 2015b). This decline is expected to continue.

6.2.3 Human health

Human health and wellbeing are defined as mental, physical, spiritual and social wellbeing with the absence of disease and infirmity. Cultural and social practices are critical contributing factors to human health and wellbeing (Larsen and Huskey, 2010). Healthy living means, at a minimum, clean water, food and air, but also a safe and secure life for the individuals, groups and communities. Housing conditions and food and water security are important in everyday life, but (as an example) the quality of tap water and well water are not monitored regularly in all municipalities in the Barents area (Nilsson et al., 2013).

To understand the impacts of climate change on rural and urban populations, it is necessary to discuss factors such as contaminants and radioactivity; social, cultural, political, and economic factors; and poverty and lack of health and other services, especially in indigenous communities (Abryutina, 2009; AMAP, 2009; Ford and Furgal, 2009; UNEP/AMAP, 2011). Changing temperatures may directly affect community infrastructure (e.g. water treatment, sewage treatment, power supply) and community food and drinking water security. But the combined effects of warming, pollution and zoonotic diseases also represent a significant risk to the security of subsistence food and water supply (AMAP, 2015a).

6.2.3.1 Indigenous and local peoples' health

Around 2% of the Barents Region population belongs to indigenous groups such as Sami, Nenets, and Vepsians. The patterns of demographic and health development of indigenous peoples in the Barents Region differ from those of the majority population, usually having a weaker health status. Nenets and Vepsians have a lower health status than that of the non-Russian North. Disease mortality of Finnish Sami was lower in the 1980s than for the general Finnish population, but during the past 30 years has increased to reach national/regional values (Soininen, 2015). As is the case for other indigenous and local populations in rural parts of the Barents area, mortality from accidents, violence and suicide in Sami is higher than national average values.

Indigenous reindeer herders have a higher prevalence of suicide and mental health disorders than the national average over recent decades (Silviken, 2009; Kaiser and Renberg, 2012; Omma et al., 2013), especially for young males in Fennoscandia and Russia. This is considered to be a consequence of interactions between climate change and socio-economic change (Daerga et al., 2008; Kaiser et al., 2013; Pogodaev et al., 2015). Efforts to prevent marginalization of children and youth are important, and it is crucial to establish early warning signs of mental illness.

6.2.3.2 Disease, and food and water security

One of the most important health impacts of climate change may be changing exposure to viruses, bacteria, parasites and contaminants. Infectious and vector-borne diseases, such as tick-borne encephalitis and Lyme disease, are spreading northward (Revich, 2008; Ogden et al., 2010; Tokarevich et al., 2011). The rapid thermal degradation of permafrost presents an increasing risk of hazardous substances and viable spores of highly virulent infections (anthrax, tuberculous) being remobilized from neglected cattle burial grounds and waste disposal sites (Revich and Podolnaya, 2011). Extreme weather events (floods, storms, wildfires) may contribute to further spread of disease through the destruction of infrastructure, buildings, roads and waste systems.

One impact of climate change is remobilization of legacy POPs (such as from ice, thawing permafrost and waste disposal sites) and Arctic residents are also likely to be exposed to higher levels of contaminants and radioactivity (UNEP/AMAP, 2011). This is especially the case for local/traditional foods. Food security has become an increasingly serious issue for many Arctic residents, especially indigenous peoples, owing to a combination of climate, development, and contamination issues (AMAP, 2015a). The global ban on some POPs and mercury, means the remobilization of legacy POPs should be seen in conjunction with declining long-range transport of contaminants to the Arctic.

Food costs in the Arctic are high, comprising 23–43% of household income in the Russian Arctic (Dudarev et al., 2013), and climate change means many wildlife species consumed as country foods have disappeared (Huntington and Fox, 2005). This is a particular issue for indigenous peoples who are tightly linked to the environment through their traditional consumption of local subsistence foods. It is also well known that indigenous communities are highly exposed to certain contaminants through their traditional subsistence diet (UNEP/AMAP, 2011; Larsen et al., 2014).

High levels of cadmium, nickel and copper have been found in mushrooms and nickel in wild berries in the Pechenga region (Dudarev et al., 2013). Elevated levels of dioxins and PCBs have been measured in the meat of reindeer calves grazing natural pastures in Finland (Holma-Suutari et al., 2014).

If communities are forced to abandon traditional hunting or fishing due to climate impacts or due to contamination of subsistence foods, this will increase their dependency on store-bought foods which are often expensive and less healthy, in turn increasing the incidence of modern diseases such as diabetes, cardiovascular disease, dental problems, and obesity (Armitage et al., 2011; Brubaker et al., 2011; Larsen et al., 2014).

Household water in six cities of the Murmansk region (Nikel, Zapolyarny, Olenegorsk, Montchegorsk, Apatity, Kirovsk) contains high levels of heavy metals. Studies also show that some cities in this region lack sanitary protection zones for water sources and that most cities require preliminary water processing; water disinfection involves only chlorination (Dushkina and Dudarev, 2015). High levels of aluminum have been found in drinking water in Kirovsk and nickel in Zapolarny and Nikel. Water taken from springs in the Pechenga region contained relatively low levels of metals, except for strontium and barium (Dushkina and Dudarev, 2015). Across the Arctic as a whole, including the Nordic countries the greatest concern is an increase in waterborne infections (Parkinson et al., 2014).

Climate-change related impacts include an increasing number of days with extreme temperatures and anomalous cold spells and heat waves, in addition to more frequent floods and storms (Revich, 2008; Revich and Shaposhnikov, 2012) associated with a higher risk of flooding capable of destroying infrastructure (building, roads, bridges, ferries, waste systems). This could lead to difficulties in ensuring safe or dependable transportation, security of food and drinking water, and the provision of critical services and medical aid. People may be forced to leave some areas due to infrastructure problems (AMAP, 2015a).

There are some positive effects of climate change, such as fewer cold-related deaths in some areas (Revich, 2008). However, if temperatures rise substantially, some population groups considered to be at particular risk, such as children and the elderly, may experience health difficulties (such as breathing, excessive sun exposure, skin disease). In northern Sweden, a 1°C increase in temperature in the period 1991–2007 led to a steep rise in the number of cases of non-fatal heart attacks (the Northern Sweden MONICA Project) (Eriksson et al., 2011).

Higher temperatures and drought are responsible for increased wildfire risk in the Barents area. For example, the number and size of the areas affected by wildfires in Arkhangelsk County have both increased over the past ten years. City dwellers in the Barents area are expected to experience increasing health problems through significantly higher levels of air pollution, especially concerning microscopic atmospheric particles (such as PM_{10}) (Revich and Shaposhnikov, 2012).

Many different factors represent a risk to future sustainability, especially for small rural communities. The combined effects of these factors create the need for good community-based adaptation planning. It is therefore important that communities in the Barents area develop monitoring and adaptation strategies to meet these risks, for the marine, terrestrial and freshwater environments.

6.3 Societal and economic change

6.3.1. Primary industries

Primary industries and livelihood activities are particularly sensitive to cumulative impacts, of which climate change is but one. The consequences of their combined impacts vary along multiple dimensions. It is therefore necessary to consider the interaction between the different drivers of change and the multiple stressors when assessing consequences for society.

6.3.1.1 Herding, hunting, fishing and gathering

Herding, hunting, fishing, and gathering are strongly related to the northern identities in the Barents area. These widespread activities represent sources of monetary income and have cultural, social, economic, recreational and dietary value (Nuttal et al., 2005; Larsen and Fondahl, 2014, Chapters 2, 7 and 9). Culture is both affected by the associated impacts of climate change on livelihoods and is a significant resource for addressing the consequences.

Globalization and a continuous quest for Arctic resources (petroleum, minerals, wood), infrastructural development, development of hydropower and wind parks, peat harvesting, and tourism (see Chapter 2) have caused fragmentation of the land used as the basis for the traditional and recreational activities and lifestyles in the Nordic countries (Jaakkola et al., 2013; Herrmann et al., 2014; Skarin et al., 2015). In Russia (Nenets Autonomous Okrug (AO) and Yamalo-Nenets AO), the oil and gas industry has had significant local impacts on pasture land and reindeer herding, by disrupting reindeer migration routes with roads and pipelines. Rapid industrial development and associated social change are major concerns in the Yamalo-Nenets AO (Forbes and Stammler, 2009).

Warmer and wetter winters have impacted reindeer herding by reducing the availability of pastures and increasing reindeer mortality in the Nordic countries (Tyler et al., 2007; Vuojala-Magga et al., 2011), Svalbard (Hansen et al., 2014) and Russia (Forbes and Stammler, 2009; Bulgarova, 2010) (see Chapters 7 and 9). In addition to several land-use factors, high long-term grazing pressure combined with lack of or poor seasonal pasture rotation have significantly

A Finnish reindeer herder in northern Finland

reduced ground lichens in reindeer pastures in Finland (Kumpula et al., 2014). Reduced availability of winter forage due to low lichen biomass combined with ice-locked pastures cause herds to 'break loose' to find forage. This has major consequences for the economics of reindeer herding through increased working hours, and the need for supplementary feeding and transportation. Challenging snow conditions have also increased reindeer losses to large carnivores (Turunen et al., 2016). Snow storms, strong winds, flooding and avalanches have dramatically impacted reindeer herding in north-west Russia (Bulgarova, 2010). Warming and longer growing seasons (see Chapter 4), mean that lichen-dominated mountain heaths will be gradually replaced by shrubs and forest vegetation (Turunen et al., 2009). The increased height and abundance of shrubs are likely to reduce visibility to the extent that it will prevent moving the herds (Forbes et al., 2010). The vegetation response to climate change varies from one region to another partly due to the interaction of many abiotic and biotic factors. The mountain birch (*Betula cordifolia*) forests have considerably reduced in several regions owing to the effect of geometrid moths (autumnal moth *Epirrita autumnata* and winter moth *Operaphtera brumata*; see Chapter 9 on moth outbreaks in Finnmark, Norway) followed by intensive reindeer grazing. The combined effect of these two factors (inhibiting forest regeneration) has been stronger than increased forest growth due to warming (Chapin et al., 2004; Rybråten and Hovelsrud, 2010).

Cumulative impacts of globalization and global resource use, climate change, large carnivores, industrialization, urbanization, pollution, institutional barriers and limited possibilities for local people to influence decision-making are expected to influence herding, hunting, fishing and gathering, consumption of local foods and income from their sale (Jansson et al., 2015). These traditional and recreational activities and lifestyles are directly affected by changes in habitat quality and the range, abundance, productivity and species composition of communities. For example, hunting has been adversely affected by the decreased abundance of game birds over recent decades in the Barents area due to loss and fragmentation of habitats, and climate change (BirdLife International, 2015). Conversely, many game species that have spread or been deliberately introduced into the Barents area from the south will benefit from climate change. For example, models suggest further range expansion of moose to the north (Jansson et al., 2015).

In addition to the interlinked consequences of changing environmental and socio-economic conditions, key future concerns for herding, hunting, fishing and gathering activities in the Barents area warranting attention by decision-makers and local communities include local and long-range transported pollution, which may prevent local access to high-quality habitats and decrease food quality (Herrmann et al., 2014; Holma-Suutari et al., 2014). The introduction of invasive species to the Barents area can present both a threat (via ecosystem impacts) and a gain (as a source of revenue for local people) (Britayey et al., 2010). New threats to traditional and recreational activities and lifestyles may also arise in the form of heat stress, climate sensitive infections and disease, parasites, and insect harassment due to warming (Härkönen et al., 2010; Jansson et al., 2015).

6.3.1.2 Agriculture

Under the present climate, the main limiting factor for agricultural crop yield is the short growing season (Himanen et al., 2013 see also Chapters 2 and 9). In addition, perennial crops have overwintering challenges due to icing and lack of snow cover (Rapacz et al., 2014). In the future, it is expected that winter temperatures and precipitation will increase, snow-cover duration will be shorter, and ground frost will occur less often (see Chapter 4). A warmer and longer growing season should enable the cultivation of more productive crops and cultivars of vegetables, potatoes and forages than at present (Höglind et al., 2010; Uleberg et al., 2014). However, despite the warming, because day length will stay the same, autumn day length will remain a limiting factor (Peltonen-Sainio et al., 2009; Thorsen and Höglind, 2010a).

Perennial leys are the basis of agricultural production in the Barents area, which means the grass varieties must be adapted to varying conditions and locations (Bjerke et al., 2015) (see Chapter 9). However, weather-driven interannual variation in the quantity and quality of grass yields will continue to lead to substantial variation in the economic output of forage-based dairy production (Kässi et al., 2015). In areas of thick snow and thin ground frost, the main reason for winter damage is low-temperature fungi (Matsumoto, 2009). Damage caused by low-temperature fungi will decrease as ice encasement, cold and ice rind may increase. Bjerke et al. (2015) predict that conditions of low snow and low soil frost combined with ground ice, which result from warming events, will become the dominant snow season type in upland areas of sub-Arctic Norway. In the lowlands the frequency will decrease (see Chapter 4). At the same time, long warm autumns weaken winter hardening and predispose grasses to winter damage (Jørgensen et al., 2010). Warm spells during winter may increase the risk of frost damage (Kalberer et al., 2006; Höglind et al., 2010; Jørgensen et al., 2010). Thorsen and Höglind (2010b) have suggested that for most locations, the risk of frost-related injury during the hardening, winter and spring growth periods will reduce according to existing scenarios.

Climate change is highly likely to result in yield increase due to the possibility for more than one harvest of crops. But as Höglind et al. (2013) pointed out, when simulating potential future yield of the grass timothy (*Phleum pratense*) under climate change, their calculations do not provide any information about whether the projected additional harvest will also be achievable in a practical sense. One consequence of higher temperatures during growing periods could be a reduction in daily plant growth (Hannukkala, 2002; Hakala et al., 2005).

Hildén et al. (2012) argued that technological advancements and improved understanding should be considered to guarantee ecological and socio-economic sustainability. Overall, agriculture is important for the economic and social viability of rural areas. Comparing Finnish and Norwegian agricultural policy, Sipiläinen et al. (2014) found evidence that the stronger liberalization of agricultural policy in Finland has provided greater flexibility for farmers to respond to change (see Chapter 9 on the importance of flexibility). Farms that have diversified outside conventional agriculture have the economic and financial means to drive development in rural areas (Hansson et al., 2013).

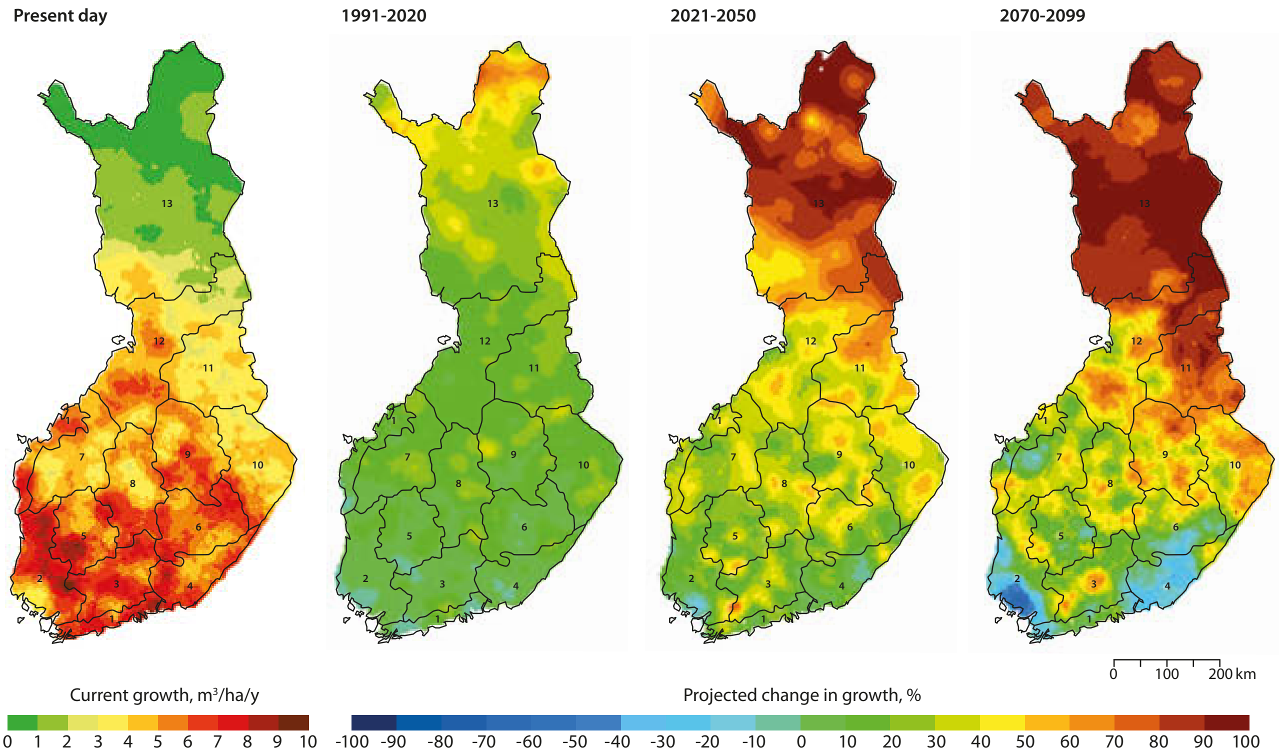


Figure 6.10 Integrated growth of Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*) and birch (*Betula* spp.) under the current climate and under projected future climates in Finland. From left to right: total current growth and percentage change in total forest growth for 1991–2020, 2021–2050 and 2070–2099. The numbers on the maps refer to the Finnish Forest Centres. Kellomäki et al. (2005).

6.3.1.3 Forestry

Extension of the treeline to higher latitudes and higher altitudes is projected to occur over the next 100 years in the Barents area under the warming climate (Wolf et al., 2007; Roderfeld et al., 2008; Hickler et al., 2012) (see Section 6.2.1.1). As a result, forest productivity is projected to increase in northern parts of Europe (Kellomäki et al., 2008; Reyer et al., 2014). As an example, forest growth in Finnish Lapland may double by the end of the century compared to the current climate (Figure 6.10). Recent observations of changes in forest growth support these projections. In Finnish Lapland, annual forest growth has shown a significant increase since the early 1960s and about 40% of this increase is attributable to the increase in annual growing degree days, which have increased by over 20% since early 1960s (Kauppi et al., 2014).

Increased forest growth will enable sustainable forest management in areas where it is not currently possible. Sustainable forest management in turn allows enhanced timber production for industry (e.g. sawmills and pulp) and renewable energy production. It not only provides new opportunities for timber-based livelihoods further north, but also contributes to climate change mitigation by sequestering carbon in timber (Roderfeld et al., 2008; Lundmark et al., 2014). Timber production can be further improved by silvicultural practices, such as soil preparation, seeding, planting, and fertilization.

However, shorter and warmer winters in the future, leading to a shorter period of ground frost, will make harvesting more difficult and more expensive especially in peatlands (see Chapter 9). The extent to which forest damage by pests and diseases is likely to increase under a warming climate is unclear. As is the extent of snow damage, resulting from warm spells and increased humidity during winter. Variable temperature, with warm spells and rain-on-snow events, are likely to change the snow structure and create ice layers, affecting winter conditions for tree seedlings. Multiple land use needs in the north, such as tourism, reindeer herding and use of non-wood forest products (berries, mushrooms, game) taking place in the same area as more intensive forestry could result in conflict (see Chapters 2 and 9).

To reach the increased forest growth predicted by models, such as that of Kellomäki et al. (2005, 2008), requires active forest management (Chapter 9). Unlike Scandinavia, where for decades timber production has been ensured through intensive forest management based on tree breeding, tree species selection, planting or seeding, and soil preparation, in Russia timber production has mainly relied on the vast forest area. Russia has over 20% of the world's forests (FAO, 2010), which has in many places made it unnecessary to actively manage forest and still produce the timber required. However, the spatial distribution of goods and services that forests provide are not adequately mapped and communicated among stakeholders to secure sustainable use of Russian forests (Elbakidze et al., 2012). In addition, there are also major problems in timber harvesting due to the poor condition of the road network in Russia, especially the lack of all-season roads. The low-level of technology used by the logging companies causes low annual yield in timber harvesting (Karvinen et al., 2006). Because there are several knowledge gaps concerning the spatial structure of Russian forestry, it is difficult to predict whether a warming climate will drive a similar increase in forest growth in Russia as predicted for areas of more intensive forest management. Furthermore, a changing climate could aggravate problems posed by poor infrastructure, such as warmer winters degrading the condition of forest roads, which can increase pressure to harvest timber in easily accessible areas. The development of biofuels, changing land use, forests as carbon stores, and change in policy will affect how forests are managed.

6.3.1.4 Ocean fisheries

Cod, haddock, saithe, herring, and capelin are the most important fish species in the Barents Sea and adjacent waters. The North East Atlantic cod stock is the world's single largest cod stock and has had a Total Allowable Catch (TAC) quota of around one million tonnes. Although the agreed TAC was reduced to almost 900,000 tonnes in 2016 and the International Council for the Exploration of the Sea (ICES) has recommended that the cod quota for 2017 be set at 805,000 tonnes (the same as recommended for 2016[12]), the economic value and contribution to the countries involved (mainly Norway and Russia) is still significant.

In terms of biological productivity as a whole, there has been a significant increase in annual net primary production across the Arctic Ocean; of roughly 30% during the period 1998–2012 (Frey et al., 2015). Productivity was particularly high on interior shelves near the shelf break (and to a lesser extent on inflow shelves), where sea-ice declines are accompanied by enough upwelled nutrients to support production (Arrigo and van Dijken, 2015; Falk-Petersen et al., 2015). A key issue is how the observed and projected rise in temperature will further influence biological productivity. The spawning stock of North East Atlantic cod has been at a very high level for several years (Gradinger, 2015). Rising temperatures and changing patterns of wind and precipitation are likely to lead to changes in the hydrographic properties of the ocean, as well as to changes in vertical stratification and ocean circulation (see also Chapter 4). An increase in biomass may stimulate primary and secondary production for some commercial fish stocks and new mixes of species may become targeted because of an increase in open water during summer (McBride et al., 2014). The key zooplankton species (*Calanus* copepods in the Arctic) play a crucial role in Arctic waters. Another species of importance for the higher-level fish stocks in the Barents Sea is capelin. According to Hopkins and Nilssen (1991), capelin is a major forage species in several highly exploited boreal shelf ecosystems, such as those off Newfoundland, Iceland, and in the Barents Sea. Their biological status will affect the future productivity of fishery species and fisheries. There is little evidence that a rise in ocean temperature and other factors caused by climate change have had an adverse impact on these fundamental trophic structures.

[12] The Joint Norwegian-Russian Fisheries commission will agree on a TAC for 2017 at their annual meeting in October 2017. It could be expected that the agreed TAC will be set along the 2016 considerations – that is closer to 900,000 tonnes.

In addition to the biological factors that currently have a positive effect on ocean productivity, the joint Norwegian–Russian fisheries management regime has had a significant positive influence on stock size and development. The Joint Norwegian–Russian Fisheries Management Commission was established in 1976 to manage the joint stocks in the Barents Sea, mainly cod, haddock and capelin, but also other commercially important fish stocks. The Commission decides on the TAC and the distribution of quotas among the involved parties (Norway, Russia and third party countries). The Commission is also involved in other aspects of fisheries regulation, and since 1993 fishery control has become an almost equally important issue. In 2002, Norway and Russia agreed to establish a new tool for sustainable precautionary management; a guideline that restricted the changes in TAC to about 10% per year. The new principle for sustainable management showed an improvement compared to the joint management regime (Hønneland, 2007). It is important to emphasize that the Joint Fisheries Commission is responsible for all fish stocks in its area of jurisdiction. This co-management regime is considered to be one of the main reasons for the healthy state of fish stocks in the Barents Sea and adjacent waters. The Joint Fisheries Commission has been broadly successful in establishing and maintaining a fisheries management regime that is both ecologically and economically sound.

The fishery in the Barents Sea is of significant economic importance for the parties involved. The TAC for cod alone constitutes an estimated firsthand value of more than NOK 20 billion annually. Value added activities and support industries and other derived activities are also of significant economic value. Considering the high economic value of the fishery, it is useful to examine the impacts of different scenarios of future climate change as a basis for future research.

- In the first scenario, the fisheries management and harvesting strategy chosen by the fishers is more important for the fate of the stocks than altered oceanographic conditions, even though a warmer Barents Sea is likely to increase biomass variability (Eide, 2008). This scenario (i.e. management more important than climate change effects) rests on a critical precondition: that the joint Norwegian–Russian Fisheries Commission pursues the same path as that followed for the past ten years. During this period the main fish stock – the NE Atlantic cod stock has grown. The sharing of a common good is generally easier if the total to share is growing.
- If the fish stocks move eastwards into the Russian Economic Zone (REZ) – scenario two – there might be a discussion of how the model for dividing the TAC should or could be altered. There are, however economic incentives among the Russian fishers operating in the Barents Sea to take a relatively large share of their catches outside of the REZ (e.g. Nilssen, 2003). But a scenario in which the current joint fisheries management breaks down and results in severe overfishing of one or several stocks is unlikely.
- A third scenario is that higher sea temperatures may lead to instability in the biomass, which may in turn cause an unforeseen drop in the production of one or more species at lower trophic levels (see Link and Tol, 2006). It is also expected that cold-water adapted fat salmonid fish species will gradually be replaced by lean cool-water adapted percid fish, and finally by warm-water adapted cyprinid fish (Wrona et al., 2013). This would lead to changes in fisheries practice and management and in fish consumption.

6.3.1.5 Freshwater fisheries

The extreme seasonality of environmental conditions has a strong influence on the hydrology and ecology of freshwater ecosystems in the Arctic (e.g. Reist et al., 2006; CAFF, 2013a,b). The Barents area is home to some of the most abundant Atlantic salmon (*Salmo salar*) populations in the world, including large river systems in Norway, Russia and Finland, where the salmon stocks are supporting major recreational fisheries and related businesses (Whoriskey et al., 2000; Niemelä et al., 2004). Some of the large lake basins in the Barents area are important for local fisheries. A good example is the large Lake Inarijärvi (Finland), which supports significant recreational and commercial fisheries with an annual catch of between 150 and 180 tonnes in recent decades (Niva et al., 2015). As biodiversity forms the basis of the ecosystem services that the fish populations provide, care should be exercised in safeguarding these resources from overexploitation, habitat degradation, and introgression from farmed fish (e.g. Erkinaro et al., 2010; Schindler et al., 2010).

Freshwaters are particularly vulnerable to climate change because species have limited ability to disperse as the environment changes, and water temperature and availability are highly climate-dependent (Woodward et al., 2010) (also see Section 6.2.1.1). In addition, projected shifts in climate forcing variables such as temperature and precipitation are highly relevant to Arctic freshwater ecosystems. The impacts of changing climate are particularly complicated for anadromous fish species, which must cope with a variety of habitats and conditions during their lifecycle (Heino et al., 2016). In a recent analysis of timing of salmon smolt migration throughout the North Atlantic, Otero et al. (2014) found that the start of migration has occurred 2.4 days earlier per decade since the 1960s, associated with changes in temperature. This change is likely to be having a profound effect on salmon growth and survival (Otero et al., 2014).

In northern lakes, climate change has extended the open water period with possible positive effects on primary production and fish biomass (Reist et al., 2006), but autumn-spawning species may suffer from delayed cooling through mismatch between development and environmental phenology. Freshwater fisheries may therefore gradually shift from autumn-spawning cold-water species to spring-spawning species (e.g. Ficke et al., 2007; Heino et al., 2016).

Freshwater aquaculture is a minor activity compared to the volume of marine aquaculture in the Barents area (see Section 6.3.1.6). In Finland, for example, aquaculture mainly produces fish for stocking into regulated waterbodies (Saarni et al., 2003). However, fish farming has recently increased in the Barents area, especially in Russia, although increasing aquaculture in the fragile Arctic environment may be contradictory from the perspective of environmental policy (Herzon et al., 2014). Since aquaculture concentrates on cold-water species, it is sensitive to the impacts of climate change; both positive (longer growing period) and negative (higher summer temperature) influences may occur (Ficke et al., 2007; Cochrane et al., 2009). Future development in aquaculture may need to adapt to rising temperatures by adjusting rearing densities, feeding strategies and water supplies (e.g. Cochrane et al., 2009).

The complex direct and indirect influences of climate change, and the currently limited understanding of the interactions of freshwater fish and climate, reduces predictive ability and mostly precludes quantitative estimation of climate change effects on northern fish populations (Reist et al., 2006). Studies coupling variation in fish populations to putative environmental drivers should be conducted for best assessment of future climate change effects on Arctic freshwater fishes (Reist et al., 2006). Because climate change cannot be stopped in the short term, both proactive management strategies (such as removing other stressors from freshwater systems) and practical mitigation actions will be necessary to sustain northern freshwater fisheries and aquaculture (e.g. Ficke et al., 2007).

6.3.1.6 Marine aquaculture

The Norwegian marine aquaculture industry is relatively new, starting in the early 1970s on the Norwegian west coast. In the early days of the Norwegian farming of salmonids in marine waters, it was farming of rainbow trout (*Oncorhynchus mykiss*) that generated the main volumes. After about ten years of extensive 'trial and error' among local enthusiasts, combined with a major research effort, Atlantic salmon took the lead as the main type of farmed marine salmonids. The farming of Atlantic salmon has faced technological, biological and market-related challenges. The positive trend in production volume has, notwithstanding, continued throughout this period (see Figure 6.11).

The salmon farming industry has gradually shifted geographical focus from the south-west and central Norwegian coastline – where the main areas of production were initially located – towards the northern areas of Norway. Between 1998 and 2015 the total production of farmed fish in the three northernmost counties of Norway increased from ~27% of Norway's total to ~40%. There are various reasons for this trend, including warmer water along the south and central west coast of Norway and vast unexploited sheltered sea areas in northern Norway. Increasing sea temperature is not favorable for salmon aquaculture for several reasons, including the spread of viral disease outbreaks (pancreas disease, infectious pancreatic necrosis), heart and skeletal muscle inflammation, and cardiomyopathy syndrome (Stene et al., 2014; Taranger et al., 2015). Warming is a significant driver for moving aquaculture activities towards areas with lower sea temperatures and with sufficient water flow. Northern Norway is an area with both qualities, and with relatively good infrastructure throughout the entire salmon farming value chain. The role and influence of the Arctic temperature regime for salmonid aquaculture needs more scientific study and documentation. It is clear that the northern areas of the Norwegian coastline represent an attractive area for future growth in the traditional salmon farming industry. Another option in the future development of the industry is the potential for developing the large High Seas structures for Atlantic salmon farming. These structures are supposed to be located outside the traditional coastline area and will face other challenges.

6.3.2 Tourism

Tourism is considered to be one of the four main drivers of economic growth in the Nordic countries (Anon, 2015). Growth in the Arctic tourist industry will continue with an increasing emphasis on large cruise vessels and land-based summer and winter tourism (Nordregio, 2011). Both winter tourism and cruise ship tourism will be strongly affected by climate change.

Over the years, access to the Arctic has increased through improved transport technologies, and as a result Arctic tourism has developed substantially both in terms of the number of tourists and of geographical and seasonal reach (Huntington, 2013). Hence, tourism is an integral part of local economies, and has become an alternative source of income for many local communities and gateway cities, enabling a positive interaction between new economic opportunities and traditional activities (e.g. Hovelsrud et al., 2011). In both Finnish and Swedish Lapland, winter tourism has been important for two or three decades (Brouder and Lundmark, 2011; Saarinen, 2014). In northern Norway, summer tourism has been the main focus but the region is increasingly expanding into winter tourism, and has also begun winter tourism research projects in order to attract winter tourists (e.g. Research Council of Norway,

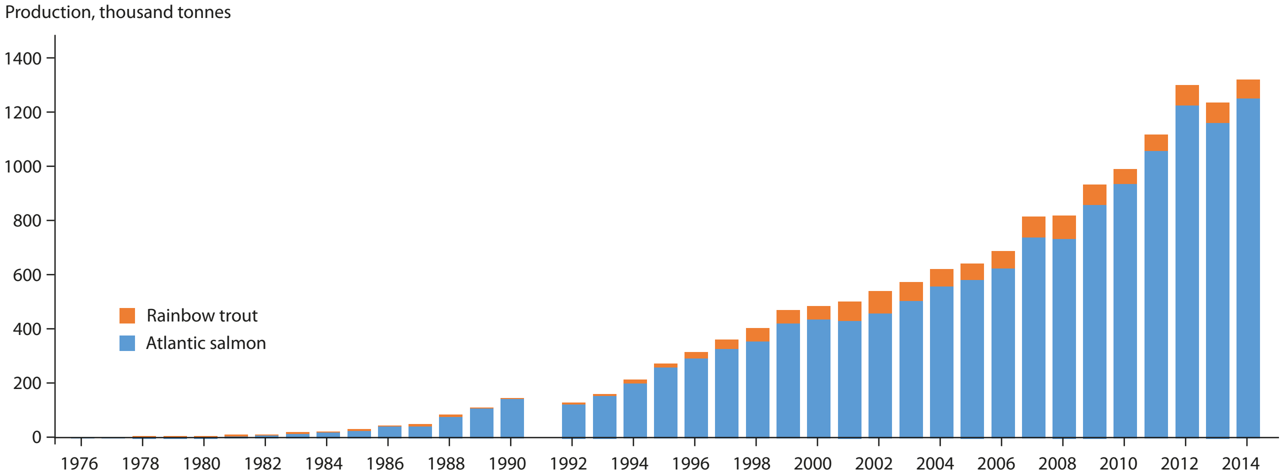


Figure 6.11 Production of farmed salmonids in Norway (Statistics Norway).

2013). The growing importance of winter tourism is one of the future trends in the Barents area. Tourism development has a positive impact on the proportion of women in some localities as the tourism industry attracts female workers. In Finnish Lapland, big ski resorts have more women and young residents than surrounding rural areas (Kauppila, 2004). More foreign workers are also used in the tourism industry and this trend is expected to increase in Norway and Finland (Tuulentie and Heimtun, 2014). Winter tourism is experiencing a major increase and becoming increasingly important in all parts of Barents area.

The impacts of climate change are expected to be both positive and negative for tourism. Tourism may decline owing to a lack of snow and other environmental changes, and in sparsely populated rural regions this could lead to a loss of retail and other services and so affect the viability of entire communities (Brouder and Lundmark, 2011, see Chapter 9). For polar tourism, environmental change represents both opportunities and challenges, while greater access and warmer summers may encourage tourism development (Saarinen, 2014; Chapter 9). Rising temperatures are likely to stimulate summer tourism demands, and more 'mild days' and 'warm days' will positively affect tourists' thermal comfort. From this perspective, a warmer climate would ease some challenges related to seasonality (Førland et al., 2013). In Finland, climate change is expected to enhance winter tourism in Lapland in the near future as the projected lack of snow will adversely affect skiing conditions in central Europe. Summer tourism will benefit if rising summer temperatures in the Mediterranean become intolerable and drive tourists north (Kietäväinen and Tuulentie, 2013). Parallel situations can be expected for the Barents area as a whole.

While cruise tourism is well established in northern Norway, it is slowly emerging in north-west Russia where it is seen as a potentially new form of tourism. The development of cruise tourism in the Russian Barents Sea and along the coast is often claimed by academics, industry and policymakers to be a promising economic activity for Russian Arctic communities and territories (for an overview see Pashkevich and Stjernström, 2014 and Lamers and Pashkevich, 2015). To develop the infrastructure to ensure regular and marine passenger transport, the investment project 'Arctic harbor' will be implemented in Murmansk, where the marine terminal will be reconstructed with new buildings and modifications to the port area, including a pier for the long-distance lines, providing capacity to accept passenger cruise ships and an opportunity to open a regular ferry line between Kirkenes and Murmansk (McBride et al., 2016).

The number of visitors to the national park 'Russian Arctic' and federal reserve Franz Josef Land almost doubled between summer 2015 (738 people and six cruise ships) and summer 2016 (1225 people and 11 cruise ships) (Figure 6.12). Opening of the new 'pilot' border location on Alexandra's Land has made access easier for foreign tourists. However, seven of the 11 cruise ships were nuclear icebreakers on their way to the North Pole and according to JSC 'Atomflot', from 2016, nuclear icebreakers will no longer be used for tourist cruises to the North Pole and Franz Josef Land and will be reassigned to their original purposes (including cargo transport, oil and gas industry, military activities). There will still be tourist cruises using the diesel powered icebreaker to Franz Josef Land and Novaya Zemlya (McBride et al., 2016).

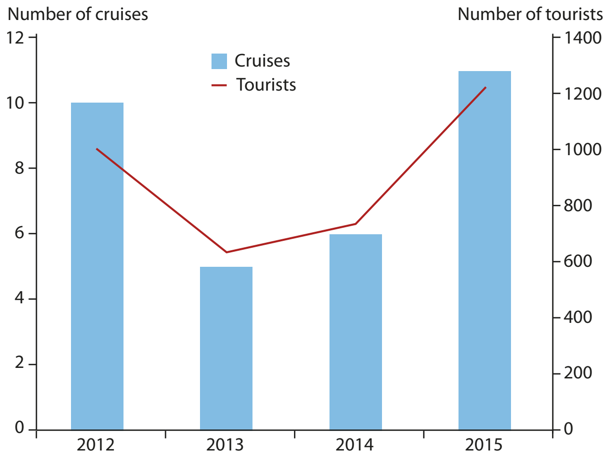


Figure 6.12 Numbers of cruise trips and tourists visiting the national park 'Russian Arctic' (*Russkaya Arktika*) between 2012 and 2016 (Russkaya Arktika).

Cruise tourism in Svalbard has increased considerably over the past 10–15 years with multiple operators and vessels (McBride et al., 2016). The number of landing sites has steadily increased and a total of 189 sites were used in 2013. Passenger numbers reached 9000 by 2012. This number has since declined probably for economic reasons and is now slightly lower. In addition to the settlements, there are a couple of landing sites suitable for passengers from overseas cruise ships. The ban on heavy crude oil limits passenger numbers and restricted access to cultural heritage sites has changed the routes of large ships and protects vulnerable areas in eastern Svalbard (McBride et al., 2016). There is a plan to extend the itinerary of the Norwegian coastal cruises of Hurtigruten to the Russian ports of Murmansk and Arkhangelsk (Lamers and Pashkevich, 2015).

The European part of the Barents area has the potential for turning the ordinary into the exotic for tourists (Kohllechner-Autto, 2011; Pashkevich and Stjernström, 2014). The high degree of heterogeneity characterizing the tourism industry in this area (in terms of business culture, level of tourism development, infrastructure, legislation and human capacity) not only hinders interregional cooperation but also creates barriers for some municipalities to the benefits of tourism (García-Rosell et al., 2013). Nevertheless, the consequences of climate change are not widely noticed in this sector. Instead, socio-economic drivers such as availability of skilled labor, economic fluctuations, international policy and consumer preferences receive more attention in marketing and planning (Amundsen, 2012; Tuulentie and Heimtun, 2014).

6.3.3 Energy

The energy sector in the Barents area is changing in response to both global market forces and regional resource demand. Increased activity in the energy sector generally leads to increased environmental impacts, both for the oil and gas industry and for alternative energy sources.

6.3.3.1 Oil and gas industry

Climate change will have variable impacts on the operational conditions for the oil and gas industry in the Arctic, in both the short term and medium term (AMAP, 2010) (Chapter 4). Some impacts are related to rising temperature and reduced sea ice which will improve the potential for oil and gas exploration offshore. Longer drilling seasons will also improve the productivity of exploration resulting in reduced logistical challenges and costs (Andrew, 2014). By replacing ice resistant constructions by conventional infrastructure, the investment costs will be reduced over the long term (Dell and Pasteris, 2010). On the other hand, a warmer climate creates conditions of 'ice infested waters' with icebergs and broken sea ice producing new types of risk that can interrupt offshore operations and development (Eskeland and Flottorp, 2006).

Other impacts in connection with thawing permafrost will reduce accessibility to onshore resources and reduce the length of the exploration activities that operate mostly in winter. Production from existing onshore installations will be disturbed because thawing permafrost will reduce the stability of the infrastructure (rigs, pipelines, roads) presenting additional logistical challenges and increasing maintenance costs (AMAP, 2010). More extreme weather conditions and their associated impacts (increased wind, more wave action, heavier precipitation, icing conditions, shoreline erosion, variable ice cover) will make long-term planning of offshore installations less predictable and thus more costly (Stepien et al., 2014). Operational conditions will be also less predictable, increasing the probability that drilling, production and transportation will be disrupted which will in turn increase operational costs. Large-scale accidents, such as oil spills and blowouts, will potentially increase with more extreme weather and will be more difficult to clean up. They will also increase the potential for long-term release of contaminants to land and sea (Kolstad and Bracegirdle, 2008).

In addition to climate-related impacts and consequences, the supply of Arctic hydrocarbons is also sensitive to future oil price developments. Simulations of the relationship between supply and demand for the oil (Figure 6.13) and gas (Figure 6.14) industries in the Barents Region are achieved by applying a comprehensive, global oil and gas model with prices, costs and reserves called FRISBEE (see Lindholt and Glomsrød, 2013). Figure 6.13 shows that in the high oil price scenario, production declines until production from large but currently undiscovered oil resources is gradually phased in with an increasing share of offshore production. This graphic also shows that in the low oil price scenario it will not be profitable to develop these resources. Figure 6.14 shows that although gas production is relatively constant over much of the period, there was a slight increase over the last 15 years in western Arctic Russia. Because oil and gas companies operate as separate industries, less profitable investment opportunities in the gas market will not affect the oil market and vice versa. Due to relatively small substitution possibilities on the demand side between oil and gas, the Arctic gas production scenario with a lower oil price is almost identical to the high oil price scenario. With favorable global prices, new investments related to oil and gas activity will follow (up to USD 100 billion according to some estimates) and production in the Barents Sea is expected to receive a substantial part of these investments (USD 6.5–23.4 billion to 2020) (Emmerson and Lahn, 2012).

Increased oil and gas activity may have several local and regional socio-economic impacts. Dependent upon the local procurement policies regulated by national governments and national oil companies / international oil companies, oil and gas procurement activity may potentially provide substantial economic gains to local communities and local companies with otherwise few employment opportunities (Emmerson and Lahn, 2012). For example, the volume of contracts going to local companies in northern Norway was in the range NOK 3.54–5.3 billion annually

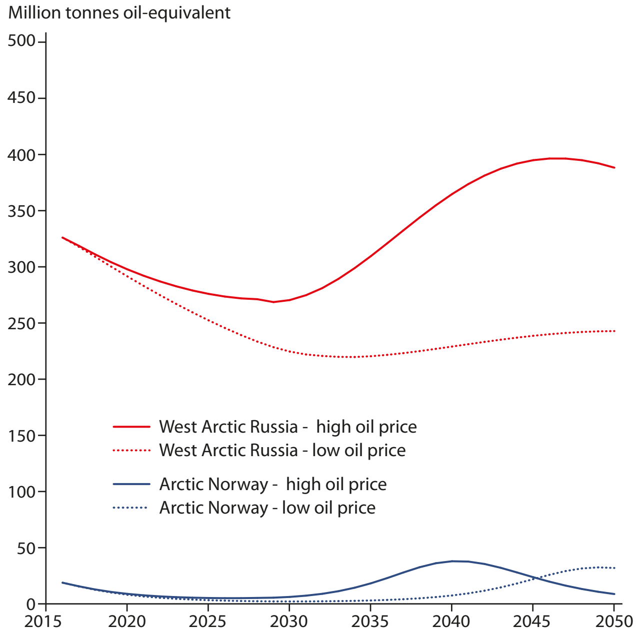


Figure 6.13 Oil supply in western Arctic Russia and Arctic Norway for a high and low oil price scenario. The high (low) oil price scenario assumes a cost per barrel of oil equivalent of USD 70 (58) by 2020 rising to USD 126 (80) by 2030 and then remaining unchanged (Lindholt and Glomsrød, 2013).

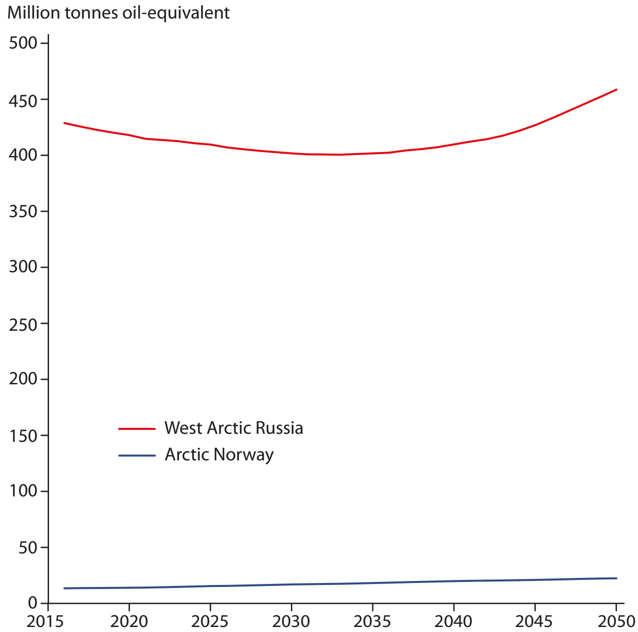


Figure 6.14 Gas supply in western Arctic Russia and Arctic Norway (Lindholt and Glomsrød, 2013).

in the period 2010–2014 (Nyvold et al., 2014). Increased oil and gas activity has also added value for delivering goods and services in related industries: the hotel trade, transport and communication, food and consumables, information technology, office buildings, office supplies, and engineering (Barlindhaug, 2005). Nevertheless and most importantly, the average benefit for the local industry in the Barents Region has not been more then 5–8% of the total value of contracts. This means that the major share of contracts went to international companies with headquarters located outside the region (Holter and Magnusson, 2014). One reason for this is a mismatch between existing local capacities (e.g. knowledge and skills needed for international oil and gas field development) and the industry's need to develop petroleum megaprojects of international quality. In the long term, increased involvement of the local industry stimulated by oil and gas industry development can potentially lead to increased urbanization which may in turn further stimulate the increased local expertise needed for further development (Arbo et al., 2007). Conversely, increased oil and gas activity may present a risk to traditional livelihoods (Stepien et al., 2014).

The combined effect of climate change and socio-economic change is that in the long-term the development of oil and gas offshore resources will be more feasible compared to onshore resources. A moderate rate of field development and investment are to be expected, mostly for the largest oil and gas fields, which will create moderate effects on the local economy in the Barents Region. The cumulative effects for the region, however, remain unclear. Development of oil and gas requires a long planning horizon with good understanding of the future economic situation supported by good historical statistics (such as for ice movement, change in operational conditions, and regional spin-off effects) (Harsem et al., 2011). Such projections are increasingly difficult to develop due to less predictable climatic, environmental, market and geopolitical conditions (Bourmistrov et al., 2015).

Any significant increase in oil and gas activities will result in ecosystem disturbance (Andrew, 2014), with a major oil spill representing the most significant ecological impact for the aquatic environment in the Arctic, especially in ice-covered waters. For example, contaminating food sources and increasing risk of fish stock losses with the consequent loss of current and future fishing revenues (AMAP, 2010) (Section 6.2.2.2, Box 6.3 and Chapter 2). Oil and gas activity will also contribute to increased greenhouse gas emissions and thus to climate change.

With even moderate increases in oil and gas activity, regional and national gross domestic product (GDP) will be stimulated by increasing local employment in the oil and gas sector, increasing the businesses supporting the oil and gas activities and increasing local population from in-migration and reduced out-migration (Barlindhaug, 2005). Local effects will be greater at the exploration and construction phases and significantly less in the production phase. Expected impacts include increased municipal tax income due to improved revenue from employment and property taxes, and increased standard of public services provision (e.g. improved standards in schools) making locations more attractive for businesses and further socio-economic development.

Another consequence of increased oil and gas activities is the potential for innovation and entrepreneurship among local and regional companies. Energy policies of Russia and Norway give oil and gas development high priority, noting that new technology (e.g. horizontal drilling, subsea production, seabed compression systems, multiphase flow), renders exploitation possible in previously inaccessible areas. Updating extraction and production technologies will mean that more challenging fields in the Barents Sea will be feasible for exploration with reduced risks (Harsem et al., 2011). In the context of climate change policy and the 2°C global temperature target from the Paris Agreement, natural gas emerges as a more attractive energy source than oil owing to the lower carbon dioxide emissions, although to meet the Paris Agreement target would actually require zero emissions. Hydrocarbon development is bound to be increasingly influenced by climate policy considerations as all the Nordic countries have set ambitious emission reduction targets. In addition, there is a need for innovation and economic activities to respond to the major future potential in the increased access to and distribution of natural gas. There may be a growing global need for liquefied natural gas to supplement natural gas supplies, and it is a promising source of energy especially in other industries such as mineral processing and shipping, and as an input to future electricity production.

6.3.3.2 Alternative energy sources

Future developments of the petroleum industry in the north will largely depend on world market prices of oil and natural gas, advances in offshore technology, maritime transport, and dynamic global energy supply (e.g. fracking and the unconventional oil revolution in the United States, and a growing demand from economic powers such as China) (Knobblock and Pettersson, 2010). Implementation of the Paris Agreement (i.e. limiting global warming to below 2°C above the pre-industrial level) will increase pressure on governments to find alternative energy sources. These include hydropower, wind power, nuclear power, solar power, and bioenergy.

Hydropower is based on the hydrological cycle, which is driven both by prevailing climate and by topology. Thus, the resource base, and therefore hydropower generation is dependent on future changes in climate including extreme weather events (Arent et al., 2014, Chapter 4). Snowmelt in the Barents area is an important factor in the annual water cycle and will affect hydropower availability in the future (Schaeffer et al., 2012). However changes in the share of precipitation falling as snow, and the climate response of glaciers make resource estimates complex (Arent et al., 2014). Reservoir storage capacity could help to reduce the potential seasonal shifts resulting from earlier snow melt (Schaeffer et al., 2012). According to Thorsteinsson et al. (2013), increasing meltwater delivery is likely to have beneficial effects on hydropower production in the Nordic region. Similarly, Kirkinen et al. (2005) estimated for Finland that hydropower production could increase by 7–11% between the periods 1961–1990 and 2021–2050.

The Barents area has excellent wind resources. There is potential to build a number of wind power plants with corresponding transmission lines to distribute the power. To adapt to Arctic conditions, technical solutions such as anti- and de-icing systems have been developed in recent years (Wallenius and Lehtomäki, 2015). Climate change models (a set of CMIP5 models) show little or conflicting changes in wind speed based on increasing energy in the atmosphere, decreasing temperature differentials between the Equator and the poles, and changes in atmospheric Rossby waves. Overall, Arent et al. (2014) concluded that the wind energy sector is unlikely to face intractable challenges from climate change. For example, Schaeffer et al. (2012) pointed out that wind power systems have a shorter lifetime than hydropower systems which makes them more adaptable to climate change over the long term.

At present, there is one Russian nuclear power plant operating in the Barents Region (Kola) and plans to build a large reactor unit in northern Finland (near Oulu). Small modular reactors are part of a new generation of nuclear power plant designs being developed in several countries. The aim of these facilities is to provide a flexible, cost-effective energy alternative, particularly for remote locations. Small nuclear reactors have been considered environment-friendly solutions to many energy applications (process and district heating in addition to power production) in remote hard-to-reach places, provided that due attention is paid to the safety of the plants during normal operation and in relation to accidents. Safe solutions for addressing the management and disposal of nuclear wastes are being introduced in several countries, including Finland and Russia.

According to climate change mitigation scenarios, solar energy is likely to increase from its present small share in the global energy mix (Arent et al., 2014). Climate change can affect solar power resources by changing atmospheric water vapor content, cloudiness and cloud characteristics (Schaeffer et al., 2012). Concentrated solar power (CSP) is most vulnerable to cloudiness. It is a common misconception that solar energy is not a viable option in the North due to low solar radiation, when in fact the Barents area has similar annual radiation to northern Germany. The timing of insolation is more concentrated in the summer months in the Arctic, which necessitates improved storage technologies and smart grid approaches, which allow higher shares of intermittent electricity generation in the grid.

Countries in the Barents area have vast forest resources, and boreal and tundra forests provide an essential source of raw materials for Arctic communities and the countries as a whole, including biomass for bioenergy. Because the treeline is expected to move northward, this may imply increased availability of forest biomass (Section 6.2.1), where forest growth could increase by up to 20–50% by 2100 depending on species (Parviainen et al., 2010). Other climate change impacts, including storms (Peltola et al., 2010) and forest pathogens and pests (Parviainen et al., 2010) will lead to forest damage and impede overall growth, which in turn will have consequences for the biomass (Section 6.3.1.3).

One of the important future challenges of the energy system in the Barents area is related to the intermittent nature of renewable power sources such as solar energy and wind power. The energy production and consumption profiles may not necessarily match, which creates a need for energy storage and intelligent power managing practices. Smart grid and building automation are key solutions – especially since buildings are a key energy consuming sector in the Barents area. Due to the small scattered communities and the large distances involved, a microgrid (a local energy grid, fully functional as a stand-alone entity) can be a cost-effective alternative to the renewal of the aging macrogrid infrastructure and a solution to increased damage to the electricity networks due to climate change (Kirkinen et al., 2005).

6.3.4 Mining

In general, socio-economic factors have a greater impact on the mining sector than climate change. Nevertheless, the sector both contributes to such change through operation emissions and needs to adapt to the impacts of climate change. The sensitivity of mining to hydrological change caused by climate change requires adaptation actions as explained in the Kittilä case study (Box 6.5; see also Box 9.3). Modern society requires mineral-based products, where the demand for a broad range of metals and minerals is increasing in parallel with modern technology, especially in resource-efficient and low carbon technologies (Andrew, 2014). This has resulted in a rapid increase in the number of mines worldwide, including in the Barents area. Current demand and supply imbalances for raw materials are likely to intensify over the coming decades. Although the development of less resource intensive technologies will continue, the anticipated rise in global population and living standards in developing countries is expected to continuously increase the demand for a wide range of resources (Andrew, 2014).

Increasing global demand will be a major factor influencing the price of raw materials. Other factors include the exhaustion of current deposits, increasing difficulty in accessing known and future deposits, higher overall costs and increasingly stringent safety and environmental standards. Current recycling rates and the provision of secondary materials appear insufficient to meet current market demand for metals. Changes in the global geopolitical situation also affect the market for raw materials, such as by curbing investment.

Environmental impacts from mining may be both direct and indirect and occur through complex impact chains, such as ecological change. External impacts include emissions to water and air, noise and odor nuisance, as well as destruction and disturbance of ecosystems. Impacts on the environment relate to different phases of the lifecycle of a mine: prospecting, mine construction, production, closure and aftercare. Mining and especially refining processes are energy intensive and thus mines represent significant indirect sources of greenhouse gas emissions. Small particles in air emissions can cause health problems and contaminate the surrounding environment (Sondergaad et al., 2011). Alternative techniques in tailings management such as storage in land-based tailings ponds or submarine tailings disposal cause different ecological impacts. Concentration processes, such as flotation processes, are very water intensive. Waste water from concentration processes and drainage from surface and underground mines as well as from waste areas may contaminate waterbodies. Acid mine drainage is responsible for the most serious and pervasive environmental problems related to mining and occurs when iron sulfide minerals are exposed to, and react with, oxygen and water (UNEP, 1997; Kauppila et al., 2013; Jantunen et al., 2015). The nature and magnitude of the emissions and environmental impacts in metal ore mining are largely dependent on the geology of the deposit, its size and shape, the concentrations of minerals, the excavation and beneficiation methods, and the technology and processes used in purification. For coal mining, the main environmental impacts are largely the same as those for metal ore mining (impacts on land use, water pollution, acid mine drainage, dust and noise). It is crucial that mine operators are committed to maintaining and developing operations in such a way that emissions into the environment are kept to minimum.

Box 6.5 Climate change impacts on mining: Kittilä gold mine, Finland

Agnico-Eagle Finland Ltd operates a gold mine in Kittilä municipality in Finnish Lapland. The mine was chosen for this case study owing to its geological, economic and environmental significance. The areal water balance modelling and global climate change scenarios were constructed to study the likely future changes in hydrology in the mine area and to assess possible consequences and necessary adaptation actions. Modelling was undertaken using SYKE's Watershed Simulation and Forecasting System (WSFS; Vehviläinen et al., 2005) based on the average scenario of 19 global climate models (Christensen et al., 2007; Kirtman et al., 2013). Short-term (2010–2039) and long-term (2040–2069) changes in climate parameters were assessed against a reference period (1971–2000).

The climate scenarios show significant average change in long-term temperature (3.18°C) and precipitation (11.5%). Changes in temperature, precipitation, evaporation, humidity, wind, run off, snow cover, river flow and groundwater level are likely to impact mining operations.

Warming in the winter period was identified as the most significant change affecting the water balance of the mine. Warming will affect snow conditions and melting of snow in the area. Instead of one clear melting period in the spring the melting is likely to take place gradually during a longer period of time. As a result, seasonal patterns in river flow are likely to change. Figure 6.15 shows the projected changes in the flow patterns for River Seurujoki. River flow may peak at different times and the first peak flow might become earlier. Low flows may require more vigilant monitoring, especially in relation to controlling the timing and amount of effluent discharge from the mine. Environmental limits for the Kittilä mine are based on both the concentration of harmful substances in the treated wastewater as well as the amount of water released in relation to flow in the River Seurujoki. As a result, supplementary measures on wastewater discharge might be needed in the future particularly during the summer if the low flow periods increase significantly.

The changes in the areal hydrology as a consequence of climate change require the mining operators to redesign the water management in the mine area.

In mining operations, increased seasonal variation in hydrology may result in: dust formation; runoff from waste rock areas and possible acid mine drainage; pumping of drainage waters and storage of waters in the area; changes in the quality and quantity of wastewaters to be purified; challenges for wastewater treatment – flexibility and capacity; a need to redesign the management of surface waters and groundwater so as to prevent groundwater contamination; and extreme precipitation that may lead to potential overflow of tailings ponds, cause flooding and road erosion as well as increased risk of environmental contamination.

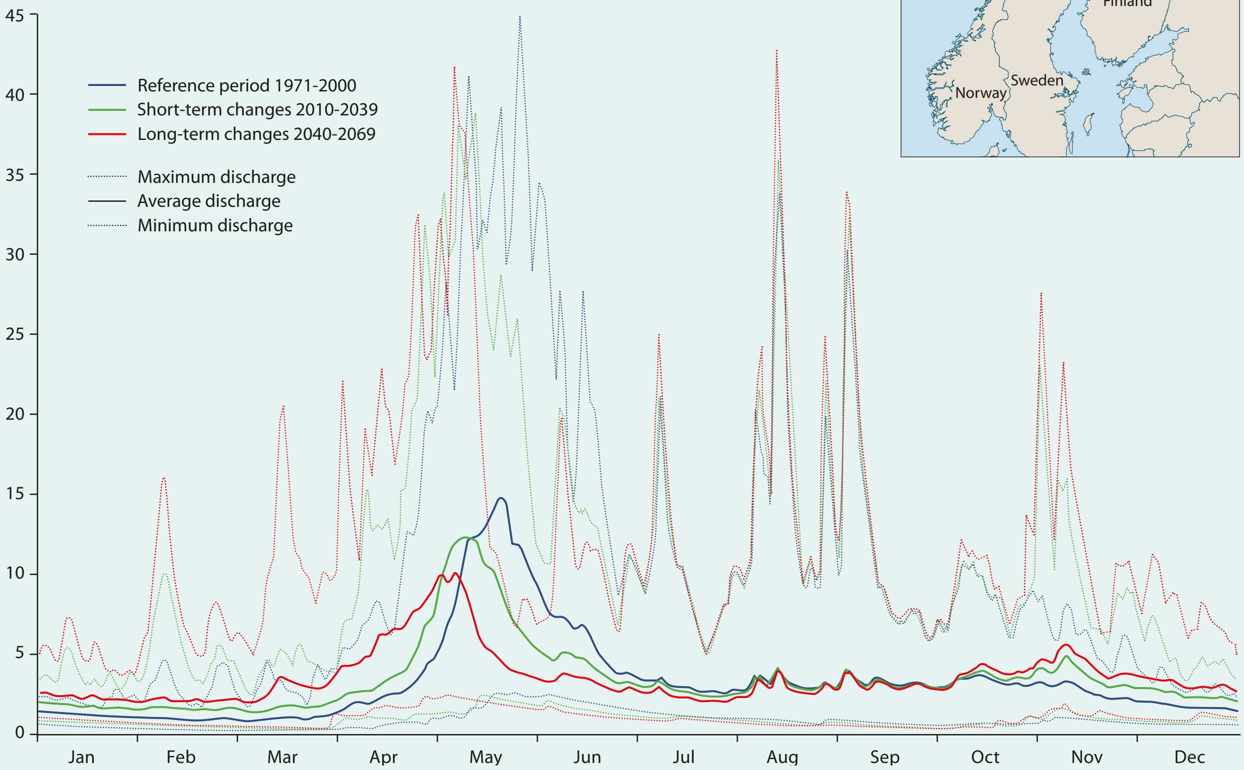


Figure 6.15 Observed daily discharge in River Seurujoki in Finnish Lapland for the period 1971–2000 and as projected over the short term (2010–2039) and long term (2040–2069). The data show maximum, average and minimum discharge (based on unpublished SYKE data). The inset shows the position of the Kittilä mine – the treated waste water from the Kittilä gold mine is discharged into the River Seurujoki.

The increase in mineral extraction has consequences for society. Negative attitudes toward the industry are strong and community conflicts appear to be increasing (Hodge, 2014). Thorough assessments and management of societal impacts of mining are important for sustainable mining and society. Acceptability comprises diverse and conflicting dimensions; economic development may be accepted, but environmental issues are simultaneously criticized (Wessman et al., 2014). The local benefit from mining is understood but mines are not accepted at any cost. Mining companies are expected to contribute to social and economic development, especially at the local level (Söderholm et al., 2015). See Chapter 9 for a discussion of adaptation in the mineral industry.

6.3.5 Shipping and infrastructure

Receding sea ice will mean shipping will be able to avoid the shallow waters of the Northern Sea Route (previously a serious limitation for shipping) and ship traffic could increase (Østreng et al., 2013). A longer open water season of up to six/seven months would also improve the regularity of shipping. Transit carriers are still very skeptical about the potential for Arctic shipping, whereas those operating destinational carriers are more optimistic (Lassere and Pelletier, 2011). This is because transit shipping through the Arctic is challenged by more logistically efficient and cheaper shipping alternatives (Stephenson et al., 2013). However, use of the Northern Sea Route for transit shipping is still expected to grow in the long term, taking over 5–10% of the Europe-Asia cargo transit shipping turnover (Tupolov, 2012).

According to Melia et al. (2016), the projected loss of sea ice is likely to increase both the frequency and length of navigable periods for Arctic-transit shipping. While substantial interannual variability will remain, it is likely that by the end of the century, the transit routes will be accessible for 10–12 months of the year for moderately ice-strengthened vessels (Figure 6.16).

Hydrocarbon transport is an important element of destinational shipping. Previous estimates indicated that export could reach 150 million tonnes by 2030 (Bambulyak and Frantzen, 2009), resulting in a demand for around 100 different new ice-class ships (Loginovich, 2012). As of 2016, with the oil price below USD 30 per barrel, the likelihood of achieving these projections is now drastically reduced, at least in the short and medium term. The low oil price will also limit investment in infrastructure and in search and rescue.

Shipping in the eastern and northern Barents Sea, however, does not depend entirely on oil and gas prices. The mineral deposits of Arctic Russia and Scandinavia (nickel, copper, iron

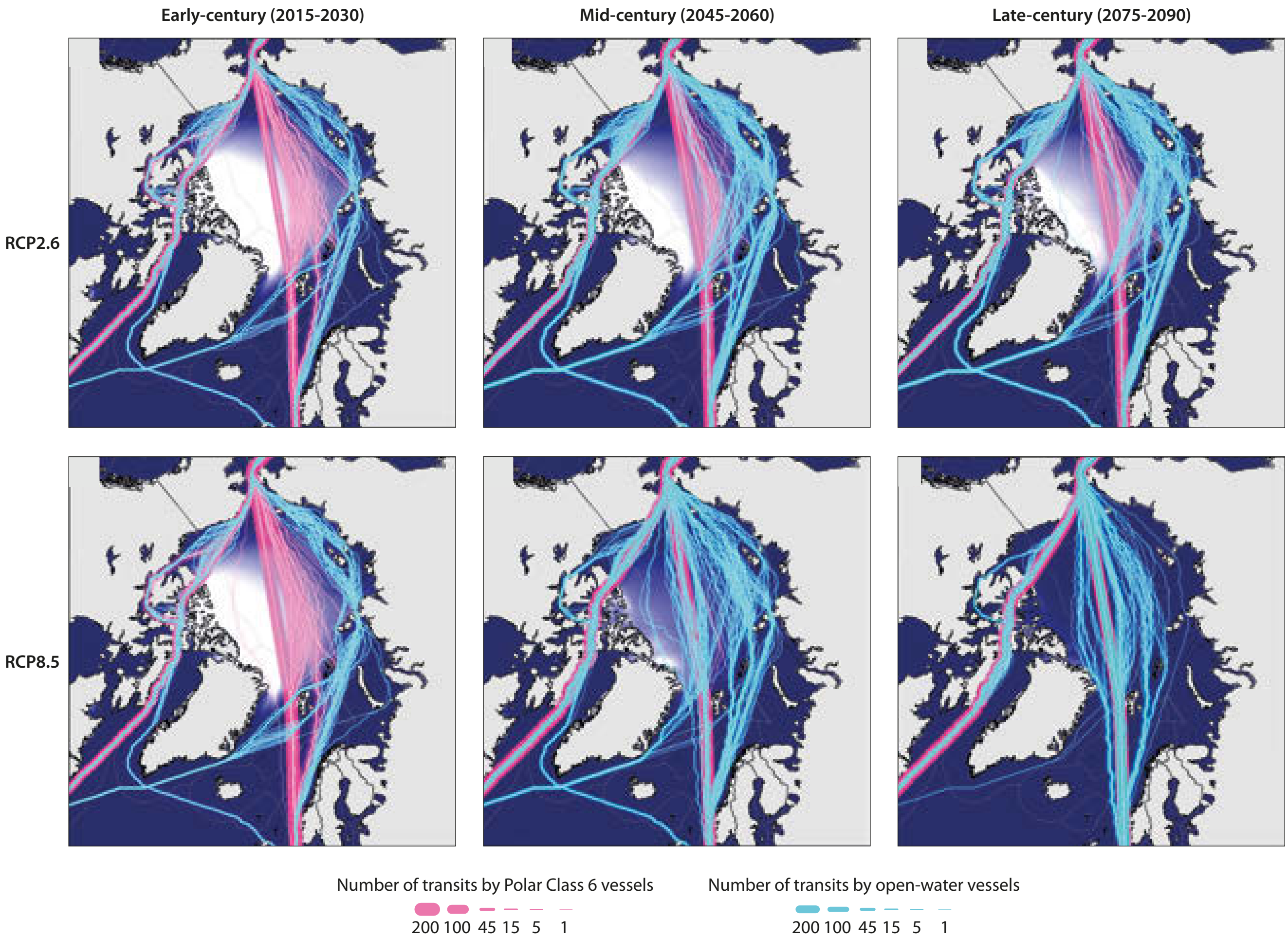


Figure 6.16 Fastest available September trans-Arctic routes from future climate projections. Routes for low emissions (equivalent to achieving the Paris Agreement; RCP2.6, upper row) and high emissions (business-as-usual, RCP8.5; lower row) split into three periods (early-, mid- and late-century), each containing 15 consecutive Septembers. Line weights indicate the relative number of transits using the same route. Faint dashed grey lines indicate the Exclusive Economic Zones (Melia et al., 2016).

ore, timber, phosphate, semi-precious stones, and bauxite) will continue to be shipped through the Barents area for a long time to come (Bambulyak et al., 2012). The exception will be shipping of coal from Svalbard where drastically declining prices of coal on the world market will end coal mining there. Svalbard will reposition to increase the use of the Northeast Passage by improving its port facilities in Longyearbyen, improving Arctic search and rescue capabilities and expanding the tourist industry to the islands (Multiconsult, 2014).

The tourist industry will become more important to the shipping industry. For example, from 2013 to 2014 cruise traffic in northern Norway increased by 10%. At the same time, it dropped slightly for Norway as a whole (Norwegian Ministry of Foreign Affairs, 2014). These operations are now expanding to include more of the Barents Region and annual growth for the Arctic cruise segment is high. However, of all cruise vessels in the world, only 13.2% are ice class. This leads to increasing risk of interaction with ice, especially free-floating ice. Risk of grounding is another issue because charting all relevant ocean areas in the Arctic could take up to 40 years (Eger and Kristiansen, 2011). In the meantime, the growth in regional shipping activity could cause a significant increase in marine incidents, including sinking, grounding, and pollution.

Search and rescue capabilities are struggling to keep up with increased shipping activities. The Norwegian Coast Guard continues to play an important role in securing the safety of shipping. The Russian authorities have invested RUB 910 million in the development of ten search and rescue centers along the Northeast Passage (Petersen, 2011). Nevertheless, many experts consider that much more is needed to create a reasonably safe operational region (Østreng et al., 2013).

6.4 Linkages and cumulative impacts

6.4.1 Connecting drivers of change to adaptation actions

The Arctic is experiencing major changes in the level and types of human activity and presence, in climate and in its ecosystems (Chapter 4 and Sections 6.2 and 6.3). Increasing interactions between natural changes within the Earth system and growing pressure from humans as drivers of change have reached the point where changes that affect the entire globe are increasingly linked to environmental and societal changes that are specific to the regional and local level. It is increasingly clear that different systems and changes are interconnected; such as changes in the regional climate system, changes in biodiversity and ocean acidification (Section 6.2). In addition to interlinkage within and between the physical systems, societal and environmental conditions are also closely and inextricably linked, and are often described as coupled social-ecological systems. The different types of factor or stressor combine to create cumulative and cascading effects for society. The consequences of multiple stressors on key economic sectors and services can be considered as risks for business-as-usual, but can also represent new economic opportunities (Section 6.3).

The preceding chapters and sections set the scene for this section and the following chapters. Chapters 1-5 present the background and current status for the region, the context of change, and descriptions of the drivers of change for different sectors, locations, and the region at large. The previous sections of Chapter 6 analyze the current knowledge on impacts and consequences for different systems (see Figure 6.7 for an example on the sources of impact and biological responses in marine ecosystems associated with offshore oil and gas activity). Importantly, discussion of these impacts and consequences does not include the effects of potential adaptation measures. This section builds on information from the earlier chapters by beginning to examine the changes and needs for specific sectors or locations that can inform the discussions of potential adaptation actions that appear in the following chapters. The aim of this section is therefore to describe a methodology for how to identify the drivers and consequences that may require adaption actions. This type of analysis will always include some level of uncertainty, but it does provide important input into decision making where uncertainty is a norm (Chapter 8, and Sections 9.4 and 10.3.3).

6.4.2 Methodology for analyzing drivers, impacts, and consequences of change

The methodology described here examines a particular sector, region, or location and assesses the impacts and consequences from various drivers of change in a step-by-step approach. While the concepts of drivers, impacts, and consequences are difficult to distinguish clearly (see Chapter 1 for use of this terminology), organizing the information in this way makes it easier to visualize the linkages between the different drivers of change, and to understand how they reinforce or counteract each other. Finally, by aggregating the results it is possible to identify the cumulative impacts and their consequences across sectors and areas of concern.

The first step is to identify the high-level drivers. These may all play a role, but do not necessarily have the same impact: any one driver may be more important and have a greater weight than another, depending on the sector, context and time scale for analysis (e.g. 2030, 2050, 2100). In addition, sectors (such as forestry) that are changing as a result of several drivers (such as climate change, technology) may themselves become a second order driver of impacts in other areas or on other sectors.

The previous chapters show there is a range of concerns and perspectives for the various sectors (see also Chapter 9). Chapter 4 highlighted the main drivers of change in the Barents area, but without weighting or priority ranking. In Chapter 5, stakeholder and expert groups identified sets of high-level drivers of change as affecting their livelihoods and lifestyles within the Barents Region – identifying and ranking drivers and issues at the local level. The list of drivers determined through a series of workshops (Section 5.4.1) was slightly modified for the analysis presented here, combining the 'recurring themes' identified in Chapter 5 with the original list of main shared SSP (shared socioeconomic pathway) elements by O'Neill et al. (2017). The resulting list of drivers, presented in Table 6.1, shows how the seven drivers were ranked differently according to their importance and uncertainty by local stakeholders (Barents area locals) and experts. The impact and consequence analysis performed (see Section 6.4.3 for forestry example), uses the average weights of these stakeholder and expert opinions (final column of Table 6.1).

Table 6.1 Relative importance of the drivers of change in the Barents area for the next 30–50 years as identified by stakeholders and experts and expressed as weighted percentages of participants' responses. Stakeholder data for Barents area locals are average values based on four local workshops.

Drivers	*Which future changes will affect this region economically, socially and environmentally in the next 30–50 years?*		
	Barents area locals	Barents area experts	Average
Economic and lifestyle changes	25	22	23
Policy shifts and institutional changes	22	14	18
Changes in human development	13	21	17
Technological changes, breakthroughs	9	19	14
Climate change (+ impacts)	11	14	12
Demographic shifts	9	7	8
Changes and trends in environmental status and natural resources	11	3	7

An advantage of this weighted list of drivers is that it includes input from both local actors and scientific experts, and that they cover the whole Barents area. A disadvantage of this list is that it is fairly unspecific for any one sector, as the average is based on assessments in different locations, with different settings and a (different) variety of sectors. Depending on the intended use, a tailored or sector-specific analysis of drivers and weights could be better, but as a general example of the approach the drivers identified in Table 6.1 and their relative weights will suffice.

Table 6.1 thus forms the basis of an analysis of consequences, where a consequence can be described as the tangible outcome of an impact or an interaction of multiple impacts that results in a change in condition of a given element of interest. When assessing the consequences of change for a sector, one approach is to use a matrix analyzing the driver-impact-consequence chain step-by-step before estimating the cumulative consequences; that is, starting with a high-level driver (e.g. climate change) and aspects of that driver and its direction (e.g. temperature, increasing), their impacts and effects (e.g. increased growing season), and arriving at the consequences (increased forest area). Another example would be the trends toward decreased levels of consumption and increased use of local and vegetarian food products (drivers) leading to decreased fossil fuel use, increased resource efficiency, and land-use changes from decreased livestock holding and feed production (impacts), resulting in increased area available for forests and forestry (consequence). This approach enables visualization and disaggregation of the overall potential future for a sector into its components.

The linkages and cumulative impacts from this list of drivers across the Barents area are many and complex. Chapter 9 highlights that one size does not fit all when it comes to understanding the process of adaptation. The chapter highlights that the contexts (sector, community, locality, etc.) will require specific measures depending on a range of factors such as the level of impact, available economic and human resources, and access to knowledge, technology and institutions. It is therefore not feasible to undertake a full-scale analysis for the whole Barents area in this section. For the purpose of demonstrating this methodology, the first step is to examine one key sector in the Barents area – forestry. This approach of disaggregating the main drivers, impacts and consequences and then recombining these into cumulative effects and consequences, can then be applied to other sectors, regardless of scale and context. These analyses of the drivers, impacts, and consequences illustrate what is likely to happen in the absence of adaptation measures. These types of analysis can thus serve as input for subsequent discussion and analyses – analyzing the adaptive capacity of a sector or society to respond to cumulative changes and consequences, what adaptation options are available and what adaptation measure can be taken to avoid, anticipate and/or deal with these changes and build resilience. Chapter 9 describes four interrelated dimensions that warrant consideration when addressing adaptation options and how they can be turned into adaptation measures; adaptation strategies, processes of adaptation, barriers and limits, and governance and tools. Chapter 8 discusses resilience decision-making in terms of building information about the drivers, impacts, and consequences of change. To reiterate, the analysis of drivers, impacts, and consequences in this section does not intend to be an exact presentation of what will happen, but rather a way of thinking that can help better inform adaptation actions, building of resilience and other forms of related decision-making on an ongoing basis.

6.4.3 Applying the methodology to the forestry sector

This section uses the forestry sector to provide an example of how the matrix analysis described in the previous section would be applied. The outcome of this step-by-step approach is presented the form of a table (Table 6.2) and in narrative form.

Economic and lifestyle changes: As the agricultural sector moves towards more productive crops, and lifestyles and diets move towards more vegetarian and less climate impacting systems, there will be more land available for food production, but in the north especially more land for forest. The market for products, especially forest pulp, energy, timber and carbon storage will increase, and be directed to growing urban centers in the region, with their increased needs for building materials and energy, but also to the national and international market. The latter will especially build on energy, but also on timber and carbon storage and be facilitated by the sea routes opening up for easier timber transport out of the region.

Table 6.2 Drivers of change with their actions and directions, impacts and effects, and consequences for the forestry sector over the next 30 to 50 years. Drivers are listed in order of relative importance based on Table 6.1 on the understanding that the relative importance will change over time. The consequences for the forestry industry as a whole (i.e. not the forests themselves) are shown in the final column, with green cells indicating positive change, red cells indicating negative change, and blue cells indicating inconclusive change.

Inputs from Chapter 4 and Chapter 5		Inputs from Chapter 4, 5 and 6	
Driver	Actions / Directions	Impacts / Effects	Consequences
Economic and lifestyle changes	• Changing consumption patterns (decreased levels of consumption, increased use of local and vegetarian food products) • Decreased traveling	• Decreased fossil fuel use • Increased resource efficiency • Significant land-use changes (decreased livestock holding and feed production)	• Increased area available for forests and forestry • Increase of forestry for carbon storage
Policy shifts and institutional changes	• Increased focus on climate targets • Growth in diversification and innovation promoted	• Mitigation and carbon capture wherever possible in all sectors, including food, fossil fuel and transport	• Decreased forestry for biofuel use and increased forestry for carbon storage
Changes in human development	• Increased level of education and environmental concern	• Decreased fossil fuel use • Increased biofuel use • Increased resource efficiency	• Increased biofuel use • Preserving forest and increase in carbon storage
Technological changes, breakthroughs	• Accelerating technological change • Decreasing distance	• Improved machinery (lighter) for harvesting trees • Improved biofuel efficiency	• Increased forestry (for biofuels and wood) and forest area
Climate change and related impacts	• Warming	• Decreased permafrost regime (treeline moving north) • Earlier greening and plant growth • Longer growing season	• Increased area and amount of standing forest and timber resources
		• Increased number of pests and parasites • Increased freeze-thaw episodes in winter	• Increased damage on trees (insect damage, forest fires) • Decreased seedling survival in winter • Rot of drying wood/timber • Decreased quality (and quantity) of trees/wood
	• Increased extreme events (drought, precipitation, heavy snow)	• Increased tree damage (insects, forest fires, rot of drying wood/timber)	• Decreased quality (and quantity) of trees/wood
Demographic shifts	• Population growth, immigration and urbanization in the Nordic countries • Decreased population and no urbanization in Russia • Increased ageing • Decreased rural development	• Fewer people of working age • Changing economics and social life • Reorganization of industries • Fly-in industries • Decreased use of forest ecosystems as pasture for livestock	• Decreased grazing pressure • Increased area of standing forest • Increased forestry options
Changes and trends in environmental status and natural resources	• Increasing demand for energy and natural resources	• Decreased fossil fuel use • Increased biofuel use	• Decreased pollution (black carbon) • Increased area of standing forest, use of forest for biofuel, and protection of forest stands for carbon capture
Cumulative effects and consequences		Overall positive change for forestry with increased forest area, increased biofuel use, and increased timber availability. Depending on policy, management and winter hardiness of species the positive consequences can be larger or smaller	

Policy shifts and institutional changes: An increased focus on climate targets will lead to an overall pressure to reduce carbon emissions and promote carbon capture that will lead to a decreased use of forests for biofuel and an increased use of forests for carbon storage.

Changes in human development: Increasing education and environmental awareness around the issue of climate change will lead to increased biofuel use and thus increased demand for biomass from forests, but conversely increased social pressure to preserve and maintain forested lands for carbon storage.

Technological changes, breakthroughs: Labor may be flown in as population in the north becomes increasingly centralized in urban areas, but lower transport costs and emissions do not hinder development of the forestry industry in the north. Potential harvest problems during wetter periods of the year may not pose a problem for machinery as technology and infrastructure improves and harvesting machines become lighter. On the other hand, studies reported in Chapter 9 indicate that agricultural policy may result in more driving between fields requiring heavy machinery which in turn harms the fields. Although the overall economic growth in the Barents area will be well below the global average, the region will continue to use its rich natural resources, including and increasingly its forest expanse.

Climate change and its impacts: Increased carbon dioxide concentrations and a warmer and wetter climate, are expected to lead to increased forest productivity in the northern parts of Europe, enabling sustainable forest management in areas where it is currently not possible. However, shorter and warmer winters will make harvesting more difficult, while increased precipitation may increase the risk of rot of timber. A warming climate might also increase the risk of forest and timber damage by pests and diseases. Winter climate may decrease seedling survival, but this can be addressed with good forest management and the selection of winter-hardy and (new) pest-resistant species. Forestry thrives on increased resources for both the timber and energy industry, and a global drive for carbon capture in forests will further promote forestry in the Barents area.

Demographic shifts: As the population in the Nordic countries grows (more in the southern parts of the Barents nations, but also in the Barents Region itself), the demand for energy will increase. Technological developments and international climate change agreements will shift the energy sector away from fossil fuel use and towards biofuels.

Changes and trends in environmental status and natural resources: Increasing demand for energy, particularly alternative energy sources will lead to decreased black carbon pollution, increased area of standing forest, use of forest for biofuel, and protection of forest stands for carbon capture.

Cumulative effects and consequences: The first four drivers listed in Table 6.2 comprise close to 75% in terms of relative importance, and are expected to play a larger role in future developments in the Barents area, including the forestry sector. Because the majority of these drivers suggest an increased forest area in the future and highlighted issues such as carbon storage do not necessarily conflict with increased biofuel use, an overall positive change for forestry is expected with increased forest area, increased biofuel use, and increased timber availability. Increased forestry creates conflicts (in some regions) with reindeer herding and agriculture. Increased standing forest also has consequences for water retention and affects local and regional climate. Economic interests, future climate developments and national pledges along with the level of commitment to a shift towards biofuel, the speed of necessary technological development and implementation of these will determine the extent of positive changes for the forestry sector.

6.4.4 Moving forward

The initial analysis shows how various drivers of change may interact, and how developments at the local, regional, and global scale and in the different sectors influence whether and how the Barents area can further develop its forests as a resource base. Near-term impacts are more likely to be affected by governance and globalization than by changes in climate. On the other hand, by 2050, climate change has the potential to be a dominant driver increasingly affecting impacts on ecosystems and the industries and people depending on these directly. More work is needed to understand the cumulative impacts and cascading effects of the bundle of drivers affecting any given sector and to understand how these cumulative impacts will evolve over time. Applying the weighted driver importance method in a combined driver-impact-consequence analysis allows for a more balanced narrative and estimation of the cumulative regional impacts for specific sectors or sub-regions.

This methodology is a tool intended to inform thinking and decision-making about the future and to inform more detailed discussion of resilience and adaptation actions (Chapter 8 and 9). Depending on the focus area (e.g. region, sector), some drivers of change are more important than others and their importance changes over time. Economic and political shifts affecting certain drivers of change are especially difficult to foresee. The impacts on a sector in one country may not be the same as those in another country, simply owing to different policies and regulations, global trade links, available infrastructure, support by or dependence on available technology, or public acceptance. Adaptation actions taken to respond to and build resilience to changes in one area may conflict between locations, sectors, and scales.

Importantly, the output of the analysis such as that for the forestry sector (Section 6.4.3) may serve as crucial input to larger resilience discussions (e.g. case studies in Section 8.6), and adaptation options (primary sectoral studies in Section 9.2). Consequences are the intersection of the scientific process (attribution of drivers to impacts to consequences) with the decision-making process (linking specific decision-making questions to issues of change in the Arctic and ultimately also to consequences) that provides the 'key' to connecting science to decision-making. As shown in Chapters 5, 8 and 9, these larger discussions of resilience and adaptation actions benefit from setting clear goals of what society or sectors want to achieve, understanding what adaptation processes entail, and involving a range of actors, sectors, and types of knowledge (see also Chapter 10 on the need for tools for analyzing the robustness of adaptation options).

Interactions between drivers and their impacts and consequences are continuously changing, and feedbacks to sectors and their interactions are difficult to identify. This also means that assessing the cumulative and cascading effects must be done repeatedly to stay up to date. Further, adaptation actions require an iterative process to assess the status of drivers, impacts, and consequences as those adaptation actions take effect and as the underlying drivers of change evolve with time (see Chapter 9 for a detailed discussion about the dimensions that are involved in the adaptation processes). As discussed in Sections 8.5 and 9.4, an iterative process is necessary to bring stakeholders together in order to co-develop knowledge, and understand the particular context in which consequences and impacts occur and why they require adaptation action. It is therefore important to view this section as a tool to assess consequences and needs for adaptation, rather than an answer to which changes will happen to a sector, region or locality. This analysis is only part of a larger ongoing discussion of resilience and adaptation actions, but is a critically important part of that discussion.

Acknowledgment

Part of Anna Degteva's work was supported by the Research Council of Norway through the 'Rievdan' project at the Sámi University of Applied Sciences and the International Centre for Reindeer Husbandry.

References

Aars, J. and A. Plumb, 2010. Polar bear cubs may reduce chilling from icy water by sitting on mother's back. Polar Biology, 33:557-559.

Abryutina, L.I., 2009. Indigenous peoples of the Russian North: social and climatic changes. In: Climate Change and Arctic Sustainable Development: Scientific, Social, Cultural, and Educational Challenges. pp. 164-173. United Nations Educational, Scientific, and Cultural Organization (UNESCO), Paris, France.

Aibulatov, N.A., 2005. Activities of Russia in marine coastal zone and problems of ecology. Nauka, Moscow. (in Russian)

AMAP, 2004. AMAP Assessment 2002: Persistent Organic Pollutants in the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

AMAP, 2007. Arctic Oil and Gas 2007. Arctic Monitoring and Assessment Programme (AMAP) Oslo, Norway.

AMAP, 2009. AMAP Assessment 2009: Human Health in the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

AMAP, 2010. Assessment 2007: Oil and Gas Activities in the Arctic - Effects and Potential Effects. Vol.2. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

AMAP, 2011. AMAP Assessment 2011: Mercury in the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

AMAP, 2014a. Trends in Stockholm Convention Persistent Organic Pollutants (POPs) in Arctic Air, Human Media and Biota. AMAP Technical Report to the Stockholm Convention. AMAP Technical Report No. 7 (2014), Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

AMAP, 2014b. Arctic Ocean Acidification 2013: An Overview. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

AMAP, 2015a. AMAP Assessment 2015: Human Health in the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

AMAP, 2015b. AMAP Assessment 2015: Radioactivity in the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

AMAP, 2017. AMAP Assessment 2017: Chemicals of Emerging Arctic Concern. Arctic Monitoring and Assessment Programme (AMAP),Oslo, Norway. In press

AMAP/CAFF/SDWG, 2013. Identification of Arctic marine areas of heightened ecological and cultural significance: Arctic Marine Shipping Assessment (AMSA) IIc. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

Amundsen, H., 2012. Differing discourses of development in the Arctic: the case of nature-based tourism in northern Norway. The Northern Review, 35:125-146.

Andrew, R., 2014. Socio-Economic Drivers of Change in the Arctic. AMAP Technical Report No. 9 (2014), Arctic Monitoring and Assessment Programme, (AMAP), Oslo, Norway.

Andriyashev, A.P. and N.V. Chernova, 1995. Annotated list of fishlike vertebrates and fish of the arctic seas and adjacent waters. Journal of Ichthyology, 35:81-123.

Anisimova, N.A., L.L. Jørgensen, P. Lubin and I. Manushin, 2011. Benthos. In: The Barents Sea. Ecosystem, Resources, Management: Half a Century of Russian-Norwegian cooperation. pp. 315-328. Tapir Academic Press.

Anon, 2015. Growth from the North: How can Norway, Sweden and Finland achieve sustainable growth in the Scandinavian Arctic? Report of an independent expert group. Prime Minister's Office Publications, Report No. 04/2015, Helsinki.

Antipova, T.V., 1975. Distribution of the Barents Sea benthos biomass. Trudy PINRO, 35:121-124. (In Russian)

Arbo, P., V. Didyk, B. Hersoug, I. Nilssen, V. Nygaard, L. Riabova, J. Sand and S. Østbye, 2007. Petrodevelopment 2030: Socio-economic consequences of an extensive oil and gas development in the Barents Sea. Norwegian College of Fishery Science, University of Tromsø.

Arbo, P., A. Iversen, M. Knol, T. Ringholm and G. Sander, 2012. Arctic futures: conceptualizations and images of a changing Arctic. Polar Geography, 36:163-182.

Arctic Council, 2013. Arctic Resilience Interim Report 2013. Stockholm Environment Institute, and Stockholm Resilience Centre.

Arent, D.J., R.S.J. Tol, E. Faust, J.P. Hella, S. Kumar, K.M. Strzpek, F.L. Toth and D. Yan, 2014. Key economic sector and services. In: Climate Change 2014: Impacts, Adaptation and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. pp. 659-708. Cambridge University Press.

Armitage, J.M., C.L. Quinn and F. Wania, 2011. Global climate change and contaminants – an overview of opportunities and priorities for modelling the potential implications for long-term human exposure to organic compounds in the Arctic. Journal of Environmental Monitoring, 13:1532-1546.

Arrigo, K.R. and G.L. van Dijken, 2015. Continued increases in Arctic Ocean primary production. Progress in Oceanography, 136:60-70.

Aschan, M., M. Fossheim , M. Greenacre and R. Primicerio, 2013. Change in fish community structure in the Barents Sea. PLoS ONE, 8:e62748, doi:10.1371/journal.pone.0062748.

Bambulyak, A. and B. Frantzen, 2009. Oil Transport from the Russian part of the Barents Region. Status per January 2009. The Norwegian Barents Secretariat and Akvaplan-niva.

Bambulyak, A., R. Rautio and M. Grigoriev, 2012. Development of Marine Russian-Norwegian Trade facilities in Northern Norway. Pre-feasibility study. Akvaplan-niva Report No. 4673-01.

Barlindhaug, 2005. Petroleumsvirksomhet i Barentshavet: Utbyggingsperspektivet og ringvirkninger. [Petroleum activity in the Barents Sea. Development perspectives and spin-off effects].

Bhatt, U.S., D.A. Walker, M.K. Raynolds, P.A. Bieniek, H.E. Epstein, J.C. Comiso, J.E. Pinzon, C.J. Tucker and I.V. Polyakov, 2013. Recent declines in warming and vegetation greening trends over pan-Arctic tundra. Remote Sensing, 5:4229-4254.

BirdLife International, 2015. European Red List of Birds. Office for Official Publications of the European Communities.

Bjerke, J.W., H. Tømmervik, M. Zielke and M. Jørgensen, 2015. Impacts of snow season on ground-ice accumulation, soil frost and primary productivity in a grassland of sub-Arctic Norway. Environmental Research Letters, 10:95007-95020.

Bochkov, Yu.A. and B.P. Kudlo, 1973. Long-term fluctuation of the water temperature in the Barents Sea and its influence to the total biomass of the benthos. In: Composition, Distribution and Ecology of the Bottom Fauna in the Barents Sea. pp. 3-7. PINRO Press. (In Russian)

Bogstad, B., I. Byrkjedal, A.V. Dolgov, K.V. Drevetnyak, H. Gjøsæter, Å. Høines, E. Johannesen, M.M. McBride, S. Mehl, M.S. Shevelev and O.V. Smirnov, 2008. Fish. In: Stiansen, J.A. and A. Filin (eds.), Joint IMR/PINRO report on the state of the Barents Sea Ecosystem in 2007. IMR/PINRO Joint Report Series.

Bogstad, B., A.V. Dolgov, H. Gjøsæter, E.H. Hallfredsson, E. Johannesen, S. Mehl, D.V. Prozorkevitcm, A.A. Russkikh and O.V. Smirnov, 2014. Fish. In: IMR/PINRO update of the "Joint Norwegian-Russian environmental status report on the Barents Sea Ecosystem" giving the current situation for climate, phytoplankton, zooplankton, fish, and fisheries during 2012-13. IMR/PINRO Joint Report Series 2014(1).

Borgå, K., H. Wolkers, J.U. Skaare, H. Hop, D.C.G. Muir and G.W. Gabrielsen, 2005. Bioaccumulation of PCBs in Arctic seabirds: influence of dietary exposure and congener biotransformation. Environmental Pollution, 134:397-409.

Bourmistrov, A. F. Mellemvik, A. Bambulyak, O. Gudmestad, I. Overland and A. Zolotukhin, 2015. International Arctic Petroleum Cooperation: Barents Sea Scenarios. Routledge Studies in Environmental Policy Series.

Braune, B.M., M.L. Mallory and H.G. Gilchrist, 2006. Elevated mercury levels in a declining population of ivory gulls in the Canadian Arctic. Marine Pollution Bulletin, 52:978-982.

Braune, B.M., M.L. Mallory, H.G. Gilchrist, R.J. Letcher and K.G. Drouillard, 2007. Levels and trends of organochlorines and brominated flame retardants in ivory gull eggs from the Canadian Arctic, 1976 to 2004. Science of the Total Environment, 378:403-417.

Bring. A., I. Fedorova, Y. Dibike, L. Hinzman, J. Mård, S.H. Mernild, T. Prowse, O. Semenova, S.L. Stuefer and M.-K. Woo, 2016. Arctic terrestrial hydrology: A Synthesis of processes, regional effects, and research challenges. Journal of Geophysical Research: Biogeosciences, 121:621-649.

Britayey, T.A., A.V. Rzhaysky, L.V. Pavlova and A.G. Dyoretskij, 2010. Studies on impact of the alien red king crab (*Paralithodes camtschaticus*) on shallow water benthic communities of the Barents Sea. Applied Ichthyology, 26:66-73.

Brodeur, R.D., M.B. Decker, L. Ciannelli, J.E. Purcell, N.A. Bond, P.J. Stabeno, E. Acuna and G.L. Hunt Jr., 2008. Rise and fall of jellyfish in the eastern Bering Sea in relation to climate regime shifts. Progress in Oceanography, 77:103-111.

Brotskaya, V.A. and L.A. Zenkevich, 1939. Quantitative studies of the Barents Sea bottom fauna. Trudy VNIRO, 4:3-127. (in Russian)

Brouder, P. and L. Lundmark, 2011. Climate change in Northern Sweden: intra-regional perceptions of vulnerability among winter-oriented tourism businesses. Journal of Sustainable Tourism, 19:919-933.

Brubaker, M., J. Berner, J. Bell and J. Warren, 2011. Climate Change in Kivalinla, Alaska: Strategies for Community Health. Alaska Native Tribal Health Consortium (ANTHC), Anchorage, AK.

Bryazgin, V.F., 1973. Ecological and geographical analysis of the sublittoral amphipod fauna of the Barents Sea / Distribution, composition and ecology of benthic fauna of the Barents Sea. pp. 11-12 Abstracts of the Murmansk regional scientific conference. PINRO Press. (In Russian)

Bulgarova, T., 2010. Climate change, vulnerability and adaptation among Nenets reindeer herders. In Hovelsrud, G.K. and B. Smit (eds.), Community Adaptation and Vulnerability in Arctic Regions. pp. 83-105. Springer.

Bustnes, J.O., K.E. Erikstad, S.A. Hanssen, T. Tveraa, I. Folstad and J.U. Skaare, 2006. Anti-parasite treatment removes negative effects of environmental pollutants on reproduction in an Arctic seabird. Proceedings of the Royal Society B, 273:3117-3122.

CAFF, 2013a. Arctic Biodiversity Assessment. Status and trends in Arctic biodiversity. Conservation of Flora and Fauna (CAFF), Akureyri, Iceland.

CAFF, 2013b. Arctic Biodiversity Assessment - Scientific report. Akureyri, Iceland.

Callaghan, T.V, M. Johansson, R.D. Brown, P.Y. Groisman, N. Labba and V. Radionov, 2011. Changing snow cover and its impacts. In: Snow, Water, Ice and Permafrost in the Arctic (SWIPA): Climate Change and the Cryosphere. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

Camia, A., G. Amatulli and J. San-Miguel-Ayanz, 2008. Past and future trends of forest fire danger in Europe. Institute for Environment and Sustainability, Joint Research Centre, European Commission.

Chapin, III F.S., T.V. Callaghan, Y. Bergeron, M. Fukuda, J.F. Johnstone, G. Juday and S.A. Zimov, 2004. Global change and the boreal forest: thresholds, shifting states or gradual change? Ambio, 33:361-365.

Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Kolli, W.-T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C.G. Menéndez, J. Räisänen, A. Rinke, A. Sarr and P. Whetton, 2007. Regional climate projections. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Cochrane, K., C. De Young, D. Soto and T. Bahri, 2009. Climate change implications for fisheries and aquaculture. FAO Fisheries and Aquaculture Technical Paper 530.

Daerga, L., A. Edin-Liljegren and P. Sjolander, 2008. Quality of life in relation to physical, psychological and socio-economic conditions among reindeer herding Sami. International Journal of Circumpolar Health, 67:10-28.

Dalpadado, P., 2002. Inter-specific variations in distribution, abundance and possible life 27 cycle patterns of *Themisto* spp. (Amphipoda) in the Barents Sea. Polar Biology, 25:656-666.

Dalpadado, P., A. Yamaguchi, B. Ellertsen and S. Johannessen, 2008. Trophic interactions of macro-zooplankton (krill and amphipods) in the Marginal Ice Zone of the Barents Sea. Deep Sea Research, 55:2266-2274.

Dalpadado, P., R.B. Ingvaldsen, L.C. Stige, B. Bogstad, T. Knutsen, G. Ottersen and B. Ellertsen, 2012. Climate effects on Barents Sea ecosystem dynamics. ICES Journal of Marine Science, 69:1303-1316.

Dalsoren, S.B., O. Endresen, I.S.A. Isaksen, G. Gravir and E. Sorgard, 2007. Environmental impacts of the expected increase in sea transportation, with a particular focus on oil and gas scenarios for Norway and northwest Russia. Journal of Geophysical Research, 112:D02310, doi:10.1029/2005JD006927.

de Wit, C.A., A.T. Fisk, K. Hobbs, D.C.G. Muir, G.W. Gabrielsen, R. Kallenborn, M. Krahn, R.J. Norstrom and J.U. Skaare, 2003. Persistent organic pollutants in the Arctic. In: AMAP Assessment Report. Arctic Pollution Issues. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

Degteva, S.V., V.I. Ponomarev, S.W. Eisenman and V. Dushenkov, 2015. Striking the balance: Challenges and perspectives for the protected areas network in northeastern European Russia. Ambio, 44:473-490.

Dell, J.J. and P. Pasteris, 2010. Adaptation in the oil and gas industry to projected impacts of climate change. In: Proceedings of the SPE International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production, 12–14 April 2010, Rio de Janeiro, Brazil.

Descamps, S., H. Strøm and H. Steen, 2013. Decline of an arctic top predator: synchrony in colony size fluctuations, risk of extinction and the subpolar gyre. Oecologia, 4:1271-1282.

Dudarev, A.A., P.R. Alloyarov, V.S. Chupakhin, E.V. Dushkina, Y.N. Sladkova, V.M. Dorofeyev, T.A. Kolesnikova, K.B. Fridman, L.M. Nilsson and B. Evengård, 2013. Food and water security issues in Russia I: food security in the general population of the Russian Arctic, Siberia and the Far East, 2000-2011. International Joournal of Circumpolar Health, 72:21848, doi:10.3402/ijch.v72i0.21848.

Dushkina, E.V. and A.A. Dudarev, 2015. Comparative evaluation of population morbidity in Pechenga district and in Kirovsk city of Murmansk oblast in connection with the increased exposure of residents to nickel and aluminum. In: Modern Problems of Epidemiology and Hygiene: Materials of the VII All-Russia scientific-practical conference of young scientists and specialists of Rospotrebnadzor. pp. 24-25. 8-10 December, St Petersburg. (in Russian)

Eger, K.M. and Ø. Kristiansen, 2011. Sjøsikkerhet i nordlige isdekte farvann – konpetansekrav og fremtidige behov til sjøs» utredning levert til Norsk Sjømannsforbund.

Eide, A., 2008. An integrated study of economic effects of and vulnerabilities to global warming on the Barents Sea cod fisheries. Climatic Change, 87:251-262.

Elbakidze, M., P. Angelstam and R. Axelsson, 2012. Stakeholder identification and analysis for adaptive governance in the Kovdozersky Model Forest, Russian Federation. The Forestry Chronicle, 88:298-305.

Ellingsen, I.H., P. Dalpadado, D. Slagstad and H. Loeng, 2008. Impact of climatic change on the biological production in the Barents Sea. Climatic Change, 87:155-175.

Elmhagen, B., J. Kindberg, P. Hellström and A. Angerbjörn, 2015. A boreal invasion in response to climate change? Range shifts and community effects in the borderland between forest and tundra. Ambio, 44:39-50.

Emmerson, C. and G. Lahn, 2012. Arctic Opening: Opportunity and Risk in the High North. Lloyd's, Chatham House, London.

Epstein, H.E., U.S. Bhatt, M.K. Raynolds, D.A. Walker, P.A. Bieniek, C.J. Tucker, J. Pinzon, H. Zeng, G.J. Jia, K.C. Guay and S.J. Goetz, 2014. Tundra Greenness. pp. 55-59. In: Arctic report card 2014.

Eriksen, E., 2016. Do scyphozoan jellyfish limit the habitat of pelagic species in the Barents Sea during the late feeding period? ICES Journal of Marine Science, 73:217-226.

Eriksen E. and P. Dalpadado, 2011. Long-term changes in krill biomass and distribution in the Barents Sea: are the changes mainly related to capelin stock size and temperature conditions? Polar Biology, 34:1399-1409.

Eriksson, M., L. Holmgren, U. Janlert, J.H. Jansson, D. Lundblad, B. Stegmayr and S. Söderberg, M. Eliasson, 2011. Large improvements in major cardiovascular risk factors in the population of northern Sweden: the MONICA study 1986-2009. Journal of Internal Medicine, 269:219-31.

Erikstad, K.E., H. Sandvik, T.K. Reiertsen, J.O. Bustnes and H. Strom, 2013. Persistent organic pollution in a high-Arctic top predator: sex-dependent thresholds in adult survival. Proceedings of the Royal Society B, 280: (1769). DOI: 10.1098/rspb.2013.1483.

Erkinaro, J., E. Niemelä, J.-P. Vähä, C.R. Primmer, S. Brørs and E. Hassinen, 2010. Distribution and biological characteristics of escaped farmed salmon in a major subarctic salmon river. Implications for monitoring. Canadian Journal of Fisheries and Aquatic Sciences, 67:130-142.

Eskeland, G . and L. Flottorp, 2006. Climate changes in the Arctic: A discussion of the impact on economic activity. In:

Glomsrød, S. and I. Aslaksen (eds.), The Economy of the North. pp. 81-94. Statistics Norway.

Evseev, A.V., A.P. Belousova, V.V. Ivanov, T.M. Krasovskaya, T.G. Sazykina and N.P. Solntseva, 2000. Environmental hot spots and impact zones of the Russian Arctic. UNEP, ACOPS, GEF PDF-B Project No.GF/1100-99-13. Moscow. http://npa-arctic.iwlearn.org/Documents/da_full/chap_03.pdf

Falk-Petersen, S., V. Pavlov, J. Berge, F. Cottier, K.M. Kovacs and C. Lydersen, 2015. At the rainbow's end: high productivity fueled by winter upwelling along an Arctic shelf. Polar Biology, 38:5-11.

FAO, 2010. Global Forest Resources Assessment 2010. Main Report. Food and Agriculture Organization (FAO) Forestry Working Paper 163.

Fauchald, P., P. Arneberg, J. Berge, S. Gerland, K.M. Kovacs, M. Reigstad and J.H. Sundet, 2014. An assessment of MOSJ - The state of the marine environment around Svalbard and Jan Mayen. Norwegian Polar Institute, Report No. 145.

Fauchald, P., T. Anker-Nilssen, R.T. Barrett, J.O. Bustnes, B.J. Bårdsen, S. Christensen-Dalsgaard, S. Descamps, S. Engen, K.E. Erikstad, S.A. Hanssen, S.-H. Lorentsen, B. Moe, T.K. Reiertsen, H. Strøm and G.H. Systad, 2015. The status and trends of seabirds breeding in Norway and Svalbard. NINA Report 1151.

Ficke, A.D., C.A. Myrick and L.J. Hansen, 2007. Potential impacts of global climate change on fresh water fisheries. Reviews in Fish Biology and Fisheries, 17:581-613.

Forbes, B.C. and F. Stammler, 2009. Arctic climate change discourse: the contrasting politics of research agendas in the West and Russia. Polar Research, 28:28-42.

Forbes, B.C., M.M. Fauria and P. Zetterberg, 2010. Russian Arctic warming and 'greening' are closely tracked by tundra shrub willows. Global Change Biology, 16:1542-1554.

Ford, J.D. and C. Furgal, 2009. Foreword to the special issue: climate change impacts, adaptation and vulnerability in the Arctic. Polar Research, 28:S1-S9.

Førland, E.I., J. Steen Jacobsen, J.M. Denstadli, M. Lohmann, I. Hanssen-Bauer, H.O. Hygen and H. Tømmervik, 2013. Cool weather tourism under global warming: Comparing Arctic summer tourists' weather preferences with regional climate statistics and projections. Tourism Management, 36:567-579.

Fossheim, M., E.M. Nilssen and M. Aschan, 2006. Fish assemblages in the Barents Sea. Marine Biology Research, 2:260-269.

Fossheim, M., R. Primicerio, E. Johannesen, R.B. Ingvaldsen, M.M. Aschan and A.V. Dolgov, 2015. Recent warming leads to a rapid borealization of fish communities in the Arctic. Nature Climate Change, 5:672-677.

Frey, K.E., J.C. Comiso, L.W. Cooper , R.R. Gradinger, J.M. Grebmeier, S.-I. Saitoh and J.-É. Tremblay, 2014. Arctic Ocean Primary Productivity, pp. 44-54 [Arctic Report Card 2014], http://www.arctic.noaa.gov/reportcard.

Frost, G.V. and H.E. Epstein, 2014. Tall shrub and tree expansion in Siberian tundra ecotones since the 1960s. Global Change Biology, 20:1264-1277.

Galkin, Y.I., 1987. Climatic fluctuations and long-term changes in benthic biomass in the Barents Sea (by the example of the mollusc *Lepeta coeca* – Gastropoda: Lepetidae). In: Biological Resources of the Arctic and Antarctic. pp. 90-122. Nauka Press. (In Russian)

García-Rosell, J.-C., M. Hakkarainen, M. Koskinen, T. Tekoniemi-Selkälä, M. Vähäkuopus, P. Paloniemi and N. Syrjälä, 2013. Barents Tourism Action Plan. LUC Tourism, Lapland University Consortium, Rovaniemi.

Gradinger, R., 2015. Status for økosystemene i Barentshavet og Polhavet [Ecosystem status in the Barents Sea and Arctic Ocean]. In: Bakketeig, I.E., H. Gjøsæter, M. Hauge, B.H. Sunnset and K.Ø. Toft. (Eds). Havforskningsrapporten 2015 [Marine Research Report 2015]. Norwegian Institute for Marine Research.

Grebmeier, J.M., J.E. Overland, S.E. Moore, E.V. Farley, E.C. Carmack, L.W. Cooper, K.E. Frey, J.H. Helle, F.A. McLaughlin and S.L. McNutt, 2006. A major ecosystem shift in the northern Bering Sea. Science, 311:1461-1464.

Hakala, K., H. Laurila and T. Mela, 2005. Increase in atmospheric CO_2 and ambient temperatures in the North. Journal of Crop Improvement, 13:239-255.

Haldorsen, S. and M. Heim, 1999. An Arctic groundwater system and its dependence upon climatic change: An example from Svalbard. Permafrost and Periglacial Processes, 10:137-149.

Hannukkala, A., 2002. Possible effects of climate change in grassland productivity and yield quality in Northern Finland. In: Duran, J-L. et al. (eds.), Multi-function Grasslands: Quality Forages, Animal Products and Landscapes, pp. 690-691. European Grassland Federation.

Hansen, B.B., K. Isaksen, R.E. Benestad, J. Kohler, A. Ø. Pedersen, L.E. Loe, S.J. Coulson, J.O. Larsen and Ø. Varpe, 2014. Warmer and wetter winters: characteristics and implications of an extreme weather event in the High Arctic. Environmental Research Letters, 9: doi:10.1088/1748-9326/9/11/114021.

Hansson, H., R. Ferguson, C. Olofsson and L. Rantamäki-Lahtinen, 2013. Farmers' motives for diversifying their farm business - The influence of family. Journal of Rural Studies, 32: 240-250.

Härkönen, L., S. Härkönen, A. Kaitala, S. Kaunisto, R. Kortet, S. Laaksonen and H. Ylönen, 2010. Predicting range expansion of an ectoparasite – the effect of spring and summer temperatures on deer ked *Lipoptena cervi* (Diptera: Hippoboscidae) performance 11 along a latitudinal gradient. Ecography, 33:906-912.

Harsem, Ø., A. Eide and K. Heen, 2011. Factors influencing future oil and gas prospects in the Arctic. Energy Policy, 39:8037-8045.

Hegseth, E.N., 1998. Primary production of the northern Barents Sea. Polar Research, 17:113-123.

Heino, M.,V. Kaitala, E. Ranta and J. Lindstrom, 1997. Synchronous dynamics and rates of extinction in spatially structured populations. Proceedings of the Royal Society B, 264:481-486.

Heino, J., J. Erkinaro, A. Huusko and M. Luoto, 2016. Climate change effects on freshwater fishes, conservation and management. In: Closs, G., M. Krkosek and J. Olden (eds.), Conservation of Freshwater Fishes. pp. 76-106. Cambridge University Press.

Herzon, I., T. Rajala, P. Heinimaa, T. Birge, E. Kiviharju, M. Keskitalo, J. Kantanen and J. Helenius, 2014. FAO State of Biodiversity for Food and Agriculture in Finland. FAO Publication 2014:11.

Herrmann, T.M., P. Sandström, K. Granqvist, N. D'Astous, J. Vannar, H. Asselin, N. Saganash, J. Mameamskum, G. Guanish, J.-B. Loon and R. Cuciurean, 2014. Effects of mining on reindeer/caribou populations and indigenous livelihoods: community-based monitoring by Sami reindeer herders in Sweden and First Nations in Canada. The Polar Journal, 4:28-51.

Hickler, T., K. Vohland, J. Feehan, P.A. Miller, B. Smith, L. Costa, T. Giesecke, S. Fronzek, T.R. Carter, W. Cramer, I. Kuhn and M.T. Sykes, 2012. Projecting the future distribution of European potential natural vegetation zones with a generalized, tree species-based dynamic vegetation model. Global Ecology and Biogeography, 21:50-63.

Hildén, M., P. Jokinen J. and Aakkula, 2012. The sustainability of agriculture in a northern industrialized country – from controlling nature to rural development. Sustainability, 4: 3387-3403.

Himanen, S.J., K. Hakala and H. Kahiluoto, 2013. Crop responses to climate and socioeconomic change in northern regions. Regional Environmental Change, 13:17-32.

Hodge, A., 2014. Mining company performance and community conflict: moving beyond a seeming paradox. Journal of Cleaner Production, 84:27-33.

Höglind, M., A.K. Bakken, J.M. Jørgensen and L. Østrem, 2010. Tolerance to frost and ice encasement in cultivars of timothy and perennial ryegrass during winter. Grass and Forage Science, 65:431-445.

Höglind, M., S.M. Thorsen and M.A. Semenov, 2013. Assessing uncertainties in impact of climate change on grass production in Northern Europe using ensembles of global climate models. Agricultural and Forest Meteorology, 170:103-113.

Holma-Suutari, A., P. Ruokojärvi, S. Laaksonen, H. Kiviranta, M. Nieminen, M. Viluksela and A. Hallikainen, 2014. Persistent organic pollutant levels in semi-domesticated reindeer (*Rangifer tarandus tarandus* L.), feed, lichen, blood, milk, placenta, foetus and calf. Science of the Total Environment, 476-477: 125-135.

Holter, M. and N. Magnusson, 2014. Arctic Oil Still Seen Decades Off as Producers Balk at Costs. Bloomberg. www.bloomberg.com/news/articles/2014-02-23/arctic-oil-still-seen-decades-away-as-producers-balk-at-costs

Hønneland, G., 2006. Kvotekamp og kyststatssolidaritet: Norsk-russisk fiskeriforvaltning gjennom 30 år [Quota Battles and Coast State Solidarity: 30 Years of Norwegian-Russian Fishery Management]. Fagbokforlaget, Bergen.

Hop, H., and H. Gjøsæter, 2013. Polar cod (*Boreogadus saida*) and capelin (*Mallotus villosus*) as key species in marine food webs of the Arctic and the Barents Sea. Marine Biological Research, 9:878-894.

Hopkins, C.C.E. and E.M. Nilssen, 1991. The rise and fall of the Barents Sea capelin (*Mallotus villosus*): a multivariate scenario. Polar Research, 10:535-546.

Hovelsrud, G.K., B. Poppel, B.E.H. van Oort and J. Reist, 2011. Arctic societies, cultures, and peoples in a changing cryosphere. In: Snow, Water, Ice and Permafrost in the Arctic (SWIPA): Climate Change and the Cryosphere. Arctic Monitoring and Assessment Programme (AMAP), Oslo.

Huntington, H.P., 2013. Provisioning and cultural services. In: Meltofte, H. (ed.), Arctic Biodiversity Assessment: Status and trends in Arctic biodiversity. pp. 485-518. Conservation of Arctic Flora and Fauna (CAFF).

Huntington, H.P and S. Fox, 2005. The changing Arctic: indigenous perspectives. In: Arctic Climate Impact Assessment. pp. 61-98. Cambridge University Press.

Huse, G. and I. Ellingsen, 2008. Capelin migrations and climate change - a modelling analysis. Climatic Change, 87:177-197.

ICES, 2015a. Second Interim Report of the Working Group on the Integrated Assessments of the Barents Sea (WGIBAR), 1-4 June 2015, Kirkenes, Norway. ICES CM 2015/SSGIEA:04.

ICES, 2015b. Barents Sea Ecoregion - Ecosystem overview. In: Report of the ICES Advisory Committee 2015. ICES Advice 2015, Book 3, Section 3.1.

ICES, 2016. Barents Sea Ecoregion – Ecosystem Overview. Version 2, 13 May 2016. ICES Ecosystem Overviews. International Council for the Exploration of the Sea (ICES).

Ims, R.A., J.U. Jepsen, A. Stien and N.G. Yoccoz, 2013. Science plan for COAT: Climate-ecological Observatory for Arctic Tundra. Fram Centre: Tromsø, Norway.

IWC, 2006. Features of sound and seismic surveys. Report of the Standing Working Group on Environmental Concerns. International Whaling Commission (IWC).

Jaakkola, L.M., M.M. Heiskanen, A.M. Lensu and M.T. Kuitunen, 2013. Consequences of forest landscape changes for the availability of winter pastures to reindeer (*Rangifer tarandus tarandus*) from 1953 to 2003 in Kuusamo, northeast Finland. Boreal Environment Research, 18:459-472.

Jakobsen, T. and V.K. Ozhigin, 2011. The Barents Sea – ecosystem, resources, management. Half a century of Russian-Norwegian cooperation. Tapir Academic Press.

Jansson, R., C. Nilsson, E.C.H. Keskitalo, T. Vlasova, M.-L. Sutinen, J. Moen, F. Chapin III, K. Bråthen, M. Cabeza, T.V. Callaghan, B. Van Oort, H. Dannevig, I.A. Bay-larsen, R.A. Ims and P. Aspholm. 2015. Future changes in the supply of goods and services from natural ecosystems: prospects for the European north. Ecology and Society, 20:32. doi:10.5751/ES-07607-200332.

Jantunen, J., T. Kauppila, M.L. Räisänen, H. Komulainen, P. Kauppila, T. Kauppinen, H. Törmä, M. Leppänen, A. Tornivaara,

A. Pasanen, E. Kemppainen, A. Raunio, M. Marttunen, J. Mustajoki, S. Kauppi, P. Ekholm, T. Huttula, H. Makkonen and K. Loukola-Ruskeeniemi, 2015. Guide: Environmental Impact Assessment Procedure for mining projects in Finland. Ministry of Employment and the Economy, Finland.

Johannesen, E., Å.S. Høines, A.V. Dolgov and M. Fossheim, 2012. Demersal fish assemblages and spatial diversity patterns in the Arctic-Atlantic transition zone in the Barents Sea. PLoS ONE, 7:e34924.

Jorgenson, M.T., C.H. Racine, J.C. Walters and T.E. Osterkamp, 2001. Permafrost degradation and ecological changes associated with a warming climate in central Alaska. Climatic Change, 48:551-579.

Jørgensen, J.M., L. Østrem and M. Höglind, 2010. De-hardening in contrasting cultivars of timothy and perennial ryegrass during winter and spring. Grass and Forage Science, 65:38-48.

Jørgensen, L.L, B. Planque, T.H. Thangstad and G. Certain, 2015. Vulnerability of megabenthic species to trawling in the Barents Sea. ICES Journal of Marine Science, 73 (suppl_1):i84-i97.

Kaiser, M.J. and S.J. de Groot, 2000. Effects of fishing on non-target species and habitats. Biological, conservation and socio-economic issues. Blackwell Science.

Kaiser, N. and E.S. Renberg, 2012. Suicidal expressions among the Swedish reindeer-herding Sami population. Suicidal Online, 3:102-113.

Kaiser, N., T. Ruong and E.S. Renberg, 2013. Experiences of being a young male Sami reindeer herder: a qualitative study in perspective of mental health. International Journal of Circumpolar Health, 72:20926, doi:10.3402/ijch.v72i0.20926.

Kalberer, S.R., M. Wisniewski and R. Arora, 2006. De-acclimation and re-acclimation of cold-hardy plants: Current understanding and emerging concepts. Plant Science, 171:3-16.

Karvinen, S., E. Välkky, T. Torniainen and Y. Gerasimov, 2006. Northwest Russian Forestry in a Nutshell. Working Papers of the Finnish Forest Research Institute, 30.

Kässi, P., H. Känkänen, O. Niskanen, H. Lehtonen and M. Höglind, 2015. Farm level approach to manage grass yield variation under climate change in Finland and north-western Russia. Biosystems Engineering, 140:11-22.

Kauppi, P., M. Posch and P. Pirinen, 2014. Large impacts of climatic warming on growth of boreal forests since 1960. PlosOne, 9(11):e111340, doi:10.1371/journal.pone.0111340.

Kauppila, P., 2004. Matkailukeskusten kehitysprosessi ja rooli aluekehityksessä paikallistasolla: esimerkkeinä Levi, Ruka, Saariselkä ja Ylläs. [The development process of tourist resorts and their role in regional development] Nordia Geographical Publications, 33.

Kauppila, P., M.L. Räisänen and S. Myllyoja, 2013. Best Environmental Practices in Metal Ore Mining. Finnish Environment 29en/2011.

Kellomäki, S., H. Strandman, T. Nuutinen, H. Peltola, K.T. Korhonen and H. Väisänen, 2005. Adaptation of forest ecosystems, forests and forestry to climate change. FINADAPT Working Paper 4, Finnish Environment Institute.

Kellomäki, S., H. Peltola, T. Nuutinen, K.T. Korhonen and H. Strandman, 2008. Sensitivity of managed boreal forests in Finland to climate change, with implications for adaptive management. Philosophical Transactions of the Royal Society B, 363:2341-2351.

Kietäväinen, A. and S. Tuulentie, 2013. Tourism strategies and climate change: rhetoric at both strategic and grassroots levels about growth and sustainable development in Finland. Journal of Sustainable Tourism, 21:845-861.

Kirkinen, J., A. Martikainen, H. Holttinen, I. Savolainen, O. Auvinen and S. Syri, 2005. Impacts on the energy sector and adaptation of the electricity network business under a changing climate in Finland. Finnish Environment Institute, Mimeographs 340.

Kirtman, B., S.B. Power, J.A. Adedoyin, G.J. Boer, R. Bojariu, I. Camilloni, F.J. Doblas-Reyes, A.M. Fiore, M. Kimoto, G.A. Meehl, M. Prather, A. Sarr, C. Schär, R. Sutton, G.J. van Oldenborgh, G. Vecchi and H.J. Wang, 2013. Near-term climate change: projections and predictability. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. pp. 953-1028. Cambridge University Press.

Kiyko, O.A. and V.B. Pogrebov, 1997. Long-term benthic population changes (1920-1930s-present) in the Barents and Kara Sea. Marine Pollution Bulletin, 35:322-332.

Kiyko, O.A. and V.B. Pogrebov, 1998. Statistical analysis of spatio-temporal structure of the bottom population of the Barents Sea and adjacent waters. Biologiya Morya, 24:3-9. (In Russian)

Knobblock, E. and Ö. Pettersson, 2010. Restructuring and risk-reduction in mining: employment implications for northern Sweden. Fennia, 188:61-75.

Kohllechner-Autto, M., 2011. Strategic tourism development in the Barents Region – an analysis. Public–Private Partnership in Barents Tourism. Lapland University Consortium, Rovaniemi.

Kolstad, E.W. and T.J. Bracegirdle, 2008. Marine cold-air outbreaks in the future: an assessment of IPCC AR4 model results for the Northern Hemisphere. Climate Dynamics, 30:871-885.

Korneev, O., O. Titov, G.I. van der Meeren, P. Arneberg, J. Tchernova and N.M. Jørgensen, 2015. Final report 2012–2015. Joint Russian-Norwegian Monitoring Project – Ocean 3. Norsk Polarinstitutt. Brief Report Series/Kortrapport no. 30.

Kortsch, S., R. Primicerio, F. Beuchel, P.E. Renaud, J. Rodrigues, O.J. Lønne and B. Gulliksen, 2012. Climate-driven regime shifts in Arctic marine benthos. Proceedings of the National Academy of Sciences, 109:14052-14057.

Kovacs, K.M., S. Moore, J.E. Overland and C. Lydersen, 2011. Impacts of changing sea-ice conditions on Arctic marine mammals. Marine Biodiversity, 41:181-194.

Kumpula, J., M. Kurkilahti, T. Helle and A. Colpaert, 2014. Both reindeer management and several other land use factors explain the reduction in ground lichens (*Cladonia* spp.) in pastures grazed by semi-domesticated reindeer in Finland. Regional Environmental Change, 14:541-559.

Lafferty, K.D., S. Allesina, M. Arim, C.J. Briggs, G. De Leo, A.P. Dobson, J.A. Dunne, P.T. Johnson, A.M. Kuris, D.J. Marcogliese, N.D. Martinez, J. Memmott, P.A. Marquet, J.P. McLaughlin, E.A. Mordecai, M. Pascual, R. Poulin and D.W. Thieltges, 2008. Parasites in food webs: the ultimate missing links. Ecology Letters, 11:533-546.

Laidre, K.L., I. Stirling, L. Lowry, Ø. Wiig, M.P. Heide-Jørgensen and S.H. Ferguson, 2008. Quantifying the sensitivity of arctic marine mammals to climate-induced habitat change. Ecological Applications, 18:S97-S125.

Laidre, K.L., H. Stern, K.M. Kovacs, L. Lowry, S.E. Moore, E.V. Regehr, S.H. Ferguson, Ø. Wiig, P. Boveng, R.P. Angliss, E.W. Born, D. Litovka, L. Quakenbush, C. Lydersen, D. Vongraven and F. Ugarte, 2015. Arctic marine mammal population status, sea ice habitat loss, and conservation recommendations for the 21st century. Conservation Biology, 29:724-737.

Lamers, M. and A. Pashkevich, 2015. Short-circuiting cruise tourism practices along the Russian Barents Sea coast? The case of Arkhangelsk. Current Issues in Tourism, doi:10.1080/13683500.2015.1092947.

Larsen, J.N. and L. Huskey, 2010. Material wellbeing in the Arctic. In: Arctic Social Indicators: A Follow-Up to the Arctic Human Development Report. pp. 47-66. TemaNord 2010:519, Nordic Council of Ministers, Copenhagen, Denmark.

Larsen, N.J. and G. Fondahl (eds.), 2014. Arctic Human Development Report 2014. Regional Processes and Global Linkages. TemaNord 2014:567. Nordic Council of Ministers.

Larsen, J.N., O.A. Anisimov, A. Constable, A.B. Hollowed, N. Maynard, P. Prestrud, T.D. Prowse and J.M.R. Stone, 2014. Polar regions. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspect. pp. 1567-1612. Contribution of working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Lassere, F. and S. Pelletier, 2011. Polar super seaways? Maritime transport in the Arctic: an analysis of shipowner's intentions. Journal of Transport Geography, 19:1465-1473.

Legagneux, P., G. Gauthier, N. Lecomte, N.M. Schmidt, D.Reid, M.C. Cadieux, D. Berteaux, J. Bety, C.J. Krebs, R.A. Ims, N.G. Yoccoz, R.I.G. Morrison, S.J. Leroux, M. Loreau and D. Gravel, 2014. Climate and herbivore body size determine how arctic terrestrial ecosystems work. pp. 67-69. In: Arctic Report Card 2014.

Lenton, T.M., 2012. Arctic climate tipping points. Ambio, 41:10-22.

Letcher, R.J., J.O. Bustnes, R. Dietz, B.M. Jenssen, E.H. Jørgensen, C. Sonne, J. Verreault, M.M. Vijayan and G.W. Gabrielsen, 2010. Exposure and effects assessment of persistent organohalogen contaminants in arctic wildlife and fish. Science of the Total Environment, 408:2995-3043.

Lindholt, L. and S. Glomsrød, 2013. The Arctic: No big bonanza for the global petroleum industry. Energy Economics, 34:1465-1474.

Link, M. and R.S.J. Tol, 2006. Economic impacts on key Barents Sea fisheries arising from changes in the strength of the Atlantic thermohaline circulation. Global Environmental Change, 19:422-433.

Loginovich, E., 2012. Enhancing the infrastructure of marine transportation system in the Russian Arctic. Collection of reports. Joint Norwegian-Russian seminars devoted to jubilees of Lomonosov and Nansen, Tromsø and Archangelsk.

Lucia, M., N. Verboven, H. Strøm, C. Miljeteig, M.V. Gavrilo, B.M. Braune, D. Boertmann, G.W. Gabrielsen, 2015. Circumpolar contamination in eggs of the high-arctic ivory gull *Pagophila eburnea*. Environmental Toxicology and Chemistry, 34:1552-1561.

Lundmark, T., J. Bergh, P. Hofer, A. Lundstrom, A. Nordin, B.C. poudel, R. Sathre, R. Taverna and F. Werner, 2014. Potential roles of Swedish forestry in the context of climate change mitigation. Forests, 5:557-578.

Lyubin, P., N. Anisimova and I. Manushin, 2011. Long-term effects on benthos of the use of bottom fishing gears. In: Jakobsen, T. and V. Ozhigin (eds.), The Barents Sea – Ecosystem, Resources, Management. Half a century of Russian-Norwegian cooperation, pp. 768-775. Tapir Academic Press.

Marcogliese, D.J., 2001. Implications of climate change for parasitism of animals in the aquatic environment. Canadian Journal of Zoology, 79:1331-1352.

Matishov, G.G. (ed.), 2007. Complex investigations of processes, characteristics and resources of Russian seas of North European Basin. Kola Science Center RAS.

Matsumoto, N., 2009. Snow molds: A group of fungi that prevail under snow. Microbes and Environments, 24:14-20.

McBride, M.M., A. Filin, O. Titov and J.E. Stiansen (eds.), 2014. IMR/PINRO update of the "Joint Norwegian-Russian environmental status report on the Barents Sea Ecosystem" giving the current situation for climate, phytoplankton, zooplankton, fish, and fisheries during 2012-13. IMR/PINRO Joint Report Series.

McBride, M.M., J.R. Hansen, O. Korneev and O. Titov (eds.), 2016. Joint Norwegian - Russian environmental status 2013. Report on the Barents Sea Ecosystem. Part II - Complete report. IMR/PINRO Joint Report Series, 2016 (2).

McKinney, M.A., S.J. Iverson, A.T. Fisk, C. Sonne, F.F. Riget, R.J. Letcher, M.T. Arts, E.W. Born, A. Rosing-Asvid and R. Dietz, 2013. Global change effects on the longterm feeding ecology and contaminant exposures of East Greenland polar bears. Global Change Biology, 19:2360-2372.

Mehlum, F. and F.F. Daelemans, 1995. PCBs in Arctic seabirds from the Svalbard region. Science of the Total Environment, 160-61:441-446.

Melia, N., K. Haines and E. Hawkins, 2016. Sea ice decline and 21st century trans-Arctic shipping routes. Geophysical Research Letters, 43:9720-9728.

Melle, W. and H.R. Skjoldal, 1998. Spawning and development of *Calanus* spp. in the Barents Sea. Marine Ecology Progress Series, 169:211-228.

Miljeteig, C., H. Strom, M.V. Gavrilo, A. Volkov, B.M. Jenssen and G.W. Gabrielsen, 2009. High levels of contaminants in ivory gull *Pagophila eburnea* eggs from the Russian and Norwegian Arctic. Environmental Science and Technology, 43:5521-5528.

Molau, U., 2010. Long-term impacts of observed and induced climate change on tussock tundra near its southern limit in northern Sweden. Plant Ecology and Diversity, 3:29-34.

Multiconsult, 2014. Strategisk Handlingsplan for Longyearbyen, 2014 [Strategic Action Plan for Longyearbyen, 2014], Vedtatt av Longyearbyen lokalstyre sak 3/14, 11.02.14 [Adopted by the Longyearbyen Community Case 3/14, 02.11.14], Longyearbyen.

Murvoll, K.M., J.U. Skaare, H. Jensen and B.M. Jenssen, 2007. Associations between persistent organic pollutants and vitamin status in Brunnich's guillemot and common eider hatchlings. Science of the Total Environment, 381:134-145.

Niemelä, E., J. Erkinaro, J.B. Dempson, M. Julkunen, A. Zubchenko, S. Prusov, M.A. Svenning, R. Ingvaldsen, M. Holm and E. Hassinen, 2004. Temporal synchrony and variation in abundance of Atlantic salmon in two subarctic Barents Sea rivers: influence of oceanic conditions. Canadian Journal of Fisheries and Aquatic Sciences, 61:2384-2391.

Nilssen, F., 2003 Economic Co-operation in the Barents Region: Russian-Norwegian trade in the Fishing Industry. In: The NEBI Yearbook 2003, North European and Baltic Sea Integration. pp. 151-164. Springer,

Nilsson, L.M., G. Destonuni, J. Berner, A. Dudarev, G. Mulvad, J.O. Odland, A. Rautio, C. Tikhonov and B. Evengård, 2013. A call for urgent monitoring of food and water security based on relevant indicators for the arctic. Ambio, 42:816-822.

Niva, T., E. Salonen, S. Raineva, A. Savikko, M. Vaajala and H. Jutila, 2015. Inarijärven ja sen sivuvesistöjen kalataloudellinen velvoitetarkkailu 2014 [Obligatory monitoring of fishing in Inarijärvi lake and its collateral water bodies 2014]. Luonnonvarakeskus.

Nordregio, 2011. Megatrends. TemaNord 2011:527. Nordregio.

Norheim, G. and B. Kjoshanssen, 1984. Persistent chlorinated hydrocarbons and mercury in birds caught off the west-coast of Spitsbergen. Environmental Pollution Series A, 33:143-152.

Norwegian Ministry of Foreign Affairs, 2014. Verdiskapning og ressurser. Klimaendringer og kunnskap. Utviklingen nord på kloden angår oss alle, 2014 [Value and resources. Climate change and knowledge. Developments in the north of the planet affect all of us. 2014], Utenriksdepartementet, Oslo.

Norwegian Polar Institute, 2016. Environmental Monitoring of Svalbard and Jan Mayen: Cruise tourism. www.mosj.no/no/pavirkning/ferdsel/cruiseturisme.html

Nuttal, M., F. Berkes, Forbes, G. Kofinas, T. Vlassova and G. Wenzel, 2005. Hunting, herding, fishing, and gathering: Indigenous Peoples and renewable resource use in the Arctic. In: Arctic Climate Impact Assessment. pp. 649-690. Cambridge University Press.

Nyvold, C.E., T. Steffensen and P.K. Husøy, 2014. Levert 2013: Supplier Industry in Northern Norway for the Petroleum Sector. KunnskapsParken, Bodø.

O'Neill, B.C., E. Kriegler, K.L. Ebi, E. Kemp-Benedict, K. Riahi, D.S. Rothman, B.J. van Ruijven, D.P. van Vuuren, J. Birkmann, K. Kok, M. Levy and W. Solecki, 2017. The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. Global Environmental Change, 42:169-180.

Ogden, N.H., C. Bouchard, K. Kurtenbach, G. Margos, L.R. Lindsay, L. Trudel, S. Nguon and F. Milord, 2010. Active and passive surveillance and phylogenetic analysis of *Borrelia burgdorferi* elucidate the process of Lyme Disease risk emergence in Canada. Environmental Health Perspectives, 118:909-914.

Omma, L., M. Sandlund and L. Jacobsson, 2013. Suicidal expressions in young Swedish Sami, a cross-sectional Study. International Journal of Circumpolar Health, 72: 19862, doi:10.3402/ijch.v72i0.19862.

Orr, J.C., V.J. Fabry, O. Aumont, L. Bopp, S.C. Doney, R.A. Feely, A. Gnanadesikan, N. Gruber, A. Ishida, F. Joos, R.M. Key, K. Lindsay, E. Maier-Reimer, R. Matear, P. Monfray, A. Mouchet, R.G. Najjar, G.-K. Plattner, K.B. Rodgers, C.L. Sabine, J.L. Sarmiento, R. Schlitzer, R.D. Slater, I.J. Totterdell, M.-F. Weirig, Y. Yamanaka and A. Yool, 2005. Anthropogenic ocean acidification over the twenty-first century and its impacts on calcifying organisms. Nature, 437:681-686.

OSPAR, 2009. Overview of the Impacts of Anthropogenic Underwater Sound in the Marine Environment. OSPAR Commission, London.

Østreng, W., K.M. Eger, B. Fløistad, A. Jørgensen-Dahl, L. Lothe, M. Mejlænder-Larsen and T. Wergeland, 2013. Shipping in Arctic Waters. A Comparison of the Northeast, Northwest and Trans Polar Passages. Springer.

Otero, J., J.H. L'Abée-Lund, T. Castro-Santos, K. Leonardsson, G.O. Storvik, B. Jonsson, B. Dempson, I.C. Russell, A.J. Jensen, J.-L. Baglinière, M. Dionne, J.D. Armstrong, A. Romakkaniemi, B.H. Letcher, J.F. Kocik, J. Erkinaro, R. Poole, G. Rogan, H. Lundqvist, J.C. MacLean, E. Jokikokko, J.V. Arnekleiv, R.J. Kennedy, E. Niemelä, P. Caballero, P.A. Music, T. Antonsson, S. Gudjonsson, A.E. Veselov, A. Lamberg, S. Groom, B.H. Taylor, M. Taberner, M. Dillane, F. Arnason, G. Horton, N.A. Hvidsten, I.R. Jonsson, N. Jonsson, S. McKelvey, T. Næsje, Ø. Skaala, G.W. Smith, H. Sægrov, N.C. Stenseth and L.A. Vøllestad, 2014. Basin-scale phenology and effects of climate variability on global timing of initial seaward migration of Atlantic salmon (*Salmo salar*). Global Change Biology, 20:61-75.

Ottersen, G., N.C. Stenseth and J.W. Hurrell, 2004. Climatic fluctuations and marine systems: a general introduction to the ecological effects. In: Stenseth, N.C., G. Ottersen, J.W. Hurrell and A. Belgrano (eds.), Marine Ecosystems and Climate Variation: The North Atlantic. pp. 3-14. Oxford University Press.

Ottersen, G., S. Kim, G. Huse, J.J. Polovina and N.C. Stenseth, 2010. Major pathways by which climate may force marine fish populations. Journal of Marine Systems, 79:343-360.

Pagano, A.M., G.M. Durner, S.C. Amstrup, K.S. Simac and G.S.

York, 2012. Long-distance swimming by polar bears (*Ursus maritimus*) of the southern Beaufort Sea during years of extensive open water. Canadian Journal of Zoology, 90:663-676.

Parkinson, A.J., B. Evengard, J.C. Semenza, N. Odgen, M.L. Borresen, J. Berner, M. Brubaker, A. Sjostedt, M. Evander, D.M. Hondula, B. Menne, N. Pshenichnaya, P. Gounder, T. Larose, B. Revich, K. Hueffer and A. Albihn, 2014. Climate change and infectious diseases in the Arctic: establishment of a circumpolar working group. International Journal of Circumpolar Health, 73:25163, doi:10.3402/ijch.v73.25163.

Parviainen, J., E. Vapaavuori and A. Mäkelä (eds.), 2010. Finland's Forests in Changing Climate. Working Papers of the Finnish Forest Research Institute 159.

Pashkevich, A. and O. Stjernström, 2014. Making Russian Arctic accessible for tourists: analysis of the institutional barriers. Polar Geography, 37:137-156.

Patin, S.A., 2008. Oil Spills in the Sea and their Impact on the Marine Environment and Living Resources. VNIRO Publishing. (In Russian)

Peltola, H., V.-P. Ikonen, H. Gregow, H. Strandman, A. Kilpeläinen, A. Venäläinen and S. Kellomäki, 2010. Impacts of climate change on timber production with implications on the regional risks of wind-induced damage to forests in Finland. Forest Ecology and Management, 260:833-845.

Peltonen-Sainio, P., L. Jauhiainen and K. Hakala, 2009. Climate change and prolongation of growing season: changes in regional potential for field crop production in Finland. Agricultural and Food Science, 18:171-190.

Perry, R.I., P. Cury, K. Brander, S. Jennings, C. Mollmann and B. Planque, 2010. Sensitivity of marine systems to climate and fishing: Concepts, issues and management responses. Journal of Marine Systems, 79:427-435.

Pettersen, T., 2011. Russia to have ten Arctic rescue centers by 2015. Barents Observer, 18 November. http://barentsobserver.com/en/topics/russia-have-ten-arctic-rescue-centers-2015.

Planque, B., J.M. Fromentin, P. Cury, K.F. Drinkwater, S. Jennings, R.I. Perry and S. Kifani, 2010. How does fishing alter marine populations and ecosystems sensitivity to climate? Journal of Marine Systems, 79:403-417 .

Pogodaev, M., A. Oskal, S. Avelova, P. Bergkvist, P. Burgess, A. Degteva, R.B.M. Eira, I.M. Gaup Eira, O.J. Gaup, A. Gerasimova, Y. Gu, K. Krarup-Hensen, M.A. Kemi, A.M. Magga, S.D. Mathiesen, H. Omma, P.J. Partapuoli, V. Parfenov, E. Sara, N. Serotetto, I. Slepushkin, A. Silviken, P. Stoor, K. Tibichi, J.D. Turi, I. Turi, E.I. Turi and E. Walkeapaa, 2015. Arctic Council EALLIN report: Youth – the future of reindeer herding peoples.

Post, E., M.C. Forchhammer, M.S. Bret-Harte, T.V. Callaghan, T.R. Christensen, B. Elberling, A.D. Fox, O. Gilg, D.S. Hik, T.T. Høye, R.A. Ims, E. Jeppesen, D.R. Klein, J. Madsen, A.D. McGuire, S. Rysgaard, D.E. Schindler, I. Stirling, M.P. Tamstorf, N.J.C. Tyler, R. van der Wal, J. Welker, P.A. Wookey, N.M. Schmidt and P. Aastrup, 2009. Ecological dynamics across the Arctic associated with recent climate change. Science, 325:1355-1358.

Prowse, T.D., F.J. Wrona, J.D. Reist, J.J. Gibson, J.E. Hobbie, L.M. Lévesque and W.F. Vincent, 2006. Climate change effects on hydroecology of Arctic freshwater ecosystems. Ambio, 35:347-358.

Raaymakers, S., 2003. Maritime transport and high seas governance – regulation, risks and the IMO regime. International Workshop on Governance of High Seas Biodiversity Conservation, 17-20 June 2003, Cairns, Australia.

Rapacz, M., Å. Ergon, M. Höglind, M. Jørgensen, B. Jurczyk, L. Østrem, O.A. Rognli and A.M. Tronsmo, 2014. Overwintering of herbaceous plants in changing climate. Still more questions than answers. Plant Science, 225:34-44.

Reeves, R.R., P.J. Ewins, S. Agbayani, M.P. Heidi-Jorgensen, K.M. Kovacs, C. Lydersen, R. Suydam, W. Elliott, G. Polet, Y. van Dijk and R. Blijleven, 2014. Distribution of endemic cetaceans in relation to hydrocarbon development and commercial shipping in a warming Arctic. Marine Policy, 44:375-389.

Reist, J.D., F.J. Wrona, T.D. Prowse, M. Power, J.B. Dempson, R.J. Beamish, J.R. King, T.J. Carmichael and C.D. Sawatzky, 2006. General effects of climate change on Arctic fishes and fish populations. Ambio, 35:370-380.

Research Council of Norway, 2013. Winter: New Turns in Arctic Winter Tourism. https://uit.no/prosjekter/prosjekt?p_document_id=345272 Accessed 22 October 2015.

Revich, B., 2008. Climate change impact on public health in the Russian Arctic, 2008. www.unrussia.ru/sites/default/files/doc/Arctic-eng.pdf

Revich, B. and M. Podolnaya, 2011. Thawing of permafrost may disturb historic cattle burial grounds in East Siberia. Global Health Action, 4:8482, doi:10.3402/gha.v4i0.8482.

Revich, B.A. and D.A. Shaposhnikov, 2012. Climate change, heat waves, and cold spells as risk factors for increased mortality in some regions of Russia. Studies on Russian Economic Development, 23:195-207.

Reyer, C., P. lasch-Born, F. Sucklow, M. Gutsch, A. Murawski and T. Pilz, 2014. Projections of regional changes in forest net primary productivity for different tree species in Europe driven by climate change and carbon dioxide. Annals of Forest Science, 71:211-225.

Rijnsdorp, A.D., M.A. Peck, G.H. Engelhard, C. Mollmann and J.K. Pinnegar, 2009. Resolving the effect of climate change on fish populations. ICES Journal of Marine Science, 66:1570-1583.

Roderfeld, H., E. Blyth, R. Dankers, G. Huse, D. Slagstad, I. Ellingsen, A. Wolf and M.A. Lange, 2008. Potential impact of climate change on ecosystems of the Barents Sea Region. Climatic Change, 87:283-303.

Rybråten, S. and G.K. Hovelsrud, 2010. Differential experiences of sheep farmers and reindeer herders in Unjárga/Nesseby, a coastal Sámi community in northern Norway. In: Smit, B. and G. Hovelstrud (eds.), Community Adaptation and Vulnerability in the Arctic Regions. pp. 313-333. Springer.

Saarinen, J., 2014. Nordic perspectives on tourism and climate change issues. Scandinavian Journal of Hospitality and Tourism, 14:1-5.

Saarni, K., J. Setälä, A. Honkanen and J. Virtanen, 2003. An overview of salmon and trout aquaculture in Finland. Aquaculture Economics and Management, 7:335-343.

Sagerup, K., L.B. Helgason, A. Polder, H. Strom, T.D. Josefsen, J.U. Skare and G.W. Gabrielsen, 2009. Persistent organic pollutants and mercury in dead and dying glaucous gulls (*Larus hyperboreus*) at Bjornoya (Svalbard). Science of the Total Environment, 407:6009-6016.

Sakshaug, E., G. Johnsen, S. Kristiansen, C. von Quillfeldt, F. Rey et al. 2009. Phytoplankton and primary production. In: Sakshaug, E., G. Johnsen, K. Kovacs (eds.), Ecosystem Barents Sea. pp. 167-208. Tapir Academic Press.

Schaeffer, R., A.S. Szklo, A.F. de Lucena, B.S. Borba, L.P. Nogueira, F.P. Fleming, A. Troccoli, M. Harrison and M.S. Boulahya, 2012. Energy sector vulnerability to climate change: A review. Energy, 38:1-12.

Schindler, D.E., R. Hilborn, B. Chasco, C.P. Boatright, T.P. Quinn, L.A. Rogers and M.S. Webster, 2010. Population diversity and the portfolio effect in an exploited species. Nature, 465:609-612.

Secretariat of the Convention on Biological Diversity, 2014. An Updated Synthesis of the Impacts of Ocean Acidification on Marine Biodiversity. Hennige, S., J.M. Roberts and P. Williamson (eds.). CBD Technical Series No. 75.

Silviken, A., 2009. Prevalence of suicidal behavior among Indigenous Sami in Northern Norway. International Journal of Circumpolar Health, 68:204-211.

Sipiläinen, T., S.C. Kumbhakar and G. Lien, 2014. Performance of dairy farms in Finland and Norway from 1991 to 2008. European Review of Agricultural Economics, 41:63-86.

Skaret, G., P. Dalpadado, S.S. Hjøllo, M.D. Skogen and E. Strand, 2014. *Calanus finmarchicus* abundance, production and population dynamics in the Barents Sea in a future climate. Progress in Oceanography, 125:26-39.

Skarin, A., C. Nelleman, L. Rönnegård, P. Sandström and H. Lundqvist, 2015. Wind farm construction impacts reindeer migration and movement corridors. Landscape Ecology, 30:1527-1540.

Skjelvan, I., E. Jeansson, M. Chierici, A. Omar, A. Olsen, S. Lauvset and T. Johannessen, 2014. Ocean acidification and uptake of anthropogenic carbon in the Nordic Seas, 1981-2013. Norwegian Environment Agency, Report M244-2014.

Skjoldal, H.R., 2004. The Norwegian Sea Ecosystem. Tapir Academic Press.

Söderholm, K., P. Söderholm, H. Helenius, M. Pettersson, R. Viklund, V. Masloboev, T. Mingaleva and V. Petrov, 2015. Environmental regulation and competitiveness in the mining industry: Permitting processes with special focus on Finland, Sweden and Russia. Resources Policy, 43:130-142.

Soininen, L., 2015. The Health of the Finnish Sami in Light of Mortality and Cancer Pattern. Thesis University of Helsinki, 2015.

Sondergaad, J., P. Johansen, G. Asmund and F. Rigét, 2011. Trend of lead and zinc in resident and transplanted *Flavocetraria nivalis* lichens near a former lead-zinc mine in West Greenland. Science of the Total Environment, 409:4053-4071.

Stene, A., H. Viljugrein, H. Yndestad, S. Tavornpanich and E. Skjerve, 2014. Transmission dynamics of pancreas disease (PD) in a Norwegian fjord: aspects of water transport, contact networks and infection pressure among salmon farms. Journal of Fish Diseases, 37:123-134.

Stephenson, S.R., L.W. Brigham and L.C. Smith, 2013. Marine accessibility along Russia's Northern Sea Route. Polar Geography, 37:111-133.

Stepien, A., T. Koivurova and P. Kankaanpää (eds), 2014. Strategic Assessment of Development of the Arctic: Assessment Conducted for the EU. The Arctic Centre, University of Lapland.

Swann, A.L., I.Y. Fung, S. Levis, G.B. Bonan and S.C. Doney, 2010. Changes in Arctic vegetation amplify high-latitude warming through the greenhouse effect. Proceedings of the National Academy of Sciences, 107:1295-1300.

Taranger, G.L., O. Karlsen, R.J. Bannister, K.A. Glover, V. Husa, E. Karlsbakk, B.O. Kvamme, K.K. Boxaspen, P.A. Bjorn, B. Finstad, A.S. Madhun, H.C. Morton and T. Svasand, 2015. Risk assessment of the environmental impact of Norwegian Atlantic salmon farming. ICES Journal of Marine Science, 72:997-1021.

Thorsen, S.M. and M. Höglind, 2010a. Assessing winter survival of forage grasses in Norway under future climate scenarios by simulating frost tolerance in combination with simple agroclimatic indices. Agricultural and Forest Meteorology, 150:1271-1282.

Thorsen, S.M. and M. Höglind, 2010b. Modelling cold hardening and dehardening in timothy. Sensitivity analysis and Bayesian model comparison. Agricultural and Forest Meteorology, 150:1529-1542.

Thorsteinsson, T., T. Jóhannesson and Á. Snorrason, 2013. Glaciers and ice caps: Vulnerable water resources in a warming climate. Current Opinion in Environmental Sustainability, 5:590-598.

Tokarevich, N., R. Buzinov, V. Boltenkov, A. Grijibovski, Zh. Varakina, N. Pshenishnaya et al., 2012. The impact of climate change on the tic-borne encephalitis and salmonellosis in the Arkhangelsk region, Northwest Russia: WHO study. 15th International Congress on Circumpolar Health, 6-10 August 2012, Fairbanks, Alaska.

Tupolov, D., 2012. Involvement of foreign shipping companies into the Northern Sea Route development: current status and prospects. Conference presentation archived by Willy Østreng.

Turunen, M., P. Soppela, H. Kinnunen, M.-L. Sutinen and F. Martz, 2009. Does climate change influence the availability and quality of reindeer forage plants? A review. Polar Biology, 32:813-832.

Turunen, M.T., S. Rasmus, M. Bavay, K. Ruosteenoja and J. Heiskanen, 2016. Coping with difficult weather and snow conditions: Reindeer herders' views on climate change impacts and coping strategies. Climate Risk Management, 11:15-36.

Tuulentie, S. and B. Heimtun, 2014. New rural residents or working tourists? Place attachment of mobile tourism workers in Finnish Lapland and northern Norway. Scandinavian Journal of Hospitality and Tourism, 14:367-384.

Tyler, N.J.C., M.A. Sundset, K. Strøm-Bull, M.N. Sara, E. Reinert, N. Oskal, C. Nellemann, J.J. McCarthy, S.D. Mathiesen, M.L. Martello, O.H. Magga, G.K. Hovelsrud, I. Hanssen- Bauer, N.I. Eira, I.M.G. Eira and R.W. Corell, 2007. Sámi reindeer pastoralism under climate change: Applying a generalized framework for vulnerability studies to a sub-arctic social-ecological system. Global Environmental Change, 17:191-206.

Uleberg, E., I. Hanssen-Bauer, B. van Oort and S. Dalmannsdóttir, 2014. Impact of climate change on agriculture in northern Norway and potential strategies for adaptation. Climatic Change, 122:27-39.

UNEP/AMAP, 2011. Climate change and POPs: Predicting the impacts. Report of the UNEP/AMAP Expert Group. United Nations Environment Programme (UNEP), Arctic Monitoring and Assessment Programme (AMAP). Secretariat of the Stockholm Convention, Geneva.

Vehviläinen, B., M. Huttunen and I. Huttunen, 2005. Hydrological forecasting and real time monitoring in Finland: the watershed simulation and forecasting system (WSFS). In: Innovation, Advances and Implementation of Flood Forecasting Technology. Conference Papers, Tromsø, Norway, 17–19 October 2005.

Verreault, J., G.W. Gabrielsen and J.O. Bustnes, 2010. The Svalbard glaucous gull as bioindicator species in the European Arctic: Insight from 35 years of contaminants research. In: Reviews of Environmental Contamination and Toxicology, Vol 205. pp 77-116.

Vilhjálmsson, H. and A.H. Hoel, 2005. Fisheries and aquaculture. In: Arctic Climate Impact Assessment. pp. 691-780. Cambridge University Press.

Von Quillfeldt, C.H., E.N. Hegseth, G. Johnsen, E. Sakshaug and E.E. Syvertsen, 2009. Ice algae. In: Sakshaug, E., G. Johnsen and K. Kovacs (eds.), Ecosystem Barents Sea. pp. 285-302. Tapir Academic Press.

Vuojala-Magga, T., M. Turunen, T. Ryyppö and M. Tennberg, 2011. Resonance strategies of Sami reindeer herding during climatically extreme years in northernmost Finland in 1970-2007. Arctic, 64:227-241.

Wallenius, T. and V. Lehtomäki, 2015. Overview of cold climate wind energy: Challenges, solutions, and future needs. Wiley Interdisciplinary Reviews: Energy and Environment.

Wassmann, P., M. Reigstad, T. Haug, B. Rudels, M.L. Carroll, H. Hop, G.W. Gabrielsen, S. Falk-Petersen, S.G. Denisenko, E. Arashkevich, D. Slagstad and O. Pavlova, 2006. Food webs and carbon flux in the Barents Sea. Progress in Oceanography, 71:232-287.

Wessman, H., O. Salmi, J. Kohl, P. Kinnunen, E. Saarivuori and U.-M. Mroueh, 2014. Water and society: mutual challenges for eco-efficient and socially acceptable mining in Finland. Journal of Cleaner Production, 84:289-298.

Whoriskey, F.G., S. Prusov and S. Crabbe, 2000. Evaluation of the effects of catch-and-release angling on the Atlantic salmon (*Salmo salar*) of the Ponoi River, Kola Peninsula, Russian Federation. Ecology of Freshwater Fish, 9:118-125.

Wienerroither, R., E. Johannesen, A. Dolgov, I. Byrkjedal, O. Bjelland, K. Drevetnyak, K.B. Eriksen, Å. Høines, G. Langhelle, H. Langøy, T. Prokhorova, D. Prozorkevich and T. Wenneck, 2011. Atlas of the Barents Sea fishes. IMR/PINRO Joint Report Series.

Wiig, Ø., J. Aars and E.W. Born, 2008. Effects of climate change on polar bears. Science Progress, 91:151-173.

Wolf, A., T.V. Callaghan and K. Larson, 2007. Future changes in vegetation and ecosystem function of the Barents Region. Climatic Change, 87:51-73.

Woodward, G., D.M. Perlins and L.E. Brown, 2010. Climate change and freshwater ecosystems: impacts across multiple levels of organization. Philosophical Transactions of the Royal Society B, 365:2093-2106.

Wrona, F.J., T.D. Prowse, J.D. Reist, J.E. Hobbie, L.M. Lévesque and W.F. Vincent, 2006. Climate change effects on aquatic biota, ecosystem structure and function. Ambio, 35:359-369.

Wrona, F.J., J.D. Reist, P.-A. Amundsen, P.A. Chambers, K. Christoffersen, J.M. Culp, P.D. di Cenzo, L. Forsström, J. Hammar, R.K. Heikkinen, J. Heino, K.K. Kahilainen, H. Lehtonen, J. Lento, L. Lesack, M. Luoto, D.J. Marcogliese, P. Marsh, P.A. Moquin, T. Mustonen, M. Power, T.D. Prowse, M. Rautio, H.K. Swanson, M. Thompson, H. Toivonen, V. Vasiliev, R. Virkkala and S. Zavalko, 2013. Freshwater ecosystems. In: Arctic Biodiversity Assessment. pp. 443-485.

WWF, 2005. Analysis of illegal fishery for cod in the Barents Sea. World Wildlife Fund (WWF).

WWF, 2007. Fisheries in the Russian Barents Sea and the White Sea: Ecological Challenges. World Wildlife Fund (WWF).

WWF, 2013. Impact of trawling fisheries on bottom ecosystems of Barents Sea. World Wildlife Fund (WWF).

UNEP, 1997. Mining – facts and figures. UNEP Industry and Environment; Mining and Sustainable Development, 20:4-9.

UNEP, 2004. Matishov, G., N. Golubeva, G. Titova, A. Sydnes and B. Voegele. Barents Sea: GIWA Regional assessment 11. University of Kalmar, Sweden.

7. Indigenous peoples' perspectives

Coordinating lead authors: Anna Degteva, Anders Oskal, Svein D. Mathiesen, Philip Burgess

Lead authors: Iulie Aslaksen, Kathrine I. Johnsen, Anne-Maria Magga, Wilbert van Rooij

Contributing authors: Camilla Brattland, Robert Corell, Andrey Dubovtsev, Per Arild Garnåsjordet, Aslak Holmberg, Konstantin Klokov, Nancy G. Maynard, Christian Nellemann, Beaska Niillas, Per Jonas Partapuoli, Mikhail Pogodaev, Erik Reinert, Per Sandström, Igor Slepushkin, Inger A. Smuk, Jannie Steffanson, Zinaida Strogalschikova, Alexey Tyskarev, Levi Westerveld

Key messages

- ***Multiple drivers of environmental and social change can be identified across the Barents area and more change is expected.*** *Infrastructure development is currently the most significant driver of change in land use. Climate change is an increasing threat to traditional livelihoods. Impacts on indigenous peoples are exacerbated by their lack of voice in the development of adaptation tools and strategies for future planning and development.*
- ***GLOBIO3 and participatory mapping could provide essential overviews of information on the cumulative impacts and future consequences of climate and socio-economic drivers.*** *They have the potential to become powerful and collaborative tools to assist both rights holders and local and regional decision-makers. Such tools improve our understanding of complex spatial issues and facilitate the development of advanced adaptation and mitigation strategies for local situations.*
- ***To better serve the challenges faced by indigenous peoples, impact assessments must include more holistic and long-term thinking, and must ensure the inclusion of traditional knowledge****. The complexity of multiple drivers and the far-reaching consequences of unrelated developments demand that impact assessments evolve to become more holistic and longer term social-ecological resilience assessments, where complex interdependent systems of people and nature persist, adapt and transform in the face of Arctic change.*
- ***Natural resources and critical landscapes need protection****. Tipping points for the continuation of traditional livelihoods exist and in some areas may be passed in the next two decades. The protection and sustainable management of critical natural resources for the practice of traditional livelihoods must be rigorously examined.*
- ***Indigenous languages are central to the identity and practices of indigenous peoples in the Barents area.*** *Strong commitment is needed for their survival, at all levels of government. Language loss is directly correlated to a loss of practical skills and coping, and ultimately, to biodiversity.*
- ***There is a need for new types of education and education delivery.*** *New education models need multidisciplinary, multicultural, holistic approaches for gender sensitive sustainable development that includes traditional knowledge. Successful adaptation to climate change requires the training of local Arctic leaders in long-term sustainable thinking, within indigenous communities and mainstream society.*
- ***All available sources of knowledge must be included in developing adaptation strategies.*** *Those practicing traditional livelihoods possess a rich, varied and valuable body of knowledge within the Barents area. Women's knowledge is a key and underutilized asset. Developing meaningful coproduction of knowledge between traditional knowledge and western science is essential for creating successful adaptation strategies in the future. There is a need to further develop indigenous trans-boundary institutions to this effect.*

7.1 Introduction

The Barents area is an economically, socially and culturally diverse region. It is home to a number of indigenous peoples: Sámi (Norway, Sweden, Finland, northwestern Russia), Nenets (Nenets Autonomous Okrug, Nenets AO; Yamal Nenets Autonomous Okrug, Yamal Nenets AO) and Vepsians (Karelia). There are also several ethnic minorities in the region, such as Karelians (Russian Karelia) and Komi (Nenets AO and Komi Republic) who share many of the same challenges and experiences as the regions' indigenous peoples. The chapter also includes data and voices from the neighboring Yamal Nenets AO. While not technically part of the Barents study area, there is a cultural continuity and practice across the regional borders and intense oil and gas development is already underway and with more planned, all of which will have significant effects on indigenous peoples across the broader Barents area as multiple drivers of land use change and interact with each other. This chapter addresses key questions and trends on the economy, climate change and governance, and their associated impacts on the livelihoods, knowledge base, living conditions and wellbeing of the region's indigenous peoples. These trends will continue to pose questions for the resilience and adaptive capacity of the region's indigenous peoples. The aim of this chapter is to give voice to the multiple concerns of indigenous peoples and to provide information and guidance toward developing adaptation tools and strategies for future planning and development in the Barents area in accordance with the AACA (Adaptation Actions for a Changing Arctic) mandate given by the Arctic Council, to "*produce information to assist local decision-makers and stakeholders…in developing adaptation tools and strategies to better deal with climate change and other pertinent environmental stressors*".

"There are scientific estimations of pasture capacity and how much reindeer it can carry. But are there assessments of how much industrial development our pastures can take?" Helena Omma (EALLIN, 2015:34)

In the Sámi language, the traditional settlement area of the Sámi people is called 'Sápmi'. This is a contiguous geographical area extending through parts of Norway, Sweden, Finland and Russia. The size of the Sámi population is a subject of some debate but most Sámi live within Norwegian borders (e.g. Hassler et al., 2004). It should also be noted that although there are no official data on current Sámi settlement patterns, it is widely known that many Sámi live outside the traditional settlement area, just as many non-Sámi live within it (Statistics Norway, 2010). Sámi are a heterogeneous people, both linguistically (there are nine distinct Sámi languages across Sápmi) and culturally, as well as economically, socially and politically. Traditional livelihoods – reindeer herding, fishing, hunting and handicraft making – are still widely practiced by Sámi. All traditional livelihoods, especially reindeer herding, are now strictly controlled by various bodies within the nation states in which they reside, in all parts of Sápmi.

In total, there are just over 42,000 people in the Nenets AO of whom just over 7500 are indigenous Nenets and 3623 are Komi. Reindeer herding and fishing are central to the traditional livelihoods of these Nenets as well as to the numerically more numerous Nenets living in the neighboring and more populous Yamal Nenets AO (nearly 30,000). The traditional lands of the Vepsians have been divided by the administrative borders of the Republic of Karelia and the Leningrad and Vologda regions. Today, most of the just under 6000 Vepsians live in the Republic of Karelia (All Russian Census, 2010).

7.2 Trends affecting indigenous peoples

Multiple drivers of environmental and social change can be identified across the Barents area. The area has experienced significant development and land fragmentation in the post-war period, but especially since the 1970s when oil and mineral resource extraction first began to show a marked increase (Vistnes et al., 2009). Indigenous peoples in the region, in common with ethnic minorities face a broad range of challenges including loss of language, loss of identity, loss of traditional food culture, loss of land to practice traditional livelihoods, and threats to rights and community sustainability. In addition to more long-term threats such as climate change, those practicing traditional livelihoods also face many everyday issues such as a poor economy, loss of reindeer due to predators, and perceived overregulation. Such issues are compounded by the inability or unwillingness of mainstream authorities, planners and local administrations to understand the specific needs of those practicing subsistence and traditional livelihoods (Tyler et al., 2007). 'Knowledge' is central to this question – not just in terms of traditional knowledge holders having their knowledge recognized, but in having it utilized in future planning steps and towards adaptation. However, current models of impact assessments are not designed to integrate or understand indigenous peoples' knowledge or to address cumulative and cascading effects of proposed developments. Possible future steps to aid adaptation include a reevaluation of impact assessments so that traditional knowledge is recognized, improved landscape and biodiversity modeling, protected areas for practicing traditional livelihoods, and appropriate models of education and delivery.

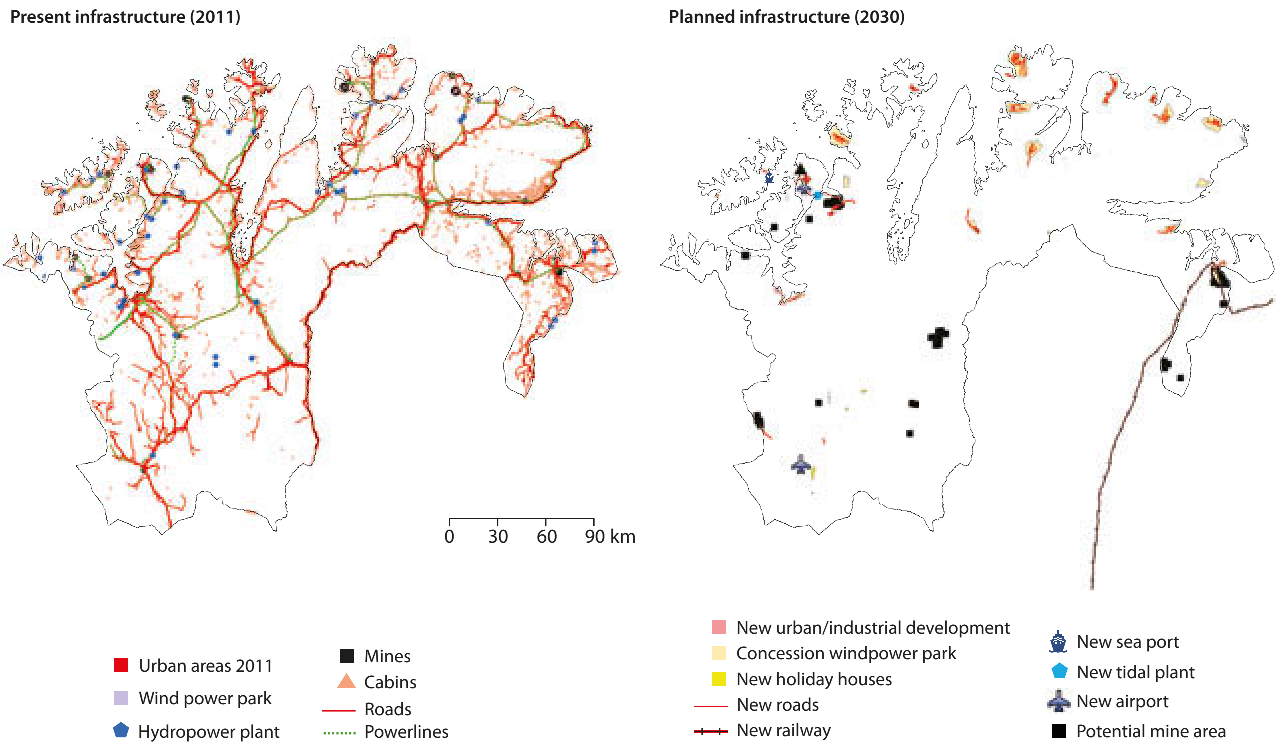


Figure 7.1 Infrastructure in Finnmark, Norway: present (left) and planned (right) (Wilbert van Rooij / Plansup).

Infrastructure development is perhaps the most significant driver of change in land use in the Barents area. Transportation corridors have been developed across northern Norway, Sweden and Finland (Vistnes et al., 2009) and the extraction of resources, such as timber, minerals and offshore oil and gas have been significant drivers of this development, as well as hydropower and wind power more recently. Although development has been less extensive in northwestern Russia, there are significant exceptions such as the cities of Murmansk and Naryan Mar. While much infrastructure has already been developed, substantial further development is likely under future 'extreme' development scenarios (see Section 7.3.1). Figure 7.1 illustrates possible developments in Finnmark.

The scenario illustrated in Figure 7.1 represents the assumption that all potential infrastructure developments, as described in municipal zoning plans, road authorities and future development scenarios as envisaged by regional planning and development bodies will be realized, with 2030 as a stipulated time horizon. The cumulative and cascading effects of these developments include increased fragmentation of the land rendering significant (particularly at the coast) land use change, which has meant a substantial loss of land for traditional activities. This is especially the case in Finnmark (Figure 7.1) and will have significant local effects in the Nenets AO (Figure 7.2). Although reindeer pastures cover a large part of the Nenets AO and reindeer husbandry is a core part of the indigenous Nenets culture, the dominant economic activity of the region concerns oil and gas, and substantial infrastructure developments are planned (Figure 7.2).

"The unpredictability of weather has an impact on herd behavior, as animals scatter in search of better pastures and in response, as an adaptation method, herders often have to resort to providing artificial food in the winter, an expensive option and sometimes harmful if reindeer are unfamiliar to it… Predators are a terrible threat to the livelihood in some areas of Sápmi, where the predators are extremely dense. Legislation from the Länsstyrelsen, Naturvårdsverket and state is a constant fight for the communities and dominantly unsuccessful for the reindeer herders. The result is that the predators run freely in the herd and are causing tremendous damage. In parts of Sápmi, suicide and depression are reactions to the increasing unpredictability, insecurity and threats facing traditional livelihoods such as reindeer herding…Another significant challenge (aside from climate change) on our territories is the presence of the mining industry, tourism, windmill parks and hydropower generation. Significant further development in these activities is planned across the whole of Sápmi. We have an immense body of knowledge about how to maintain the land and live sustainably from it. To not recognize this is to ultimately threaten the regions overall biodiversity." Jannie Steffanson, Member of the Saami Council's Arctic and Environment Unit

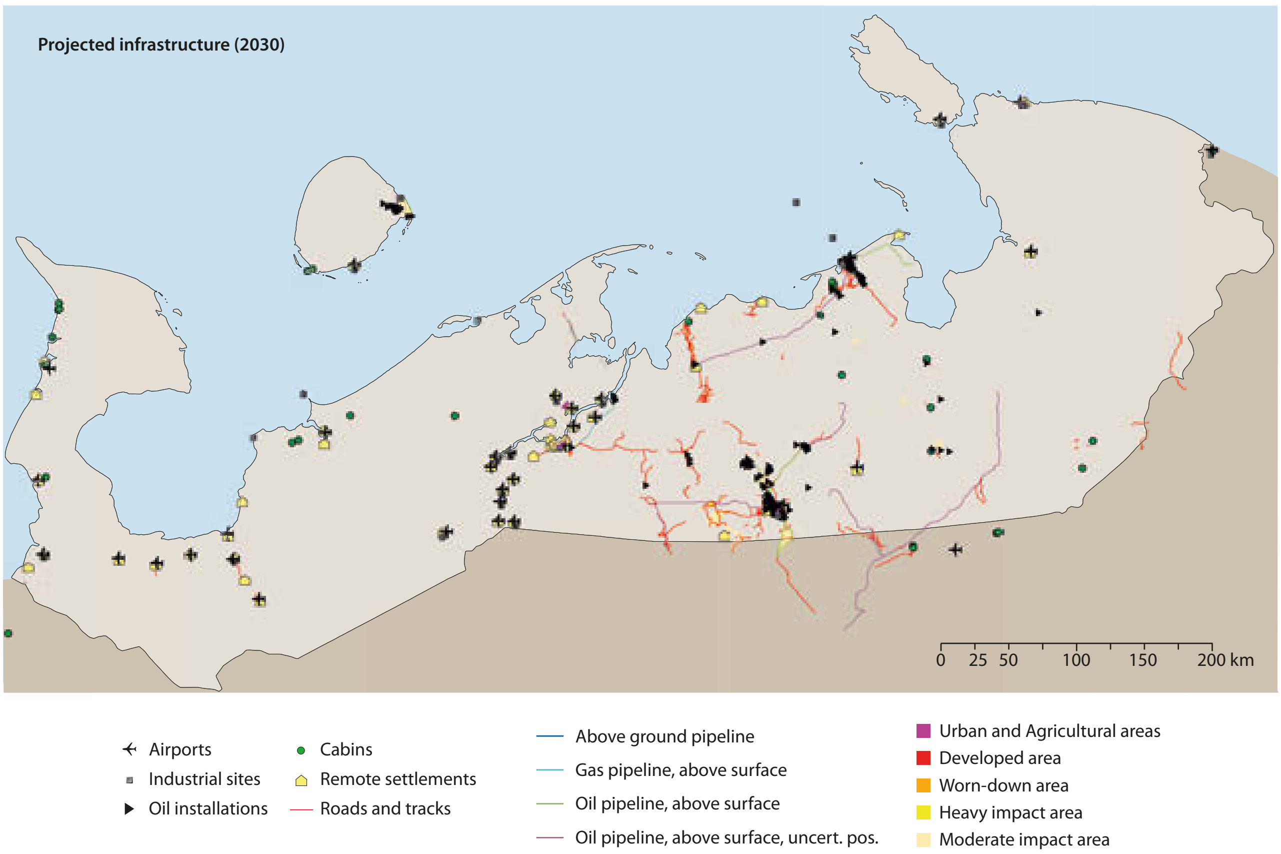


Figure 7.2 Projected infrastructure development in the Nenets Autonomous Okrug, Russia (Wilbert van Rooij / Plansup).

> *"The struggles of the Vepsian Peoples to first be recognized* [as an indigenous people, in 1999] *is compounded by the administrative steps that have been taken in more recent times that effect much hardship, such as changes to social pension policies that removed Vepsian from pension rolls. Regional authorities have also taken steps to 'optimize' the network of educational and social institutions in the places of their traditional residence, which has been to the detriment of Vepsians who have seen valuable kindergartens and grade schools being closed down in villages where Vepsians are located; meaning long travel times to schools or entry into the boarding school system which has often been to their detriment."* Zinaida Strogalshchikova, Chair of the Society of Vepsian Culture, Republic of Karelia

A recent study commissioned by the Finnish Prime Minister's Office (Husbekk et al., 2015) reported that sustainable growth in the Fennoscandian Arctic would be achieved by the promotion of four drivers: liquefied natural gas and renewable energy sources (led by Norway), 'greener' mining solutions (led by Sweden), increased tourism (led by Finland), and cold-weather technologies.

7.2.1 Economic change and indigenous societies

Traditional economies are central to the health and future survival of indigenous peoples' communities. It has been argued that indigenous economic systems should play a far stronger role in considerations of indigenous governance.

> *"Indigenous economic systems need to play a more central role in envisioning and shaping meaningful, comprehensive, and sustainable systems of contemporary indigenous self-governance. If indigenous economies are not taken into account, there is a serious danger of losing the very identities that constitute indigenous peoples. Indigenous economies such as household production and subsistence activities extend far beyond the economic sphere: they are at the heart of who people are culturally and socially. These economies, including the practices of sharing, manifest indigenous worldviews characterized by interdependence and reciprocity that extend to all living beings and to the land. In short, besides an economic occupation, subsistence activities are an expression of one's identity, culture, and values. They are also a means by which social networks are maintained and reinforced."* Kuokkanen (2011)

7.2.1.1 Reindeer herding and the Sámi *Siida*

For most of human history, the economic organization of mankind has been different from today's capitalist principles. Karl Polanyi in his classic 1944 work *The Great Transformation* defined this economic system as the absence of the three 'fictitious commodities' that came to define capitalism: the private ownership of land, labor as a commodity, and money (Polanyi, 1963). Although well integrated into the market economy, the internal organization of Sámi reindeer herding still largely corresponds to Polanyi's definition: the system is based on *sequential usufruct of land*, on *shared (unpaid) labor within the siida* 'clan', and on the *internal* exchange of products as barter rather than on market transactions. The sequential usufruct of land can be compared to modern time-sharing, when ownership, for example of a holiday apartment is agreed for certain weeks of the year.

Global development away from this system was slow. Farmers were also mostly largely self-sufficient until about a hundred years ago, and only in about the last 40 years has marketization come to threaten the traditionally organized societies of the Arctic. The huge technological advances of the 18th century Industrial Revolution, primarily in the textile industry created the breakthrough of a modern market society. 19th-century authors were perplexed by the 'alienation' of production from consumption. However, the mode of production of the Sámi reindeer herders stayed the same. For example, in Norway, their relationship to the market was, until the 1978 Reindeer Law, limited to the sale of their final product to traders.

The dominant mode of production in the 20th century was what has come to be called 'standardized mass production' or 'Fordism'. Huge cost reductions, and corresponding rising real wages, were achieved though standardized mass production where huge fixed costs could be amortized (made profitable) only by standardizing the final product. 'Modernization' tended to become identical to 'standardized mass production'.

> *"When we finally managed to gather all reindeer, and had delivered reindeer for slaughtering to a slaughterhouse, we got the message that the slaughterhouse was bankrupt. We did not get any income from the slaughtering. It was very tough to live a year without income. One simply had to borrow money to survive."* Piere Bergqvist, EALLIN (2015:39)

When this so-called modernization hit Sámi reindeer herding in Norway with a new law in 1978, it was with the prevailing logic of Fordism built in. In Norway, reindeer herding governance was inspired just as much by the Soviet version of modernization – within a planned economy – as by Fordism of the Western kind. As a production philosophy, however, these systems were virtually identical. Against local advice a huge reindeer slaughterhouse, with an annual capacity to slaughter most of Norway's reindeer was built in Kautokeino. But this centralization led to a loss of core activities for the herders: not only in terms of slaughtering and the preparation of final meat products but also in the loss of by-products (from hides to intestines) because their conversion into clothing, shoes, and all kinds of utensils were also key carriers of the Sámi culture. Fordist modernization came to threaten the very core of Sámi culture. The governance of reindeer herding became the responsibility of the Ministry of Agriculture. However, both the decentralized mode of production and the cyclical nature of the reindeer herding – determined by natural climatic cycles – were completely alien to Norwegian agricultural practices. To this clash of cultures (between Fordist mass production and the traditional system which is the only one that enables survival in the harsh Arctic climate) an important problem of economic vested interest was added. Refusing to recognize the natural cyclicity of reindeer herding, the Ministry of Agriculture imposed the fixed 'target price' system from sedentary agriculture on the price of reindeer meat. When

Box 7.1 Sea Sámi insights and perspectives in Norway

First person view by Beaska Niillas, a member of the Sámi Parliament from Hillágurra in Tana. He is President of the Sámi Association of Norway (NSR) and vice leader of the NSR parliamentary group.

We have already observed physical changes such as warmer waters and stronger winds, perhaps due to changes in prevalent wind directions from the east towards the west/southwest. In the fjords of eastern Finnmark, mackerel have been appearing over the last couple of years. While fun for kids to fish, those depending on fishing for a living are very concerned saying "the high number of mackerel are a threat and it eats everything, it does not belong naturally in our waters".

The small boat coastal fishing fleet represents a great system of value production in the fjords where they operate, while contributing little to emission releases. However, this small boat economy is more vulnerable to change. Under pressure, more chances with weather and distance are taken, which is risky with only one crew aboard – this is already the most dangerous workplace in Norway. Being a fisherman is a lifestyle with a lot of freedom, and a great deal of responsibility, but also risk.

Conflict over space is seen as a great concern in the fjords. Primarily this is connected to municipal spatial planning and the desire to create new employment opportunities. Fish farmers want to place their pens in areas with stronger currents to clear away the waste more efficiently, yet they need the protection a fjord can offer. These areas are also the best areas for fishing. Fishermen feel they need to be ever more engaged in the planning process and be proactive towards the municipality more than they feel they have time for, simply to protect their livelihood.

With the introduction of fish farming (salmon) in the north of Norway in the 1980s, salmon prices fell dramatically. This had a great impact on those who fished salmon in the fjord during spring/summer for part of their income, mainly the small communities along the fjords (Várjjat and Deatnu). During the same period the fjord salmon fishermen faced considerable reductions and limitations to their fishing through regulations: fewer days to fish, restrictions on equipment and a difficult process to apply for fishing places. These same communities in the 1960s and 1970s were offered *fraflytningstilskudd*, a financial encouragement to move out of the small villages and resettle in the coastal towns, which resulted in many abandoned villages along the coast. All the above factors have made recruitment to fjord salmon fishing very challenging.

Today the broader market cannot tell the difference between wild and farmed salmon. Fishermen cannot compete on price with the farmed fish. The fish farming is a business that faces accidents from time to time and fish escape from their farming nets and genealogical mixing with the wild salmon has already been reported. A real concern for the future is if there will still be such a thing as wild North Atlantic salmon, or will it be some kind of genetic mix. Fish farming also has considerable local effects from their parasites and effluent and also on the local stocks of other fish, which becomes accustomed to large amounts of artificial feed.

Coastal Sámi Resource Centre

Salmon fisherman in Porsanger, Norway

production rose, as a natural result of the cycles, prices were not allowed to fall and massive stocks of unsold reindeer meat were frozen for stockpiling and future consumption. That the sale of reindeer meat had gradually been taken over by the Farmers' Cooperative (*Norsk Kjøtt*) – where the reindeer herders had little economic interest – compounded the problem. It is clear that it was more profitable for the Farmers' Cooperative to have the government pay them for large-scale stockpiling of reindeer meat than to make efforts to sell the meat belonging to the Sámi. Prices were also prevented from rising when reindeer meat experienced a natural fall in production volume. Therefore a fairly normal downturn of production in the 1990s led to an economic disaster for many reindeer herders: production volume shrank dramatically but the government-fixed price was not allowed to rise. From a peak price (all prices in NOK 2013) for reindeer meat of NOK 108 per kilogram in 1976, the price fell to NOK 51 per kilogram in 1990, a year when total production was very low. From a political perspective most parties in the Norwegian parliament failed to recognize that the reindeer herders were trapped in a collectivist system from which they should be freed. A new production paradigm, exemplified by Schwab's *The Fourth Industrial Revolution* was presented at the 2016 World Economic Forum in Davos (Schwab, 2016), in which *economies of scale in hierarchies* are replaced by *economies of scope in networks*, a mode of production surprisingly close to the traditional production system of reindeer herders. Reindeer herders traditionally work in a system similar to that of a contemporary rideshare arrangement (Horton and Zeckhauser, 2016) with the difference that the core is controlled by an internal system of democratic consensus. As previously indicated, the Sámi invented time-sharing which is now used in a wide range of sectors (holiday apartments, cars, etc.). The Sámi *siida* also practiced crowdsourcing hundreds of years before the term was invented. The question is whether society at large can free the Sámi reindeer herders from the remnants of the old-fashioned Fordist planned economy so deeply entrenched in the approach of the Norwegian Ministry of Agriculture, thus enabling them to recover their status as entrepreneurs in the new economy where they provide sustainability and where world markets are eager to embrace their healthy and exotic products. See Reinert (2006, 2008) for a deeper analysis of the points raised here. The intense centralization and 'modernization' process has had a deleterious effect on role of women in reindeer husbandry:

> *"The main challenge in Sámi reindeer husbandry today is that a large part of the raw materials of the slaughtered reindeer such as skin, bones, heads, blood and intestines are regarded as waste and are thrown away and not used for food production or economic development. In this modernized processing of reindeer, I believe that as much as sixty percent of the reindeer is not utilized. The bulk slaughtering of calves in our industry has been a major threat to women's active participation in Sámi reindeer herding, since the raw materials that Sámi women traditionally used are no longer available, thereby forcing us away from the herding business. If the traditional materials for clothes and food production are not available, the specialized language and traditional knowledge related to these processes will disappear. The calf slaughtering strategy imposed upon us as a reindeer herding people, has so impacted women's roles and perspectives in reindeer husbandry that this is having significant consequences for the continued survival of family based reindeer husbandry as we once knew it."* Inger Anita Smuk, reindeer herder from eastern Finnmark, Chair of Board of International Centre for Reindeer Husbandry

7.2.2 Governance

Across most of the western Barents Region there has been a broad-based movement toward indigenous self-determination. In Scandinavia there are Sámi parliaments that are directly elected by Sámi. Sámi parliaments have been directly elected by Sámi since 1989 in Norway (www.sametinget.no), 1993 in Sweden (www.sametinget.se), and 1996 in Finland (whose parliament was preceded by a 'Sámi delegation' established in 1973) (www.samediggi.fi). The idea that there could be an institution that could speak on behalf of Sámi is an old one – Sámi pioneer Elsa Laula Renberg wrote on this in the early 1900s[13]. In 1988, the Constitution of Norway was amended to include the rights of the Sámi people: "The authorities of the state shall create conditions enabling the Sami people to preserve and develop its language, culture and way of life".[14] In recent times, much political and academic Sámi energy has been expended on the Draft Nordic Sámi Convention[15], the ratification of ILO 169[16] and in Norway, the Finnmark Act[17]. Pan-Sámi cooperation is channeled through the Saami Council (established in 1956), a non-governmental organization comprising Sámi member organizations in Finland, Russia, Norway and Sweden. The main task of the Saami Council is to consolidate the feeling of affinity among the Sámi people, to attain recognition for the Sámi as a nation and to maintain the cultural, political, economic and social rights of the Sámi in the legislation of the four states and in agreements between states and Sámi representative organizations. The political

[13] In 1904, Renberg wrote and published a 30-page pamphlet in Swedish entitled *Infor lif eller död? Sanningsord i de Lappska förhållandena* [*Do we face life or death? Words of truth about the Lappish situation*]

[14] https://stortinget.no/globalassets/pdf/english/constitutionenglish.pdf

[15] The Draft Nordic Sámi Convention is an agreement between Sámi and the governments of Norway, Sweden and Finland intending to harmonize legislation and other regulation of significance for Sámi activities across nation-state borders. The working group submitted a draft in 2005 to the Nordic ministers in charge of Sámi affairs and the presidents of the three Sámi Parliaments for their approval but the negotiations have been stalled particularly by the governments of Sweden and Finland.

[16] Established in 1989, ratified by Norway (1990) but not Finland (rejected in 2015) nor Sweden, ILO 169 is a major binding international convention concerning Indigenous Peoples, and a forerunner of the Declaration on the Rights of Indigenous Peoples. www.ilo.org/dyn/normlex/en/f?p=NORMLEXPUB:12100:0::NO::P12100_ILO_CODE:C169

[17] The Finnmark act attempts to strengthen the Sámi rights, by giving the *entire* population of Finnmark greater influence over property in the county. However, the act does not cover fishing rights in saltwater, mining, or oil rights.

Box 7.2 Nenets insights and perspectives from the Yamal Nenets AO, Russia

First person view by Igor Slepushkin, a Nenets reindeer herder from Yar-Sale, Yamal Nenets AO. He works in the Administration of Reindeer Husbandry, Yar-Sale, Russia.

In Yamal, we have the largest domestic reindeer herd in the world and reindeer are the foundation of our life in the tundra. Thanks to our traditional knowledge accumulated over centuries while living in harmony with animals, the land and the climate, we Nenets have kept our traditional lifestyle of herding and thriving in the harsh climatic conditions of the Arctic, all the while our region is undergoing dramatic and in some cases, irreversible change.

Living with the reindeer, its character and habits, consolidates our Nenets ways and means by which to live with nature, a means by which also children and adults can learn a reciprocal relationship with the land upon which we all depend. As for conservation, appropriate use of resources and norms of behavior, people have long-established restrictions, compliance with which is compulsory for all. The goal of these prohibitions, embedded in multiple customs and traditions is the nurturing of a nomadic life on the move, on the tundra. The passing on of these lived experiences and this multi-generational knowledge is a key component of Nenets survival.

Pasture quality and access are considered the foundation of our animals. In some areas of the okrug, the question of pastures is acute and a significant lack of pasture is observed mainly in two districts: Yamal and Taz. At the same time there are significant reserves of food resources in the forest-tundra and taiga areas of the region, which cannot however solve the problem of lack of pastures, as the movement of animals is simply not always possible. The placement of winter and summer pastures and migration routes have been developed and adapted over many generations and are integral to the practice of the livelihood.

The biggest threat for our reindeer pastures is industrial development. Oil and gas facilities, roads, railway tracks and other related activities remove and fragment reindeer pastures and prevent reindeer from accessing them. The rapid development of the Yamal region's oil and gas reserves, while it has been directly on top of or bisecting reindeer pastures in some key areas, has conversely led to an improvement in the regions' economy, which has led to a steady growth in the demand for reindeer meat and other reindeer products. It is important to mention that the regional administration has also invested in processing, packaging and marketing facilities for reindeer meat as well as direct supports to reindeer herders.

Despite the adverse weather conditions (the dramatic icing events of 2014 whereby tens of thousands of reindeer died) the reindeer in Yamal survived and continue to grow. The people of the reindeer have not yet been discouraged and continue to do their work, live their lives and move with the reindeer.

Svein D. Mathiesen

Oil and gas development on the Yamal Peninsula, a significant area for Nenets reindeer husbandry, has been rapid. Herders have had to adapt situation of Sámi differs between the three Nordic countries – for example the annual budget of the Norwegian Sámi Parliament for 2010 was USD 54.4 million compared to USD 2.2 million in Finland. Despite the broad trends towards indigenous self-determination the practice of traditional livelihoods such as hunting and herding in Scandinavia is controlled by (in general) various Ministries of the State.

In Russia, the interests of indigenous peoples are represented from the regional to federal level by the Russian Association of the Indigenous Peoples of the North (RAIPON), which was founded in 1990. RAIPON is an umbrella organization that organizes 35 regional and ethnic organizations of indigenous peoples in the regions where they live and represents 41 groups of indigenous peoples of the North, Siberia and the Far East. The purpose of RAIPON is to protect indigenous peoples' human rights, defend their legal interests, assist in solving environmental, social, economic, cultural and educational issues, and to promote their right to self-governance. RAIPON works with the State Duma and the Government of the Russian Federation on legislation related to indigenous peoples' issues.

7.2.2.1 Key challenges for coastal Sámi in Norway

Conflict between fish farming and traditional and coastal Sámi fisheries is a contentious issue due to spatial competition and disputes over the impacts of fish farms on the marine environment, particularly local fish stocks. With a changing climate, northern waters are becoming more attractive for the aquaculture industry. The current policy of the Norwegian government is to expand the use of marine areas for aquaculture purposes, with the aim of making this one of the main industries in the north. Aquaculture is currently seen as more sustainable in northern waters than elsewhere, partly owing to the reduced occurrence of disease and sea lice in Atlantic salmon pens. However, spatial conflicts and environmental effects on Sámi and other local marine fisheries are pressing and unresolved issues following the northwards aquaculture expansion.

Norwegian authorities are required to include experience-based or traditional knowledge in environmental management, as well as basing decisions on the best available scientific knowledge (Nature Diversity Act, §8). According to central legislative measures, management authorities are also required to take into account concern for the "natural basis for Sámi culture" in municipal planning, including planning of activities in the coastal zone (Planning and Building Act, §3-1). The policy of the Norwegian Sámi Parliament is to secure enough space for traditional fisheries in coastal zone plans, and the Sámi Parliament has the power to intervene on plans that do not fulfill the above mentioned requirements. In many cases, local governments cooperate well with the Sami Parliament and are able to incorporate experience-based knowledge and due regard for traditional marine usage in their coastal zone plans. Regional authorities also generally take into account the Sámi Parliament's objections in cases of conflict, and make sure that the legislation is followed by local governments and industries.

However, in cases of conflict over marine areas that are desired by the aquaculture industry and which are traditionally used by indigenous communities, local (municipal) governments may choose to prioritize economic benefits and the added employees to the municipality provided by the industry over concern for indigenous culture. In these cases, a lack of knowledge production regarding the natural basis for indigenous culture, as well as a lack of methods for measuring the value of traditional marine use in relation to other use forms, leads to a systematic failure to secure the natural basis for Sami culture in marine areas (Brattland and Eythórsson, 2016). Because traditional use is not documented or gathered in relevant datasets and published under relevant categories in environmental databases, it is not readily available in decision-making processes regarding the use of marine space for aquaculture sites. In both local government coastal zone planning processes and in large-scale planning processes such as establishment of oil processing plants, the value of traditional use of space in principle also holds lower economic value than that of the incoming industry. Since there are few strategies in place for securing continued access for Sami communities to traditional use areas in the context of changing climate and increasing marine use activities, this poses challenges for indigenous communities' future adaptation opportunities. If key use areas are already occupied by new industries facilitated by a changing climate, there will be fewer options for indigenous communities to adapt to a warmer climate and secure their traditional and changing land and marine use for the future. Increased production and integration of traditional use data in the environmental knowledge basis for management, as well as sound methods for traditional use valuation are thus of central importance to plan for Sámi land use in a warming northern climate.

7.2.2.2 Reindeer husbandry and its governance in Sápmi

The material basis for Sámi pastoralists' culture and livelihoods is access to seasonal pastures. But despite national and international laws that require Norway to recognize and protect the Sámi right to land (Reindeer Husbandry Act of 2007 and the ILO Convention 169 – ratified by Norway in 1990), it is unclear to what extent customary land use is protected against encroachment (Einarsbøl, 2005; Bjørklund, 2013). According to Ravna (2015), the legal protection of Sámi rights to natural resources and lands in Norway is not adequate. Reindeer herders all over Norway face increasing pressure from infrastructure development on their pastures; for example, from military activities, snow-mobile tourism, agriculture, wind power and hydropower, development of new areas for recreational homes, and mineral exploration and mining. In 2008, the State established the Finnmark Commission to investigate individual and collective rights of the people of the county (Sámi and non-Sámi) to land and water. However, the investigations are slow and only four areas have so far been examined (Skogvang, 2014). In addition, the Finnmark Commission has yet to recognize actual land and water areas to which Sámi have acquired use or ownership rights (Ravna, 2015). Furthermore, as shown by Johnsen (2016a) the standard procedure for assessing impact and the cost/benefit of land-use change is not adequate to understand the domino and cumulative effects of development projects on reindeer husbandry, or the project's consequences for the unsettled land rights of the pastoralists. Turi and Eira (2016) have also shown that even though Norwegian legislation requires the inclusion of Sámi traditional knowledge in land-use planning, this knowledge is often ignored in decision-making processes.

Another factor that has undermined the customary rights of herding groups to land is that since the late 1970s the State has recognized the grazing lands of inner Finnmark as communal land. The so-called 'commons' are however winter, spring and autumn pastures traditionally managed by the siida in a complex system controlling access and use of the land (Sara, 2009; Marin and Bjørklund, 2015). The introduction of 'commons', undermined the traditional management and distribution of the land and made it possible for herding groups to start using pastures to which they were not entitled according to customary rights.

State incentives for intensive herding practices are another hindrance to using the potential of one's pastures. The theory is that herds heavily dominated by females will produce many calves in the spring, which can be sold and create income the following autumn. However, a lack of diversity within the herd prevents it from utilizing the full range of pastures within a herding district. Bucks are more tolerant of human disturbance and can graze areas that females and calves will avoid, while a herd with many calves but few bucks is more vulnerable in winter when snow conditions make it difficult for reindeer to access lichen through the snow (a condition known as *guohtun* in northern Sámi) (Eira et al., 2010).

During the 1970s, Norwegian government officials became increasingly concerned that too many reindeer and too many people engaged in pastoralism would cause overgrazing and jeopardize the economic viability of the reindeer industry (Stortinget, 1976-1977; Lenvik, 1998). There was also a perception that Sámi reindeer husbandry had not progressed at the same pace as the rest of Norwegian society. These concerns together formed the basis for a political reform of reindeer husbandry governance (Storli and Sara, 1997). Scholarly experts, rather than practitioners were appointed as advisors of the reform (Paine, 1994; Riseth, 2000) and science on how to optimize reindeer meat production formed the value and knowledge-base for reindeer husbandry governance from the 1970s onwards. The political reform – often referred to as modernization, rationalization or optimization of Sámi reindeer husbandry (Lenvik, 1990; Paine, 1994; Berg, 1996; Riseth, 2000; Reinert, 2008; Hausner et al., 2011) – aimed to stimulate herding practices in line with scientific knowledge about optimal herd structures, harvest strategies and reindeer numbers for maximizing meat production. For almost 40 years, the State has regulated reindeer husbandry through a concession system for owning and managing reindeer and has promoted 'rational' herding practices through economic incentives and sanctions (Johnsen et al., 2015).

New reindeer husbandry policies in 2007 aimed to facilitate self-governance and participation in public decision-making related to the management of reindeer and pastures (Landbruks og matdepartementet and Reindriftsforvaltningen, 2007). However, Johnsen (2016b) recently identified several barriers to participation in the decision-making processes. Despite new tools for the internal management of pastoralism and a state rationale promoting participation, the main objective of the current governance regime is still 'rationalization' of Sámi pastoralism and State governance of reindeer husbandry, which is in conflict with the social organization and herding strategies of Sámi pastoralists. This threatens the traditional knowledge and language of pastoralists, affects their ability to participate in decision-making, and ignores Sámi customary rights (Turi and Keskitalo, 2014; Johnsen et al., 2015; Eira et al., 2016; Johnsen and Benjaminsen, 2017).

Although it is difficult to predict future changes in the Norwegian governance of reindeer husbandry in Norway, it is possible to explore two alternative developments and their possible consequences for Sámi pastoralism: decreased and increased self-governance.

Decreased self-governance

Over the past 40 years, the State has strengthened its control over reindeer, pastures and herders (Johnsen and Benjaminsen, 2017). This trend is still ongoing. In 2015, the government introduced the option of labeling each animal as a measure to increase the control of reindeer numbers (Nationen, 2015), and proposed an amendment to the Act in order to increase the State's ability to destock the herds (Landbruks og matdepartementet, 2015). A future that includes further measures to turn reindeer husbandry into a uniform meat-producing industry could erode the diversity, flexibility and mobility of and within herds – all of which are important elements of Sámi pastoralists' traditional knowledge. The State-promoted reindeer industry could also threaten the traditional social organization and customary rights of individual pastoralists and the siida and thereby reduce the resilience and adaptive capacity of the herding groups to cope with environmental and human-induced change. Ignoring the historical co-evolution of reindeer pastoralists and the ecosystems that support them could also undermine the integrity and resilience of these social-ecological systems (Comberti et al., 2015).

Increased self-governance

Internationally, the recognition of indigenous peoples' rights to self-governance is increasing and Norway is among the countries at the forefront of ratifying and supporting relevant conventions and initiatives (for example, ILO 169, 1990; UNDRIP, 2007 and the CBD Art. 8(j) and 10(c)). Recent legislation for reindeer husbandry also acknowledges the siida as a key Sámi pastoral social institution. This acknowledgement could, if taken seriously, also become a basis for self-management based on siida land rights, customs, traditions, and autonomous processes of knowledge (Sara, 2009). In 2015, the government established a working committee with the mandate to explore how the autonomy of the pastoralists could be improved. A governance regime facilitating autonomy could strengthen the siida and enable pastoralists to use a combination of situated, traditional knowledge, science and technology when considering herding practices and slaughter strategies. Increased self-governance could therefore build resilience and adaptive capacity of the pastoral community by maintaining and enhancing flexibility, mobility and social-ecological diversity (Turi, 2016).

Box 7.3 Life on the Kola Peninsula – A reindeer herders perspective

First person view by Andrey Dubovtsev, a Sámi reindeer herder from the Kola Peninsula, Russia, and Deputy Director of the Tundra cooperative slaughterhouse in Lujávri.

Reindeer herders on the Kola Peninsula face the following problems: poaching of their reindeer on the tundra and the negligence of the supervisory authorities in relation to the protection of grazing rights for their reindeer. We are very concerned regarding the situation relating to the rent of grazing lands, for example the lands of the Forest Fund. Land surveys are required and then an open competition is held. The winners are those who offer the largest sum of money. It creates an unequal playing field between those engaged in traditional livelihoods and the representatives of tourism and industry.

Another major issue has been the development of salmon fishing camps for tourists on the Kharlovka, Rynda, Zolotaya and Iokonga rivers. This has impeded the Sámi traditional salmon and trout fishery and has prioritized fly fishing tourists. The Russian legislation is on the side of the camp owners, not the reindeer herders concerning this issue.

Financial support for reindeer herding in the Murmansk region is not sufficient. The constantly rising prices on petroleum, oil products, electricity, food, equipment and needed appliances limits the growth of reindeer related businesses, and therefore directly impacts the quality of our lives, restricts the development of our livelihood and threatens the maintenance of our livelihood and its traditional knowledge and culture.

Climate changes are already being noted with later slaughtering times – in the past, slaughtering was completed by December 31st, but now can reach into the month of March. It is difficult to predict the impacts of such shifts at this early stage.

The challenges we face may negatively impact our traditional ways of life in the tundra, impacting Sámi biodiversity, culture and language. We see support of traditional livelihoods such as reindeer herding as being the only way to preserve traditional life on the tundra.

Chris Schmetz

Reindeer husbandry on the Kola Peninsula needs concerted support if it is to remain a traditional livelihood in the region

Academic studies of the cultural resilience of reindeer herding in the Nenets and Yamal Nenets AO offer an interesting comparison. The institutions that administer reindeer husbandry have remained flexible, especially on the Yamal Peninsula. This has been augmented by the herders' own considerable agency while on the tundra (particularly since the end of the Soviet Union) – even in the midst of an intense expansion of oil and gas activities (Forbes, 2013).

7.2.2.3 Key challenges for Sámi in Finland

The key challenges for Sámi in Finland include different kinds of encroachment on traditional Sámi lands, and self-determination. The participatory rights of the Sámi have been substantially strengthened lately in the new Finnish Mining Act (Kaivoslaki, 621/2011), which includes paragraphs that protect the Sámi homeland (the municipalities of Inari, Enontekiö, Utsjoki and the reindeer herding cooperative of

Lappi in Sodankylä) from mining activities that can adversely affect the status of the Sámi as an indigenous people. The participation of Sámi and reindeer herders in management and land use has developed on an *ad hoc* basis through the implementation of Akwé:kon guidelines in wilderness area planning in Hammastunturi (Juntunen and Stolt, 2013). These guidelines will also be implemented in the planning of Käsivarsi and Kevo wilderness areas that are important reindeer herding areas in northern Finland.

Despite these major developments, encroachments on traditional Sámi lands and restrictions on Sámi self-determination will continue to pose serious challenges for traditional livelihoods. Forestry is an important income source for the Finnish national economy and at the same time, over 90% of the Sámi home area (a geographical entity in northern Finland that comprises the three northernmost municipalities and the community of Vuotso) is managed and controlled by the State enterprise *Metsähallitus* which has overseen conflicts between Sámi reindeer herding and the forest industry, especially in Inari (Raitio, 2008).

The conflicts are likely to continue because the newly amended act on Metsähallitus (Laki Metsähallitus, 234/2016) does not include protection for Sámi lands from the adverse effects of activities controlled by Metsähallitus. In general, the Sámi are in a weak position in the governance of traditional livelihoods. In contrast to the situation in Norway and Sweden, reindeer herding is not an exclusive right of the Sámi in Finland, which means that the Sámi are in a minority position in the national reindeer herders' association, which is an important administrative link between Ministries and reindeer herders (Heikkilä, 2006). It is also the case that the proposed updates to the fishing convention between Norway and Finland is likely to restrict traditional fishing methods, which threatens traditional Sámi fishing on the Deatnu/Teno/Tana river.

These drawbacks are symptoms of the marginal position of the Sámi in legislative drafting processes and land use management in general. The powers of the Sámi Parliament in Finland is restricted to cultural autonomy which excludes traditional livelihoods. The Sámi are also in a minority in all municipalities in the Sámi homeland area (except for Utsjoki), which means it is hard for the Sámi to affect decision-making over land use and planning at the municipal level.

7.2.2.4 Karelian insights and perspectives

The final document of the Congress of Karelian people identifies demographic decline as the main challenge that Karelian people are facing. This document reports a 48.3% decline in the Karelian population between the Russian censuses of 1989 and 2010 (All Russian Census, 2010). Vepsians in the Republic of Karelia show very similar tendencies.

A primary threat for language survival is not only the number of speakers, but also the status of the language in society and the rights ensured by the different language speaking communities. A central issue is their use in education, media and governance – the Republic of Karelia recognizes only one official language: Russian.

The most important issue for Karelians and Vepsians is therefore education: the teaching of national languages and their transmission to the next generations. Because there are no 'national schools' in the Republic of Karelia, where all or even some part of particular subjects are studied in the Karelian or Vepsian language, teaching of these languages acquires special importance.

According to the UNESCO Atlas of the World's Languages in Danger (Mosely, 2010), as of 28 February 2016 the Karelian language is definitely endangered and the Vepsian language is severely endangered. For both languages it is typical that "*the language is no longer being learned as the mother tongue by children in the home. The youngest speakers are thus of the parental generation*". Because the inter-generational language ties are broken there is an emerging need for immersion language education systems and methods, such as the 'language nests' used by Maori in New Zealand and Sámi in Finland.

Karelians and Vepsians are underrepresented in the Government and the Legislative Assembly of the Republic. Good representation exists only at the municipal level. Existing structures for participation in decision-making have an advisory nature only, and their decisions are not obligatory for the authorities. Karelian and Vepsian decision-making bodies are mainly resource poor non-governmental organizations. Extractive industries and logging companies are active in the region and while some local and *ad hoc* negotiations have protected culturally or economically important territories, there are no established programs or agreements between indigenous communities and businesses.

The main objective of the indigenous peoples movement in Karelia is to survive as a distinct people, to preserve and develop native languages and cultures, and ensure their dignity and quality of life. Karelians and Vepsians are striving for better institutions of influence on decision-making and better representation at all levels with an improvement in legislation one of the most important fields of work for future years.

7.2.3 Climate

There is now evidence from across the Barents area that climate change is underway (see Chapter 4). Global and regional models project future changes in temperature, precipitation and snow condition in key areas for indigenous communities. In Finnmark and the Yamal Nenets AO, temperature over the period 1961–1990 increased most in spring, while overall precipitation increased throughout the year (Vikhamar-Schuler and Hanssen-Bauer, 2010a,b; Vikhamar-Schuler et al., 2010, 2013; Benestad et al., 2016). Snow season duration is typically 220 to 250 days per year in the northern Barents area, with spring snowmelt in Finnmark now 15 days earlier than 30 years ago. In this area, climate variation is partly correlated with the North Atlantic Oscillation (NAO) (Vikhamar-Schuler et al., 2010, 2013). Eira (2012) found a positive NAO to be associated with bad grazing years caused by severe snow conditions in western Finnmark, Norway and even large losses of animals due to starvation. Ecological relationships do not define the trajectory that reindeer pastoralism will follow over the next human generation but do represent fundamental constraints

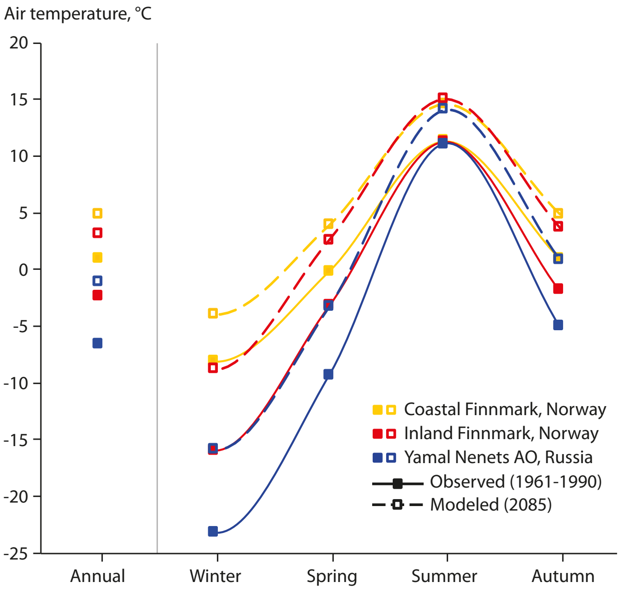


Figure 7.3 Annual and seasonal mean air temperature in coastal Finnmark, Norway (Nordreisa), inland Finnmark, Norway (Karasjok) and the Yamal Nenets AO, Russia (Salekhard). Solid lines show the observed 1961–1990 mean. Dotted lines show the mean for 50 downscaled climate models for 2085 (based on Magga et al., 2011).

and opportunities with which herders adapting to a changing world must work. The powerful effect of calf body mass in summer on calf body mass at the end of winter, highlights the importance of the first growing season for the subsequent development of reindeer calves (Hendrichsen and Tyler, 2014). In the Nenets AO, Lavrinenko (2011) found rapid changes in weather events to cause change in vegetation.

Future climate scenarios indicate that summer temperatures in the Barents area may increase by 2–4°C within the next 100 years, while winter temperatures may increase by 7–8°C (Benestad et al., 2016). The greatest temperature increase is projected to occur in inland Finnmark, but substantial warming is also projected for the Yamal Peninsula, which could be related to changes in sea-ice conditions. Yamal winter temperatures in the period 2070–2100 may be comparable to the inland Finnmark winter temperatures observed in 1961–1990, while inland temperatures in Finnmark, Norway by 2070–2100 may resemble those of coastal Finnmark (Nordreisa) today (Magga et al., 2011) (see Figure 7.3). This graphic indicates that future warming depends on location and that Norway will need to plan for a future climate in inland northern Norway that is similar to the coastal climate of today. More detailed scenarios for Finnmark up to 2100, show annual precipitation may increase by 5–30%, the snow season may be 1–3 months shorter, and annual maximum snow depth may increase by 5–60% (Engen-Skaugen et al., 2007). The greatest reductions in snow duration and snow depth are projected to occur in coastal areas. A comparison of reindeer herders reports and climate data for the areas investigated show temperature and precipitation conditions alone are not critical for the reindeer (Vikhamar-Schuler et al., 2013). However, combinations of these variables lead to different snow structures and it is these that will make the pastures more or less available for the reindeer. An increase in precipitation with rapid changes in temperature in winter are expected to create the main climate challenges for reindeer herding. In winter 2013/2014, 61,000 reindeer are estimated to have died from starvation on the Yamal Peninsula alone due to severe autumn/winter rain-on-snow events (Forbes et al., 2016). In the past, herd mobility and herders' flexibility usually decreased the effects of poor winter grazing conditions, but pasture losses and land use change have reduced this flexibility which has in turn reduced herders' ability to adapt in the future.

These climate-driven changes may be viewed from different perspectives. From the herders' perspective, it is the changes that are already underway that are of greatest concern, while broader society is more concerned about what these changes may mean for the future. This can be illustrated by reference to the anthrax outbreak on the Yamal Peninsula in 2016. Anthrax spores, possibly from the carcasses of reindeer that had died from anthrax 75 years earlier were reactivated due to the intense heat of summer 2016. One child died, many people were hospitalized and over 2300 reindeer died. The area was quarantined and cordoned off and an intense clean-up was initiated by the Russian authorities (Gainer, 2016). For herders, this climate related-event (full investigations are still underway) was catastrophic on multiple levels – for herder health and reindeer health but also through the loss of an area for migration that was still unaffected by infrastructural development. For herders, these cumulative impacts are reducing their adaptive flexibility, a key strength of nomadic herding. For broader society, the concern is that this event is a harbinger of worse to come.

Other events that appear to be climate-related are the appearance of 'methane holes' on the tundra (Moskvitch, 2014), which are hazardous for herders and their animals. Warmer summers have led to increased risk of fire especially in the Russian sector of the Barents area (e.g. Kharuk et al., 2012) and winter pastures for reindeer in the Nadym region have experienced intense fires this summer. A warming climate has also led to a 'greening' of the Arctic. On the ground, this warming has accelerated the growth of tall shrubs, treeline trees, and grasses (Bernes et al., 2015). Anecdotally, herders across the Barents area speak about the difficulty that greening poses on the ground for the movement and locating of animals (e.g. Forbes et al., 2010). A change in the vegetation will also drive a change in snow structure and snow accumulation in winter, which can restrict the use of some areas at certain periods. Such trends are expected to continue and even strengthen but are extremely hard to predict, model or prepare for. However, a recent review of over 6000 peer-reviewed articles (related to the impacts of reindeer grazing on Arctic and alpine vegetation) showed that research and management must consider local conditions, and that policy and management must work at the local scale to more fully understand the dynamics between plants, animals and humans (Bernes et al., 2015). It could also be argued (see Section 7.4) that more meaningful and comprehensive inclusion of traditional knowledge in research and management would increase understanding of this dynamic.

7.2.4 Technology – far-reaching impacts

The impact of new technologies on indigenous peoples across the Barents area is multifaceted. Indigenous peoples have incorporated new technologies as needed and have adapted them, or to them as required. However, not all new technologies are embraced. For many reasons they may not meet the demands of what is in effect a rigorous and demanding workplace environment.

The snowmobile has transformed reindeer herding in the Nordic countries, allowing herders to access their herd more quickly but at the cost of spending less time with the animals. The 'snowmobile revolution' is now a well-worn phrase, but its effect has been significant. The main impacts of the early technological revolution were a heightened dependence on outside factors such as the need to purchase fuel (Pelto, 1973).

In addition, many technological advances are introduced to larger markets first and take time to arrive in remote areas, if they arrive at all. However, the lack of one technological advance may assist a region in leapfrogging straight to the next stage of innovation – the rapid spread of mobile telephony and mobile-enabled internet access is one such example. In fact, there is some support for referring to this as the 'mobile phone revolution' (Stammler, 2009, 2013) because this technology has altered indigenous peoples' lives immeasurably. In 1981, the first cellphone network was launched in the Nordic countries and anecdotal evidence suggests reindeer herders in Norway were early users of this technology as they quickly realized its potential. By 1988, Norway had the world's highest density of mobile phones (Telenor Group, 2012).

> *"Of course, I understand that it's the 21st century, computers, big cities, mobilization and so on. In this case, those who want to become a reindeer herder and live in the forest would be very few. But why does everyone think in clichés? We can perfectly combine our traditions and new traditions and new technologies, and not only combine, but also extract the maximum benefit from it. If we develop this idea and bring it to life, we will have more benefits."*
> Workshop participant, EALLIN (2015:36)

Just as with mechanized transportation, the integration of cell phone technologies into reindeer herding societies was rapid and complete in Scandinavia long before it was in northwestern Russia. But once introduced, its spread there was also rapid. However, herders and hunters work in remote areas, often far from villages, roads and cellphone towers. Cell phone coverage is patchy even in many herding areas in Scandinavia. In northwestern Russia, coverage is extremely patchy and focused on towns, villages and industrial installations. Technology has certainly connected indigenous peoples in ways that could not be imagined in the past – social networking sites such as Facebook and Vkontakte have transformed the way that indigenous peoples in the region connect and share information. Indeed, the Sámi language appears to be thriving on the social network Facebook, although this has yet to be fully studied. Devices with GPS capabilities are making life in the tundra and mountains safer. GPS devices are being attached to reindeer and predators across the Nordic countries to monitor their movements and increase understanding. The interpretation of results by herders and scientists is often contested however.

A future technological gain that would quickly assist life in the remote regions of the tundra would be portable and renewable power generation for recharging devices, currently achieved through expensive and heavy diesel which must be carried by reindeer sledge.

7.3 Actions for adaptation in indigenous peoples' societies

Research and education in indigenous peoples' societies over the past 30 years may not be enough to face the climate-related challenges expected in the coming decades. This section describes four possibilities that indigenous peoples' societies in the Barents area could use in developing the tools and solutions needed to adapt to the multiple challenges they are likely to experience: advanced land-use modeling tools, repurposed impact assessments, better use of the knowledge base, and different ways of education delivery. Together, these should lead to a more effective science-policy interface to better prepare communities, especially the youth for the coming changes.

7.3.1 Modeling and maps

Understanding cumulative impacts and the future consequences on Arctic nature of climate and socio-economic drivers through modeling may become a powerful means to assist local and regional decision-makers in understanding and mitigating potential future developments and in advancing adaptation strategies. Climate change impacts, as well as increased demand by the global economy for Arctic natural resources will have a major impact on the livelihood, living conditions, and wellbeing of the people and communities in the Barents area. Modeling the individual and integrated impacts of human-induced pressures on biodiversity may help strengthen the integrated knowledge basis for policies on sustainable development (Glomsrød et al., 2017).

The GLOBIO3 model (see Box 7.4) has been developed to estimate and illustrate the global trends in integrated impacts of climate change and human-induced pressures on terrestrial biodiversity (Alkemade et al., 2009). It incorporates the impact of five different pressures: land use change, infrastructure development, land fragmentation, nitrogen deposition, and climate change. For this study, an assessment was made for three pilot areas in the Barents Region. The aim of this pilot analysis was to gather information to raise awareness about the consequences of the multi-drivers of change in indigenous peoples' societies. Because the impact of nitrogen deposition in the Arctic is low (levels are below thresholds for impacts on Arctic biomes) this pressure is excluded from the present analysis.

The pilot studies concern three key areas: Finnmark county in Norway, the 'Laponia' area in Sweden, and the Nenets AO in Russia. 'Laponia' is located in Norrbotten county, Sweden and its borders comprise ten neighboring *Sameby*, as well as the Laponia region added to the World Heritage List by UNESCO in 1996. The three case studies are all located within the traditional reindeer herding areas of Sámi and

Box 7.4 GLOBIO3: Assessing biodiversity in the Barents Region

GLOBIO3 was developed by the Netherlands Environmental Assessment Agency (PBL) for assessing global and regional biodiversity. GLOBIO3 has been successfully used in several integrated assessments at global, regional, national and sub-national level. It is well known for its application in global biodiversity assessments such as the Global Biodiversity Outlooks (GBOs) of the Convention on Biological Diversity, UNEP's Global Environment Outlooks (GEOs) and the OECD's Environmental Outlooks. It has also been applied for sub-national assessments in several temperate and tropical countries.

GLOBIO3 uses a Mean Species Abundance (MSA) indicator in which the species abundance of a disturbed ecosystem is compared with that of a reference state ecosystem. The MSA of originally occurring species is defined as the average abundance of originally occurring species relative to their abundance in the original or reference state. The model does not provide detailed information at individual species level. The impact of each pressure is expressed as a value between 1 (undisturbed, green on the output map) and 0 (completely disturbed, red on the output map). In general, the reference state refers to primary or untouched ecosystems with 'natural intactness', but the model can also be used to assess impacts on older cultural ecosystems such as heathland, semi-natural grasslands and grazed tundra. GLOBIO3 is built on simple cause-effect relationships between pressures and biodiversity impacts derived from available literature, using meta-analysis for comparable ecosystems. The quality of the model output can be improved using local data, traditional knowledge and expert knowledge. GIS maps are used as the primary input from these cause-effect relationships. Scenario information is used to estimate the impact of pressures in the future. The model output comprises a remaining intactness map (measured by MSA), plus maps that display the contribution of each of the different pressures. The model is designed as a decision-support tool for illustrating impacts on biodiversity, making it easier to understand the drivers

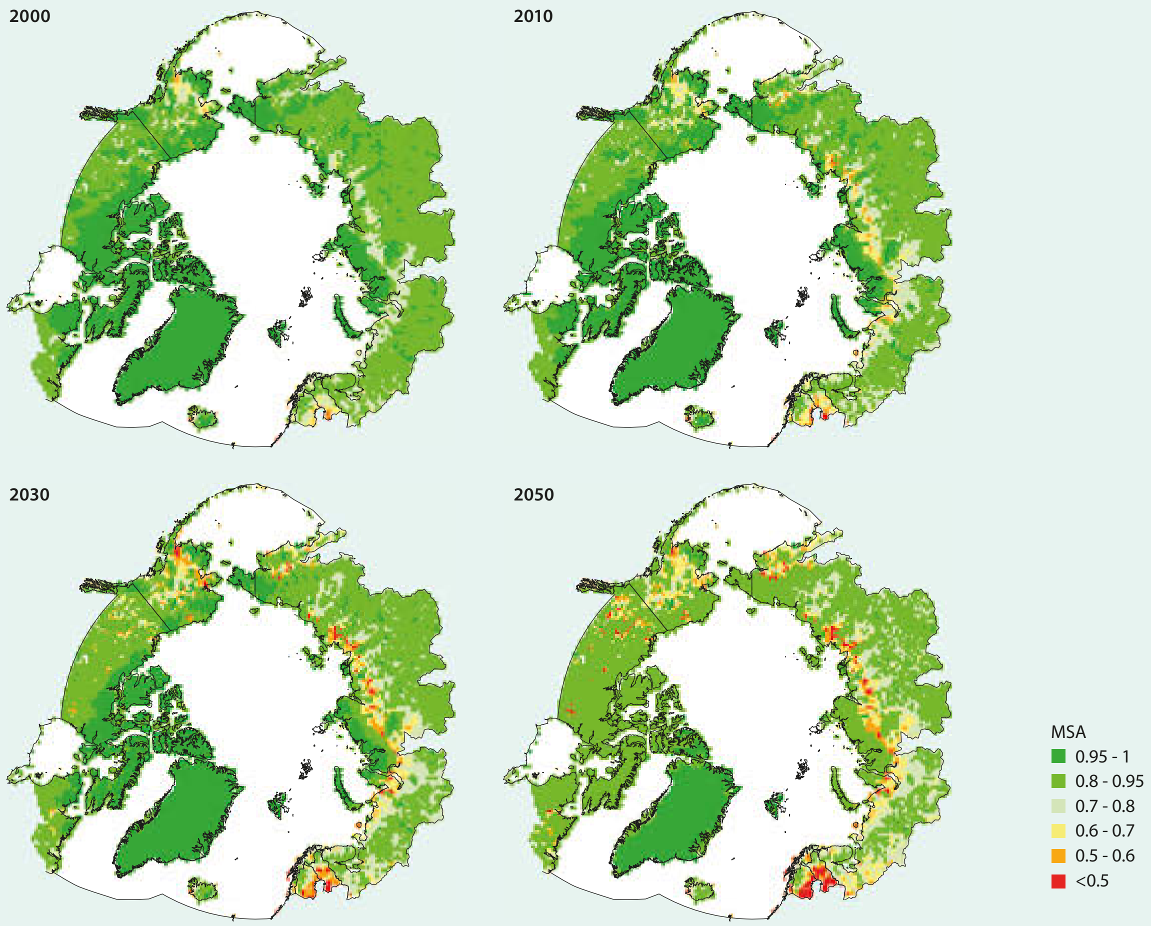


Figure 7.4 Trend in mean species abundance (MSA) in the Arctic for the baseline scenario of the Rethinking Study (based on data from the Netherlands Environmental Assessment Agency, 2010).

of ecosystem change. The aim of the model is to provide policymakers with information about the current and possible future status of biodiversity and expected trends in land-use and ecosystem services for different scenarios or policy options.

The GLOBIO3 model is designed such that each of four pressures (land use, infrastructure development, land fragmentation, climate change) are independent, in the sense that they impact biodiversity (expressed in MSA) in different ways. *Land use* change implies that biodiversity is negatively impacted through loss of natural area, from conversion of land into a different type with a lower intactness (e.g. by urban and agricultural development, forestry, mining, urbanization, and other socio-economic developments). *Infrastructure development* affects biodiversity negatively by disturbances that can be linked to the presence and use of the infrastructure (e.g. by disturbance caused by cars or people on or near the roads and other installations). *Land fragmentation* implies a loss of connected nature areas (e.g. representing a barrier to migration of species). *Climate change* impacts are represented by changes in migration or disappearance of characteristic species from their original natural habitat areas. The structure of the model is such that the impact of the four pressure types can be combined to generate a total impact on biodiversity. The impact of climate change in the current GLOBIO3 model is based on global model data and is limited to cause-effect relations between the fraction of remaining species in a biome and average change in global mean temperature (Bakkenes et al., 2006; Arets et al., 2014; van Rooij et al., 2017). The global model data referred to here are climate output data from IMAGE (Integrated Model for the Assessment of Global Environmental Change) and are used to simulate the environmental consequences of human activity worldwide (Stehfest et al., 2014).

In this study, an assessment of current and future biodiversity in the circumpolar Arctic was first made with GLOBIO3 based on global data and a baseline scenario from the Rethinking Global Biodiversity Strategies Study (Netherlands Environmental Assessment Agency, 2010). However, the scenarios in the Rethinking study are based on global macroeconomic assumptions and not adjusted to Arctic conditions (see Figure 7.4). For an accurate analysis at the regional Arctic level, detailed spatial data must be used.

Nenets. This chapter presents the full outcome for Finnmark (Section 7.3.1.1) and preliminary results for the Nenets AO (Section 7.3.1.2). The aim is that by including key drivers of change for Arctic ecosystems and using local data, traditional knowledge and expert knowledge, this study will help to establish whether GLOBIO3 could be a useful tool for assessing impacts on biodiversity in the Arctic. For this reason, key drivers of change for Arctic ecosystems are used as well as local data, traditional knowledge and expert knowledge (van Rooij et al., 2017). Additional map data of the Laponia area were derived from the Swedish RenGIS model. RenGIS was developed with the support of 51 reindeer herding units in Sweden, and offers much guidance as to how participatory mapping can inform and empower practitioners on the ground on issues related to land-use change (see Section 7.4.1).

7.3.1.1 GLOBIO3 – Finnmark, Norway

At the local scale, the GLOBIO3 model was first applied to Finnmark county, a core area for Sámi reindeer herding in Norway. The aim was to determine the current and future impacts of land use, infrastructure development, land fragmentation and climate change on biodiversity. Data from national and local sources were used and included spatial data from ecosystem mapping and municipal zoning plans (for infrastructure development). The projection of future biodiversity was based on the assumption that land use and infrastructural developments found in existing provincial and municipal development plans would be realized by 2030. In addition, extreme climate change was represented by a temperature increase of 7°C in Finnmark added to the future scenario.

Figure 7.5 shows the resulting impact maps of land use, infrastructure development, land fragmentation and climate change on present-day (2011) biodiversity. Land use clearly has the greatest impact, followed by land fragmentation and infrastructure development, which both have strong local impacts. The climate change impact is still relatively limited. The corresponding impacts on future (2030) biodiversity are also shown in Figure 7.5. The most eye-catching differences between the current and future sets is seen in the land use and infrastructure maps. The four pressure-related impact maps have also been combined, resulting in a total impact map of the current (2011) and future (2030) biodiversity situation in Finnmark (Figure 7.6).

A useful way to envisage the challenge that pastoralists face in moving with their animals through time and space in Finnmark is to overlay their migration routes onto the combined impact maps (Figure 7.7). For reindeer herders, it became clear during the GLOBIO3 GIS workshop on 3 September 2016 in Skaidi, Norway, that the 'devil is in the detail'. Using insets, the graphic shows three reindeer herding districts: *Fálá*, *Fiettar* and *Gearretnjárga* and compares the situation in 2011 and 2030. By 2030, the reindeer herding districts highlighted are likely to be experiencing significant impacts on biodiversity, mainly through infrastructure developments and land fragmentation. Reindeer herders at the workshop mentioned that some of the large impact areas overlap with calving grounds and important bottleneck zones of migration routes.

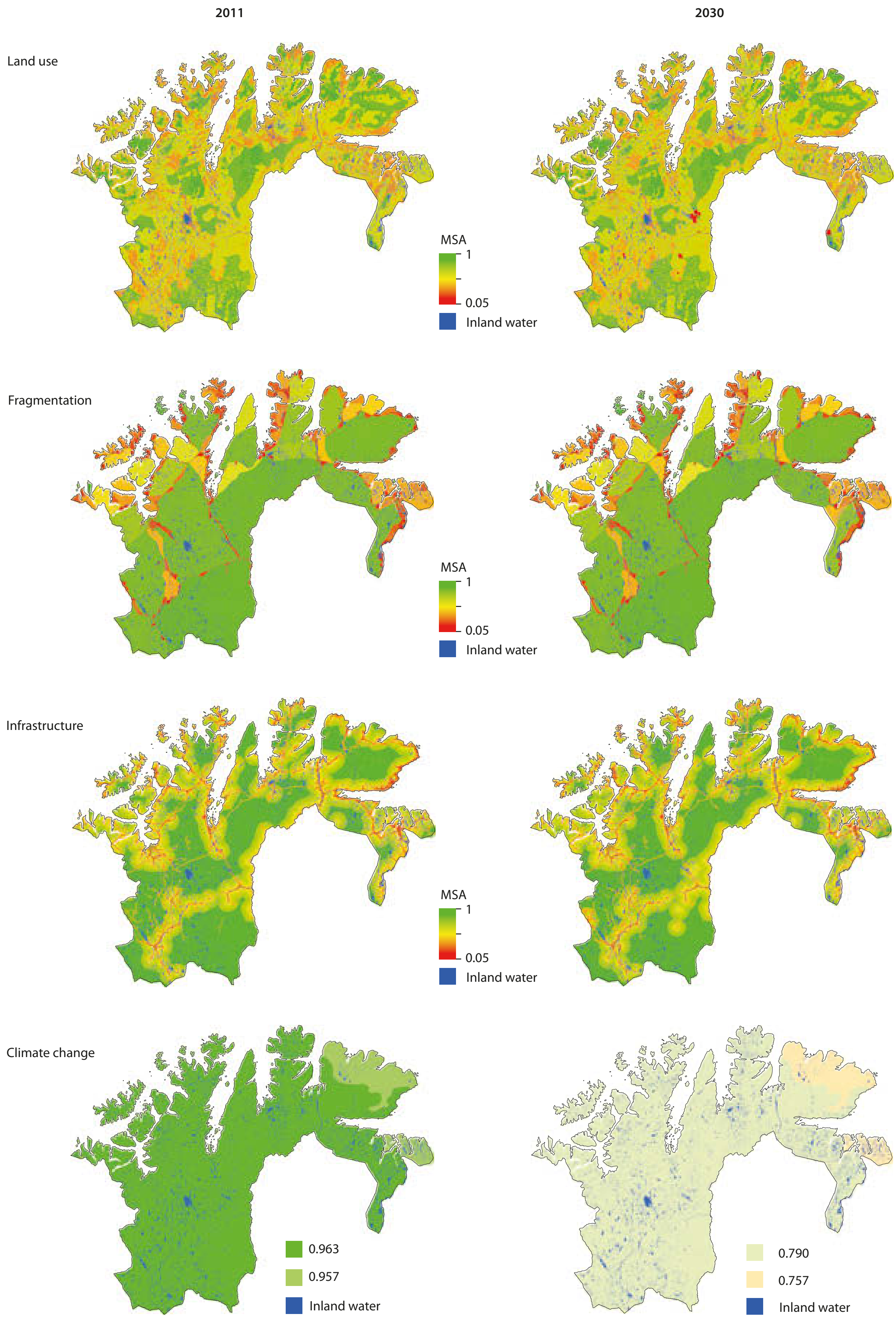


Figure 7.5 Mean species abundance (MSA) in Finnmark from GLOBIO3 showing present-day (2011; left) and future (2030; right) impacts on biodiversity of land use, infrastructure development, land fragmentation and climate change (Wilbert van Rooij / Plansup).

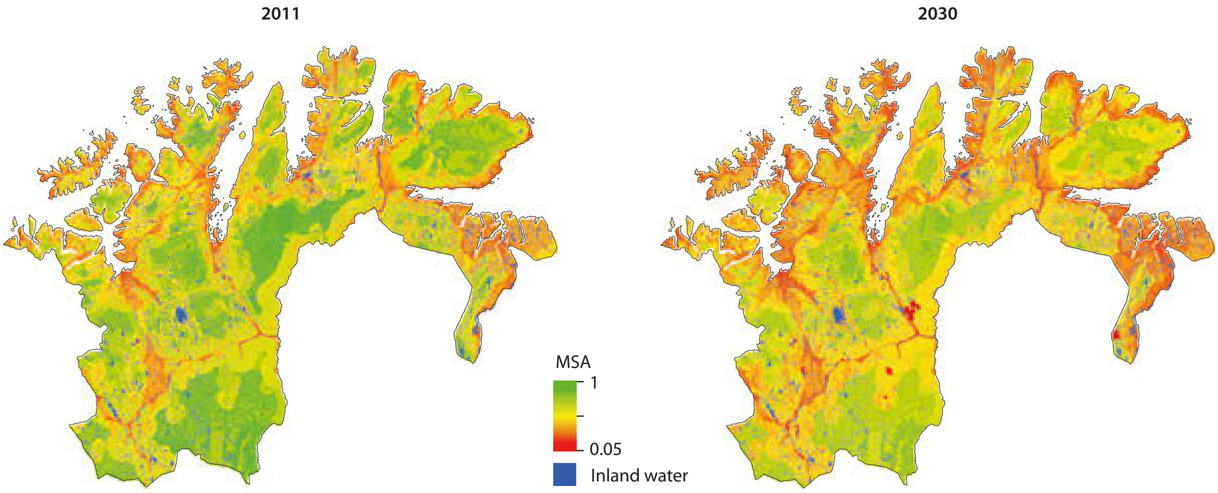


Figure 7.6 Mean species abundance (MSA) in Finnmark from GLOBIO3 showing the combined impacts of land use, infrastructure development, land fragmentation and climate change on current (2011) and future (2030) biodiversity (Wilbert van Rooij / Plansup).

Because land-use change between 2011 and 2030 is limited in Finnmark, the change in biodiversity status over this period is largely due to climate change and current plans for new infrastructure that increase land fragmentation. The additional infrastructure and fragmentation impact is caused by the planned development of new roads, a railway track, wind farms, mines, energy infrastructure, urban areas and cabins. While climate change has a limited impact across the entire Finnmark area, the impacts of infrastructure developments can be very high but are also local.

7.3.1.2 GLOBIO3 – Nenets AO, Russia

The GLOBIO3 model was also applied to the Nenets AO to assess cumulative impacts for present (2009) and future (2030) biodiversity. The total MSA map for this region is shown in Figure 7.8 (upper plot). The okrug is a core area for Nenets reindeer herding and other traditional livelihoods. To create a picture of current and planned infrastructure development, data on land use and other pressures were obtained from the MODIL-NAO report (Dallman et al., 2010) and the Nenets AO 2030

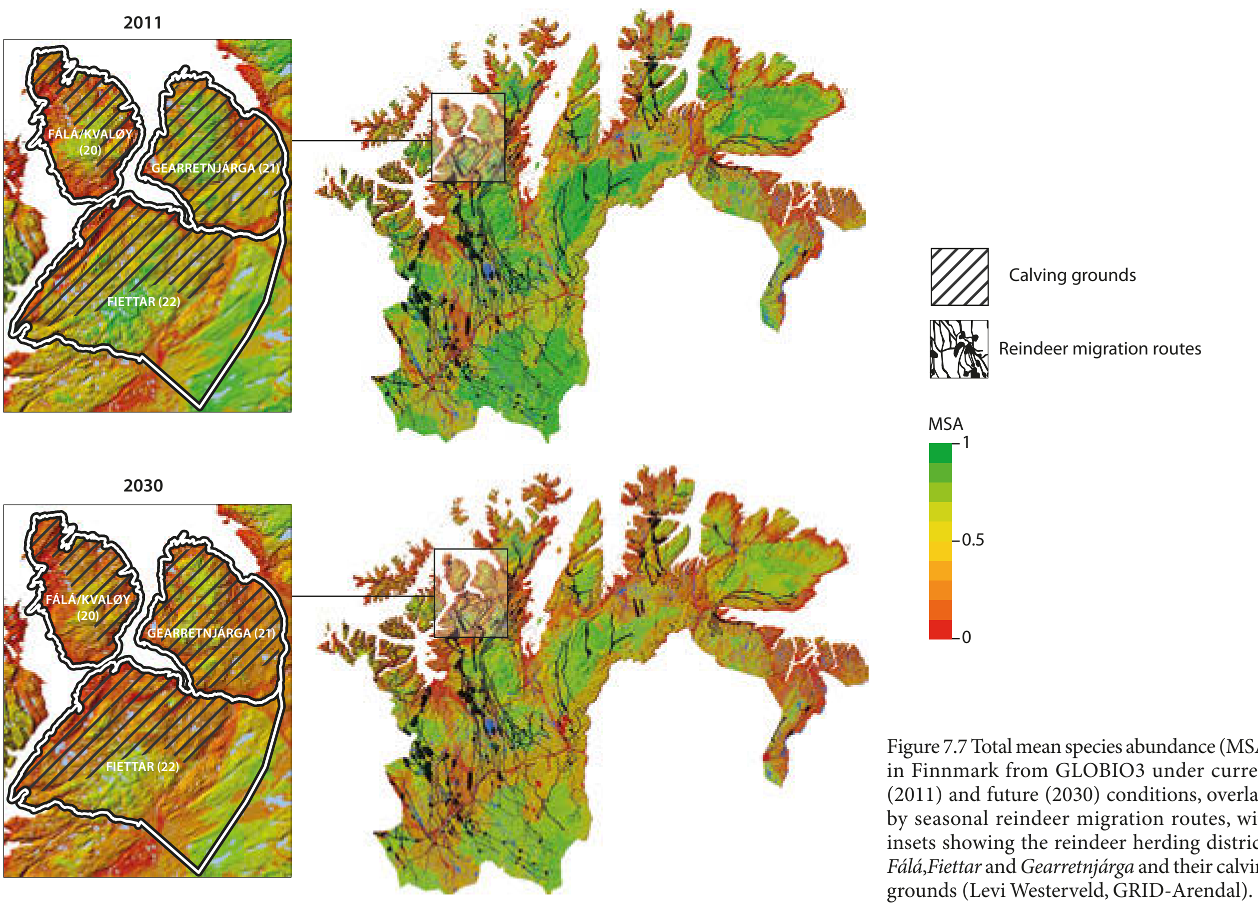


Figure 7.7 Total mean species abundance (MSA) in Finnmark from GLOBIO3 under current (2011) and future (2030) conditions, overlain by seasonal reindeer migration routes, with insets showing the reindeer herding districts *Fálá*, *Fiettar* and *Gearretnjárga* and their calving grounds (Levi Westerveld, GRID-Arendal).

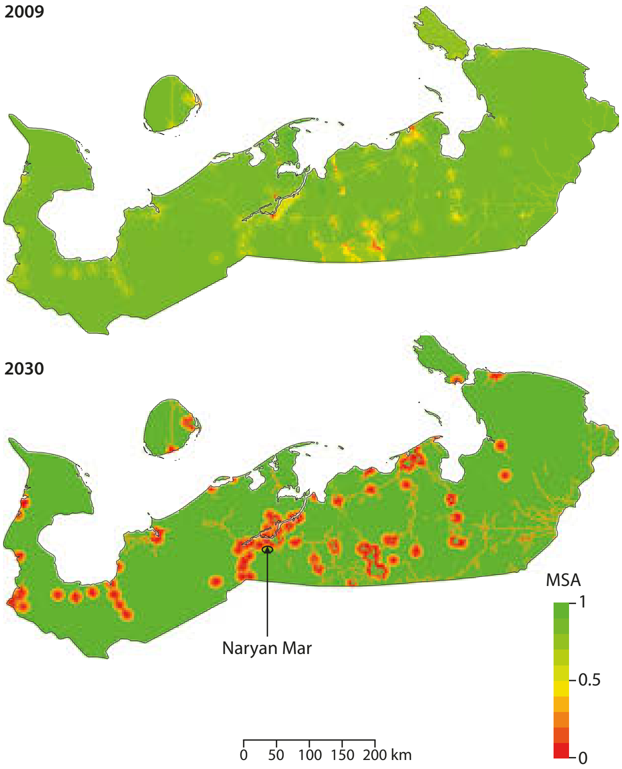


Figure 7.8 Mean species abundance (MSA) across the Nenets AO in 2009 (upper). Local disturbance is centered around the city of Naryan Mar, and the surrounding extensive oil fields to the north and south. The lower plot shows MSA across the Nenets AO for the future infrastructure scenario. (Wilbert van Rooij / Plansup).

report (Nenets Autonomous Okrug, 2009a,b), as well as various other reports by commercial organizations active in the region (Bambulyak et al., 2015). For the estimate of future biodiversity, it was assumed that several of the infrastructure developments mentioned in the above reports would be implemented and that new mines would be created near the planned roads and railways. As for Finnmark, the Nenets AO future scenario includes a 7°C increase in temperature. To calculate the future infrastructure and fragmentation impact, the current (2009) fragmentation lines in the Nenets AO were combined with the new fragmentation lines (i.e. new roads, terminals, railways and above ground pipelines, and the planned mineral and gravel extraction) following the same methodology as for the Finnmark study. As land in the Nenets AO is used extensively for reindeer herding and little urban and agricultural expansion is expected, the future land use impact will be similar to that of 2009. However, the prospects for hydrocarbon and mining developments are considerable, especially near the planned new roads and railway tracks. Such developments will have a significant local impact on biodiversity and traditional land use in these areas, all of which are important for reindeer herding and other traditional livelihoods (see Figure 7.8, lower plot).

7.3.1.3 First conclusions on the use of modeling tools

The GLOBIO3 model is currently the main tool for determining the cumulative impact of drivers of biodiversity loss. It provides support to planners and decision-makers investigating potential development projects within the vicinity of indigenous peoples' communities and grazing lands. The results reported here have contributed to the development of the GLOBIO3 model for Arctic conditions and show the need for further improvements in order to represent the specific characteristics of important Arctic socio-ecological systems such as reindeer herding. The preliminary results and maps were presented for dialogue with Sámi reindeer herders to test the quality and relevance of the model calculations in view of their traditional and local knowledge. It was emphasized in the dialogue that the maps are potentially useful tools if they are supplemented with interpretations based on traditional and local knowledge. An important lesson gained from this dialogue is that the biodiversity loss illustrated in red on the maps must be interpreted with caution. While red is clearly a warning that planned developments may be detrimental to biodiversity in these grazing areas, it does not mean the affected areas should be considered completely lost because they could still be important for migration and grazing at certain times.

Knowledge of the cumulative impacts and potential future consequences of climate and socio-economic drivers achieved through modeling, and improved by traditional and local knowledge gained through dialogue with the indigenous peoples affected, may provide a powerful tool to assist local and regional decision-makers in planning future developments and advancing adaptation strategies.

GLOBIO3 provides a mechanism for indigenous societies to plan for future change. Success depends on a full engagement and consultation with local rights holders and use of their traditional knowledge in discussions about future possible consequences. Figure 7.7 demonstrates the future challenges that three reindeer herding districts in Norway are likely to face should development proceed as projected up to 2030. Lands designated as calving grounds by the state would be strongly impacted. This raises serious questions for the agricultural and land use policies in Norway because the model governing the economy of reindeer herding is based on maximizing calf production and slaughter.

The Intergovernmental Panel on Climate Change (IPCC) recently concluded that protecting grazing lands would be the most important adaptation measure for reindeer herders under climate change (Nymand Larsen et al., 2014). The cumulative effects of multiple drivers of change on the calving grounds and summer pastures used by reindeer herders in Norway, added to by inappropriate governance strategies is already affecting the inland pastures of Finnmark. One possibility could be to develop specially protected areas for reindeer herding, such as the protected areas developed in Laponia, Sweden (Green, 2009) and the concept of 'territory of traditional nature use' in Russia (Russian Federation, 2001; Kryazhkov, 2008).

7.3.2 Impact assessments

The Impact Assessment (IA) process in Norway, Sweden and Finland is broadly similar in scope and aim, and input is generally open to all citizens as well as to non-governmental organizations, representative authorities and those directly affected by a proposed project. The process as currently practiced in the Barents area has flaws, particularly for indigenous peoples practicing traditional livelihoods. General failings include short time frames and budget constraints, a lack of local knowledge in the field, the adversarial nature of IAs, a poor understanding of broader societal issues, cutting and pasting material from previous reports, and rushed completion to meet deadlines set by legislators or to avoid project delays (Wright et al., 2013). Additional issues include an assumption that what can be 'counted' is more important than what cannot, short-term perspectives (decades rather than centuries), and a lack of consideration for cumulative and cascading effects. IAs also lack a holistic approach, and do not include traditional knowledge from practitioners. As a result, the role that indigenous peoples should or could play in the process, their knowledge, economies, stewardship and/or perspectives, as well as the broader question of land rights are subsumed to meet the demands of the IA. O'Faircheallaigh (2009) reported that the exclusion of indigenous peoples from the IA process (the example given was from Australia, but is still relevant here) mirrors the broader exclusion of Aboriginal peoples from their ancestral lands initially, and from the benefits of mainstream society subsequently.

Johnsen (2016a) has written about a planned mine development – the Nussir project – in Kvalsund, Finnmark. Johnsen (2016a) noted that the IA process focused on the 'square meters on the ground' that would be affected by the development. But as a herder interviewed by Johnsen pointed out, disturbance from mining is far more extensive than the actual area of mineral extraction. The IA also gave no consideration to the cumulative impacts of the mining combined with other encroachments on the pastures and, as the same herder explained, if the spring pastures are impacted calves cannot make efficient use of summer pastures and are thereby at risk of not surviving the winter if conditions are bad. In addition, a cost benefit analysis of the planned mine was not constructed fairly; with mineral extraction coming at the expense of pastoralism and the herding communities carrying all the risk.

A herder from the *Fálá* reindeer herding district (their summer pastures are near Hammerfest) who participated in the 2016 GLOBIO3 participatory mapping workshop pointed out what he saw as a fundamental flaw: that herders are included too late in the process (this is also reflected in the literature, see Herrmann et al., 2014) – after the *Områderegulering* (Area planning) stage. This sets out broad use plans for large-scale areas of land and does not require an IA. Herder input is only sought at the *Reguleringsplan* (zoning plan) stage, which is where decisions are taken at a smaller scale. By that stage, people are already envisioning the land in a different way and mental landscapes have already shifted.

Johnsen (2016a) also noted how various arms of the state can play different and conflicting roles. The proposal for the Nussir copper mine was approved in 2014 by KMD (the Ministry of Local Government and Modernization which is responsible for the Planning and Building Act, and Sámi affairs among other things). KMD acknowledged that reindeer husbandry is a livelihood protected by international law and that a substantial violation of the material basis of Sami culture could not be allowed. However, the approval did not address what that might mean in practice, and did not look at the cumulative or cascading effects of the project. In this sense, the question of a 'tipping point' beyond which it would no longer be possible to practice reindeer husbandry was not addressed. A participant at the GLOBIO3 GIS workshop in 2016 made a point of asking whether a future in reindeer husbandry could be guaranteed. Another participant asked why the question of how these developments would limit herders' ability to grow their economy was left unasked and, even more pertinently, why the potential for growth in reindeer husbandry was not discussed either by the authorities or by the reindeer husbandry sector itself. Another participant raised the issue of calling for more self-governance for reindeer husbandry in order to increase the protection of remaining areas.

However, there might be merit to a broader application for IAs, and more attention has recently been paid to how new approaches in planning and impact assessment could help communities engage in the processes in a more meaningful way. One emerging field is participatory scenario planning in which different groups of people use their local and scientific knowledge to develop sets of scenarios that provide multiple perspectives on real-world social-ecological problems (see Chapter 5). Scenario planning is not new, but little attention has been paid to how scenarios actually affect aspects such as social learning, innovation or empowerment (Oteros-Rozas et al., 2015). A social-ecological resilience assessment where the capacity of interdependent complex systems of people and nature persists, adapts and transforms in the face of change should be further developed. Assessments that include social-ecological resilience insights are rapidly developing and diversifying as they combine social dynamics (e.g. learning, multiple knowledge systems, social memory) with analysis of social structure (e.g. social networks, leadership, cross-scale institutional linkages) and practical social-ecological methods (e.g. participatory scenario planning, adaptive management, resilience assessment) (Resilience Alliance, 2010). Resilient indigenous peoples in the Barents area might then be better able to absorb disruptions in the form of abrupt disturbance events as well as more gradual drivers of change.

Concrete examples of changes that need to be made to the IA process include: (1) legitimation of traditional knowledge (see Section 7.4), (2) the adversarial nature of the IA process, (3) the lack of capacity in indigenous communities (see Sections 7.4.2 and 7.4.3), (4) the lack of financial resources for participation and indigenous expertise, (5) short time frames, (6) the fact that many IAs seek input from indigenous peoples after the process has already begun, (7) a lack of 'procedural fairness', and (8) ignoring questions related to ethics and indigenous land rights (O'Faircheallaigh, 2009; Booth and Skelton 2011; Johnsen, 2016a).

The Russian legal system has quite a lot of possibilities to protect the interests of indigenous peoples, but in law they are considered primarily as an object, not as a subject of regional and municipal policy (Kryazhkov, 2010; Popkov, 2011). In addition, mechanisms to ensure the active participation of indigenous peoples in decision-making on the management and control of environmental and natural resources, including resources for Arctic indigenous livelihoods have not been sufficiently developed.

Currently, one of the more effective mechanisms for such participation in the Russian sector of the Barents area is built into an EIA process, but constitutes its last stage, namely public hearings (Klokov and Bocharnikova, 2013). However, the final decision on approving resource development projects is made on the basis of a state ecological review (gosudarstvennaya ekologicheskaya ekspertiza), which must take into account the outcome of a public hearing. State ecological review assessments of development projects are included in Russian federal laws, but are not laws of direct action. This means that for the laws to be implemented some statutory and non-normative Acts must be adopted (e.g. instructions, regulations and standards, and legislative instruments). These vary between regions if not decided by the Federal Court. As a result, the involvement of indigenous peoples is implemented differently in different regions (Matveev and Kotov, 2004).

The only region of the Russian Federation where the active participation of indigenous peoples is ensured is in the Republic of Sakha (Yakutia), during the final decision-making stage of an EIA. There, an ethnological review is carried out together with the state ecological review, to analyze the cumulative impacts of planned industrial activities and the consequences for the original inhabitants and traditional livelihoods. The ethnological review must be conducted before the decision on project approval is taken, and indigenous peoples and their associations have the right to representation on the expert committee.

While the Russian sector of the Barents area has not achieved this level of legal protection and process, the region has developed some sustainable practices for ensuring the participation of indigenous peoples in decision-making. The existing procedures require an EIA to focus not only on the natural environment, but also on the social, cultural and economic aspects of life (Klokov and Degteva, 2012; Klokov, 2013a). Developers must ensure opportunities for indigenous peoples to participate at public hearings, which is particularly important for remote communities and nomadic herders. Companies have contributed to the development of the territory, which has included the building of schools and the provision of educational opportunities for indigenous youth. These practices have received considerable publicity in areas where large industrial developments are planned on the traditional lands of reindeer herders. One example occurred on the Yamal Peninsula, where regional and municipal authorities were both involved in helping to facilitate the participation of indigenous peoples in decision-making and in pursuing their interests during assessments of the environmental impacts of infrastructure and oil and gas development (Klokov, 2013b).

The diversity of regional legislation and practices involved in undertaking EIAs, public hearings, state ecological expertise investigations and the implementation of ethnological expertise investigations in the Russian Federation, offers considerable potential for means to advance the participation of indigenous peoples in the governance of their homeland (Klokov and Degteva, 2012; Klokov and Bocharnikova, 2013; Klokov and Khrushchev, 2014). Public hearings should not be the only mechanism through which indigenous peoples can participate outside regional and public governments; an analysis of social, cultural and economic consequences of proposed developments should be mandatory; livelihoods other than reindeer herding should have formal rights to participate and be included in all stages of impact assessment; and traditional knowledge holders and practitioners should be included at earlier stages of an EIA. There is an urgent need to consider regional laws and best practices to issue the federal laws of direct action on EIAs, and mechanisms ensuring the active participation of indigenous peoples in decision-making should be formalized. In terms of landscape protection for traditional activities, the legal structure entitled 'territories of traditional nature use' offers some avenues for the delimiting of landscapes for the continuation of traditional livelihoods (Russian Federation, 2001). However, amendments to this legislation in 2013 have diluted their effectiveness, particularly in areas of interest for economic development (Kryazhkov, 2015).

7.4 Towards a broader use of traditional knowledge

Through observation, practitioners of traditional livelihoods gain knowledge about the landscape, weather, and climate, and how these environmental factors interrelate. This comprises a rich, varied and valuable body of knowledge. However, research has shown that traditional knowledge is given less attention than scientific knowledge because the authorities consider the latter to be more objective and rational (Turi and Keskitalo, 2014; Johnsen et al., 2015). This is a short-sighted view, as Eira (2012) and Eira et al. (2013) have shown in the case of reindeer herders' knowledge of snow. This knowledge is extensive, deep, accumulated over time and tested – much like traditional scientific knowledge albeit from a different perspective (Riseth et al., 2010).

Traditional knowledge is continuously practiced and refined. Bull et al. (2001) and Sara (2009) gave examples for reindeer herding. Within reindeer husbandry it is local knowledge (concerning pasture areas, herd structures, animal behavior, climatic conditions) that enables pastoralists to choose from the many herding strategies available and so apply situated resilience-enhancing strategies (Mathiesen et al., 2013; Sara, 2015; Eira et al., 2016). For example, a herder may respond to less favorable grazing conditions by altering the use of pastures and migration patterns of the herd. Sámi pastoralists also have a specialized language that helps them articulate ecological variability and serves as a tool to minimize risk (Magga, 2006; Eira, 2012a). A consequence of weakened traditional knowledge and declining use of language could be weakened adaptive capacity within the herding community (Mathiesen et al., 2013).

Indigenous and local community participation in research is key to improving the management of nature in the North and to avoiding conflicts over nature use. According to O'Brien et al. (2009), the Norwegian social contract currently focuses on autonomy and rights, and fails to recognize the factors and knowledge that underlie the livelihoods of Sámi reindeer herders, such as the importance of maintaining diversity in reindeer herds. The state-assumed responsibility for regulating reindeer production undermines the resilience of reindeer pastoralists by insisting on the use of equilibrium-based management tools such as carrying capacity. This is also true

Andreas Ausland

Much knowledge is embedded within indigenous food systems and cultures; traditional Sámi reindeer slaughtering techniques are one such example

in fishing communities, where government control of fisheries has had a negative effect on local livelihoods.

The need for a new social contract between science and society is clear, one based on knowledge partnerships where indigenous peoples' traditional knowledge is included.

> *"In regards to the important Sámi traditional livelihood of river fishing, an unspoken but considerable threat to its future continuation is that traditional knowledge related to traditional fishing methods is not being passed down between generations in a systematic manner. In fact, I personally know only a handful of people around my age who actually know how to make a buođđu, a traditional Sámi dam net fishing structure. I feel that the perceived primary value of wild salmon is ever more leaning towards its value as a commodity for tourists, rather than food security, or traditional right or practice – which I see as being a threat to our regional food security itself. This of course has also an effect on the broader Sámi society. If people become ever more dependent on tourism and its related activities we are depending on the economic situation of others outside our region, rather than investing our future on the salmon run itself."* Aslak Holmberg, a young Sámi who grew up by the Deatnu River and now teaches in the Sámi College of Applied Sciences, Kautokeino, Norway

Indigenous traditional knowledge, culture, and language provide a central foundation for adaptation and for building resilience in the face of rapid environmental change, which implies that education based upon traditional knowledge, culture and language should be provided locally. The Permanent Participants to the Arctic Council recently developed the Ottawa Traditional Knowledge Principles. Traditional knowledge has been formally recognized by the Arctic Council as important to understanding the Arctic in many Ministerial Declarations, including the 1996 Ottawa Declaration on the establishment of the Arctic Council. The "…*role of Arctic Indigenous Peoples and their traditional knowledge in the conservation and sustainable use of Arctic biological resources*" was also emphasized in the Tromsø Declaration (2009). Furthermore, the Kiruna Declaration (2013) called for the Arctic Council to "*recognize that the use of traditional and local knowledge is essential to a sustainable future in the Arctic, and decide to develop recommendations to integrate traditional and local knowledge in the work of Arctic Council.*" Permanent Participants represent traditional knowledge holders and are integral to the inclusion and use of traditional knowledge in the work of the Arctic Council.

These fundamental principles represent the foundation for the long-term vision and framework for incorporating traditional knowledge in Arctic Council activities. Traditional knowledge and science are different yet complementary systems and sources of knowledge, and when appropriately used together may generate new knowledge and may inform decision-making, policy development and the work of the Arctic Council. The co-production of knowledge requires creative and culturally appropriate methodologies and technologies that use both traditional knowledge and science applied across all processes of knowledge creation.

The Arctic Council Scientific Cooperation Task Force for Enhancing Scientific Cooperation in the Arctic (SCTF) reached recent *ad referendum* agreement on a new *Agreement on Enhancing Arctic Scientific Cooperation* and indigenous peoples' traditional knowledge was noted to have a role in enhancing international scientific cooperation in the Arctic.

7.4.1 RenGIS: co-learning, co-production, and participatory mapping

"In conflict (situations) herding-interests often lack resources, capacity, information and tools…It is a challenge to illustrate the cumulative effect of encroachments. We need a tool. Sweden is ahead: it has established a GIS system as a planning tool, which show the cumulative effects." Anders Eira, EALLIN (2015:34-35)

In the northern 55% of Sweden, reindeer husbandry takes place on the same lands as forestry, wind power and hydropower, mining, and other infrastructure developments (Sandström et al., 2016). This results in a challenging and complicated land-use situation for reindeer herding communities as well as for other land managers and decision-makers, both in a legal and administrative sense. Land-use dialogue between reindeer herding communities and other land users and agencies has long been inadequate. This is partly due to the unequal power structures involved, but also to ineffective communication of existing knowledge. In an attempt to overcome these issues, reindeer herding communities took the initiative and contacted researchers as well as regional and state agencies. This initiative instigated the process of developing reindeer husbandry plans in 2000 that is still ongoing today (Sandström et al., 2003; Sandström, 2015). The process incorporates the development and use of a custom-made GIS toolbox – named RenGIS – for communication of land uses.

Extensive co-learning sessions involving hundreds of users, led to a widespread use of RenGIS. This is now the primary tool for reindeer herding communities in their work on compiling and digitizing indigenous knowledge and field measurements for their seasonal grazing lands. In RenGIS, this comprehensive data set on reindeer habitat use is combined with the most extensive compilation of historic and ongoing land use by others. RenGIS organizes and makes available these datasets for visualization and analysis, not just for GIS experts but also for the real end-users – the reindeer herders (Sandström, 2015). New datasets such as those produced by GLOBIO can easily be incorporated into RenGIS.

Experience gained through this process highlights the importance of working closely together; co-producing knowledge, methods and tools (Sandström, 2015). The process begins with partially defined goals that are tested and re-evaluated over the course of hundreds of meetings and training sessions. By co-producing tools and strategies and applying these in real-life settings, participants' engagement and adaptive capacity are reinforced. The work provides a strong foundation for safeguarding the complex land-use system of reindeer husbandry, a fundamental element of Sámi culture, as well as a means to meet societies' overall goal of successful sustainable landscape management. This process successfully combines indigenous and scientific knowledge in the planning processes used at both the local and landscape level. The use of participatory mapping empowers reindeer herding communities by improving their knowledge base and their dialogue with other land users. It has also enhanced understanding of how the various sectors affect each other, and has provided means by which new knowledge and tools for communication can be integrated. There are clear advantages to researchers, agency personnel, reindeer herders and other stakeholders working 'side-by-side' with testing and implementing new tools for data compilation. Although there is still some way to go in

Wilbert van Rooij

Participatory mapping workshops bring herders and researchers together to better understand the complexities of land use and land use change maximizing the use of current knowledge for better land-use decisions, using collaboratively developed tools and strategies through a pGIS has enhanced stakeholders' mutual learning and adaptive capacities.

7.4.2 Supporting indigenous languages

The health of the indigenous peoples' language is critical, because embedded within the language are the ways and means to survive and thrive on the land, and to relate to the animals upon which people depend. Language is central to identity. However, the vibrancy of the language in question is not just related to traditional livelihoods, and any steps that help support indigenous languages in a region will assist in building community confidence and resilience. The Sámi language is especially rich in terms related to reindeer (Eira, 1994).

> *"If there is no reindeer, indigenous languages will disappear! When people leave traditional occupations, the language will be forgotten. Reindeer are the very foundation of reindeer peoples' universe."* Arkadiy Gashilov, EALLIN (2015:24)

While Sámi in all regions of Sápmi have experienced strong assimilation processes particularly since the Second World War, it is also true that recent decades have seen a period of resurgence of Sámi language, identity, pride and recognition to varying degrees in the countries in which they reside. This is less true in the Russian part of Sápmi and is not true in all regions of Sápmi. According to the UNESCO Atlas of the World's Languages in Danger (Mosely, 2010), as of 28 February 2016 some languages in the southern parts of Sápmi are critically endangered with only handfuls of speakers – in Sweden, the Ume and Pite Sámi languages are also critically endangered. The same is true of Skolt and Inari Sámi languages in Finland, whose speakers number in the low hundreds and are definitely endangered. The Kildin and Ter Sámi languages of the Kola Peninsula are also critically endangered. Even 'North Sámi', the most widely spoken Sámi language in Norway, Sweden and Finland is listed as definitely endangered by UNESCO. Language is key, because it is central to a peoples identity and in terms of traditional livelihoods (e.g. freshwater and coastal fishing, reindeer herding), a vibrant language is a crucial element of a thriving livelihood.

Use of indigenous languages in the Russian sector of the Barents area has been less well studied, however the Vepsian (severely endangered), Karelian and Nenets (definitely endangered) languages are all in trouble (Mosely, 2010). The knowledge and practice of reindeer herding, for example is embedded in the language such that language loss has a direct correlation to loss of practical skills and coping, and ultimately to biodiversity. It is interesting to note that where traditional livelihoods are most vibrant, the languages tend to be in a stronger position. For example, the North Sámi and Tundra Nenets languages are flourishing in the very places where reindeer herding is strongest: Finnmark and the Yamal Peninsula.

Actively supporting indigenous languages is a critical piece of the puzzle if administrations in the Barents Region are committed to supporting indigenous peoples living a thriving and vibrant cultural practice.

7.4.3 Education – new tools for the future

A new kind of education is needed in the North, one that incorporates multidisciplinary, multicultural, and holistic approaches to sustainable development. Scientific and traditional experience-based knowledge, knowledge transformation, education, gender equity and the training of future Arctic leaders are key factors in the future sustainability of societies. Directly engaging indigenous youth in traditional practices and providing enhanced education are important factors in this sustainability and its cultural foundations (Gávnnadeapmi, 2015). To strengthen adaptation to climate change, local Arctic leaders within indigenous communities as well as mainstream society, must be trained in long-term sustainable thinking. This educational goal must be based on the best available knowledge about adaptation. Technology offers new means of delivering education to practitioners of traditional livelihoods, especially those in remote areas.

> *"From the reindeer herding youth's perspective, there is need to both integrate traditional knowledge into education and also include training about international and national law and governance pertaining to reindeer husbandry in education programs. Also, more cooperation with other reindeer herding peoples' is needed…We need more information about the ways of participating in decision-making and the mechanisms to protect our livelihoods from outside infringements. This could be done by organizing training tailored for reindeer herding youth about relevant national legislation and international human rights mechanisms."* Anne-Maria Magga (EALLIN, 2015:29 &35)

7.5 Conclusions

Although written thirty years ago, the strong language within the UN report *Our Common Future* is still relevant, yet remains largely unacted upon:

> *"Tribal and Indigenous Peoples will need special attention as the forces of economic development disrupt their traditional lifestyles – lifestyles that can offer modern societies many lessons in the management of resources in complex forest, mountain, and dry-land ecosystems. Their traditional rights should be recognized and they should be given a decisive voice in formulating policies about resource development in their areas"* (Brundtland, 1987)

According to the IPCC, while Arctic indigenous peoples with traditional lifestyles are facing unprecedented impacts from climate change and resource development (oil and gas, mining, forestry, hydropower, tourism, etc.), they are already implementing creative ways of adapting (Nymand Larsen et al., 2014). Examples include changing resource bases, shifting land use and/or settlement areas, combining technologies with traditional knowledge, changing the timing and location of hunting, gathering, herding, and fishing, and improving communications and education. The impetus to include traditional knowledge has not only come from indigenous communities: the International Polar Year resulted in a clear mandate for the inclusion of Arctic indigenous knowledge, and members of Arctic indigenous communities contributed to the drafting of the fifth IPCC assessment report.

As well as being important for indigenous peoples' societies in the Barents area, the AACA has also been important for the scientific community and has enabled new insights and understanding based on different worldviews, knowledge, and values. Developing adaptation strategies using all available knowledge will ensure a more holistic approach, one that offers security and a more predictable future for indigenous societies in the Barents area. Engaging indigenous communities and including their traditional knowledge in planning for adaptation action in the Barents area is thus essential. Universities and colleges in the Barents area should develop a joint collaboration model for adaptation training, based on traditional and scientific knowledge. The University of the Arctic could provide the network and platform for such a collaboration. In this respect, it is very important that the flow of information and insights within indigenous peoples' communities is increased in the direction of both scientific study and policy implementation.

Acknowledgments

This work was supported by the Research Council of Norway through the 'Rievdan' project at the Sámi University of Applied Sciences, the International Centre for Reindeer Husbandry, the Arctic Council CAFF 'Nomadic Herders Sápmi' project funded by the Norwegian Ministry of Climate and Environment, and the Arctic Council ECONOR project. Figures 7.5 to 7.8 were produced by the Nomadic Herders Sápmi project.

References

Alkemade, R., M. van Oorschot, L. Miles, C. Nellemann, M. Bakkenes and B. ten Brink, 2009. GLOBIO3: A framework to investigate options for reducing global terrestrial biodiversity loss. Ecosystems, 12:374-390.

All Russian Census 2010. Ethnic Composition, Languages and Citizenship. Chapter 4. Accessed 9 December 2016. www.gks.ru/free_doc/new_site/perepis2010/croc/perepis_itogi1612.htm

Arets, E.J.M.M., C. Verwer and J.R.M. Alkemade, 2014. Meta-analysis of the effect of global warming on local species richness. WOt Paper 34. Wageningen, Statutory Research Tasks Unit for Nature & the Environment, Wageningen University and Research Centre.

Bakkenes, M., B. Eickhout and R. Alkemade, 2006. Impacts of different climate stabilisation scenarios on plant species in Europe. Global Environmental Change, 16:19-28.

Bambulyak, A., B. Frantzen and R. Rautio, 2015. Oil Transport from the Russian part of the Barents Region. 2015 Status Report. The Norwegian Barents Secretariat.

Benestad, R.E., K.M. Parding, K. Isaksen and A. Mezghani, 2016. Climate change and projections for the Barents region: what is expected to change and what will stay the same? Environmental Research Letters, 11:054017.

Berg, B.A., 1996. Government intervention into Sámi reindeer management in Norway: has it prevented or provoked 'tragedies of the commons'? Acta Borealia, 13:69-89.

Bernes, C., K.A. Bråthen, B.C. Forbes, J.D.M. Speed and J. Moen, 2015. What are the impacts of reindeer/caribou (*Rangifer tarandus* L.) on arctic and alpine vegetation? A systematic review. Environmental Evidence, 4:4, doi:10.1186/s1375001400303.

Bjørklund, I., 2013. Gruvedrift og reindrift om nordområdesatsing, folkerett og trojanske hester i Sápmi [Mining and reindeer in the High North Strategy, law and Trojan horses in Sápmi]. In: Jentoft, S., J.I. Nergård and K.A. Røvik (eds.), Hvor går NordNorge? Bind 3 Politiske tidslinjer [Where is North Norway? Volume 3 Political timelines], Orkana akademisk.

Booth, A.L. and N.W. Skelton, 2011. Improving First Nations' participation in environmental assessment processes: recommendations from the field. Impact Assessment and Project Appraisal, 29:49-58.

Brattland, C. and E. Eythórsson, 2016. Bruk og forvaltning av sjøområder [Use and management of sea areas]. In: Perspektiver til fremtidig areal og miljøpolitikk i Sápmi. Sámediggi, Karasjok. [Perspectives on Future Spatial and Environmental Policy in Sápmi].

Brundtland, G.H., 1987. Our common future: Report of the World Commission on Environment and Development. Oxford University.

Bull, K.S., N. Oskal and M.N. Sara, 2001. Reindriften i Finnmark: rettshistorie 1852-1960. [Reindeer herding in Finnmark: Legal History 1852-1960] Cappelen akademisk.

Comberti, C., T.F. Thornton, V. Wyllie de Echeverria and T. Patterson, 2015. Ecosystem services or services to ecosystems? Valuing cultivation and reciprocal relationships between humans and ecosystems. Global Environmental Change, 34:247-262.

Dallman, W.K., V.V. Peskov and O.A. Murashko (eds.), 2010. Monitoring of Development of Traditional Indigenous Land Use Areas in the Nenets Autonomous Okrug, NW Russia. An interdisciplinary, collaborative project carried out by the Norwegian Polar Institute and the Association of Nenets People Yasavey, financed by the Research Council of Norway in the framework of the International Polar Year 2007-08 and the Norwegian Polar Institute.

EALLIN, 2015. Youth. The Future of Reindeer Herding Peoples. Executive Summary. Arctic Council EALLIN Reindeer Herding Youth Project 2012-2015. International Centre for Reindeer Husbandry.

Einarsbøl, E., 2005. Reindeer Husbandry in Norway. www.reindeer-husbandry.uit.no/online/Final_Report/norway.pdf

Eira, N.I., 1994. Bohccuid Luhtte. Gulahallat ja ollašuhttit boazodoalu. DAT Guovdageaidnu.

Eira, I.M.G., 2012. Muohttaga Jávohis Giella: Sámi Árbevirolaš Máhttu Muohttaga Birra Dálkkádatrievdanáiggis [The Silent Language of Snow: Sámi Traditional Knowledge of Snow in Times of Climate Change]. Ph.D. Thesis, University of Tromsø, Norway.

Eira, I.M.G., M.O. Henrik and N.I. Eira, 2010. Muohtatearpmaid sisdoallu ja geavahus [North Sami snow concepts and terminology]. Sámi dieđalaš áigečála, 2/2010, 324. http://site.uit.no/aigecala/2010-2/

Eira, I.M.G., C. Jaedicke, O.H. Magga, N.G. Maynard, D. Vikhamar-Schuler and S.D. Mathiesen, 2013. Traditional Sámi snow terminology and physical snow classification – two ways of knowing. Cold Regions Science and Technology, 85:117-130.

Eira, I.M.G., M.N. Sara, H. Svarstad and S.D. Mathiesen, 2016. Å se som en stat eller som en Sámisk reineier: To forståelser av bærekraftig reindrift [Seeing as the state, or seeing as a Sámi reindeer herder: Two understandings of sustainable reindeer husbandry]. In: Benjaminsen, T.A., I.M.G. Eira and M.N. Sara (eds.), Sámisk reindrift, norske myter. [Sámi reindeer husbandry, Norwegian myths] Fagbokforlaget.

Engen-Skaugen, T., J.E. Haugen and O.E. Tveito, 2007. Temperature scenarios for Norway: From regional to local scale. Climate Dynamics, 29:441-453.

Forbes, B.C., 2013. Cultural resilience of social-ecological systems in the Nenets and Yamal-Nenets Autonomous Okrugs, Russia: a focus on reindeer nomads of the tundra. Ecology and Society, 18:36, doi:10.5751/ES05791-180436.

Forbes, B.C., M.M. Fauria and P. Zetterberg, 2010. Russian Arctic warming and 'greening' are closely tracked by tundra shrub willows. Global Change Biology, 16:1542-1554.

Forbes, B., T. Kumpula, N. Meschtyb, R. Laptander, M. Macias-Fauria, P. Zetterberg, M. Verdonen, A. Skarin, K.-Y. Kim, L.N. Boisvert, J.C. Stroeve and A. Bartsch, 2016. Sea ice, rain-on-snow and tundra reindeer nomadism in Arctic Russia. Biology Letters, 12:20160466, doi:10.1098/rsbl.2016.0466.

Gainer, R., 2016. Yamal and anthrax. Canadian Veterinary Journal, 57:985-987.

Gávnnadeapmi, 2015. Gávnnadeapmi Declaration. http://reindeerherding.org/blog/gavnnadeapmi-2015-declaration-photos/

Glomsrød, S., G. Duhaime and I. Aslaksen (eds), 2017. The Economy of the North 2015. Statistical analyses 151. Statistics Norway, Oslo.

Green, C., 2009. Managing Laponia: A World Heritage Site as Arena for Sami Ethno-Politics in Sweden. Doctoral thesis. Uppsala University, Sweden.

Hassler, S., P. Sjölander and A.J. Ericsson, 2004. Construction of a database on health and living conditions of the Swedish Sámi population. In: Lantto, P. and P. Sköld (eds.), Befolkning och bosättning i norr: Etnicitet, identitet och gränser i historiens sken. [Population and settlements in the North: Race, Identity and Borders in the light of history]. Centre for Sámi Research, Umeå University. Miscellaneous publications No. 1. pp. 107-124.

Hausner, V.H., P. Fauchald, T. Tveraa, E. Pedersen, J.L. Jernsletten, B. Ulvevadet and K.A. Brathen, 2011. The ghost of development past: the impact of economic security policies on Saami pastoral ecosystems. Ecology and Society, 16:4, doi:10.5751/es04193160304.

Heikkilä, L., 2006. Reindeer Talk. Sámi Reindeer Herding and Nature Management. University of Lapland.

Hendrichsen, D.K. and N.J.C. Tyler, 2014. How the timing of weather events influences early development in a large mammal. Ecology, 95:1737-1745.

Herrmann, T.M., P. Sandström, K. Granqvist, N. D'Astous, J. Vannar, H. Asselin, N. Saganash, J. Mameamskum, G. Guanish, J.-B. Loon and R. Cuciurean, 2014. Effects of mining on reindeer/caribou populations and indigenous livelihoods: community-based monitoring by Sami reindeer herders in Sweden and First Nations in Canada. The Polar Journal, 4:28-51.

Horton, J.J. and R.J. Zeckhauser, 2016. Owning, using and renting: some simple economics of the 'sharing economy. National Bureau of Economic Research (NBER) Working Paper No. 22029.

Husbekk, A., M. Andersson and R.E.J. Penttila, 2015. Growth from the North. How can Norway, Sweden and Finland achieve sustainable growth in the Scandinavian Arctic? Report of an independent expert group. Prime Minister's Office Publications 04/2015, Helsinki.

Johnsen, K.I., 2016a. Landuse conflicts between reindeer husbandry and mineral extraction in Finnmark, Norway: Contested rationalities and the politics of belonging. Polar Geography, 39:58-79.

Johnsen, K.I., 2016b. Medbestemmelse, makt og mistillit i reindriftsforvaltningen. [Participation, power and distrust in the governance of reindeer husbandry] In: Benjaminsen, T.A., I.M.G. Eira and M.N Sara (eds.), Samisk reindrift, norske myter. [Sámi reindeer husbandry, Norwegian myths] pp. 195-220. Fagbokforlaget.

Johnsen, K.I. and T.A. Benjaminsen, 2017. The art of governing and everyday resistance: "rationalization" of Sámi reindeer husbandry in Norway since the 1970s. Acta Borealia, 34:1-25..

Johnsen, K.I., T.A. Benjaminsen and I.M.G. Eira, 2015. Seeing like the state or like pastoralists? Conflicting narratives on the governance of Sámi reindeer husbandry in Finnmark, Norway. Norwegian Journal of Geography, 69:230-241.

Juntunen, S. and E. Stolt, 2013. Application of Akwé:kon guidelines in Management and Land Use Plan for the Hammastunturi Wilderness Area. Natural Heritage Services.

Kaivoslaki, 2011. [Mining Law] 10.6.2011/621 Finland. www.finlex.fi/fi/laki/ajantasa/2011/20110621#O1

Kharuk, V.I., M.L. Dvinskaya and K.J. Ranson, 2012. Fire return intervals within the northern boundary of the larch forest in Central Siberia. International Journal of Wildland Fire, 22:207-211.

Kiruna Declaration, 2013. The Eighth Ministerial Meeting of the Arctic Council. 15 May 2013. Kiruna, Sweden.

Klokov, K.B., 2013a. Metodologicheskie podkhody k ocenke kachestva zhizni korennogo naseleniya Severa, zanyatogo v olenevodstve [Methodological approaches to assessing the quality of life of indigenous population of the north engaged in reindeer herding]. Izvestiya Sankt-Peterburzhskogo gosudarstvennogo universiteta, 31:193-196.

Klokov, K.B., 2013b. Vozdeystvie izmeneniy klimata i promyshlennnogo osvoeniya na olenevodcheskoe khozyaystvo

Yamala: kumulyativnyy effect [Impacts of climate change and industrial development on reindeer economy of Yamal: cumulative effect]. Izvestiya Sankt-Peterburzhskogo gosudarstvennogo universiteta, 30:211-214.

Klokov, K.B. and A.V. Bocharnikova, 2013. Institucional'nye struktury korennykh malochislennykh narodov Severa i ikh rol' v regional'nykh problemakh prirodopol'zovaniya [Institutional structures of indigenous small numbered peoples of the north and their role in regional problems of nature use]. Izvestiya Sankt-Peterburzhskogo gosudarstvennogo universiteta, 33:190-194.

Klokov, K.B. and A.D. Degteva, 2012. Metodicheskie podkhody k ocenke vozdeystviya promyschlennogo osvoeniya na tradicionnoe khozyaystvo narodov Severa (na primere olenevodcheskogo khozyaystva Yamala) [Methodical approaches to impact assessment of industrial development on traditional economy of the peoples of the north]. Izvestiya Sankt-Peterburzhskogo agrarnogo universiteta, 31:193-196.

Klokov, K.B. and S.A. Khrushchev, 2014. Teoreticheskoe obosnovanie etnologicheskoy ekspertizy dlya ocenki vozdeystviya industrial'nogo osvoeniya na tradicionnoe prirodopolzovanie korennogo naseleniya Severa [Theoretical base for ethnoecological expertise for assessing impacts of industrial development on traditional nature use of indigenous peoples of the north]. Regional'nye issledovaniya № 1:98-108.

Kryazhkov, V., 2008. Territorii tradicionnogo prirodopol'zovaniya kak realizacia prava korennyx malochislennykh narodov na zemli [Territories of traditional nature use as realization of the right of Indigenous small numbered peoples to land]. In: Gosudarstvo i parvo, 1:44-51.

Kryazhkov, V.A., 2010. Korennye malochislennye narody Severa v rossiyskom prave [Indigenous small numbered peoples of the North in the Russian legislation]. Norma, Moscow.

Kryazhkov, V.A., 2015. Legal regulation of the relationships between indigenous small-numbered peoples of the North and subsoil users in the Russian Federation. The Northern Review, 39:66-87.

Kuokkanen, R., 2011. Indigenous economies, theories of subsistence and women: Exploring the social economy model for indigenous governance. American Indian Quarterly, 35:215-240.

Laki Metsähallitus, 2016. Laki Metsähallituksesta 234/2016. Helsinki. https://finlex.fi/fi/laki/alkup/2016/20160234 Accessed 2 Sept 2016.

Landbruks og matdepartementet, 2015. Høring Forslag til endring i reindriftsloven og forslag til forskrift [Ministry of Agriculture and Food. Consultation on the proposed amendments to the Reindeer Herding Act and Draft Regulations]. www.regjeringen.no/no/dokumenter/horingforslagtilendringireindriftslovenogforslagtilforskrift/id2468763

Landbruks og matdepartementet and Reindriftsforvaltningen, 2007. Orientering om Reindriftsloven av 15 juni 2007. [Ministry of Agriculture and Food, and Reindeer Husbandry Administration, Norway] www.regjeringen.no/Upload/LMD/Vedlegg/Brosjyrer_veiledere_rapporter/Reindriftsloven_Norsk.pdf

Lavrinenko, I.A., 2011. Dinamika rastitelnogo pokrova ostrova Vaygach pod vliyaniem klimaticheskikh izmemeniy [The dynamic of vegetation cover of Vaygach Island under the impact of climate change]. Sovremennye problemy distancionnogo zondirovaniya Zemli iz kosmosa [Modern Problems of Remote Sensing of the Earth from Space]. 8:183-189.

Lenvik, D., 1998. Utfordring og hovedstrategi i reindriftspolitikken [Challenge and the main strategy in the reindeer herding policy] (Notat).

Lenvik, D., 1990. Flokkstrukturering: tiltak for lønnsom plassering og ressurstilpasset reindrift. [Herd Structure: measures for profitable placement and resource custom reindeer] Rangifer, Special Issue No. 4, 2135.

Magga, O.H., 2006. Diversity in Saami terminology for reindeer, snow, and ice. International Social Science Journal, 58:25-34.

Magga, O.H., S.D. Mathiesen, R.W. Corell and A. Oskal, 2011. Reindeer Herding, Traditional Knowledge and Adaptation to Climate Change and Loss of Grazing Land. International Centre for Reindeer Husbandry, Kautokeino.

Marin, A. and I. Bjørklund, 2015. A tragedy of errors? Institutional dynamics and land tenure in Finnmark, Norway. International Journal of the Commons, 9:19-40.

Mathiesen, S.D., B. Alfthan, R. Corell, R.B.M. Eira, I.M.G. Eira, A. Degteva and J.M. Turi, 2013. Strategies to enhance the resilience of Sámi reindeer husbandry to rapid changes in the Arctic. In: Arctic Council, Arctic Resilience Interim Report 2013. pp. 109-112. Stockholm Environment Institute and Stockholm Resilience Centre.

Matveev, A.V. and V.P. Kotov, 2004. Ocenka vozdeystviya na okruzhayushchuyu sredu i ekologicheskaya ekspertiza [Environmental impact assessment and ecological expertise]. SPbGUAP, St. Petersburg.

Moseley, C. (ed.), 2010. Atlas of the World's Languages in Danger. 3rd edn. UNESCO Publishing. Online version: www.unesco.org/culture/en/endangeredlanguages/atlas

Moskvitch, K., 2014. Mysterious Siberian crater attributed to methane. *Nature News* (31 July 2014), doi:10.1038/nature.2014.15649.

Nationen, 2015, Listhaug: – Historisk reduksjon i reintallet.[Listhaug: - Historical reduction in the number of reindeer.] Nationen. www.nationen.no/landbruk/listhaughistoriskreduksjonireintallet

Nenets Automous Okrug, 2009a. Administracia Nenetskogo avtonomnogo okruga. Strategiya social'no-economicheskogo razvitia Nenetskogo avtonomnogo okruga na perspektivu do 2030 goda. Chast 1: Socialno-economicheskoe polozhenie NAO [Administration of Nenets Autonomous District. Strategy of Social-economic Development of Nenets Autonomous District for the period until 2030. Part 1:]. Centre for Strategic Developments: North-West. St. Petersburg.

Nenets Automous Okrug, 2009b. Administracia Nenetskogo avtonomnogo okruga. Strategiya social'no-economicheskogo razvitia Nenetskogo avtonomnogo okruga na perspektivu do 2030 goda. Chast 2: Strategiya razvitia NAO na period do 2030 goda [Administration of Nenets Autonomous District. Strategy of Social-economic Development of Nenets Autonomous District for the period until 2030. Part 2: Strategy of Development of NAO for the period until 2030]. Centre for Strategic Developments: North-West. St. Petersburg.

Netherlands Environmental Assessment Agency, 2010. Rethinking Global Biodiversity Strategies: Exploring structural changes in production and consumption to reduce biodiversity loss. Report No. 500197001. Netherlands Environmental Assessment Agency (PBL), The Hague/Bilthoven.

Nymand Larsen, J., O.A. Anisimov, A. Constable, A.B. Hollowed, N. Maynard, P. Prestrud, T.D. Prowse, and J.M.R. Stone, 2014. Polar regions. In: Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

O'Brien, K., B. Hayward and F. Berkes, 2009. Rethinking social contracts: building resilience in a changing climate. Ecology and Society, 14:12, http://www.ecologyandsociety.org/vol14/iss2/art12/

O'Faircheallaigh, C., 2009. Effectiveness in social impact assessment: Aboriginal Peoples and resource development in Australia. Impact Assessment and Project Appraisal, 27:95-110.

Oteros-Rozas, E., B. Martín-López, T. Daw, E.L. Bohensky, J. Butler, R. Hill, J. Martin-Ortega, A. Quinlan, F. Ravera, I. Ruiz-Mallén, M. Thyresson, J. Mistry, I. Palomo, G.D. Peterson, T. Plieninger, K.A. Waylen, D. Beach, I. C. Bohnet, M. Hamann, J. Hanspach, K. Hubacek, S. Lavorel and S. Vilardy, 2015. Participatory scenario planning in place-based social-ecological research: insights and experiences from 23 case studies. Ecology and Society, 20:32, http://dx.doi.org/10.5751/ES-07985-200432.

Paine, R., 1994. Herds of the tundra: A portrait of Saami reindeer pastoralism. Smithsonian Institution Press.

Pelto, P., 1973. The Snowmobile Revolution: Technological and Social Change in the Arctic. Cummings Publishing Company.

Polanyi, Karl. 1963. The Great Transformation. Beacon Press.

Popkov, Y.V., 2011. Korennye malochislennye narody Severa v global'nom i regional'nom kontekste [Indigenous small numbered peoples of the north in global and regional context]. ЭКО. 9:71-88.

Raitio, K., 2008. "You can't please everyone" Conflict Management Practices, Frames and Institutions in Finnish State Forests. University of Joensuu, Finland.

Ravna, Ø., 2015. Sámi rights to natural resources and lands in Norway. In: Loukacheva, N. (ed.), Polar Law and Resources. pp. 63-77. Nordic Council of Ministers.

Reinert, E., 2006. The economics of reindeer herding: Saami entrepreneurship between cyclical sustainability and the powers of state and oligopolies. British Food Journal, 108:522-540.

Reinert, H., 2008. The corral and the slaughterhouse: knowledge, tradition and the modernization of indigenous reindeer slaughtering practice in the Norwegian Arctic. Ph.D. Thesis. University of Cambridge.

Resilience Alliance, 2010. Assessing Resilience in Social-Ecological Systems. Workbook for practitioners. Version 2.0.

Riseth, J.Å., 2000. Sámi reindeer management under technological change 1960-1990: implications for common pool resource use under various natural and institutional conditions : a comparative analysis of regional development paths in West Finnmark, North Trøndelag, and South Trøndelag/Hedmark, Norway. Doctoral thesis. Agricultural University of Norway.

Riseth, J.Å., H. Tømmervik, E. Helander Renvall, N. Labba, C. Johansson, E. Malnes, J.W. Bjerke, C. Jonsson, V. Pohjola, L.E. Sarri, A. Schanche and T.V. Callaghan, 2010. Sámi traditional ecological knowledge as a guide to science: snow, ice and reindeer pasture facing climate change. Polar Record, 47:202-217.

Russian Federation, 2001. O territoriyakh tradicionnogo prirodopol'zovaniya korennyx malochislennykh narodov Severa, Sibiri I Dal'nego Vostoka Rossiiskoy Federacii. [On territories of traditional nature use of indigenous small numbered peoples of the North, Siberia and the Far East of the Russian Federation]. Federal Law from 07.05.2001 N 49-FZ.

Sandström, P., 2015. A Toolbox for Coproduction of Knowledge and Improved Land Use Dialogues. The Perspective of Reindeer Husbandry. Ph.D. Thesis, Umeå University, Sweden.

Sandström, P., T.G. Pahlen, L. Edenius, H. Tommervik, O. Hagner, L. Hemberg, H. Olsson, K. Baer, T. Stenlund, L.G. Brandt and M. Egberth, 2003. Conflict resolution by participatory management: Remote sensing and GIS as tools for communicating land use needs for reindeer herding in northern Sweden. Ambio, 32:557-567.

Sandström, P., N. Cory, J. Svensson, H. Hedenås, L. Jougda and N. Brochert, 2016. On the decline of ground lichen forests in the Swedish boreal landscape – Implications for reindeer husbandry and sustainable forest management. Ambio, 45:415-429.

Sara, M.N., 2009. Siida and traditional Sámi reindeer herding knowledge. Northern Review, 30:153-178.

Sara, M.N., 2015. Siida ja siiddastallan / Å være en siida – om forholdet mellom siidatradisjoner og videreføringen av siidasystemet / Being siida [On the relationship between siida tradition and continuation of the siida system]. Ph.D. Thesis. Arctic University of Norway.

Schwab, K., 2016. The Fourth Industrial Revolution. World Economic Forum / The Fourth Industrial Revolution.

Skogvang, S.F., 2014. Finnmarkskommisjonen. Store norske leksikon [Finnmark Commission. Norwegian Encyclopedia]. https://snl.no/Finnmarkskommisjonen

Stammler, F., 2009. Mobile phone revolution in the tundra? Technological change among Russian reindeer nomads.

In: Ventsel, A. (ed.), Generation P in the Tundra. Pp. 47-78. Estonian Literary Museum.

Stammler, F., 2013. Narratives of adaptation and innovation: ways of being mobile and mobile technologies among reindeer nomads in the Russian Arctic. In: Miggelbrink, J., J.O. Habeck, N. Mazzullo and P. Koch (eds.), Nomadic and Indigenous Spaces: Productions and Cognitions. pp. 221-245. Ashgate.

Statistics Norway, 2010. Sámi Statistics 2010. Statistics Norway, Oslo.

Stehfest, E., D. van Vuuren, T. Kram, L. Bouwman, R. Alkemade, M. Bakkenes, H. Biemans, A. Bouwman, M. den Elzen, J. Janse, P. Lucas, J. van Minnen, M. Muller and A. Gerdien Prins, 2014. Integrated Assessment of Global Environmental Change with IMAGE 3.0 - Model description and policy applications. Netherlands Environmental Assessment Agency, The Hague.

Storli, I. and O.K. Sara, 1997. Reindrift før og nå. Landbruksforl. The Law of Republic of Sakha (Yakutia) No. 820-3 N 537-IV on ethnological expertise in places of traditional residence and traditional economic activities of indigenous small numbered peoples of the north of the Republic of Sakha (Yakutia). Adopted 14.04.2010.

Stortinget, 1976-1977. Om lov om reindrift [Norwegian parliament report on the reindeer husbandry law].

Telenor Group, 2012. The Mobile Phone Adventure. Online: www.telenor.com/media/articles/2012/the-mobile-phone-adventure.

Tromsø Declaration, 2009. The Sixth Ministerial Meeting of the Arctic Council. 29 April 2009.

Turi, E.I., 2016. State steering and traditional ecological knowledge in reindeer herding governance cases from western Finnmark, Norway and Yamal, Russia. Ph.D. Thesis. Umeå University, Sweden.

Turi, E.I. and I.M.G. Eira, 2016. Bruk av tradisjonell kunnskap i miljø og arealforvaltning i Norge. Rapport til Sametinget. [Use of traditional knowledge in environmental and land management in Norway. Reporting to the Sámi Parliament.]

Turi, E.I. and E.C.H. Keskitalo, 2014. Governing reindeer husbandry in western Finnmark: barriers for incorporating traditional knowledge in local level policy implementation. Polar Geography, 37:234-251.

Tyler, N.J.C., J.M. Turi, M.A. Sundset, K.S. Bull, M.N. Sara, E. Reinert and R.W. Corell, 2007. Saami reindeer pastoralism under climate change: Applying a generalized framework for vulnerability studies to a subarctic social-ecological system. Global Environmental Change, 17:191-206.

van Rooij, W., I.Aslaksen, P. Burgess, P.A. Garnasjordet and S.D. Mathiesen, 2017. Ecological change in Arctic regions – a GLOBIO3 pilot study of impacts on biodiversity. In: Glomsrod, S., G. Duhaime and I. Aslaksen (eds), The Economy of the North 2015. pp. 149-161. Statistics Norway, Oslo.

Vikhamar-Schuler, D. and I. Hanssen-Bauer, 2010a. Long-term climate trends of Yamalo-Nenets AO, Russia. Norwegian Meteorological Institute, met.no Report No. 08/2010.

Vikhamar-Schuler, D. and I. Hanssen-Bauer, 2010b. Long-term climate trends of Finmarksvidda, Northern-Norway. Norwegian Meteorological Institute, met.no Report No. 06/2010.

Vikhamar-Schuler, D., E.J. Førland, I. Hanssen-Bauer, H.O. Hygen, Ø. Nordli and P. Svyashchennikov, 2010. Arctic communities and reindeer herders' vulnerability to changing climate: Climate conditions in northern Eurasia since year 1900. Norwegian Meteorological Institute, met.no Report No. 14/2010.

Vikhamar-Schuler, D., I. Hanssen-Bauer, T.V. Schuler, S.D. Mathiesen and M. Lehning, 2013. Use of a multilayer snow model to assess grazing conditions for reindeer. Annals of Glaciology, 54:214-226.

Vistnes, I.I., P. Burgess, S. Mathiesen, C. Nellemann, A. Oskal and J.M. Turi, 2009. Reindeer Husbandry and Barents 2030: Impacts of Future Petroleum Development on Reindeer Husbandry in the Barents Region. International Centre for Reindeer Husbandry.

Walker, B.H. and D. Salt, 2012. Resilience Practice. Island Press.

Wright, A.J, S.J. Dolamn, M. Jasny, E.C.M. Parsons, D. Schiedek and S.B. Young, 2013. Myth and momentum: a critique of environmental impact assessments. Journal of Environmental Protection, 4:72-77.

8. A resilience approach to adaptation actions

Co-ordinating lead authors: Marcus Carson, Martin Sommerkorn

Contributing authors: Rasmus Kløcker Larsen, Rebecca Lawrence, Tero Mustonen, Claudia Strambo, Tatiana Vlasova, Sylvia Zhang

Key messages

- ***A resilience approach to adaptation actions emphasizes building and strengthening the underlying capacity to respond effectively to change.*** *It offers both a pathway to prepare for surprises and flexibility to respond to developments as they unfold. Such lines of action are indicated because accurate prediction of important, even defining, developments in the region remains a significant challenge.*
- ***Resilience can be assessed and enhanced through attention to specific 'ingredients' that encompass both social and ecological characteristics, and which contribute to overall resilience in specific ways.*** *These ingredients include: assuming change, diversity, knowledge and capacity for ongoing learning, capacity for self-organization, and sustainable livelihoods. Each of these speaks to distinct qualities that can facilitate effective adaptation to disturbances or support transformational change where desired.*
- ***This chapter develops a resilience indicators framework and applies it to five cases from within the Barents area, which entail livelihoods closely integrated with nature.*** *This provides a test for resilience indicators and suggests ways for developing indicators in other settings, including their utility for strengthening resilience. Resilience indicators support awareness, planning, prioritization and assessment of adaptation actions.*

8.1 Introduction: *Árvitmeahttun* - (un)predictability in the Arctic

The future in which adaptation actions will be pursued is likely to be peppered with surprises – developments that are not anticipated because we could not imagine how they could take place, or could not predict how people would respond to developments that preceded them. Indigenous languages of the Arctic have their own terms for this condition, because unpredictability has been a part of the reality Arctic indigenous communities have had to navigate. In the North Sámi language, *árvitmeahttun* translates to English as 'unexpected' or 'unpredictable'. The concept reflects Sámi understandings of the world as characterized by emergence and manifestation. Rooted for millennia in sub-Arctic ecosystems and their traditional occupancies, indigenous peoples develop specific concepts for phenomena that are important parts of their reality. It is not clear how the 'new' Arctic will be, but it will include *árvitmeahttun* – the unexpected.

Such insights are not limited to the Arctic; the unexpected is part of the broader social and ecological reality. A related insight on a global scale argues that "*in almost every domain of human life, change is accelerating...it is not just that change is fast, it is getting faster and faster*" (Chambers and Conway, 1991). As a result, these authors argued that, "*future conditions become harder and harder to predict*". Even given the major strides made in scientific methodology and knowledge over the quarter century since their influential discussion paper (Chambers and Conway, 1991), there have been many surprises. In the Arctic region, fisheries have collapsed (Hamilton, 2007), local food sources have become more insecure (Schreiber, 2002; Nilsson and Evengård, 2013), and outmigration threatens the existence of once-thriving communities (Huskey et al., 2004; Howe, 2009; Martin, 2009). Noting the rapid pace of change in the Arctic has become a standard feature of discussions about the Arctic, but the reality is also that the pace of change is itself uneven as a function of diverse causal forces, non-linear processes and changing feedbacks.

Caution about relying on predictions – or making them – is also common among scientists. Describing a recent effort to assess how ecosystem services in the Barents area might be impacted by climatic and other important drivers of change, one team of highly accomplished scientists noted that: "*forecasts of ecosystem services are hampered by uncertainty about drivers, unknown responses to climate and ecosystem change, stochasticity and nonlinearities in interactions among species, ecosystem components, and ecosystems... Methods to synthesize information and provide predictions relevant to society at regional scales are still largely lacking*" (Jansson et al., 2015). While these limitations did not (and should not) lead scientists to abandon their efforts to better understand the interactions that carry these change processes forward, they constrain the ability to project accurately into the future.

These observations should not be interpreted as an argument that preparation for potentially disruptive change is not critically important. Some of the drivers and elements of change can be anticipated with a high level of confidence, as can some sources of social or ecosystem vulnerability. Many of the predictions of broader changes arising from climate change, such as temperature increase, sea-level rise, or an increase in the frequency and magnitude of severe weather events are highly robust (see Chapter 4). Yet each of these expected impacts will also entail social responses that may also have regional and local consequences, and which are less foreseeable. What is very clear from the insights highlighted above and the preceding chapters of this report is that while it is possible to discern important trends among key biophysical and social drivers, the major uncertainties that remain are even further magnified when the uncertainties are considered together. This poses a crucial question for communities and regions preparing to take adaptation action: how does one prepare to respond effectively to change under conditions characterized by *árvitmeahttun*, where the precise nature and pace of those changes is neither known nor knowable in advance?

The response proposed here is to focus on the underlying capacity to respond to change, to successfully ride out disruption and disturbance, and to deliberately and effectively steer a path toward chosen goals in a less-than-predictable future. This capacity can be characterized as *resilience* – defined in the Arctic Resilience Report (Arctic Council, 2016) as the capacity of people to learn, share and make use of their knowledge of social and ecological interactions and feedbacks, to deliberately and effectively engage in shaping adaptive or transformative social-ecological change. Now widely used in many settings, resilience is being applied in a variety of different ways (discussed further in Section 8.2). This definition of resilience emphasizes human agency, capacity for learning and use of knowledge, and the tight coupling and interaction between social and ecological systems.

In addition to emphasizing the human capacity for deliberate action, two characteristics common in work on resilience are especially relevant for the purposes of this chapter. Resilience science employs a social-ecological systems approach that conceives humans as an integral part of nature, and as such, a resilience approach shares important commonalities with the holistic perspective reflected in accumulated wisdom of the indigenous peoples of the Arctic (Section 8.2). The chapter also draws on insights from a large body of empirical research that has identified key ingredients of resilience (Section 8.3). Building on these ingredients, Section 8.4 outlines an approach to developing indicators of resilience that represent characteristics which, if strengthened, can contribute to building resilience and thereby strengthen the capacity to engage in adaptation actions.

This chapter therefore proposes tools to facilitate preparations for responding to and adapting to change that will surely include surprises. The aim is to provide concrete tools for assessing resilience not only at the scale of local communities, but also at higher scales. To provide a basis for these tools, this chapter reviews definitions of resilience and the social-ecological systems framework and clarifies the relationships between resilience, adaptation, and transformative change. It then examines resilience ingredients that when assessed and developed as a collection of indicators, can provide feedback useful both to policymakers and community leaders. Such indicators will provide useful insights about concrete actions that can be taken or curtailed to strengthen resilience. The framework of indicators is then applied to a selection of case studies from the Barents area (Section 8.5). To illustrate the tight coupling between ecological and social systems that is central to resilience, this chapter focuses on cases in which communities are pursuing livelihoods closely linked with nature.

Traditionally, human activities in the Arctic have been tightly coupled with ecosystems. Among the indigenous cultures of the Arctic, nature is conceptualized as the dynamic and evolving interactions between the biological and the physical world – and humans are an integral part of that world (Henry et al., 2013). This appreciation of the close coupling between humans and nature arguably stems from the need to navigate sometimes harsh and inhospitable conditions and the fact that traditional livelihoods are often dependent on resources which vary with natural cycles and external changes.

8.2 Resilience of social-ecological systems

The use of 'resilience' has expanded dramatically over the past few years. The term figures strongly in the two major international agreements adopted in 2015: the Sustainable Development Goals (United Nations, 2015) and the Paris Agreement on climate change (UNFCCC, 2015), and in other important international initiatives such as the Sendai Framework on Disaster Risk Reduction (UNISDR, 2015). As a function of its diverse applications, resilience is used with varied meanings (Brand and Jax, 2007; Baggio et al., 2015). Not unlike the term sustainable development, which has usefully encouraged discussion and innovative work across different disciplines and practices, widespread use of the concept – and the many ways in which it has been applied – has also generated confusion.

8.2.1 Diverse meanings of resilience

Resilience has diverse roots that can be traced to several areas of policy and research, including engineering (resilient buildings, resilient cities), psychology (resilient individuals, resilient communities), risk reduction, and systems ecology (ecosystems resilience). It emerged from its origins in systems ecology (Holling, 1973) to become an important conceptual framework for understanding systemic processes that involve both stability and fundamental change of ecosystems – particularly those upon which societies depend (Chapin et al., 2009). Interestingly, Holling's original definition of ecosystems resilience was goal neutral. It assumed constant evolutionary, and sometimes abrupt change. The characterization of resilience as "*the capacity of a system to absorb disturbances while retaining essentially the same function, structure, identity and feedbacks*" (Walker et al., 2004) remains a common working definition of resilience. 'Disturbance' may be generated by natural phenomena such as a thunderstorm or fire, or it may be either an intended or unintended result of human activities. In this form, resilience is a property of the social-ecological system and is independent from judgments that might be made about its desirability.

Resilience is used increasingly in discussions in which the capacity to ride out or recover from disruption or shocks, whether expected or unexpected, is given high priority. In these circumstances, resilience is sometimes used in the context of seeking to maintain current ecological conditions to which communities have already accustomed themselves (Kofinas et al., 2013). This more goal-oriented definition of resilience is clearly part of the reason for its appeal (Walsh, 2013). Yet, while a part of the widespread popularity of the concept is based on positive associations of 'bouncing back' after disruption, returning to the conditions that existed prior to the disruption may not be a desirable outcome (Matyas and Pelling, 2015) and in practice, may not even be possible. This has led to characterizations of 'bouncing forward' (Manyena et al., 2011; Kresge Foundation, 2015). As defined in this chapter, resilience is considered a positive attribute – not regarding any particular system state, but regarding a community's capacity to navigate into the future on terms of its own choosing, considering knowledge of the dynamics of ecosystem function and change.

8.2.2 Social-ecological systems

Many scientists investigating complex social-ecological challenges such as the consequences of climate change, chemical pollutants, or biodiversity loss, have concluded that these issues cannot adequately be understood without proper attention to interactions that play out both within social and ecological systems, and between them. Among the variety of analytical frameworks that seek to consider all three types of interaction, most treat either environmental/ecological factors or social factors as a source of drivers of change, but do not analyze each of the sides of this equation with comparable depth (Binder et al., 2013). The social-ecological systems (SES) framework has attracted the attention of a variety of scholars and practitioners seeking to ensure proper attention is accorded to both social and ecological components (Miller et al., 2010; Brown, 2014; Standish et al., 2014; Stone-Jovicich, 2015).

The social-ecological systems framework conceptualizes humans and nature as integral parts in a system of nested, interconnected and interacting elements, linked in a complex web of causal relationships that includes reinforcing and mitigating feedbacks (Figure 8.1). These sub-systems are often referred to as 'linked' or 'closely coupled' systems that constitute a larger whole, but the distinction between social and ecological is largely analytical.

Owing to its systemic orientation, resilience research is attentive to the interactions that play out both within the social and biophysical spheres, and across the interfaces where the social and the biophysical meet. These interactions are influenced by feedbacks and non-linear processes that sometimes produce rapid and irreversible change (Berkes and Folke, 1998). The web of mitigating and amplifying feedbacks extends not only across social and ecological sub-systems, but also across spatial scales from local to global, and across a wider range of time scales. It is these multiple interactions which make accurate prediction such a challenge (Allen et al., 2014).

8.2.3 Co-evolution of social-ecological systems

Change occurs through processes in which "*evolving socio-cultural systems are increasingly affecting their biophysical environment…*" and "*evolving ecological systems are increasingly affecting socio-cultural change*" (Gual and Norgaard, 2008). There are many examples of such co-evolution. As just one example, recent research has identified a genetic change among the Inuit in Greenland that has helped them adapt both to cold and to the high fat diet available from locally available foods such as seal and whale (Fumagalli et al., 2015). Outside the Arctic, the domestication of animals over the past 10,000 years has shaped the evolution of the most important agricultural species – goat, pig, sheep, chicken, horse, and dog (and in the Arctic also reindeer) (Paul Thompson, 2001). At the same time, the development and distribution of these species has helped shape the evolution of cultural and economic systems. Socio-cultural evolution has also influenced human genetic evolution; most adult humans worldwide lack the enzyme (lactase) that enables people to metabolize milk (in most populations the relevant gene is switched off in adolescence). The ability to digest milk as an adult is found primarily in regions with a long history of dairy farming (Bersaglieri et al., 2004).

An important example of social-ecological co-evolution at a regional and global scale is the burning of the fossil fuels that remain the hallmark of modern industrial societies. A myriad of social and economic activities have developed in conjunction with substituting human or animal muscle power with fossil energy. At the same time, humans have altered both the geophysical and ecological systems of the planet through the activities required to secure these resources and through the side-effect pollution generated by their use (Rockström et al., 2009; Zalasiewicz et al., 2010).

Research on socio-cultural and/or socio-economic evolution emphasizes that such processes are by no means deterministic,

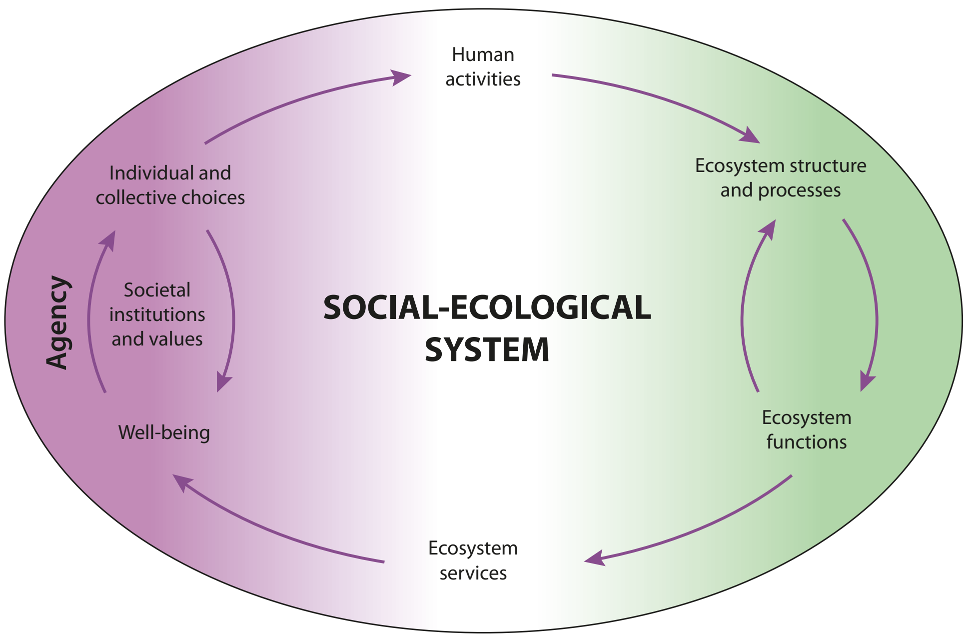


Figure 8.1 Conceptual model of a social-ecological system (Carson and Sommerkorn et al., 2016).

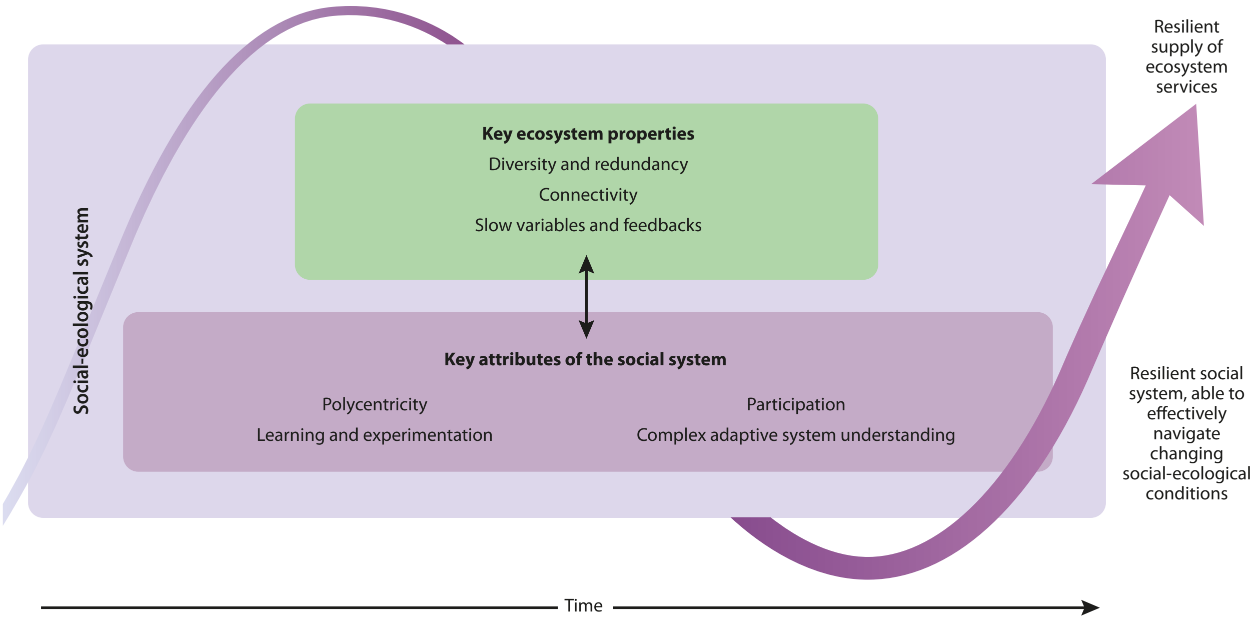


Figure 8.2 Co-evolution of social and ecological systems (Carson and Sommerkorn et al., 2016).

nor do they necessarily result in progress (Dietz et al., 1990; Burns and Dietz, 1992; Dietz and Burns, 1992; Gual and Norgaard, 2008). What these and other studies clearly indicate is that while socio-cultural and biological evolution influence one another, they play out through very different processes and mechanisms. Figure 8.2 highlights the co-evolving relationship between nature and society, acknowledging the distinction between the two is an analytical one that takes account of the different mechanisms by which change unfolds iteratively over time.

8.2.4 Social side of social-ecological resilience: agency, knowledge and power

The definition of resilience employed in this chapter emphasizes human agency. Agency is exercised by people – in groups, organizations, or communities at different levels – making use of social and ecological systems-related knowledge as an explicit element of their adaptive and/or transformative capacity. The fact that societal actors have the capacity to choose how they respond to drivers of change – and to choose to themselves be drivers of change (Davidson, 2010) is an influential force in social-ecological systems and a fundamental difference between the two subsystems (this is not to say that there are not real limits on such choice, imposed by nature, or lack of needed resources or by socially constructed limits such as laws). This capacity to plan and carry out deliberate action is essential to efforts to define community or social resilience. It is a fundamental property of both the capacity to adapt and the sense of choice that empower a community to consciously engage in transformative change – whether in response to unwanted or unavoidable disturbances, or in pursuit of a more desirable set of arrangements (Davidson, 2010).

Agency is of course not a stand-alone property; it is influenced by other factors that are also basic elements of social systems. A second key factor that distinguishes social-ecological resilience from ecological resilience is the human capacity for learning, applying and revising knowledge. This applies particularly to knowledge regarding continued capacity of ecosystems to provide support for human life and well-being, and to knowledge about the likely ecosystems impacts of human activities. Both inform the choices communities make and actions they take at all scales. While agency is a property only of social systems – and a key ingredient for social or community-level resilience – knowledge and the capacity to continue learning and to apply that knowledge to inform action, links social and ecological systems through providing feedbacks that can inform agency.

A third vital social factor also influences agency; the answer to the question of 'resilience of what, to what' is contingent on social values and power, and may therefore be contested (Tanner et al., 2015). The potential for contestation contributes to uncertainty, and to the systems process character of agency to play out along different paths. There will be multiple resiliences in any particular social-ecological system, and the strengthening of some may have the effect of weakening others. This is true also for ecosystems, where systems with different appearance (i.e. different sets of species and different distributions of functions) can be resilient in the same physical environment (Scheffer et al., 1993), for example, as cultural and natural landscapes.

In this chapter, *adaptation* refers to actions taken to maintain system functions and feedbacks in roughly the same configuration as previously, so that stronger adaptive capacity is an expression of greater resilience. *Transformation* of a social-ecological system, on the other hand, entails fundamental change in some aspects of a social-ecological system while maintaining its core identity. The capacity to navigate this type of fundamental change is also enhanced by greater resilience. Fundamental change in which identity and function are lost is defined as collapse or failure. Adaptive and transformative capacity should therefore be understood as expressions of resilience (Folke et al., 2010).

8.3 'Ingredients' of resilience

With the intention of operationalizing the above concepts as resilience indicators, a three-step approach is taken. First, key ingredients of social-ecological resilience are identified from empirical research and their specific qualities are explored (Section 8.3). Second, the strength and weaknesses of the indicator concept is discussed to shed light on ways in which useful indicators might be constructed and applied (Section 8.4). Last (Section 8.5), a framework is proposed that provides a bridge between the resilience ingredients and their implementation as indicators in a particular context, focusing on applications where strengthening particular ingredients of resilience supports adaptation to change, including as yet unknown disturbances.

Key ingredients of resilience – distinct qualities that can facilitate effective adaptation to disturbances or support transformational change where desired – have been identified from a wide-ranging body of empirical research. Based on these studies, Folke et al. (2003) identified four qualities as fundamental ingredients of social-ecological resilience: assuming change, fostering diversity, ongoing learning and knowledge development, and capacity for self-organization. To this list can be added a fifth: sustainable livelihoods (Tanner et al., 2015), which speaks to the activities in which households and communities engage to provide for themselves basic sustenance and other benefits.

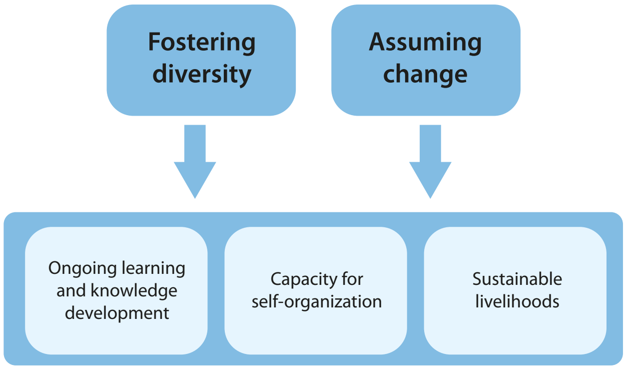


Figure 8.3 Five key 'ingredients' of social-ecological resilience. The two in the upper tier are cross-cutting and contribute resilience to each of those in the lower tier.

8.3.1 Assuming change

Assuming change - or rather, acknowledging change as the norm – means accepting uncertainty and surprise as part of reality. Change, including abrupt and disruptive change, can be approached as an opportunity for pursuing developmental goals when maintaining current conditions may not be optimal, desirable, or perhaps even viable (Folke, 2006). Most importantly, assuming change leads to different kinds of choices than does an expectation that constancy will be the norm. A novice hiker who sets off into the mountains expecting warm, sunny conditions to persist is more likely to be caught off-guard and ill-prepared than a more experienced hiker who knows that all conditions are temporary and prepares accordingly. Supporting communities to prepare to navigate a diverse range of challenges is a far more complex undertaking, but the same basic principle applies.

8.3.2 Diversity

Diversity is important because it broadens the range of possible response paths. Also characterized in terms of redundancy, diversity can be seen as a form of insurance; when disturbance or changing conditions lead to the failure of one type of response, other mechanisms are available to carry out or secure essential functions. In the social context, diversity of knowledge or skills can provide the foundations for creative problem solving by maintaining a stock of elements that can be combined in novel ways in response to change (Carayannis et al., 2008; Ostrom, 2009; Fabinyi et al., 2014). In an ecosystems context, biodiversity is one example of diversity that has been identified as enhancing the resilience of ecosystem states that are desirable for social-ecological adaptation and transformation. Biodiversity supports essential functions upon which human life and well-being depend, from local to planetary scales, and which, from a social-ecological perspective, can be looked at as producing sets of desirable ecosystem services. Within biodiversity, the diversity of responses to environmental change among species can contribute to maintaining a given ecosystem function. Response diversity is particularly important for ecosystem self- and re-organization in the light of ongoing variability and change, and for ecosystem renewal following rapid change (Elmqvist et al., 2003). Response diversity thus also links to the capacity of self-organization as it applies to social systems (discussed in Section 8.3.4).

Among the five ingredients of resilience, the first two (assuming change and diversity) are cross-cutting, meaning that they contribute resilience in each of the other categories. While *diversity* is a property of both social and ecological sub-systems, *assuming change* is clearly a property of only the social. Diversity and the orientation toward change are important properties of a resilient system, while the remaining three (livelihoods, knowledge/learning, self-organization) represent spheres of activity. Considered together in this manner, they can inform options for actions that influence the capacity to respond effectively to changing conditions. Figure 8.3 illustrates these ingredients of resilience.

8.3.3 Knowledge and learning

Knowledge and capacity to learn to modify and augment existing knowledge is the key means by which community choices can be directed in ways that foster greater resilience. A growing body of research on the capacity to adapt and respond to climate and other change, acknowledges that knowledge represents both an important determinant and an indicator (Klein et al., 2014; Williams et al., 2015). It helps people to make sense of their world, enables them to more accurately anticipate future developments, and "*empowers people to participate more effectively in local, national and international conversations*" (Williams et al., 2015). One way in which knowledge of the iterative nature of cause-and-effect relationships between communities and ecosystems supports better choices is that it makes it possible to more accurately anticipate the social and ecosystems consequences of those choices. Decisions can then be made cognizant of at least some of the trade-offs embedded in choices between what are often competing priorities.

Knowledge is here defined in a broad sense, with experiential and experimental knowledge taken as largely complementary and therefore parts of a whole (Watson et al., 2003; Folke, 2004, 2006; Folke et al., 2004).

The broad consensus regarding the importance of knowledge of the Arctic is clearly apparent in the investment of time and other resources in the scientific endeavors of the Arctic Council working groups, and in the efforts of the Arctic Council to determine how to better integrate other forms of knowledge, such as traditional knowledge[18] and local knowledge. These efforts are wide-ranging, with the common thread being the desire to better understand how human activities affect people and nature in the Arctic, and how such effects might in turn impact future Arctic development.

Experiential knowledge, of which traditional and local knowledge are particular types, is distinguished from conventional scientific knowledge. Where conventional science produces knowledge on the basis of focused experimental studies and simulations that draw on bodies of accumulated research, use of experiential knowledge draws on and builds local-scale expertise and capacity. It can provide baseline data and a source of historical impacts and adaptations in Arctic communities that can also help guide and formulate hypotheses for conventional research (Riedlinger and Berkes, 2001). These complementary modes of knowledge are important in filling gaps, informing one another, addressing change driven by developments at different scales, and changes that reach beyond previous experience. In short, diversity in knowledge is strengthened when conventional science is combined with traditional and local (experiential, observational) knowledge.

The fundamental challenge with integrating diverse knowledge forms, including traditional knowledge, is that they are often incommensurable – not directly comparable or translatable (see, for example, Thomas Kuhn's classic work on scientific revolution; Kuhn, 1970). The challenge entailed in comparing or bridging knowledge systems is on display in the debate between Howard and Widdowson (1996) and Berkes and Henley (1997) in the Canadian journal *Policy Options*, where Berkes and Henley argued that shared learning and collaborative-production of knowledge are essential processes for integrating different knowledge traditions. In such processes, new knowledge is created that is more than the sum of its parts (Jasanoff, 2004).

Knowledge diversity is also important in other ways. For example, in their work on Arctic Social Indicators (ASI), Nymand Larsen et al. (2010) concluded that the number of years of formal education completed is the preferred proxy indicator of knowledge resources because the data are readily available. However, meaningful and relevant knowledge such as traditional or local knowledge is missed because one criterion of the ASI work is that the data be readily available, that is, collected on an ongoing basis. This is not a flaw of the highly thoughtful work carried out by research involved with the ASI, but a consequence of the challenges entailed in collecting comparable, scalable data in the circumpolar north. This highlights the value of complementary forms of knowledge to provide needed insights.

It is important to note that knowledge is not neutral; relevant knowledge helps to shape perception of the action options in any given situation. For example, knowledge of the status of ecosystem capacity to provide desired functions – and the trajectory of that capacity vis-a-vis anticipated changes – can guide decisions about what actions to take or not take. Similarly, knowledge of functional diversity and of response diversity is important in considering how to strengthen resilience in a given social-ecological system, as is knowledge of social and cultural needs and trends. Even in conventional science this is an inherently social, even political, process in which proponents for competing views may struggle for primacy (Kuhn, 1970).

Power can therefore influence competition regarding what kinds of knowledge are considered relevant or legitimate. The very ways in which social problems are defined tend to identify particular types of knowledge and expertise as relevant and appropriate (Carson, 2008). Definitions of what constitutes legitimate knowledge also vary depending widely on disciplinary training and on methods of data collection and analysis, or on whether it is considered scientific (Jasanoff and Martello, 2004). In this respect, knowledge is not a neutral asset, but subject to claims regarding knowledge domains and reflections on whose knowledge counts.

The important precursor for knowledge is the capacity for ongoing learning and thereby adding to existing knowledge, or modifying or replacing knowledge that proves incomplete or flawed. Integrating different forms of knowledge and understanding changing conditions both entail learning. Learning takes place via different kinds of process, some of which are better suited than others to the types of challenge communities face in preparing for an uncertain future. Table 8.1 highlights these different modes, which vary according to several factors, including assumptions about the nature of the learning and decision environment, who the decision-makers are, and how systematic is the process of learning and incorporating new knowledge. It should be emphasized here that the category 'deliberation with analysis' most closely fits the type of learning process needed for navigating under conditions of uncertainty and was developed with the aim of providing knowledge for decision support in the context of climate change. With its assumptions of changing conditions, focus on learning as an iterative process with attention to ongoing monitoring and incorporation of new learning, and collaborative modes of learning, it meshes well with the criteria outlined for the development of resilience indicators proposed in this chapter (Section 8.5).

8.3.4 Self-organization

Filotas et al. (2014) defined self-organization as "*the process whereby local interaction among a system's components cause coherent patterns, entities, or behaviors to emerge at higher scales of the hierarchy, which in turn affect the original components*

[18] There is ongoing discussion as to whether the label 'traditional knowledge' adequately represents the nature of the knowledge held by the indigenous peoples of the Arctic, the ways in which it is systematically collected and passed on, and who is qualified to assess its value. See Johnson et al. (2016) for a summary.

Table 8.1 Modes of policy learning (National Research Council, 2009).

Characteristics	Learning modes			
	Unplanned[a]	Program evaluation[b]	Adaptive management[c]	Deliberation with analysis[d]
Assumed decision environment	Stable	Stable	Changing	Changing
Assumed decision-maker	Unitary	Unitary	Unitary	Diverse
Goals	Implicit	Set by decision-maker. Stable	Set by decision-maker. Stable	Emerge from collaboration. Potentially challenging
Data for learning	Unsystemic	Explicit indicators. Evaluation at end	Explicit indicators. Continual monitoring	Explicit indicators. Continual monitoring
Means of appraisal	Ad hoc	Formal assessment. Usually summative	Formal or informal. Continuing	Formal assessment with deliberation on its import. Continuing
Incorporation of learning	Unplanned	Adjust after evaluation complete	Continual	Continual

[a]Refers to actions undertaken without consideration of learning; [b]involves formal assessment and expectations of project adjustments; [c]actions are experiments designed to perturb the decision environment in iteration; [d]builds on the latter but starts with the many participants of a decision to work together defining its objective and staying involved during iterative information-producing, assessment and re-assessment stages.

through feedbacks". Although this particular definition is applied to ecosystem self-organization, it also provides a useful umbrella definition for the self-organization of social-ecological systems. As noted earlier, the capacity for self-organization is defined primarily in social terms, meaning the ability of a community to substantially influence its own direction and fate, bringing in the key element of human agency. Here it is important to note that the community in question can be defined at different geographic scales (for example, a village, a city or even a country). It can also be defined as a community of interest that transcends geographic location, such as groups of people that share particular cultural practices or economic interests.

Capacity for self-organization is essential for the effective exercise of agency. Self-organization as used here applies primarily to the social component of social-ecological systems and overlaps with concepts used elsewhere that include governance or fate control. It encompasses the multiple factors that contribute to a community's capacity to identify developments that require a collective response: to define the nature and cause(s) of those challenges, and to come to some measure of agreement on suitable responses and implement those responses. This capacity is also influenced by factors exogenous to the community, including legal rights or norms that may facilitate or constrain the ways in which such efforts might be organized, or which define ownership or authority over certain resources or activities. The self-organizational capacity of a community should therefore be understood in terms of its capacity to steer itself, both in its social context and in relation to the ecosystems upon which it is dependent for the various kinds of benefits or services it enjoys. As these are provided from across scales local to global, the self-organizational capacity of communities needs to reflect these various scales. In the context of social-ecological systems, the key feature is a community managing itself within the ecosystems and resource base in which it is embedded. Resilience is therefore influenced by the choices a community makes and carries out and the subsequent effects of those actions on social-ecological systems, and the capacity to take such actions has itself been demonstrated to be an important property of resilience.

Defined in these terms, the capacity for self-organization is influenced by a variety of factors that can be organized in terms of their location or source being either endogenous or exogenous to the community, and in terms of the social world (including economic and political factors) and biophysical world in which the community is embedded. Scale is an important element of both social and biophysical elements of the social-ecological system, in part because of the way the influence flows. The concept of multi-level governance (Hooghe and Marks, 2001) provides one useful example. Policy and decision authority differ by level, as does the mode of exerting influence. Nation-states operate as an exogenous, context-defining, factor for local communities engaged in their more localized governance activities. Yet, local communities may also exert significant (endogenous) influence on the national governments within which they are embedded. Other sources of endogenous influence can be from outside the political-policy hierarchy, from other communities at a similar scale (whether within or outside the country of which the community is part), or higher scale such as other national or international actors – what was characterized by Ostrom (2009) as 'polycentric'. Table 8.2 identifies some of the key factors influencing the capacity for self-organization on the basis of this endogenous/exogenous distinction.

These types of structure are considered within the work on ASI (Nymand Larsen et al., 2010, 2015) to be an indicator of capacity for fate control. For any such formal structure to be operationalized, however, capacities that are endogenous to the community are also required. These can be characterized generally in terms of a community's ability to effectively organize itself within the externally given parameters and come together around particular courses of action. Endogenous characteristics that contribute to defining this internal community capacity include qualities such as social capital, trust, cultural capital, available traditional and conventional knowledge resources

Table 8.2 Endogenous and exogenous aspects of self-organization in social and ecological systems.

System	Endogenous	Exogenous
Social (defined as community at a given scale)	• Social capital • Traditional knowledge, local knowledge resources • Routines and procedures for coming to agreement, keeping promises, enforcing agreements • Internal legitimacy and perceived fairness of social structure (touches on formal and informal leadership, traditional models, democratic structures, wealth and knowledge distribution etc.)	• System of legal rights • Formal procedures defined by political representation at higher levels of governance • Other external/higher scale factors that influence the capacity to pursue a particular course of action (i.e. economic opportunity) • The community level may exercise influence at higher levels, but formal authority generally lies with the higher level
Biophysical (defined in terms of ecosystem at a given scale)	• Ecosystems that are substantially influenced by the activities of the particular community, or relied on by the community • Local or regional land use • Local population of species used for food (fish or terrestrial wildlife)	• Biophysical systems defined and operative at a scale that is larger than that which can be substantially influenced by the community (i.e. climate system) • Ice and snow extent • Seasonal variation • Range shifts in fish stocks, birds, and marine mammals

Under *exogenous/social*, externally defined structural factors are seen that set the parameters for self-organization and shape the ways in which it may be carried out, for example systems of formal legal rights and constitutional structure. These are most often defined at the level or scale at which national governments are active, and they therefore vary among the eight Arctic countries. Some of these structures or rights are established in international agreements such as the various UN Conventions, provide an overarching framework of rights that signatories agree to observe, and transpose into national law.

(see Section 8.3.3), and the strength of local networks and organizations. Conversely, high levels of social conflict could be expected to undermine this capacity. These qualities may also be prominent characteristics of the larger system in which the community is embedded, and available to be accessed via social networks that extend across scales within a given country, or which extend across country boundaries.

Among the biophysical (including ecological) influences on the capacity for self-organization, scale also plays a defining role. Some phenomena are influenced by forces that operate at a much larger scale than the community in question, with the result that while they might exert some influence, developments may lie largely outside their control. Examples of the type of global influences that have a defining impact on local Arctic communities include climate change, accumulation of persistent organic pollutants from outside the Arctic region, or range-shifts of species. Larger-scale biophysical factors can also be influenced by activities on a more local scale. Land use provides examples of activities carried out at a local scale that have significant impacts on regional biophysical conditions, regardless of the level at which decisions about land use are made. Examples include distribution of agriculture, forestry, mineral extraction (mining), or maintaining areas suitable for grazing of reindeer. For the marine environment, fisheries provide a good example, with catch volume and age characteristics of fish caught possibly influencing fish populations significantly over time.

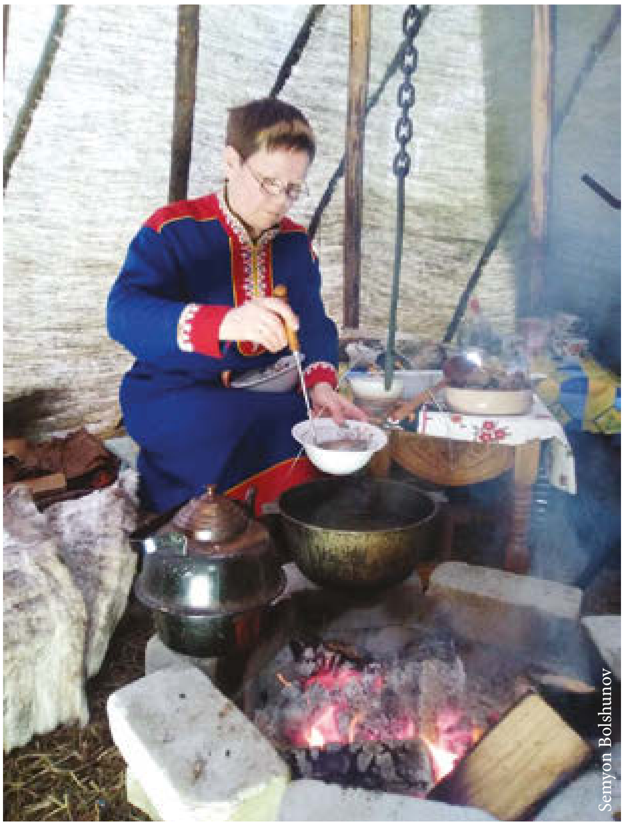
It becomes quickly apparent that conditions and/or changes in each of the quadrants (see Table 8.2) have strong potential for influencing the capacity for self-organization overall, and that changes can cascade from one quadrant to impact conditions in another. As just one example, effective local management of important ecosystem services could be weakened by the inability of the local community using those resources/services to build consensus on the goals for guiding management of such resources. A typical example includes conflict over local land use for which local actors have significant decision-making authority (endogenous social to endogenous biophysical). However, there are also many instances in which exogenous social influences, such as higher-scale political or economic decisions, have significant impact on local ecosystems. Rules that define harvest limits for fisheries or terrestrial species, or which define arrangements by which priorities are determined for land use are examples of cross-scale influence on local ecosystem services (for example, rules determining priority ranking between the siting of a mine, a major road or dam, and other priorities that maintain the land in an undeveloped state for other uses).

8.3.5 Livelihoods

One way to embed agency in resilience thinking and more explicitly identify socio-political aspects of resilience is to combine it with the livelihoods and social well-being approaches. Not only, as Janssen and Scheffer (2004) argued, is the relationship between well-being, livelihoods, and natural and social capital important for long-term sustainability, but it is also key for resilience and people's capacity to respond effectively to change (Kofinas and Chapin, 2009).

Livelihoods of individuals and households include their capabilities, tangible assets and activities required for a means of living (Chambers and Conway, 1991). This perspective highlights human agency and needs, and also raises issues of human rights and empowerment (Tanner, 2015). Therefore, livelihood resilience is the "*capacity of all people across generations to sustain and improve their livelihood opportunities and well-being despite environmental, economic, social and political disturbances*" (Tanner, 2015).

Livelihoods speaks more generally to the activities by which individual, family and community-level agents seek to provide for the necessities of life. Without the fruits of these labors, the social aspects of social-ecological resilience are not possible. The livelihoods definition commonly referenced by United



Host of kouvaksa (Saami housing) Lida Bolshunova, Loparskaya community, Kola Peninsula

Nations organizations (FAO, 2010) and many others is broadly embraced here:

> *"a livelihood comprises the capabilities, assets (including both material and social resources) and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stress and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base"* (Chambers and Conway, 1991)

This definition builds on earlier thinking by the World Commission on Environment and Development, which says that "*a household may be enabled to gain sustainable livelihood security in many ways – through ownership of land, livestock, or trees; rights to grazing, fishing, hunting or gathering; through stable employment with adequate remuneration, or through varied repertoires of activities*" (WCED, 1987). These definitions emphasize three points critical to the conceptualization of sustainable livelihoods used here: they speak to the necessity of meeting basic physical needs, they point to the diversity of means (both market and non-market) employed in pursuing that goal, and they speak to the need for long-term viability.

The specific weakness in the just-quoted livelihoods definition is that it passes over non-material aspects of well-being that when absent, can have material consequences. For example, one indigenous leader from Barrow, Alaska, noted in an interview that "*we have to hunt whale – it makes us who we are – it makes us cooperate*" (Itta, E., US Arctic Research Commission, pers. comm., 2014). Others note the critical links between livelihoods activities and identity that are especially strong within, although certainly not exclusive to, Arctic indigenous communities (Henry et al., 2013). Nor are such concerns new; consideration of the consequences of alienation from work that lacks non-material meaning dates in the social sciences back at least to Marx, and before him, the philosopher Hegel (Gouldner, 1980). For this reason, it is argued here that the concept of sustainable livelihoods goes beyond material well-being to include the meaning derived from the culturally, spiritually, and socially-rooted aspects of livelihoods activities that give them meaning and so fulfill essential non-material needs. While this meaning creation is not exclusive to livelihoods pursued in close contact with and interdependent with ecosystems, it is a key feature of many of the traditional livelihoods pursued within the indigenous communities of the Arctic.

As it encompasses both material and non-material (cultural/spiritual/social) well-being, focus on sustainable livelihoods highlights issues connected to social values, balancing interests, and making choices that may prioritize some types of livelihood over others (Tanner et al., 2015). Especially in the Arctic, the mixed economy nature of many livelihood activities is more a norm than an exception, that is, many Arctic livelihoods entail a mix of market and non-market activities (i.e. securing food and other benefits from nature, or from other members of the community through sharing networks, barter or other non-monetary forms of exchange) that provide for both material and non-material needs. And while non-market aspects of Arctic livelihoods are typically closely integrated with nature and access to nature, many common market-oriented activities are also either directly tied to nature (reindeer herding, fisheries, tourism), or significantly impact or are impacted by them (development of natural resources). Mixed livelihoods are therefore a fundamental aspect of many Arctic communities.

The role of sustainable livelihoods in providing for social-ecological (and vice versa) resilience is in many ways quite clear. Greater capacity to respond to disruptive developments or events exists where material and non-material well-being are at least sufficient; poverty is a non-resilient condition (Baez et al., 2010). Diversity plays an important role, as greater resilience can be reinforced where there is room for either the cash economy or subsistence activities to pick up 'slack' when the other is operating less well than planned or hoped. Evidence in literature shows the importance of mixing market and non-market activities in increasing the resilience of communities in the circumpolar Arctic. In many instances, individual households of Arctic communities are inherently different to those of the south – Arctic households act as both the production and consumption units of an economy, rather than the traditional economic model where firms produce and households only consume (Usher et al., 2003). The Arctic model allows the integration of wage or cash income from conventional market activities with traditional non-market subsistence activities.

More specifically, cash income generated by conventional waged labor, sport hunting tourism, and selling animal products such as skins, furs, ivory, or meat, is often invested by Arctic households into equipment necessary for subsistence hunting. As imported technology has become integrated with traditional hunting, snowmobiles, gasoline, firearms, ammunition, and other expensive supplies have become essential to subsistence hunting or herding. As summarized by Wolfe and Walker (1987), "*the money generated in the commercial-wage sector of the economy enables families to capitalize in the subsistence sector*".

The Nunavuk Inuit community at Clyde River provides an example of the mixed-economy experience. Due to a lack of waged labor, Clyde River Inuit relied on market sales of the skins of ringed seal (*Pusa hispida*) to bring in cash starting after the Second World War. When the sealskin market crashed in 1983 due to international restrictions, the amount of biomass collected from traditional subsistence hunting in the community also fell sharply, signifying that sealskin-generated income was financially supporting subsistence hunting (Wenzel, 1989, 2011). Eventually, the community began to generate income by selling about 20% of their annual polar bear (*Ursus maritimus*) hunting quota to non-indigenous trophy hunters. Polar bear sport hunting, required by Nunavuk law to be executed through traditional means, generates a large amount of cash across the Inuit community, from the outfitters to the guides to the dogsled owners. Wenzel (2011) showed that roughly half the income generated from polar bear hunts is invested into subsistence hunting equipment such as snowmobiles and gasoline. In many Arctic communities, a decentralized resource sharing mechanism often means that hunting gear, income or food will always be shared among families, further increasing resilience (Berman et al., 2004). At Clyde River, market activities are vital in sustaining the subsistence hunting culture and identity of the community, creating a truly mixed economy.

Therefore, indicators relating to mixed economies, such as the percentage of calories consumed from traditionally gathered or hunted food and estimated value of such food (Usher, 1976; Berkes et al., 1994), capital expenditure on hunting equipment (Wenzel, 2011), or assessments such as the Survey of Living Conditions in the Arctic (SLiCA; Poppel and Kruse, 2009) may be helpful in assessing the livelihoods resilience of Arctic communities.

8.4 From 'ingredients' to indicators

> *"Indicators arise from values (we measure what we care about), and they create values (we care about what we measure)"* (Meadows, 1998)

Using indicators to assess and monitor resilience serves multiple functions. The effort required to characterize key aspects of resilience and define the nature of indicators supports the development of a more precise understanding of what factors contribute to resilience and in which contexts (Prior and Hagmann, 2014). Especially within the context of this assessment, carefully developed indicators can make information on complex issues more easily accessible to decision-makers (Niemeijer and de Groot, 2008), thus supporting policy planning, prioritization of potential actions for strengthening adaptive capacities, and reassessment and follow-up. At a very basic level, for example, indicators can be used for establishing baselines and to assess the direction of change (Davidson et al., 2013). Monitoring these indicators can also be useful in elaborating and adjusting adaptation strategies by providing critical information and feedback on policy effectiveness (Davidson, 2010; Prior and Hagmann, 2014).

In all aspects of their use, it is important to remember that indicators are subject to limitations. From a policy-making perspective, indicators are often expected to be specific, timely, sensitive, reliable, and cost-effective (Boulanger, 2007). This contributes to an appearance of objectivity and neutrality, and it is sometimes assumed that indicators can be constructed in ways that mechanically and automatically inform policy-making (Hezri and Dovers, 2006). However, this idea of a mechanistic and objective translation into policy-making of the information provided by indicators is a myth (Innes and Booher, 2000). Neither the way indicators are conceived nor their operationalization are completely neutral; choices about indicators and the types of solution that are called for reflect belief systems and values and perceptions through which policy issues are viewed (Innes and Booher, 2000; Boulanger, 2007). While the value of developing and using indicators to make assessments in the Arctic has been argued elsewhere – see for example, the excellent work on ASI (Nymand Larsen et al., 2010, 2015), and the Arctic Human Development Reports (AHDR, 2004; Nymand Larsen and Fondahl, 2015), it is also important to emphasize the difference between the phenomenon of interest here – resilience – and the measures used to assess it. Indicators are by nature only a limited representation of the phenomena they help us to understand; as expressed by Magritte in his masterpiece *Treachery of images [This is not a pipe]*.[19] Hence while we are (and should be) interested in what they **indicate** about reality, indicators provide, by definition, a glimpse of only a limited view of reality.

Nevertheless, properly developed indicators can be extremely useful and influential. Through processes of negotiation and learning (Reed et al., 2006), debates about indicators shape actors' thinking about related policy and represent one way of developing consensus. Therefore, in developing indicators, the process itself is crucial for building shared understanding of issues at stake and possible responses (Innes and Booher, 2000). In addition, such participatory processes of development and assessment can contribute not only to the quality of indicators developed, but also to their legitimacy (Cabell and Oelofse, 2012) and the effectiveness of actions subsequently undertaken.

8.5 Operationalizing a resilience indicators framework

Following the general logic for social-ecological resilience outlined in Section 8.2, indicators must capture interactions between social and ecological systems and cannot be alienated from nature. It is also important to acknowledge and make

[19] In this word-image painting, the French surrealist painter René Magritte painted a pipe and added the words underneath "*This is not a pipe*". He wanted to convey the message that what appears on the painting is not reality, but only an image, his own representation.

more explicit the normative, social and political issues related to resilience, and reintroduce agency into the equation (see Cabell and Oelofse, 2012). However, meaningful linkages between biophysical variables and socio-economic variables remain understudied, under-monitored and under-assessed (Jarvis et al., 2013).

Designing resilience indicators entails significant methodological challenges, some of which are general to social indicators. The focus on interacting social and ecological systems adds a new layer of complexity, as the abstract, multidimensional and dynamic character of resilience makes it especially difficult to measure. Notwithstanding these challenges, a framework of well-constructed indicators can contribute to greater clarity not only about whether resilience is growing or declining, but also about important directional trends in the underlying factors that contribute to resilience. The basic framework proposed includes the five resilience ingredients discussed in Section 8.3. With this framework providing an overall structure, a wider body of research is drawn upon to propose the following general principles to develop such a framework:

Process has its own value – indicators are likely to be most valuable where elaborated on through a process of co-production, using participatory methods similar to those used in the scenarios work discussed in Chapter 5. Many of the benefits of participatory methods have already been enumerated in Chapter 5, with processes of shared reflection, social learning, and local engagement important vehicles for developing the information needed to fill the indicators framework. But beyond providing important information, the process itself can also contribute to building local capacity for further learning and self-organization, and is envisioned as a means for further developing the indicators themselves by testing what has meaning for participants.

Qualitative indicators invite further discussion – while it is sometimes assumed that indicators should be quantitative, there are many easily accessible and highly useful indicators that are either qualitative or make use of tools such as the Likert scale. This is especially important in a setting such as the Arctic, where quantitative social data are typically not readily available (Nymand Larsen et al., 2010, 2015). Qualitative assessments of particular characteristics can be placed on a simple scale based on whether or not the status is deemed adequate – or based on whether or not it is trending in a desired direction. Inviting further discussion about how the indicators are structured and what they actually reveal is expected to support further refinement and testing of these measures.

Cross-cutting ingredients – *Diversity* and *assuming change* are cross-cutting ingredients, and can therefore inform the types of information sought for assessing the status of each of the three remaining ingredients (knowledge/learning, self-organization, livelihoods). While diversity is manifested in substantively different ways in knowledge/learning, self-organization and livelihoods, can each be analyzed on a continuum with diversity characterized in terms of conventional at one end of the continuum and traditional at the other. As a cross-cutting indicator, it is important to assess overall diversity of livelihood options (for example, market and non-market food sources), knowledge (conventional education and traditional knowledge) and capacity for self-organization (formal rights and responsibilities and the level of social cohesion). Some authors recognize the importance of *diversity* in the resource base (see Cabell and Oelofse, 2012). The other cross-cutting factor, embracing change as the norm, would be expressed in the ease with which new conditions are recognized and acknowledged, in the readiness to modify established practices and engage in less routine activities.

Knowledge transmission and learning processes – Learning constitutes another recurrent element in resilience indicator frameworks, especially indicators of conventional education (Jordan and Javernick-Will, 2012). Examples of operational indicators include secondary school completion, take up of post-secondary training and number of master degrees and doctorates in the region (Ross et al., 2010), as well as household education average (FAO, 2010; Morrone et al., 2011). This is basically the metric proposed in the ASI work (Nymand Larsen et al., 2010). However, such an indicator cannot inform about the status of traditional or local knowledge in a community. There are other forms of information that could be employed for making such assessments, that include key milestones, use of indigenous languages, and number of young people participating in particular rites of passage or cultural activities, among others.

Social or collaborative learning processes are deeply embedded in theories of resilience (Krasny et al., 2010). Examples of indicators proposed in this context can inform the kind of composite knowledge/learning indicator proposed here. Bergamini et al. (2013) included in some kind of resilience indicators: documentation of agriculture biodiversity; innovation in agricultural biodiversity management for improved resilience and sustainability; access and exchange of agricultural biodiversity; transmission of traditional knowledge from elders, parents and peers to the young people in a community; cultural traditions related to biodiversity; number of generations interacting with the landscape; practices of documentation and exchange of local knowledge; use of local terminology or indigenous languages; and women's knowledge about biodiversity and its use.

Being able to assess the two-way linkages between social and ecological systems is crucial and the link between peoples and places also constitutes a recurrent theme (Jordan and Javernick-Will, 2012). Linking back to learning and knowledge, Magis (2010) suggested measuring "*how well people understand the opportunities and limitations of the natural environment in and surrounding their community*" or "*community members' belief in their ability to affect community's well-being*". Ross et al. (2010) proposed assessing "*people-to-place connections*" notably through stewardship, level of attachment to the community, connection to the country for indigenous groups, and community shared vision. These types of qualitative information can be assembled in participatory processes or collected using questionnaires, where respondents indicate to what extent they agree or disagree with a statement. Such results can be expressed using an ordinal scale method such as the Likert scale.

Capacity for self-organization – Capacity for self-organization resides in the dynamic between actions taken and social structure. For example, one element often mentioned is the strength, extension and quality of community networks, especially in community resilience framings (see Ross et al., 2010; Morrone et al., 2011). Here two kinds of indicator are suggested. The first is linked to social cohesion, for example the number of arts and sports organizations per 10,000, the number of civic organization per 10,000, voting participation, and the number of religious adherents per 1000 (Sherrieb et al., 2010). The second relates to population turnover. Examples include the migration-related net change in the number of family members in a household over a five-year period (Perz et al., 2012) and the proportion of the population living in the same general location after a five-year period (Ross et al., 2010). Indicators that reflect external connections are also mentioned, for example the number of individuals within a community that represent the community and manage relationships with external organizations and the percentage of community members that have access to external media sources (IFRC, 2012). Other approaches to social indicators measure other important aspects of the social fabric, for example, the single parent household ratio (Morrone et al., 2011). These kinds of indicators provide an approximation of the nature and level of linkages between members of a community, and which increase the basis for coming to agreement and working together.

Equity also constitutes an important theme for social organization (Magis, 2010; Ross et al., 2010; Bergamini et al., 2013). It can be assessed with indicators such as the diversity of community members engaged in governance (Ross et al., 2010), autonomy with which land and resource management decisions can be made, and the degree of gender equality in decision-making (Bergamini et al., 2013). Other types of indicator assess trust and satisfaction with governing, the extent to which methods for governance are culturally appropriate (Ross et al., 2010), and whether community decision-making and planning processes engage diverse perspectives and reflect cultural differences (Magis, 2010). An interesting indicator that brings together social organization and the physical environment is the number of effective laws governing natural resources (Morrone et al., 2011).

Social participation and leadership also appear in resilience indicator frameworks, notably through volunteering (Ross et al., 2010) or social self-organization (Cabell and Oelofse, 2012). Examples of operational indicators include the percentage of community members that actively manage their natural resources, the number of active community organizations, and the percentage of community members that are members of two or more community organizations (IFRC, 2012).

Livelihoods – In the category of livelihoods, diversity contributes to resilience by providing alternative modes for securing the basic resources needed for material and non-material sustenance. Relevant indicators that have been developed in other settings include the percentage of households with two or more income generating activities (IFRC, 2012), heterogeneity and multi-functionality of the landscape (Bergamini et al., 2013), agriculture and food systems diversity (Bergamini et al., 2013), diversity of livelihoods and diversity of the main employing industries (Ross et al., 2010). Of particular interest here is the diversity represented by mixed economies where one part can be represented by household income, but where non-market activities are not typically assessed because lacking exchange in easy to measure monetary terms, there is little readily available data.

The pool of available resources related to livelihoods is one key dimension considered for defining resilience indicators (e.g. Magis, 2010; Bergamini et al., 2013). It is also referred to using terminology such as assets (FAO, 2010; IFRC, 2012) or capitals (Sherrieb et al., 2010; Morrone et al., 2011). Examples of operationalized indicators include employment ratio (FAO, 2010), socio-economic status of the population (Ross et al., 2010), land owned (FAO, 2010), and percentage of community members that can access grants and loans (IFRC, 2012). Indicators often privilege quantity, that is, more of something is better (Jordan and Javernick-Will, 2012). However, other characteristics can also be assessed, such as adequacy and access to resources and infrastructure (FAO, 2010; Ross et al., 2010).

8.6 Indications of resilience in the Barents area

8.6.1 Analysis through case studies

As already noted, the resilience indicators framework is strongly rooted in previous empirical research. It has also proven to resonate well with the types of concern expressed in consultative processes both within the region (see Chapters 5) and elsewhere (for example, consultations carried out in the Baffin Bay / Davis Strait region). This section adds substance to the framework by using it to analyze five case studies in the Barents area that have been previously published and/or developed by local experts. Four of the case studies were qualitatively analyzed using the structure presented in Table 8.3 with the fifth summarized in narrative form. Boxes 8.1 to 8.5 present summaries of this exercise; further details are available in the appendix to Chapter 8 in the electronic version of this report.

Table 8.3 Analytical template for resilience assessment.

Case study title and summary			
	Livelihoods	Knowledge/learning	Self-organization
Diversity			
'Embracing change'			

Box 8.1 Case study: Resilience of social-ecological systems of reindeer-herding nomads in northwestern Russia

Forbes (2013) analyzed the resilience of social-ecological systems of reindeer-herding nomads in the Nenets Autonomous Okrug (NAO) and the neighboring Yamal-Nenets Autonomous Okrug (YNAO), two regions of northwestern Russia in the Barents Sea region. These communities have remained relatively resilient in the face of a changing climate and land loss due to oil and gas infrastructures. Using the framework presented in Table 8.3 to analyze this research, clear and strong distinctions are apparent between factors related to livelihood, knowledge, and self-organization.

Climate change has caused many changes in the NAO and YNAO, including later first-freeze in autumn, earlier breakup of ice cover in spring, and more rain-on-snow events in winter. Rain-on-snow events reduce the amount of accessible pasture to reindeer. However, nomads have shown more concern about oil and gas infrastructure than about changes in climate. Oil and gas fields have an immediate effect in limiting access to pastures and fishing resources as well as restricting the free movement of animals, changes to which the nomads are much more vulnerable. Owing to their pastoral lifestyle, the social-ecological system of reindeer-herding nomads is robust against temporal variation (such as changes in seasonal climate) but is extremely vulnerable to spatial changes (such as changes in access). For example, if a large rain-on-snow event covers some pastures, nomads can normally lead their herds elsewhere. But if there are physical barriers such as oil pipelines, the adaptive capacity of the herd is significantly reduced.

Because the vast open tundra has been broken up by new oil and gas developments, collectively owned reindeer herds have begun to shift to smaller privately-owned reindeer herds. Smaller herds are more flexible and have an advantage in smaller territories and can migrate more quickly and easily when pastures are found inaccessible. However, the interests of private herd managers are "*poorly represented in development decisions since most of them do not belong to a registered land-using entity*". In an attempt to mitigate this, private herds have self-organized in the *obschchina* movement, where an *obshchina* is "*a registered union of private herders who wish to sell produce jointly*," and/or "*a social unit that helps strengthen the collectivity of an indigenous community when it…seeks to claim land against another actor*." Forbes believes that if the collective units continue to splinter into smaller, privately managed herds, the increase in heterogeneity is likely to facilitate resilience (all direct quotes from Forbes, 2013).

The nomadic peoples of the NAO and YNAO primarily relate their identity to herding reindeer, but reindeer are not their only source of livelihood. Diversity within their livelihood is simultaneously a factor of resilience but also exposes them to a wider range of impacts. Fish is a critical source of food for the nomads in summer when they do not slaughter reindeer, and they have sustainably fished for generations. However, the recent influx of temporary workers at oil and gas sites (who fish wastefully in the eyes of the nomads) are decreasing the availability of fish. Small game, such as geese, is another source of food for the nomads. The annual goose hunt in spring is also an important socio-cultural event as it enables sedentarized people to rejoin their relatives on the tundra.

To maintain their sustainable livelihoods, an extensive amount of knowledge about animal population ecology is transferred through the generations. In order to maintain the fish population, the nomads are considered in their fishing methods; they neither overfish nor underfish the population (underfishing could cause a population boom of fish that can damage the lake ecosystem). The nomads also only deal with predators or pests when they present a significant problem – for example, it is natural for the nomads to allow a wolf pack to take the occasional reindeer, but the nomads will kill a wolf that goes on a rampage and kills many reindeer. Most importantly, the nomads are knowledgeable about herd demographics and have agency to control it. They can control the number of breeding females and castrated males, which then controls the rate of growth of their herds. This understanding of population dynamics is complemented by a cultural spirit of stewardship.

School-age children (6 to 16 years old) of nomadic families are required to attend boarding school for most of the year and so are prevented from learning traditional knowledge during that period. However, in the YNAO especially, young people have continued to show interest in returning to and staying on the tundra as nomadic herders. The knowledge necessary to survive on the tundra cannot be learned at school and must be acquired during periods of intensive mentoring on the tundra.

These nomadic communities have been affected by contact with Soviet-era policy, showing cross-scale influences on self-organization. Most significantly, Soviet policy forced upon the nomads sedentarization (transitioning from a nomadic society to a lifestyle that remains in one place permanently) and collectivization (consolidation of individual landholdings, livestock, labor, and other assets into collective farms). These policies became more established in the NAO than the YNAO because of the actions of local Soviet bureaucrats. In the YNAO, the local Soviet bureaucrats conformed to Soviet policy on paper, but allowed the YNAO nomadic communities to maintain a traditional social organization and manage their herds according to their own timetables. Therefore, the nomads of the YNAO seem to be more resilient than those of the NAO, where there was a greater loss of tradition and recruitment of youth because of the stricter enforcement of Soviet collectivization of herds and sedentarization.

These reindeer-herding communities have remained resilient because of the diversity within their livelihoods (e.g. dependence on many types of animal, ability to break up into smaller herds) as well as their knowledge of sustainable animal population management. Temporal variability related to climate change has also proved little problem, with the herders far more affected by the spatial constraints created by oil and gas infrastructure. Forbes (2013) reported that herders remain confident in their abilities to manage the reindeer as long as they retain unfettered access to pastures and fish stocks remain viable and as long as they are allowed to use their own judgment and agency when it comes to day-to-day herding decisions.

Box 8.2 Case study: Resistance of the Semisjaur Njarg reindeer herding community to a proposed open-pit copper mine in Laver, northern Sweden

This case study (see Lawrence and Larsen, 2016) presents an examination of the resistance of the Semisjaur Njarg reindeer herding community in Norrbotten County, Sweden, to Boliden's proposed open-pit copper mine on the community's winter pastures in the area of Laver, near Älvsbyn in northern Sweden.

Reindeer husbandry is a traditional Sámi livelihood and all members of the Semisjaur Njarg Sámi community have a connection to reindeer herding. Some are more or less full-time herders, whereas others are primarily active during the intense periods of the reindeer herding yearly cycle, such as calf-marking in summer or slaughters in autumn. This section reviews key aspects of the resistance that the community exhibited in response to the experience of an external threat, adding to a community-based impact assessment undertaken by the authors together with the community during 2014 and 2015.

Traditional livelihoods practiced in the landscape are diverse, and include reindeer herding, fishing, and hunting. Reindeer herding is not only a livelihood, but a dynamic cultural practice that offers a vital part of the life of families and community, keeps culture vibrant and connects people to the landscape. Through the customary use of their traditional lands, the community has also earned property rights to those same lands. However, these property rights are often unrecognized by Swedish environmental courts and government authorities in decisions concerning industrial developments on Sámi lands This has contributed to reindeer herding becoming increasingly less economically viable, through among other things, higher costs associated with disturbances from industrial activities, infrastructure and tourism. As a result, this semi-subsistence economic activity is often complemented by family members taking various part-time jobs, in order to maintain the family's economic viability (Lawrence and Åhrén, 2016).

Reindeer herding in Semisjaur Njarg is critically dependent on access to a diverse landscape with interconnected pastures in both mountains and forest regions. The winter pasture is the bottleneck in the seasonal migrations of the herds, because this is where pastures are most limited and external pressures – in terms of industrial developments and infrastructure – are greatest. This dependence on landscape connectivity and diversity is becoming ever more crucial as climate variability is exacerbated: warmer summers heighten the plague of insects and unpredictable freeze-thaw patterns in winter that 'lock' the vegetation and hinder the herds from grazing on lichen underneath the snow (e.g. Löf et al., 2012). Moreover, developments in the mining industry, wind power sector, and forestry increasingly reduce the adaptive capacity of the community by constraining it spatially. In many parts of Swedish Sápmi, reindeer herding communities have in recent years seen an almost exponential increase in development pressure and a general inability of government regulation to contain the unintended cumulative impacts on Sámi communities (Larsen et al, 2016).

Boliden, a mining company, claimed that its proposed open-pit copper mine near Laver could co-exist with the Sámi community's herding activities. This claim was made despite the company acknowledging that several herders would be forced out of reindeer husbandry as a direct result of the extensive loss of pastures due to the mine. This type of result is not unusual for Environmental Impact Assessments (EIAs) in Swedish Sápmi. Regarding potentially unavoidable impacts, such as loss of pastures, the Boliden EIA concluded that: "*the consequences can normally be alleviated through the developer adopting certain compensatory measures...*" (Lindeström and Eriksson, 2015:80). The compensatory measures suggested by the company included extensive artificial feeding of reindeer and that those reindeer herders forced out of reindeer husbandry could be offered alternative employment by Boliden, presumably at the proposed mine. Yet, the long-term impacts of the compensatory measures themselves were largely unaddressed in the company EIA.

In contrast, the community's own impact assessment (Lawrence and Larsen, 2016) made a fundamentally different assessment of the long-term impacts of the mine and concluded that the community would become dependent on a corporate-sponsored mode of reindeer farming, based on artificial feeding, rather than free-grazing, which is inconsistent with traditional Sámi culture. As the chairman noted: "*Then it's just not reindeer herding anymore!*". As such, the next generation of herders would be forced to engage in a form of herding so far from the traditional Sámi livelihood that it would lead to the gradual loss of traditional knowledge and the extinction of Pite Sámi language (a severely threatened minority language). Moreover, the forced dislocation of reindeer herders from their traditional livelihoods would lead to the loss of their culture and traditional lands (and hence, their property rights).

The disparity between the two impact assessments demonstrates the inherently political nature of the EIA and permit process in which competing views struggle for primacy: in essence the two EIAs offered competing claims to truth and were largely based on incompatible worldviews. One useful illustration of this point arose in a meeting between the community and the mining company regarding the company's EIA process. Here, the content of the EIA was contested, with the community pressing the company to provide greater detail about the precise nature of the expected impacts and the company unwilling to do this. However, after a long debate, one company representative suddenly changed approach, saying: "*We will gladly supplement the EIA* [with more detailed information regarding reindeer herding]. *Anything that helps us get a* [mining] *permit is good*".

The community thus concluded that the company welcomed facts and details as a part of its EIA process, as long as these were consistent with the interests of the company. This serves as a reminder that proponent-driven impact assessments invariably have development approval as a main goal (Michell and McManus, 2013). In contrast, the insights from Semisjaur Njarg's own impact assessment provided arguments to


imageBROKER / Alamy Stock Photo

Ore mine in northern Sweden

challenge the myth of co-existence and adaptability espoused in company EIAs and permit decisions. When permit authorities and courts grant mining permits in Sápmi it is commonly assumed that mining and reindeer herding can co-exist (see, for example, Supreme Court decision HFD-443-11 Vapsten vs Nickelmountain). This assumption builds on a well-established and widely held myth of the continuous adaptability and infinite resilience of Sámi communities and reindeer herding in the face of industrial expansion (e.g. Löf, 2014:63). Yet, this myth is spun with a narrative that expects communities to simply accept change imposed from outside. It also requires communities to participate in permit and EIA processes that integrate their knowledge into an EIA method that claims to be value neutral and technical, yet which remains laden with cultural and political assumptions about development as inevitable and necessarily positive. Arguably, this is in strong contrast with the view of the Semisjaur Njarg community and other Sámi communities that want a greater say in steering their own path into the future through use of their own traditional knowledge, which is inherently situated and connected to place (in relation to resilience theory see also Arora-Jonsson, 2016).

The community-based impact assessment became embroiled in a larger process of self-organization and learning for the community. A positive outcome was how the assessment process supported Semisjaur Njarg community members to come together in ways that they would probably not have done, to discuss and construct ideas about the potential impacts of the mine. For instance, it was only at a workshop organized in connection with the community's own impact assessment, that community members were for the first time able to discuss the mine as a collective. Equally important, the community also invited representatives from Boliden and were for the first time able to ask questions directly to the company about the proposed project.

At the time of writing, the company's permit application for a mining concession was still with the Mining Inspectorate. So although it is too early to know which path the permit process will take, it is worth noting that the County Board did reject the mine proposal, seemingly incorporating some of the community's arguments into their own comments to the Mining Inspectorate. The County Board of Norbotten's (2015) pronouncement contained several arguments that were similar to those of the community; for instance adopting a view on a more extensive loss of pasture, partly based on research on buffer zones, as argued by the community-based impact assessment.

As with any form of resistance, Semisjaur Njarg's self-organization in response to the threat posed by Boliden's planned mine demonstrates the community's resilience. However, the space within which this resistance was enacted was narrow, constrained and ultimately shaped by a Swedish policy and legal regime that still reflects its colonial origins of decades ago within which Sámi rights receive little recognition. Moreover, the concern remains that this community-based impact assessment was in some ways setting a precedent for a non-viable path for communities. The work behind the community's 'shadow EIA' was extremely demanding on time and financial resources, for both the community and the researchers. The financial resources necessary are not currently available for communities to adopt such a strategy as a normal alternative. And even if they were, most communities would not have the time or personnel capacity to commit to such a process. Thus, this approach is not envisioned as a viable path for Sámi communities in the future; rather, it constitutes a crisis response given the disabling conditions in the planning and permit system today in Sweden.

Box 8.3 Case study: Fishing-dependent Sámi coastal settlements of Finnmark, Norway

Broderstad and Eythórsson (2014) analyzed the collapse and subsequent recovery of a social-ecological system in two fishing-dependent coastal settlements of Finnmark, Norway, both primarily comprising Sámi residents. Their analysis fits the framework shown in Table 8.3, but their work presents more information on livelihoods and self-organization and less information on knowledge and learning. In this case study, the capacity for self-organization was a tool to help achieve resilience in a traditional livelihood. Separating these elements made it easier to analyze the nature of resilience in the two communities, especially as they experienced significant ecological changes at different times.

The social-ecological system studied here is the fishing of coastal cod (*Gadus morhua*) in two fjords, Várjat vuotna fjord and Porsáŋgu fjord, which connect to the Barents Sea. Along these two fjords are rural coastal settlements that have been historically dependent on fishing cod and other marine resources. On the ecological side of the system, the cod population in Finnmark fjords collapsed in the 1980s due to multiple factors. One of the primary factors was an invasion of harp seals (*Pagophilus groenlandicus*) from the Barents Sea, which devastated cod populations in the fjords. The invasion took place in Várjat vuotna fjord in 1979 and then spread to Porsáŋgu fjord in 1987. The cod populations crashed within a year of each invasion. Although what drove the harp seal invasions is unclear, they could have been caused by overfishing of cod in the Barents Sea, which would have forced the seals to move from the sea to the fjords in search of food. Following the crash in the cod population, the number of fishers in these communities declined, capturing the impact of ecological changes on livelihoods.

In addition to the changing ecological conditions (i.e. cod populations), there were also changes in governance that contributed to the decrease in number of fishers. Individual Vessel Quotas (IVQs) were implemented in 1990 as a means to alleviate pressure on the cod populations, but the IVQs systematically excluded small-scale fishers that were already suffering the consequences of the harp seal invasions. A government-sponsored buyout program that ran from 2002 to 2009 also removed many small fishing vessels from the fleet in Finnmark. These examples show cross-scale impacts of higher-level policy on local communities.

Nevertheless, these communities exhibited resilience and the fishing communities have begun to rebound; starting in 1990 in Várjat vuotna fjord and in 2010 in Porsáŋgu fjord. Several factors have contributed to this resilience, as highlighted by Broderstad and Eythórsson (2014).

First, in terms of diversity within livelihoods, Sámi communities traditionally deal with poor fishing seasons by diversifying their livelihood sources. They rely more heavily on subsistence self-employment or seeking employment in other sectors during

Box 8.4 Case study: Traditional activities and seasonal movements in the Ponoi basin, Murmansk Russia

This case study (Mustonen, T., pers. comm., 2016) presents an analysis of a rich social-ecological region with intact ecosystems, struggling to accommodate economic and administrational reforms, while maintaining traditional activities and seasonal movements in the Ponoi Watershed, Murmansk Russia (Mustonen and Mustonen, 2016).

The Ponoi catchment has been described as the last wilderness of northern Europe with intact aquatic ecosystems and a small human footprint (Mustonen and Feoderoff, 2015). Preserving the natural state of the Ponoi basin contributes to the biodiversity, climate security and socio-cultural diversity of the European North. The catchment is also home to the Indigenous Eastern Sámi (Ter), the local Komi (Fryer and Lehtinen 2013), Russian Pomor and other groups, spread out across the villages of Krasnochelye, the seasonal settlement of Chalme-Varre, Kanevka, and the coastal Sosnovka outside the basin. Traditional livelihoods include reindeer herding, fisheries, hunting, and gathering. The settlements were created by the arriving Komi in the 1800s who mixed with the existing Sámi siidas, which were amalgamated into Soviet towns during the 1930s. Some of the villages were abandoned in the 1960s due to the Soviet policy of settlements without perspectives (Mustonen and Mustonen, 2011).

Despite the low number of residents in the villages, several ethnic identities are present – Komi, Sámi, Russian Pomor, and others. While the Komi have their own national organizations, the Sámi are recognized as federal indigenous peoples, a source of tension for rights and privileges, whether imagined or real. The villages today, despite high levels of alcoholism, unemployment and other social issues, portray examples of traditional, monumental pine log buildings, including new ones, and preservation of traditional practices. Reindeer herding has seen the collapses since 1990s also seen elsewhere, but has also been a vehicle for the obschina, Sámi indigenous clan communities, that have tried to re-define and reform small scale herding in the Ponoi basin. These rights were both embraced and sometimes abused by the local Sámi, causing trouble locally with the Komi and other residents. However, they have also provided new opportunities for Sámi self-organization post 2002. Most of the obschina were lost by 2016.

The Ponoi villages reflect a range of demographic trends. In post-Soviet Russia there is an outflow of residents from these fly-in communities. Tourists arrive for hunting (and sometimes poaching) and Atlantic salmon fisheries. Residents in the villages preserve and maintain semi-nomadic cycles of reindeer herding and seasonal movements and settlements along the Ponoi River. During summer months, the populations of villages like Kanevka and Sosnovka expand, as people spend their summers in villages. All of these preserved seasonal movements and presences maintain the knowledge networks locally. In early 2015, there was a surprise initiative during community workshops, which entailed a return to the abandoned settlement of Ponoi (Mustonen, 2015) for a re-birth of traditional lifestyles and culture.

Communities in the Ponoi basin have also been influenced by the broader, contextual changes of governance over the past 20 years. Following the collapse of state support mechanisms bad fishing years. This diversification occurs, however, at the household scale, for example as the result of action taken by individual households rather than a coordinated shift within the community. Broderstad and Eythórsson (2014) emphasized that diversifying income sources at the household level is a short-term coping mechanism to deal with seasonal fluctuations, and not a conscious long-term adaptation strategy.

Second, in 1989 there was a major political development that influenced self-organization of these communities: the establishment of the Sámi Parliament. The Sámi Parliament quickly became an important institutionalized voice for the Sámi people to the Norwegian national government. It also supported resilience in the fjord communities by offering accessible loans and grants to residents, such as for buying a small fishing vessel. Consultations with and points raised by the Sámi Parliament have also concluded in new fishing management regimes that benefit the fjord communities. For example, an agreement between the Sámi Parliament and the Norwegian government led to higher quotas for small-scale, open group fishers in the Sámi business development area, improving livelihood opportunities through fishing for many Sámi. It is important to note that although the Sámi Parliament has been modestly successful in representing Sámi concerns, their success is highly dependent on the political agenda at the national level, emphasizing that cross-scale interactions are still key factors influencing the capacity for self-organization.

Coastal Sámi Resource Centre

Sea sámi community Smørfjord, Finnmark, Norway

and systems, there was an outflow of people and capital from the region and the villages were left to find their own way. Post-Soviet realities are eroding the human settlements of Krasnochelye, seasonal settlement of Chalme-Varre, Kanevka, and the coastal Sosnovka but are also providing new, emerging land use patterns of seasonality and territoriality due to their extreme remoteness and total dependency on the surrounding ecosystems for food security. However, this also maintains the traditional knowledge systems that have been eroded or lost in many other parts of the Arctic. One central issue for endemic resilience is that the villages, even in the Soviet era, chose not to have a road, instead requiring visitors to fly in. This was a conscious choice by the settlements after they had witnessed the socio-economic change and havoc caused by road access to the district center, Lovozero (Mustonen and Mustonen, 2011). It seems therefore that even under Soviet rule these remote villages were able to preserve and exercise their autonomy and endemic resilience. This has contributed to the social cohesion and sense of community, although it also represents a barrier to services, goods, jobs and modernity. If this reduces the overall diversity of livelihood options in the form of reduced space for conventional economic activity, it could also reduce resilience.

Since the mid-1990s, the Ponoi River and its tributaries have been the target of international salmon tourist companies (Arctic Council, 2013). These companies arrived to 'rent' large tracts of the Ponoi and sub-catchment areas for highly lucrative Atlantic salmon fisheries. The local view remains that this was an infringement both by the companies and by the regional administration, i.e. local rights to fish and waters have eroded. The companies maintain that they provide socio-economic benefits to the local residents and that there is no equity problem. The activities have been a source of equity discussions as the companies use private security assets and checkpoints to control and limit local access to the Atlantic salmon fisheries (Mustonen and Mustonen, 2011; Mustonen and Feodoroff, 2013, 2014, 2015). While this tourist fishery remains contested, no significant changes in status or practice are expected.

The traditions and knowledge of the Ponoi villages in the post-Soviet period were surveyed by Mustonen and Mustonen (2011) and Mustonen and Feodoroff (2015), limnological data for this period were also reviewed. That some of the most problematic pollutants in the Arctic – polychlorinated biphenyls, phenol, mercury, oil and other harmful substances – could be found shows a need to examine the impacts of the Soviet legacy on the freshwaters and terrestrial environment of this area.

In the past decade, there have been drivers of stability as well as the erosion of rights, cultural processes and traditional economies. Salaries and state support systems, such as flights to the villages had largely stabilized through 2014. A fear currently held by many in the villages is another round of village closures, such as occurred in the 1960s, in favor of new mining and industrial developments. Since 2014, the negative impacts of the economic decline are again forcing local dependence on the surrounding ecosystems for food security.

Box 8.5 Case study: Skolt Sámi in the Näätämö basin, northern Finland

This case study (Mustonen and Feodoroff, 2013; Mustonen, 2015) concerns the Skolt Sámi in the Näätämö basin in northern Finland, where initiatives ranging from language nests to rights, co-management, climate change and preservation of traditions have been undertaken.

The Skolt Sámi arrived in the Atlantic Salmon-rich basin of the Näätämö river in the 1940s, after their traditional lands had been ceded to Russia in the Finnish-Russian wars of 1939–1944. Historically, another tribe of Skolts had occupied this basin, but assimilated with the Norwegians and Finns in the late 1800s. Despite the trauma of the re-location, the families reinstated their siida family use areas in the Näätämö basin – preserving their Skolt Sámi traditional indigenous governance, the siida system and the associated village council. (A siida is the endemic community level organization unit of the Sámi that has been lost in most of their current living area, but preserved as a governance regime among the Skolts. Siida is used by North Sámi in a modern context to refer to a use area in herding, but here refers to the socio-political historical system of the Sámi society.) Tucked away during decades of the Cold War, the Skolts emerged in the early 1990s to discuss revitalizing their culture, language and traditions. The central Skolt community is the Sevettijärvi village with 500 inhabitants. Traditional economies are reindeer herding, fisheries, and some hunting and gathering economies. There are specific laws within Finland that address the Skolts, putting them in a special legal category of their own separate from the Inari and North Sámi of Finland.

The Skolts witnessed an out-migration in the 1950s and 1960s from Sevettijärvi, and since the early 1970s there has been a process of addressing cultural and language loss. The first Skolt 'ABC' books were developed in the 1970s. Their traditional economies have been maintained to this day. In the 1990s and 2000s, the Skolts initiated wide-ranging cultural documentation and oral history gathering projects with partners covering, for example, traditional songs, language, and handicrafts, mapping of land use and occupancy, and traditions and knowledge relevant for climate variability and change. The Skolts have been the subject of much research, and have successfully emerged to create research partnerships on water quality monitoring and co-management. In an acknowledgement of their historic presence on the land, their Gramota edicts, were recently accepted to the UNESCO Memory of the World Register, a landmark decision for all Arctic indigenous peoples. The Gramota edicts were issued by the Russian Czars between the 17th and 19th centuries, and documented Sámi rights and privileges to lands and waters.

In the period 2009–2015 and after much community self-reflection, the Skolts developed the first co-management project in Finland to address the impacts of climate change on the Näätämö river and the Atlantic salmon (*Salmo salar*). This included an assessment of salmon dynamics in the Barents Sea and beyond as well as the Norwegian side of the Näätämö basin, with the Kven minority as a partner. The process has also looked at historical damage created by the state forestry company Metsähallitus to the waterways, and a cross-disciplinary discussion with scientists on water quality and future resilience. The result has been a very hands-on method to increase the Näätämö and Skolt resilience, including the harvest of predator fish, plans to restore the Vainosjoki sub-catchment areas, and rigorous monitoring of water and

Atle Staalesen

At the opening of the Skolt Sami museum in Neiden, Norway, June 2017 fish quality utilizing Sámi knowledge and science. This model contributes to addressing cross-scale issues in the Barents area between Finland and Norway and in the local context.

Over the past 20 years, there have been three major changes in the overall governance context. These include the breakup of the Soviet Union, and Finland joining the European Union in the 1990s. This allowed Skolts to visit their traditional lands and re-instate contact with relatives in the former Soviet Union. It also provided for the expansion of Sámi rights, such as the creation of the Sámi Parliament. Between 2001 and 2009, there was a rapid development of rights, language nests (an approach to language revitalization in which older speakers take part in early-childhood education), cultural organizations, and discourses to assert and mainstream indigenous rights. Since 2010, however, the Skolts have seen some erosion of this earlier progress. The government of Finland has shown less interest in considering further development of rights, with policies oriented towards natural resources perceived to be having a negative impact on the Näätämö basin and on Skolt Sámi resilience through infrastructure and potential mining. At the same time, however, the Skolts have implemented the very first co-management plan for the Näätämö watershed. Their participation in discussions concerning the ratification of the Indigenous and Tribal Peoples Convention, and seeing their Gramota edicts registered at UNESCO, has shifted their focus to international fora for cooperation while the domestic situation is considered less favorable. (The Indigenous and Tribal Peoples Convention, 1989 is an International Labour Organization Convention, also known as ILO-convention 169, or C169. It is the major binding international convention concerning indigenous peoples, and a forerunner of the Declaration on the Rights of Indigenous Peoples.)

The Skolts are today seen to lead many discussions of the new indigenous self-governance in Finland. Their cultural identity continues to be supported by Sámi traditional indigenous governance, the siida system and the associated village council, and each family preserving a certain degree of autonomous decision-making. In addition to the village council there are powerful cultural associations, such as the Saa'mi Nue'tt. The reindeer-herding cooperatives of the region may also be seen as vehicles of limited self-governance.

Knowledge gaps are a limiting factor for learning from the past to improve going forward. Climate change is considered a major driver of change in the Näätämö basin, but future impacts are still unclear. Research is needed to understand and document developments between 1948 and 1990, when many aspects of the basin were managed by state organizations, which created ecological imbalances. Collecting the oral histories for the Skolts would help provide a more holistic view of developments in this period.

The Skolt Sámi are a resilient people. Despite a very difficult period between 1917 and 1990 they survived, and since the 2000s have pursued many cutting-edge resilience initiatives. Although they are unable to influence macro-economic drivers such as mining and infrastructure projects directly, they have taken their case to the media and the research world, and have so far preserved their territories relatively intact. This is largely due to leadership by Sámi women, who have led the process.

8.6.2 Way forward for resilience indicators: reflections from the case studies

Although the resilience indicators framework has only been discussed here in relation to indigenous communities, in practice the framework could equally well be applied to any Arctic community. History, traditions, livelihood activities and connection to nature may differ widely between different communities in the Arctic, but the application of the framework need not be limited by these factors.

The true test for the type of framework proposed here is through a series of applications at the local level, with skilled facilitators and engaged community members. Here the key questions would focus on what the activities/categories represented in the case study template (see Table 8.3) mean to the community in concrete and tangible terms, and how the community itself would assess and indicate the general condition of these ingredients. Are diverse livelihood activities pursued in a given community? What is the balance between conventional and non-market livelihood activities? How is traditional or local knowledge perceived in comparison with conventional education and knowledge? Is there sufficient flexibility and support at the local level to pursue innovative responses to local and regional challenges? And if so, does the community possess the social cohesion and local practices required to make use of this flexibility?

The likely responses to these general questions, and the tangible terms and metrics used to assess status and trends will probably vary from one community to the next depending on local circumstances. More general insights that could be derived from these responses are likely to be more comparable and generalizable at higher scales. And the assessment activity itself can be expected to constitute a resilience-building exercise as community members gain experience in engaging in these kinds of shared assessment process.

References

AHDR, 2004. Arctic Human Development Report. Stefansson Arctic Institute, Akureyri, Iceland.

Allen, C.R., D.G. Angeler, A.S. Garmestani, L.H. Gunderson and C.S. Holling, 2014. Panarchy: theory and application. Ecosystems, 17:578-589.

Arctic Council, 2013. Arctic Resilience: Interim Report 2013. Stockholm Environment Institute and Stockholm Resilience Centre.

Arctic Council, 2016. Arctic Resilience Report. M. Carson and G. Peterson (eds). Stockholm Environment Institute and Stockholm Resilience Centre, Stockholm.

Arora-Jonsson, S., 2016. Does resilience have a culture? Ecocultures and the politics of knowledge production. Ecological Economics, 121:98-107.

Baez, J.E., A. de la Fuente and I. Santos, 2010. Do natural disasters affect human capital? An assessment based on existing empirical evidence. IZA Discussion Paper 5164. Institute for the Study of Labor (IZA). https://ideas.repec.org/p/iza/izadps/dp5164.html.

Baggio, J.A., K. Brown and D. Hellebrandt, 2015. Boundary object or bridging concept? A citation network analysis of resilience. Ecology and Society, 20: doi:10.5751/ES-07484-200202.

Bergamini, N., R. Blasiak, P. Eyzaguirre, K. Ichikawa, D. Mijatovic, F. Nakao and S. Subramanian, 2013. Indicators of resilience in socio-ecological production landscapes (SEPLs). UNU-IAS Policy Report. United Nations University (UNU) Institute of Advanced Studies.

Berkes, F. and C. Folke, 1998. Linking Sociological and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience. Cambridge University Press.

Berkes, F. and T. Henley, 1997. Co-management and Traditional Knowledge: threat or opportunity? Policy Options, 18:29-31.

Berkes, F., P.J. George, R.J. Preston, A. Hughes, J. Turner and B.D. Cummins. 1994. Wildlife harvesting and sustainable regional native economy in the Hudson and James Bay lowland, Ontario. Arctic, 47:350-360.

Berman, M., C. Nicolson, G. Kofinas, J. Tetlichi and S. Martin, 2004. Adaptation and sustainability in a small Arctic community: results of an agent-based simulation model. Arctic, 57:401-414.

Bersaglieri, T., P.C. Sabeti, N. Patterson, T. Vanderploeg, S.F. Schaffner, J.A. Drake, M. Rhodes, D.E. Reich and J.N. Hirschhorn, 2004. Genetic signatures of strong recent positive selection at the lactase gene. American Journal of Human Genetics, 74:1111-1120.

Binder, C.R., J. Hinkel, P.W.G. Bots and C. Pahl-Wostl, 2013. Comparison of frameworks for analyzing social-ecological systems. Ecology and Society, 18: doi:10.5751/ES-05551-180426.

Boulanger, P.-M., 2007. Political uses of social indicators: Overview and application to sustainable development indicators. International Journal of Sustainable Development, 10:14-32.

Brand, F.S. and K. Jax, 2007. Focusing the meaning(s) of resilience: resilience as a descriptive concept and a boundary object. Ecology and Society, 12: www.ecologyandsociety.org/vol12/iss1/art23/

Broderstad, E.G. and E. Eythórsson, 2014. Resilient communities? Collapse and recovery of a social-ecological system in Arctic Norway. Ecology and Society, 19: doi.org/10.5751/ES-06533-190301

Brown, K., 2014. Global environmental change I: A social turn for resilience? Progress in Human Geography, 38:107-117.

Burns, T.R. and T. Dietz, 1992. Cultural evolution: Social rule systems, selection and human agency. International Sociology, 7:259-283.

Cabell, J.F. and M. Oelofse, 2012. An indicator framework for assessing agroecosystem resilience. Ecology and Society, 17: doi.org/10.5751/ES-04666-170118

Carayannis, E.G., A. Kaloudis and Å. Mariussen (eds.), 2008. Diversity in the Knowledge Economy and Society: Heterogeneity, Innovation and Entrepreneurship. GWU/ NIFU STEP Series on Science, Innovation, Technology and Entrepreneurship. Edward Elgar.

Carson, M., 2008. Of mind and matter: policy paradigms and institutional design. In: Flam, H. and M. Carson (eds.), Rule System Theory: Applications and Explorations. pp. 171-190. Peter Lang.

Carson, M. and M. Sommerkorn et al. (C. Behe, S. Cornell, J. Gamble, T. Mustonen, G. Peterson and T. Vlasova), 2016. An Arctic resilience assessment. In: Arctic Resilience Report 2016. pp. 2-26. Stockholm Environment Institute and Stockholm Resilience Centre.

Chambers, R. and G.R. Conway, 1991. Sustainable rural livelihoods: practical concepts for the 21st century. IDS Discussion Paper 296. Institute of Development Studies, Brighton, UK.

Chapin, F.S. III, C. Folke and G.P. Kofinas, 2009. A framework for understanding change. In: F.S. Chapin, III, G.P. Kofinas and C. Folke (eds.). Principles of Ecosystem Stewardship. Resilience-Based Natural Resource Management in a Changing Climate. pp. 3-28. Springer.

County Board of Norbotten, 2015. Yttrande Avseende Bearbetningskoncession För Laver K Nr 1, Älvsbyns Kommun. Länsstyrelsen Norrbotten [Decision regarding mining concession for Laver K NR 1, Älvsbyns municipality, county of Norrbotten].

Davidson, D.J., 2010. The applicability of the concept of resilience to social systems: some sources of optimism and nagging doubts. Society and Natural Resources, 23:1135-1149.

Davidson, J.L., I.E. van Putten, P. Leith, M. Nursey-Bray, E.M. Madin and N.J. Holbrook, 2013. Toward operationalizing resilience concepts in Australian marine sectors coping with climate change. Ecology and Society, 18: doi:10.5751/ES-05607-180304

Dietz, T. and T.R. Burns, 1992. Human agency and the evolutionary dynamics of culture. Acta Sociologica, 35:187-200.

Dietz, T., T.R. Burns and F.H. Buttel, 1990. Evolutionary theory in sociology: an examination of current thinking. Sociological Forum, 5:155-171.

Elmqvist, T., C. Folke, M. Nyström, G. Peterson, J. Bengtsson, B. Walker and J. Norberg, 2003. Response diversity, ecosystem change, and resilience. Frontiers in Ecology and the Environment, 1:488-494.

Fabinyi, M., L. Evans and S.J. Foale, 2014. Social-ecological systems, social diversity, and power: insights from anthropology and political ecology. Ecology and Society, 19: doi:10.5751/ ES-07029-190428

FAO, 2010. Measuring Resilience: A Concept Note on the Resilience Tool. Food and Agruiculture Organization of the United Nations (FAO).

Filotas, E., L. Parrott, P.J. Burton, R.L. Chazdon, K.D. Coates, L. Coll, S. Haeussler, K. Martin, S. Nocentini, K.J. Puettmann, F.E. Putz, S.W. Simard and C. Messier, 2014. Viewing forests through the lens of complex systems science. Ecosphere, 5:1-23.

Folke, C., 2004. Traditional knowledge in social–ecological systems. Ecology and Society, 9: http://www.ecologyandsociety.org/vol9/iss3/art7/

Folke, C., 2006. Resilience: the emergence of a perspective for social–ecological systems analyses. Global Environmental Change, 16:253-267.

Folke, C., J. Colding and F. Berkes, 2003. Synthesis: building resilience and adaptive capacity in social-ecological systems. In: Navigating Social-Ecological Systems. pp. 352-387. Cambridge University Press.

Folke, C., S. Carpenter, B. Walker, M. Scheffer, T. Elmqvist, L. Gunderson and C.S. Holling, 2004. Regime shifts, resilience, and biodiversity in ecosystem management. Annual Review of Ecology Evolution and Systematics, 35:557-581.

Folke, C., S.R. Carpenter, B. Walker, M. Scheffer, T. Chapin and J. Rockstrom, 2010. Resilience thinking: integrating resilience, adaptability and transformability. Ecology and Society, 15: http://www.ecologyandsociety.org/vol15/iss4/art20/

Forbes, B.C., 2013. Cultural resilience of social-ecological systems in the Nenets and Yamal-Nenets Autonomous Okrugs, Russia: A focus on reindeer nomads of the tundra. Ecology and Society, 18: doi:10.5751/ES-05791-180436

Fryer, P., and A. Lehtinen, 2013. Iz'vatas and the diaspora space of humans and non-humans in the Russian North. Acta Borealia, 30:21-38.

Fumagalli, M., I. Moltke, N. Grarup, F. Racimo, P. Bjerregaard, ME. Jørgensen, T.S. Korneliussen, Pascale Gerbault1, L. Skotte, A. Linneberg, C. Christensen, I. Brandslund, T. Jørgensen, E. Huerta-Sánchez, E.B. Schmidt, O. Pedersen, T. Hansen, A. Albrechtsen and R. Nielsen, 2015. Greenlandic Inuit show genetic signatures of diet and climate adaptation. Science, 349:1343-1347.

Gouldner, A.W., 1980. Alienation from Hegel to Marx. In: The Two Marxisms: Contradictions and Anomalies in the Development Theory. pp. 177-198. Oxford University Press.

Gual, M.A. and R.B. Norgaard, 2008. Bridging ecological and social systems coevolution: A review and proposal. Ecological Economics, 69:707-717.

Hamilton, L.C., 2007. Climate, fishery and society interactions: observations from the North Atlantic. Deep Sea Research II: 54:2958-2969.

Henry, C., S. Meakin and T. Mustonen, 2013. Indigenous perceptions of resilience. In: Arctic Resilience Interim Report 2013. Stockholm Environment Institute and Stockholm Resilience Centre.

Hezri, A.A. and S.R. Dovers, 2006. Sustainability indicators, policy and governance: Issues for ecological economics. Ecological Economics, 60:86-99.

Holling, C.S., 1973. Resilience and stability of ecological systems. Annual Review of Ecology and Systematics, 4:1-23.

Hooghe, L. and G. Marks, 2001. Types of Multi-Level Governance. http://eiop.or.at/eiop/pdf/2001-011.pdf.

Howard, A. and F. Widdowson, 1996. Traditional knowledge threatens environmental assessment. Policy Options, 17:34-37.

Howe, E.L., 2009. Patterns of migration in Arctic Alaska. Polar Geography, 32:69-89.

Huskey, L., M. Berman and A. Hill, 2004. Leaving home, returning home: migration as a labor market choice for Alaska Natives. Annals of Regional Science, 38:75-92.

IFRC, 2012. Characteristics of a Safe and Resilient Community: Community Based Disaster Risk Reduction Study. International Federation of Red Cross and Red Crescent Societies (IFRC).

Innes, J.E. and D.E. Booher, 2000. Indicators for sustainable communities: a strategy building on complexity theory and distributed intelligence. Planning Theory and Practice, 1:173-186.

Janssen, M.A. and M. Scheffer, 2004. Overexploitation of renewable resources by ancient societies: sunk cost effects as explanation for their collapse. Ecology and Society, 9: http://www.ecologyandsociety.org/vol9/iss1/art6/

Jansson, R., C. Nilsson, E.C.H. Keskitalo, T. Vlasova, M.-L. Sutinen, J. Moen, F.S. Chapin III, K. Bråthen, M. Cabeza, T.V. Callaghan, B. Van Oort, H. Dannevig, I.A. Bay-larsen, R.A. Ims and P. Aspholm, 2015. Future changes in the supply of goods and services from natural ecosystems: prospects for the European North. Ecology and Society, 20: doi:10.5751/ES-07607-200332.

Jarvis, D., C. Ringler, A. Farrow, A. Gassner and K.D. Shepherd, 2013. Review of the evidence on indicators, metrics and monitoring systems. Department for International Development, UK Government. http://r4d.dfid.gov.uk/Output/192446/Default.aspx.

Jasanoff, S., 2004. The ideom of co-production. In: Jasanoff, S. (ed.), States of Knowledge. The Co-production of Science and Social Order. pp. 1-12. Routledge.

Jasanoff, S. and M. Martello (eds.), 2004. Earthly Politics: Local and Global in Environmental Governance. MIT Press.

Johnson, N., C. Behe, F. Danielsen, E.M. Krummel, S. Nickels and P.L. Pulsifer, 2016. Community-based monitoring and indigenous knowledge in a changing Arctic: a review for the sustaining Arctic observing networks. Inuit Circumpolar Council. www.inuitcircumpolar.com/community-based-monitoring.html

Jordan, E. and A. Javernick-Will, 2012. Measuring community resilience and recovery: a content analysis of indicators. Construction Research Congress, 2012:2190-2199.

Klein, R.J.T, G.F. Midgley, B.L. Preston, M. Alam, F.G.H. Berkhout, K. Dow and M.R. Shaw, 2014. Adaptation opportunities, constraints, and limits. In: Field, C.B., V. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, et al. (eds.), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, pp. 899-943. Cambridge University Press.

Kofinas, G.P. and F.S. Chapin III, 2009. Livelihoods and human well-being during social-ecological change. In: Folke, C., G.P. Kofinas and F.S. Chapin (eds.), Principles of Ecosystem Stewardship. pp. 55-75. Springer.

Kofinas, G.P., D. Clark and G.K Hovelsrud, 2013. Adaptive and transformative capacity. In: Arctic Resilience Interim Report 2013. pp. 73-93. Stockholm Environment Institute and Stockholm Resilience Centre.

Krasny, M.E., C. Lundholm and R. Plummer, 2010. Resilience in social–ecological systems: the roles of learning and education. Environmental Education Research, 16:463-474.

Kresge Foundation, 2015. Bounce Forward: Urban Resilience in the Era of Climate Change. Island Press.

Kuhn, T.S., 1970. The Structure of Scientific Revolutions. Vol. 2nd. University of Chicago Press.

Larsen, R.K., K. Raitio, P. Sandström, A. Skarin, M. Stinnerbom, J. Wik-Karlsson, S. Sandström. C. Österlin and Y. Buhot, 2016. Kumulativa effekter av exploateringar på renskötseln - vad behöver göras inom tillståndsprocesser? [Cumulative effects of exploitation on reindeer husbandry: what is needed in the permitting process?] Report No. 6722. Swedish Environmental protection Agency.

Larsen, T.S., T. Kurvits and E. Kuznetsov, 2011. Lessons Learned From ECORA: An Integrated Ecosystem Management Approach to Conserve Biodiversity and Minimise Habitat Fragmentation in the Russian Arctic. CAFF Strategy Series Report 4. CAFF International Secretariat.

Lawrence, R. and M. Åhrén, 2016. Mining as colonisation: The need for restorative justice and restitution of traditional Sami lands. In: Head, L., S. Saltzman, G. Setten and M. Stenseke (eds.), Nature, Temporality and Environmental Management: Scandinavian and Australian Perspectives on Landscapes and Peoples. Taylor and Francis, UK.

Lawrence, R. and R.K. Larsen. 2106. Då är Det Inte Renskötsel - Konsekvenser Av En Gruvetablering I Laver, Älvsbyn, För Semisjaur Njarg Sameby [Then it's not reindeer husbandry – Consequences of citing a mine in Laver, Älvsbyn for the Semisjaur Njarg Sámi Community]. SEI Project Report 2016-01. Stockholm Environment Institute. www.sei-international.org/mediamanager/documents/Publications/SEI-PR-2016-sami-mining-swedish.pdf

Lindeström, R. and T. Eriksson, 2015. Laver – ansökan om bearbetningskoncession [Laver – application for a mining concession]. Environmental Impact Assessment, Svensk MKB & Zitroworks (2015).

Löf, A., 2014. Challenging Adaptability : Analysing the Governance of Reindeer Husbandry in Sweden. PhD thesis. Umeå University, Sweden.

Löf, A., P. Sandström, K. Baer, M. Stinnerbom and G. Ericsson, 2012. Renskötsel Och Anpassningsmöjligheter I Vilhemina Norra Sameby [Reindeer herding and adaptation options in Vilhelmina northern reindeer herding community]. Research Report 2012:4. Umeå University, Sweden.

Magis, K., 2010. Community resilience: an indicator of social sustainability. Society and Natural Resources, 23:401-416.

Manyena, S.B., G. O'Brien, P. O'Keefe and J. Rose, 2011. Disaster resilience: a bounce back or bounce forward ability? Local Environment, 16:417-424.

Martin, S., 2009. The effects of female out-migration on Alaska villages. Polar Geography, 32:61-67.

Matyas, D. and M. Pelling, 2015. Positioning resilience for 2015: the role of resistance, incremental adjustment and transformation in disaster risk management policy. Disasters, 39(S1):1-18.

Meadows, D., 1998. Indicators and Information Systems for Sustainable Development. The Sustainability Institute. www.iisd.org/pdf/s_ind_2.pdf

Michell, G. and P. McManus, 2013. Engaging communities for success: social impact assessment and social licence to operate at Northparkes Mines, NSW. Australian Geographer, 44:435-459.

Miller, F., H. Osbahr, E. Boyd, F. Thomalla, S. Bharawani, G. Ziervogel, B. Walker, J. Birkmann, S. Van der Leeuw, J. Rockström, J. Hinkel, T. Downing, C. Folke and D. Nelson, 2010. Resilience and vulnerability: complementary or conflicting concepts? Ecology and Society, 15: www.ecologyandsociety.org/vol15/iss3/art11/

Morrone, A., K. Scrivens, C. Smith and C. Balestra, 2011. Measuring vulnerability and resilience in OECD countries. Paper Prepared for the IARIW-OECD Conference on Economic Insecurity, Paris. 22-23 November, 2011.

Mustonen, T., 2015. Communal visual histories to detect environmental change in northern areas: Examples of emerging North American and Eurasian practices. Ambio, 44:766-777.

Mustonen, T. and P. Feodoroff, 2013. Neiden and Ponoi Co-Management Plan. Snowchange Cooperative, Kontiolahti.

Mustonen, T. and P. Feodoroff, 2014. Neiden and Ponoi Co-Management Work Report 2014. Snowchange Cooperative, Kontiolahti.

Mustonen, T. and P. Feodoroff, 2015. Neiden and Ponoi Co-Management Work Report 2015. Snowchange Cooperative, Kontiolahti.

Mustonen, T. and K. Mustonen, 2011. Eastern Sámi Atlas, 2011. Snowchange Cooperative, Kontiolahti.

Mustonen, T. and K. Mustonen, 2016. Life in the Cyclic World: A Compendium of Traditional knowledge from the Eurasian North. Snowchange Cooperative, Kontiolahti.

National Research Council, 2009. Informing Decisions in a Changing Climate. Panel of strategies and methods for climate-related decision support, committee of the human dimensions of global change. Division of Behavioral and Social Sciences and Education. National Academies Press.

Niemeijer, D. and R.S. de Groot, 2008. A conceptual framework for selecting environmental indicator sets. Ecological Indicators, 8:14-25.

Nilsson, L.M. and B. Evengård, 2013. Food and Water Security Indicators in an Arctic Health Context. Report by the AHHEG/SDWG and the AMAP/HHAG during the Swedish chairmanship of the Arctic Council 2011-2013. Umeå University, Sweden.

Nymand Larsen, J. and G. Fondahl (eds.), 2015. Arctic Human Development Report: Regional Processes and Global Linkages. TemaNord 2014:567. Nordic Council of Ministers.

Nymand Larsen, J., P.P Schweitzer and G. Fondahl, 2010. Arctic Social Indicators: A Follow-up to the Arctic Human Development Report. Nordic Council of Ministers.

Nymand Larsen, J., P. Schweitzer and A. Petrov, 2015. Arctic Social Indicators: ASI II: Implementation. Nordic Council of Ministers.

Ostrom, E., 2009. A general framework for analyzing sustainability of social-ecological systems. Science, 325:419-422.

Paul Thompson, R., 2001. History of scientific agriculture: animals. eLS. John Wiley.

Perz, S.G., A. Shenkin, G. Barnes, L. Cabrera, L.A. Carvalho and J. Castillo, 2012. Connectivity and resilience: a multidimensional analysis of infrastructure impacts in the southwestern Amazon. Social Indicators Research, 106:259-285.

Poppel, B. and J. Kruse, 2009. The importance of a mixed cash- and harvest herding based economy to living in the Arctic – An analysis on the survey of living conditions in the Arctic (SLiCA). In: Møller, V. and D. Huschka (eds.), Quality of Life and the Millennium Challenge: Advances in Quality-of-Life Studies, Theory and Research. pp. 27-42. Springer.

Prior, T. and J. Hagmann, 2014. Measuring resilience: methodological and political challenges of a trend security concept. Journal of Risk Research, 17:281-298.

Reed, M.S., E.D.G. Fraser and A.J. Dougill, 2006. An adaptive learning process for developing and applying sustainability indicators with local communities. Ecological Economics, 59:406-418.

Riedlinger, D. and F. Berkes, 2001. Contributions of traditional knowledge to understanding climate change in the Canadian Arctic. Polar Record, 37:315-328.

Rockström, J., W. Steffen, K. Noone, Å. Persson, F.S. Chapin III, E. Lambin, T.M. Lenton, M. Scheffer, C. Folke, H. Joachim Schellnhuber, B. Nykvist, C.A. de Wit, T. Hughes, S. van der Leeuw, H. Rodhe, S. Sörlin, P.K. Snyder, R. Costanza, U. Svedin, M. Falkenmark, L. Karlberg, R.W. Corell, V.J. Fabry, J. Hansen, B. Walker, D. Liverman, K. Richardson, P. Crutzen and J. Foley, 2009. Planetary boundaries: exploring the safe operating space for humanity. Ecology and Society, 14: www.ecologyandsociety.org/vol14/iss2/art32/

Ross, H., M. Cuthill, K. Maclean, D. Jansen and B. Witt, 2010. Understanding, Enhancing and Managing for Social Resilience at the Regional Scale: Opportunities in North Queensland. Report to the Marine and Tropical Sciences Research Facility. Reef and Rainforest Research Centre Limited, Cairns.

Scheffer, M., S.H. Hosper, M.-L. Meijer, B. Moss and E. Jeppesen, 1993. Alternative equilibria in shallow lakes. Trends in Ecology and Evolution, 8:275-279.

Schreiber, D., 2002. Our wealth sits on the table: food, resistance, and salmon farming in two First Nations communities. American Indian Quarterly, 26:360-377.

Sherrieb, K., F. Norris and S. Galea, 2010. Measuring capacities for community resilience. Social Indicators Research, 99:227-247.

Standish, R.J., R.J. Hobbs, M.M. Mayfield, B.T. Bestelmeyer, K.M. Suding, L.L. Battaglia, V. eviner, C.V. Hawkes, V.M. Temperton, V.A. Cramer, J.A. Harris, J.L. Funk and P.A. Thomas, 2014. Resilience in ecology: Abstraction, distraction, or where the action is? Biological Conservation, 177:43-51.

Stone-Jovicich, S., 2015. Probing the interfaces between the social sciences and social-ecological resilience: insights from integrative and hybrid perspectives in the social sciences. Ecology and Society, 20: doi:10.5751/ES-07347-200225.

Tanner, T., D. Lewis, D. Wrathall, R. Bronen, N. Cradock-Henry, S. Huq, C. Lawless, R. Nawrotzki, V. Prasad, A. Rahman, M.R. Alaniz, K. King, K. McNamara, M. Nadiruzzaman, S. Henly-Shepard and F. Thomalla, 2015. Livelihood resilience in the face of climate change. Nature Climate Change, 5:23-26.

UNFCCC, 2015. Adoption of the Paris Agreement. United Nations Framework Convention on Climate Change (UNFCCC). https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf

UNISDR, 2015. Sendai Framework for Disaster Risk Reduction 2015-2030. United Nations Office for Disaster Risk Reduction (UNISDR). http://www.unisdr.org/files/43291_sendaiframeworkfordrren.pdf

United Nations, 2015. Draft Outcome Document of the United Nations Summit for the Adoption of the Post-2015 Development Agenda. www.un.org/ga/search/view_doc.asp?symbol=A/69/L.85&Lang=E

Usher, P.J., 1976. Evaluating country food in the northern Native economy. Arctic, 29:105-120.

Usher, P.J., G. Duhaime and E. Searles, 2003. The household as an economic unit in Arctic aboriginal communities, and its measurement by means of a comprehensive survey. Social Indicators Research, 61:175-202.

Walker, B., C.S. Holling, S.R. Carpenter and A. Kinzig, 2004. Ecology and society: resilience, adaptability and transformability in social-ecological systems. Ecology and Society, 9: www.ecologyandsociety.org/vol9/iss2/art5/

Walsh, B., 2013. Adapt or die: Why the environmental buzzword of 2013 will be resilience. Time Magazine.

Watson, A., L. Alessa and B. Glaspell, 2003. The relationship between traditional ecological knowledge, evolving cultures, and wilderness protection in the circumpolar North. Conservation Ecology, 8: www.consecol.org/vol8/iss1/art2/

WCED, 1987. Food 2000: Global Policies for Sustainable Agriculture. A Report of the Advisory Panel on Food Security, Agriculture, Forestry and Environment to the World Commission on Environment and Development. Zed Brooks.

Wenzel, G.W., 1989. Sealing at Clyde River, NWT: A discussion of Inuit economy. Études/Inuit/Studies, 13:3-22.

Wenzel, G.W., 2011. Polar bear management, sport hunting and Inuit subsistence at Clyde River, Nunavut. Marine Policy, 35:457-465.

Williams, C., A. Fenton and S. Huq, 2015. Knowledge and adaptive capacity. Nature Climate Change, 5:82-83.

Wolfe, R.J. and R.J. Walker, 1987. Subsistence economies in Alaska: productivity, geography, and development impacts. Arctic Anthropology, 24:56-81.

Zalasiewicz, J., M. Williams, W. Steffen and P. Crutzen, 2010. The new world of the anthropocene. Environmental Science and Technology, 44:2228-2231.

9. Adaptation options

Coordinating lead authors: Grete K. Hovelsrud, Helene Amundsen

Lead authors: Halvor Dannevig, E. Carina H. Keskitalo, Elena Nikitina, Monica Tennberg

Contributing authors: Robert Corell, Marianne Karlsson, Sari Kauppi, Nancy Maynard, Ilona Mettiäinen, Ilari Nikula, Nina Poussenkova, Camilla Risvoll, Stine Rybråten, Päivi Soppela, Minna Turunen, Vilena Valeeva

Key messages

- ***Adaptation to cumulative and interacting changes is taking place at various societal scales by actors, sectors, and local governments and takes different forms depending on a number of factors such as institutional capacity, access to knowledge and to human and economic resources.*** *Such adaptation takes place with or without national guidelines. Adaptation is either a reactive or a proactive (planned) response to combined effects of change in biophysical and socio-economic conditions. Climate change is not the only or most salient driver of change in the region; it interacts with socio-economic, political and cultural changes and provides both opportunities and challenges for people (indigenous and non-indigenous) living and operating in the Barents area. Adaptation emerges as a process that interacts with society at large.*
- ***Adaptation in practice is ahead of national developments and guidelines****. In the primary industries adaptation is predominantly reactive and adaptation by local governments is predominantly proactive, such as spatial planning, regional and local climate strategies and programs, avalanche protection, and adjusting location of buildings to account for sea-level rise.*
- ***Adaptation takes multiple forms depending on the nature of cumulative and interactive effects in societal and environmental conditions.*** *These range from engineering and technical solutions to changing societal structures, for instance infrastructural improvements, economic mechanisms, new knowledge, innovation and entrepreneurship, changed or new institutional structures, and production practices and routines. In most cases a broad range of strategies are needed to adapt. This is because the combined effects of climatic and non-climatic drivers are complex, interactive and cumulative.*
- ***Four dimensions constitute adaptation options – current adaptation strategies, processes that activate adaptation, barriers and limits to adaptation, and adaptation governance.*** *Attention to future trends along these dimensions is critical for developing further adaptation actions. Attention to the complex relationships between these dimensions increases the likelihood of developing relevant and feasible adaptation options.*
- ***Several societal trends will require adaptation in the Barents area.*** *The most significant include urbanization, unbalanced outmigration by gender from the rural areas, consequences of climate change for primary industries, industrial activities (including shipping), public sector responsibilities (floods, health), and infrastructure.*

9.1 Introduction

This chapter outlines the potential adaptation options available for responding to the cumulative and interacting changes ongoing within the Barents area. The analyses and assessments are based on a wide range of information types from the countries, sectors, and communities making up the Barents area. The analyses include a focus on actions and strategies, barriers and limits, challenges and opportunities, and the processes and motivations that play a role in adaptation. Early adaptation studies tended to focus on traditional small-scale primary industries (e.g. Tyler et al., 2007; Keskitalo, 2008), with adaptation responses driven largely by changes affecting production (i.e. economic) conditions (as highlighted in studies focusing on multiple stresses, see for example O'Brien and Leichenko, 2003). However, new challenges are now emerging from the unprecedented climatic and societal changes taking place, and these are likely to require a new way of thinking about adaptation, especially given the speed and magnitude of these changes (Smit and Pilisofova, 2003; Smit and Wandel, 2006). In simple terms, climate perturbations interact with the socio-economic challenges to which society responds. Climate change impacts may also exacerbate existing challenges in society.

Adaptation to current and future changes and perturbations must be seen in connection with past responses to weather and climate, as well as local context and national governance. Adaptation measures fall into two broad categories: (1) reactive or autonomous measures (also denoted as coping strategies), applied in response to something that has actually occurred (such as an extreme weather event); and (2) proactive or planned measures, which are used to reduce negative impacts or take advantage of positive impacts, or are anticipated measures for addressing future change (Fankhauser et al., 1999; IPCC, 2007). Globally, most adaptation measures are reactive or autonomous (Berrang-Ford et al., 2011). To date, autonomous adaptations have been documented in fisheries, agriculture, forestry, tourism and reindeer herding, whereas, planned adaptation in the Barents Region is mainly documented in governmental sectors. While climate sensitive primary industries are subject to changes in resource availability, climate related natural hazards are a major concern for local governments (Hovelsrud et al., 2010a). Adaptation processes take place through multiple actors, at multiple scales and within and between societal scales, and among actors/ stakeholders at each of these scales and may therefore be seen as a governance issue. Chapter 2 provides an overview of stakeholders in the Barents area at multiple scales.

Adaptation governance in practice means the application of a range of actions, measures, strategies, plans and programs. This list signifies an increase in formality, from adaptation actions to adaptation programs.

While climate change increases the opportunities for industrial development and other economic activities in the Barents area, it also interacts with socio-economic, political and cultural changes and creates both opportunities and challenges for people living and operating within the region. The interactions between climate change impacts and socio-economic and environmental conditions create direct and indirect cumulative, and often unforeseen, consequences for society (e.g. Hovelsrud et al., 2011) (see Chapter 6). While the opportunities emerging in the Barents area are highly likely to be exploited and developed, society may not be as well prepared for the challenges. Challenges such as extreme weather events, storms, extreme rainfall, floods, wildfires and heat waves are all expected to increase and are currently addressed to varying degrees in the Barents area countries.

Adaptation to the consequences of climate change is inevitable, irrespective of whether the world succeeds in achieving the necessary reductions in greenhouse gases (GHG). The unprecedented effects of climate change expected in the near future will further increase the focus on adaptation. In this chapter, 'adaptation' is applied as an analytical term and used to describe responses or activities undertaken or planned to address change, but within a broader context of multiple stresses to acknowledge that climate change is rarely the only factor to which society must adapt (e.g. Leichenko and O'Brien, 2008). This includes existing coping strategies and actions undertaken in response to general changes in society that may be relevant for adaptation to climate change (e.g. Smit and Wandel, 2006).

This multiple understanding of adaptation mirrors an increasingly complex understanding of adaptation in the literature. Adaptation has moved from being a sign of humanities' failure to deal with GHG emissions to become a household concept. Adaptation is nevertheless a new area for many national policy approaches and has recently been suggested for inclusion within the Intended Nationally Determined Contributions (INDC) under the United Nations Framework Convention on Climate Change (UNFCCC) – framed in terms of strategic planning for the future.

The focus of this chapter is on adaptation options and draws on the definition adopted by the Intergovernmental Panel on Climate Change (IPCC) "*The array of strategies and measures that are available and appropriate for addressing adaptation needs. They include a wide range of actions that can be categorized as structural, institutional, or social*" (IPCC, 2014b). In this assessment, the IPPC definition is broadened to capture the complexities of interacting and cumulative societal and environmental (including climate) changes, and discuss how adaptation options are shaped by these interactions and the ways adaptation takes place in a local, societal, political, globalized and financial context. In this report, the approach to adaptation includes diverse and dynamic aspects such as understanding impacts on natural resources, livelihood flexibility, enabling institutions across societal scales, and trade-offs between options. This means assessing adaptation options as processes and drivers that shape the development of measures including awareness of factors that both facilitate and impede such measures.

The Barents area broadly covers northern Europe and northernmost Russia and includes large ocean areas (see Chapter 1 for a detailed geographical description). The area has a diverse physiography ranging from very sparsely inhabited High Arctic areas, such as Svalbard, to mainland areas that are well integrated into the respective states, and with comparatively high population and cities. The market-integrated economies of the region are affected by the consequences of cumulative impacts of changing socio-economic conditions, including resource demand driven by increasing globalization such as urbanization trends, the impacts of global markets, climate change and other environmental impacts, and national and international policies. The latter include drivers such as commitments of the Barents countries to international agreements (e.g. CITES 1976, Bern Convention 1986, Council Directive 92/43/EEC, CBD 1994, World Trade Organization), European Union regulations, national laws and management practices regarding taxation, level of local autonomy (municipal/local council level), regional processes in the different countries, infrastructure, health and education systems related to the welfare states of Norway, Sweden and Finland; and specific resource use, nature protection and other environmentally related rights. Given the increasingly global context of market competition and regulative influence there is increased risk that local and indigenous peoples will be negatively affected by current and future changes through loss of the ability to maintain locally based livelihoods and occupations in the relatively sparsely populated areas of the region (see Chapter 7).

The increased focus on renewable and non-renewable resources in the Barents area, by businesses within and outside the region brings challenges as well opportunities for residents and policymakers. Opportunities to exploit northern and Arctic Ocean resources carry great responsibility in terms of safeguarding and including local and indigenous communities in decision-making processes and environmental protection. Adaptive strategies therefore require attention to multiple stressors and to cumulative and cascading effects.

The recent Arctic Council report *Taking stock of adaptation programs in the Arctic: Adaptation Actions for a Changing Arctic* (Arctic Council, 2013a) concludes that adaptation to climate change in the Arctic remains at an early stage. The report also notes that the information gathering methodology may overlook some community level activities. The work that underpins the present chapter shows that although adaptation takes place across various scales and sectors, it is predominantly occurring at the local level. Concerns noted include permafrost thaw, sea-level rise and flooding, ecosystem change, and consequences for infrastructure and traditional practices and ways of life (Arctic Council, 2013a). The report was based on a survey providing an overview of the status of adaptation programs across the Arctic. Five main categories of adaptation activity were identified (planning and decision-support tools, awareness-raising, monitoring and provision of data, training, mainstreaming) and within each category the majority of activities were aimed at enabling adaptation, such as the development of community adaptation plans, hazard and vulnerability assessments and maps, communication products, monitoring, and training. The survey showed that adaptation activities related to infrastructure were the most common, especially in areas such as transport, the built environment and water management.

9.2 Adaptation as a policy issue

9.2.1 Adaptation in major reports: A brief overview

The 2015 Paris Agreement (UNFCCC, 2015) seeks to strengthen adaptation efforts and requires countries to take action on adaptation. While it remains to be seen how the 2015 Paris Agreement will play out in the Barents area countries, it is likely to influence how adaptation work proceeds. Under the agreement, the objective of adaptation is 'enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change', and countries are to plan their adaptation activities and implement adaptation actions accordingly. Thus adaptation planning should preferably include vulnerability and impact assessments, national adaptation priorities, and a description of how actions are to be implemented, followed up and evaluated. The agreement requires countries to submit and periodically update an adaptation communication; outlining adaptation priorities, actions and support needs. Strengthened international and regional cooperation on adaptation is called for, which may facilitate Barents Region cooperation on adaptation.

The 2014 IPCC Assessment Report contains no fewer than four chapters dedicated to adaptation (IPCC, 2014a), illustrating the importance and complexity of the issue and also that the focus on adaptation has increased significantly in science and policy in recent years. The report shows there are significant regional variations in the degree to which adaptation has been studied and implemented, ranging from detailed, cooperative national adaptation strategies (e.g. Europe) to limited small-scale community-based research case studies (e.g. Africa/Asia), with implementation generally lagging behind planning in most countries (IPCC, 2014a). In the polar regions, the focus is on indigenous, isolated, and rural populations in the Arctic, owing to their close relationship with the environment for food, culture and way of life. The IPCC concluded that indigenous peoples are facing unprecedented climate impacts (such as increasingly risky harvesting) while, in some cases, communities are already beginning to plan and implement creative adaptation strategies (Larsen et al., 2014; see also Chapter 7). Examples of indigenous adaptation strategies include changing resource bases, shifting land use and/or settlement areas, combining technologies with traditional knowledge, changing the timing and location of hunting, gathering, herding, and fishing areas, and improving communications and education (Larsen et al., 2014).

The 2013 Arctic Resilience Interim Report (Arctic Council, 2013b) also acknowledges that Arctic peoples and cultures have a long history of adapting to a highly variable environment, and maintains that the factors that have enabled them to adapt and maintain resilience are primarily linked to flexibility and diversity in food, subsistence and livelihood practices. However, it should also be acknowledged that indigenous and rural populations constitute a minority in these regions and that urbanization has proceeded rapidly around the world, including in northern areas. However, there is a continuum from rural and urban (e.g. Hedberg and Haandrikman, 2014). The Arctic Resilience Interim Report emphasized that policy can prepare and enable Arctic peoples to adapt through strengthening livelihood flexibility and maintaining diversity in Arctic social-ecological systems (Arctic Council, 2013b).

In its latest assessment, the IPCC reported significant differences in adaptation planning among countries and communities that are related to the needs, values, resources, and perceptions within and among populations, as well as to the different attitudes and awareness among agencies, countries, and international organizations that fund adaptation (Mimura et al., 2014). There are also clear ethical implications about the selection and implementation of adaptation options owing to the differences in the very values that adaptation is seeking to protect, as well as in the ways that adaptation funds are distributed (Klein et al., 2014). The IPCC noted that adaptation is not necessarily focused on biophysical vulnerabilities but more on the broader socio-economic drivers of vulnerability (gender, ethnicity, age, health, social status) (Noble et al., 2014). In recent years, the definition of 'needs' has changed to focus on the underlying causes of vulnerability (financial, institutional, technological, informational, capacity etc.) rather than on impacts (Noble et al., 2014).

Recognition that climate change is but one of several change processes affecting Arctic societies is highlighted in the 2014 Arctic Human Development Report (Larsen and Fondahl, 2015). With its specific emphasis on gender, climate change and globalization, the report highlights the connectivity of different change processes and their combined influence on human development across and within Arctic societies (Larsen and Fondahl, 2015). Gender dimensions are shown to influence factors such as risk perception, migration patterns and decision-making; factors that have clear linkages to adaptation and adaptive capacity. The report also shows that processes of (economic, political and cultural) globalization influence employment, natural resource use and settlement patterns in the Arctic. Adaptation to changes in markets, employment and income are highlighted as equally or more challenging than climate change (Keskitalo, 2008; Keskitalo and Southcott, 2015). However, globalization is also shown to have strengthened Arctic (especially indigenous) identities, which may constitute a motivation for adaptation. In light of the changes resulting from globalization, the report emphasizes that public policy and mobility will shape how communities adapt and observes that stable populations that are gender and age balanced are key to maintaining viable Arctic communities (Rasmussen et al., 2015).

The 2014 Arctic Social Indicators Report (Larsen et al., 2015) focuses on tracking critical domains for Arctic human development and social wellbeing across seven indicators. Along with more commonly used human development indicators, such as life expectancy and degree of education, this report adds three areas specific to Arctic human development; fate control, cultural vitality and contact with nature. Fate control 'the ability to guide one's destiny' is important in order to be able to adapt to interacting change processes – whether it concerns adopting new and global tendencies or maintaining traditional lifestyles (Larsen et al., 2015). Fate control is often related to opportunities and resources provided in relation to regulative and market frameworks.

The 2014 Arctic Human Development Report (Larsen and Fondahl, 2015), the 2013 Arctic Resilience Interim Report (Arctic Council, 2013b) and the 2014 Arctic Social Indicators Report (Larsen et al., 2015) do not have a specific geographic focus on the Barents area, although several case studies within these reports do concern this region. Projects specific to the Barents area include the Barents Euro-Arctic Council's adoption of the Action Plan on Climate Change for the Barents Co-operation (see Chapter 3). To support the development and implementation of climate strategies that include both mitigation and adaptation activities within the Barents area, Sorvali (2015) analyzed current strategies for each Barents area country and found that the implementation of adaptation measures has received less attention than emission reduction measures.

9.2.2 Organization of adaptation policies and governance

This section describes adaptation policies and governance by country in order to highlight the different ways that adaptation is currently organized within the Barents Region. Table 9.1 outlines the different national adaptation strategies and vulnerability assessments.

In addition to national policy focus on adaptation, the Barents Euro-Arctic Council (BEAC) has addressed climate change regionally through 'the Action Plan on Climate for the Barents Cooperation' (climatesmart.fi). This initiative is designed to develop regional strategies for mitigation and adaptation to climate change in the Barents Region and to improve the exchange of ideas and experience between countries. Activities and themes relevant to adaptation that are to be realized under different BEAC working groups include water management, transport, reindeer husbandry and protected areas. See Chapter 3 for a more extensive outline of regional cooperation in the Barents area.

9.2.2.1 Norway

Climate change adaptation in Norway is organized in a similar way to that in Sweden and Finland, in that responsibilities are delegated to sectoral institutions but with the main responsibility for climate change adaptation falling to the municipalities, loosely coordinated by the regional level (county governor). A governmental commission on adaptation delivered an Official Norwegian Report to the Ministry of the Environment in 2010 (Norwegian Ministry of the Environment, 2010), which built on a range of peer reviewed scientific reports and papers on current and projected impacts of climate change in Norway. As a follow-up the Norwegian White Paper on Adaptation (2013), focused on climate change challenges and on how Norway could handle such changes in order to become more resilient (Norwegian Ministry of the Environment, 2013). The core principle is that responsibility for adaptation is placed with the actor responsible for the task or function impacted by climate change (Norwegian Ministry of the Environment, 2013). It follows that key responsibilities for adaptation lie with the municipalities because they are responsible for overall societal development, infrastructure, and spatial planning. The Government has commissioned several scientific reports on projected climate change and impacts since the Official Norwegian Report of 2010 (Norwegian Ministry of the Environment, 2010), and in 2015 an updated report with new, downscaled projections for climate change, hydrological impacts, flooding, sea-level rise and geohazards was delivered (Hanssen-Bauer et al., 2015). The Norwegian Environment Agency has been assigned the responsibility of coordinating the national level work on adaptation, while the county governor is coordinating, advising and overseeing the municipal activities on adaptation in their county, and checking that municipal and county level planning adheres to national policies. The White Paper on Adaptation focuses in particular on spatial planning, local and regional preparedness and emergency planning, and overseeing that climate change adaptation is included within the areas of the public actors' responsibilities as the main areas for adaptation (Norwegian Ministry of the Environment, 2013).

Adaptation activities in Norway within the public sector have mainly focused on natural hazards, for example avalanche protection in Hammerfest and the need to incorporate increased flood levels and rising sea level in spatial planning (Hovelsrud et al., 2010b; Stokke 2014). A focus in the agricultural sector has been attention to agricultural crops that can thrive in a warmer and wetter climate and the 24-hour daylight of the northern Norwegian summer (Kvalvik et al., 2011; Uleberg et al., 2014). As is the case in Finland and Sweden, municipalities are in the early stages of developing adaptation plans and activities, and currently there are no formal requirements to develop such plans. Few municipalities in northern Norway have included adaptation in their planning documents to date, notable exceptions are Hammerfest and Tromsø municipalities (Hovelsrud et al., 2010b; Dannevig et al., 2013; Stokke, 2014), but this is unlikely to be the case for much longer. Formal guidance on the inclusion of adaptation in municipal planning is currently being prepared at the national level and is also being requested by the municipalities themselves.

The Norwegian Arctic region is the only geographical area subject to particular attention in the White Paper on Adaptation (Norwegian Ministry of the Environment, 2013). The white paper justifies this by the rapid warming in the Arctic and the reliance of Arctic communities on climate sensitive industries. It also highlights the need for continued ecosystem-based management of the Norwegian Sea and Barents Sea as a response to climate change.

9.2.2.2 Sweden

In Sweden, adaptation policy at the national level has mainly been developed through the Swedish Commission on Climate and Vulnerability (2007). This is followed up in a Climate Bill (Government Offices of Sweden, 2009), and in guidelines by departments, linked to the Swedish environmental quality objectives processes (e.g. Rydell and Lind, 2009; Persson and Rummukainen, 2010). The Commission report presents a broad overview of impacts and adaptation needs in multiple sectors in Sweden, with forestry and reindeer husbandry of relevance for northern areas, in addition to universally relevant sectors such as water management, construction and infrastructure (Swedish Commission on Climate and Vulnerability, 2007). The Climate Bill (Government Offices of Sweden, 2009) focused on financial support for regional (county administrative boards) coordination of climate change adaptation work, development

Table 9.1 National climate change vulnerability assessments and national adaptation strategies in the Barents area.

	Norway	Sweden	Finland	Russia
National vulnerability assessments	Official Norwegian report, 2010 (Norwegian Ministry of the Environment, 2010)	Swedish Commission on Climate and Vulnerability (2007)	National adaptation strategy, 2005 (Finnish Ministry of Agriculture and Forestry, 2005)	First and Second Climate Change Assessment Reports of the Russian Federation (Roshydromet, 2008, 2014)
National adaptation strategy or policy	White paper, 2013 (Norwegian Ministry of the Environment, 2013)	Swedish Commission on Climate and Vulnerability (2007); Climate Bill 2009, policy development e.g. in specific sectoral agencies	National adaptation strategy, 2005 (Finnish Ministry of Agriculture and Forestry, 2005) Implementation plan for adaptation 2022 (Finnish Ministry of Agriculture and Forestry, 2014)	Climate doctrine of the Russian Federation 17.12.2009 (Russian Federation, 2009; www.kremlin.ru)
Followed up by legislation	Yes Planning and Building Act, 2008	Yes Such as in the Climate Bill (Government Offices of Sweden, 2009)) and in specific cases such as flood protection	Yes Climate Law, 2015, and several programs and plans, including water management, flood protection management, climate program for agriculture, biodiversity, forestry, land use, traffic and security	Yes RF Government Ordinance No 730-p, 25.04.2011 (www.global-climate-change.ru/official documents); National strategy of the Russian Federation for development of the Arctic zone, 2013

of a detailed topographical database on flood risk, and mapping of landslide risk (Keskitalo, 2010a). Legislative change in the existing Planning and Building Law in relation to increasing flood risk has also been addressed and changes in force since 2008 include the requirement to consider 'flooding and erosion' in planning and local infrastructural development, in addition to health and security (Keskitalo, 2010a).

Similar to Finland, the national approach to climate change adaptation in Sweden includes both sectoral and administrative levels, where sectors, such as forestry and agriculture, have coordinating responsibilities. The counties have regional administrative responsibilities. Local governments are the authorities for local planning and thus have significant self-determination. They have responsibility for local climate change adaptation, but without formalized requirements or allocated funding for specific adaptation action. Earlier studies and assessments have indicated that this may result in climate change adaptation becoming limited in practice, and potentially dependent on resources at the municipal level (where municipalities with large populations and consequently a higher tax income are better able to respond) (Keskitalo 2010a; Andersson et al., 2015). Many northern municipalities cover large geographic areas but are sparsely populated. They have relatively few resources with which to target climate change and so need allocated funding, although if particular high-impact vulnerabilities are identified this could result in climate change adaptation being prioritized above other crucial sectors or requirements for action. In the recent assessment of how climate change adaptation is organized in Sweden, recommendations for resolving this issue include permanently funding regional level coordination, harmonizing regulatory frameworks, and providing funding such that municipalities can develop and implement climate change adaptation strategies and measures (Andersson et al., 2015). As a result of the assessment, a commission on climate change adaptation and a commission addressing climate change with respect to national heritage have been established (Kulturdepartementet, 2015; Swedish Ministry of Environment and Energy, 2015). A Climate Act is under development in Sweden, although this mainly focuses on mitigation (Government Offices of Sweden, 2016).

Despite limitations at the national level, strategies and policies on climate change adaptation exist at the regional and local level in Sweden. For example, those produced by the County Administrative Board (2012) and the County Administrative Board of Stockholm (2010a,b,c). In Norrbotten and Västerbotten, reports have been published on potential impacts and adaptation (County Administrative Board of Norrbotten, 2009), on infrastructure and built areas, technical supply systems, natural environment and land-based industries, and health, including effects on water catchments (County Administrative Board of Norrbotten, 2010, 2012). Other efforts integrate work on flood management (e.g. County Administrative Board of Västerbotten, 2007).

9.2.2.3 Finland

The Finnish approach to climate adaptation is mostly administrative and sectoral, both nationally and regionally. Its programs and plans cover several areas, such as water and flood protection management, biodiversity, agriculture, forestry, traffic and security. The national adaptation work is led and coordinated by the Ministry of Agriculture and Forestry, supported by other ministries, state authorities and national research institutes. The national strategy for adaptation was adopted in 2005, evaluated in 2009 and 2013, and a new plan for adaptation to 2022 was published in 2014. Adaptation is also included in the new Climate Law adopted in 2015. The rationale for adaptation in the most recent national plan is to ensure that "*Finnish society will have the capacity to manage climate change related risks and adapt to changes in the climate*" (Finnish Ministry of Agriculture and Forestry, 2014:4). Adaptation of peoples and livelihoods (including reindeer husbandry and tourism) in northern Finland has been raised as a national issue, and highlights the concern that the northern regions are particularly sensitive to climate change. Climate change is also increasingly being seen as an opportunity for new economic activities, products and services, such as shipping, extraction of renewable and non-renewable energy sources and tourism in the Arctic (Regional Council of Lapland, 2011; Finnish Government, 2013). In northern Finland, three regional strategies were made to support adaptation in northern Ostrobothnia, Kainuu and Lapland. In addition, some larger cities, such as Oulu and Rovaniemi, have developed their own climate programs, including mitigation and adaptation. These regional strategies were prepared through a broad participatory process, which was a laborious but highly valuable learning process (Himanen et al., 2012). The so-called Lapland Agreement, identifies 'climate change and bioeconomy' as focal points and addresses adaptation and mitigation, carbon neutrality and energy politics, and increasing demand for and sustainable use of natural resources (Regional Council of Lapland, 2014a). In a similar document for the Oulu Region, the Council commits to participate in climate change mitigation and adaptation, especially regarding flood prevention and flood risk management (Council of Oulu Region, 2014). The Finnish government places strong emphasis on the role of cities and regions to advance mitigation of climate change and support adaptation to climate change impacts (Finnish Ministry of Employment and Economy, 2011).

9.2.2.4 Russia

In the Russian Federation, national climate adaptation is currently being developed and incorporated into the national Climate Doctrine of the Russian Federation adopted 17 December 2009 (Russian Federation, 2009). According to this Doctrine, 'climate change results in risks to national security' including society, its stakeholders and individuals. The Doctrine states that thorough and detailed assessments of economic, social, and institutional aspects of climate change impacts are essential to design adaptation measures to reduce negative consequences, and benefit from new and emerging opportunities. Adaptation planning is based on assessments of vulnerability to negative consequences and associated losses due to climate change impacts; opportunities arising from the consequences of climate change; possible costs of adaptation action; and the adaptation potential of economic sectors, population and the most vulnerable groups and institutional structures of particular regions. Developing short-term and long-term adaptation measures are among key goals (Russian Federation, 2009).

Adaptation strategies in the Russian part of the Barents area are linked to forecasting of and operational responses to extreme events and emergencies. The Russian Federation Ministry for Emergencies (Emercom) affiliations are established in the Russian Barents area with subdivisions in municipalities. A network for monitoring and data-processing for floods, wildfires, avalanches, extreme weather events and other natural disasters has been strengthened. In Russia, some adaptation actions take the form of independent regional programs, while others are undertaken within a framework of international programs that includes other Arctic partners.

Adaptation policy presupposes a multi-scale approach across federal, regional and sectoral programs and action plans, with adaptation to be included in plans for socio-economic development at the national level and by the federation subjects ('federation subjects' is a common term to denominate the administrative level below the national level, such as okrug, republic and oblast; federation subjects have their own parliament, constitution and legislation). The national climate policy framework envisages the development of regulations, norms and institutional structures at the national level and interactions within and between the regions. The 2015 Paris Agreement, adds to the Russian INDC, which currently does not include a detailed national adaptation strategy for the period 2020–2030. Presenting a refined adaptation strategy will be among the future national commitments under the UNFCCC.

A climate strategy for the Russian part of Barents Region is currently under development, under the umbrella of the BEAC. Its design and procedures for implementing adaptation measures are sealed by a 2011 legal act of the government ordinance 'Integrated plan for Climate Doctrine implementation up to 2020' (Russian Federation Government, 2011). This names the government agencies responsible for undertaking adaptation action, including the RF Ministry for natural resources (MinPriroda) with its five agencies (water, forestry, mineral resources, hydrometeorology, environmental inspection), the RF Ministry for economic development (MinEcDev) and sectoral ministries for agriculture, construction and housing, and public health. Detailed responsibilities and tasks are assigned to each. For example, the federal agency for forestry is responsible for minimizing the negative impacts of more wildfires, for assessing related risks and damage, and for designing adaptation measures in forestry within the regions. Establishing a dedicated center for monitoring and assessment of climate change impacts under HydroMet is envisaged to integrate data from existing government and corporate monitoring networks. MinPriroda is to be responsible for organization and institutional coordination of adaptation actions: to develop guidelines for methodology in assessment of climate change impacts and risks in particular sectors, to undertake vulnerability assessments for different regions of Russia, and to design specific response measures. Every federal agency involved in adaptation has its territorial affiliations in the northern federation subjects of the Barents Region which in turn are engaged in direct adaptation actions. Interactions between federal and regional authorities in climate adaptation policy implementation are defined by the general principles of the Russian new federal system of territorial governance established after the collapse of the Soviet Union in 1991.

9.3 Examples of adaptation action within the Barents area

9.3.1 The Barents area in an international context

The Barents area is experiencing rapid environmental change driven by climate change (ACIA, 2004; AMAP, 2011; Arctic Council, 2013b), in parallel with rapid changes in socio-economic systems driven by industrial developments such as extractive industries and tourism, migration and urbanization, new technologies, and economic challenges and opportunities (e.g. Hovelsrud et al., 2011; Nordic Council of Ministers 2011; Larsen and Fondahl 2015; Larsen et al., 2015). General social trends show net outmigration from the rural areas where employment opportunities are reduced, to regional centers

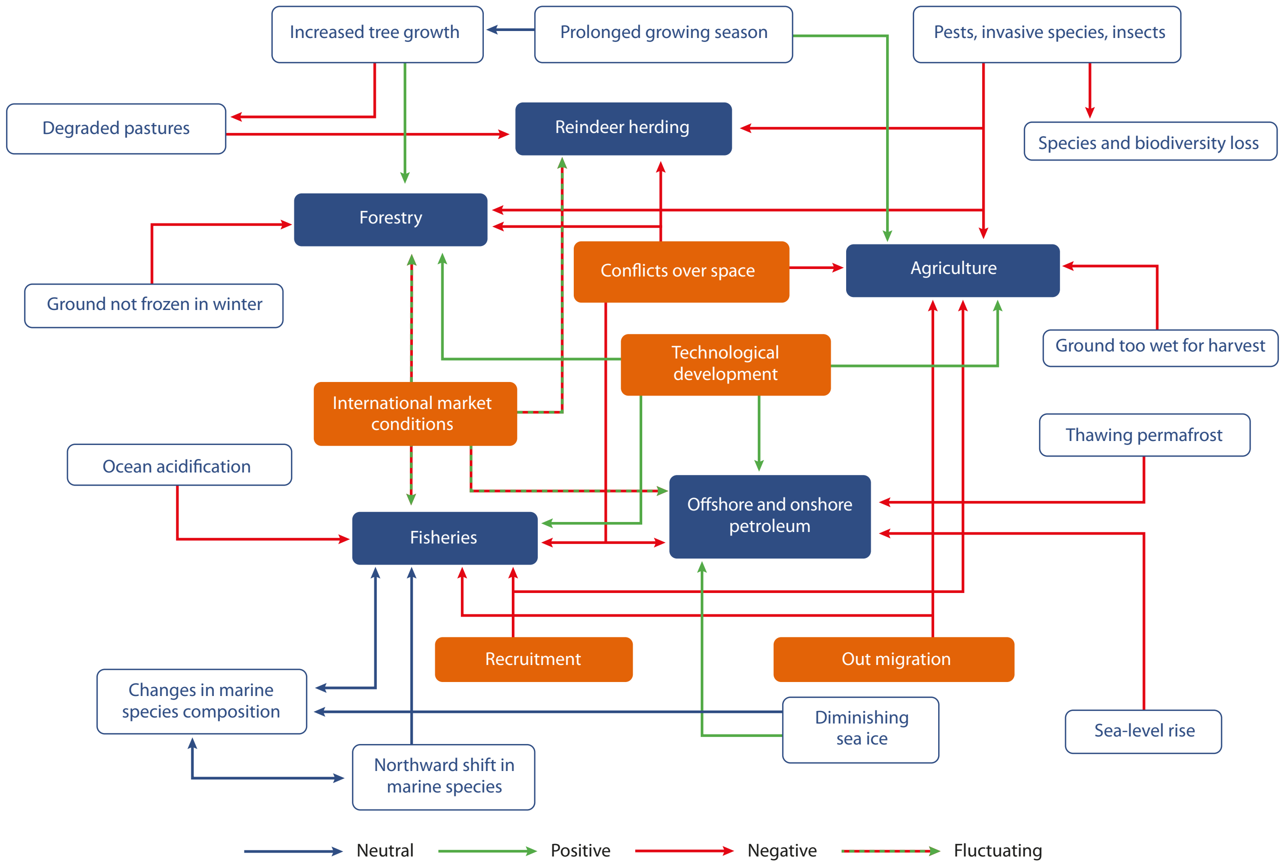


Figure 9.1 Interacting factors and cumulative effects on society from biophysical and socio-economic impacts. Interacting socio-economic drivers of change (orange boxes), effects of climate change impacts on natural systems (white boxes) and the cumulative impacts on a selection of key industries/ sectors (blue boxes). This graphic shows examples of the different impacts and drivers of change and is by no means exhaustive. The purpose of the graphic is to illustrate the complexities, and interactions of cumulative effects (Halvor Dannevig).

in the Barents area where service sector jobs are increasing (e.g. Larsen et al., 2015). Adaptation actions need to take into account all of these interlinked and cumulative changes.

On a global scale the opportunities emerging in the Barents area and the Arctic in general are matched by challenges in other countries, where climate change impacts exacerbate already difficult socio-economic conditions creating substantial challenges for human security (Adger et al., 2014; see also Chapter 10 for a discussion of human security). The indirect effects of climate change elsewhere in the world such as influxes of refugees, lower food production due to drought, and a general decline in the world economy may in turn create serious challenges for the Barents area. The global linkages, therefore, serve as a back-drop for the more immediate concerns and possibilities in the Barents area. The region is also a player in a globalized resource system, and world markets and international trade have implications for the economy and livelihoods. Direct regional and local control is circumscribed by national and supranational regulations, which may affect the room to maneuver and the economic resources available at the local level (tax systems, global markets, buyer and production networks as found in global mining and forestry companies) (see Keskitalo and Southcott, 2015). The Nordic countries are either members of the EU or the European Economic Area, and all four countries are members of the World Trade Organization (WTO) which in effect integrates several economic sectors into European and global trade networks. Examples of interacting changes are many; the reduced global demand for paper for newspapers drives down the price of timber, the market for reindeer meat faces competition from game meat from other regions (such as red deer meat from New Zealand), and the global nature of the fish market directly affects communities in the Barents area (Keskitalo, 2008). This underscores the fact that local conditions are inextricably linked to global forces (e.g. Keskitalo and Southcott, 2015). Across the Barents area, the population in rural settlements is decreasing and conversely is increasing in the regional centers. Jobs in agriculture, forestry and fisheries are in a steady decline. These examples of cumulative effects serve as a point of departure for understanding adaptation actions. The following sections describe the current knowledge and research status on adaptation in the sectors and livelihoods of relevance to the Barents area (see Chapter 2 for a detailed description of the sectors concerned).

9.3.2 Interacting factors and cumulative effects on society

Adaptation research in the Barents area has significantly increased knowledge about the impacts and drivers of change, and the complexity of the interacting factors and cumulative effects on society (Figure 9.1). This includes the impact and responses to change in indigenous and non-indigenous communities and on a wide range of sectors (e.g. Tyler et al., 2007; Hovelsrud and Smit, 2010 and references therein; West and Hovelsrud, 2010; Keskitalo et al., 2011; Dannevig et al., 2015; Jansson et al., 2015). The sectors include, but are not limited to, municipalities, forestry, fisheries, reindeer herding, nature-based tourism, shipping and energy (e.g. Tyler et al., 2007; Keskitalo, 2008; Moen, 2008; Hovelsrud and Smit, 2010; West and Hovelsrud, 2010; Brouder and Lundmark, 2011; Keskitalo et al., 2011; Löf, 2014; Dannevig et al., 2015; Jansson et al., 2015). Understanding the changes that create hazards and risks for communities are of great importance for developing adaptation strategies, and impacts must be seen in relation to demography, outmigration, employment opportunities and access to resources (Hovelsrud and Smit, 2010). Furthermore, changes that may be exacerbated by climate change are filtered through the economic production system and the social and institutional framework conditions (see Table 9.1). Consequences from cumulative impacts affect resource-demand driven by global markets, climate change, pollution, and national, EU and international policies and agreements. It is also likely that tensions and conflicts between competing land use activities and local utilities will increase due to cumulative and interactive consequences from increasingly accelerated land use pressures, climate change, change in biodiversity and changing socio-economic and political drivers. Adapting to interlinked and cumulative changes poses a significant governance challenge, and more effective governance actions and options are needed.

Examples from Russia show that areal conflicts can involve governments, industry (e.g. mineral extraction, logging companies, commercial berry picking), land owners, researchers, and reindeer herders (Stammler and Peskov, 2008; Forbes and Kofinas, 2015). Government priorities at different scales and sectors are likely to generate trade-offs with implications for adaptation. For example, in northern Norway, the government's two-fold objective of preserving biodiversity and maintaining traditional local livelihoods, has implications for sheep farmers' adaptive capacity as they need to respond to a larger predator population on the pasture lands (Risvoll et al., 2016).

A Russian survey of the Barents area shows adaptation measures cover a relatively wide range of issues: flood control, managing inundation risk, emergency rescue, reinforcing coastal infrastructure, application of innovative tools in water resource management under climate change (Archangelsk oblast), diversification of hydro-meteorological monitoring systems to include additional climate change parameters, and increasing the effectiveness of regional environmental and sustainable development policy and thereby strengthening adaptation (Murmansk oblast) (Nikitina, 2013).

The cumulative and interlinked changes that trigger adaptation are associated with changing socio-economic and climatic conditions, which produce both risks and opportunities. The impacts are many and they sometimes interact and accumulate in unexpected ways (see Figure 9.1 for examples) with follow-on consequences for governance and understanding of adaptation options.

9.3.2.1 Agriculture and forestry

Climate trends of relevance to agriculture and forestry include a longer growing season, shorter winters and earlier spring, an increase in precipitation in autumn and summer, and changing snow and ice cover (see Table 9.2) (e.g. Øseth, 2010; Council of Oulu Region, 2010; West and Hovelsrud, 2010; Kvalvik et al., 2011; see also Chapter 6). The consequences of these changes include increased yield, damaged harvests, better growth conditions for trees, sheep on pastures earlier in the season, changes in crop variety, increased pests and diseases, and wetter conditions in the fields. Farmers in northern Norway are cautiously optimistic about future climate change impacts on agriculture, but worried about the prospects of new pests and diseases moving north. Fewer farms with more rented land increase transportation costs, and heavier machinery is needed to cover the distances between the fields cultivated. However, heavy machinery can become unusable if conditions become too wet, which can create unexpected challenges in a situation previously considered an opportunity. The frequency of occasions when conditions are too wet to harvest fodder and produce has increased (Kvalvik et al., 2011). Farmers currently see change in agricultural policy and recruitment to the industry as their main concern, which may be exacerbated by climate change (Kvalvik et al., 2011).

In forestry, cumulative and interacting effects include invasive species and pest outbreaks, and changing storm patterns may result in the need to review and adapt forest management (see Table 9.2). If change is not too rapid then the forest industry will have time to adjust. Carbon sequestration by forests (i.e. forests acting as a 'carbon sink') is considered an opportunity that will increase with the expected increase in forest growth. There is great potential for using more wood for energy and in new materials; more renewable energy is currently produced than used in parts of the Barents area. In multi-use forests, in northern Sweden for example, existing conflicts over land-use between forestry, reindeer husbandry, and environmental protection may be intensified by increased pressures caused by changes in climatic conditions and by economic pressures and structural changes (Keskitalo, 2010b). One reason for this is increasingly unpredictable weather, such as extensive ice cover on pastures that means reindeer must be moved to new areas for grazing (Risvoll and Hovelsrud, 2016), while economic pressures in the forestry sector result in increased logging. Furthermore, forestry may already perceive itself as limited by environmental protection areas (e.g. Keskitalo and Lundmark, 2010).

Winter logging in the Barents area is increasingly challenged because the ground may not be frozen (due to warmer winters) and the heavy forestry machinery is designed for use on frozen ground (technology adapted to frozen conditions) (Keskitalo, 2008; Dannevig et al., 2015). In the Murmansk and Arkhangelsk Oblasts higher temperatures are likely to increase crop yield and the diversity of cultivated crops (Berdin et al., 2009; Kokorin et al., 2013; Roshydromet, 2014). However, while higher temperatures increase tree growth they also result in changes in species composition and increase the risk of pest and insect attacks (Jansson et al., 2015). Under the IPCC RCP8.5 scenario the fire-risk season in some parts of Arkhangelsk Oblast is expected to increase by 30 to 49 days by the end of the 21st

Table 9.2 Examples of exposure-sensitivities and adaptive strategies in selected sectors.

Sector	Climate change effects/ Exposure-sensitivities	Adaptive actions and strategies	References
Forestry	Warmer winters limit winter logging due to lack of frozen winter roads	Build year round roads, intensify forestry, detailed planning of routes for forestry machines to avoid rutting of soil	Keskitalo, 2008, 2010c, 2016; Dannevig et al., 2015; Jansson et al., 2015
	Warmer summers cause fires and drought	Changes in forest management	Keskitalo, 2008, 2010c, 2016; Dannevig et al., 2015; Jansson et al., 2015
	Pests and diseases	Increase pest control, new pest resistant species, changes in forest management	Keskitalo, 2008, 2010c, 2016; Jansson et al., 2015
	Increased tree growth	Increased outtake	Keskitalo, 2010c, 2016; Jansson et al., 2015
Agriculture	Longer growing season	Try new, higher yielding grass varieties	Kvalvik et al., 2011; Uleberg et al., 2014
	Wetter conditions hamper harvest	Better field drainage, lighter equipment	Kvalvik et al., 2011; Uleberg et al., 2014
Reindeer husbandry	Reindeer grazing limited by winter thaw. Impact on migration	Supplementary feeding, reorganize husbandry practices, modify legislative and support framework	Kumpula and Colpaert, 2007; Keskitalo, 2008, 2010c; Turunen and Vuojala-Magga, 2014; Dannevig et al., 2015; Jansson et al., 2015; Rasmus et al., 2016; Risvoll and Hovelsrud, 2016; Turunen et al., 2016
	Loss of reindeer due to new pests and diseases	Develop counteract strategies, medication and compensation for losses	Laaksonen et al., 2010
	Tundra replaced by shrub land	Reorganize husbandry practices	Keskitalo, 2010c; Turunen et al., 2016
Winter tourism	Shorter season, unpredictable snow cover	Marketing and product development	Keskitalo, 2008; Dannevig et al., 2015
Coastal fisheries	Northward shift in fish stocks	Require response from fish buyer, mandate changes in regulation	Hovelsrud et al., 2010b; Drinkwater, 2011
	Ocean acidification	More knowledge needed	AMAP, 2013
Aquaculture	Ocean acidification	More knowledge needed	AMAP, 2013
Marine operations	Less sea ice increases access for shipping and petroleum exploration, which increases exposure to storms and severe icing events	Better forecasting, new industry standards, technology	Meier et al., 2011

century, partly through an increase in extreme weather events, such as strong winds and drought (Roshydromet, 2014).

Studies from communities in Varanger, northern Norway, where the majority are coastal Sámi, highlight the ways species respond differently to rising temperature, with cumulative effects for communities. Warmer winters have increased larvae outbreaks of autumnal moth (*Epirrita autumnata*) and winter moth (*Operophtera brumata*), leading to birch defoliation and, after consecutive years of moth larvae attacks, extensive areas of dead birch forests (Rybråten and Hovelsrud, 2010; Jepsen et al., 2013; Rybråten, 2013). This deforestation has profound impacts on the birch forest ecosystem and the available local resources. The moth larvae outbreaks have destroyed previously important berry localities, thereby decreasing the local berry harvest. While some people have responded by travelling long distances to pick berries elsewhere, others rely on getting berries through barter or as gifts (Rybråten and Hovelsrud, 2010; Rybråten, 2013).

For farmers and reindeer herders, impacts on the understory layer in the affected birch forests have implications for pasture rotation for sheep and semi-domesticated reindeer. While some sheep farmers experience an immediate positive effect on summer pastures due to an increased abundance of grass, farmers are nonetheless concerned about the possible long-term effect of an eventual increase in future moth larvae outbreaks (Rybråten and Hovelsrud, 2010; Rybråten, 2013). As the affected birch forests form part of the autumn and winter reindeer pastures, reindeer herders are concerned about a gradual displacement from lichen to grass in the winter pastures, eventually reducing the nutritious value of this pasture (Rybråten and Hovelsrud, 2010). The reindeer also prefer grazing in areas least impacted by moth larvae outbreaks. The outbreaks seem to have reduced the reindeer pasture quality (Jepsen et al., 2013). Moth attacks on the birch forests have caused local concern about consequences for the ecosystem as a whole, and reductions in the local moose (*Alces alces*) and ptarmigan (*Lagopus lagopus*) populations have been linked to a possible decline in their choice of feed. With further warming, particularly in winter, moth larvae outbreaks may occur more frequently in northern areas, causing further challenges for the Varanger birch forest ecosystem and coastal Sámi traditional livelihoods.

Adaptation in agriculture and forestry is primarily a response to changes in economic, structural and social factors (see Keskitalo, 2010c), and to a lesser degree to climate change impacts (Hovelsrud et al., 2010b). Adaptation action is shaped by the local context of fewer jobs within sectors, coupled with an increased focus on technological adaptations (such as more drainage ditches along fields to adapt to wetter conditions) (Kvalvik et al., 2011). Current adaptation strategies in forestry largely focus on increasing or maintaining wood production levels through building year-round roads and modernizing machine parks to ensure logging in varying weather conditions. In northern Russia the increased risk of wildfires, which affects reindeer husbandry and forestry, has helped improve the coordination of effort between regional and local government bodies responsible for forest fire protection. Reducing wildfire risk has been included in regulatory measures (technical instructions and guidelines, plans and regulations for the local forestry service, local integrated schemes of fire mitigation) and practical adaptation measures (maintenance of local fire-monitoring sites, upgraded fire-protection equipment, ensuring access to water reservoirs, professional staff, aircraft used in fire mitigation) (Rosleshoz, 2016; ARSPAS, 2017). Fire protection operational activities increasingly use local weather forecasts, data on precipitation patterns, and land use monitoring from space.

Adaptation actions with attention to resilient land use, such as diversified cropping, and the economic feasibility of adaptation may play a key role in improving adaptive capacity of agriculture in the north (Himanen et al., 2012). The importance of plant breeding is likely to increase, to ensure that plants are adapted to the local growing conditions, including longer days, higher temperatures, and more variable seasonal conditions (Peltonen-Sainio et al., 2009; Uleberg et al., 2014). Adaptation strategies among sheep farmers in Finnmark include replacing sheep breeds with those that have a better natural instinct to protect themselves from the increasing number of predators (Rybråten and Hovelsrud, 2010).

Attention to diversity within the agriculture sector may also be necessary to avoid negative consequences of adaptation activities. Greater diversity in farm type reduces impacts of climate variability for the sector at the regional level, but some farm types may still be vulnerable. Socio-economic conditions, how farmers manage their farms, agricultural policy and regulations management strongly influence current farm performance and are also likely to influence adaptation to future change (Reidsmaa et al., 2010; Kvalvik et al., 2011).

9.3.2.2 Reindeer husbandry

Interlinked changes are creating challenges for reindeer husbandry (see also Box 9.1 and Chapter 7). Reindeer husbandry is particularly sensitive to climate change because the animals often rely on natural grazing all year round (see Table 9.2). Future concerns in reindeer husbandry include heat stress, predators, disease, parasites, and insect harassment, as well as competition with other land uses, such as forestry (Bulgakova, 2010; Moen and Keskitalo, 2010; Turunen et al., 2016). Reindeer herders are reporting warmer winter conditions and more thawing then re-freezing events (Maynard et al., 2010; Risvoll and Hovelsrud, 2016). Such events, which are characterized by snow melt followed by rain and a subsequent drop in temperatures below freezing, have increased in the last decades and limit pasture access (Oskal et al., 2009; Keskitalo, 2010b,c; Dannevig et al., 2015; Risvoll and Hovelsrud, 2016). Ice crusts make it difficult for reindeer to access forage and herders either need to move the animals to alternative pastures or must compensate with additional fodder, which is costly (Keskitalo, 2008; Dannevig et al., 2015; Risvoll, 2015).

In Russia, increased risk of tundra and forest-tundra fires during dry summer periods adds to the growing vulnerability of local communities and reindeer herders (Shvidenko and Nilsson, 2000). Reindeer pastures are regularly damaged by fire and local people involved in rescuing reindeer are exposed to serious risk. Research in the Yamalo-Nenets Autonomous Okrug (YNAO), the Nenets Autonomous Okrug (NAO) and Murmansk Oblast found that reindeer herders are observing an increased frequency in extreme weather events (Bulgakova, 2010; ACIA, 2005). Herders are expressing concern about reindeer herding in the future due to the cumulative effects of climate change, changes in management regulations, widespread damage from the extractive industries, and the added consequence of their adaptive strategies being less applicable (ACIA, 2005; Bulgakova, 2010; Martynova and Novikova, 2012). On the other hand, reindeer herders in these areas retain high resilience to the current changes because they are actively developing adaptive strategies to the many new challenges (Forbes et al., 2009; Forbes, 2013).

It is worth repeating that it is not a changing climate in itself that is the main challenge for reindeer herding. Research shows that non-climatic challenges, such as decreasing access to pasture through encroachment, market conditions and changes in policy are key concerns among reindeer herders (Tyler et al., 2007; Keskitalo, 2008; Ulvevadet and Hausner, 2011; Jaakkola et al., 2013; Jansson et al., 2015), and together it is these changes that are affecting the opportunities for adaptation available to herders (see also Chapter 7).

The area used as reindeer pasture is steadily diminishing or being disrupted through multi-level challenges such as increased predator numbers, industrial development, urbanization, institutional barriers, and increasing temperatures (Tyler et al., 2007; Oskal et al., 2009; Risvoll and Hovelsrud, 2016). For reindeer husbandry, these factors either individually or combined lead to fragmentation of pastures, and together with the increasingly unstable and unpredictable weather conditions constrain mobility and flexibility, which in turn affects adaptive capacity. Fragmented pastures also exacerbate the impact of climate change, as the latter is expected to make pastoral mobility progressively critical (Homewood et al., 2012). In Finnish reindeer husbandry, keeping reindeer in pens is an adaptation strategy in some areas (Keskitalo, 2008, 2010c).

Historically, reindeer herders have relied on experience, knowledge, and flexibility to respond to changing conditions, including herd composition, and changed migration timing and routes (Tyler et al., 2007; Riseth et al., 2011). Research in Nordland, northern Norway shows reindeer herders change traditional migration patterns by using coastal pastures during winters with unfavorable icy conditions (Risvoll and Hovelsrud, 2016). Adaptation strategies in reindeer husbandry concern the maintenance of herds (and thereby meat production), and include supplementary feeding during difficult weather conditions, and a call for financial compensation for these supplementary feeding costs (Keskitalo, 2008; Dannevig et al., 2015; Risvoll and Hovelsrud 2016) or for unexpected losses of animals due to new pests and diseases (Laaksonen et al., 2010). The economic costs of supplementary feeding, as well as the rising cost of reindeer surveillance by snowmobile or helicopter, or transport by trailer truck as a new form of reindeer migration,

Box 9.1 Adaptation tools and options in reindeer husbandry

The main challenges for reindeer herding in the Barents area at present and in the near future (by 2030) concern cumulative and interacting impacts of a warming climate, accelerated resource demand by other land use activities, losses due to predators, industrialization, urbanization, institutional barriers, generational change and limited possibilities for herders to influence policymaking. Adaptation strategies that aim to secure reindeer herding as a viable livelihood and culture is important throughout the Barents area (Finnish Ministry of Agriculture and Forestry, 2005, 2014). In Sweden, reindeer husbandry plans are developed in parallel with forest management plans. In preparing the plans, reindeer movements have been tracked using GPS collars to identify the range of land used by the herds. A recently developed centralized GIS database of reindeer herding districts and land-use activities combined with satellite inventories of pasture resources aims to provide a tool for land-use planning of reindeer husbandry in Nordic countries (Sandström et al., 2012, Oinonen et al., 2014; Shemeikka et al., 2014). This centralized database will combine the knowledge of reindeer herders, land-use authorities and researchers. Reindeer herding's EIA (Environmental Impact Assessment) guide is another example of tools for improving participatory planning between reindeer husbandry and other land-use activities in Finland (RHA, 2014), as are the use of guidelines that secure both indigenous use and environmental protection (Secretariat of the Convention on Biological Diversity, 2004). An example of co-management in Norway includes a new conservation model, which provides a mechanism for local participation in protected area governance. Reindeer herders are now participating in decision-making processes with different actors related to national parks where they have pasture access. While challenges still exist, there are promising opportunities for co-production of knowledge and social learning among stakeholders involved in protected area governance (e.g. Risvoll et al., 2014).

Adaptation options used on a daily basis in reindeer husbandry in the Barents area vary greatly by area and include managing herd structure and reindeer numbers, selecting animals for slaughter and breeding, supplementary feeding, seasonal pasture rotation, and use of reserve pastures (Keskitalo, 2008; Saijets and Helander-Renvall, 2009; Helander-Renvall, 2014; Turunen and Vuojala-Magga, 2014). The ability of reindeer herding communities to respond to disturbance and change depends strongly on regulations concerning land and water use, social and economic capital, and aspects of governance. The elements promoting adaptation include local and traditional knowledge, social networks, dynamic working structures, flexibility regarding access and use of pasture areas, and trade and collaboration between communities (Tyler et al., 2007; Brännlund and Axelsson 2011; Helander-Renvall, 2014). Moreover, participating in boards and committees relevant to reindeer husbandry is an important strategy for herders to secure their rights. Nevertheless, participation brings tradeoffs because these activities take herders away from time spent tending their herd on the pastures (Risvoll and Hovelsrud, 2016). Options for future diversification within and beyond reindeer husbandry have been examined. Direct selling and refining of meat products, re-use and recycling of waste materials, design and handicraft, reindeer tourism, and combination with other livelihood activities may support the viability of reindeer husbandry (Rantamäki-Lahtinen, 2008).

> *"When it comes to climate change, it is our view that the less reindeer and reindeer herding are disturbed (by other land use), the better resources and capacity they have to adjust to consequences of climate change, for example by means of undisturbed grazing lands"*
> Representative of management in Finland (2015).

Carl-Johan Utsi

Reindeer at Larkim, northern Sweden. Kebnekaise mountain in the background may increase to the extent that they become a limiting factor for adaptive capacity in reindeer husbandry. While it is possible to maintain herd numbers through supplementary feeding, individual reindeer herders must either carry the cost, or receive financial support. And, although money to compensate for financial loss is important, it cannot cover cultural losses from the integrated challenges facing reindeer herders and their communities (see also Chapter 7).

To ensure the best possible conditions for husbandry, herders are increasingly seeking to influence decision-making through lobbying and participation in the decision making process (Hukkinen et al., 2006; Keskitalo, 2008; Rybråten and Hovelsrud, 2010; Risvoll, 2015). Reindeer herding is known to be highly adaptive to changing conditions, however this capacity is reliant on the flexibility to move between pasture areas, and to change herding practices and organization. Increasingly these mechanisms are diminishing in applicability (see also Chapter 3). For instance, flexibility to move reindeer between seasonal pastures and to alternate pastures under unfavorable conditions is crucial for reindeer herders, and when this is not possible adaptation options are reduced (Turi and Keskitalo, 2014; Risvoll and Hovelsrud, 2016).

9.3.2.3 Fisheries

Large-scale fisheries and small-scale coastal fisheries differ in their capacity to adapt to changes in the distribution of fish species. The large-scale fisheries have a greater capacity to follow the fish than coastal fishing vessels, and are perhaps more adaptive to these particular changes (Hovelsrud et al., 2010b). The focus here is thus on the interacting and cumulative effects of changing conditions on coastal fisheries (see also Table 9.2).

Trends and shifts in fish stocks in the Barents Sea are described in Chapters 2 and 6. They include northward shifts in economically important fish stocks such as those for cod (*Gadhus morea*) and pollock (*Pollachius virens*) (Drinkwater, 2011), as well as shifts in the distribution and migratory patterns of less regionally common species such as mackerel (*Scomber scombrus*) and the arrival of new fish species due to the warming ocean (Sundby, 2015). Further warming could lead to a continued eastward and northward shift, taking stocks beyond the Norwegian Economic Zone, to the benefit of Russian fishers. However, there is a high level of uncertainty regarding whether climate change may create more favorable conditions for fisheries in the Russian part of the Barents Sea (Kokorin et al., 2013). The current state of scientific knowledge on the Russian Arctic waters is not yet enough to clearly determine the consequences of climate change for commercial fisheries (Roshydromet, 2014) and there is a need for more research and monitoring of fish stocks in the Russian waters of the Barents Sea. Fish quotas and policy shifts are crucial for analyzing cumulative and interacting effects on coastal fisheries. Local and regional fishery resources could play a less important role in regional and local economic development in northern Norway, if the ownership of fish quotas is transferred out of the region, and catches are not landed locally, both likely outcomes of a current policy proposal (Norwegian Ministry of Trade and Industry, 2014).

The cumulative and interacting effects that require adaptation action in coastal fisheries include the northward shift of fish species due to warmer waters. The coastal fishers themselves are seeing this northward shift, and are adapting to it (Hovelsrud et al., 2010b). The adaptive strategies are contingent on various factors including the regulatory framework, available fishing technology, market price and available fish landing facilities (Hovelsrud et al., 2010b; West and Hovelsrud, 2010). Case studies in northern Norway show that in some years, coastal fishers have had to travel further out to sea and find new places to fish, where their local knowledge is not as useful (Keskitalo, 2008; Hovelsrud et al., 2010b; West and Hovelsrud, 2010). Recent years have seen record catches and profits due to large quotas and good prices, which has been attributed to warmer conditions and thus higher marine productivity (Sundby, 2015). However, a continued northward shift in important commercial species will require vessels large enough to travel longer distances to fish, such as from the Lofoten Island to the Finnmark coast, and the ability to deliver the catch in new places. But quota regulation limits the size of vessels and parts of the allowable catch of cod is reserved for smaller vessels. In addition, Norwegian coastal fishing vessels are insured to a certain distance from shore, with implications for fishers if the targeted stocks are located further out to sea. The land-based fish processing industry south of Finnmark, adapts to the fish being landed in new locations further north by for example transporting the fish to the production facilities by lorry (Hovelsrud et al., 2010b). When fishers land their catch in new communities the income from fisheries is reduced elsewhere, and local jobs may be lost as a consequence. This in turn reduces the municipal tax base, resulting in fewer financial resources for the municipality, which could in turn affect schools and health care (Keskitalo, 2008; Hovelsrud et al., 2010b). The fishing industry is accustomed to variability in resource and market conditions and has over time established mechanisms for handling this, for example through innovation in products and an increase in productivity through technological development (Hovelsrud et al., 2010b, 2015).

As the production from mature oil fields in the North Sea is slowing, attention to northern Norway as the next largest petroleum province in Norway is increasing. Oil prices will affect the rate of development in this region. The declining Arctic sea ice is expected to result in new areas for petroleum exploration (Harsem et al., 2011), but the societal impact of this development may be both positive and negative (Duhaime et al., 2004; Kumpula et al., 2011). An increase in offshore petroleum activity is worrying for fishers because petroleum exploration and production competes with fisheries over space (Kristoffersen and Dale, 2014).

9.3.2.4 Public sector

Climate change adaptation in the public sector, at municipal and county level, primarily addresses extreme events resulting in flooding, avalanches, wind damage, storm surge, closed roads, infrastructure damage, and harm to the population (Hovelsrud et al., 2010b; Keskitalo, 2010b; Tennberg et al., 2010, 2017; Vuojala-Magga and Turunen, 2013). In the Russian North, sea-level rise and ice jams in rivers are expected to result in more frequent and severe flooding (Berdin et al., 2009; Anisimov and Kokorev, 2013; Kokorin et al., 2013), particularly in the Severnaya Dvina and Pechora rivers and in the cities of Naryan-Mar and Arkhangelsk, located on their bays (Anisimov and Kokorev, 2013). Suggested adaptation measures for floods in the Russian Barents area include coastal protection, construction of flood protection systems, building relocation, and drainage works. The responsibility for land use planning makes local governments in Norway, Sweden and Finland key actors for adaptation governance (Norwegian Ministry of the Environment, 2010; Dannevig et al., 2013). The regional and local governments have several tools available for climate adaptation planning, such as spatial or land use planning, risk and vulnerability assessments (RVAs) and various management plans. Local governments are required to consider climate change, including sea-level rise, storm surges and flooding, when carrying out mandatory RVAs tied to spatial planning. Municipal RVAs may identify flood risks, and increase understanding of climate risks (e.g. Mossberg Sonnek et al., 2013). However, research in Sweden has shown that given the broad scope of RVAs it is sometimes difficult to fully include climate change (Mossberg Sonnek et al., 2013). In Norway, governmental agencies, county council, county governors and municipalities are producing plans and climate change risk assessments that can aid adaptation. Designated tools, mandatory in spatial planning are the flood maps produced by the Norwegian Water and Energy Directorate which include climate change projections, and the tables for sea-level rise and increase in storm surge produced by the Norwegian Directorate for Civil Protection. At the local level, a reactive approach to adaptation is often the case when considering how adaptation reaches the municipal agenda, i.e. municipalities with experience of extreme weather events are more concerned with climate and weather (Amundsen et al., 2010; Rauken and Kelman, 2010; Dannevig et al., 2012). However, access to researchers and networks has been shown to have a stronger influence on the amount and type of adaptation action, compared to size, and financial and human resources (Dannevig et al., 2012, 2013).

Flooding has been a major issue considered in connection to climate change in northern Finland and in Sweden. In both countries, this has largely been associated with the requirements of the EU Water Framework Directive and the EU Floods Directive. Flood protection plans for major river areas were developed in the period 2013–2015. Flood levels are not projected to increase significantly in the near future (2030), and may even decrease by 2080 in northern Finland. Concerns about future flood risk include those associated with city floods following extreme precipitation, and autumn/winter floods (rather than the spring floods more typical of the current climate) (Veijalainen, 2014). Municipalities are major actors in developing and implementing flood protection measures locally, such as land use planning, permission and technical requirements for buildings, and the building of flood banks and other flood protection measures (Tennberg et al., 2017).

The adaptation focus in local governments at the time of this assessment is largely *ad hoc* and depends in many cases on engaged individual(s), as well as physical evidence and observations of climate change, extreme events and contact with researchers (Dannevig et al., 2013). For example, the municipal master plan in Hammerfest municipality, northern Norway, includes attention to future sea-level rise, which is not the case in most other municipalities (Stokke, 2014). In addition to engaged officials in the municipal administration, this work is also driven by collaboration with researchers and the ability to build networks with relevant actors (Dannevig et al., 2013; Stokke, 2014). The close relationship between vulnerability and adaptation is illustrated by Hammerfest municipality's activities to reduce its vulnerability to avalanches, and by including adaptation in policy and planning documents (Angell and Stokke, 2014).

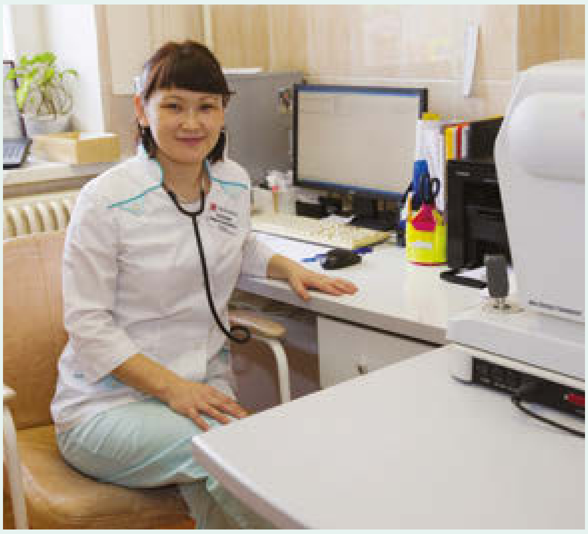
In Norrbotten and Västerbotten, Sweden, the focus on potential impacts and adaptation includes communications and communications infrastructure, technical supply systems, built-up areas and buildings, land-based industries and tourism, natural environment, and health, including effects on water catchments (County Administrative Board of Norrbotten, 2010, 2012). A 2007 report on climate change and urban planning provides recommendations for physical planning and new constructions in flood risk area, suggesting that a risk analysis should be conducted and measures taken to mitigate consequences of high water levels (County Administrative Board of Västerbotten, 2007). This would include attention to climate change impacts in land use planning, in planning for energy supply, roads and railways, and to account for natural disasters (County Administrative Board, 2006; County Administrative Board of Västerbotten, 2007). It was also noted that the municipalities need to undertake more detailed investigations of areas at risk of flooding, landslides or mudslides, and to update flood maps and information pertaining to soil stability, such as related to risk of landslides (County Administrative Board of Västerbotten, 2007). However, even in cases where there has been increased attention towards natural hazard mitigation, such as flood or avalanche risk reduction measures, this is not necessarily driven by anticipation of climate change. Haparanda, a municipality situated in the Swedish-Finnish Torne River valley has been rated as one of Sweden's 18 flood risk areas under the EU Floods Directive. Projects arising from EU directives could well drive the development of flood risk mitigation, adding resources to otherwise limited emergency response structures, but largely omitting the adaptation context (Keskitalo et al., 2013).

9.3.2.5 Health

Climate change, changing patterns of resource extraction and accompanying infrastructure will pose new challenges and threats to public and animal health in the Barents area. In the Nordic countries this is an emerging topic for study. The 2014 Arctic Human Development Report showed the geographic range of diseases and infections has extended northward as a consequence of climate change and globalization (Rautio et al., 2014). Shipping, tourism and infrastructure used for extractive industries enhance the spread of disease, while a warmer climate enables disease vectors to live in new areas. Zoonotic infectious diseases including tularemia, tick-born encephalitis, brucellosis (and to a degree rabies and anthrax) are increasing among humans and domestic animals in Arctic Russia (Revich et al., 2012). New and changing patterns of disease and infection in the Barents area are likely to place increasing demands on public health services and to call for disease prevention strategies as well as accessible health care and (veterinary) services across the region (Rautio et al., 2014).

Box 9.2 Russian adaptive governance and health

In Russia, there is growing understanding that adaptive governance is an integral part of regional sustainable development strategies in the North (Nikitina, 2011) and that *coordination* between a broad range of institutions is essential. Coordination practices are currently at an early stage of development, but useful insights from northern Russia are emerging and lessons learned can be widely disseminated. *Adaptation to climate change impacts on health of population in Archangelsk oblast and Nenets Autonomous Okrug (NAO)* (Sidorov et al., 2012) is an innovative program developed as a result of the international WHO project on climate change impacts on public health and adaptation options in northern Russia (WHO, 2009). It coordinates adaptive governance efforts by regional institutions responsible for health care, and includes a combination of multi-sectoral strategies and actions; the cluster of the Ministry of Health of Archangelsk oblast, Northern State Medical University, Territorial branch of Rospotrebnadzor, Emercom Regional administration, RosHydromet administration for the North, and the Department for Social Protection and other regional executive authorities. Currently this is a unique regional adaptation program targeting the incorporation of multi-sectoral adaptive management tools, which takes local and regional differences and contexts into account (Roshydromet, 2014). Its strategic approach to coordinate practices under climate change between the Ministry of Health of Archangelsk oblast and Emercom is also valid for other countries in the Barents area as it aims to diversify medical care infrastructure in remote areas of the NAO and create mobile medical units and sanitary laboratories to handle emergencies expected from the growing intensity of river floods. Detailed operational data, early warning and heat wave forecasts from regional RosHydromet allows the health care services to take practical actions and adjust to emergency situations. Examples of coordinated institutional action towards adaptive governance include longer working hours for local medical centers, additional mobile medical services to the northern communities, and user-friendly information related to risks of heat stress, especially for vulnerable social groups such as children and elders.



B&C Alexander / ArcticPhoto

Olesya Serotetto, a Nenets woman from a reindeer herding family, works as a nurse in the hospital in Yar-Sale, Yamal-Nenets Autonomous Okrug, Russia

In a study of tularemia in a boreal forest area in Sweden, Rydén et al. (2012) found a significant correlation between mosquito prevalence and the number of human tularemia cases. The study suggests that warm summers are important for the replication of the infectious agent of tularemia. In addition, outdoor activities such as berry picking, hiking and hunting, common throughout the Barents area, increase exposure to mosquitoes. Rydén et al. (2012) suggested that it is possible to identify geographical areas associated with tularemia where specific disease prevention measures could be undertaken.

Different aspects of climate change and animal health, particularly among reindeer have been studied in Norway, Sweden and Finland. Laaksonen et al. (2010) found that warm episodes promote severe outbreaks of the parasitic worm *Setaria tundra*, in Finland. Other factors such as the characteristics of summer pastures and herd density also influence the emergence and outbreak of the disease. Tryland et al. (2016) conducted a survey among reindeer herders in Norway and Sweden concerning local knowledge of infectious keratoconjunctivitis (IKC) a contagious eye disease affecting reindeers. If left untreated IKC can result in permanent blindness and therefore cause mortalities. Herding, gathering, transporting and handling stress the animals and can have negative impacts on the immune system, rendering the reindeer more susceptible to infections and disease (Tryland et al., 2016). Climate change is affecting access, quality and availability of winter pastures and reindeer husbandry has adapted by supplementary feeding of animals often in corrals. Supplementary feeding is likely to expose the herd to stress and reduce their immune response; contact between animals can also spread outbreaks of disease more rapidly. The study points to greater access to veterinary services and increased knowledge about the treatment of IKC as necessary adaptation measures (Tryland et al., 2016).

Negative impacts of climate change on health in the Russian Barents area, include tick borne encephalitis, which has increased in the Arkhangelsk Oblast and will require adaptation measures by local government (Roshydromet, 2014). Measures include enhancing epidemiological surveillance and the development of preventive measures and interagency cooperation, especially between services concerned with weather/climate, health, and social welfare. An innovative program *Adaptation strategy to climate change impacts on health of population in Archangelsk oblast and Nenets Autonomous Okrug (NAO)* has been in place since 2012 (see Box 9.2). The program aims at developing medical care infrastructure and better preparedness for emergencies such as floods. It involves the Ministry of health for Archangelsk Oblast, the northern state medical university, the territorial branch of Rospotrebnadzor, Emercom Regional administration, the RosHydromet administration for the North, the Department for social protection, and other regional executive authorities.

9.3.2.6 Tourism

The Arctic is an increasingly popular tourist destination (Hall and Saarinen, 2010), and tourism has become one of the main industries in many communities in the Barents area, although with great regional variability. Winter tourism, with attractions such as the northern lights, skiing and other snow-related activities, is especially important (see Table 9.2). Changes in winter conditions, particularly a shorter snow season, will have negative consequences for tourism, while warmer summers may be beneficial. Seasonal changes may bring opportunities and challenges (Ministry of the Environment and Statistics Finland, 2013) and both will require adaptation.

The Murmansk Oblast, Russia, has the greatest potential for tourism (Berdin et al., 2009). The number of tourists visiting the Kola Peninsula and its nature reserves in summer is expected to increase due to higher temperatures (Kokorin et al., 2013). This might lead to the development of summer recreational activities in the Murmansk Oblast, including ecotourism and Arctic cruises, due to a longer season for navigating the Northern Sea Route (Berdin et al., 2009). However, warmer winters and more extreme weather events could have negative impacts on the prospects for winter tourism in the Murmansk Oblast. Cruise operators along the Norwegian coast are concerned that regrowth of trees may obscure the cultural landscape (Fyhri et al., 2009). Tourism operators are quick to respond when opportunities arise, such as the recent whale influx outside Tromsø and the rapid development of whale tourism products (Norum et al., 2016).

Kietäväinen and Tuulentie (2013) found climate change is an abstract problem among tourism entrepreneurs in northern Finland. This corresponds with studies in northern Sweden (Keskitalo, 2010b,c) and northern Norway (Rauken et al., 2010) which indicate that the main concerns are the weather and seasonal change. Whether or not climate change is considered a problem varies among operators, within and between tourist destinations. It also varies with the capacity to turn challenges into opportunities (for example "seeing the icebergs before they melt"). On the other hand, the threat of shorter winters and delayed snow cover are motivating tourist centers and entrepreneurs in northern Finland to adapt by developing a more versatile range of services, including indoor activities, and snow storing and production of artificial snow (Kietäväinen and Tuulentie, 2013). Seasonality is a consideration for the tourism sector in the Barents area, and increased uncertainty about snowfall has led some winter tourism businesses to consider expanding into summer tourism (Keskitalo, 2010c; Keskitalo et al., 2014). In Gällivare municipality, northern Sweden, nature-based tourism actors have largely focused adaptation efforts on those economic factors that affect the viability of the sector (Keskitalo, 2008, 2010c). The extent to which climate and weather conditions were taken into account depended on their influence on economic factors. Research in northern Norway found similar trends, that weather and climate aspects were not the primary concern for tourism operators, since the region is not generally attracting tourists because of its nice weather (Rauken et al., 2010).

While tourists are attracted to the Barents area, accessibility by air or train are major constraints in some areas. In addition, future climate policy may affect transportation costs (especially for air traffic) and environmental policy may restrict cruise ship tourism. Furthermore, despite current growth in the industry it is unlikely that tourism will create a sustained high level of income and job creation in many northern communities (Müller and Jansson, 2007; Amundsen 2012). There is also the possibility that growing environmental awareness in consumers may affect tourism demand (Norum et al., 2016). Alongside an increase in marine cruise and expedition tourism due to less sea ice and more accessible sea routes, is the issue of invasive species and the need for environmental guidelines (Hall et al., 2010). This highlights the need for better understanding of the systemic effects of tourism-related climate change adaptation and mitigation policy on the environment (Hall et al., 2010). From a destination perspective, adaptation requires more than a consideration of economic, social and environmental vulnerabilities, it brings the need to consider the extent to which constructed place branding and images remain appropriate and acceptable to the local context (Nyseth and Viken, 2009; Amundsen, 2012; Tervo-Kankare et al., 2013; Hall, 2014).

9.3.2.7 Energy and extractive industries

The Barents area is an important energy province with follow-on changes, challenges and opportunities for the region and its communities (see also Chapter 6). For example, the development of the *Snøhvit* gas field north of Finnmark in Norway has spurred an economic boom in the city of Hammerfest and the surrounding region of western Finnmark. In response, the Norwegian Government presented two strategies for the development of Norway's northern regions centered on resource development, the relationship between Norway and Russia, and regional economic development (Norwegian Ministry of Foreign Affairs, 2006, 2009), the High North White Paper in 2011 (Norwegian Ministry of Foreign Affairs, 2011) and the follow-up report 'Nordkloden' in 2014 (Norwegian Ministry of Foreign Affairs, 2014). In this context, the declining sea ice and increasingly ice-free Arctic Ocean is framed as an economic opportunity due to increased accessibility to the Northern Sea Route and new areas for oil and gas exploration (Norwegian Ministry of Foreign Affairs, 2014). The idea of opportunistic adaptation pertains to how the economic benefits of climate change supersede the need to address the causes of climate change (Kristoffersen, 2015). While Hammerfest will benefit from the production phase of the new *Goliat* oil field, the prospects for oil and gas development in other parts of the Norwegian Barents area are less clear, as plummeting markets for oil and gas have halted further field development. Although climate change provides opportunities for increased petroleum activity in the Barents area, weather conditions in the Barents Sea area pose a threat to equipment and marine operations (Kristoffersen, 2014). For example, storms, polar lows and icing events have led to shut down and damage at the *Snøhvit* LNG plant in Hammerfest (Hovelsrud et al., 2010b), requiring adaptive measures.

In the official Russian discourse, climate change is perceived as an opportunity for offshore oil and gas development, especially in the Barents and Kara seas. The development of offshore Arctic resources has high priority in the official plans (Poussenkova, 2011; Norwegian Ministry of the Environment, 2013). Offshore production has only started in the *Prirazlomnoe* oil field in the Pechora Sea. Development of the ambitious *Shtockman* gas and condensate field in the Barents Sea was put on hold due to market

Box 9.3 Adaptation actions in the mining sector – opportunities and challenges

Mining activities depend strongly on the global demand for raw materials and changes in global mineral and metal market prices. The impacts of climate change create challenges and opportunities for mining (Pearce et al., 2009). The mining industry has developed adaptation guidelines (Nelson and Schuchard, 2011; ICMM, 2013) in order to enhance good practice in the industry in the face of climate change. In the Barents area, the most important climate factors are rising temperatures and changing hydrological conditions. Many of the required engineering solutions already exist but the economic benefits are not necessarily perceived; investing in strengthened holding facilities is expensive, but the costs of extreme storm events may be even higher (Pearce et al., 2009). According to a study at Kittilä mine in Finland (Chapter 6), modelling and forecasting the water balance will become even more important in the future, and could become the greatest challenge for mining in the Arctic region. The mining managers need to assess the amount of water flowing to the mine per unit time and make firm decisions on how to manage the water balance. In the future, modelling will be important especially for the snow melt period when water volume in the mine area increases. This may occur at different times of the year and at different intervals during spring. Risk management of a mine must take into account the projected increase in extreme weather events and the water balance must be updated continuously. Post-operational and closure phases of mines will need periodic review because mine infrastructure is based on the design criteria relevant to climate conditions at the time and this creates the potential for structural failure in the future (Pearce et al., 2009). Engineering solutions may exist or be found for many adaptation problems (Pearce et al., 2009). Flexible technical solutions are important in economically profitable mine design. Supply chains in the mining industry are long and so the impacts of climate change should also be considered globally, from the perspective of supply of chemicals. Mining is a highly energy intensive sector and therefore everything that affects the energy sector also has an impact on mining.

Vladimir Melnik / Shutterstock

Mine in Barentsburg, Svalbard

conditions and technological challenges (Norwegian Ministry of the Environment, 2013). The Kara Sea seemed particularly promising when ExxonMobil and Rosneft discovered a major oil field, but joint ventures of Statoil, ExxonMobil and Eni have now been halted owing to economic sanctions against Russia and low oil prices (Keil, 2015). Russian companies are unable to develop the Arctic shelf on their own because of technological and financial limitations. In addition, a general question can be raised about the readiness of petroleum companies to develop such resources in the Arctic in an environmentally sustainable manner, particularly in the less accessible ice-dominated areas (Poussenkova, 2013). Climate change impacts add further risks and uncertainties to such operations.

Climate change would bring risks for offshore installations and infrastructure in northwest Russia, as well as in northern Norway, through icing conditions and extreme weather events (Berdin et al., 2009). Onshore petroleum development in the Russian Barents area would also experience negative impacts, with permafrost thaw and coastal erosion creating risks for the industry-related infrastructure in the NAO and YNAO (Roshydromet, 2014). On the other hand, climate change will increase the potential for wind and hydropower development (Berdin et al., 2009).

There has also been an increase in land-based mineral extraction in the Barents area (see Box 9.3). A new wave of investment in mining in northern Fennoscandia is now taking place: there are currently 18 mines in northern Norway. The region is rich in mineral resources and interest in extraction was driven by a sharp rise in the prices for gold, copper and iron (see Chapter 6). However, this has now reversed and low mineral prices in the period 2015–2016 have resulted in the industry declaring a mining crisis, with 'boom' being replaced by 'bust'. One mine in Finnmark, Norway (Sydvaranger gruver) and one in Sweden (Pajala) have declared bankruptcy. As a result, Swedish mining experts are now calling for a more innovative industry.[20] Despite this recent development, new projects are still being approved. One in Finnmark is causing a major controversy with reindeer herders and coastal fishers (Dannevig and Dale, in press), again an added stressor for the regions' primary industries. Higher temperatures and a shorter winter season will result in new areas becoming available for exploration (Nelson and Schuchard, 2011; ICMM, 2013). These factors may also benefit the construction and operational stage of a mine (ICMM, 2013). For example, risk of increased temperatures causing heat exposure or the need for new technical cooling systems, is lower in the Arctic than in other mining areas under climate change. Concerns are emerging about environmental impacts on reindeer herding, tourism, local livelihoods and recreational use of nature as well as on ecology in the vicinity of the mine. These conflicts have also initiated discussion about food production versus the metal industry.[21]

Climate change adaptation measures represent a relatively new area of consideration for northern business operations, at the same time they can draw on significant experience from operating in severe northern conditions (Kotov and Nikitina, 1996, 1998). In Russia, petroleum and mining companies operating in the Barents area have implemented adaptation projects (Makarov and Stepanov, 2015). Adaptive management options are applied in production and infrastructure located in permafrost zones, in coastal zones and on the continental shelf, and in technologies that are especially vulnerable to extreme events. In most cases these corporate actions are not necessarily labeled officially as 'adaptations', but nevertheless contribute to problem solving in this field. In some companies, such projects are becoming a component in corporate social responsibility and corporate sustainable development programs (Nikitina et al., 2015; Poussenkova and Nikitina, 2016).

9.3.2.8 Infrastructure and transportation

Owing to their topography, climate and settlement patterns, some parts of the Barents area, such as northern Norway, are exposed to natural hazards such as avalanches, leading to road closures and the disruption of people, goods and services. Climate change is exacerbating such challenges for infrastructure through an increase in the frequency of landslides, mudslides and rockfalls, and snow and slush avalanches (NGI, 2013). Reliable and well-functioning infrastructure has become essential for the social and economic functioning of remote communities, because they often depend on commuting and the transport of goods and services to other areas. Infrastructural disruptions may have a long-term influence on regional labor markets, work commutes and settlement patterns in the Barents area. In Finnmark, northern Norway, studies show that road maintenance crew and transport sectors are particularly concerned about weather conditions around 0°C; whether ambient temperature is above or below 0°C makes a difference for safety and keeping roads clear (Hovelsrud et al., 2010b). Companies operating at sea or near shore are aware that managing icing conditions on installations and helicopters requires careful attention to weather forecasts and development of technology. Regulatory mechanisms, amendments and adjustments to existing standards and norms are being designed and introduced to help adapt to the changing environment. In Norway, a recent report outlines how the institutional responsibility for runoff water and urban flood risk should be organized (Norwegian Ministry of Climate and Environment, 2015). The Norwegian Energy and Water Directorate has assessed the risk on hydropower dams of the projected increase in floods (Midttømme, 2015) and the impact of storm surges and sea-level rise on energy supply (NVE, 2015). In Russia, the existing Construction Codes are adding new standards to reflect the current and projected changes in climate parameters including, frequency and amplitude of daily temperature fluctuations above and below 0°C, freeze-thaw cycles, snow load, and precipitation. These parameters are to be taken into account in the selection of construction materials for buildings and roads and their durability and reliability characteristics (Alexandrovsky, 2004); attention to the particularities of the northern regions are taken into account (Uvarov, 2012). Due to increased precipitation and intensity currently experienced especially during winter, the Construction Code "Loads and Stresses" (SNIP 2.01.07-85) was implemented in 2011, with stricter requirements to measure snow load (Roshydromet, 2014). More research and monitoring data are essential to adapt and develop reliable construction materials in line with the future climate change scenarios projected for the Barents area.

By way of illustration, Table 9.3 summarizes concerns regarding transport and infrastructure in the Finnish national strategy for adaptation. The Lapland climate strategy notes the impact of difficult weather conditions and the consequences for travel conditions (Regional Council of Lapland, 2011).

While the Finnish attention is towards the Baltic Sea (harbors, marine traffic), it is also relevant for the Barents area in general. The Barents Transport Plan from 2013 addresses the consequences of climate change elements that are relevant for infrastructure, including increased precipitation, thawing permafrost, more frequent storm events, more frequent freeze-thaw cycles, more frequent and high-risk flood events and landslides. The report cautions that infrastructure managers must be aware of the threats and must develop the necessary adaptation strategies. It is noted that these adaptation strategies may be expensive to develop and maintain (BEAC, 2013).

Many adaptation actions to reduce geocryological risk associated with permafrost thaw are being designed and implemented in the Russian north. They concern technical methods to reinforce buildings and infrastructure such as pipelines, railways, roads, and airport facilities. Measures to avoid or reduce permafrost thaw in northern Russia include thermo-stabilization (used since the 1960s). Thermo-siphons are installed to pump cold air into the upper layer of the

[20] http://uli-geoforum.se/nyheter/278-event/2582-kris-i-gruv-och-mineralindustrin-tid-for-gis
[21] http://www.ifinnmark.no/matproduksjon-viktigere-enn-gruver/s/5-81-179420

Table 9.3 Expected impacts of climate change in traffic and transportation in Finland (Finnish Ministry of Agriculture and Forestry, 2005).

Damage	Direction of impact	Benefit
• Wash-outs in railways and roads • Floods and rain damage to infrastructure, problems with maintenance • Current drying systems inadequate • Bridges and other structures not built for future water levels in rivers • Equipment problems maintaining safety for rail, roads and marine traffic • Difficult weather conditions for rail, road, sea and air traffic • Increased disruption and related costs of repairs and preparedness • Slippery roads, salt needed on northern roads • Changing ice conditions in sea areas disturb marine traffic • Winds, storms and rain disturb/damage electricity production and distribution (wires and cables)	• Impacts may change preferences for transport modes • The need to salt may increase and decrease • The considerable annual fluctuations in ice and snow conditions will increase	• Shorter ice-covered season reduces costs of marine transport and harbor maintenance • Thinner ice cover and shorter winters reduces costs of winter maintenance for roads, railways and airports

permafrost. Another engineering response presupposes installation of ventilation canals along the elevated transport infrastructure, or special ventilation systems in the basement of buildings (Roshydromet, 2014). Basements are monitored regularly and if structures show signs of deformation additional piles or thermo-siphons can be installed as required.

To ensure operational safety, energy companies operating in northern Russia must increase efforts to adapt to risks associated with permafrost damage. For example, among the reasons for the serious 1994 oil leak accident at the oil pipeline in Komi were multiple breaks on the pipeline due to uneven thermokarst (Oberman, 2007). Reconstruction of the Vasilkovo–Naryan-Mar gas pipeline in the NAO just a few years after it first became operational was attributed to uneven thermokarst through permafrost thaw. These are examples of 'maladaptation'; the permafrost factor was taken into account in the initial design of the pipeline but permafrost dynamics due to climate change were not (Streletskiy et al., 2012). Other companies aim to enhance the safety of their operations in permafrost zones and their preparedness for possible accidents. For instance Transneft-Siberia, one of the leading oil transportation companies in Russia, recently reported on the innovative techniques used at its northern facilities, including materials for accidental oil spills mitigation at northern rivers and lakes (https://sibnefteprovod.transneft.ru/press/news).

9.3.2.9 Summing up: Adaptation practices and processes

Adaptation is a response to multiple changes and drivers, and each industrial sector and community provides a different context within which the adaptation takes place. One size does not fit all when it comes to adaptation. It is also the case that climate change, often associated with adaptation is not the main driver and only challenge. However, many of the measures, which are taken as a response to current conditions and stress, nevertheless reduce vulnerability to projected climate change impacts. In general terms, adaptation emerges as a cross-scale process involving multiple sectors (e.g. municipal, water management, forestry, fishery, energy, tourism, agriculture) and actors (businesses, individuals, policymakers). The ways these processes manifest empirically are to a great extent context-dependent, and take place in a landscape in which conflicts between and within sectors and in land use may emerge. In the same area, adaptation for some may create a challenge for others (road construction to adapt to extreme weather may encroach on grazing or agricultural land). The processes are also driven by and interact with society at large. Despite the context-dependent nature of adaptation, factors that are relevant across sectors, regions or nations are emerging. Table 9.4 presents examples of salient and comparable aggregated categories involved in adaptation processes found in the Barents area. The purpose of the table is to illustrate the type of adaptations in use in the Barents area. In practice these are interlinked and dependent on local contexts, framework conditions, and other factors.

9.4 Understanding adaptation options

9.4.1 Adaptation as a process

From what is known about current and past responses to multiple and interacting causes of change it is possible to identify adaptation options that are highly likely to be relevant for addressing future impacts and challenges. There are four interrelated dimensions that warrant consideration: existing adaptation strategies, the processes of adaptation, barriers and limits, and governance and tools.

Previous sections have illustrated the interlinkages between changing climatic, environmental and societal conditions and have identified a number of ongoing adaptation strategies in the Barents area. There are major differences between sectors, and between and within communities, regions and nations with respect to what the consequences of change may be and what are likely to be the most efficient and best adaptation strategies. This means that the different contexts will require specific measures depending on a range of factors, such as

Table 9.4 Examples of adaptations in use in the Barents area.

Category	Current strategies
Engineering technical solutions and innovation; infrastructural improvements	• Drainage pipe dimensions • Flood, fire and avalanche protection • Dam reinforcements • Building and infrastructural reinforcements especially in relation to permafrost • New technologies for societal protection (wildfires, internet warnings of avalanches and floods) • Barents exchange of best practices
Regulatory mechanisms	• Standards and norms • Technological standards • Building codes (e.g. new materials to withstand increased freeze-thaw cycles, snow loads) • Application of best available technologies • Land use planning and zoning • Regulation of access to natural resources (water, fish) • Emergency and rescue regulations and codes • Healthcare instructions and guidelines to prevent spread of new infectious deceases and harmful pests, development of and treatment for the spread of new viruses
Economic mechanisms	• Changing insurance policies, incentives by national governments, project funding (e.g. Cities of the Future), corporate funding • Subsidies • Taxes • Voluntary approaches • Incentives for small and medium-sized enterprises (SMEs) and new products
Innovation and entrepreneurship; product development and marketing	• Diversification of tourism activities, crop varieties, local food products, and aquaculture • Innovation in organization
New knowledge	• Climate projections and improved weather forecasts, agricultural crop development, new cattle fodder • New, innovative solutions for presenting climate change related knowledge to different audiences, stakeholders and decision-makers
Institutional structures	• Search and rescue, spatial planning regulations, interagency coordination, adaptation research – as a way to build knowledge for supporting adaptation • Enhanced regional cooperation
Production practices and routines	• Timing of production cycles (grazing, planting, harvesting), new fish species, spatial utilization, supplementary feeding of livestock
Cross-sectoral interactions	• Agriculture, fisheries, public sectors

framework conditions, incentives, severity of the projected impacts, human and financial resources available, access to technical, local and expert knowledge, assessment capabilities and the extent to which institutions are enabling.

The first of the four dimensions concerns current adaptation strategies in the Barents area (summarized in Table 9.4), while the second concerns factors that initiate and facilitate adaptation processes. The third dimension illustrates barriers and limitations for initiating the adaptation processes, even if the strategies are in place. The fourth dimension, adaptation governance, encompasses the first three dimensions and is crucial for securing implementation of adaptation measures. The time frame in which measures are developed, whether short-term or long-term, becomes important.

Together the four dimensions of the adaptation process constitute the adaptation options, and underscore the fact that it is not possible to identify such options just from looking at the potential adaptation strategies. Such strategies can only be implemented if they are enabled and activated. It is also necessary to understand the factors that affect the societal, political and economic processes behind the adaptation strategies, and how they affect the potential adaptation options.

9.4.2 Adaptation governance

Adaptation processes require governance: governance of the complex, cumulative changes and their impacts. There are many tools in use for this purpose and this is the focus of this section.

Cooperation and coordination of adaptation processes are taking place within and across all scales, and the contexts and interactions will drive both the process and outcome. International cooperation in the Barents Region appears to be a powerful tool in adaptation strategic planning and research. Social learning and the transfer of knowledge and best practice from one Arctic state to another is a useful tool for developing adaptive governance (see Chapter 10). In the Barents Region, cooperation on adaptation has been an important way of enabling the development of adaptation strategies at the regional level. The effectiveness of social learning in the Barents area from joint regional programs is greater than unilateral efforts in the other northern regions of Russia (Nikitina, 2013). For example, the initiative to develop an integrated climate change adaptation strategy for Northwest Russia relies on active adaptation partnerships with the BEAC and Nordic partners. Dissemination of adaptive governance tools in Murmansk, the Archangelsk oblasts, the NAO, and the Karelia and Komi republics, is an example of a recent Russian activity as a result of the BEAC collaboration in the development of the climate strategy. A regional climate strategy, as well as local plans are both being developed for the Barents regions of Russia.

Most multi-national initiatives involve a wide variety of partners. They include governments, indigenous peoples organizations, civil society organizations, multinational research networks and academic or research groups, and industry. Regional governments and local authorities usually play an important role in these projects. Some large-scale projects receive government funding as well as funding from other national and international research sources and international non-governmental organizations, such as WWF (Arctic Council, 2013a). One example of an effective partnership is that between Finland, Norway, Sweden and Russia (Archangelsk and Murmansk oblasts, Karelia) addressing climate change and water resources management. The aim of the project is to develop an integrated strategy on climate change adaptation in Northwest Russia, based on experience in the Arctic countries. In addition to new regional collaboration, cooperation is often already in place between border municipalities, such as that between Haparanda in Sweden and Tornio in Finland on water risk management (e.g. Keskitalo et al., 2013).

Whether adaptation decisions address immediate or long-term strategies, they often depend on how adaptation is organized (Rauken et al., 2014). In municipalities where the approach is holistic and horizontal coordination is promoted, more long-term decisions are made, whereas a single department approach to adaptation work ensures more short-term solutions (Rauken et al., 2014).

In the Barents Region there are international policy and regulatory frameworks that affect the governance of adaptation; one example is the EU climate policy, which applies to Finland and Sweden (both EU countries), and to a lesser degree to Norway (a member of the European Economic Area). These frameworks include the EU Adaptation Strategy, the EU Floods Directive and the EU Water Framework Directive. As Table 9.1 shows, all three countries have adopted adaptation legislation with implications for the actions of various actors. Hence, legislation is a tool for governing adaptation. For example, the Norwegian Planning and Building Act requires local governments to include risk of landslides and floods in their spatial planning. Tools designed to assist in this effort are the flood maps produced by the Norwegian Water and Energy directorate, which include climate change projections, and the tables for sea-level rise and increase in storm surge produced by the Norwegian Directorate for Civil Protection, and more recently the Norwegian Mapping Authority.

Adaptation governance is ultimately about implementation, and this chapter shows the multifaceted interlinkages between the various dimensions with respect to adaptation processes, and the complexities involved in activating adaption strategies. Several conditions are required for successful adaptation. In fisheries management, for example, a combination of science, regulation and enforcement are necessary for addressing adaptive measures (Harsem and Hoel, 2013). To date, adaptation has been integrated into Swedish national government structure to a relatively small degree, which has meant adaptation options at the municipal level have often been voluntary and thus gained lower priority than mandatory actions (Keskitalo, 2013; IPCC, 2014a; Andersson et al., 2015; see also Swedish Ministry of Environment and Energy, 2015). In Finland, implementation of programs, plans and strategies are more advanced in some fields than others. The aim of the 2022 implementation plan is that adaptation will be included as a standard practice in the planning and activities for different sectors and actors. This means that they will apply the tools needed to assess and manage climate risk; and research and development, education and communication will increase societal adaptive capacity, advance development of new innovative solutions and increase general awareness of issues related to climate change adaptation (Finnish Ministry of Agriculture and Forestry, 2014).

For effective governance, there needs to be a clear distribution of responsibility for adaptation at different levels. At the Norwegian national level, a reallocation of responsibility for adaptation has taken place at the directorate level. The directorate responsible for adaptation was transferred from the Directorate for Civil Protection to the Environment Agency, which already has responsibility for mitigation. This has created a unclear allocation of responsibility for climate change adaptation between the two directorates, which has taken some time to resolve.

Because adaptation is context-specific, the sub-national levels are also important for adaptation governance, and Norway is considered to have adaptation governance potential at the regional level that is yet to be realized (Hanssen et al., 2013; Dannevig and Aall, 2015). Giving the counties a stronger role in adaptation increases the potential for a more holistic approach. This is because the counties have a territorial focus, while the national ministries follow a sectoral approach (Hanssen et al., 2013).

In Sweden, the future structure of climate change adaptation is currently being re-assessed, especially with regard to funding at the different levels and in clarifying the distribution of responsibilities among multiple actors (Andersson et al., 2015; Swedish Ministry of Environment and Energy, 2015).

In Russia, as part of the decentralization reform after the collapse of the Soviet Union many competences and responsibilities have been transferred from the federal level to the regional level. Implementation of climate and environmental policies are the joint responsibility of the federal authorities, and authorities of the federation subjects and their municipalities. Specific adaptive governance responsibilities of the regional authorities include developing legislation by federation subjects that addresses climate change; elaboration and realization of adaptation measures and their incorporation into regional and municipal mid- and long-term socio-economic strategies and sectoral planning; and the development of regional schemes for the operational response to extreme events (Russian Federation, 2009). The Russian Strategy for the Development of the Arctic Zone adopted in 2013 emphasizes a joint consolidation of institutional frameworks for adaptation by the federation and federation subjects and enacts provisions for adaptation actions, especially for the Barents regions of Russia (Pelyasov, 2013).

Best practice guidelines and handbooks are developed by various public bodies to aid the adaptation processes. These contain advice for municipal adaptation, including descriptions of local climate change scenarios, review potential risks arising from these changes and offer a consideration of adaptations that may be included in planning (County Administrative Board of Västerbotten, 2007; County Administrative Board, 2012). Such reports may provide examples of adaptations relating to flood risk and spatial planning (County Administrative Board, 2006) and building construction (County Administrative Board of Västerbotten, 2007). The Norwegian Water and Energy Directorate has produced a guide for including flood and landslides in spatial planning. The guide recommends a 20% safety margin on flood estimates for flood maps that does not include climate change projections (Norwegian Water and Energy Directorate, 2014). Recent handbooks, guides and manuals have also been are developed to support local governments in considering climate change impacts in the development of their spatial plans (County Administrative Board of Stockholm, 2010a,b,c; Norwegian Directorate for Civil Protection, 2015).

Various information webpages have been established by public bodies (Sweden: Klimatanpassning.se; Norway: klimatilpasning.no; Finland: ilmasto-opas.fi), in addition to a range of knowledge and tools portals reporting from research projects. These provide adaptation tools for different sectors, the Swedish Climatools portal for planners and decision makers (www.foi.se/climatools), and tools targeting specific sectors such as the housing sector to increase Nordic homeowners' adaptive capacity to climate change (www.cspr.se). These websites and handbooks are addressing the information need with respect to adaptation processes. Lack of information and knowledge is considered a barrier to adaptation.

Networks and meeting points may be applied as tools to enhance governance processes, and several examples of networks are noted in the region, for instance an annual adaptation conference with large municipal participation in Sweden (*Klimatanpassning Sverige*). In Finland, informal networks have been formed in connection with participatory planning processes for climate strategies. These are important in their own right, and are also a potential resource for future action. In Norway, the Environment Agency promotes exchange of experience and network building, and hosts a secretariat for a frontrunner municipality network. The network aims to provide new information, sharing knowledge and expertise through joint projects. The network will also, when relevant, support national Climate change adaptation processes.

Peter Prokosch

Spring-meltwater floods in a forest near Rovaniemi, Finland

9.4.3 Barriers and limits to adaptation

Adaptation options for responding to changing conditions are embedded in how society facilitates the implementation of adaptation strategies. But although a municipality or primary sector may be aware of the best strategies to use for any given situation, it may be that there are barriers and limits to their use. Thus, to fully understand adaptation options also requires attention to barriers and limits. One view is that these barriers and limits can be expressed as the absence of the factors that drive or facilitate the processes and governance of adaptation, such as lack of capacity building, lack of flexibility to diversify livelihoods, or inaccessible knowledge. But this does not help in defining and identifying adaptation options; an understanding of the reasons behind the barriers and limits becomes critical. However, according to the IPCC increased understanding of barriers and limits to adaptation has not yet resulted in systematized, description-focused analyses (IPCC, 2014a). This is underscored by the Barents area studies presented in this assessment, which show there are clear barriers and limits to implementing adaptation warranting attention (see Chapter 10 for a discussion of barriers at a more aggregate level). It could be argued that there is a need to understand better the systemic factors at the national level that to date have reduced the negative impacts of globalization, but that may with increased urbanization result in increased outmigration from rural areas (Keskitalo and Southcott, 2015).

In Finnish Lapland, the tourism and forestry sectors are forerunners in climate awareness and were the first to bring climate viewpoints to the regional development strategies (Mettiäinen, 2013). Community adaptation and vulnerability assessments in northern Norway have found that the perceived need to adapt varies considerably between occupational groups within the same communities (e.g. Hovelsrud et al., 2015; Dannevig and Hovelsrud, 2016). While municipal spatial planners perceive planned adaptation to be necessary, fishers and fish industry actors do not and argue that they always adapt to changing conditions (Hovelsrud et al., 2015). Other studies suggest that perceptions of high adaptive capacity may mask the need to develop adaptation strategies, and thereby increase vulnerability to changing conditions (e.g. West and Hovelsrud, 2010). A perception that adaptation is not needed (Dannevig et al., 2013) and a lack of political commitment (Himanen et al., 2012) are both barriers to developing adaptation strategies. A study that engaged community stakeholders in co-production of climate change knowledge was only successful with municipal officials; fishers did not perceive such knowledge to be of interest (Hovelsrud et al., 2015; Dannevig and Hovelsrud, 2016). Such perceptions may create barriers for developing adaptation strategies, which in the long-term may exacerbate the consequences of changing conditions.

When assessing barriers and limits, it is useful to examine lessons learned from climate adaptation that are applicable to other cumulative effects of changing conditions (including climate change). Those identified for the Barents area span a broad range of complex and unexpected factors and can be loosely categorized in the following terms: motivation and the perceived need to adapt; trade-offs between adaptation concerns and mandatory and more pressing tasks; available and relevant knowledge; lack of resources; transferability of national goals and guidelines to local concerns; unclear responsibilities and insufficient frameworks; and ignoring local and indigenous knowledge.

9.4.3.1 Motivation and the perceived need to adapt

Motivation for adaptation may be divided into motivation in terms of agency and capacity of an individual or community to cope with change, and the perceived need to adapt (e.g. to projected climate change). The distinction is related to the difference between reactive and planned (proactive) adaptation. For actors involved in natural resource based activities, adaptation is motivated largely by impacts on the production factors that in turn determine the economic outcome and potential for continued livelihood (Keskitalo, 2008).

B&C Alexander / ArcticPhoto

Sovietskaya Street, Yar-Sale, Yamalo-Nenets Autonomous Okrug, 1993 (upper) and 2017 (lower)

9.4.3.2 Trade-offs

Municipalities are responsible for safeguarding their residents and communities; they are also responsible for addressing pressing tasks required by law. There is a clear lack of financial and human resources when mandatory and more tangible tasks, such as those concerning healthcare, schools and education, and care for elderly, are being discussed. This means that long-term adaptation planning, which is not mandatory, is not prioritized when resources are distributed at local government level. Local governments in both Sweden and Norway point to a lack of resources to implement adaptation measures, and the need to focus on mandatory tasks, such as education, healthcare, roads and waste handling (e.g. Dannevig et al., 2013; Keskitalo, 2013). Climate adaptation, for example, only becomes relevant when coinciding with these concerns and tasks.

9.4.3.3 Available and relevant knowledge

Studies on adaptation to changing climatic and societal conditions in northern Norway show that the lack of available and relevant knowledge about future climate change and how it will affect communities and sectors, creates a barrier for responding to such changes. Knowledge can only be used if it is available, understandable and relevant for local conditions and activities. Several actors, including local governments and farmers, have been requesting tailor-made climate scenarios to help them understand the potential impacts of climate change for their own activities. In Finnish regional climate strategies, climate scenarios and projections (such as the potential for fewer snow cover days and increased precipitation) have been elaborated with local and practitioners' and sectorial expert knowledge so as to identify those questions that are most important for the region and to livelihoods. These projections are freely available on websites.

Availability and relevance pertain both to whether the knowledge is tailored to local contexts and to whether it is presented in a way that is understandable. Limits to adaptation are created when the knowledge and information providers ignore or are not aware of this dilemma. Therefore the problem is not about lack of knowledge in many cases, but more about relevant and understandable knowledge that is transferable or applicable to local contexts.

9.4.3.4 Lack of resources

A limiting factor in the municipal sector is funding and time for municipal employees to integrate adaptation into their daily practice. Municipalities in the Barents area are generally geographically large but sparsely populated, which means a small tax basis from the residents and with some redistribution nationally. However, the headquarters of large companies that may contribute to earnings to several percentage points of gross national product (GNP), are often located in capital cities or outside the country. The real income at municipal level depends on local employment, and is diminished by fly-in fly-out workers (oil platforms or mining) who do not pay taxes at their places of work. In Sweden, taxes are not paid in the locality of second homes, which has increasing disadvantages for northern areas with a high proportion of second homes. For example, Borgafjäll in Sweden has 75 permanent residents but more than 400 second homes (Robertsson and Marjavaara, 2014). Given these conditions (being sparsely populated and with commuters), local governments generally have limited resources for integrating adaptation (although exceptions do arise). There is progress in Sweden in terms of dedicated funding for climate change adaptation, which will also affect other adaptive measures, given that climate change impacts are not isolated from other changes.

9.4.3.5 Transferability of national goals and guidelines to local concerns

In Finland, there is a strong tradition of climate change research and impact assessments but this information is mostly oriented to mitigation and to the national level. Transferability to local or regional levels and adaptation needs is not direct, and regional and local climate strategies are developed in order to identify specific regional and local needs. These regional and local climate strategies must also address national goals. Although the transferability of national goals to a regional and local context may be problematic, regional and local decision-makers are requesting better guidelines and support from the national level (Amundsen et al., 2010; Himanen et al., 2012).

9.4.3.6 Unclear responsibilities and insufficient frameworks

In Sweden, a fundamental barrier to climate change adaptation is the limitation in the existing framework for adaptation: there is a need for a clearer distribution of responsibilities of different actors and clear and long-term funding (including to some extent to municipalities) (Keskitalo, 2010a; Andersson et al., 2015). At the Norwegian national level, there has been a reallocation of responsibility relevant to adaptation, both among the ministries and the directorates. The ministerial responsibility for the land-use planning section of the Planning and Building Act no longer sits with the Ministry of Climate and Environment, but with the Ministry of Local Government and Modernisation. This shift may have implications for the inclusion of adaptation. As noted in Section 9.4.2, the directorate responsible for adaptation was transferred from the Norwegian Directorate for Civil Protection to the Environment Agency, which was already responsible for mitigation. This shift has caused some ambiguity regarding responsibility for adaptation, especially because the Norwegian Directorate for Civil Protection retains responsibility for adaptation within the areas under its jurisdiction, including risk analysis. The effects of the national level changes on adaptation are yet to be seen. With respect to resource management (such as fisheries and agriculture), adaptation will have limited success if the measures do not include a combination of scientific knowledge, regulations and implementation. Lack of cross-sectoral measures is a tangible barrier to adaptation.

9.4.3.7 Ignoring local and traditional knowledge

Local and traditional knowledge play a significant role in developing efficient and relevant adaptation measures (see also Chapter 7). Its use in local adaptation plans within the Barents area varies widely, from Finnish Lapland where such knowledge plays a central role, to other countries where it is not addressed at all. Not using local and traditional knowledge in adaptation processes and governance can be a major barrier to adaptation. However, its inclusion is a complex matter and even if efforts are being made to ensure indigenous and local participation in the processes, it is not a given that they will have the human or financial resources or trust in the system to contribute (Risvoll and Hovelsrud, 2016). The barriers may manifest as resistance to measures because local communities may not recognize their own situation in the measures that are being developed. Adaptation measures may also be limited in scope and relevance if local knowledge is ignored. Research and education in indigenous peoples' society over the past 30 years may not be adequate for future solutions, in light of the speed and magnitude of the changes taking place and projected for the Arctic. There is a need for a new kind of education in the North; one that incorporates multidisciplinary, multicultural, and holistic approaches for sustainable development and that also includes indigenous peoples world views and traditional knowledge as well as the prevailing worldview (see also Chapter 7). Scientific and traditional experience-based knowledge is key to developing successful adaptation measures and securing viable livelihoods and communities.

9.4.4 Key insights on adaptation options

This chapter has illustrated the interlinkage between changing climatic, environmental and societal conditions and has identified various adaptive strategies and processes for the Barents area. Building on Tables 9.2 and 9.4, Table 9.5 provides an overview of the dimensions requiring attention when developing adaptation options. The first column indicates some of the current adaptation strategies found in reports and scientific studies from the Barents area (based on Table 9.4). This is not an exhaustive list, but indicates the broad range of adaptation strategies that people, communities and sectors have developed. These strategies are either reactive adaptation responses to changes or challenges – to events that have happened; or are proactive (planned) adaptation responses – to projected or expected events or trends. The strategies are interlinked in practice, and applying only one strategy is rarely sufficient. The second column highlights the salient factors that activate the adaptation process. Whether adaptation strategies are feasible and successful depends on the ways these processes are shaped and activated. Worth noting is the dynamic and qualitative nature of these factors, which is mirrored in the cumulative and interacting changes to which the adaptation processes are responding. The third column highlights some of the barriers and limits that may have a bearing on both the adaptation processes and the strategies. Research has found that adaptation processes may be driven by the best intentions and willingness to address challenges (or opportunities) only to be limited by, sometimes unexpected, societal or governance factors, at another scale or with other and potentially conflicting goals (such as fisheries management through quotas that are not in step with shifting fish stocks as a result of ocean warming; see also examples in Boxes 9.1 and 9.3). This illustrates that both the will to adapt and the plans to adapt may be in place but are met by structural or resource related barriers and limits. Adaptation governance cross-cuts the three dimensions and is expressed

Table 9.5 Dimensions of adaptation options.

Dimensions of current adaptation strategies	Dimensions in activating adaptation processes	Barriers and limits to adaptation
Engineering technical solutions and innovation; infrastructural improvements	Knowledge about the change and challenges/ opportunity	Motivation and the perceived need to adapt
Regulatory mechanisms	Attention to the change	Trade-offs between adaptation concerns and mandatory and more pressing tasks
Technological standards	Observations of real events (local outmigration, unemployment, longer growing seasons)	Available and relevant knowledge
Economic mechanisms	Extreme weather events (floods, avalanches)	Lack of resources
Innovation and entrepreneurship; product development and marketing	Engaged officials and residents	Transferability of national goals and guidelines to local concerns
New knowledge	Direct contact and involvement with research	Unclear responsibilities and insufficient frameworks
Institutional structures	Enabling institutions (municipality or county for example)	Ignoring local/ traditional knowledge
Production practices and routines	Livelihood flexibility and diversification	
Cross-sectoral interactions	Access to knowledge	
	Access to human and financial resources,	
	Capacity building	
	Long term or short term perspective on adaptation	

Governing tools
Cooperation and coordination on international, national, regional and local levels
Distribution of responsibility for adaptation – at different levels
Legal, regulatory, strategic and policy frameworks at various levels
Climate scenarios and projections
Policy and planning tools regional and local level – risk and vulnerability assessment, spatial planning
Handbooks and guidelines on climate change adaptation planning; spatial planning taking climate change into account
Networks and meeting points for sharing experience and knowledge dissemination among public agencies, ex. conferences
Webpages as information hubs
Cost-benefit analyses of adaptation in order to assess different options

here in terms of governance tools. To develop adaptation strategies, activate and facilitate adaptation processes, and to address limits and barriers for adaptation, a broad range of tools is needed.

Adaptation options are shaped by the outcome of complex linkages; the potential of such options cannot be understood without taking into account the factors that activate the adaptation processes, the limits and barriers to such measures and the governing potential. The adaptation options may be found in how the policies facilitate or enable processes. Planning under such complexity carries much uncertainty, as is always the case in planning for the future. Added to this is the issue of how to address future trends (see Chapter 10). Societal trends relevant to adaptation include increased urbanization, gender-imbalanced outmigration from smaller communities (women leave, men stay), an increased gap in higher education among people in rural and urban areas, a growing influx of refugees and migrants, global warming and the associated changes in weather with consequences for society such as increased precipitation, thawing permafrost, higher temperatures, seasonal shifts, new species, health problems, and increasing flood risk (see also Chapter 10).

9.5 Science-policy interface and knowledge gaps

Adaptation to challenges and opportunities takes place within the context of multiple factors, which means decisions concerning adaptation options must take into account the complex dynamics between local, regional, national and international scales and between interacting and cascading consequences of change. This is challenging because it requires balancing climate science (including natural and social sciences), policy, and governance with local contexts and cultural aspects. Although all societal scales are involved in adaptation it ultimately takes place at the local level, and lack of attention to local concerns has been seen to delay regional and local policy responses. This is because national goals and policy development may not necessarily coincide with local concerns, whether long-term or short-term. The science generated to address adaptation options, whether physical science or social science, has a greater chance of being successful if it is co-produced and combined with local and traditional knowledge. Efforts are now being made to start with user needs when developing tools for adaptation, which includes giving priority to process over products; linking information between producers and users; building connections between actors, disciplines and organizations; seeking institutional stability; and developing design for learning (see also Chapter 10).

Adapting to the combined impacts of climatic and other changes is fraught with uncertainty. The adaptation challenge is a classic example of a 'wicked problem' (Rittel and Webber, 1973), where finding the optimal policy is not considered possible and collaboration between a range of actors is necessary to find possible solutions. With this in mind this chapter has approached adaptation options in terms of processes in order to capture the essence of that which can be applied to local conditions, compared and learned across science-policy contexts. Addressing the wicked problem as a science-policy interface issue requires that the process is salient (information must make sense and be relevant to those that it addresses); that it is credible (the science has credibility among those concerned, whether local fishers or municipal planners); and that it is legitimate (i.e. that the sources of insight and knowledge have authority and grounding, and that affected parties perceive that their interests have been considered) (e.g. Cash et al., 2003; Mitchell et al., 2006). Uncertainty is the norm in planning and strategy development, and perhaps not the greatest cause for concern. The critical issue is identifying and defining adaptation policy goals and gaps in knowledge on how to ensure and make adaptation processes more manageable.

Given the importance of a science-policy interface when addressing adaptation options, there is an urgent need to address knowledge gaps. There is enough knowledge to act on climate change itself (i.e. mitigating greenhouse gas emissions and developing adaptation efforts), but not enough about how climate change will interact with other changing conditions and possibly result in entirely new sets of multiple stressors. This creates a major challenge in designing the best adaptation options for the Barents area. What is currently known from empirical research and observations is merely scratching the surface in terms of the factors and processes driving adaptation options.

Adaptation options in the future will be affected by the extent to which Norway, Sweden and Finland maintain the currently high level of healthcare, education and physical infrastructure in areas with increasingly smaller populations due to urbanization. Attractiveness for employment will be highly dependent on access to such services. In the Russian part of the Barents there are knowledge gaps concerning how best to combine research and assessments of climate change risks and impacts with the interests of stakeholder groups, and to incorporate research findings into the sustainable development agendas of federation subjects in the Russian North. A dedicated science-policy interface is needed to ensure the development of databases, information exchange and the development of networks to share the expertise and knowledge about adaptation between the regions of the Russian Arctic.

Current major trends such as urbanization and increasing focus on employment in services will also be important for adaptation. In comparison to the significant role of globalization in the region, climate change is likely to play a smaller role in the short term. In the long term, however, and possibly coupled with changes in energy use ('peak oil' has now been reached), the consequences of climate change are likely to affect global food security which may result in an increased focus on regional food production. This could in turn reverse some of the trends towards reduced agricultural production. However, gaps in knowledge about agricultural crops that can thrive in a warmer climate and cope with long summer nights have already been identified. The iterative exchange needed between science and policy to fully engage adaptation processes and develop options is reflected in the following summary of such gaps.

It is clear that changing industrial and sectoral conditions will affect communities in the Barents area, but what the interlinked impacts of changing geopolitical conditions will be are not yet clear. There are gaps in knowledge with respect to the way increasing urban development will affect local communities, and whether the trend will shift away from urban centers back to local communities in the event that employment opportunities in rural areas increase. This indicates gaps in knowledge concerning the financial, social, political and environmental resources needed to facilitate such reversals.

There are significant gaps in knowledge about how climate change will impact society (see Chapter 6 for details). The science-policy interface is highly relevant for developing useful climate and socio-economic scenarios, that can also be combined for better assessments of the localized impacts. There are also significant gaps in knowledge about how to develop and apply climate- and socio-economic scenarios, individually and combined. There is limited knowledge about economic and societal costs of climate change damage, risk mitigation, and adaptation efforts, set against the economic and societal costs of not adapting. This is essential knowledge for adaptation-related decision-making across nations, sectors, and livelihoods. There is a need for statistics and economic analysis in order to be able to assess the costs and benefits of adaptation measures and options at different levels, and for comparing successful adaptation across and within a given region.

The development of culturally-specific risk communication addressing multiple and perhaps partially unknown stressors is associated with both knowledge gaps and the science-policy interface.

For the Barents area, there are significant knowledge gaps on the impacts of external socio-political and climatic factors. For example, it is unclear how the increased influx of refugees will affect the demography of the region (immigrants are currently the main source of population increase in northern Scandinavian communities), and the potential for increased immigration driven by climate change further south.

Given the role of governance tools in adaptation processes, there is a need to develop knowledge about the effectiveness of current adaptation processes, level of implementation, lessons learned, best management practices, and how to consider future adaptation measures.

The different types of cumulative and interacting effects across local and international scales presented in this chapter are at the heart of gaps in knowledge and the science-policy interface. To be able to anticipate such effects and develop robust adaption options it is necessary to engage both scientific and other evidence-based sources of knowledge (such as time-tested traditional, local and indigenous knowledge) in recognizing the challenge in co-production of both knowledge and knowledge gaps.

Acknowledgments

Amundsen, Dannevig, Karlsson and Hovelsrud are funded by the Norwegian Environment Agency and by home institutions. Keskitalo's work on this chapter is funded by the MISTRA Arctic Sustainable Development research program.

References

ACIA, 2004. Arctic Climate Impact Assessment: Impacts of a Warming Arctic. Arctic Climate Impact Assessment (ACIA). Cambridge University Press.

ACIA, 2005. Arctic Climate Impact Assessment. Cambridge University Press.

Adger, W.N., J.M. Pulhin, J. Barnett, G.D. Dabelko, G.K. Hovelsrud, M. Levy, Ú. Oswald Spring and C.H. Vogel, 2014. Human security. In: Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. pp. 755-791. Cambridge University Press.

Alexandrovsky, S.V., 2004. Dolgovechnost naryzhnuh ograzdayshih konstrukcy [Durability of outer fence constructions]. NIISF RAACN, Moscow.

AMAP, 2011. Snow, Water, Ice and Permafrost in the Arctic (SWIPA): Climate Change and the Cryosphere. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

AMAP, 2013. AMAP Assessment 2013: Arctic Ocean Acidification. Arctic Monitoring and Assessment Programme (AMAP), Oslo Norway.

Amundsen, H., 2012. Differing discourses of development in the Arctic: The case of nature-based tourism in northern Norway. The Northern Review, 35:125-146.

Amundsen, H., F. Berglund and H. Westskog, 2010. Overcoming barriers to climate change adaptation – a question of multilevel governance? Environment and Planning C, 28:276-289.

Andersson, L., A. Bohman, L. Well, A. Jonsson, G. Persson and J. Farelius, 2015. Underlag till kontrollstation 2015 för anpassning till ett förändrat klimat [Basis for control station 2015 for adaptation to a changing climate]. Swedish Meteorological and Hydrological Institute (SMHI). Report No. Klimatologi Nr 12, SMHI, SE-601.

Angell, E. and K.B. Stokke, 2014. Vulnerability and adaptive capacity in Hammerfest, Norway. Ocean and Coastal Management, 94:56-65.

Anisimov, O. and V. Kokorev, 2013. Constructing optimal ensemble projections for predictive environmental modelling in Northern Eurasia. Ice and Snow, No. 1. 83-92. (in Russian).

Arctic Council, 2013a. Taking stock of adaptation programs in the Arctic Adaptation Actions for a Changing Arctic: Part B. Arctic Council.

Arctic Council, 2013b. Arctic Resilience Interim report 2013. Stockholm Environment Institute and Stockholm Resilience Centre.

Arspas, 2017. Russian Federation Ministry for Emergencies (MCHS). Forest and pit fires. ARSPAS Information and Exhibition Center of MCHS. www.arspas.ru/mchs/spravochnik/1/les.php

BEAC, 2013. Joint Barents Transport Plan: Proposals for development of transport corridors for further studies. Barents Euro-Arctic Council (BEAC).

Berdin, V.H., D.A. Gershinkova, Y.S. Dobrolyubova and V.A. Masloboev, 2009. Kompleksnye klimaticheskie strategii dlja ustojchivogo razvitija regionov rossijskoj Arktiki v uslovijakh izmenenija klimata: model'nyj primer Murmanskoj oblasti [Integrated Climate Change Strategies for Sustainable Development of Russia's Arctic Regions Case Study for Murmansk oblast]. United Nations Development Programme & Russian Regional Environmental Centre, Moscow.

Berrang-Ford, L., J.D. Ford and J. Paterson, 2011. Are we adapting to climate change? Global Environmental Change, 21:25-33.

Brännlund, I. and P. Axelsson, 2011. Reindeer management during the colonization of Sami lands: A long-term perspective of vulnerability and adaptation strategies. Global Environmental Change, 21:1095-1105.

Brouder, P. and L. Lundmark, 2011. Climate change in northern Sweden: intra-regional perceptions of vulnerability among winter-oriented tourism businesses. Journal of Sustainable Tourism, 19:919-933.

Bulgakova, T., 2010. Climate change, vulnerability, and adaptation among Nenets reindeer herders. In: Hovelsrud, G.K. and B. Smit (eds.), Community Adaptation and Vulnerability in Arctic Regions. pp. 83-105. Springer.

Cash, D.W., W.C. Clark, F. Alcock, N.M. Dickson, N. Eckley, D.H. Guston and R.B. Mitchell, 2003. Knowledge systems for sustainable development. Proceedings of the National Academy of Sciences, 100:8086-8091.

Council of Oulu Region, 2010. Pohjois-Pohjanmaan ilmastostrategia [Climate strategy of Northern Ostrobothia] www.pohjois-pohjanmaa.fi/file.php?93 (In Finnish)

Council of Oulu Region, 2014. The Region Development Plan 2014–2017. www.pohjois-pohjanmaa.fi/file.php?3108 (In Finnish)

County Administrative Board [Länsstyrelserna], 2006. Översvämningsrisker i fysisk planering. Rekommendationer för markanvändning vid nybebyggelse [Flood risks in land use planning. Recommendations for land use in new Developments]. www.lansstyrelsen.se/uppsala/SiteCollectionDocuments/Sv/publikationer/2006/oversvam-fysisk-planering.pdf

County Administrative Board [Länsstyrelserna], 2012. Klimatanpassning i fysisk planering – Vägledning från länsstyrelserna [Climate adaptation in land use planning – guidance from the County Administrative Boards]. www.lansstyrelsen.se/vasterbotten/SiteCollectionDocuments/Sv/Publikationer/2012/Klimatanpassning%20i%20den%20fysiska%20planeringen.pdf

County Administrative Board of [Länsstyrelsen] Norrbotten, 2009. Klimatförändringar i Norrbotten – konsekvenser och anpassning [Climate changes in Norrbotten – consequences and adaptation]. www.lansstyrelsen.se/norrbotten/SiteCollectionDocuments/Sv/publikationer/miljo%20och%20klimat/Anpassning%20klimat/Klimatförändringar%20i%20Norrbotten%20%20%20konsekvenser%20och%20anpassning.pdf

County Administrative Board of [Länsstyrelsen] Norrbotten, 2010. Föroreningsrisker för vattentäkter [Pollution risks for water sources]. www.lansstyrelsen.se/norrbotten/SiteCollectionDocuments/Sv/publikationer/miljo%20och%20klimat/Anpassning%20klimat/Föroreningsrisker%20för%20vattentäkter.pdf

County Administrative Board of [Länsstyrelsen] Norrbotten, 2012. Sektorer och områden [Sectors and areas]. www.lansstyrelsen.se/norrbotten/Sv/miljo-och-klimat/klimat-och-energi/anpassning-till-forandrat-klimat/sektorer-och-omraden/Pages/default.aspx

County Administrative Board of Stockholm [Länsstyrelsen i Stockholms län], 2010a. Klimatanpassningsplan – process och verktyg [Climate adaptation plan – process and tools]. www.lansstyrelsen.se/stockholm/SiteCollectionDocuments/Sv/publikationer/2010/systemtyper-klimatfaktorer-lathund.pdf

County Administrative Board of Stockholm [Länsstyrelsen i Stockholms län], 2010b. Konsekvens- och sårbarhetsanalys – metodbeskrivning [Consequence and vulnerability analysis – description of method]. www.lansstyrelsen.se/stockholm/SiteCollectionDocuments/Sv/publikationer/2010/konsekvens-sarbarhetsanalys-metodbeskrivning.pdf

County Administrative Board of Stockholm [Länsstyrelsen i Stockholms län], 2010c. Systemtyper och klimatfaktorer – Lathund som stöd vid konsekvens- och sårbarhetsanalyser [System-types and climate factors – guidance for consequence and vulnerability analyses]. www.lansstyrelsen.se/stockholm/SiteCollectionDocuments/Sv/publikationer/2010/systemtyper-klimatfaktorer-lathund.pdf

County Administrative Board of [Länsstyrelsen] Västerbotten, 2007. Klimatförändringar och samhällsplanering – Risker och rekommendationer i den fysiska planeringen [Climate changes and planning – risks and recommendations in land use planning]. www.lansstyrelsen.se/vasterbotten/SiteCollectionDocuments/Sv/Publikationer/2007/Klimatf%C3%B6r%C3%A4ndringar%20och%20samh%C3%A4llsplanering.pdf

County Administrative Board of [Länsstyrelsen] Västerbotten, 2012. Klimatsmart Västerbotten -Klimat- och energistrategi för Västerbottens län [Climate Smart Västerbotten – Climate and energy strategy for Västerbotten county]. www.lansstyrelsen.se/vasterbotten/SiteCollectionDocuments/Sv/miljo-och-klimat/klimat-och-energi/Klimat-%20och%20energistrategi.pdf

Dannevig, H. and C. Aall, 2015. The regional level as boundary organization? An analysis of climate change adaptation governance in Norway. Environmental Science and Policy, 54:168-175.

Dannevig, H. and B. Dale, in press. The Nussir case and the battle for legitimacy: Scientific assessments, defining power and political contestations. In: Dale, B., I. Bay-Larsen and B. Skorstad (eds), The Will to Drill – Mining and Arctic Communities. Springer Polar Sciences.

Dannevig, H. and G.K. Hovelsrud, 2016. Understanding the need for adaptation in a natural resource dependent community in northern Norway: Issue salience, knowledge and values. Climatic Change, 135:261-275.

Dannevig, H., T. Rauken and G.K. Hovelsrud, 2012. Implementation of adaptation at the local level. Local Environment, 17:597- 612.

Dannevig, H., G.K. Hovelsrud and I.A. Husabø, 2013. Driving the agenda for climate change adaptation in Norwegian municipalities. Environment and Planning C: Government and Policy, 31:490-505.

Dannevig, H., I. Bay-Larsen, B. Oort and E.C.H. Keskitalo, 2015. Adaptive capacity to changes in terrestrial ecosystem services amongst primary small-scale resource users in northern Norway and Sweden. Polar Geography, 38:271-288.

Drinkwater, K.F., 2011. The influence of climate variability and change on the ecosystems of the Barents Sea and adjacent waters: Review and synthesis of recent studies from the NESSAS Project. Progress in Oceanography, 90:47-61.

Duhaime, G., A. Lemelin, V. Didyk, O. Goldsmith, G. Winther, A. Caron, N. Bernard and A. Godmaire, 2004. Economic systems. In: The Arctic Human Development Report. pp. 69-84. Stefansson Arctic Institute, Akureyri, Iceland.

Fankhauser, S., J.B. Smith and R.S.J. Tol, 1999. Weathering climate change: some simple rules to guide adaptation decisions. Ecological Economics, 30:67-78.

Finnish Government, 2013. Finland's Strategy for the Arctic Region 2013. Government resolution, 23 August 2013. Prime Minister's Office Publications 16/2013. http://vnk.fi/documents/10616/334509/Arktinen+strategia+2013+en.pdf/6b6fb723-40ec-4c17-b286-5b5910fbecf4

Finnish Ministry of Agriculture and Forestry, 2005. Finland's National Strategy for Adaptation to Climate Change. http://climate-adapt.eea.europa.eu/countries-regions/countries/finland

Finnish Ministry of Agriculture and Forestry, 2014. Kansallinen ilmastonmuutokseen sopeutumissuunnitelma 2022 (Implementation plan of national climate adaptation strategy 2022). Maa- ja metsätalousministeriö. http://mmm.fi/documents/1410837/1516663/2014_5_lmastonmuutos.pdf/1716aa76-8005-4626-bae0-b91f3b0c6396

Finnish Ministry of Employment and Economy, 2011. Valtakunnalliset alueiden kehittämistavoitteet 2011-2015 – Taloudellisesti, sosiaalisesti ja ympäristöllisesti kestävä Suomi [Goals for national regional development 2011-2015 – Economically, socially and environmentally sustainable Finland].

Forbes, B.C., 2013. Cultural resilience of social-ecological systems in the Nenets and Yamal-Nenets Autonomous Okrugs, Russia: a focus on reindeer nomads of the tundra. Ecology and Society, 18: doi: 10.5751/ES-05791-180436

Forbes, B.C. and G. Kofinas, 2015. Resource governance. In: Larsen, J.N. and G. Fondahl (eds.), Arctic Human Development Report: Regional Processes and Global Linkages. pp. 255-298. Nordic Council of Ministers, TemaNord 2014:567.

Forbes, B.C., Stammler, F., Kumpula, T., Meschtyb, N., Pajunen, A. and Kaarlejärvi, E. 2009. High resilience in the Yamal-Nenets social-ecological system, West Siberian Arctic, Russia. PNAS, 106:22041-22048.

Fyhri, A., J.K.S. Jacobsen and H. Tømmervik, 2009. Tourists' landscape perceptions and preferences in a Scandinavian coastal region. Landscape and Urban Planning, 91:202-211.

Government Offices of Sweden, 2009. En sammanhållen klimat- och energipolitik. Klimat [An integrated climate and energy policy – climate]. Regeringens proposition 2008/09:162.

Government Offices of Sweden [Miljömålsberedningen], 2016. Ett klimatpolitiskt ramverk för Sverige. Delbetänkande av miljömålsberedningen. [A Climate Policy Framework for Sweden. Proposal from the Cross-Party Committee on Environmental Objectives]. SOU 2016: 21, Stockholm.

Hall, C.M., 2014. Will climate change kill Santa Claus? Climate change and high-latitude Christmas place branding. Scandinavian Journal of Hospitality and Tourism, 14:23-40.

Hall, C.M. and J. Saarinen, 2010. Polar tourism: definitions and dimensions. Scandinavian Journal of Hospitality and Tourism, 10:448-467.

Hall, C.M., M. James and S. Wilson, 2010. Biodiversity, biosecurity, and cruising in the Arctic and sub-Arctic. Journal of Heritage Tourism, 5:351-364.

Hanssen, G.S., P.K. Mydske and E. Dahle, 2013. Multi-level coordination of climate change adaptation: by national hierarchical steering or by regional network governance? Local Environment, 18:869-887.

Hanssen-Bauer, I., E.J. Førland, I. Haddeland, H. Hisdal, S. Mayer, A. Nesje, J.E.Ø. Nilsen, S. Sandven, A.B. Sandø, A. Sorteberg and B. Ådlandsvik, 2015. Klima i Norge 2100: Kunnskapsgrunnlag for klimatilpasning oppdatert i 2015 [Climate in Norway 2100. Knowledge base for climate adaptation, updated in 2015]. Norsk klimasenter, NCCS report no. 2/2015.

Harsem, O. and A.H. Hoel, 2013. Climate change and adaptive capacity in fisheries management: the case of Norway. International Environmental Agreements-Politics Law and Economics, 13:49-63.

Harsem, Ø., A. Eide and K. Heen, 2011. Factors influencing future oil and gas prospects in the Arctic. Energy Policy, 39:8037-8045.

Hedberg, C. and K. Haandrikman, 2014. Repopulation of the Swedish countryside: Globalisation by international migration. Journal of Rural Studies, 34:128-138.

Helander-Renvall, E., 2014. Relationships between Sámi reindeer herders, lands, and reindeer. Handbook of Human-Animal Studies. pp. 246-258. Routledge.

Himanen, S., J. Inkeröinen, K. Latola, T. Väisänen and E. Alasaarela, 2012. Analysis of Regional Climate Strategies in the Barents Region. Reports of the Ministry of the Environment. http://www.barentsinfo.fi/beac/docs/Analysis_of_Regional_Climate_Strategies_in_the_Barents_Region_MFA_FIN_2012.pdf

Homewood, K.M., P. Chevenix Trench and D. Brockington, 2012. Pastoralist livelihoods and wildlife revenues in East

Africa: a case for coexistence? Pastoralism: Research, Policy and Practice, 2:19, doi: 10.1186/2041-7136-2-19.

Hovelsrud, G.K. and B. Smit (eds.), 2010. Community Adaptation and Vulnerability in Arctic Regions. Springer.

Hovelsrud, G.K., J.L. White, M. Andrachuk and B. Smit, 2010a. Community adaptation and vulnerability integrated. In: Hovelsrud, G.K. and B. Smit (eds.), Community Adaptation and Vulnerability in Arctic Regions. pp. 335-348. Springer.

Hovelsrud, G.K., H. Dannevig, J. West and H. Amundsen, 2010b. Adaptation in fisheries and municipalities: three communities in northern Norway. In: Hovelsrud, G.K. and B. Smit (eds.), Community Adaptation and Vulnerability in Arctic Regions. pp. 23-62. Springer.

Hovelsrud, G.K., B. Poppel, B. van Oort and J.D. Reist, 2011. Arctic societies, cultures, and peoples in a changing cryosphere. Ambio, 40:100-110.

Hovelsrud, G.K., J. West and H. Dannevig, 2015. Exploring vulnerability and adaptation narratives among fishers, farmers and municipal planners in Northern Norway. In: O'Brien, K. and E. Selboe (eds.), The Adaptive Challenge of Climate Change, pp. 194-212. Cambridge University Press.

Hukkinen, J., L. Müller-Wille, P. Aikio, H. Heikkinen, O. Jääskö, A. Laakso, H. Magga, S. Nevalainen, O. Pokuri, K. Raitio and N. West, 2006. Development of participatory institutions for reindeer management in Finland: A diagnosis of deliberation, knowledge integration and sustainability. Ecological Studies, 184:47-71.

ICMM, 2013. Adapting to a changing climate: implications for the mining and metals industry, 2013. International Council on Mining and Metals (ICMM). www.icmm.com/document/5173

IPCC, 2007. Summary for Policymakers. In: Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds.), Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

IPCC, 2014a. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.). Cambridge University Press.

IPCC, 2014b. Annex II: Glossary In: Agard, J., E.L.F. Schipper, J. Birkmann, M. Campos, C. Dubeux, Y. Nojiri, L. Olsson, B. Osman-Elasha, M. Pelling, M.J. Prather, M.G. Rivera-Ferre, O.C. Ruppel, A. Sallenger, K.R. Smith, A.L. St. Clair, K.J. Mach, M.D. Mastrandrea, and T.E. Bilir (eds.), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. pp. 1757-1776. Cambridge University Press.

Jaakkola, L.M., M.M. Heiskanen, A.M. Lensu and M.T. Kuitunen, 2013. Consequences of forest landscape changes for the availability of winter pastures to reindeer (*Rangifer tarandus tarandus*) from 1953 to 2003 in Kuusamo, northeast Finland. Boreal Environment Research, 18:459-472.

Jansson R, C. Nilsson, E.C.H. Keskitalo, T. Vlasova, M.-L. Sutinen, J. Moen, F. Chapin III, K. Bråthen, M. Cabeza, T.V. Callaghan, B. Van Oort, H. Dannevig, I.A. Bay-larsen, R.A. Ims and P. Aspholm, 2015. Future changes in the supply of goods and services from natural ecosystems: prospects for the European north. Ecology and Society, 20:32. doi: http://dx.doi.org/10.5751/ES-07607-200332.

Jepsen, J.U., M. Biuw, R.A. Ims, L. Kapari, T. Schott, O.P.L. Vindstad and S.B. Hagen, 2013. Ecosystem impacts of a range expanding forest defoliator at the forest-tundra ecotone. Ecosystems, 16:561-575.

Keil, K., 2015. Spreading oil, spreading conflict? Institutions regulating Arctic oil and gas activities. The International Spectator, 50:85-110.

Kietäväinen, A. and S. Tuulentie, 2013. Ilmastonmuutokseen varautuminen Pohjois-Suomen matkailussa [Adaptation to climate change in tourism in Northern Finland]. Alue ja ympäristö, 42:42-52.

Keskitalo, E.C.H., 2008. Climate Change and Globalization in the Arctic: An Integrated Approach to Vulnerability Assessment. Earthscan Publications.

Keskitalo, E.C.H., 2010a. Adapting to climate change in Sweden: National policy development and adaptation measures in Västra Götaland. In: Keskitalo, E.C.H. (ed), The Development of Adaptation Policy and Practice in Europe: Multi-level Governance of Climate Change. pp. 189-232. Springer.

Keskitalo, E.C.H., 2010b. Vulnerability and adaptive capacity in a multi-use forest municipality in northern Sweden. In: Hovelsrud, G. and B. Smit (eds.), Community Adaptation and Vulnerability in Arctic Regions. pp. 189-232. Springer.

Keskitalo, E.C.H., 2010c. Adaptive capacity and adaptation in Swedish multi-use boreal forests: sites of interaction between different land uses. In: Armitage, D. and R. Plummer (eds.), Adaptive Capacity: Building Environmental Governance in an Age of Uncertainty. pp. 89-106. Springer.

Keskitalo, E.C.H. (ed.), 2013. Climate Change and Flood Risk Management: Adaptation and Extreme Events at Local Level. Edward Elgar.

Keskitalo, E.C.H. and L. Lundmark, 2010. The controversy over protected areas and forest-sector employment in Norrbotten, Sweden: forest stakeholder perceptions and statistics. Society and Natural Resources, 23:146-164.

Keskitalo, E.C.H. and C. Southcott, 2015. Globalization. In: Larsen, J.N. and G. Fondahl, (eds), Arctic Human Development Report. Regional Processes and Global Linkages. pp. 397-421. Nordic Council of Ministers, Copenhagen.

Keskitalo, E.C.H., N. Klenk, R. Bullock, A.L. Smith and D.R. Bazely, D.R., 2011. Preparing for and responding to disturbance: examples from the forest sector in Sweden and Canada. Forests, 2:505-524.

Keskitalo, E.C.H., J. Åkermark and J. Vola, 2013. Flood risks along the Torne River between Sweden and Finland. In: Keskitalo, E.C.H. (ed.), Climate Change and Flood Risk Management: Adaptation and Extreme Events at Local Level. pp. 67-94. Edward Elgar, Cheltenham.

Keskitalo, E.C.H., J. Baird, E. Laszlo Ambjörnsson and R. Plummer, 2014. Social network analysis of multi-level linkages: a Swedish case study on northern forest-based sectors. Ambio, 43:745-758.

Keskitalo, E.C.H., J. Bergh, A. Felton, C. Björkman, M. Berlin, P. Axelsson, E. Ring, A. Ågren, j.-M. Roberge, M.J. Klapwijk, J. Boberg, R.J. Keenan and E.J. Jokela, 2016. Adaptation to climate change in Swedish forestry. Forests, 7:28. doi:10.3390/f7020028.

Klein, R.J.T., G.F. Midgley, B.L. Preston, M. Alam, F.G.H. Berkhout, K. Dow and M.R. Shaw, 2014. Adaptation opportunities, constraints, and limits. In: Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea and L.L. White (eds.), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. pp. 899-943. Cambridge University Press.

Kokorin, A., E. Smirnova and D.G. Zamolodchikov, 2013. Izmenenie klimata. Regiony severa evropeyskoy chasti Rossii i Zapadnoi Sibiri. [Climate change. The book for teachers of upper classes of secondary schools. Issue 1. Northern regions of the european part of Russia and Western Siberia]. www.wwf.ru/resources/publ/book/807

Kotov, V. and E. Nikitina, 1996. Norilsk nickel: Russia wrestles with an old polluter. Environment: Science And Policy For Sustainable Development, 38:6-37.

Kotov, V. and E. Nikitina, 1998. Regime and enterprise: Norilsk Nickel and transboundary air pollution. In: The Implementation and Effectiveness of International Environmental Commitments: Theory and Practice. pp. 549-574. MIT Press.

Kristoffersen, B., 2014. Securing geography: Framings, logics and strategies in the Norwegian High North. In: Powell, R.C. and K. Dodds (eds.), Polar Geopolitics? Knowledges, Resources and Legal Regimes. pp. 131-148. Edward Elgar.

Kristoffersen, B., 2015. Opportunistic adaptation: new discourses on oil, equity, and environmental security. In: O'Brien, K. and E. Selboe, The Adaptive Challenge of Climate Change. pp. 140-159. Cambridge University Press.

Kristoffersen, B. and B. Dale, 2014. Post petroleum security in Lofoten: how identity matters. Arctic Review on Law and Politics, 5:201-226.

Kulturdepartementet, 2015. Regleringsbrev för budgetåret 2016 avseende Riksantikvarieämbetet. Regeringsbeslut [Department of Culture, 2015. Letter of regulation for the budget year 2016 concerning the Swedish National Heritage Board. Government decision].

Kumpula, J. and A. Colpaert, 2007. Snow conditions and usability value of pastureland for semi-domesticated reindeer (*Rangifer tarandus tarandus*) in northern boreal forest area. Rangifer, 27:25-39.

Kumpula, T., A. Pajunen, E. Kaarlejärvi, B.C. Forbes and F. Stammler, 2011. Land use and land cover change in Arctic Russia: ecological and social implications of industrial development. Global Environmental Change, 21:550-562.

Kvalvik, I., S. Dalmannsdottir, H. Dannevig, G. Hovelsrud, L. Rønning and E. Uleberg, 2011. Climate change vulnerability and adaptive capacity in the agricultural sector in Northern Norway. Acta Agriculturae Scandinavica B, 61:27-37.

Laaksonen, S., J. Pusenius, J. Kumpula, A. Venäläinen, R. Kortet, A. Oksanen and E. Hoberg, 2010. Climate change promotes the emergence of serious disease outbreaks of filarioid nematodes. Ecohealth, 7:7-13.

Larsen, J.N. and G. Fondahl (eds.), 2015. Arctic Human Development Report: Regional Processes and Global Linkages. TemaNord 2014:567. Nordic Council of Ministers.

Larsen, N., O.A. Anisimov, A. Constable, A.B. Hollowed, N. Maynard, P. Prestrud, T.D. Prowse and J.M.R. Stone, 2014. Polar regions. In: Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea and L.L. White (eds.), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. pp. 1567-1612. Cambridge University Press.

Larsen, J.N., P. Schweitzer and A. Petrov, 2015. Arctic Social Indicators: ASI II: Implementation. Nordic Council of Ministers.

Leichenko, R.M. and K. O'Brien, 2008. Environmental Change and Globalization. Double Exposures. Oxford University Press.

Löf, A., 2014. Challenging Adaptability: Analysing the governance of reindeer husbandry in Sweden. Department of Political Science, Umeå University, Sweden.

Makarov, I.A. and I.A. Stepanov, 2015. Environmental Factor of Economic Development of the Russian Arctic. ECO, No 11. S120-138.

Martynova, E.P. and N.I. Novikova, 2012. Tazovskie nentsy v usloviyakh neftegazovogo osvoeniya: Etnologicheskaya ekspertiza 2011 goda [Taz Nenets under oil and gas exploration: Ethnological assessment 2011]. Yakovlev Publisher, Moscow. (In Russian)

Maynard, N.G., A. Oskal, J.M. Turi, S.D. Mathiesen, I.M.G. Eira, B. Yurchak, V. Etylin and J. Gebelein, 2010. Impacts of arctic climate and land use changes on reindeer pastoralism: indigenous knowledge and remote sensing. In: Eurasian Arctic land Cover and land Use in a Changing Climate. Springer Science.

Meier, W.N., S. Gerland, M.A. Granskog, J.R. Key, C. Haas, G.K. Hovelsrud, K.M. Kovacs, A. Makshtas, C. Michel, D. Perovich, J.D. Reist and B. Oort, 2011. Sea ice. In: Snow, Water, Ice and Permafrost in the Arctic (SWIPA): Climate Change and the Cryosphere. pp. 9-1-9.87. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

Mettiäinen, I., 2013. Climate change turn in the regional development strategies of an arctic region, case Finnish Lapland. In: Gudmundur, A. and T. Koivurova (eds.), The Yearbook of Polar Law. Vol. 5. pp. 143-183. Martinus Nijhoff.

Midttømme, G.H., 2015. Klimaendringer og damsikkerhet: Analyse av dammers sårbarhet for økte flommer. Report 94-2015. Norwegian Water and Electricity Directorate, Oslo.

Mimura, N., R.S. Pulwarty, D.M. Duc, I. Elshinnawy, M.H. Redsteer, H.Q. Huang, J.N. Nkem, and R.A. Sanchez Rodriguez, 2014. Adaptation planning and implementation. In: Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. pp. 869-898. Cambridge University Press.

Ministry of the Environment and Statistics Finland, 2013. Finland's Sixth National Communication under the United Nations Framework Convention on Climate Change. http://stat.fi/tup/khkinv/fi_nc6.pdf

Mitchell, R.B., W.C. Clark, D.W. Cash and N.M. Dickson (eds.), 2006. Global Environmental Assessments: Information and Influence. MIT Press.

Moen, J., 2008. Climate change: effects on the ecological basis for reindeer husbandry in Sweden. Ambio, 37:304-311.

Moen, J. and E.C.H. Keskitalo, 2010. Interlocking panarchies in the multi-use boreal forests in Sweden. Ecology and Society, 15(3), 17. www.ecologyandsociety.org/vol15/iss3/art17/

Mossberg Sonnek, K., B. Johansson and J. Lindgren, 2013. Risk and vulnerability analysis: A feasible process for local climate adaptation in Sweden? Local Environment, 18:781-800.

Müller, D.K. and B. Jansson, 2007. The difficult business of making pleasure peripheries prosperous: perspectives on space, place and environment. In: Müller, D.K. and B. Jansson (eds.), Tourism in Peripheries: Perspectives from the far North and South. pp. 3-18. CAB International.

Nelson, J. and R. Schuchard, 2011. Adapting to Climate Change: A Guide for the Mining Industry. Business for Social Responsibility (BSR). www.bsr.org/en/our-insights/report-view/adapting-to-climate-change-a-guide-for-the-mining-industry

NGI, 2013. Impacts of extreme weather events on infrastructure in Norway (InfraRisk) - Final report to the RCN project 200689. By: Frauenfelder, R., A. Solheim, K. Isaksen, B. Romstad, A.V. Dyrrdal, K.H.H. Ekseth, R. Gangstø, A. Harbitz, C.B. Harbitz, J.E. Haugen, H.O. Hygen, H. Haakenstad, C. Jaedicke, Á. Jónsson, R. Klæboe, J. Ludvigsen, N.M. Meyer, N.M., Rauken, R., Sverdrup-Thygeson, K., Aaheim, A. Norwegian Geotechnical Institute (NGI). Report no. 20091808-05-R. (In Norwegian)

Nikitina, E., 2011. Russian Arctic: problems of ecologically sustainable development. In: Simoniya, N.A. (ed.), Arctic. Interests of Russia: Energy, Ecology. pp. 125-157. (In Russian)

Nikitina, E., 2013. A changing Arctic: adaptation to climate change. The Arctic Herald, 1:46-53.

Nikitina, E., N. Poussenkova, J. Loe and I. Kelman, 2015. Sustainable oil and gas practices in the Arctic: Business responsibility towards communities. The Arctic Herald, 3:60-74.

Noble, I.R., S. Huq, Y.A. Anokhin, J. Carmin, D. Goudou, F.P. Lansigan, B. Osman-Elasha and A. Villamizar, 2014. Adaptation needs and options. In: Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. pp. 833-868. Cambridge University Press.

Nordic Council of Ministers, 2011. Megatrends. Nordic Council of Ministers, TemaNord 2011:527.

Norum, R., Kramvig, B. and B. Kristoffersen, 2016. Arctic whale-watching and anthropocene ethics. In: Gren, M. and Hujbens, E. (eds.), Tourism and the Anthropocene. pp. 94-110. Routledge.

Norwegian Directorate for Civil Protection, 2011. Samfunnsikkerhet i Arealplanlegging. Kartlegging av risiko og sårbarhet [Civil protection in spatial planning. Mapping of risk and vulnerability]. Tønsberg, Norway. Tema 11. (In Norwegian)

Norwegian Ministry of Climate and Environment, 2015. Overvann i byer og tettsteder - Som problem og ressurs. Official Norwegian Report, NOU 2015:16. Ministry of Climate and Environment, Oslo, Norway.

Norwegian Ministry of Foreign Affairs, 2006. Regjeringens nordområdestrategi [The Norwegian Government's High North Strategy]. Norwegian Ministry of Foreign Affairs, Oslo.

Norwegian Ministry of Foreign Affairs, 2009. Nye byggesteiner i Nord. Neste trinn i regjeringens nordområdestrategi [New building blocks in the North. Next step in the Government's High North Strategy]. Norwegian Ministry of Foreign Affairs, Oslo.

Norwegian Ministry of Foreign Affairs, 2011. Meld. St. 7, (2011-2012) Nordområdene, Visjon og virkemidler [The Northern Regions. Visions and instruments].

Norwegian Ministry of Foreign Affairs, 2014. "Nordområdene 2014". The Northern Globe. Northern regions update 2014. Norwegian Ministry of Foreign Affairs, Oslo.

Norwegian Ministry of the Environment, 2010. Tilpassing til eit klima i endring - Samfunnet si sårbarheit og behov for tilpassing til konsekvensar av klimaendringane [Society's vulnerability and adaptation needs to consequences of climate change]. Official Norwegian Report, NOU 2010:10. Ministry of Climate and Environment, Oslo, Norway

Norwegian Ministry of the Environment, 2013. St.meld. 33. (2012-2013) Klimatilpasning i Norge [Climate change in Norway – Meld St. 33 (2012-2013) Report to the Starting (white paper). Ministry of the Environment, Oslo, Norway.

Norwegian Ministry of Trade and Industry, 2014. Sjømatindustrien – Utredning av sjømatindustriens rammevilkår [The regulatory conditions for the sea food industry]. Official Norwegian Report, NOU 2014: 16. Norwegian Ministry of Trade and Industry.

Norwegian Water and Energy Directorate, 2014. Flaum- og skredfare i arealplaner [Risk of floods and landslides in spatial planning] Retningslinjer 2/2011, revidert 2014. Norwegian Water and Energy Directorate.

NVE, 2015. Mulige effekter av havnivåstigning og stormflo på norsk energiforsyning [Potential consequences of sea level rise and storm surge on Norwegian energy supply]. Norwegian Water Resources and Energy Directorate (NVE), Oslo.

Nyseth, T. and A. Viken (eds.), 2009. Place Reinvention: Northern Perspectives. Routledge.

Oberman, N.G., 2007. Global warming and changes in the permafrost zone of the Pechora-Urals region. Razvedka I Ohrana Nedr, 7:20-30. (In Russian)

O'Brien, K. and R.M. Leichenko, 2003. Winners and losers in the context of global change. Annals of the Association of American Geographers, 93:89-103.

Oinonen, K., J. Kumpula, P. Shemeikka, M. Väänänen, P. Kontio, J. Siitari, S. Siitari and H. Törmänen, 2014. Tools for taking reindeer herding into account in land use planning – POROT Project. NJF Report Vol 10, No 8/2014.

Øseth, E., 2010. Klimaendringerer i Norsk arktis: Konsekvenser for livet i nord [Climate change in the Norwegian Arctic – consequences for life in the North]. Norwegian Environment Agency, Report 136.

Oskal, A., J.M. Turi, S.D. Mathiesen and P. Burgess, 2009. EALÁT. Reindeer Herders Voice: Reindeer Herding, Traditional Knowledge and Adaptation to Climate Change and Loss of Grazing Land. International Centre for Reindeer Husbandry, Kautokeino / Guovdageadnu, Norway.

Pearce, T., J.D. Ford, J. Prono, F. Duerden, L. Berrang-Ford, T.R. Smith, J. Pittman, A. Reid, M. Beamier and D. Marshall, 2009. Climate Change and Canadian Mining: Opportunities for Adaptation. Arctic North. The David Suzuki Foundation.

Pelyasov, A., 2013. Russian National strategy for development of the Arctic zone and the Provision of National Security until 2020 (adopted by the President of the Russian Federation on February 8, 2013, No.Pr-232).

Peltonen-Sainio, P., L. Jauhiainen, K. Hakala and H. Ojanen, 2009. Climate change and prolongation of growing season: changes in regional potential for field crop production in Finland. Agricultural and Food Science, 18:171-190.

Persson, G. and M. Rummukainen, 2010. Klimatförändringarnas effekter på svenskt miljömålsarbete [The Effects of Climate Change on Swedish Environmental Work]. Klimatologi Report 2/2010. Swedish Meteorological and Hydrological Institute (SMHI).

Poussenkova, N., 2011. The Arctic oil and gas saga: breakthroughs and failures in creation of the new hydrocarbon province. In: The Arctic. Interests of Russia: Energy, Environment. INEK, Moscow.

Poussenkova, N., 2013. Russia's Eastern Energy Policy: A Chinese Puzzle for Rosneft. Russie. Nei. Visions. V.70

Poussenkova, N. and E. Nikitina, 2016. Petroleum CSR in Russia: affordable luxury or basic necessity? Russian Analytical Digest, 181:3-8.

Rantamäki-Lahtinen, L., 2008. Porotalouden taloudelliset menestystekijät [Reindeer managements economic success factors]. MTT:n selvityksiä 156:170s.

Rasmus, S., S. Kivinen, M. Bavay and J. Heiskanen, 2016. Local and regional variability in snow conditions in northern Finland: A reindeer herding perspective. Ambio, 45:398-414.

Rasmussen, R.O., G.K. Hovelsrud, S. Gearheard et al., 2015. Community viability and adaptation. In: Larsen, J.N, and G. Fondahl (eds.), Arctic Human Development Report: Regional Processes and Global Linkages. pp. 425-473. TemaNord 2014:567. Nordic Council of Ministers.

Rauken, T. and I. Kelman, 2010. River flood vulnerability in Norway through the pressure and release model. Journal of Flood Risk Management, 3:314-322.

Rauken, T., I. Kelman, J.K.S. Jacobsen and G.K. Hovelsrud, 2010. Who can stop the rain? Perceptions of summer weather effects among small tourism businesses. Anatolia, 21:289-304.

Rauken, T., P.K. Mydske and M. Winsvold, 2014. Mainstreaming climate change adaptation at the local level. Local Environment, 20:408-423.

Rautio, A., B. Poppel and K. Young, 2014. Human health and well-being. In: Arctic Human Development Report: Regional Processes and Global Linkages. pp. 297-346. Nordic Council of Ministers, Copenhagen.

Regional Council of Lapland, 2011. Lapin ilmastostrategia 2030 [Lapland climate strategy 2030]. www.lappi.fi/lapinliitto/c/document_library/get_file?folderId=53864&name=DLFE-12332.pdf

Regional council of Lapland, 2014a. Lappi-sopimus [Lapland agreement]. www.lappi.fi/lapinliitto/c/document_library/get_file?folderId=26465&name=DLFE-24375.pdf

Regional Council of Lapland, 2014b. Lapin maakuntaohjelma 2014-2017 [Regional Development plan 2014-2017]. www.lappi.fi/lapinliitto/c/document_library/get_file?folderId=26465&name=DLFE-24375.pdf

Reidsma, P., F. Ewert, A.O. Lansink and R. Leemans, 2010. Adaptation to climate change and climate variability in European agriculture: The importance of farm level responses. European Journal of Agronomy, 32:91-102.

Revich, B., N. Tokarevich and A.J. Parkinson, 2012. Climate change and zoonotic infections in the Russian Arctic. International Journal of Circumpolar Health, 71:18792, http://dx.doi.org/10.3402/ijch.v71i0.18792

RHA, 2014. Guide to Examining Reindeer Husbandry in Land Use Projects. Reindeer Herders' Association (RHA). Pohjolan Painotuote Oy, Rovaniemi.

Riseth, J-Å, H. Tømmervik, E. Helander-Renvall, N. Labba, C. Johansson, E. Malnes, J.W. Bjerke, C. Jonsson, V. Pohjola, L.-E. Sarri, A. Schanche and T.V. Callaghan, 2011. Sámi traditional ecological knowledge as a guide to science: snow, ice and reindeer pasture facing climate change. Polar Record, 47:202-217.

Risvoll, C., 2015. Adaptive capacity within pastoral communities in the face of environmental and societal change. PhD thesis, Nord University, Norway.

Risvoll, C. and G.K. Hovelsrud, 2016. Pasture access and adaptive capacity in reindeer herding districts in Nordland, northern Norway. The Polar Journal, 6:87-111.

Risvoll, C., G. Fedreheim, A. Sandberg and S. BurnSilver, 2014. Does pastoralists' participation in the management of national parks in northern Norway contribute to adaptive governance? Ecology and Society, 19:71. http://dx.doi.org/10.5751/ES-06658-190271.

Risvoll, C., G.E. Fedreheim and D. Galafassi, 2016. Tradeoffs in pastoralism governance: challenges for biodiversity and adaptation. Pastoralism: Research, Policy and Practice, 6:1-15.

Rittel, H.W. and M.M. Webber, 1973. Dilemmas in a general theory of planning. Policy Sciences, 4:155-169.

Robertsson, L. and R. Marjavaara, 2014. The seasonal buzz: knowledge transfer in a temporary setting. Tourism Planning and Development, 12:251-265.

Roshydromet, 2008. First Assessment report on climate change and its consequences for the territory of the Russian Federation. Roshydromet, Moscow.

Roshydromet, 2014. The Second Roshydromet Assessment Report on Climate Change and its Consequences in the Russian Federation. Federal Service for Hydrometeorology and Environmental Monitoring (Roshydromet), Moscow. http://downloads.igce.ru/publications/OD_2_2014/v2014/pdf/resume_ob_eng.pdf

Rosleshoz, 2016. Federal Agency for Forestry. Forest fires. Organization of forest fires protection. www.rosleshoz.ru/forest_fires

Russian Federation, 2009. Climate Doctrine of the Russian Federation. http://en.kremlin.ru/supplement/4822

Russian Federation Government, 2011. Распоряжение Правительства РФ от 25 апреля 2011 г. No.730-р Об утверждение комплексного плана реализации Климатической доктрины РФ на период до 2020 г [RF Government Order dated April 25, 2011 No.730-p On approval of an integrated plan for the implementation of the Climate Doctrine of the Russian Federation for the period up to 2020].

Rybråten, S., 2013. This is not a wilderness. This is where we live. Enacting nature in Unjárga-Nesseby, northern Norway. PhD Thesis. University of Oslo.

Rybråten, S. and G.K. Hovelsrud, 2010. Local effects of global climate change: differential experiences of sheep farmers and reindeer herders in Unjárga/Nesseby, a coastal Sámi community in northern Norway. In: Hovelsrud, G.K. and B. Smit (eds.), Community Adaptation and Vulnerability in Arctic Regions. pp. 313-334. Springer.

Rydell, B. and B. Lind, 2009. Mål och indikatorer för anpassning till förändrat klimat med avseende på naturolyckor [Aims and indicators for adapting to climate change with focus on natural hazards]. Swedish Geotechnical Institute.

Rydén, P., R. Björk, M.L. Schäfer, J.O. Lundström, B. Petersén, A. Lindblom, M. Forsman, A. Sjöstedt and A. Johansson, 2012. Outbreaks of tularemia in a boreal forest region depends on mosquito prevalence. The Journal of Infectious Diseases, 205:297-304.

Saijets, M. and E. Helander-Renvall, 2009. Ihmisen, poron ja luonnon vuorovaikutus – Perinnetiedon merkitys saamelaisessa poronhoidossa Utsjoella [Interaction between human, reindeer and nature – the role of traditional knowledge in Sámi reindeer herding in Utsjoki]. Lapin yliopisto, Arktinen keskus.

Sandström, P., C. Sandström, J. Svensson, L. Jougda and K. Baer, 2012. Participatory GIS to mitigate conflicts between reindeer husbandry and forestry in Vilhelmina Model Forest, Sweden. Forest Chronicle, 88:254-260.

Secretariat of the Convention on Biological Diversity, 2004. Voluntary Guidelines for the Conduct of Cultural, Environmental and Social Impact Assessment regarding Developments Proposed to Take Place on, or which are Likely to Impact on, Sacred Sites and on Lands and Waters Traditionally Occupied or Used by Indigenous and Local Communities Montreal. CBD Guidelines Series.

Shemeikka, P., M. Väänänen, J. Kumpula, H. Törmänen and J. Siitari, 2014. Producing GIS data on reindeer management and land use in the POROT Project – How to utilize this data? NJF Report, Vol 10, No 8/2014.

Shvidenko, A.Z. and S. Nilsson, 2000. Extent, distribution, and ecological role of fire in Russian forests. Ecological Studies, 138:132-150.

Sidorov, P.I., L.I. Menshikova, R.V. Buzinov, A.M. Vyazmin, G.N. Degteva and A.L. Sannikov, 2012. The adaptation strategy to climate change impacts on human health for the Arkhangelsk Region and the Nenets Autonomous District of the Russian Federation. Ministry for health and social development of Archangelsk oblast, Northern state medical university.

Sorvali, J., 2015. Climate Strategy Work in the Barents Region. www.climatesmart.fi/work

Smit, B. and O. Pilifosova, 2003. From adaptation to adaptive capacity and vulnerability reduction. In: Smith, J., R.T.J. Klein and S. Huq (eds.), Climate Change, Adaptive Capacity, and Development. pp. 9-28. Imperial College Press.

Smit, B. and J. Wandel, 2006. Adaptation, adaptive capacity and vulnerability. Global Environmental Change, 16:282-292.

Stammler, F. and V. Peskov, 2008. Building a 'Culture of Dialogue' among Stakeholders in North-West Russian Oil Extraction. Europe-Asia Studies, 60:831-849.

Stokke, K.B., 2014. Adaptation to sea level rise in spatial planning – Experiences from coastal towns in Norway. Ocean & Coastal Management, 94:66-73.

Streletskiy, D.A., N.I. Shiklomanov and V. Grebenets, 2012. Chnages of foundations bearing capacity due to climate warming in northwest Siberia. Earth's Cryuosphere, XVI:22-32.

Swedish Commission on Climate and Vulnerability, 2007. Sweden facing climate change – threats and opportunities. Swedish Government Official Report, SOU 2007:60.

Swedish Ministry of Environment and Energy [Miljö- och energidepartementet], 2015. Kommittédirektiv. Ett stärkt arbete för anpassning till ett förändrat klimat [Strengthening the work of adapting to a changing climate]. Dir. 2015:115.

Sundby, S., 2015. Vi risikerer kraftig temperaturøkning I Barentshavet. Da blir det for varmt for torsk og hyse [We run the risk of powerful temperature rsie in the Barents Sea. When it becomes too hot for cod and haddock]. Havforskningsrapporten, spesial utgave 1 av Fisken og Havet.

Tennberg, M., T. Vuojala-Magga and M. Turunen, 2010. Ivalo River and its habitants: There have always been floods – what is different now? In: Hovelsrud, G. and B. Smit (eds.), Community Adaptation and Vulnerability in Arctic Regions. pp. 221-237. Springer.

Tennberg, M., T. Vuojala-Magga, J. Vola, H. Sinevaara-Niskanen and M. Turunen, 2017. Political economy of extreme events in Northern Finland. In: Hiyama, T. and H. Takakura (eds.), Global Warming and the Human–Nature Dimension in Northern Eurasia. Springer.

Tervo-Kankare, K., C.M. Hall and J. Saarinen, 2013. Christmas tourists' perceptions to climate change in Rovaniemi, Finland. Tourism Geographies, 15:292-317.

Tryland, M., S.M. Stubsjøen, E. Ågren, B. Johansen and C. Kielland, 2016. Herding conditions related to infectious keratoconjunctivitis in semi-domesticated reindeer: a questionnaire-based survey among reindeer herders. Acta Veterinaria Scandinavica, 58: doi 10.1186/s13028-016-0203-x.

Turi, E.I. and E.C.H. Keskitalo, 2014. Governing reindeer husbandry in western Finnmark: barriers for incorporating traditional knowledge in local-level policy implementation. Polar Geography, 37:234-251.

Turunen, M. and T. Vuojala-Magga, 2014. Past and present winter feeding of reindeer in Finland: herders adaptive learning of the practices. Arctic, 67:173-188.

Turunen, M.T., S. Rasmus, M. Bavay, K. Ruosteenoja and J. Heiskanen, 2016. Coping with difficult weather and snow conditions: Reindeer herders' views on climate change impacts and coping strategies. Climate Risk Management, 11:15-36.

Tyler, N.J.C., J.M. Turi, M.A. Sundset, K.S. Bull, M.N. Sara, E. Reinert, N. Oskal, C. Nellemann, J.J. McCarthy, S.D. Mathiesen, M.L. Martello, O.H. Magga, G.K. Hovelsrud, I. Hanssen-Bauer, N.I. Eira, I.M.G. Eira and R.W. Corell, 2007. Saami reindeer pastoralism under climate change: Applying a generalized framework for vulnerability studies to a sub-arctic social-ecological system. Global Environmental Change, 17:191-206.

Uleberg, E, I. Hanssen-Bauer, B. van Oort and S. Dalmannsdottir, 2014. Impact of climate change on agriculture in northern Norway and potential strategies for adaptation. Climatic Change, 122:27-39.

Ulvevadet, B. and V.H. Hausner, 2011. Incentives and regulations to reconcile conservation and development: thirty years of governance of the Sami pastoral ecosystem in Finnmark, Norway. Journal of Environmental Management, 92:2794-2802.

UNFCCC, 2015. The Paris climate agreement (2015). https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf

Uvarov, P.P., 2012. Aktyalnye problemy teplovoy zashity zdanyi na severe [Current problems of insulation protection of housing in the north] "Zhilishnoe Strroitelstvo", N 1 pp. 25-27.

Veijalainen, N., 2014. Ilmastonmuutoksen vaikutukset tulviin Rovaniemellä [Effects of climate change to floods in Rovaniemi]. Presentation to the flood management planning group of Kemijoki drainage basin. www.ymparisto.fi/download/noname/%7B2E4416D6-6F85-4445-BA12-6CF697AA7683%7D/97739

Vuojala-Magga, T. and M. Turunen, 2013. Experiences with an Arctic river – flood prevention in the town of Ivalo. In: Keskitalo, C.H. (ed), Climate Change and Flood Risk Management: Adaptation and Extreme Events at the Local Level. pp. 237-270. Edward Elgar.

West, J.J. and G.K. Hovelsrud, 2010. Cross-scale adaptation challenges in the coastal fisheries: Findings from Lebesby, northern Norway. Arctic, 63:338-354.

WHO, 2009. Protecting health from climate change in the Russian Federation. World Health Organization (WHO). www.euro.who.int/__data/assets/pdf_file/0020/132950/Protecting_health_RUS.pdf?ua=1

10. Synthesis

Coordinating lead authors: Annika E. Nilsson, Grete K. Hovelsrud
Lead author: Marianne Karlsson
Contributing author: Karoliina Pilli-Sihvola

Key messages

- ***Adaptation needs to be considered as part of a long-term proactive process that encourages learning, holistic thinking and conflict resolution****. Current adaptation efforts are largely reactive to current conditions and immediate threats, and many actors lack knowledge and insight about future trends, and sometime also access to salient information that is credible in their particular context. Because adaptation is shaped by cumulative and interacting impacts from climate change, globalization, demography, and market conditions, there is a need for holistic thinking that includes insights from both traditional knowledge and science. Moreover, proactive adaptation processes need mechanisms for identifying goal conflicts and ways to develop trust that make it possible to address potential conflicts.*
- ***There is a need to develop analytical frameworks and practical tools that can support analysis of adaptive capacity and resilience by communities and sectors.*** *Because of the complexity, pace and scope of changes facing the Barents area, adaptation processes must go beyond current practices. There is also a need to monitor and assess how today's adaptation actions and decisions may affect the capacity to adapt in the future. Current indicators require further development to meet this need.*
- ***Scenarios provide a tool for examining the robustness of adaptation options in the face of different potential futures.*** *Social changes that affect adaptation processes are often difficult to forecast. Moreover, while knowledge about long-term trends appears robust, short-term volatility (e.g. market prices) and unforeseen events can affect adaptation processes. Exploratory scenarios can highlight uncertainties that need to be considered in decisions about adaptation and can also provide a platform for learning across different knowledge communities.*
- ***Support for participatory processes that encourage knowledge sharing and social learning would increase the appreciation for different perspectives, a prerequisite for conflict resolution.*** *Research has moved from studying adaptation as technical responses, to adaptation as social processes. This creates a demand for attention to priorities regarding society's future directions as well as to how existing power relations affect who has a say in how a desirable future could look.*
- ***Adaptation needs to be analyzed in a multilevel governance perspective that includes attention to allocation of decision-making power.*** *While impacts of cumulative change manifest locally and it is the local communities, municipalities and sectors that usually adapt, responses needed often span different sectors and levels of governance. Current adaptation efforts often meet barriers, such as unclear responsibilities and insufficient frameworks, that limit implementation of needed efforts.*

10.1 Introduction

Adaptation is a normal part of everyday life as individuals, communities, corporate actors, and entire societies adjust their activities in relation to observed and anticipated changes. However, the unprecedented rate of climate change in the Arctic and globally has made adaptation a major political priority. Furthermore, a new context involving the complex interactions of rapid social and environmental change (at scales ranging from global to local) has made it necessary to assess and support the capacity for adaptation in ways that go beyond business-as-usual. This is driving a need for strategies that can support proactive measures and build preparedness for further changes.

Chapters 1 to 9 of this report provide up-to-date reviews of a wide range of challenges and multiple and interacting changes currently taking place within the Barents area, and of ongoing adaptation activities. Based on a synthesis of this knowledge base, the present chapter places adaptation in the context of broader policy goals related to sustainable development and aims to highlight social processes that need strengthening to support long-term adaptation action to multiple and interacting changes.

The basic premise is that adaptation strategies need to be an integral part of planning and policy-making, and that rapid and interacting societal and environmental changes require close attention to the social context within which adaptation takes place. Casting adaptation as a process means addressing adaptation needs and strategies across different societal groups and scales. While adaptation takes place locally – where the changes manifest – the regional, national and international scales shape the configuration and success of the adaptive measures (Chapter 9). There is also a need to place adaptation in the broader context of resilience, or general capacities to deal with change and uncertainty (Chapter 8), and within the context of the rich, varied and valuable knowledge held by indigenous peoples (Chapter 7). In the light of new challenges, it is necessary to discuss how planning and decision-making can be undertaken in ways that strive for shared understanding between actors while respecting conflicting priorities.

10.1.1 Regional policy commitments

When the Arctic Council was created in 1996, its mandate emphasized sustainable development as an overarching goal, in addition to environmental protection (Arctic Council, 1996). The broad mandate was closely linked to the growing international attention to human development in the 1990s as a necessary complement to safeguarding the natural environment. Sustainable development as an overarching goal is also highlighted in the Kirkenes Declaration that established the Barents regional cooperation (Kirkenes Declaration, 1993).

While the meaning of sustainable development has been debated with respect to the content of environmental, social, and economic development since it was first launched (Owens, 2003), the concept remains a common normative base for global and regional policy actions. Recently, 17 global Sustainable Development Goals (SDGs) were adopted as a follow-up of earlier work towards the Millennium Development Goals, with the overarching aim to "*end poverty, protect the planet, and ensure prosperity for all*" by 2030 (United Nations, 2015a). Following increased awareness that human well-being is often linked to functioning ecosystems (Millennium Ecosystem Assessment, 2005), several of the SDGs explicitly highlight environmental processes. In parallel, and particularly relevant for the Arctic context, is an increasing recognition of indigenous peoples' holistic understanding of society-nature relationships and a political commitment to respect traditional knowledge (see Chapter 7).

The commitment to sustainable development, the recognition of how closely human well-being and the environment are interlinked, and the increasing recognition of indigenous perspectives form the policy context in which the Arctic Council project Adaptation Actions for a Changing Arctic (AACA) was developed. However, the more immediate impetus came from an urgent need for many Arctic communities, economic sectors and indigenous peoples to adapt to rapidly changing conditions in society and climate, initially highlighted in the Arctic Climate Impact Assessment (ACIA, 2005), and further emphasized in the Snow, Water, Ice, and Permafrost in the Arctic (SWIPA) assessment (AMAP, 2011) and the Arctic Human Development Report II (AHDR II) (Nymand Larsen and Fondahl, 2014). In 2012, the Arctic Council committed to an assessment of adaptation options, with a focus on identifying adaptation actions to multiple changes in the Arctic (Chapter 1). The Iqaluit Ministerial Declaration of 2015 reaffirmed this commitment in the broader context of Arctic change: "*Recognize the importance of risk assessments in relation to climate change, and the need to evaluate the widest possible range of impacts, … and welcome the efforts within the project Adaptation Actions for a Changing Arctic to integrate climate projections with knowledge about other drivers of change, in order to inform decisions and develop adaptation strategies*" (Arctic Council, 2015, emphasis in original).

The AACA is one of many activities within the Arctic Council that now address the impacts of rapid change. Others include the Arctic Resilience Assessment (Arctic Council, 2016), continued work on the Arctic Marine Shipping Assessment (AMSA), and updates of the SWIPA assessment, plus various initiatives aimed at ensuring food, water and energy security for people living in the region and efforts related to ecosystem-based management. In addition, AHDR II has provided an up-to-date assessment of many social and cultural dimensions of Arctic change, highlighting the diversity of challenges across the Arctic as well as how the Arctic is connected to the rest of the world (Nymand Larsen and Fondahl, 2014). The overarching commitment of sustainable development is today a matter of navigating a complex and rapidly changing social and physical environment, where vulnerabilities stemming from past developments come to the fore, and where the Arctic is an integral part of global change.

10.1.2 Global climate policy commitments: UNFCCC and the Paris Agreement

The Arctic is part of a larger global policy landscape and of direct relevance for the AACA is the UN Framework Convention on Climate Change (UNFCCC), which focuses on mitigation of greenhouse gases and on climate adaptation. Article 4 in the UNFCCC commits all parties to "*(f)ormulate, implement, publish and regularly update national and, where appropriate, regional programmes containing… measures to facilitate adequate adaptation to climate change*" and to "*(c)ooperate in preparing for adaptation to the impacts of climate change*" (United Nations, 1992). While UNFCCC's specific programs and activities related to adaptation mainly concern support for particularly vulnerable developing countries, the overarching commitment is relevant for all parties, and has also played a role in how Arctic countries have developed their national reporting on adaptation activities (for example from Sweden, see Nilsson et al., 2012) (see also Chapter 9).

The agreement from the Paris Conference of the Parties in December 2015 further strengthened the commitment to adaptation action with the goal of "*enhancing adaptive capacity, strengthening resilience, and reducing vulnerability to climate change, with a view to contributing to sustainable development and ensuring an adequate adaptation response in the context of the temperature goal*" (United Nations, 2015b; Article 7, subparagraph 1). In the agreement, the parties also "*recognize that the current need for adaptation is significant and that greater levels of mitigation can reduce the need for additional adaptation efforts, and that greater adaptation needs can involve greater adaptation costs*" (Article 7, subparagraph 4). The agreement highlights the need for a "*gender responsive, participatory and fully transparent approach*" that should "*be based on and guided by the best available science and, as appropriate, traditional knowledge, knowledge of indigenous peoples and local knowledge systems...*" (Article 7, subparagraph 5).

10.1.3 The goals of adaptation

While the policy commitment to adaptation is solid at both the global and circumpolar level, adaptation is a strategy and a process rather than an end in itself. There are diverse backdrops against which adaptation can be discussed and assessed. In this chapter, the approach has been to focus on sustainable development and human security, which are perspectives that situate adaptation outcomes within a normative frame. Insights have also been drawn from studies of social-ecological resilience (Chapter 8) and adaptation in practice (Chapter 9), which highlights the capacity to live with change.

Successful adaptation actions may best be measured against some normative goal. One such example is the globally agreed

SDGs, many of which relate closely to basic human security needs. The 2014 IPCC Assessment introduced human security as a measure against which it is possible to systematically assess climate change risks to livelihoods, cultures and indigenous peoples globally, including increased vulnerability from migration and violent conflict (Adger et al., 2014). While climate change, as such, may not be the main challenge for many communities and sectors in the Barents area, its impacts do exacerbate vulnerabilities stemming from socio-economic, political and environmental conditions (e.g. Keskitalo, 2008; Hovelsrud and Smit, 2010; see also Chapters 7 and 9). It is therefore a logical development to link assessment of adaptation actions to their direct and indirect impacts on human security.

Human security can be defined as a condition that exists when the vital core of human lives is protected and when people have the freedom and capacity to live with dignity (Adger et al., 2014:759). Two aspects of human security that have become particularly relevant in relation to climate change in the Arctic are food security and health (Nilsson and Evengård, 2013; also emphasized in Chapter 6). Several aspects need to be included when addressing human security: socio-economic conditions, governance structures, educational opportunities, inequalities and equity, gender balance, the role of culture and values in the society or community, how local/ traditional knowledge is recognized and applied, demographic and migration trends, whether the community has access to human and financial resources, displacement of people and entire communities, and potential for conflict. The consequences and cumulative effects of climate change must be viewed in relation to all these conditions, which cut across most aspects of society.

Multiple and interacting changes and challenges (including the consequences of climate change) may threaten human security by undermining livelihoods, by compromising culture and identity, and by increasing migration that people would rather avoid such as planned or forced relocation due to thawing permafrost or flood risk (Adger et al., 2014:756-777). In addition, the interacting changes may challenge the ability of states to provide the conditions necessary for human security including critical infrastructure, resource management, governance, stable geopolitics, managing land use conflicts and pollution risk, and search and rescue operations. In contrast to the SDGs, a human security perspective explicitly emphasizes the multilevel governance challenge of adaptation, linking individual security to that of communities, states and global society. It also directs attention to the highly complex interactions and feedbacks between climate change, livelihoods, industrial development, urbanization, culture, and migration. Moreover, to invoke the term security is also a political act "*to draw attention to 'something' that should be valued above all other things*" (Hoogensen Gjørv and Goloviznina, 2013:1) and thus a way to guide political priorities. However, human security is still a contested term and work on linking human and environmental security to larger security concerns is still at an early stage (e.g. Hoogensen et al., 2013). Moreover, there is a need to further develop means to actually measure and assess human security in ways that are relevant for Arctic communities.

The normative perspectives underpinning SDGs and human security may benefit from an explicit focus on the social and environmental factors that support the capacity for adaptation (Chapters 8 and 9). Several attempts have been made to categorize and conceptualize these factors, which centers on adaptive capacity and resilience (e.g. Kofinas et al., 2013 and Chapter 8). Social-ecological resilience is a concept that highlights the dynamic relationships between ecosystem processes and society, with special attention to processes that maintain or have the potential to alter the very identity or integrity of the system (Folke, 2006). Resilience has been

Arctic Council Secretariat / Linnea Nordström

Saami Council delegates at the 10th Ministerial Meeting of the Arctic Council in Fairbanks, Alaska, USA 11 May 2017 defined as a community's capacity "*to learn, share and make use of their knowledge of social and ecological interactions and feedbacks, to deliberately and effectively engage in shaping adaptive or transformative social-ecological change*" (Arctic Council, 2016); see also Chapter 8. Chapter 8 of this report makes the case that building resilience involves cultivating the diversity that is necessary for reorganization and renewal of a system, and combining different types of knowledge for learning and management. While the systems perspective represents a shift from compartmentalized command and control management of one specific resource towards focusing on interactions between different resource systems, it does lack attention to power issues, such as who defines the system and for whom it should be resilient (Arctic Council, 2013).

In summary, the goals of adaptation actions need to include attention to at least two important dimensions. One is their outcome in terms of normative policy goals, such as basic human security or the SDGs. The other is how they affect the capacity to deal with further changes. In both cases, there is a need to develop tools with which decision-makers in various contexts can assess the potential impacts of their decisions. Some such work is underway. An example is the Arctic Social Indicators Report, which is an Arctic-specific development of the global Human Development Index (Nymand Larsen et al., 2010, 2015). Another is work related to the implementation of the global SDGs. To ensure that adaptation actions support sustainable development over the long term, there is also a need to integrate measures to increase the capacity to live with change and unpredictability.

Chapters 1 to 9 have mapped the social and environmental landscapes of the Barents area in which adaptation takes place in the present and have also highlighted some future challenges and opportunities. However, the approach used also shows the limits of analytical frameworks that start by describing drivers and impacts of change. This information is an important knowledge base for adaptation actions but in itself is not enough for assessing the outcomes of adaptation activities. New tools are needed to ensure that today's adaptation does not create future problems by undermining the long-term capacity to adapt. However, such tools are not currently available and an important insight from the AACA process is that assessing adaptation actions in ways that can guide local communities and policy-makers at the national and international level will require concerted efforts at method development.

10.2 Adaptation in context

Adaptation to climate change takes place within the context of changing environmental, political, societal, and cultural conditions. The regional environmental changes expected from global climate change are summarized in Box 10.1, while Box 10.2 proves a summary of global social drivers of change in relation to the Barents area. The complex and interacting challenges arising from a combination of global drivers of change and the unique characteristics of the Barents area affect both barriers to and potentials for adaptation.

Box 10.1 The context of environmental change

This box describes the changing environmental context in the Barents area and identifies those issues that have major implications for adaptation. The material is based on information presented in Chapters 2, 4, and 6.

Climate and weather

The Arctic is warming faster than the global average. While there is strong confidence in the general trend towards a warmer climate, there is uncertainty about the extent of future temperature change. Downscaled model results suggest that winter temperatures in the Barents area are likely to increase by 3–10°C between 2010 and 2080 if future greenhouse gas (GHG) emissions follow a low emission scenario. However, results from some regional climate models using higher GHG emission scenarios suggest that winter temperatures in the Barents area may rise by considerably more (Chapter 4). Future summer temperatures are also likely to rise but not at the same rate. Overall, precipitation is expected to increase in the Arctic and to increase more than the global average and with a greater proportion of rain than snow compared to the past. While the overall picture is robust, it is harder to estimate the magnitude of change in precipitation. The future will continue to see major year-to-year variations in temperature, precipitation, wind, snow, and ice.

Some of the most difficult conditions to adapt to concern extreme weather events and their consequences. In the Barents area, extreme weather events can cause avalanches, floods, and rock and mud slides. Storms that affect offshore activities, transportation and infrastructure are another example (Chapter 6).

The Polar Low is an extreme weather event particular to the marine areas of the Barents area. Polar Lows develop when cold air from the polar ice cap is forced out over the warmer waters of the North Atlantic Current creating storms that are local and short-lived but with hurricane-force winds and sometimes heavy snowfall. Such events pose a serious threat to all offshore activities owing to their rapid onset and because they create weather conditions that are beyond the operating limits for aviation and oil and gas operations. Climate change is likely to cause Polar Lows to shift northward to the northern and central Barents area (Chapter 4). While it remains difficult to know whether the frequency of extreme weather events and storms will increase in the future, preparedness for such events will continue to be critical for adaptation.

Ecosystem changes

Changes in climate have direct impacts on snow and ice, as well as on terrestrial, freshwater and marine ecosystems. In addition to climate change, ecosystems are influenced by chemical pollution, invasive species and an intensification of human activities such as shipping and extractive industries (Chapter 6).

In terrestrial ecosystems, climate change impacts depend on a combination of temperature changes, snow cover changes and specific weather conditions. Seasonal snow cover plays a critical role in the hydrological regime and for plant and animal life. Snow depth has declined in inland regions but increased in coastal areas. Another observed trend is towards earlier snow-free dates (Chapter 2).

In winter, the impacts of climate change are likely to be most pronounced when there is a sudden switch from sub-zero temperatures to conditions above freezing, and when temperatures fluctuate around freezing creating so-called rain-on-snow events.

The long-term ecological implications of a warmer terrestrial environment are related to higher biomass production and changes in community structure. Arctic plants and animal species will be challenged by the spread of invasive species and new incidences of pests and diseases, particularly from 2030 onwards (Chapter 6). In some cases, such shifts may affect the structure and functioning of entire ecosystems, with implications for conservation management. In the Barents area, warming combined with changes in hydrology has already led to tall shrubs expanding their range, while mosses and lichens are declining. There are also changes in forest vegetation, with a shift from boreal evergreens to deciduous species (Chapter 6). Forest ecosystems are also increasingly affected by pest outbreaks and forest fires, with implications for forestry that require adaptive responses (Chapter 9).

Freshwater ecosystems include lakes, rivers and wetlands that support large populations of migratory birds, provide drinking water and food, and regulate the flow of water within the landscape. Climate change drives changes in water flow and thawing permafrost, but these are also influenced by a range of other factors such as hydropower generation (especially dams), roads and pipelines (with direct impacts on peatlands), building, open pit mining, unregulated traffic, and surface contamination. Adaptation needs relate to changes in flood risk, movement of contaminants, and impacts on fish populations. In the Barents area, large rivers support major recreational fisheries and related businesses as well as subsistence fishing (Chapter 6).

In the marine environment, a warmer climate entails warmer and less saline water, changes in sea-ice extent and thickness, and changes in sea level (Chapter 4). Ocean acidification is another concern (Chapter 4 and Browman, 2016). The reduction in sea ice and northward retreat of the ice edge is a major driver of change for marine species and ecosystems, especially those directly associated with the sea ice. Changes include increased phytoplankton productivity in previously ice-covered waters and the expansion of boreal zooplankton species at the expense of Arctic zooplankton species (Chapter 6). Whether increased productivity at the base of the food web translates into more abundant populations of fish and marine birds depends on many other factors, such as the timing of access to food, pressure from harvesting, shifts in the spatial distribution of species, and ecological interactions.


Annika E. Nilsson

Bleiken wind farm, Västerbotten county, Sweden

Marine mammals within the Barents area are affected by the changes in community structure linked to the declining sea ice and are also sensitive to pollution and disturbance by human activities. Changes in seabird and marine mammal populations can serve as indicators of ecosystem health. They also have direct impacts on those local economies that rely on such species (i.e. tourism operators, hunters) (Chapter 5).

Significant environmental challenges are associated with the spread of new species, from migration or through ballast water (Chapters 2 and 6). At a regional and sub-regional level, commercial fishing, increased transport of oil by tankers, and discharge of ballast water are considered the strongest ecological threats (Chapter 6). Other activities and sources of environmental impact in the region tend to be more localized.

Changes in the marine environment also affect the coast. In addition to sea-level rise, reduced sea ice in combination with wind can result in significantly higher waves and storm surges, which is a challenge for coastal infrastructure. However, future projections are uncertain. This is because the land is still rising in some areas (as it continues to readjust to the disappearance of the heavy Fennoscandian ice sheet after the last glaciation) and because impacts depend on the nature of the coastline (low-lying erosion-prone coastlines versus steep rocky cliffs) as well as on the location and quality of coastal infrastructure.

Changes in ecosystems will in turn affect ecosystem services, but the translation from ecosystem impacts to effects on ecosystem services also depend on adaptation actions and on other changes in the social context. Chapter 2 highlights likely increases in wood production, summer outdoor recreation and species richness, and likely decreases in winter outdoor recreation and native Arctic species that have high cultural value (e.g. for hunting). Many other changes in ecosystem services are uncertain owing to a lack of knowledge about future species interactions, changes in land-use, and tourist behavior.

Box 10.2 The context of global social drivers of change

Projecting the future impacts of climate change is challenging, and the difficulties increase exponentially when other human interactions with the environment are included in the projections. Such interactions include harvesting, the direct and indirect impacts of infrastructure and industrial development, the introduction of new species and the spread of new diseases, and pollution (Chapter 6). These interactions are also expected to be influenced by social megatrends, by shifting world views or policy orientations, and by specific policy decisions related to climate mitigation and adaptation. The broader context of societal change includes megatrends that are global in scope and can affect the Barents region through trade and politics, migration, and knowledge exchange and media messaging.

Global population trends and their regional implications
Global and national population trends do not translate directly to population changes in the Barents area, although regional population trends (see Section 10.2.1) may be affected by global changes. Such impacts are difficult to determine in a long-term perspective, however, and the current refugee crisis highlights the uncertainties associated with how migration patterns may be affected by global politics and conflicts. Climate change is likely to play an increasingly important role in future conflicts (Adger et al., 2014:771-777 and references therein). Migration from conflict areas and from areas of drought may potentially increase the influx of new people to the Barents area (Chapter 4). If immigrants remain in the region, they could slow the current population decline.

Global and regional economic development
The global economy is expected to continue to grow, driven mainly by the transformation of developing country economies into economies based on industrial or post-industrial modes of production. Moreover, the number of people that can afford resource-demanding lifestyles is growing. The growing global resource demand linked to these shifts can affect the Barents area owing to the importance of energy and mineral resource production in the region's economy. However, growth rates are likely to vary. The recent slow-down in economic growth in China highlights the risk of short-term fluctuations that are both unpredictable and potentially responsible for cascading effects worldwide. Moreover, the sharp drop in energy and mineral prices in recent years shows how difficult it is to predict future changes in resource markets.

In the Barents area, economic growth will depend in the short term on the development of extractive industries affected by market 'boom and bust' cycles. Over the long term, economic development in the region will also depend on the diversification of local economies, the ability to attract skilled people, and the capacity for innovation.

Global interconnectedness
One of the most dramatic changes in global society in recent decades is better information flow and faster communication. Money and ideas now cross the world in microseconds. Further expansion of information infrastructure is highly likely and will continue to influence the spatial organization of activities and perceptions of place and space. One consequence of increasing global interconnectedness is that activities that can be conducted remotely become less dependent on distance. Examples of services that use web-based applications include medical consultations, library services, education and telephone support. As long as the relevant infrastructure is in place, this could benefit economic development in remote parts of the Barents area. However, because new technologies are enhancing the possibility of managing industrial processes from a distance it cannot be assumed that new industrial developments will automatically mean increased employment opportunities in the region. Remote-control technologies may also be accompanied by fly-in-fly-out workers, making it difficult to predict long-term consequences for local job opportunities.

Governance and geopolitics
Ideologies play a role in shaping world politics in ways that have had major impacts in the Barents area. The 'Iron Curtain' that for several decades divided the region into East and West is a case in point, as are various cooperative efforts since the end Cold War, which include the Arctic Council and the Barents regional cooperation (see Chapter 3 for further discussion about their relevance in relation to adaptation action). Long-term trajectories of political developments are difficult to foresee, but some general trends are worth noting. One is that national politics are increasingly interlinked with the development of international governance frameworks that articulate common normative goals. Sustainable development, the commitment to limit the impacts of anthropogenic climate change, and the increasing recognition of indigenous peoples' rights are three examples (see also Section 10.1 and Chapter 7). Others focus on free trade and providing rules for resolving potential conflicts. An example of the latter that is particularly relevant for the Barents area is the UN Convention on the Law of the Sea (UNCLOS), which has been essential for establishing maritime borders between Norway and Russia, and for successfully regulating international maritime activities (e.g. naval, shipping) and marine activities (e.g. fisheries, offshore oil industry) in the region.

However, within this overall context of international cooperation, national interests still play a major role. The extent to which conflicting interests within the Barents area can be resolved through peaceful means has a major implication for all aspects of society, including adaptation activities. So far, cooperation continues despite increasing political tension. In the coming decades, global actors from outside the region are likely to play an increasing role, not least through their financial power. Events in other parts of the world may also spill over into the Arctic and influence the regional geopolitical climate, as could developments that are internal to the different countries. In local and regional adaptation action and a longer time perspective, such developments are difficult to foresee.

10.2.1 Social context

The capacity to adapt to change in the Fennoscandian part of the Barents area appears to be higher than in many other parts of the Arctic, due to its well-educated work force, more developed infrastructure and better integration of the population into social security systems. The Russian Arctic has experienced general challenges due to the economic downturn of the 1990s and the present structure of the economy and governance systems (Chapter 2). However, a high adaptive capacity does not automatically translate into adaptation actions (see Chapter 9). The societal barriers to adaptation in the Barents area can broadly be classed under the interconnected themes of demography and economic diversity, conflicting interests, decision-making authority and capacity, and lack of access to salient and relevant knowledge.

10.2.1.1 Demography and economic diversity

The Barents area is one of the most densely populated regions of the Arctic, and home to a number of indigenous peoples (Chapters 2 and 7). Population trends within the region vary greatly within an overall pattern of urbanization. While rural communities lose population through lack of higher education and employment opportunities, especially for youth and women, cities that serve as hubs for economic activities have grown. Examples include Umeå, Oulu, Bodø, and Tromsø (Heleniak, 2014). Trends in Russia are somewhat different and are partly linked to the decline in government subsidies in the 1990s. In contrast to Fennoscandia, large cities such as Murmansk and Archangelsk have declining populations.

Lack of opportunity for the young in obtaining higher education and relevant employment in rural areas can be considered a barrier to adaptation because out-migration strains municipal revenue and contributes to a skewed age composition in ways that affect social and human capital. The recent wave of immigrants and refugees from the Middle East, Asia and Africa indicates that the Barents area is subject to global demographic trends in ways that have already had consequences for the economy, government expenditure, social life and the demographic structure of some rural areas. Long-term consequences may be both positive and negative depending on how well immigrants can be integrated (Chapters 2 and 5).

While extractive industries and tourism offer employment opportunities, these are mostly temporary positions and only partly filled by local labor supply. Temporary residents usually relate to the local social and natural environment in a different way to permanent residents and potentially have less interest in long-term community objectives, unless these are directly related to their employment prospects (Chapter 5).

The current economic focus on export from primary production in forestry, fisheries, mining, agriculture and the hydrocarbon industry means the region is highly vulnerable to global market volatilities, and the lack of diversity in local economic structures makes many communities sensitive to change (Chapters 5, 6, 7 and 9). Because of the link to employment and the local tax base, this sensitivity can serve as a barrier to adaptation. The current push for diversification, such as government investments in tourism and in deriving new types of products from forestry and agriculture, is relevant for ensuring employment opportunities that can provide a local tax base that is necessary for adaptation actions. However, such investments may also lead to conflicts of interest.

10.2.1.2 Conflicting interests

The Barents area is one of the most industrially developed regions of the Arctic, with relatively intensive use of both land and marine areas. It also includes major areas designated as national parks or under other forms of nature protection. In recent years, land use has become even more intensive with new activities, such as wind farms and increased mining and hydrocarbon extraction. These often compete for the same space as has traditionally been used for reindeer herding, farming, forestry and fisheries (Chapter 6, 7 and 9; see Chapter 7 for further details concerning conflicting interests that affect indigenous peoples). The ongoing replacement of a local small-scale work force by large machinery and mobile entrepreneur units can also affect acceptability and legitimacy among local people. The development in forestry is one example. Community conflicts surrounding the mining industry are also increasing, where potential contributions to local social and economic development many not be enough for societal acceptance if environmental impacts are regarded as unacceptable (Chapter 6) or because of negative impacts on already fragmented pastures for reindeer herding (Chapters 7 and 9).

Increased land use has major implications for adaptation in some sectors, especially for reindeer husbandry where flexibility to access different grazing land is a critical adaptation strategy

B&C Alexander / ArcticPhoto

Nenets reindeer herder sitting in front of a gas drilling derrick on the Yamal Peninsula

(Chapters 7 and 9). Loss of land and forage to other land uses (e.g. forestry and mines), increasing predation pressure due to national conservation policies (Chapter 5), increasing costs, poorly recognized indigenous land rights, and limited influence over other land uses and in governance systems all limit the opportunities of reindeer herders to adapt to the changing condition (Chapters 2, 7, 8 and 9). Many of the challenges that the reindeer herders are facing are not new, and result from long-standing conflicts of interest and power relations. If development is not undertaken in collaboration with reindeer herders, it may lead to serious barriers to being able to adapt reindeer herding to future change (Chapter 7). Although reindeer husbandry provides only a minor contribution to the national and regional economy and labor force, it is an important part of the regional culture (Chapters 2, 6, 7 and 8), and some of the Barents area nations are bound by the ILO 169 Convention to protect indigenous rights to livelihoods (see Chapter 7 for further details).

Conflicting interests regarding land use rights and their effects on the livelihoods of indigenous peoples is a recurring theme throughout the Barents area. Although countries govern the situation through laws and regulations, land use conflicts remain (Chapters 2, 6, 7, 8 and 9). While conflicting interests are difficult to avoid completely, unresolved conflicts or solutions that are perceived to be unfair can negatively affect trust in social relations and governance processes, including those related to adaptation. They can also divert limited financial and human resources that might otherwise be used for adaptation actions and processes.

10.2.1.3 Decision-making authority and capacity

While most adaptation decisions are made at the local level, local and regional decision-making in the Barents area is heavily integrated into national political structures, connected to the global economy and governance structures, and in the case of Sweden and Finland directly (Norway indirectly) subject to EU regulatory systems. Furthermore, the increasing role of transnational corporations, particularly in the primary sectors, leads to less local power over decisions with major local implication. Municipalities are thus highly exposed to priorities and decisions by actors outside the region. At the same time, profits are often transferred out of the region, which affects the financial capacity of regional and local governments (Chapter 3).

Power over decision-making was raised as a concern at several scenario workshops (Chapter 5) and is also a major issue in relation to self-organization as a key feature of resilience (Chapter 8). The issues concern the relative power between national government versus regional and local governments, as well as between corporate actors versus local decision-makers. Another issue is related to indigenous rights and the extent to which they are respected, not least in relation to conflicts over land use (Chapter 7).

Some changes in the Nordic part of the Barents area are tending toward increasing the role of regional self-government, potentially providing more regional power over decisions that affect adaptation over the long term. However, as highlighted in Chapter 9, responsibilities for developing adaptation measures are often unclear and major challenges exist in translating national goals into local contexts. This indicates a need for further analysis of decision-making structures, both in terms of administrative functionality and in relation to power over decisions that are relevant for adaptation, including decisions that may not be labelled adaptation.

European Union legislation can be a limiting factor when deciding optimal adaptation measures in the Barents area. However, the EU has several funding programs that support regional development and cross-border cooperation, thereby providing financial opportunities for adapting to change (Chapter 3). Given these close links to the EU, together with the EU as a major market for resources from the region (Cavalieri et al., 2010) and the flow of immigrants, the Barents area is highly exposed to potential changes in European cooperation, which are very difficult to predict. Local sensitivity is likely to be dependent on how economic and demographic structures develop, as well as on local decision-making powers.

The Barents area is highly exposed to global geopolitical change, even if the impacts are moderated by national and international cooperation. After a 25-year period of increasing cross-border collaboration, political tensions and military presence have recently increased. As highlighted in Chapter 5, the impacts on local futures of changing geopolitical priorities and interests are difficult to assess but nevertheless should be included in any analyses of changing conditions and the need for adaptation processes.

10.2.1.4 Access to salient and relevant knowledge

Knowledge of climate change and its immediate impacts on the physical environment has increased significantly over recent decades (see Box 10.1). The knowledge base includes scientific analysis of observed changes as well as increased efforts to document and include indigenous observations and knowledge and to integrate these in the published literature (Chapters 6 and 7). New efforts that combine scientific and indigenous peoples' monitoring are also underway (Chapter 7). Downscaled scenarios for future climate change generate information at scales that are relevant to local and regional decision-makers. Some of this information is available via interactive websites, providing details at the watershed-scale and even further (Chapter 5). Nevertheless, Chapter 9 highlights the need for 'tailor-made' scenarios that are easy to understand and salient for users' purposes, where lack of relevant knowledge is currently a barrier to adaptation in specific weather-dependent sectors.

Despite the increasing availability of information, the Barents area still faces several challenges related to knowledge (Chapter 3). These include communication gaps between producers and users of knowledge, as well as the lack of frameworks for integrating knowledge about different types of change. Moreover, indigenous peoples and minority groups throughout the Barents area have often been kept from expressing their culture and language and thus eroding the capacity to communicate traditional knowledge (Chapter 7). The situation began to improve in the 1970s, but the effects of the old policies and practices are still felt today (Chapters 5, 6 and 7). Another challenge is to assess cumulative and interacting impacts of different types of change (Chapter 6). Ways of making current and future cumulative impacts visible for planners and decision-makers remain a challenge, and methods that aim to integrate both ecological and socio-economic drivers need to be further developed (Chapters 6 and 7).

Access to relevant knowledge can affect the perceived need to adapt. Such perceptions vary widely and can create tensions in decisions about resource allocation. An observed lack of interest in climate change adaptation in some primary sectors and communities has been linked to perceptions of high adaptive capacity that are often grounded in the fact that these sectors and communities have always been able to adapt to high natural variability in weather and resource base in the past and so the assumption is that they will continue to do so (Dannevig and Hovelsrud, 2016; see also Chapter 3). This further underscores the importance of access to salient, co-produced and up-to date knowledge about likely future trends.

Producing knowledge about climate change and its impacts requires financial and human resources. Much of the climate-related information is produced as part of national or international efforts, but increasingly also links to subnational adaptation and policy processes within the different countries of the Barents area. It may also be relevant to create a common knowledge base across the Barents area, as discussed in the example of the BEAC Working Group on Environment (Chapter 3). At the same time, adaptation to climate change is a context-dependent endeavor and its impacts need to be assessed in relation to other challenges such as those concerning demographic patterns, employment opportunities and access to resources. In spite of the increasing amount of available information, many communities have called for specific information to help them identify key vulnerabilities and appropriate adaptive measures. These include regional impact maps, cost-benefit analyses of adaptation options and statistical data for assessing implementation progress and making comparisons between sub-regions (Chapter 3). The tools and analytical frameworks that are currently available to local or sectorial decision-makers who need to integrate information about all relevant drivers and impacts of change are insufficient and new approaches needed (Chapter 9). One approach that could be part of a growing toolbox is the use of explorative scenarios (see Chapter 5 and Section 10.4). Another is to develop resilience indicators. In addition to serving as direct policy tools, the process of developing indicators can also function as a learning process (Chapter 8). Developing adaptation options requires attention to four interlinked dimensions: current adaptation strategies, factors that activate the adaptation processes, barriers and limits to adaptation, and governing tools (Chapter 9).

10.3 What processes are needed to support future adaptation?

Adaptation takes many different forms in a region as diverse as the Barents area. In practice, adaptive measures are often triggered by observations of real world events, engaged officials, and contact with researchers (Dannevig et al., 2013 and Chapter 9). But to ensure that adaptation becomes more proactive and adaption efforts more systematic, there is also a need to focus on adaptation as a long-term process. Despite large differences between communities and countries in the Barents area, the social processes involved in adaptation share elements that allow for some generalization. This section examines the key dimensions of adaptation processes, practices and actions.

10.3.1 Adaptation as a social process

Adaptation as a social process involves responses to change in a wide range of conditions, including climatic, environmental, socio-economic, and political conditions, and where responses are shaped by policy, culture and socio-economic factors. This understanding of adaptation is reflected in IPCC's definition: "*The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects*" (IPCC, 2014).

While earlier framings of adaptation tended to focus on technical responses to specific climate change impacts, adaptation approached as a social process shifts attention towards the social actors and institutions that generate adaptation practices and actions, including their embedded knowledge, values, power and resources.

Adaptation processes are embedded in specific social contexts where participating actors have different means to respond to change and often also divergent preferences for the outcome of change. It is therefore important to pay attention to the political dimensions of adaptation processes. Done in ways that build trust and social capital, the processes leading to the development and implementation of adaptation actions can contribute to building adaptive capacity (Chapter 9).

Measuring and projecting change have always been a conundrum for scientists and decision-makers, and the difficulties involved in projecting change renders adaptation measures geared towards future change riddled with uncertainty. It is often easier to gather support for adaptation to changes that are projected to occur in the near future; a function of political cycles and the difficulties and uncertainties involved in planning for long-term futures (Chapter 9). Developing long-term adaptation strategies is challenging and may be at odds with the current adaptation practices, which are often embedded in everyday practices, routines and responsibilities. Nevertheless, given the magnitude of expected climate change and the uncertainties regarding social changes that can affect sustainable development in the region, adaptation planning does need to address future challenges. One approach is to plan for building generic capacity to enable and facilitate adaptation processes both in the present and in the near- and long-term future.

The chapters in this report point to a number of interlinked dimensions that are important for understanding adaptation processes and ultimately have a role in securing adaptive capacity. Based on the review of chapters and of the current barriers, three dimensions are highlighted here: processes for learning, holistic understanding, and conflict resolution. Adaptive capacity is in itself a major research topic that is also interlinked with ideas from resilience research (Chapter 8), and the intention of the considerations presented here is to provide a basis for discussing future directions.

Cody Duncan

Lofoten Islands, Norway

10.3.1.1 Processes for learning

Knowledge plays a central role in local and regional adaptation actions. However, knowledge is not static, uncontested or unitary (Chapters 5 and 8) and the production of knowledge is a complex and often challenging social process that involves actors with various world views and capacities to communicate their specific insights or values (Chapter 3). Building knowledge for adaptation actions thus requires processes and arenas for communication and sharing of insights. The capacity for social learning is emphasized as an important prerequisite throughout this report (Chapters 2, 3, 5, 7, 8 and 9).

Processes for social learning are important because people construct mental models, often in the form of grand narratives that serve as frames of reference when trying to understand the world. Different actors in society often operate with different frames of reference, derived from previous experience and priorities which in turn has a bearing on agreements about common problem definitions or solutions. Building knowledge in joint social processes can be a means to overcome such differences.

A strong message is that the integration of traditional, local and scientific knowledge is required to make adaptation decisions robust. There are good examples of how knowledge forms can be combined. Successful collaboration between researchers and practitioners particularly with reindeer herders are documented in Chapters 2 and 7. Such efforts often require rethinking the terms and framing of an issue into a language that is meaningful for all parties, for example by referring to weather phenomena rather than climate change.

For indigenous peoples, traditional knowledge, culture, and languages together provide a foundation for resilience because they embody experience-based expertise of how societies have adapted to change in the past (see Chapter 7 for testimonials). In addition to integrating indigenous perspectives into mainstream planning, indigenous peoples stress the urgent need for education based upon traditional knowledge, culture and language (Chapters 6 and 7). Engaging indigenous youth in traditional practices and combining such activities with enhanced education has been identified as especially important for being able to build future sustainability on strong cultural foundations (Chapter 7). Given the magnitude and rate of change in the Barents area, traditional knowledge by itself may not be adequate for meeting future challenges and building a sustainable society. Rather, there is a need for a new kind of education that incorporates both scientific and experience-based knowledge and creates holistic approaches that communicate across cultures (Chapter 8). Such innovative knowledge practices are likely to be essential for the success of adaptation processes and the sustainability of future societies. The integration of different knowledge traditions and co-production of knowledge is beneficial for both indigenous peoples and for society at large.

Scientific knowledge of climate change and potential impacts in the Barents area has grown significantly in recent years and is increasingly presented in ways that are accessible and useful to the public. Despite such initiatives there is still an unmet demand for locally relevant information. Moreover, a shared understanding of complex phenomena such as climate change cannot be assumed because social groups have their own experiences, perceptions and knowledge. Climate science may not even be seen as a legitimate, meaningful or relevant source of information for all regional and sectoral actors (e.g. Dannevig and Hovelsrud, 2016). In livelihoods and sectors tied to renewable resources, actors are used to living with high natural variability in both weather and the resource base, which can lead to challenges in communicating long-term change and the potential need for more extensive adaptation strategies (e.g. West and Hovelsrud, 2010).

Chapter 3 suggests that social networks stretching over several communities of practice or institutions can function as meeting points for different knowledge producers and keepers (Wenger, 1998; Wenger et al., 2002). Adaptation to climate change can be described as a 'wicked' problem (Rittel and Webber, 1973). Typical of wicked problems is that they defy simple definitions and explanations, have many possible solutions, and assessing the effectiveness of suggested solutions is difficult. The larger context of social change within which climate change takes place makes the 'wickedness' even more apparent. While new knowledge can contribute to society's ability to address a wicked problem, there is a need to overcome the tendency for knowledge communities to focus only on one sector at a time. Instead a cross-sectoral focus (Chapter 9) is increasingly and clearly called for when addressing wicked problems (for example agriculture, transport and finance sectors are involved when farmers develop adaptation strategies). In addition, there is a need for multidisciplinary networks and partnerships of knowledge producers and keepers as well as for 'knowledge brokers' as translators of knowledge between different fields of society, especially between research and policy-making communities (specifically highlighted in Chapter 3). Chapter 3 emphasizes the importance of extending knowledge networks to include decision-makers such as regional and local politicians with formal capacity to take adaptation decisions. Major efforts have indeed been made to find new ways of producing knowledge that can serve as starting points for such networks. For example, social networks have often been established around specific issues, such as water management. There is also a need to recognize some of the limitations of networking, including issues of decision-making power, where not everyone has an equal voice and access to resources. Another limitation relates to 'problem definition' within which such discussions often take place and where basic assumptions are not open for discussion. Moreover, many efforts to produce new knowledge and to involve societal actors are run as time-limited projects with poor integration into policy processes and practical planning at the municipal level. The challenge of creating long-term engagement is further hampered by the fact that other mandatory tasks have higher priority for municipalities. Engagement with the business sector faces similar challenges.

Despite the shortcomings, opportunities to share knowledge, experience and priorities have the potential to enable social learning. An important component of such processes is collective negotiations, where participants conjointly negotiate understandings of their particular situation, which can enable a common understanding of the problem, or at least an appreciation of different ways of seeing the issues at hand. Visionary and scenario workshops (mentioned in Chapter 3, explored in-depth in Chapter 5) can also function as arenas for sharing experience and knowledge that enable social learning and can build collaborations and networks. Participatory approaches that can bring together stakeholders and knowledge are essential for broader proactive adaptation initiatives. The process of discussing what current and future changes might mean for sectors, livelihoods and communities is itself a means of generating and strengthening adaptive capacity (Chapters 8 and 9).

10.3.1.2 Holistic understanding

A key message throughout all chapters is that adaptation planning needs to be cross-sectoral and to adopt a holistic approach. However, most adaptation work in the Barents area has been characterized by a sectoral approach (as noted above and Chapter 9). Processes for creating a holistic understanding are also relevant for identifying influences that may not be immediately apparent when a challenge is viewed from a narrow perspective. A shared holistic understanding is often a prerequisite for conflict resolution.

Holistic approaches that also enable social learning can facilitate awareness about how current ways of framing a challenge may limit the attention needed to linkages across sectors, cumulative effects and connections between global and local processes. This is illustrated by studies in Norwegian municipalities where those that coordinated adaptation in a holistic and horizontal manner promoted long-term decisions, while those that followed a more sectorial approach often resulted in shorter-term measures (Rauken et al., 2015).

Restructuring institutions to allow for holistic adaptation planning and the implementation of concrete adaptation actions has been forwarded as a long-term priority to strengthen adaptive capacity (Chapter 9). Co-management and ecosystem-based approaches to natural resources are being tested in several places, which could contribute to a holistic outlook. For example, co-management of national parks in northern Norway has been found to strengthen the adaptive capacity of resources users (Risvoll et al., 2014).

10.3.1.3 Conflict resolution

Participatory approaches and deliberation of adaptation options often reveal preferences for adaptation outcomes. Sometimes a transformative change may be more feasible than adapting within the current system (Chapter 8). Participation as such must therefore be distinguished from the actual ability of different groups to influence decision-making, highlighting the recognition that conflicting interests and asymmetric power relations are embedded in all adaptation processes. Chapter 3 underscores the need for establishing better cooperation and communication between different knowledge producers and decision-makers. Such improved communication can be seen as an essential element of conflict resolution mechanisms that are needed for negotiating between actors with diverging priorities.

There can also be trade-offs between adaptation measures taken at different scales (Pelling, 2010). Strengthening adaptive capacity in one area may also weaken adaptive capacity in others. For example, although extractive industries can be a way for a municipality to secure jobs and tax revenue, the same activities may affect access to land that other resource users and sectors such as reindeer husbandry need in order to adapt. Another example is provided by fishers in northern Norway that land their catch in new communities due to the northward shift in commercial fish species. Although this brings new income to some municipalities, it also reduces income from fisheries resources elsewhere (Chapter 9). Cross-sectoral and holistic adaptation planning is better equipped to foresee trade-offs and to minimize conflicts. In addition to developing processes that ensure communication across scales, there is a need for mechanisms that facilitate transparent negotiations and resolutions of conflict between local, regional, national and global priorities.

10.3.2 Mainstreaming adaptation

The idea of mainstreaming adaptation proposes the merging of climate change adaptation into existing policy, and promotion through existing agencies and institutions. In its fifth climate change assessment (AR5), the IPCC recognized climate-social policy linkages and suggested that mainstreaming as a policy approach may capture opportunities for adaptation otherwise not identified. Utilizing existing structures and institutions for adaptation planning saves resources and is arguably a more pragmatic approach. This approach is highly relevant for adaptation to multiple stressors and cumulative effects, not just to climate change.

Local governments in Sweden, Norway and Finland are to some degree mainstreaming climate adaptation into land-use planning, risk and vulnerability assessment and management plans (Chapter 9). A major issue across the Fennoscandian cases studied is that climate change adaptation is not mandatory for authorities responsible for land-use planning, which has consequences for whether adaptation becomes a priority or not in relation to other tasks.

10.3.3 Taking uncertainty to heart

The fact that global trends and major world events are likely to influence local communities in the Barents area creates an increasing need for local and regional capacity to assess global developments. Assessments of trends and drivers tend to be heavily influenced by current events, which highlights a need for caution in trying to make projections about the future. The inevitable uncertainty about the future makes it necessary to think about adaptation as a long-term process rather than a one-time activity. While society has many mechanisms for managing predictable change, uncertainties about the level and direction of change often create extra challenges. Given the many uncertainties related to the direction, magnitude and consequences of change in environmental, political, societal, economic and cultural conditions discussed earlier, there is a need to find approaches that take uncertainties to heart ('assuming change') (Chapter 8). Living with and planning under uncertainty is nothing new for any segment of society, as decisions are constantly made in an uncertain world. Nevertheless there are some approaches that address how to further assume and address such uncertainties. Two such approaches are discussed in this report, where Chapter 5 looks at the potential of exploratory scenarios and Chapter 8 looks at indicators that could help highlight the salient features of social-ecological systems that facilitate living with change.

Exploratory scenarios are simplified descriptions of how the future may develop based on key driving forces and relationships and can be used for assessing whether current policy options are robust in the face of different potential futures. Such scenarios can be developed in many ways, both top-down by experts who take their starting point in global processes and attempt to scale down relevant trends and by local participatory bottom-up processes. An advantage with a participatory bottom-up process is that it can be used as an opportunity for learning across different knowledge communities and for challenging pre-defined ways of framing certain issues. The scenario methodology presented in Chapter 5 specifically links different potential trajectories for global megatrends with identifying issues that are relevant at the community or sector level.

Chapter 8 and the Arctic Resilience Assessment focus on features of social-ecological systems that are central to adaptive capacity. One critical feature relevant to both society and ecosystems is diversity (see also Chapter 9). For example, livelihood diversity is a key element of resilience and highlights how market and non-market livelihoods can buffer one another when conditions are less than optimal (Chapters 8 and 9). As for ecosystems, species diversity is important, because it has been demonstrated to provide more functional redundancy within the ecosystem (Chapter 2).

Chapter 8 also highlights the capacity to self-organize at the local scale, which includes having significant local decision-making authority. However, the fact that human activities often have implications beyond the local and beyond the present makes the role of local self-organization and power over decision-making complex, accentuating the need for more attention to how decisions, activities, and interactions across space and time have cumulative impacts on society in future that are difficult to foresee in the here and now. The complex processes behind anthropogenic climate change are a case in point.

Some uncertainties and many specific risks related to impacts of climate change, such as more frequent extreme weather events, will remain unavoidable. Societies have often handled this type of risk with various forms of insurance. For risks that are difficult or very costly to avoid, adaptation action can therefore be a matter of deciding what level of risk is acceptable and how much to invest in buffer capacity or other types of insurance.

10.4 Implications for decision-makers and further research

Adaptation occurs in the context of multiple stressors shaped by cumulative and interacting impacts of climate change, globalization, demography, and market conditions. When changing socio-economic, environmental and political conditions create complex challenges for communities, livelihoods, sectors and municipalities, it is the totality of change that both requires adaptation and influences adaptation processes. What is emerging is a set of nested societal scales (broadly defined as local, regional, national, and international) in which the needs for adaptation, the capacity to adapt, the processes needed to address the changes, and the barriers and limits are situated. Governing adaptation must take these interconnected and nested scales into account.

Moving beyond an analysis that focuses on drivers of change and the impacts to which society has to adapt, this chapter has emphasized adaptation as a social process. As such, adaptation needs to be understood both in different specific local contexts and within a larger global context and multilevel governance perspective that influences power over local and sectoral decision-making. The chapter specifically highlights the need for continuous learning in ways that can lead to acceptable solutions across groups with conflicting interests. This has implications for how both knowledge production and decision-making are organized and formally governed. While some adaptive management strategies are already taking place, there is a need to systematically evaluate their performance in relation to learning outcomes and how they affect general adaptive capacity, or resilience. The need for systematic evaluation is also relevant to the use of scenario methodologies, which can be valuable for understanding uncertainty but which come with a caution that the scenario process can also embed existing power relations in ways that do not support the overarching policy goals of sustainable development.

The chapter also highlights a need to move from reactive adaptation action to proactive strategies that take long-term goals and interacting challenges into account. A major conclusion is that there is a need to focus on supporting adaptive capacity that is relevant across a range of current and potential future challenges facing the region. There are no off-the-shelf or one-size-fits-all methods for conceptualizing, measuring and assessing adaptive capacity or resilience. There is thus a need for the research and policy communities to work together to develop new interactive tools that can be used by decision-makers at different levels of governance, from local communities to the international level.

Last, but not least, the chapter highlights a need to create spaces for discussing adaptation action in relation to overarching normative goals and political processes. What do we want to achieve through adaptation actions? How do adaptation actions and the processes created to support them relate to other local, national and international goals and how can adaptation be mainstreamed into normal policy and planning processes? While research can contribute knowledge and insights, these questions may also concern conflicting perspectives, and further discussion needs to be incorporated within the relevant political processes.

References

ACIA, 2005. Arctic Climate Impact Assessment 2005. Cambridge University Press.

Adger, W.N., J.M. Pulhin, J. Barnett, Geoffrey D. Dabelko, Grete K Hovelsrud, Ü Oswald Spring and C.H. Vogel, 2014. Human security. In: Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea and L.L. White (eds.), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. pp. 755-791. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

AMAP, 2011. Snow, Water, Ice and Permafrost in the Arctic (SWIPA): Climate Change and the Cryosphere. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

Arctic Council, 1996. Declaration on the Establishment of the Arctic Council. 19 September 1996. Ottawa, Canada.

Arctic Council, 2013. Arctic Resilience Interim Report 2013. Stockholm Environment Institute and Stockholm Resilience Centre.

Arctic Council, 2015. Iqaluit Declaration. The Ninth Ministerial Meeting of the Arctic Council. 24 April 2015. Iqaluit, Yukon, Canada.

Arctic Council, 2016. Arctic Resilience Final Report. Carson, M. and G. Peterson (eds). Stockholm Environment Institute and Stockholm Resilience Centre, Sweden.

Browman, H.I., 2016. Applying organized scepticism to ocean acidification research. ICES Journal of Marine Science, 73:529-536.

Cavalieri, S., E. McGlynn, S. Stoessel, F. Stuke, M. Bruckner, C. Polzin, T. Koivurova, N. Sellheim, A. Stepien, K. Hossain, S. Duyck and A.E. Nilsson, 2010. EU Arctic Footprint and Policy Assessment. Final Report. Ecologic Institute, Berlin, Germany.

Dannevig, H. and G.K. Hovelsrud, 2016. Understanding the need for adaptation in a natural resource dependent community in northern Norway: Issue salience, knowledge and values. Climatic Change, 135:261-275.

Dannevig, H., G.K Hovelsrud and I.A Husabø, 2013. Driving the agenda for climate change adaptation in Norwegian municipalities. Environment and Planning C, 31:490-505.

Folke, C., 2006. Resilience: the emergence of a perspective for social–ecological systems analyses. Global Environmental Change, 16:253-267.

Heleniak, T., 2014. Arctic populations and migrations. In: Nymand Larsen, J. and G. Fondahl (eds.), Arctic Human Development Report. Regional Processes and Global Challenges. pp. 53-104. TemaNord, 2014:567. Nordic Council of Ministers, Copenhagen, Denmark.

Hoogensen Gjørv, G. and M. Goloviznina, 2013. Introduction. In: Hoogensen Gjørv, G., D. Bazely, M. Goloviznina and A. Tanentzap (eds.), Environmental Change and Human Security in the Arctic. pp. 1-13. Earthscan.

Hoogensen, G., D. Bazely, M. Goloviznina and A. Tanentzap (eds.), 2013. Environmental Change and Human Security in the Arctic. Earthscan.

Hovelsrud, G.K. and B. Smit (eds.), 2010. Community Adaptation and Vulnerability in Arctic Regions. Springer.

IPCC, 2014. Annex II: Glossary. Mach, K.J., S. Planton and C. von Stechow (eds.). In: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.). pp. 117-130.

Keskitalo, E.C.H., 2008. Climate Change and Globalization in the Arctic. An Integrated Approach to Vulenrability Assessment. Earthscan.

Kirkenes Declaration, 1993. The Kirkenes Declaration from the Conference of Foreign Ministers on Co-Operation in the Barents Euro-Arctic Region. Kirkenes, Norway 11 January 1993.

Kofinas, G.P., D. Clark and G.K Hovelsrud, 2013. Adaptive and transformative capacity. In: Arctic Resilience Interim Report 2013. pp. 73-93. Stockholm Environment Institute and Stockholm Resilience Centre.

Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being. Synthesis. Island Press.

Nilsson, L.M. and B. Evengård, 2013. Food and Water Security Indicators in an Arctic Health Context. Report by the AHHEG/ SDWG and the AMAP/HHAG during the Swedish chairmanship of the Arctic Council 2011-2013. http://umu.diva-portal.org/ smash/record.jsf?searchId=1&pid=diva2:585006.

Nilsson, A.E., Å.A Gerger Swartling and K. Eckerberg, 2012. Knowledge for local climate change adaptation in Sweden: challenges of multilevel governance. Local Environment, 17:751-767.

Nymand Larsen, J. and G. Fondahl, 2014. Arctic Human Development Report. Regional Processes and Global Challenges. TemaNord, 2014:567. Nordic Council of Ministers, Copenhagen, Denmark.

Nymand Larsen, J., P.P Schweitzer, G. Fondahl, 2010. Arctic Social Indicators. Nordic Council of Ministers, Copenhagen.

Nyman Larsen, J., P. Schweizer and A. Petrov (eds), 2015. Arctic Social Indicators. ASI-II. Implementation. Nordic Council of Ministers, Copenhagen.

Owens, S., 2003. Is there a meaningful definition of sustainability? Plant Genetic Resources, 1:5-9.

Pelling, M., 2010. Adaptation to Climate Change: From Resilience to Transformation. Routledge.

Rauken, T., P.K. Mydske and M. Winsvold, 2015. Mainstreaming climate change adaptation at the local level. Local Environment, 20:408-423.

Risvoll, C., G.E. Fedreheim, A. Sandberg and S. BurnSilver, 2014. Does pastoralists' participation in the management of national parks in northern Norway contribute to adaptive governance? Ecology and Society, 19:doi:10.5751/ES-06658-190271.

Rittel, H. and M. Webber, 1973. Dilemmas in a General Theory of Planning. Policy Sciences, 4:155-169.

United Nations, 1992. United Nations Framework Convention on Climate Change (UNFCCC). http://unfccc.int/files/ essential_background/background_publications_htmlpdf/ application/pdf/conveng.pdf.

United Nations, 2015a. Sustainable Development Goals. www. un.org/sustainabledevelopment/sustainable-development-goals

United Nations, 2015b. Paris Agreement. Adopted at the UNFCCC Conference of the Parties 21st Session, Paris 11 December 2015. FCCC/CP/2015/L.9. United Nations Framwork Convention on Climate Change.

Wenger, E., 1998. Communities of Practice: Learning, Meaning, and Identity. Cambridge University Press.

Wenger, E., R.A. McDermott and W. Snyder, 2002. Cultivating Communities of Practice: A Guide to Managing Knowledge. Harvard Business Press.

West, J.J. and G.K. Hovelsrud, 2010. Cross-scale adaptation challenges in the coastal fisheries: Findings from Lebesby, northern Norway. Arctic, 63:338-354.

Acronyms and abbreviations

AACA	Adaptation Actions for a Changing Arctic
AHDR II	Arctic Human Development Report II
ALT	Active layer thickness
AMAP	Arctic Monitoring and Assessment Programme
AO	Arctic oscillation
AR5	Fifth assessment report (IPCC)
ASI	Arctic social indicators
BC	Black carbon
BEAC	Barents Euro-Arctic Council
C	Elemental carbon
CO2	Carbon dioxide
EEZ	Exclusive economic zone
EIA	Environmental impact assessment
EU	European Union
GCM	Global climate model / General circulation model
GDP	Gross domestic product
GHG	Greenhouse gas
GRP	Gross regional product
IA	Impact assessment
INDC	Intended nationally determined contribution
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
LNG	Liquefied natural gas
MSA	Mean species abundance
NAO	Nenets Autonomous Okrug / North Atlantic Oscillation
NOK	Norwegian Krone
OECD	Organisation for Economic Co-operation and Development
OSPAR	Commission supporting the Convention for the Protection of the Marine Environment of the North-East Atlantic
POP	Persistent organic pollutant
RCM	Regional climate model
RCP	Representative concentration pathway (IPCC)
RCP4.5	RCP based on a mid-range scenario for emission growth
RCP8.5	RCP based on a business-as-usual scenario for emission growth
RF	Russian Federation
ROS	Rain-on-snow event
RUB	Russian ruble
RVA	Risk and vulnerability assessment
SCD	Snow-cover duration
SD	Snow depth
SDG	Sustainable development goal (UN)
SPA	Shared policy assumption
SSP	Shared socioeconomic pathway
SWE	Snow-water equivalent
SWIPA	Snow, Water, Ice, and Permafrost in the Arctic
TAC	Total allowable catch
UN	United Nations
UNCLOS	United Nations Convention on the Law of the Sea
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States dollar
WHO	World Health Organization
WWF	World Wildlife Fund
YNAO	Yamal-Nenets Autonomous Okrug

Arctic Monitoring and Assessment Programme

The Arctic Monitoring and Assessment Programme (AMAP) was established in June 1991 by the eight Arctic countries (Canada, Denmark, Finland, Iceland, Norway, Russia, Sweden and the United States) to implement parts of the Arctic Environmental Protection Strategy (AEPS). AMAP is now one of six working groups of the Arctic Council, members of which include the eight Arctic countries, the six Arctic Council Permanent Participants (indigenous peoples' organizations), together with observing countries and organizations.

AMAP's objective is to provide 'reliable and sufficient information on the status of, and threats to, the Arctic environment, and to provide scientific advice on actions to be taken in order to support Arctic governments in their efforts to take remedial and preventive actions to reduce adverse effects of contaminants and climate change'.

AMAP produces, at regular intervals, assessment reports that address a range of Arctic pollution and climate change issues, including effects on health of Arctic human populations. These are presented to Arctic Council Ministers in 'State of the Arctic Environment' reports that form a basis for necessary steps to be taken to protect the Arctic and its inhabitants.

This report has been subject to a formal and comprehensive peer review process. The results and any views expressed in this series are the responsibility of those scientists and experts engaged in the preparation of the reports.

The AMAP Secretariat is located in Oslo, Norway. For further information regarding AMAP or ordering of reports, please contact the AMAP Secretariat (Gaustadalléen 21, N-0349 Oslo, Norway) or visit the AMAP website at www.amap.no.

AMAP Secretariat

Gaustadalléen 21
N-0349 Oslo, Norway

T +47 21 08 04 80
F +47 21 08 04 85

www.amap.no

ISBN – 13 978-82-7971-102-5

ARCTIC COUNCIL

AMAP
Arctic Monitoring and Assessment Programme