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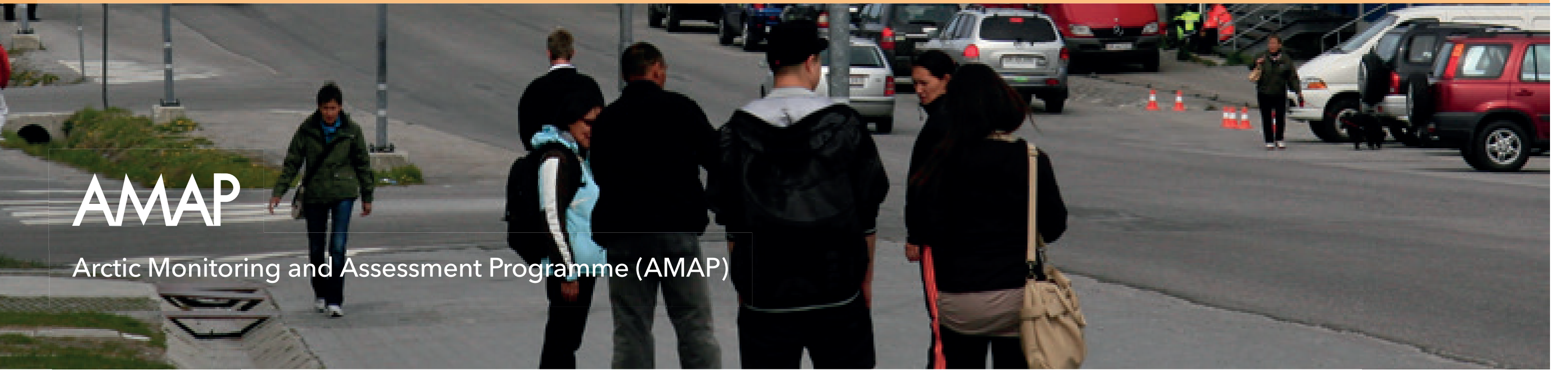
ADAPTATION ACTIONS FOR A CHANGING ARCTIC

PERSPECTIVES FROM THE BAFFIN BAY/DAVIS STRAIT REGION



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Arctic Monitoring and Assessment Programme (AMAP)

AMAP 2017

Adaptation Actions for a Changing Arctic: Perspectives from the Baffin Bay/Davis Strait Region

AMAP

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The Executive summary was written by the assessment leads and Knud Falk, and commented by the lead authors

Contents

Preface

This report presents the results of the 2018 AMAP Assessment of *Adaptation Actions for a Changing Arctic (AACA): Perspectives from the Baffin Bay/Davis Strait Region*. 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 project. The first is the Barents Area, which includes the northern parts of Finland, Norway, Sweden and North-western part of Russia and the second 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.

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 Baffin Bay/Davis Strait Region – 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 Baffin Bay/Davis Strait region was conducted between 2013 and 2016 by an international group of experts. Lead authors were appointed following a national nomination process. 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 Baffin Bay/Davis Strait 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 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 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 Canada and the Kingdom of Denmark for taking the lead country role in this assessment and to thank ArcticNet (Canada), Indigenous and Northern Affairs Canada, The Environment Protection Agency of Denmark, The Self-Rule of Greenland and the Norwegian Ministry of Foreign Affairs for financial support to the assessment work.

AMAP further acknowledges and appreciates the in-kind contribution made to the project by the authors and their employers.

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

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Tromsø, May 2018

Executive summary to the report on *Adaptation Actions for a Changing Arctic: Perspectives from the Baffin Bay/Davis Strait Region*

1 Approaches to adaptation

People in the Arctic have been highly adaptive and resilient for millennia, but now the pace of change is faster than ever – and increasingly complex, globalized, socio-economic structures have developed. As a result, adjustments to ways of planning and organizing are needed to keep up with the changing conditions. Although Adaptation Actions for a Changing Arctic (AACA) stakeholder consultations in Nunavut and Greenland revealed a desire for concrete "recipes" on how to adapt, this report, with very few exceptions, does not provide simple checklists that planners can just tick off and then trust that their investments and plans have been made "climate proof." This report does, however, provide ideas and suggest ways of thinking. It also offers a number of specific suggestions for how people and society can stand ready to embrace the unavoidable changes underway.

Difficulties in identifying the most appropriate actions for responding to climate change are compounded by the fact that climate is not the only driver of change in the Baffin Bay/Davis Strait (BBDS) region (Figure A). A feature common to all adaptation actions is the need to build in flexibility and the ability to adjust to increasing variability and new extremes – considering the cumulative impacts of not only climate and weather but also economic change and a host of other socio-economic drivers.

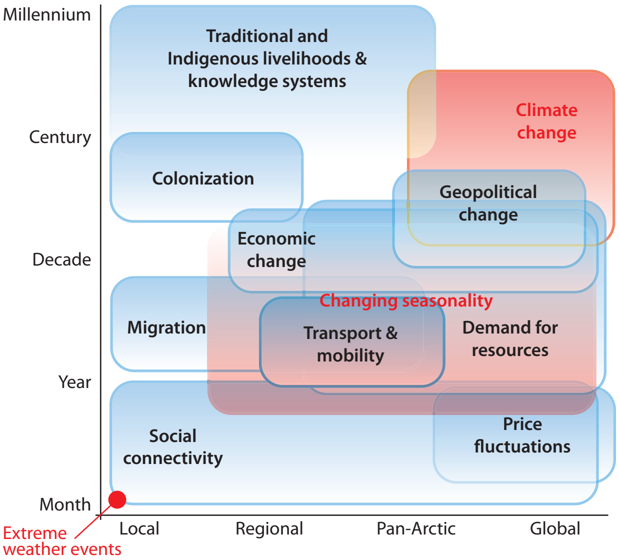

Figure A. Some socio-economic drivers (blue boxes) and climatic drivers (red) of change in the Arctic, and the temporal and spatial scales over which they act (modified from Arctic Council, 2013). Although changes in the social drivers are more difficult to project with scientific rigor than are changes in the climatic drivers, they are usually more important than environmental/climatic drivers in shaping policies and personal decisions (see Andrew, 2014; IPCC, 2014). Climate change effects include changing seasonality and an increase in the incidence of very localized extreme weather events, which can last from hours (e.g., heavy rains or snowfall, flash floods, storms) to days, weeks, or months (e.g., heat waves or cold waves, droughts). These types of changes are already being felt much more than the changes in long-term average conditions (for example, ice conditions and mean temperature) that are affecting most of the Arctic and the globe.

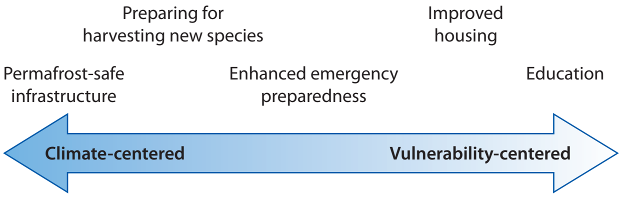

Figure B. Adaptation options can be related to the changing patterns of climate to varying extents. Some options are clearly "climate centered" in that they address specific challenges posed by a changing climate – for example, preparing infrastructure for conditions of thawing permafrost. Other long-term options are just "good development." These "vulnerability-centered" options address existing vulnerabilities that could be exacerbated by changes in a variety of external factors, climatic as well as socio-economic (see further explanations in Chapter 11, Figure 11.2, and the summary table in Chapter 12).

Although some climate change effects will come gradually (for example, receding sea ice, higher average temperatures, and reduced permafrost; see below and Chapter 3), there are also more immediate effects – in particular, more intense and frequent extreme weather events such as intense rainfall or snowfall, storms, and dry spells. In the short term, adaptation efforts can be relatively "climate centered" by planning for the handling of more extreme weather events and the few impacts that are certain (e.g., permafrost thawing). But when preparing for longer-term impacts, responses need to also target the other drivers of change – including social/economic/demographic conditions and development trajectories – that determine how climate change will affect people and society. These sorts of adaptation options may be more "vulnerability centered" – that is, focused on reducing existing vulnerabilities, which could be exacerbated by changing climate conditions. Many ideas proposed in this report fall somewhere on the continuum between "climate centered" and "vulnerability centered" (Figure B). These ideas all help to build resilience – the capacity to deal with change and continue to develop (Chapters 11 and 12).

In this executive summary, we first review general trends and the implications of climatic, environmental, and socio-economic drivers of change. Then we summarize some crosscutting findings and adaptation options for priority issues addressed in the following thematic chapters.

2 Trends and implications of climatic and environmental change

The earth's climate is warming due to greenhouse gas emissions. This warming will continue throughout the century, and weather will become more unpredictable and variable with larger extremes and "surprises." The climate is changing faster in the Arctic region than in temperate regions mainly because of feedback mechanisms associated with now having less snow and ice in the Arctic. It is important to realize that there is considerable uncertainty related to climate projections, both because (a) it is unknown to what extent climate gas emissions will be curtailed and (b) there is still an incomplete understanding of the complex climate system, which limits the projection skills of scientific models.

Climate projections for the BBDS region show that, relative to the reference climate period of 1986–2005, mean near-surface ***air temperatures*** are expected to increase, in winter, by about 1–4°C by 2030 and 1.5–10°C by 2080 and, in summer, by about 0.5–2°C by 2030 and 1–5°C by 2080. ***Total precipitation*** (i.e., rain and snow) is projected to increase over most BBDS areas, with the largest relative wintertime changes in the northwestern parts of the region. However, ***snow cover duration*** is expected to decrease by about 40–60 days, mainly due to later snow onset, with reductions being most pronounced in coastal regions. Also, the ***thawing season length*** is expected to increase by about 1–2 months by the end of the century.

Sea ice conditions are expected to undergo major changes in the BBDS region, with implications for safety, traditional and commercial activities (e.g., hunting and fishing), and shipping, as well as for ecosystem components (e.g., marine wildlife, biodiversity, and primary production; Chapter 6). The largest seasonal ***reductions in sea ice cover*** (15–20% by 2080) are expected during the autumn, related to a later freeze-up; decreases of 10–15% are expected in spring due to earlier break-up. ***Winter ice thickness*** is projected to decrease by about 20–30 cm, with the largest changes being in the northern parts of the region. The ***timing*** of these changes (i.e., when they might be seen during this century) is difficult to predict because of considerable variation across the scientific model results. Multi-year ice is likely to remain a shipping hazard for the foreseeable future in the Canadian Arctic Archipelago. A ***freshening and warming of the Baffin Bay*** surface layer of about 0.2°C per decade over the next fifty years is projected. Models also project increased inflow of warm Atlantic-origin water, a decrease of cold Arctic water through the Canadian Arctic Archipelago, and an intensification of the counterclockwise circulation in Baffin Bay. Expected changes in sea ice and circulation will likely reduce the duration of ice bridges in Nares Strait and, consequently, the duration of the ***Pikialasorsuaq/North Water Polynya,*** one of the Arctic's largest and most productive polynyas (recurrent areas of open water in the sea ice).

Projected changes in the terrestrial cryosphere (i.e., the "frozen" environment) are expected to affect mainly infrastructure. In the BBDS region, ***permafrost*** is projected to warm and thaw near the surface. This thawing will exacerbate infrastructure vulnerabilities, especially in ice-rich sediments that are sensitive to ground settlement and landslides. As a result of isostatic uplift ("land rise") associated with past and projected ice mass decreases and a reduced gravitational pull from the dwindling Greenland Ice Sheet, ***relative sea level*** in the BBDS region is projected to *fall* in most of the region (in contrast to most of the world, where the sea level is rising at an ever faster pace). This decrease in local sea level has important implications for the planning of coastal infrastructure, especially harbor facilities.

It is expected that ***long-range contaminants*** will remain an ongoing concern in the BBDS region. Long-transport pollution will likely cause ***mercury*** concentrations to increase in the Arctic environment and in wildlife during this century, possibly affecting wildlife and human health. ***Persistent organic contaminants*** are expected to decrease due to national and international regulations. However, ***new emerging compounds***, which are not yet fully understood in terms of contaminant and human health issues, will likely be found in the Arctic environment; some that are already known may increase in concentration. In addition, increased development in the BBDS region, particularly of the industrial sector (e.g., mining and oil and gas), increases the likelihood of there being local sources of contaminants in the environment (Chapter 7). A large ***oil spill*** in the marine environment will remain a concern related to oil and gas activities and to increased shipping.

3 Trends and implications of social and economic change

The basis and methods of projecting social and economic changes several decades into the future are much less well developed than the scientific basis and methods for projecting climate changes. However, some recent trends can be extrapolated. At the circumpolar scale, for instance, new ***international governance gaps***, especially in relation to shipping, continue to emerge.

The BBDS region shows a very clear trend of more localized ***governance and devolution of power***, with regional governments now being the main players for domestic development – empowered to attempt to offset negative trends affecting people. The outcome of ongoing devolution and of any industrial development depends on adequate access to relevant ***education and training*** in order for the region's population to continue to take an increasingly active role in governing and to benefit from the changes to come. The dependence of various sectors, including service and public administration, on workers from outside the BBDS region is a continued challenge.

Development of the ***formal economy***, with an increasing number of wage jobs, is an important driver for development as well as independence in the region. Another significant trend is the continued economic importance of the subsistence economy. Fishing, hunting, and gathering activities are a key part of the mixed economy, where the ***subsistence and wage economies*** support each other. However, this subsistence trend is sensitive to changes in policy and climate. Although elements of a formal economy are required to underpin the subsistence economy, it is likely that tension between the two economies will increase, as nonrenewable resource exploitation and its associated activities may affect local economies, social fabrics, and environments.

Demographic trends differ between Nunavut and West Greenland. In Canada, the Inuit population is younger than in Greenland and is the fastest-growing segment of the general population (see Chapter 2 and Subchapter 3.3); the Nunavut population as a whole is increasing. In Greenland, urbanization and migration are the main processes affecting population size, which is slightly decreasing. It is anticipated in both Nunavut and Greenland that ***in-migration*** related to increased resource extraction activities may affect future population growth. Particularly in Nunavut, it is projected that ***population growth***

will create new pressures for the health system (Chapter 4), as well as for infrastructure (Chapter 10).

Language is closely linked to the above issues of governance and economic development, as well as issues of identity and well-being. The strength of the ***Inuit language*** in the BBDS region shows different trends. In Greenland, *Kalaallisut* stands strong. In Nunavut, *Inuktitut* is widely used but shows signs of erosion, especially in younger generations.

Finally, the region is still quite isolated, with communities dispersed over a vast territory (more so in Nunavut than in Greenland) but showing trends of increased ***connection within the region***. Bottlenecks and changes in the physical infrastructure, including transportation and telecommunication, remain key drivers that affect security, health, education, and various economic sectors.

4 Crosscutting key findings and adaptation options

Health and well-being

Peoples' health, well-being, and resilience is a higher-level goal for all planning and adaptive action regarding future change. In this assessment, it is stressed that a holistic approach is important in order to secure this goal. When planning adaptation, health must be viewed outside the traditional model of solely describing disease and negative health outcomes. Adaptation in a health context focuses mainly on ***preventive efforts*** in which surveillance, early warning systems, and improved data collection are critical for anticipating and responding to changing risk patterns. This approach includes the monitoring and securing of ***water quality*** and quantity in a changing environment.

Food security in the region is a crosscutting issue that challenges health and well-being in some areas. Food security is affected by changing opportunities for maintaining traditional subsistence lifestyles; these changes are due to climatic as well as socio-economic factors.

Priorities and adaptation efforts in other sectors all have implications for health and well-being. ***Addressing current vulnerabilities*** in relation to health, socio-economic risk factors, and other main development gaps is the fast track to building resilience. If we solve the current challenges, they will at least not be exacerbated by a changing climate.

In addition, elements of the present-day ***medical system*** provide some space for projection into the future. Recent advances in the diagnosis of tuberculosis and latent tuberculosis in Nunavut and in Greenland would suggest that health technologies have the potential to offer quicker diagnosis, treatment, and contact tracing, thereby reducing the burden of disease. Further, it is anticipated that ***technologies such as telehealth*** can be expanded and advanced as connectivity increases due to continuous improvements in telecommunication infrastructure bottlenecks (see Subchapter 3.3).

Formal and informal education, learning, and training

Enhanced education and learning is a priority issue raised in all of the BBDS thematic chapters. As already recognized in formal government strategies on both sides of the BBDS region, it is important for people to develop relevant skills and to seize opportunities for ***diversifying livelihoods*** in order to take advantage of new job openings. It is also important to maintain and develop traditional and new hunting and fishing practices in a changing environment. Diversification and knowledge (Western and traditional) are key ingredients in creating the flexibility to handle external change – i.e., building resilience. Education is always a worthy investment in ensuring future flexibility.

Stakeholder consultations revealed a strong interest across the region in continued ***development and modernization*** and in maintaining the possibility for more ***traditional livelihoods*** – often in combination. So education to facilitate the continued development of wage job opportunities is needed, as is the maintenance and development of sustainable subsistence hunting and fishing. There is also a need to help these sectors adapt to changing conditions.

The development and adaptation of all kinds of formal and informal education, learning, and training are central tools in adapting to societal change. Preparing for jobs and entrepreneurship in traditional as well as developing sectors is pivotal to social well-being, and education and learning should incorporate as much flexibility as possible to prepare for unknown future possibilities. Many challenges in the socio-economic sectors are quite similar in Nunavut and Greenland: at present, the main focus is on achieving higher completion rates in various educational programs because dropout rates remain a significant problem.

Inuit social values (i.e., the Inuit concept of *Inuit Qaujimajatuqangit*, IQ) should be respected and considered when developing educational programs. ***Language programs*** also require strengthening on both sides of the BBDS region. It is not enough to have an educational system with only one language, with students sometimes being taught in their secondary or tertiary languages. In Greenland, the process of *Greenlandization* has led to a wide range of Greenlandic and Danish language skills across the population; the dominant language of primary school is Greenlandic, while the dominant language of high school teachers is Danish. In Nunavut, there is a focus on Inuktitut, but English is widely used across the territory. Proficiency in English is an important life skill in a changing and increasingly globalized world.

Infrastructure

The condition of the built environment is also an important crosscutting issue in the BBDS region, with implications for health, safety, and well-being, as well as the development and sustainability of all social and economic sectors. Overall, the BBDS built infrastructure currently suffers from major deficits (e.g., housing crisis, municipal services, and coastal infrastructure), which to some extent is a limiting factor for development. Already, the region is facing the challenge of maintaining and adapting its existing infrastructure to the consequences of ongoing climate warming (e.g., permafrost thawing); anticipated socio-economic changes will likely exacerbate pressures on the construction sector, as well as the need for additional infrastructure.

Improvements in the ***design of housing*** can positively affect, in particular, respiratory health. Currently, rates of respiratory illness – especially among children – are high (see Chapters 4 and 10). Housing designs adapted to not only permafrost and a harsh Arctic climate but also Inuit culture and lifestyle would contribute to improving quality of life and well-being and would likely encourage better maintenance practices through an increased sense of belonging.

Governance, collaboration, and planning across sectors

This study took advantage of ***combining knowledge and experience across national borders*** in the BBDS region, and it appears that further knowledge transfer and collaboration will be rewarding. This further exchange could occur bilaterally between Nunavut and Greenland and also within a circumpolar knowledge exchange facilitated by the Arctic Council and the Inuit Circumpolar Council. Interestingly, we found that *international* cooperation within sectors was often more well established than *national* collaboration across sectors, possibly because of more competition or conflicting interests among different sectors at the national level.

More collaboration and planning across sectors among and within each country can open the way for a more efficient development and adaptation process. In this respect, cross-sector adaptation planning by national and local governments could play a key role. ***Mainstreaming climate risk management*** is key to ensuring that climate information guides long-term development and that all major planning decisions are assessed in relation to their climate change adaptation, mitigation, and resilience-building potential. According to the BBDS stakeholder consultations and national reports, some ongoing efforts for mainstreaming climate risk management into relevant sectoral legislation, policies, and financing streams – and into local planning – are on the right track and could be accelerated. Therefore, ***enhancing the capacity of government agencies*** at different levels to support such mainstreaming efforts might be worth some investment.

One example of planning across the different sectors discussed in this assessment is ***ecosystem-based management*** (Chapters 6 and 7). Maintaining and developing ecosystem services in a rapidly changing Arctic is presently a challenge and will remain a challenge for future generations. All major activities in the BBDS region (e.g., traditional hunting and fishing, industrial fishing, tourism, extraction industries, shipping) rely on ecosystem functions while also, in turn, generating impacts upon ecosystems. To manage adaptation to ecosystem change while coping with potentially competing interests and activities, it is important to monitor ecosystem changes and stressors and to involve stakeholders and experts across sectors in decision processes and the development of strategies.

Managing living resources

Wise ecosystem management is one of the key ingredients required to ***strengthen the adaptive capacity*** of the BBDS region toward climate change and other external stressors and, thus, to ***optimize the potential for utilizing ecosystem services as opportunities emerge***. Management should build on robust knowledge, ***including scientific research and traditional/local knowledge***, about harvests and harvested or sensitive species and their ecosystems. Resource management should take into consideration the set of precautionary principles that guides the Arctic Council working groups' work on the identification of ecologically or biologically significant areas (EBSAs) and marine protected area (MPA) networks. It is important to identify biological and fishery hotspots that will require protection in the context of future development of the oil and gas and mining sectors and the increasing tourism industry.

Developing management plans for living resources in general will increasingly require ***concerted efforts across national borders in the management of joint resources***. This process also calls for increased inputs from and collaborations among scientific advisors, local communities, and stakeholders. This adaptive management would help to better accommodate the harvests to changes in resource abundance and distribution, taking into account potential social and economic impacts at local and regional scales. It would also provide a basis for eco-certification of the resources, which in turn increases the value of the fisheries.

To achieve sustainable management plans, it will be crucial to prioritize, promote, and support ***flexibility*** –e.g., multi-species fisheries in support of a ***sustainable fishery industry and the establishment of dynamic protection zones***. It will be important to secure ***connectivity*** among biological and fishery hotspots (known ones and new ones) in a protected area network that will require protection in the context of future developments in other socio-economic sectors. Facilitating ***alternative uses of living resources*** (e.g., eider down collection, macroalgae or mussel cultivation, wildlife watching or other tourist activities) as an alternative to traditional ecosystem services (e.g., hunting) would represent a good way to promote management flexibility. Exploiting alternative uses would also help to build community resilience by developing a ***broader range of livelihood options*** considered to be culturally relevant and locally appropriate. Improving ecosystem-based management principles and mechanisms across sectors and scales would also help to cope with the more intense population size fluctuations expected for the most important marine and terrestrial resources (e.g., shrimp, caribou).

Finally, ***combining occupations*** within farming and herding with alternative services such as tourism, infrastructure, manufacture of handicrafts, and the use of local renewable energy (e.g., micro water-power plants) would allow residents to take advantage of future possibilities while also limiting impacts on sensitive and rapidly changing Arctic ecosystems.

Risk management

A cross-sectoral approach is key to limiting the impacts of social and economic activities on ecosystems (services/resources) while also meeting development aspirations. For instance, developing ***codes of conduct for tourists and operators*** to reduce impacts on wildlife will contribute to enhancing the quality of wildlife watching and the preservation of environmentally or culturally sensitive sites. ***Increases in shipping activity*** resulting from reduced sea ice and increased resource exploitation will possibly augment the risk of harmful algal blooms and the introduction of ***aquatic invasive species*** into the BBDS region. Programs to share up-to-date monitoring information across all sectors could be implemented in ports and communities to identify potentially invasive species.

Overall, there is a need to plan for more extreme weather events. For almost all investment decisions – including those related to general infrastructure and mineral exploration and extraction (Chapter 7) – an ***integrated risk management*** (IRM) approach could be helpful. In an IRM context, impact assessments do not analyze merely a project's effect on the environment – they consider also the environment's (climate's) impact on the project and its risks. In large-scale investments, proper climate risk screening ensures better investments. Likewise, the increasing frequency and severity of extreme weather also calls for building on ongoing ***emergency preparedness*** efforts across the Arctic, with continuous upgrading of contingency and search and rescue planning at a regional and community scale to anticipate and prepare for these changing risks. Development and ***adaptation of all marine activities*** – including fisheries, cruise tourism, shipping, and resource exploration – to expanding opportunities (e.g., afforded by changes in ice cover and seasonality) depend on coordinated (BBDS-wide or pan-Arctic) national-level investments in enhanced information, safety measures, and regulations. Such investments would include contingency planning, operational guidelines for vessels, continued improvements in ice and weather monitoring and warning capabilities, and scaled-up efforts to improve the coverage and accuracy of sea charts and navigation aids.

5 About this report

The Arctic is changing at a fast pace. In the Baffin Bay/Davis Strait region, both climate change and modernization are inducing significant changes. Some changes offer new opportunities for the people living in the region, while others can pose severe challenges. For both the opportunities and the challenges, proper preparation and planning can help people to make the best of the changes. Despite inherent uncertainties in projections of future conditions – of climate and, especially, socio-economic development – it is better to use the available knowledge to plan for adaptation rather than risk ignoring the early warnings of changing future conditions. This report is compiled to assist in the planning of adaptation in the BBDS region – and it is hoped that the range of ideas and suggestions it offers will inspire decision-making at all levels.

With the Paris Agreement, world leaders in 2015 committed to limit global warning to as close to 1.5°C as possible and, at most, to 2°C by the end of this century – on average across the globe. In the Arctic, however, the warming will continue to be above these average figures, so the Arctic nations have long been motivated to reduce greenhouse gas emissions and help limit global warming. Still, even if humankind manages to meet the Paris ambitions, there is an increasing need to adapt to the unavoidable effects that are already, over the past decades, affecting people and communities.

Hence, the Arctic Council initiated the Adaptation Actions for a Changing Arctic project to help identify pathways to adapt to the changes and build resilience in the Arctic. This BBDS report (one of three regional AACA reports) deals specifically with adaptation options deemed most relevant to inhabitants of the Baffin Bay/Davis Strait region. It is important to realize that adaptation options are not available to deal fully with all adaptation needs. A continued adaptation deficit will remain, thus necessitating a sustained focus on climate change mitigation (i.e., limiting greenhouse gas emissions) – not only through practical measures in the BBDS region but also through persistent international diplomacy to support and encourage bold steps toward meeting the Paris Agreement goals. Nevertheless, while acknowledging the importance of continued climate change mitigation efforts, the AACA and BBDS project teams' emphasis is on identifying adaption options.

The process of developing this BBDS report included several workshops with stakeholders and experts in both Nunavut and Greenland, and these workshops guided the subsequent literature reviews and analyses conducted by more than a hundred specialists from Canada, Greenland, and Denmark. The resulting draft text was reviewed by other experts and stakeholders. Based on local stakeholder input (see Chapter 1) and existing regional strategies (Chapter 2), seven themes were selected for analysis and assessment of likely changes and potential adaptation options: health (Chapter 4), education (Chapter 5), living resources (Chapter 6), non-living resources (Chapter 7), tourism (Chapter 8), shipping (Chapter 9), and infrastructure (Chapter 10). Drivers of regional change are discussed in Chapter 3. Cross-theme considerations and approaches to adaptation planning and resilience building are also presented (Chapter 11), along with a summary of key adaptation options distilled from the entire report and other recent Arctic Monitoring and Assessment Programme (AMAP) products (Chapter 12).

The task of looking decades ahead has been challenging for all involved and has brought the multidisciplinary specialist teams onto thin ice in their attempts to consider what the projections for the future may mean for their respective areas of expertise. The report presents few final answers but should be seen as a pilot project and as part of a process.

6 Concluding remarks

Building resilience for individuals, for society, and for ecosystems could be a guiding principle in preparing for future changes, which bring a great deal of uncertainty to planning efforts. As defined in the Arctic Council's 2013 *Arctic Resilience Interim Report*, resilience is the "*capacity of a social-ecological system* *to cope with disturbance, responding or reorganizing in ways that maintain its essential function, identity and structure, whilst also maintaining the capacity for adaptation, learning and transformation*" (Arctic Council, 2013, p. viii) – or, more simply, the capacity to deal with change and continue to develop (see also Chapter 11). In the future, resilience will be essential to manage extreme shifts in society due to multiple drivers, including climate change and continued rapid societal transition.

In any scenario of future change, the BBDS region would benefit from enhanced efforts to provide reliable and sustainable environmental and ecosystem monitoring. In this regard, mechanisms that foster connection and collaboration among scientists and locals in producing knowledge at the community and regional levels (e.g., community-based monitoring) could also help to improve our understanding of changing environmental conditions, to enhance safety, and to support research and decision-making for the sustainability of Arctic societies.

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1. Introduction and framing issues

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This assessment is about the range of current and future changes in the Baffin Bay/Davis Strait (BBDS) region, as well as options to adapt to these changes. The coming decades are projected to bring a number of alterations to the region, with climate and modernization processes and the global economy being among the significant drivers (Chapter 3). The current and anticipated changes pose serious challenges but also emerging opportunities for the region's people, societies, economic foundations, and governmental institutions. Developing appropriate adaptation strategies and actions to effectively address the multiple natural and human-induced stressors and their cumulative effects will be challenging. However, changes are not new to the Inuit people and other northerners living in the region. BBDS residents have shown an impressive ability for adaptation and development and have coped with large changes during the past decades of rapid climate change and modernization. This BBDS assessment contributes information to further the development of adaptation actions to provide good life conditions and environments, as well as diverse opportunities for the people of the region in the future.

It is widely agreed that efforts to enhance adaptation and resilience are needed in order to lessen the impacts of existing levels of climate variability and change and to prepare for unavoidable climate impacts in the future. There is also a growing realization that adaptation needs and costs are affected not only by the extent of climate change but also by regulatory, environmental, and socio-economic context and trends. The sooner that adaptation responses are planned and implemented, the better equipped society will be to cope with the cumulative impacts of socio-economic and climate changes.

In recognition of the changes occurring in the Arctic and of the need for Arctic communities and governments to respond to these changes, the Arctic Council launched the Adaptation Actions for a Changing Arctic (AACA) project in 2013. The council requested that the Arctic Monitoring and Assessment Programme (AMAP) working group "*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.*" Further details on the evolution of the AACA enterprise and its relation with previous international assessments are presented in Box 1.1.

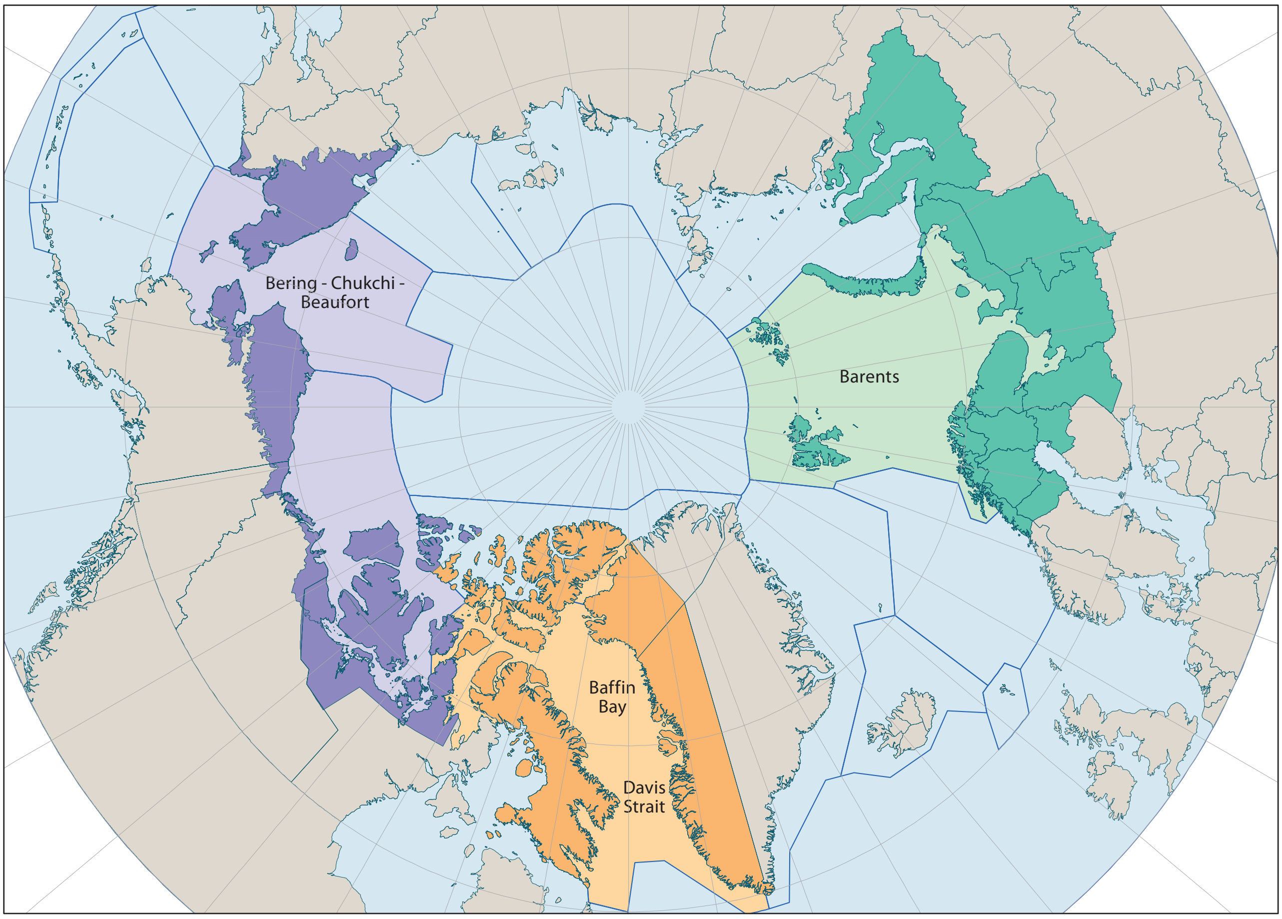

Figure 1.1 The three AACA pilot regions. The Bering-Chukchi-Beaufort region. The Baffin Bay/Davis Strait region. The Barents study area.

Box 1.1 Relation to previous international assessment work

As a precursor to the current AACA project, the Arctic Council produced two background reports (AACA parts A and B), which were finalized in 2013. AACA-A, led by the Arctic Council's Sustainable Development Working Group, consists of a compilation of assessments and reports prepared by Arctic Council working groups over the past ten years, with findings and recommendations that could inform adaptation options and actions (Arctic Council, 2013a). AACA-B, led by Canada and Russia, focuses on the adaptation activities that are already being implemented by Arctic Council member states and the Indigenous peoples on national, subnational, regional, and local levels (Arctic Council, 2013b).

A report on socio-economic drivers of change in the Arctic, which presents an overview of the potential directions of non-climatic drivers affecting the Arctic, was produced in 2014 (Andrew, 2014). Together with AACA parts A and B, this 2014 report serves as background for the follow-on AACA-C project, which includes more specific work within three pilot regions: (1) the Barents study area, (2) the Baffin Bay/Davis Strait region, and (3) the Bering-Chukchi-Beaufort region (Figure 1.1).

Key risks have been identified by previous assessments, such as the *Arctic Human Development Report* (Larsen and Fondahl, 2014); the Arctic Climate Impact Assessment (ACIA, 2005); the Snow, Water, Ice and Permafrost in the Arctic (SWIPA) assessment (AMAP, 2017b); the Arctic Biodiversity Assessment (ABA) (CAFF, 2013); and work under the Arctic Council's Sustainable Development Working Group (SDWG), including the EALÁT (a study of reindeer herding, traditional knowledge, adaptation to climate change, and loss of grazing land) and EALLIN ("the voice of the reindeer herding youth," 2012–2014) projects, as well as the fifth assessment report (AR5) of the Intergovernmental Panel on Climate Change (IPCC, 2014). Their findings state that there are risks for fresh water, terrestrial ecosystems, and marine ecosystems, due to the changes in ice, snow cover, permafrost, and freshwater/ocean conditions that are affecting species, habitat quality, and productivity, as well as dependent economies and livelihoods. These risks in turn pose a risk to the health and human well-being of Arctic residents and communities, due to the complex interlinkages among climate-related hazards and societal factors. Both Indigenous and non-Indigenous peoples in the Arctic have a history of adapting to natural variability in climate and natural resources. However, the changes occurring now – which are more rapid than previous changes – will test people's adaptive capacities.

The work performed under the AACA project follows up, at a regional level, the findings of the ACIA, SWIPA, Life Linked to Ice (Eamer et al., 2013), and ABA projects, as well as also the IPCC Fifth Assessment Report. This IPCC (2014) report identifies several factors that would enhance adaptation and resilience in the Arctic, such as enhanced understanding through scientific and Indigenous knowledge, to produce more effective solutions and technical innovations; enhanced monitoring, regulation, and warning systems, to achieve safe and sustainable use of ecosystem resources; co-production of knowledge, important for robust solutions that combine science and technology with Indigenous/local knowledge and technology; and improved education and training.

In order to accomplish its mandate, the AACA project collects and summarizes existing knowledge related to past, current, and possible future changes in the Arctic region and also comments on the potential impacts of these changes on people, society, public institutions, economies, and social and economic development strategies. The primary changes considered in the assessments include climate change, growth of world demand for energy and mineral resources, industrial and infrastructural development, and demographic and land use changes. Other (secondary) changes are considered as well.

Inspired by the ArcticNet Integrated Regional Impact Study (IRIS) approach, AACA is breaking new ground by integrating knowledge from many different fields of expertise and from across regions characterized by great cultural diversity, multiple uses and users of local resources, and ambitious development plans. Developing a comprehensive knowledge base on how the drivers of the rapidly changing Arctic interact to generate cumulative impacts – and how drivers connect to specific impacts and ultimately to specific stakeholder issues and challenges – can help provide the baseline information needed to respond to these challenges.

This AACA Baffin Bay/Davis Strait assessment is one component of a pilot project initiated by the Arctic Council for three regions. The other two AACA pilot regions are the Bering-Chukchi-Beaufort (BCB) region and the Barents study area (Figure 1.1). Each AACA assessment has three distinct characteristics: (i) a *regional approach* that crosses national borders, (ii) an *integrated multidisciplinary and interdisciplinary approach* that includes natural science, social science, and health science, and (iii) a focus on *local needs, as identified through dialogue with local and regional stakeholders.* AMAP defines regional and local stakeholders (in the AACA context) as those who live, work, or have an active interest in the region or area of concern.

This AACA Baffin Bay/Davis Strait assessment has been coordinated by a Regional Integration Team (RIT) headed by co-chairs from Canada, Greenland, and Denmark; the team members are listed on page viii. The Baffin Bay/Davis Strait region is large and diverse, encompassing western Greenland and most of the eastern Canadian Arctic (Chapter 2). The geographic scope of the assessment includes both terrestrial and marine areas, where the nature of the available data and information has made it necessary to define the BBDS boundaries somewhat flexibly. A key issue in the geographic delineation has been the large marine ecosystem – Baffin Bay and Davis Strait – that is central in the region, sustaining shared resources of fish, seabirds, and marine mammals. On each side of the sea are two young

Box 1.2 Stakeholder involvement in Greenland

In Greenland, where political parties and traditional interest organizations share a long history, stakeholder representation often occurs within formal organizations. In recognition of this tradition of professionalized, formal organization and also the democratically governed access to stakeholder perspectives provided by these organizations, the AACA project chose to garner stakeholder perspectives through consultation with formal organizations – e.g., interest organizations, public service agencies, and Greenland Self-Government administration agencies. Representatives of large industries, such as oil and gas and fisheries, were also invited for consultations. The process included the following steps:

1. Workshop with planners and technicians from municipalities

10 March 2014, Qaqortoq. In cooperation with KANUKOKA (association of Greenland's municipalities), a two-hour workshop was conducted with 23 municipal planners and technicians from Greenland's four municipalities. The workshop started with a brainstorming session among participants, regarding climate change challenges in the everyday work of the municipalities. Each municipality subsequently engaged in group discussions that were guided by three questions: (1) Which possibilities and challenges do we see as a result of climate change, and which adaptation models do we see? (2) How are we already working to adapt to climate change? and (3) What types of knowledge and what tools do we need in order to adapt to climate change? The oral presentations of the groups were recorded and transcribed, and their notes and posters were collected for archiving and analysis.

2. Invitation to provide written contributions

May 2014, Nuuk. Stakeholders were sent a written invitation to provide input to the AACA report. This invitation was distributed to the Greenland Self-Government ministries; key public service providers (store supply, housing, transport, communication); interest organizations representing key economic sectors (fishing, tourism, agriculture, extractive industries, and others); and social organizations representing Greenland's children (MIO, a national advocacy center), Indigenous peoples (ICC Greenland, a branch of the Inuit Circumpolar Council), and the civil society (nongovernmental organizations and associations). The invitation material invited stakeholders to send any perspectives on climate change previously formulated by their organizations or to provide new input based on the three questions that had proven fruitful in the municipal workshop described above. Six organizations provided written input (Royal Greenland; the Ministry of Education, Church, Culture & Gender Equality; Landslægeembedet, Greenland's health authority; the Ministry of Environment, Nature and Justice; and WWF).

3. Workshop with the Inuit Circumpolar Council, fisheries organizations, and stakeholders within the oil and mining industries

2 June 2014, Greenland Climate Research Centre, Nuuk. This AACA workshop included participants from the AACA BBDS Regional Integration Team; the Greenland Ministry of Nature, Environment and Justice; the Danish Environmental Protection Agency; and the Arctic Monitoring and Assessment Programme. Three stakeholder sessions of 2½ hours each were held with: (a) representatives of Inuit Indigenous peoples (the Inuit Circumpolar Council and ICC Greenland) and representatives of the Association of Fishermen and Hunters in Greenland; (b) representatives of the offshore fishing industry (Greenlandic Business Association); and (c) stakeholders associated with the oil and mining industries (Shell; True North Gems Inc.; True North Gems Greenland A/S; the Mineral Licence and Safety Authority; the Environmental Agency for Mineral Resources Activities; Tanbreez Mining Greenland A/S; Nunaoil A/S; the health, safety, and environment group of the Greenland Oil Industry Association; and the Ministry of Industry and Mineral Resources).

For more information about these first three steps, see the stakeholder report of Jacobsen (2016).

4. Project status presentation

20 November 2015, Katuaq, Nuuk. A presentation on AACA stakeholder involvement and project progress was delivered at a climate change adaptation workshop arranged by Greenland's Ministry of Nature, Environment and Justice and the Danish Meteorological Institute. This presentation was followed by a discussion session that included input from the stakeholders in attendance.

5. Chapter presentations and author–stakeholder meetings

2–5 February 2016, Nuuk. The AACA chapter lead authors presented their draft report chapters at a stakeholders meeting at the Greenland Climate Research Centre, Greenland Institute of Natural Resources. Subsequently, the lead authors and the RIT members held additional meetings with stakeholders relevant to specific chapters, to discuss chapter contents and recommendations for adaptation options. Sixteen of these stakeholder meetings were held over two days, and several additional follow-up discussions occurred by phone. These meetings focused on exchanges regarding stakeholder needs and inputs from the stakeholder organizations, the lead authors, and the Regional Integration Team.

6. Stakeholder reviews

As a final step, the draft assessment report was distributed for stakeholder review. This step allowed stakeholders to submit additional comments before the lead authors finalized their report chapters.

Carsten Egevang

The Parliament of Greenland, Inatsisartut

Inuit societies – both engaged in devolution and nation building, both having mixed traditional and modern lifestyles, and both with a focus on developing their tourism and mineral resource industries. And yet they are two very different societies. In this assessment report, the strategies of the governments of Nunavut and Greenland have been included as relevant background information (see Subchapter 2.3).

The Indigenous self-governance institutions on each side of the sea have also developed different structures for political representation. Different methodologies for involving stakeholders were therefore chosen for the societies of Nunavut and Greenland, as the AACA project worked to collect and include a broad range of stakeholder perspectives (see Boxes 1.2 and 1.3).

The BBDS assessment work

Based on stakeholder dialogue and input, seven BBDS themes were selected for analysis: human health and well-being, education, living resources, non-living resources (mineral extraction and other aspects), tourism, shipping, and infrastructure. For each theme, the co-chairs of the Regional Integration Team appointed a multidisciplinary and binational author team to analyze potential development trajectories and potential adaptation options for the future. The more than 100 authors and contributors came from a variety of universities and knowledge institutions in Canada, Greenland, and Denmark. Along the way, the appointed lead authors supplemented their original teams with contributing authors to help cover the diversity of disciplines needed. We have made an effort to integrate perspectives and information from communities, industry, and government administrations (see below and Boxes 1.2 and 1.3).

The BBDS authors have analyzed the seven themes, summarized current knowledge in relation to climate change and other stressors, and described potential adaptation options. The assessment is based on peer-reviewed literature and other relevant sources that are duly referenced throughout the text. Both scientific knowledge and traditional and local knowledge are drawn upon to obtain a more holistic approach and view. We have used different methods and approaches to describe future trends, impacts, and consequences, depending on the topic and available knowledge. The intention is that the assessment should be transparent, both in its sources of information and in conveying the large uncertainties involved. Because predicting the future is difficult, the original ambition to discuss each thematic area in relation to development scenarios for 2030 and 2080 has not been realized in most cases. Instead, the likely trajectories of future development are often characterized more generally, as "medium-term" and "long-term" development scenarios. Sometimes the conclusions and potential adaptation options are based more on expert judgments than on firm science; in such cases, we have tried to make this distinction apparent in the text. Also, as a general strategy for coping with the uncertainties, the adaptation options are often phrased to be flexible, with the aim of producing resilience and robustness to the variety of changes that may occur with more or less force in the years to come.

Box 1.3 Stakeholder involvement in Nunavut

In Nunavut, the AACA process of stakeholder consultation benefited from the earlier work of the ArcticNet Integrated Regional Impact Study of the Canadian Eastern Arctic Region (IRIS-2), which covered Kivalliq and Qikiqtaaluk (formerly called the Baffin region) (ArcticNet, 2010–2013). This IRIS project provided up-to-date and relevant background information for the BBDS Regional Integration Team. Since 2008, ArcticNet scientists have worked closely with Inuit organizations, local government, industries, and other networks to help Nunavut decision-makers prepare for challenges and opportunities associated with climate change and modernization. Considerable effort has been invested in summarizing the knowledge thus produced on climate change priority issues in Nunavut, based on *Inuit Qaujimajatuqangit* (IQ), community knowledge, and research. Various surveys and studies have documented environmental changes and related impacts as observed by Inuit and by scientists (e.g., workshops, conferences, project reports, and scientific literature – see supplementary material).

The IRIS consultation process was greatly facilitated by a steering committee composed of representatives from regional organizations (e.g., Nunavut Tunngavik Inc., the Government of Nunavut, the Nunavut Research Institute), national organizations (e.g., Inuit Tapiriit Kanatami, Indigenous and Northern Affairs Canada), and academia. The IRIS Steering Committee helped to establish a communication network to support reporting processes, information flows, and feedback from within the region. An Inuit Research Advisor (IRA) also played a key role in informing local communities of research in the region, directly connecting researchers and community members, and acting as a liaison to relay information among different groups.

The IRIS Steering Committee members were regularly involved in consultation workshops, public hearings, and community meetings in the region, and they continuously reported relevant information regarding IRIS developments. The IRIS project benefited greatly from regional workshops that enabled team members to connect with the region, key stakeholders, and decision-makers; to receive feedback on the IRIS report; and to meet face-to-face with organization and government representatives. In 2012, a regional science meeting was held 6–8 November at the Parish Hall in Iqaluit (ArcticNet, 2012), to bring together the lead authors to present their draft outlines or chapters to a wide range of decision-makers for feedback. Individuals were invited to participate and contribute their knowledge and experience to the meeting. More than a hundred regional decision-makers and experts from 21 organizations contributed to the discussions. Their comments and feedback greatly helped to guide the final chapter writing and shape the chapter contents, thereby making the IRIS report more effective and useful for the region.

The regular publication of IRIS newsletters (ArcticNet, 2010–2013) also encouraged information exchanges among ArcticNet scientists and local decision-makers. The newsletters provided information on the IRIS approach and goals and also gave communities and individuals an opportunity to help identify the climate change impacts, regional adaptation needs, and priority issues that would frame the contents of the assessment report. The newsletters also profiled (a) ArcticNet research projects active in the study region – in order to highlight new scientific information relevant to climate change impacts and adaptation strategies, and (b) a series of regional research projects carried out as community-based research – thus highlighting the nature of the information being generated, as well as the array of relevant organizations and researchers active in the region. Ultimately, the IRIS newsletters served to make the scientists and their areas of expertise well known to policy-makers and decision-makers in the region and, conversely, to make regional policy-makers and decision-makers and their knowledge needs well known to the IRIS scientists.

In addition to producing the newsletters, the IRIS-2 team also developed a strong collaboration with the Government of Nunavut Climate Change Centre (NC^3), to maximize the exposure of ArcticNet research in the region. The NC^3 website provides an interactive climate change resource that fosters collaboration with other organizations, including the Nunavut Research Institute (NRI), Natural Resources Canada, and nongovernmental and Inuit organizations, including ArcticNet and Nunavut Tunngavik Inc. (NTI). Because numerous groups are developing tools and community resources for climate change adaptation and research in Nunavut, incorporating all of these resources into one centralized location serves to facilitate the sharing and dissemination of climate change knowledge across the territory. (For more information, see the NC^3 website: www.climatechangenunavut.ca.)

Finally, an online survey (available at www.surveymonkey.com/s/ArcticNet_IRIS2) was used to document and better understand how ArcticNet-supported research is influencing (or could potentially influence) decision-making in the Canadian Eastern Arctic. All scientists involved in the region, from project leaders to graduate students, were asked to fill out the short questionnaire. This survey helped to gauge the overall level of interaction between the IRIS contributing authors and regional decision-makers.

Cindy Hopkins/Alamy Stock Photo

Nunavut's Legislative Assembly building

Note that, as defined in the Arctic Council's 2013 *Arctic Resilience Interim Report*, resilience is the *capacity of a social-ecological system to cope with disturbance, responding or reorganizing in ways that maintain its essential function, identity and structure, whilst also maintaining the capacity for adaptation, learning and transformation* – or, stated more simply, resilience is the capacity to deal with change and continue to develop. The links between adaptation and resilience are discussed further in Chapter 11.

To consolidate the BBDS assessment information and conclusions, the assessment report has undergone scientific peer review in a process organized by the International Arctic Science Committee. The report has also been reviewed by national institutions (in National Reviews) and stakeholders (in Public Reviews). The final version of each chapter reflects the authors' careful consideration of all reviewers' comments.

This assessment report is organized into three parts. The introductory part sets the scene in the region (Chapter 2) and describes drivers of change (Chapter 3). The main body of the report is the analytical part, with a chapter devoted to each of the seven themes (Chapters 4 through 10). The last part of the report summarizes the adaptation options, with a focus on crosscutting issues and the building of resilience (Chapters 11 and 12).

This BBDS report is not meant to dictate policy and decision-making but rather to assist it. In line with these intentions, the report's target audiences include the scientific research community, residents of the Arctic, industries operating in the Arctic, and all types of Arctic policy- and decision-makers at different geographical and organizational scales. However, the assessment is written in the AMAP tradition, with peer review to ensure a product with academic quality assurance. Hence, the report can in some places be rather technical and academic. The report therefore begins with a concise Executive Summary and ends with an accessible summary table (Chapter 12). In addition, an accompanying (less technical) overview report is available on the AMAP website (amap.no): *Adaptation Actions for a Changing Arctic (AACA): Baffin Bay/Davis Strait Region Overview Report* (AMAP, 2017a). We recommend that additional applied products are developed to reach a wide audience and facilitate local discussions.

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2. General description of the BBDS region

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Introduction

The Baffin Bay/Davis Strait (BBDS) region includes only two nations: Nunavut, a territory in Canada, and Greenland, an autonomous part of the Kingdom of Denmark. These two land areas are separated by Baffin Bay in the north and Davis Strait in the south (Figure 2.1). Although the entire BBDS region is inside the Arctic climatic zone (except southernmost Greenland), significant differences are found between the two parts – in the natural environment and in political, social, and socio-economic aspects.

The differences in the natural environment are governed mainly by the sea surface currents, which bring relatively warm water from the Atlantic up along the West Greenland coast. This phenomenon also has a profound influence on sea ice conditions. A large part of West Greenland remains ice free throughout the year, thus allowing navigation even in winter. The Nunavut side, in contrast, is often blocked by sea ice until mid-summer.

The Greenland side of the BBDS region is more densely populated than the Nunavut side. In Greenland, several towns and villages are distributed along the entire coastline. In Nunavut, the people are much fewer in number and more localized, limited mostly to just a single town and a few small settlements.

As of January 2015, the Greenland part of the BBDS region had almost 53,000 inhabitants distributed among 16 towns and 53 villages (in addition to a few sheep farms and other named sites). The definition of a "town" is based on administrative structure prior to 2008, with towns being defined as those communities that served as the political/administrative centers of their respective municipalities and that seated a local town council and mayor. With the municipal reform of 2008, the previous 18 Greenland municipalities (with 16 being in the BBDS region) were combined into 4 larger municipalities, each of which encompasses several towns and villages. The capital of Greenland is Nuuk (population 17,000), which is situated in the central part of Southwest Greenland.

On the Nunavut side, the BBDS region covers most – but not all – of the Qikiqtaaluk administrative region (formerly called Baffin). However, the statistics presented in this report for the BBDS region of Nunavut represent the entire Qikiqtaaluk

Figure 2.1 The BBDS marine and terrestrial regions.

region because it was not possible to filter out data from just the communities and villages situated inside the BBDS region (only 3 of the Qikiqtaaluk region's 13 villages are outside the BBDS boundary: Igloolik, Hall Beach, and Sanikiluaq; see Figure 2.1). The total population in Qikiqtaaluk in 2016 was almost 20,000. All 13 communities are considered to be municipalities, and each has its own elected local town council and mayor. Iqaluit, Nunavut's capital, is the largest community, with 7,740 inhabitants counted in 2016 (corresponding to a "town" in Greenland).

The ice-free conditions on the Greenland side of the region form the basis for an intensive modern fishery that operates with modern trawlers in offshore waters and with smaller boats and dinghies in inshore areas. This fishery is the basis for Greenland's export revenue. On the Nunavut side, marine resources are generally exploited on a subsistence harvest basis and mining plays a larger role than in Greenland.

Biodiversity also shows marked differences between the two national parts of the BBDS region. Seabirds are, for example, much more numerous on the Greenland side, mainly due to the ice conditions and much higher primary production in the sea. The Nunavut side has many more terrestrial species of plants and mammals because the sea around Greenland has been a barrier for immigration since the last Ice Age.

These aspects are considered in more detail in the following sections of Chapter 2.

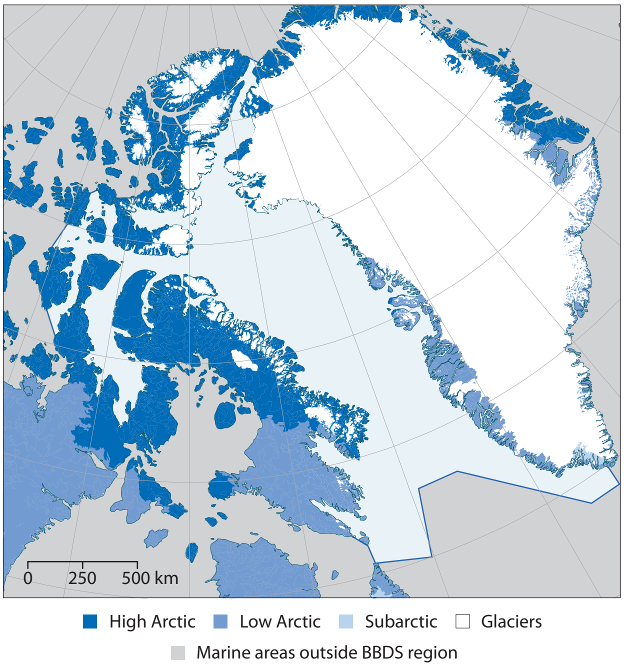

Figure 2.2 The BBDS region lies mostly within the Low Arctic and High Arctic climate zones; only a small area in South Greenland is Subarctic. Adapted from CAVM Team (2003) data set.

2.1 The biophysical environment of the BBDS region

2.1.1 The BBDS region delineated

The marine part of the BBDS region includes Davis Strait and Baffin Bay, the northern Labrador Sea, Hudson Strait, Prince Regent Inlet, Lancaster Sound, Jones Sound, Kane Basin, Nares Strait, and Fury and Hecla Strait. The terrestrial areas encompass West Greenland, Ward Hunt Island, Ellesmere Island, the Sverdrup Islands (including Axel Heiberg, Ellef Ringnes, and Amund Ringnes Islands), some of the Parry Islands (including Melville, Bathurst, and Cornwallis Islands), Devon Island, some of Somerset and Prince of Whales Islands, Bylot Island, and Baffin Island (Figure 2.1).

2.1.2 Climate

The BBDS region is situated mainly within the Arctic climate zone (Figure 2.2). A small part of south Greenland is, however, considered Subarctic because the July mean temperature is >10°C. North of the Subarctic zone, the Arctic climate zone is divided into the Low Arctic, where the July mean temperature is 5–10°C, and the High Arctic, where the July mean temperature is <5°C (Figure 2.2). In Figure 2.3, subzones D and E constitute the Low Arctic; subzones A, B, and C constitute the High Arctic.

The true Arctic climate zones are treeless, with open tundra in flat areas. For example, in subzone A (Figure 2.3), the vegetation is extremely sparse, with <5% cover and only scattered plants in the almost barren coastal lands (Table 2.1). However, in moist and fertile places, vegetation cover may be locally higher – for instance, below snowdrifts and in wetlands. In the Low Arctic, the dominant plant growth consists of low shrubs, dwarf shrub heath, and ferns; in some areas (subzone E), willow and birch may form dense thickets with 80–100% vegetation cover (Young, 1971; Chernov and Matveyeva, 1998). Farther south, in the Subarctic, tree growth is restricted to forest tundra and birch shrubs. With decreasing latitude and increasing temperature, diversity increases such that there is an increase of about 25 species with every 1°C increase in mean July temperature (Rannie, 1986).

2.1.3 The marine environment

The Baffin Bay/Davis Strait region (Figure 2.1) includes part of the waterway that connects the Arctic and Atlantic oceans. To the north is Nares Strait (Figure 2.5), which separates Greenland and Ellesmere Island and connects the Lincoln Sea with northern Baffin Bay (Figure 2.4). Uninhabited Hans Island, in the middle of the strait, is claimed as sovereign territory by both Canada and Denmark (Byers, 2009). Baffin Bay is roughly 1,450 km long, up to 650 km wide, and, in the center of the basin, more than 2,000 m deep. The bay connects to the Atlantic Ocean via Davis Strait and the Labrador Sea.

The marine environment of the BBDS region is shaped by a number of factors, including large-scale and regional ocean currents, ocean temperatures, sea ice, and glacial ice (detailed in Subchapters 3.1 and 6.2). The oceanographic system on the Canadian side encompasses Lancaster Sound, Baffin Bay, Davis Strait, and the northern Labrador Sea (Figure 2.4). Here, large southward flows of water (Arctic Ocean outflow), sea ice, and glacial ice converge along the eastern Canadian coastline. Much of this water originates from the Pacific Ocean and has spent more than a decade transiting the High Arctic, where it was

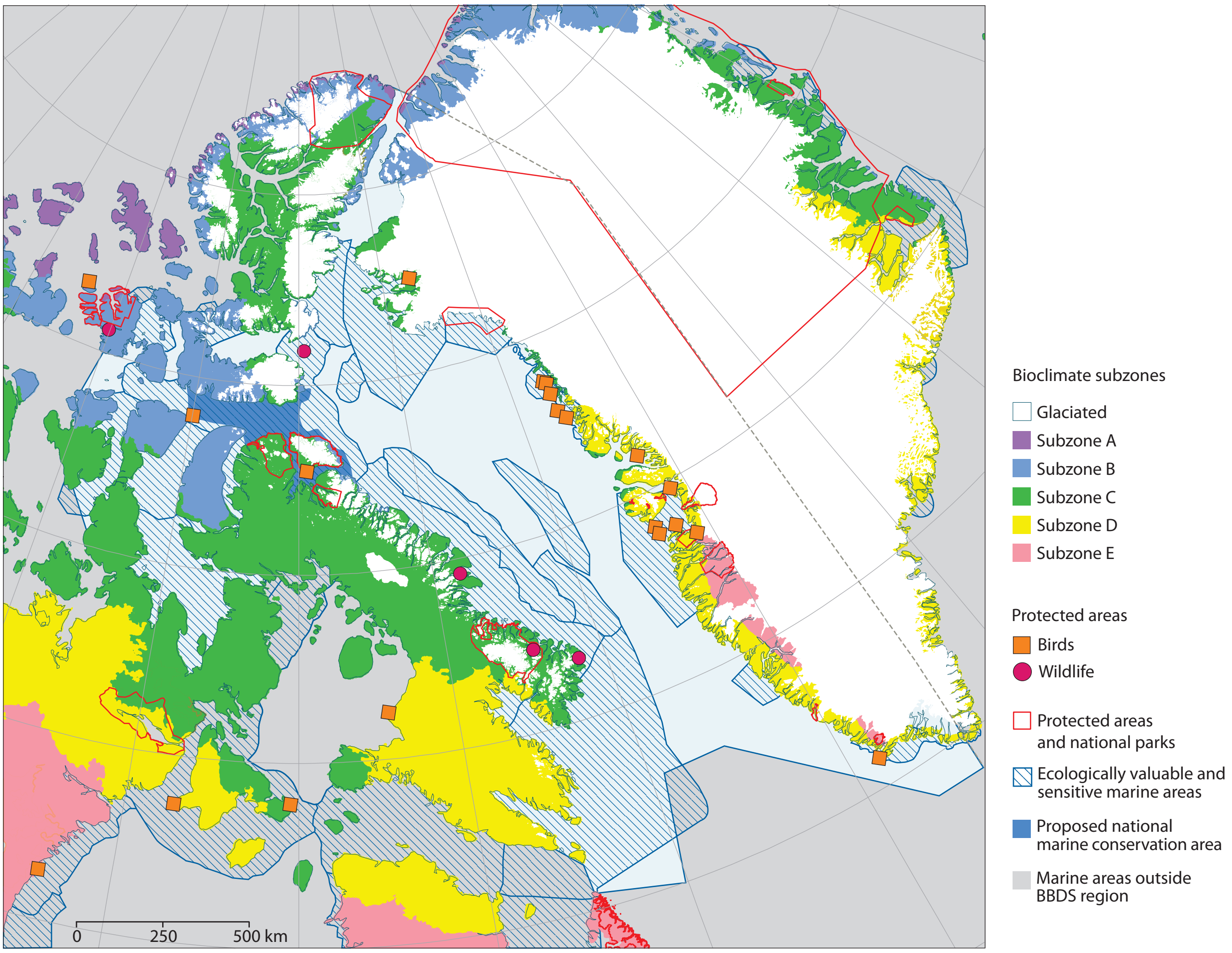

Figure 2.3 Bioclimate subzones and protected areas in the vicinity of the BBDS region. The protected areas include ecologically or biologically significant marine areas (EBSAs), bird protection areas, wildlife protection areas, national parks, and marine protected areas. Adapted from CAVM Team (2003) data set, DFO (2011), Parks Canada (2013), and Environment Canada (2016).

Table 2.1 Vegetation properties of the bioclimate subzones (from Walker et al., 2016). (The subzone colors in the table match the colors on the Figure 2.3 map.)

Subzone	Mean July temperature[1] (°C)	Summer warmth index[2] (°C)	Vertical structure of plant cover[3]	Horizontal structure of plant cover[3]	Number of vascular plant species in local floras[4]
A (High Arctic)	0–3	<6	Mostly barren. In favorable microsites, one lichen or moss layer <2 cm tall, widely scattered vascular plants that are barely taller than the moss layer.	<5% cover of vascular plants, up to 40% cover by mosses and lichens	<50
B (High Arctic)	3–5	6–9	Two layers: moss layer 1–3 cm thick and herbaceous layer 5–10 cm tall. Prostate dwarf shrubs <5 cm tall.	5–25% cover of vascular plants, up to 60% cover of cryptogams	50–100
C (High Arctic)	5–7	9–12	Two layers: moss layer 3–5 cm thick and herbaceous layer 5–10 cm tall. Prostate and semi-prostate dwarf shrubs <15 cm tall.	5–50% cover of vascular plants, open patchy vegetation	75–150
D (Low Arctic)	7–9	12–20	Two layers: moss layer 5–10 cm thick and herbaceous and dwarf-shrub layer 10–40 cm tall.	50–80% cover of vascular plants, interrupted closed vegetation	125–250
E (Low Arctic)	9–12	20–35	Two to three layers: moss layer 5–10 cm thick, herbaceous/dwarf-shrub layer 20–50 cm tall, sometimes with low-shrub layer to 80 cm.	80–100% cover of vascular plants, closed canopy	200–500

[1] Based on Edlund (1990) and Matveyeva (1998).
[2] Annual sum of mean monthly temperatures greater than 0°C, modified from Young (1971).
[3] Chernov and Matveyeva (1998).
[4] Number of vascular species in local floras based mainly on Young (1971).

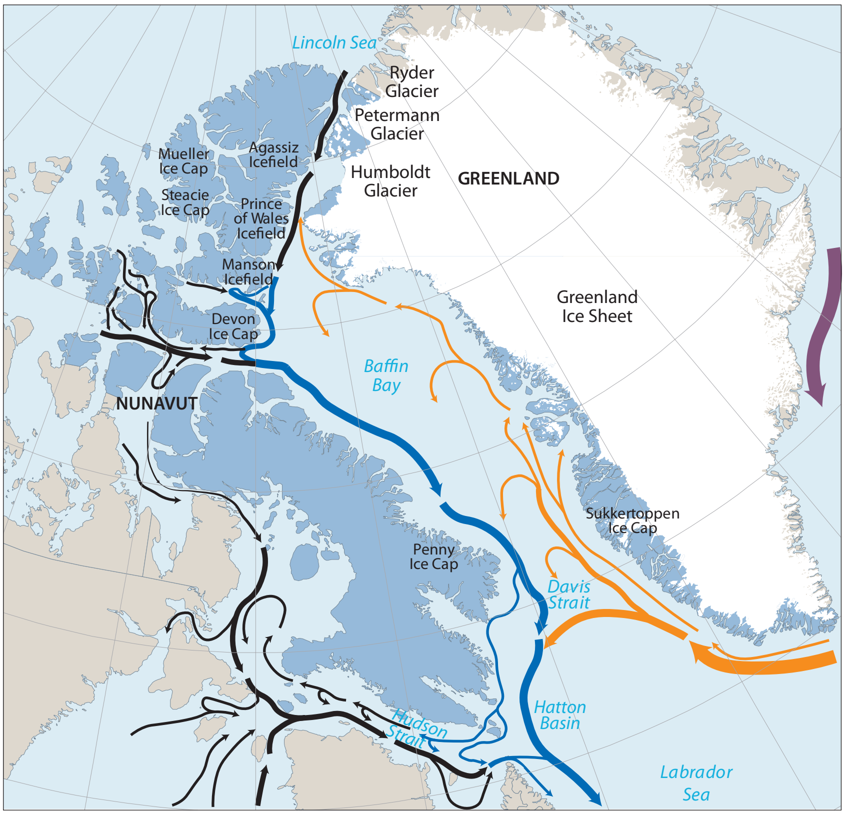

Figure 2.4 Major surface ocean currents (black lines) and bathymetric features in the BBDS region. Derived from Curry et al. (2014).

modified by ice growth and decay, precipitation, river discharge, and biological activity (Azetsu-Scott et al., 2010). The water along the western coast of Greenland is transported northward by the West Greenland Current, which carries relatively warm and salty water from the Atlantic. The cold current flowing southward along East Greenland cools coastal southwest Greenland and, in the spring, carries polar drift ice ("storis") around the southern tip of Greenland (see below). As this water travels, it collects meltwater produced by Greenland's glaciers. Most of the water in the West Greenland Current arcs westward and then southward in northern Baffin Bay (Figure 2.4). This regional circulation affects the physical and chemical properties of waters in the BBDS region and is responsible for transporting organisms from the north and the south. Further, the circulation has a profound influence on the climate in coastal areas, with Low Arctic conditions being found all along the West Greenland coast to as far north as about 71°N. High Arctic conditions are found on Baffin Island to as far south as 65°N (Figure 2.2).

A polynya is a geographically fixed region of open water that is surrounded by sea ice (Hannah et al., 2009). Polynyas are an important component of the BBDS marine system because their open waters create a refuge for marine mammals and seabirds to feed, breathe, and rest. In addition, springtime primary production is able to start much earlier in polynyas than in ice-covered waters (see details in Subchapter 6.2). Fifteen polynyas recur in the same position each year in the BBDS region (Figure 2.5). The Pikialasorsuaq/North Water Polynya (NOW), which lies between Greenland and Canada in northern Baffin Bay, is the region's largest polynya (see details in Subchapter 6.2). With one of the most productive food webs in the Arctic Ocean, the North Water Polynya attracts numerous marine mammals and millions of seabirds (Stirling, 1980; Dunbar, 1981; Deming et al., 2002; Egevang et al., 2003; Boertmann and Mosbech, 2011; DFO, 2015). Because of its year-round open-water conditions and its abundance of marine mammals, this polynya has also attracted Inuit hunting communities and 19th-century whaling and exploring expeditions. Today, the North Water Polynya sustains Greenlanders' livelihoods in the Qaanaaq district of northwest Greenland.

The oceanography of the BBDS region is described in more detail in Chapter 6.

2.1.3.1 Ice conditions

Most of the BBDS region is covered by sea ice in winter. Only the southwest coast of Greenland (north to 67°N) remains normally ice-free or is at least navigable through the winter (Figure 2.6). (This area is referred to as the "open water area."). The sea ice of the BBDS is mainly first-year drift ice of local origin; only small amounts of Arctic Ocean pack ice are transported in through the Nares Strait. This means that Baffin Bay and Davis Strait become free of ice each summer, but ice may linger in adjacent areas. Especially along Baffin Island's east coast, the ice remains until late July; among the High Arctic Canadian islands, ice may persist throughout the summer – e.g., in Foxe Basin. The trend, though, is that these permanently ice-covered areas are diminishing (details in Section 3.1.5).

Fast ice (ice that is anchored to land or the seabed) occurs in fjords and bays and in the waters between the High Arctic Canadian islands.

Another characteristic feature is the presence of icebergs, which originate either from glaciers on the West Greenland side of the BBDS region or from East Greenland glaciers, to then be carried by currents into the BBDS region.

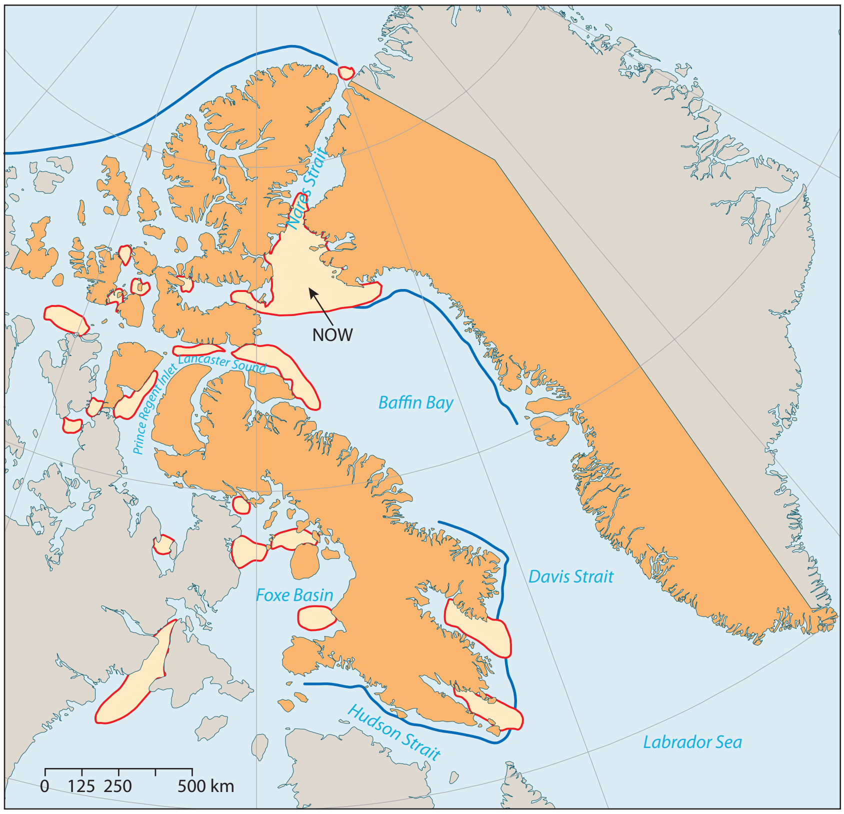

Figure 2.5 Known polynyas in the BBDS region. "NOW" indicates the North Water Polynya. Adapted from Stirling (1980), Barber and Massom (2007), and Hannah et al. (2009).

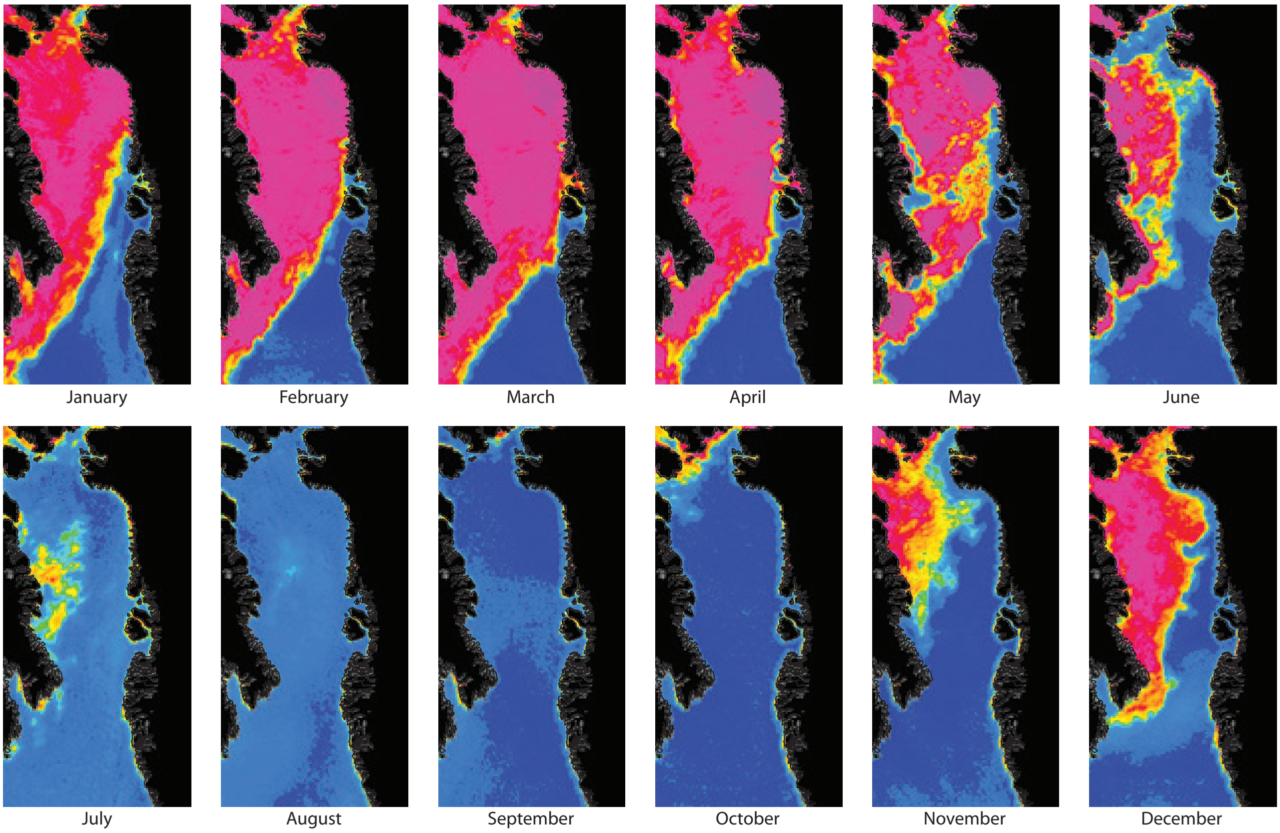

Figure 2.6 Annual cycle in sea ice cover in Baffin Bay and Davis Strait in 2010. Images based on multichannel microwave radiometer data (Advanced Scanning Microwave Radiometer, ASMR, and Scanning Multichannel Microwave Radiometer, SMMR). Red and magenta indicate very dense ice (8/10 to 10/10), while yellow indicates somewhat looser ice. The loosest ice (1/10 to 3/10) is not recorded. (Data source: Danish Meteorological Institute.)

Today's trends of declining ice cover extent and duration are pronounced. These changes affect the occurrence of ice-dependent fauna and the ways of living for people who depend on ice cover for hunting and traveling (see details in Section 3.1.5 and Chapter 6).

2.1.3.2 Flora and fauna

The marine fauna is characterized by relatively few species, but these species are well adapted to the BBDS environment – e.g., mammals and seabirds (further detailed in Chapter 6). The benthic fauna is an exception, in that it is characterized by a very high number of species (e.g., more than 270 species have been identified in the Disko Bay area; Boertmann et al., 2013).

Many mobile species move out of the region when winter restricts food availability – e.g., many seabirds and a number of whales, such as minke whales (*Balaenoptera acutorostrata*) and fin whales (*Balaenoptera physalus*). However, some areas of the BBDS region – those that are more or less ice-free in winter, off southwest Greenland – are also very important winter habitats for seabirds from all over the northern Atlantic, indicative of the high production of these waters. Some marine mammals even winter in ice-covered waters – e.g., narwhals (*Monodon monoceros*) in the drift ice of Baffin Bay and ringed seals (*Pusa hispida*) in drift ice areas and in waters with shore-fast ice – where they can maintain breathing holes in the ice.

Low annual primary productivity is characteristic of most of the BBDS region (Figure 6.3). However, increased production is found on the banks off West Greenland and in the area of the North Water Polynya. The primary production in these areas sustains aggregations of zooplankton, especially the very important species of copepods of the genus *Calanus*. These multi-year copepods accumulate lipids for hibernation, and these lipids constitute an extremely important resource for organisms higher up in the food web. Fish, seabirds, and large baleen whales are dependent on these copepods, to a degree that the fatty acids from *Calanus* lipids can be traced to the top predators of the Arctic (e.g., Dahl et al., 2000). The open water in polynyas and shear zones attracts seabirds and marine mammals, which both forage and surface in these areas. At such sites, very high concentrations of these organisms are found. Further, these areas have been and still are important hunting grounds for the human populations of the region. For example, the coasts of the North Water were important areas for the immigrating Thule Inuit, before they spread further south and east in Greenland (Appelt and Gulløv, 1999; Grønnow and Sørensen, 2006).

Marine mammals

The BBDS region hosts a number of marine mammals year-round, with all species more or less associated with the sea ice. Bowhead whales (*Balaena mysticetus*) move between winter quarters in the Labrador Sea and summer quarters in the Canadian Archipelago, traveling in early spring along the marginal ice zone in Davis Strait and Baffin Bay and congregating in the Disko Bay waters of central West Greenland. Beluga whales (also known as white whales, *Delphinapterus leucas*) move from summer habitats in the Canadian Archipelago to winter habitats in the North Water Polynya and along the West Greenland coast. Narwhals from several discrete summer populations in Canada and Greenland congregate in the Baffin Bay drift ice in winter. Polar bears (*Ursus maritimus*) occur in relatively high numbers on the drift ice of Davis Strait, Baffin Bay, and in the High Arctic Canadian islands, as they follow the annual movements of sea ice. Hooded seals (*Cystophora cristata*) whelp on the ice in central Davis Strait in late winter and then disperse to the open waters of the entire region in summer; harp seals (*Phoca groenlandica*) are numerous in open water areas throughout the year. Two discrete populations of walrus (*Odobenus rosmarus*) move between habitats on the Canadian side and the Greenland side of the region. Additional resident species include ringed seal and bearded seal (*Erignathus barbatus*). The region is also a summer habitat for many migrating species of marine mammals, such as large baleen whales – minke whale, blue whale (*B. musculus*), fin whale, sei whale (*B. borealis*), and humpback whale (*Megaptera novaeangliae*) – and also sperm whales (*Physeter macrocephalus*) and pilot whales (*Globicephala melas*). All migrate into the BBDS region from southern latitudes. The harbor porpoise (*Phocoena phocoena*), a small toothed whale, inhabits the ice-free water year-round.

Most of these species are harvested by the people living in the BBDS region (further discussed in Subchapter 6.5). The different species have different significances to the hunters. Seals constitute the basis of the hunt, due to their high abundance and the fact that they provide both meat and skin (which today is almost unsalable on international markets). Beluga whale and narwhal provide meat and mattaq (edible skin), which has a high commercial value (at least in Greenland); these animals are important to hunters in a few small sites. Walrus also provide large quantities of meat, but only locally. In districts where sea ice allows for dog sledding, the meat from seals, walrus, and whales is also important as dog food. Both walrus and narwhal, moreover, provide ivory for carving and art making. Finally, the baleen whales provide large quantities of meat and blubber, which is marketed on a national scale (see Chapter 4).

Seabirds

Seabirds are very numerous in the BBDS region during the summer. The most important seabirds – in terms of numbers – are northern fulmar (*Fulmarus glacialis*), little auk (*Alle alle*), thick-billed murre (*Uria lomvia*), Arctic tern (*Sterna paradisaea*), and common eider (*Somateria mollissima*). Several species of gulls also occur. Less numerous seabird species of conservation concern include Ross's gull (*Rhodostethia rosea*), Atlantic puffin (*Fratercula arctica*), and ivory gull (*Pagophila eburnea*). The king eiders (*Somateria spectabilis*) move in numbers of hundreds of thousands from breeding areas on the Canadian tundra to molting and wintering habitats on the shelves and along the coasts of Greenland. The higher primary production on the West Greenland shelf areas is reflected in the immense number of seabird breeding colonies along the West Greenland coastline – much greater than on the Canadian side (Figure 2.7). Another factor contributing to this difference is the sea ice, which disintegrates much earlier in spring on the Greenland side than on the Canadian side. See also the sea current pattern (Figure 2.4).

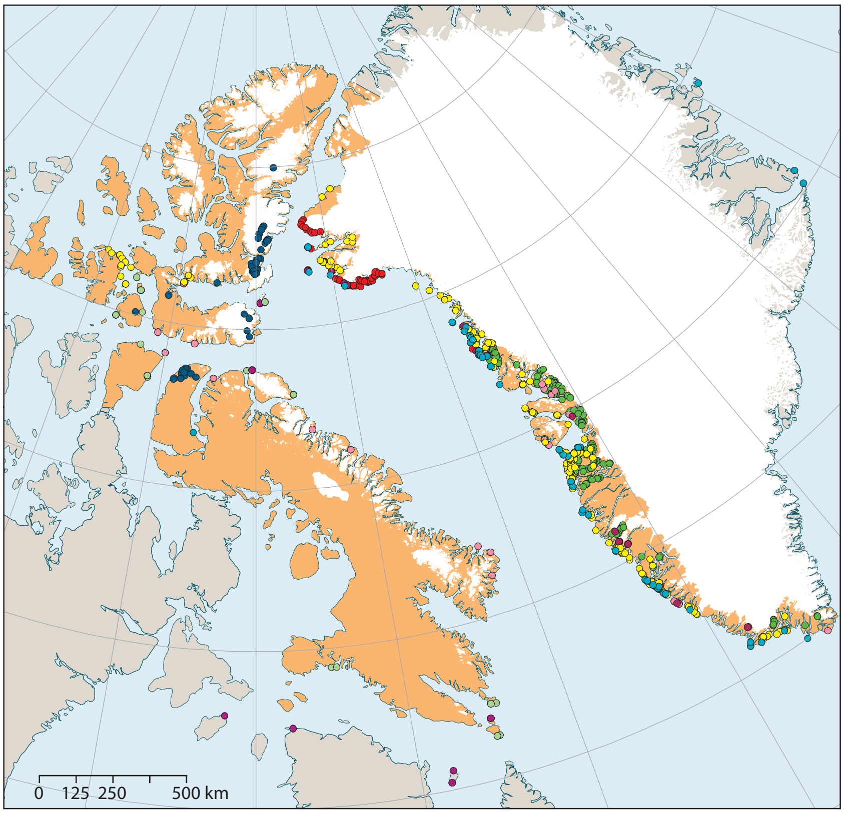

Figure 2.7 Distribution of breeding colonies of selected seabird species in the BBDS region. Note the high density of little auk (dovekie) colonies along the northwest Greenland coast adjacent to the area of the North Water Polynya (see Figure 2.5). (Data from the Greenland Seabird Colony Register and Seabirds.net: Circumpolar Seabird Data Portal.)

The North Water Polynya is extremely important to breeding seabirds. For example, more than 80% of the single most abundant seabird species in the North Atlantic, the little auk (*Alle alle*), breed along the Greenland coasts of the polynya (Nettleship and Evans, 1985; Egevang et al., 2003).

In winter, the open water area of southwest Greenland is a very important habitat for seabirds from breeding populations all over the North Atlantic. Most numerous are the thick-billed murres, common eiders, and king eiders (Merkel et al., 2002; Boertmann et al., 2004, 2006).

Seabirds, like marine mammals, are important resources for people living in the BBDS region. The use and management of these species are described in Chapter 6.

Fish and invertebrates

More than 200 species of marine fish are known from the BBDS region, and most of these live on or near the seabed (i.e., they are demersal) (Møller et al., 2010). The number of species decreases with latitude. The sill between Canada and Greenland, at approximately 69°N, forms a barrier for many deep-water species; the number of known species north of the sill is much lower than the number south of the sill. Important species, in an ecological context, are the schooling fish such as capelin (*Mallotus villosus*), sand eel (*Ammodytes dubius*), and polar cod (*Boreogadus saida*). These species are key species because they serve as essential food resources for higher levels of the food web, including seabirds, seals, and whales. The most important species for commercial fisheries in the BBDS region is the Greenland halibut (*Reinhardtius hippoglossoides*). Many other species are utilized on a subsistence basis. Atlantic cod (*Gadus morhua*) was a very important resource on the West Greenland shelf, until the stock collapsed in 1970 due to overharvesting and a slight drop in water temperature (Horsted, 2000). The environmental changes observed in the marine environment provide hope for the reestablishment of this stock, with West Greenland cod stocks now slowly recovering (Subchapter 6.4) – and new potential commercial species moving in. Atlantic mackerel (*Scomber scombrus*) is one such new arrival, and a fishery on this species was initiated in 2014 in waters off southeast Greenland.

As mentioned above, the seabed fauna (benthos) is very rich (i.e., diverse and with high densities of organisms) in the BBDS region – for example, on the shallow shelves and along the shelf breaks. A few species are utilized on a commercial basis – primarily northern shrimp (*Pandalus borealis*) and, locally, snow crab (*Chionoecetes opilio*) and scallops (*Chlamys islandica*). Blue mussels (*Mytilus edulis*) are utilized, at least in Greenland, on a subsistence basis.

The Arctic Biodiversity Assessment of the Conservation of Arctic Flora and Fauna (CAFF, 2013) has identified threats to Arctic biodiversity, including the BBDS region. One of their key findings (key finding 2) was that climate change is by far the most serious threat to Arctic biodiversity. In the BBDS region, the ice-associated organisms will be especially affected – for example, walrus, narwhal, bowhead whale, and harp seal. Overharvesting was an earlier problem (CAFF key finding 7) that has now been generally overcome. Some populations of marine mammals and seabirds in the BBDS region still suffer from unsustainable harvest practices, but sound management in recent decades may have reversed the earlier trends (Heide-Jørgensen et al., 2014; Witting and Born, 2014). This possible reversal applies, for example, to walrus and beluga whale (in Greenland, at least). Other threats to the biodiversity of the region are the long-range transport of contaminants (see Subchapter 3.2 and also CAFF key finding 5) and threats on the winter grounds of migratory species, such as many of the seabirds (CAFF key finding 3).

Several marine mammals of the BBDS region are included on the International Union for Conservation of Nature (IUCN) list of threatened species ("red list"). The polar bear is listed as Vulnerable; the beluga whale as Near Threatened; narwhal, Near Threatened; fin whale, Endangered; and blue whale, Endangered. Among birds, the ivory gull is classified as Near Threatened (IUCN, 2016).

2.1.3.3 Marine conservation areas

Over the past few decades, national and international organizations have been working toward protecting ocean resources as global pressures on those resources increase. The government of Canada is working with the provinces and territories to protect Canada's marine ecosystems through the development of a national network of marine protected areas (MPAs) (Grant and Archambault, 2018). Canada's network of MPAs will be composed of 13 bioregional networks (Figure 2.3) – 12 within Canada's oceans and 1 in the Great Lakes. Each network will be designed to suit its own unique geography, management tools, and ecological and socio-economic objectives. The BBDS region overlaps with two of the Canadian marine ecoregions: the Arctic Archipelago and the Eastern Arctic (DFO, 2009).

Ecologically or biologically significant areas (EBSAs)

Canada and Greenland recently applied the tools of the Convention on Biological Diversity to call attention to areas of particularly high ecological or biological significance – "ecologically or biologically significant areas" (EBSAs; Christensen et al., 2012; Dunn et al., 2014). In October 2012, the Convention on Biological Diversity proposed 7 scientific criteria for identifying EBSAs (see Figure 2.3) in need of protection in Canadian open-water and deep-sea habitats: (1) uniqueness or rarity, (2) special importance for life history stages of species, (3) importance for threatened, endangered, or declining species and/or habitats, (4) vulnerability, fragility, sensitivity, or slow recovery, (5) biological productivity, (6) biological diversity, and (7) naturalness. A total of 61 EBSAs have been identified in the Canadian Arctic; 17 of these are located on the Nunavut side of the BBDS region (Figure 2.3). Included in these 17 EBSAs are the Hatton Basin and the entrance to Hudson Strait, the South Baffin Bay narwhal overwintering area, Lancaster Sound, and the North Water Polynya.

The Hatton Basin and the entrance to Hudson Strait (Figure 2.4) are the major outflow sites for water moving from the Canadian Arctic shelf seas into the Labrador Sea (Grant and Archambault, 2018). The strong currents and associated high productivity in this area support large populations of invertebrates, fishes, marine mammals, and seabirds. This area is also heavily fished for shrimp and Greenland halibut. In addition, the Hatton Basin and the entrance to Hudson Strait are important areas for deep-sea corals and sponges (Edinger et al., 2007a; Kenchington et al., 2011). This area has the highest rate of coral bycatch in standardized survey trawls in the Canadian Arctic or Newfoundland and Labrador shelf regions (Edinger et al., 2007b). In 2007, an effort was put in place to protect the central part of the Hatton Basin from fishing impacts, with a 12,500 km^2 voluntary closure (MPA News, 2007).

The southern end of Baffin Bay (Figure 2.4) is the most southerly of two overwintering areas for narwhals. This location also coincides with deep-sea coral aggregations that include bamboo corals (*Keratoisis grayi*) and other coral species such as black corals (antipatharians) and sea pens (DFO, 2007; Wareham, 2009). This area has been fished with gillnets for Greenland halibut but now has protection under a Fisheries Act closure (DFO, 2007).

In Greenland, EBSAs have not been formally designated, but similar criteria have been used to identify ecologically valuable and sensitive marine areas (Christensen et al., 2012). Seven of these areas are located within the BBDS region (Figure 2.3; see also Box 9.1).

As noted above, the North Water Polynya and to some extent Lancaster Sound (Figure 2.5) are among the Arctic's most productive marine areas (Figure 6.3). Lancaster Sound is characterized by two polynyas that are kept open from ice by winds and currents. One is located along the northern coast of Lancaster Sound, and the other is at the eastern outflow of the sound (Barber and Massom, 2007). This area's high productivity supports high benthic abundance, biomass, and diversity, as well as the Arctic's highest density of sea mammals and seabirds.

National marine conservation areas (NMCAs)

In Canada, Parks Canada is responsible for developing a network of MPAs, called national marine conservation areas (NMCAs) (Figure 2.3). An NMCA is managed and used in an ecologically sustainable way, and each one includes zones that fully protect special features and sensitive ecosystem elements. On the Nunavut side, the BBDS region overlaps with three of the Parks Canada marine regions: the Arctic Archipelago, Lancaster Sound, and Baffin Island. Since 2009, Parks Canada, the Government of Nunavut, and the Qikiqtani Inuit Association have been working toward the creation of an NMCA in Lancaster Sound (*Tallurutiup Tariunga* in Inuktitut). In 2017, the final boundary for the national marine conservation area was announced. Fisheries and Oceans Canada (DFO) also establishes, under the Oceans Act, marine protected areas to protect and conserve important fish and marine mammal habitats, endangered marine species, unique features, and areas of high biological productivity or biodiversity. To date, no Oceans Act MPAs have been established in the BBDS region.

In Greenland, there are no areas comparable to the Canadian NMCAs.

In January 2016, the Inuit Circumpolar Council (ICC, 2016) established a special commission to consult Inuit to explore locally driven management options in advance of increased shipping, tourism, fishing, and nonrenewable resource exploration and development in the Pikialasorsuaq (North Water Polynya).

2.1.4 The terrestrial environment

2.1.4.1 Geology and topography

The Canadian margin of the BBDS is dominated by the Arctic Cordillera, a deeply dissected mountain chain extending south from Ellesmere Island to the Labrador Peninsula (Figure 2.1). Precambrian igneous and metamorphic rocks dominate the Canadian Shield areas of Baffin Island and western Greenland in the central BBDS region. The mountainous eastern edge of Baffin Island hosts the Barnes and Penny ice caps and numerous upland ice fields (Figure 2.4); farther west, the terrain slopes gently toward the coastal lowlands of Foxe Basin. The highlands of southeastern Baffin Island are dissected by Cumberland Sound and Frobisher Bay and are separated from northern Labrador and Quebec by Hudson Strait. To the north, Lancaster Sound separates Devon and Baffin islands, forming the eastern entrance to the Northwest Passage. All four of these marine basins hosted large outlet glaciers during past glaciations.

On western Greenland, the vast Inland Ice (Greenland Ice Sheet) masks much of the terrestrial physiography. The ice-free coastal perimeter is generally about 150 km wide but narrows north of 73°N, where the Inland Ice reaches the coast of Melville Bay (Figure 2.4). Glacial valleys and fjords dissect the rugged coastal uplands (many 500 m high or higher) and also extend offshore, largely following the geological structure. For example, south of Disko Bay, the valley systems follow the predominant east–west trend of the Archean terrane. North of Disko Bay, the topography of the West Greenland volcanic province has characteristically flat plateaus of Cretaceous and Tertiary volcanic and sedimentary rocks.

The Palaeozoic Franklinian Basin that extends from Ellesmere Island to northern Greenland dominates the geology of the northern BBDS region. This area hosts one of the highest mountain ranges in Canada, with elevations on northern Ellesmere Island exceeding 2,500 m. Extensive upland regions host large ice caps and ice fields (Figure 2.4). On the Greenland side, several outlet glaciers extend from the Inland Ice to the coast to form tidewater glaciers – for example, Humboldt Glacier, Petermann Glacier, and Ryder Glacier.

2.1.4.2 Snow and permafrost

Permafrost, one of the most significant features of the Arctic terrestrial environment, is being increasingly affected by rising ambient temperatures, which in turn causes changes in hydrology, snow drift patterns, and landscape stability (see details in Section 3.1.3 and Chapter 10). Land instability results in problems for the residential, municipal, and transportation infrastructure placed on the permafrost. Moreover, the infrastructure itself often becomes an additional driving factor that can greatly exacerbate the impact of climate change on permafrost stability. Chapter 10 describes in detail why BBDS infrastructure is currently being affected by both climate-induced changes and the cumulative effects of human/infrastructure-induced changes.

On the Nunavut side of the BBDS region, many permafrost infrastructure issues originate from infrastructure that was built on sediment deposits prior to climate warming in the region. In addition, permafrost stability was poorly understood at the time and construction projects were often implemented without sufficient knowledge of ground conditions (e.g., amount of ground ice). Consequently, the construction designs of many buildings and infrastructure in Nunavut are not appropriate for the underlying permafrost conditions. In Greenland, in contrast, infrastructure has been placed on solid rock or in thaw-stable areas. Therefore, the permafrost problems encountered thus far are less critical than in Nunavut and other areas of the circumpolar Arctic. For more details, see Chapter 10 and also the report of the Snow, Water, Ice and Permafrost in the Arctic (SWIPA) project (AMAP, 2011).

One of the most crucial abiotic factors for terrestrial biodiversity in the region is snow cover and its duration, stability, and thickness. A late snowmelt, for example, prevents ground-nesting birds (e.g., shorebirds) from establishing nests. For lemming winter survival, a stable and thick snow layer is required. Midwinter thaws may create ice crust on the snow, thus preventing muskoxen (*Ovibos moschatus*) and caribou (*Rangifer tarandus*) from finding food (see Section 3.1.3 for more information about snow trends and variability).

2.1.4.3 Vegetation

The plant communities in the region are dominated by dwarf shrub heath and grassland on dry lands and by widespread marshes with grasses and sedges in moist areas and wet areas. Especially in inland areas, conditions can be so dry that the grasslands become steppe-like. In more protected areas, low shrubs of willow and *Alnus* can be found, and at homeothermic springs and on sloping hillsides with stable water supply (e.g., from snow drifts), herb slopes can develop with a relatively high species richness. At higher elevations and in exposed sites where the soil is dynamic due to solifluction, vegetation (herbaceous plants and dwarf shrubs) becomes scarce and the soil is covered by a dark layer of lichens and mosses – a very widespread habitat described as "fell field."

The large herbivores of the BBDS region ‑ caribou and muskoxen ‑ utilize the grasslands and dwarf shrubs to a wide degree, and geese are also dependent on areas with dense vegetation for feeding. The human use of the vegetation is limited to the gathering of berries in the heath lands and, in Greenland, to the sampling of *Angelica* on lush herb slopes. Berry picking represents an important activity and a source of healthy food in the region (Chapter 4).

2.1.4.4 Fauna

The terrestrial fauna is – compared to the marine fauna – poor in species, especially on the Greenland side of the region, where there are only three species of mammals: Arctic fox (*Alopex lagopus*), hare (*Lepus arcticus*), and caribou, supplemented by the introduced muskoxen. Only in the northernmost part – to the east of the Humboldt Glacier – are more species found: wolf (*Canis lupus*), stoat (*Mustela erminea),* naturally occurring muskoxen, and collared lemming (*Dicrostonyx torquatus*). There are four distinct herds of caribou on the Greenland side of the region, and in some areas they are very numerous. Caribou is a popular game animal for the local people in Greenland; in addition, small herds of domestic reindeer occur in Greenland (Subchapter 6.6).

On the Nunavut side of the BBDS region, the number of mammal species is higher, with wolverine (*Gulo gulo*), an additional species of lemming, and seven distinct caribou herds. These herds are heavily utilized – so much so that a moratorium on harvesting caribou on Baffin Island was established in 2015.

In Greenland, bird species associated with terrestrial habitats (including freshwater ones) are few. Examples of widespread birds include ptarmigan (*Lagopus mutus*), common raven (*Corvus corax*), and a number of species of geese, ducks, and songbirds. The gyrfalcon (*Falco rusticolus*) – a top predator exclusive to the Arctic – is a scarce breeder across the BBDS region. The shorebirds/waders are astonishingly few in West Greenland, both in terms of number of species (n=3) and population densities. In contrast, the Canadian side of the region has many more species (n=15) and higher densities of shorebirds/waders. The relative lack of terrestrial-associated bird species in Greenland is a general feature and could be the result of delayed immigration since the most recent glaciation (Boertmann, 1994). At least two bird species have established new and viable populations in Greenland during the past three decades – the Canada goose (*Branta canadensis*) from the North American continent and the lesser black-backed gull (*Larus fuscus*) from Europe – indicating continued immigration (Boertmann, 2008; Fox et al., 2012).

2.1.4.5 Protected areas, national wildlife areas, and migratory bird sanctuaries

Within the Nunavut portion of the BBDS region, there are nine protected areas, with each site protecting both marine and terrestrial environments (Figure 2.3). Five are National Wildlife Areas (NWAs) and four are Migratory Bird Sanctuaries (MBSs). Environment and Climate Change Canada, directly and/or through partnerships, establishes and manages these protected areas.

In Greenland, a number of areas and sites are protected (Figure 2.3) according to the national Nature Protection Act and executive orders. The Melville Bay nature reserve is designated primarily to protect denning polar bears, but it is also an important summer habitat for narwhals. A number of smaller protected sites are found in the Greenland part of the BBDS region (not shown in Figure 2.3). The very productive glacier at Ilulissat and its surroundings were designated as a United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage Site in 2004. Six areas are designated as Ramsar Sites (designated according to the international Convention on Wetlands, signed in Ramsar, Iran, in 1971). In addition, 13 important bird cliffs are protected from disturbing activities during the breeding season.

National parks

On the Canadian side of the BBDS region, there are currently four national parks: Quttinirpaaq National Park (Ellesmere Island), Auyuittuq National Park (Baffin Island), Qausuittuq National Park (Bathurst Island), and Sirmilik National Park (Bylot Island, Oliver Sound, and the Borden Peninsula) (Figure 2.3). Quttinirpaaq National Park, on the northeastern corner of Ellesmere Island, is the second largest park in Canada. It was established in 1989 as Ellesmere Island National Park Reserve, and in 2000, the reserve became a national park. Quttinirpaaq is dominated by hundreds of glaciers and includes the highest mountain (2616 m) in Eastern North America. Auyuittuq National Park, on Baffin Island's Cumberland Peninsula, features many terrains of Arctic wilderness, such as fiords, glaciers, and ice fields. Auyuittuq was established as a national park reserve in 1976, then upgraded to a national park in 2000. Qausuittuq National Park, located on northwest Bathurst Island was established in 2015. This national park represents a high Arctic environment that is home to the endangered Peary caribou and has been an important traditional hunting and fishing area for Inuit of Resolute Bay since the time of their relocation in the 1950's. Sirmilik National Park comprises three areas: most of Bylot Island, Oliver Sound, and Baffin Island's Borden Peninsula. This national park was established in 1999 and is amidst a landscape of glaciers, valleys, and nesting areas for many birds. There are no national parks on the Greenland side of the BBDS region.

2.2 The human dimension

2.2.1 Communities and demographics of the BBDS region

The Nunavut side of the BBDS region overlaps the Qikiqtaaluk (formerly Baffin) administrative region of easternmost Nunavut, situated within the Eastern Canadian Arctic. Qikiqtaaluk Region, covering nearly a million square kilometers, is Nunavut's largest. The territory's other two regions are Kivalliq (formerly Keewatin) and Kitikmeot. The communities within the BBDS portion of the Qikiqtaaluk region are Resolute on Cornwallis Island; Grise Fiord on Ellesmere Island; and Arctic Bay, Pond Inlet, Clyde River, Qikiqtarjuaq, Pangnirtung, Iqaluit, Kimmirut, and Cape Dorset on Baffin Island (Figures 2.1 and 2.8).

The Nunavut Land Claim Agreement (NLCA) was signed by the Prime Minister of Canada on May 25, 1993, making Nunavut the largest Aboriginal land claim settlement in Canadian history (350,000 km^2). In 1999, Nunavut was officially made a territory. The objectives of the NLCA are to (1) provide for certainty and clarity of rights to ownership and use of lands and resources, and of rights for Inuit to participate in decision-making concerning the use, management, and conservation of

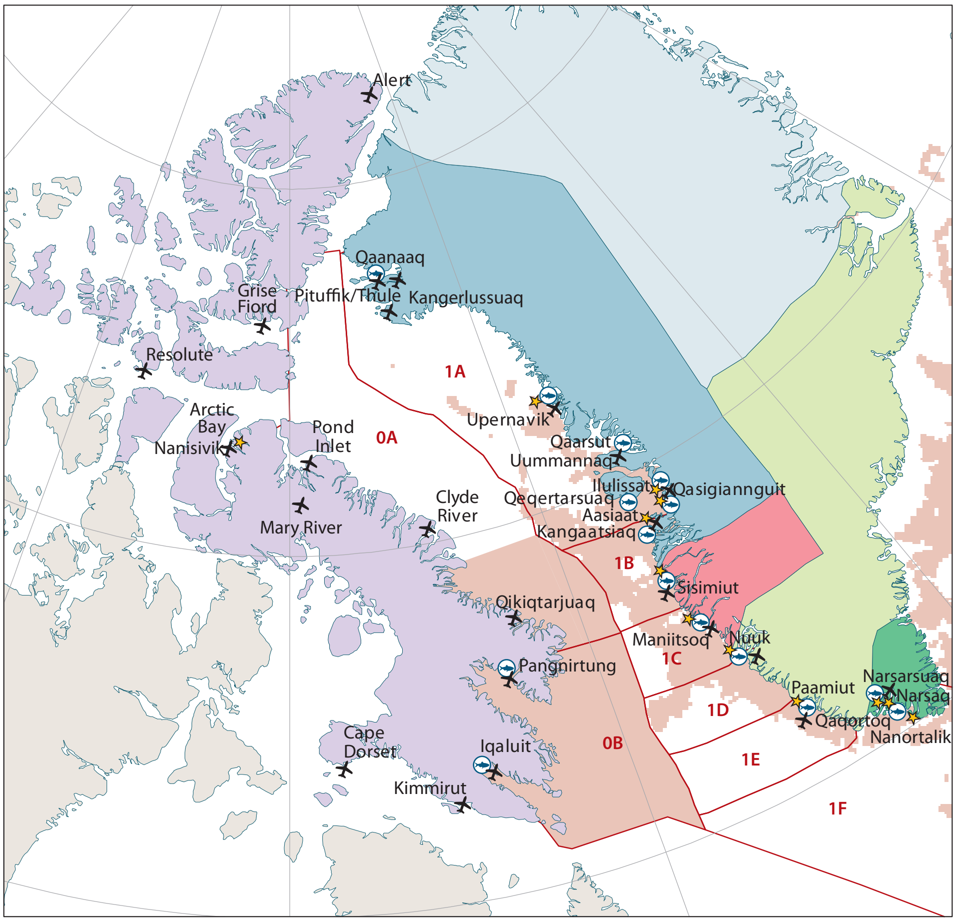

Figure 2.8 Towns and major villages, administrative units (municipalities in Greenland), NAFO fishing areas, major fish plants, and transportation facilities in the BBDS region. (NAFO data were extracted from www.nafo.int/Data. Transportation facilities data were obtained from Tables 10.2 and 10.3.)

land, water, and resources, including the offshore; (2) provide Inuit with wildlife-harvesting rights and rights to participate in decision-making concerning wildlife harvesting; (3) provide Inuit with financial compensation and means of participating in economic opportunities; and (4) encourage self-reliance and the cultural and social well-being of Inuit.

The Qikiqtaaluk region is the most populated region of Nunavut, with 18,988 people living there, according the most recent (2016) population estimate (Nunavut Bureau of Statistics, 2017). Iqaluit, the capital of Nunavut, has the largest local population, with 7,740 individuals. Grise Fiord and Resolute have the smallest populations, with 129 and 198 individuals, respectively. Figure 2.9 illustrates the population distribution by sex and age groups in the Qikiqtaaluk region. The percentage of individuals under the age of fifteen years in the Qikiqtaaluk region (31%) is similar to the rest of Nunavut (33%) but higher than the rest of Canada (17%).

The Greenland side of the BBDS region overlaps the regions of Kitaa (West Greenland) and Avanaarsua (North Greenland). The land, a narrow fringe (maximum 200 km wide) between the Inland Ice and the sea, covers 141,000 km^2. Kitaa covers the main part and is the most populated part of Greenland (14 towns and 50 settlements/villages). In Avanaarsua, there is only 1 town (Qaanaaq) and 3 small settlements. As of January 2015, the Greenland part of the BBDS region had 52,515 inhabitants; the distribution by sex and age groups is shown in Figure 2.10. Comparison of Figures 2.9 and 2.10 illustrates the different demographic structures in Nunavut and Greenland. The largest towns in Greenland are Nuuk (with approximately 17,000 residents), Sisimiut (5,500), and Ilulissat (4,500). West and North Greenland are now, after the fusion of 16 municipalities in 2009, divided into four large municipalities (Figure 2.8).

Over the period 2005–2015, West Greenland experienced a net population decrease of 856 individuals. This number includes a net increase of 998 inhabitants in the towns of West Greenland and a net decrease of 1857 in the villages and other localities. Population forecasts are not available in a form that allows for the extraction of information for the BBDS region alone, but the Statistics Greenland forecasts for all of Greenland predict a population decrease of 4,000 persons and a doubling of the older part of the population (persons over age 70) by 2040 (Statistics Greenland, 2015). The population model also predicts interregional redistribution of the population, with smaller communities and towns depopulating while the capital (Nuuk) alone experiences a significant increase in population. In contrast to these Greenland trends, the population of Nunavut's Qikuqtaaluk Region showed a consistently increasing trend over the period 2006–2014. The Nunavut Bureau of Statistics population projections show that this positive growth is expected to remain constant until the year 2035.

Greenland has been part of the Danish/Norwegian realm since the Norse period (980–1400) and is today an autonomous part of the Kingdom of Denmark with its own Self-Government, instituted in 2009 (but with a Home Rule Government since 1979). A number of jurisdictions are still maintained from Denmark – for instance, foreign affairs, justice, the monetary system, civil rights, and national security/defense. The political

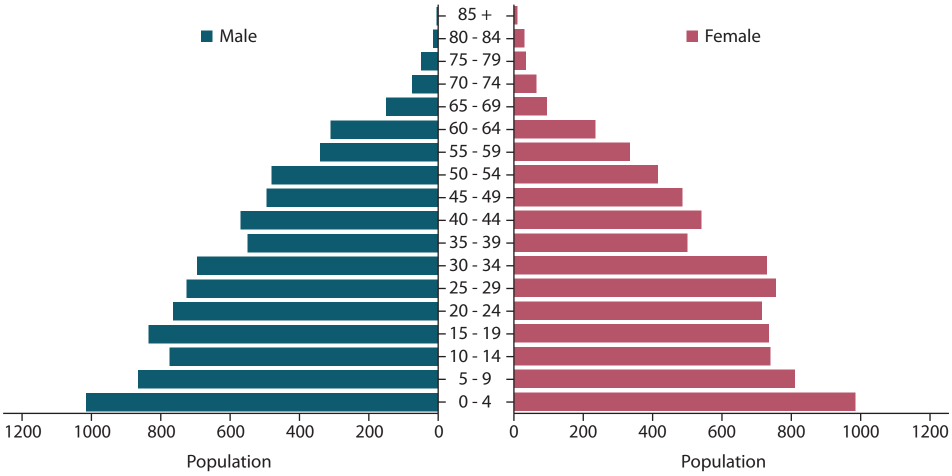

Figure 2.9 Number of individuals in the Qikiqtaaluk region in 2011, classified by sex and age groups. (Data from Statistics Canada.)

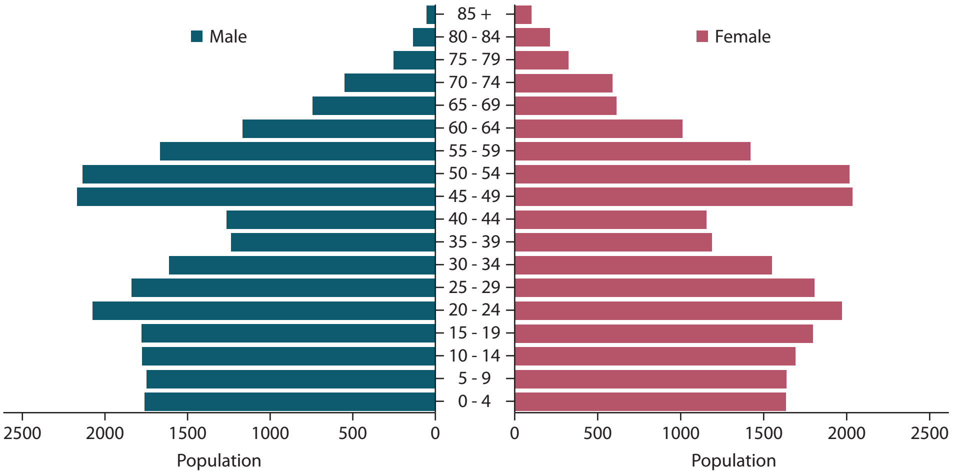

Figure 2.10 Number of individuals on the Greenland side of the BBDS region in 2015, classified by sex and age groups. (Data from Statistics Greenland.)

system is a parliamentary democracy within a constitutional monarchy, with the Inatsisartut (elected parliament) and the Naalakkersuissut (government) located in the capital, Nuuk.

2.2.2 Language

Aside from English, which is common throughout the Qikiqtaaluk region, Inuktitut is spoken on the Nunavut side of the BBDS region. Within Qikiqtaaluk Region, there are three recognized Inuktituk dialects: North Baffin (Qikiqtaaluk uannangani), Central Baffin (Qikiqtaaluup kanannanga), and South Baffin (Qikiqtaaluup nigiani). The Qikiqtaaluk uannangani dialect is spoken in Resolute, Grise Fiord, Pond Inlet, and Arctic Bay. Qikiqtaaluup kanannanga is spoken in Clyde River, Qikiqtarjuaq, and Pangnirtung. Qikiqtaaluup nigiani is spoken in Iqaluit, Kimmirut, and Cape Dorset. Despite the various dialects, fluent Inuktitut speakers within the region would normally understand one another with only minor difficulties.

The official language in Greenland is Kalaallisut (West Greenlandic). However, Danish may still be used in official matters and is spoken in many of the larger towns; the main newspapers are bilingual. In the northern part of Greenland (Avanaarsua), the Inuktun (North Greenlandic) dialect is spoken by the Inughuit (Polar Inuit). In Greenland, English is taught only as a third language (see Chapter 5).

For additional information see Section 3.3.4.

2.2.3 Economic sectors and employment

The mixed economy of the BBDS region consists of a wage economy, government transfer payments, and subsistence harvesting. On the Canadian side, in the Qikiqtaaluk region, government and private sector jobs (e.g., tourism, mineral exploration) comprise the wage economy. As of 2011, the employment and unemployment rates in the Qikiqtaaluk region were 55% and 9%, respectively. These rates were similar to Nunavut's (52% and 11%, respectively) but differed from the national rates (61% and 5%, respectively) (Statistics Canada, 2011). Traditional activities such as hunting, trapping, fishing, and gathering, as well as arts and crafts, are important for providing households with food, income, and a connection with the environment (Stern and Gaden, 2015).

The Greenland economy is based primarily on fisheries, supplemented with tourism (anually together, approximately 3 billion Danish kroner, DKK, or about 560 million Canadian dollars, CAD (2015)) and an annual block grant from Denmark (DKK 3.5 billion). Commercial fisheries produce over half of the total service and goods export value in Greenland (57% of DKK 4.2 billion in 2011; Copenhagen Economics, 2013), and fisheries is the main occupation for most people along the coast (see Subchapter 6.4). In southernmost West Greenland, there is also sheep farming, caribou husbandry, and agriculture (Subchapter 6.6). Finally, many people in Greenland are engaged in manufacturing arts and crafts, but such activity is considered as leisure activity and is not recorded in employment statistics. Overall, the unemployment rate in the Greenland part of the BBDS region in 2013 was 10%.

For additional information, see Section 3.3.3.

2.2.4 Resource utilization: living resources

2.2.4.1 Hunting

Activities such as hunting and trapping on the Canadian side of the BBDS region are important for providing households with food and are essential parts of the culture and well-being of people (further discussed in Chapters 4, 5, and 6). Three species of seal (ringed, harp, and bearded) are hunted without regulation. For walrus, no total allowable harvest (TAH) has been established. However, the species is generally managed under an individual quota of 4 walrus per Inuk per year unless a community quota has been put in place. Polar bears are also harvested and are regulated by quotas, which in 2011–12 were set at 249 total for the Qikiqtaaluk region.

For bowhead whales, the annual TAH in Nunavut is 5, of which the Qikiqtaaluk region has a TAH of 2. The Canadian hunt for beluga and narwhal is regulated by the Fisheries Act and are co-managed by Fisheries and Oceans Canada, the Nunavut Wildlife Management Board, regional wildlife organizations, and hunter and trappers organizations. A TAH for beluga whale stocks in Nunavut has not been established; however, the only beluga population hunted in Nunavut is the Cumberland Sound population, for which there is a quota of 41 belugas per year. For narwhals, the TAH, which was established in 2012, is 1,320. The catch of some other cetaceans (e.g., minke, harbor porpoise, pilot whales) is unregulated.

Hunting is also an important part of the traditional way of living in West Greenland (Subchapter 6.5). While still very important in many settlements, hunting is now becoming more of a recreational activity, especially in the larger towns. Hunters need a license and are required to report their catch; the data are subsequently used for assessing impacts on the affected populations and for updating quotas in the future (Piniarneq, 2014; Ford et al., 2016). The products are mainly used for private consumption and for sale at local markets. Only a few products are marketed commercially. Mattaq from narwhals and beluga whales is distributed nationally, and seal skins are marketed internationally, although demand for this product is low. In addition to these hunting activities, trophy hunting is also taking place on muskoxen and caribou (Chapter 6).

Four species of seal (ringed, harp, hooded, and bearded) are hunted without regulation in Greenland. Approximately 125,000 total were reported in the Greenland catch statistics for 2012 (Piniarneq, 2014). Walrus and polar bears are also taken, and the catch of these species is regulated by quotas. In 2015, the walrus and polar bear quotas were set at 152 and 80, respectively, on the Greenland side of the BBDS region.

The Greenland catch of large whales – fin, minke, humpback, and bowhead whales – are also regulated by quotas, which in 2016 were set at 19, 164, 10, and 2, respectively. The 2016 Greenland quotas for narwhals and belugas were 424 and 340, respectively. The catch of smaller whales (e.g., harbor porpoise, pilot whales) is unregulated.

Seabirds are also hunted to a wide degree in Greenland, with the most popular species being thick-billed murre and common eider. The catch is regulated by open seasons and, for a number of species, daily quotas. In total, 66,000 thick-billed murres and 31,000 common eiders were reported to the catch statistics in 2012 (Piniarneq, 2014; Statistics Greenland, 2015).

Hunting in terrestrial habitats in Greenland is limited to caribou, introduced muskox, hare, fox, and ptarmigan. In 2012, the following numbers were reported to the catch statistics for the Greenland side of the BBDS region: 11,500 caribou, 2,000 muskoxen, and 14,000 ptarmigans.

In Greenland, the quotas on hunted species are set annually, and hunters' organizations often consider them to be too low.

An obvious characteristic of the populations of marine mammals and seabirds is that they are shared between Greenland and Nunavut – and some also with Norway and Iceland, as well as areas south of the BBDS region. These populations are international and therefore cannot be managed on a local or national level. This characteristic poses a challenge to the ambitions of co-management – the sharing of responsibility and power among governmental institutions and local resource users (Subchapter 6.5 and Chapter 12).

2.2.4.2 Fisheries

Fisheries play a significant role in the economy of the BBDS region (see details in Subchapter 6.4). As noted above, commercial fisheries produce over half of the total service and goods export value in Greenland. The shrimp fishery constitutes over 50% of the total fishery in terms of volume and value. Off the Canadian territory of Nunavut, commercial fisheries are rapidly expanding, increasing in value from CAD 38 million to CAD 86 million between 2006 and 2014. In 2012, Greenland halibut was the third most important export good for Nunavut (Lambert-Racine, 2013). Within the BBDS region, very little fishing takes place north of 72°N. The fishing fleets of the BBDS region also engage in economically and biologically significant offshore fisheries outside the region (e.g., for Greenland halibut, redfish, and pelagic species).

The offshore fisheries of the BBDS region are currently dominated by bottom trawling for Greenland halibut and northern shrimp. On the Nunavut side, the Greenland halibut fishery resides mainly within the Northwest Atlantic Fisheries Organization (NAFO) Subarea 0 (Figure 2.8) (DFO, 2006). The fishery originated in Division 0B in 1981, and since 1996 there has also been an exploratory fishery in Division 0A (Figure 2.8 – see further details in Subchapter 6.4). None of the offshore shrimp is caught by Nunavut vessels, and none is processed in Nunavut. There is potential for the development of a commercial fishery for clams, scallops, and crabs in Nunavut in the future (Brubacher Development Strategies Inc., 2004).

The Greenland fishery for northern shrimp was initiated in 1935 with a local fishery in a fjord near Sisimiut. The modern fishery, however, started after WWII, first with inshore fisheries in Disko Bay and, since 1969, also offshore fisheries on the major fishing banks in the NAFO 1B and 1C areas (Figure 2.8). In recent decades, shrimp have been taken in the region between 60°N and 74°N (NAFO 1A–F), and the fishing grounds are now showing a tendency to move northward. The offshore catches are taken by large Greenland trawlers that process the catch on board, while the inshore catches are taken by smaller vessels that offload their catch to processing plants in the towns. Greenland halibut, the other species important to the Greenland fishery, has both inshore and offshore components. The inshore fishery takes place by longlines in deep fjords and in Subarea 1A, while the offshore fishery is mainly a trawl fishery carried out in two areas in NAFO Subareas 1C/D and 1A/B (Figure 2.8). Previously, West Greenland cod supported the most important fishery, but since the collapse of the stock in the 1980s, catches have been negligible in all but a few years. Both snow crabs (*Chionoecetes opilio*) and scallops (*Chlamys islandica*) have at times been taken on a commercial basis in Greenland.

Greenland's coastal fisheries are composed of a mosaic of harvesting activities. In the inshore region, Greenland halibut, shrimp, and cod are the most important target species of commercial interest, but the fishery for lumpfish (*Cyclopterus lumpus*) is also important during a brief period of the spring (the roe is marketed). The harvesting cycle of coastal fishers may also include Atlantic halibut (*Hippoglossus hippoglossus*), wolffish (*Anarhichas minor*), Arctic char (*Salvelinus alpinus*), and Atlantic salmon (*Salmo salar*), fished primarily for subsistence use and local or national marketing.

On the Nunavut side of the BBDS region, inshore fisheries are largely limited to Arctic char and Greenland halibut in Cumberland Sound. Nunavut's largest fish processing plant is in Pangnirtung (Pangnirtung Fisheries Ltd.), with a smaller operation in Iqaluit (Iqaluit Enterprises Ltd.) (Figure 2.8) (Government of Nunavut, 2007a). Both fisheries normally operate between April and December. Iqaluit Enterprises concentrates on char, while Pangnirtung Fisheries concentrates heavily on turbot (the Nunavut name for Greenland halibut), with more limited production of char (or in some years, none). Most towns and many villages in Greenland have fish plants (Figure 2.8), where catches are processed – mainly Greenland halibut and northern shrimp but also Atlantic cod caught by Greenland trawlers outside Greenland.

The marked difference between the two sides of the BBDS region regarding the importance and development of local fisheries is due to the West Greenland Current, which brings relatively warm water from the Atlantic Ocean to Greenland's west coast (Figure 2.4). This input provides for open (ice-free) waters and a supply of nutrients. The seabed topography of the offshore areas is well suited for trawling, and the shelf breaks create upwelling events that supply the shallow areas with nutrient-rich water.

The recent years of environmental change have brought new species of fish to Greenland waters, and in the future, some of these may become commercially attractive. As mentioned above, a fishery for mackerel has been in development and it may expand into the BBDS region. On the other hand, the fishery for northern shrimp seems to be moving northward now, leaving its southernmost grounds off southwest Greenland (details in Subchapter 6.4).

2.2.4.3 Farming

Agriculture was introduced to the BBDS region by the Norse (900–1400), but only to the southwest region of Greenland. This way of living was taken up again in the subarctic region of Greenland in the late 1800s. Today, the primary agricultural practice is sheep farming. Reindeer herding has been tried a couple of times in the past in southwest Greenland; today, two sites are active (see Subchapter 6.6 for details). No farming takes place on the Nunavut side of the BBDS region.

2.2.5 Resource utilization: non-living resources

2.2.5.1 Minerals

The economic and socio-cultural history of the BBDS region has been linked to nonrenewable resources – notably lead, zinc, nickel, copper, iron, rubies, oil and gas, and diamonds. Greenland is rich in minerals, and its modern mining history dates back to the mid-nineteenth century. However, only two mines have until now had a significant impact on Greenland's economy: a cryolite mine in South Greenland (active for 133 years, 1854–1987) and a lead–zinc mine in Uummannaq (active 1973–1990). Mineral exploration is currently taking place at many sites in the BBDS region, and exploration expenditures have been generally increasing in Greenland (at least through 2012, the most recent year for which data are available; see Figure 7.2). Although exploration activity has been high in many years and exploitation licenses have been granted, only two small projects were expected to go into production in Greenland in 2016 (see Chapter 7).

The Greenland oil and mineral strategy (Government of Greenland, 2014a) states, based on the global mineral demand, that iron ore, copper and zinc, rare earth elements, uranium, gold, and gemstones are the minerals with potential to be extracted in Greenland.

On the Canadian side of the BBDS region, mineral development dates back to the late 1950s, but by the early 2000s there were no active mines (Carter et al., 2018). Large-scale mining developments in the Qikiqtaaluk region have existed, such as the lead–zinc mines in Nanisivik on North Baffin Island (opened in 1976, Canada's first High Arctic mine) and the Polaris zinc mine on Little Cornwallis Island (opened in 1982). These mines were operational until 2002 (Carter et al., 2018). One major mine, the Mary River iron mine on North Baffin Island (Figure 2.11), started production in 2014 and is currently still in operation (Baffinland Iron Mines Co., 2015; Carter et al., 2018). Mining continues to be seen as one of the most important sectors for growth in Nunavut, and in 2014 it represented 18% of the territory's gross domestic product (GDP). Construction, some of it

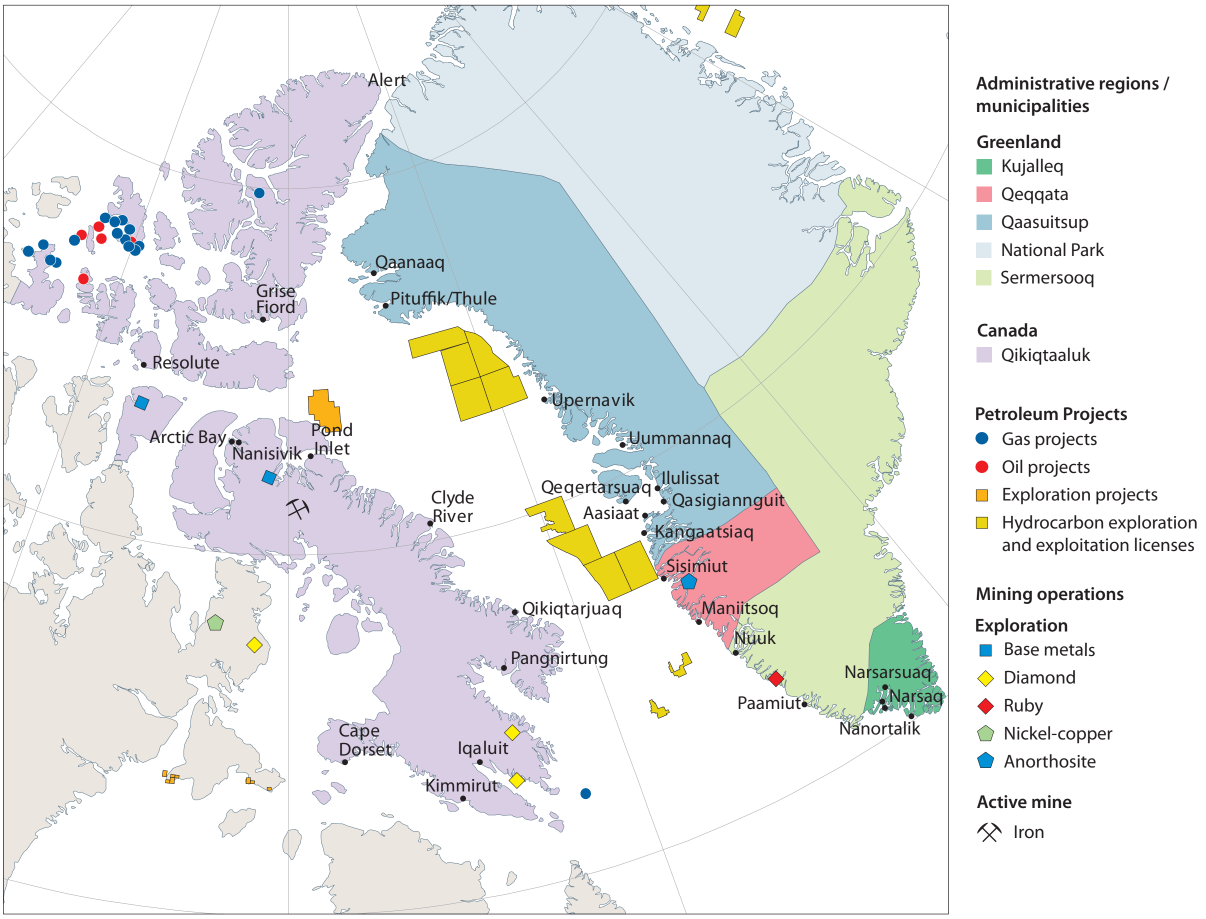

Figure 2.11 Mining operations and hydrocarbon exploration and utilization activities in the BBDS region, as of 2014. The Mary River mine became operational in 2015. (Data for Canada were obtained from www.aadnc-aandc.gc.ca/eng/1100100036298/1100100036301, cngo.ca/app/uploads/Exploration_Overview-2014-Map-English.pdf, and Baffinland Iron Mines Corporation, 2017; data for Greenland were obtained from www.govmin.gl/petroleum/current.)

related to mining, represented an additional 16% of GDP. Exploration expenditures have increased substantially over the past 15 years (see Figure 7.3 and more detailed descriptions in Chapter 7).

2.2.5.2 Oil and gas

The marine part of the BBDS region is among those Arctic areas with a very high potential for undiscovered oil reserves (Gautier et al., 2009). Exploration has taken place on the Greenland shelf since 1969 (Christiansen, 2011). Five exploration wells were drilled in 1976/77, and activities later increased when the Greenland government issued an exploration strategy in 1989. These activities, which included primarily the collection of geophysical data (seismic exploration), peaked in 2010/11 when 8 exploration wells were drilled in Davis Strait and Baffin Bay. These drillings increased the number of exploration wells in West Greenland to a total of 15, including one onshore well. However, activity has since ceased, with the decline of oil prices. The number of exploration and exploitation licenses in the Greenland part of the BBDS region (Figure 2.11) decreased from 18 in 2013 to 11 in early 2016. New license rounds are planned to take place in 2016, 2017, and 2018, including both offshore and onshore areas. The exploratory activities in Greenland have so far not caused any significant environmental impacts.

Nunavut has 5% and 15% of Canada's known reserves of oil and natural gas, respectively (Government of Nunavut, 2007a). Starting in the late 1960s, significant exploration was undertaken in Nunavut's Sverdrup Basin (MacIsaac, 2015), which sprawls beneath the northern Canadian Arctic islands, and while there has been little activity over the past 20 years, this region is still considered to be a potential future production site. Drilling in Lancaster Sound was approved in 1974; however, no well was drilled and a moratorium was put in place following an environmental review in 1978. Oil and gas companies remain interested in this area, but a national marine conservation area is currently proposed there. The Bent Horn site on Cameron Island produced a high-quality oil from 1985 to 1996 – most of which was used to supply energy to the Polaris mine. Increasing global gas prices are increasing the likelihood that development of Nunavut's reserves will become feasible. These reserves are estimated to contain ultimate initial marketable gas at 16.7 trillion cubic feet (Tcf) and ultimate recoverable oil at 0.8 billion barrels (Barnes, 2015). The oil and gas industry has expressed an ongoing interest in the Nunavut side of the BBDS region. To date, however, exploration for oil and gas in the Qikiqtaaluk region has been limited to seismic testing and geologic fieldwork along the margins of the Sverdrup Basin (Figure 2.11). As well, there is one Husky Energy gas project south of Baffin Island and one major Royal Dutch Shell exploration project north of Bylot Island.

As is the case throughout the Arctic region, there is a great deal of BBDS concern about offshore oil and gas developments and their potential environmental impacts. Compared to onshore developments, offshore developments are seen as being potentially more damaging to the subsistence activities of local Indigenous communities. In addition, communities feel they have not been properly consulted nor told how they will benefit from oil and gas developments (Varga, 2014).

For additional information, see Chapter 7.

2.2.6 Infrastructure

The transportation infrastructure in the BBDS region presents many similarities between Greenland and Nunavut, although the infrastructure is generally much more developed in Greenland. Sea and air are the dominant modes of transportation, as no villages or towns are connected by roads. Sea ice, moreover, prevents sailing in large parts of the BBDS region in winter and spring; only the southwestern coast of Greenland is navigable throughout the year (Figure 2.6). However, sea ice also provides a means of transportation, at least when stable and solid. Dog sledding is the traditional way of traveling in the winter, and driving vehicles is also practiced here and there. Consequently, many socio-economic activities rely greatly on airports, especially during the sea-ice season. Food is available year-round and comes in by ship (for most of Greenland) or air. Fuel for heating and transportation, as well as construction materials for housing and basic infrastructure, are always shipped in during the ice-free window of summer. Chapter 10 describes the infrastructure in detail, and Chapter 9 focuses on shipping, including expected changes in the BBDS region.

2.2.7 Contaminants

Studies conducted in the early 1970s indicated that pollutants originating from remote sources were being measured at relatively high levels in Canadian Arctic and Greenland biota. However, it wasn't until the 1990s that extensive long-range contaminant data for the whole Arctic region, including the BBDS region, became available, largely due to national programs (see Subchapter 3.2) and promotion by the Arctic Monitoring and Assessment Programme (AMAP). Although long-range atmospheric and aquatic transport are the primary pathways by which persistent organic pollutants (POPs) reach the BBDS region (Macdonald et al., 2000), local sources within the region (e.g., mining sites, military sites) also exist and can contaminate local food webs. For example, studies in the 1960s in West Greenland revealed local heavy metal contamination from a large zinc–lead mine at Uummannaq, as well as two older mines (Johansen and Asmund, 1999). Local sources of contamination in the Baffin region have included Distant Early Warning line (DEW-line) stations, mines, and other industrial sites that are often close to communities. For example, extensive terrestrial polychlorinated biphenyl (PCB) contamination from a former military station was discovered in the early 1990s at Resolution Island, just off the southeastern tip of Baffin Island. This particular site contained at least 20 buildings that required demolition, along with large amounts of debris, fuel tanks, and barrels, and an estimated 5000 m^3 of contaminated soil with PCB levels above Canadian Environmental Protection Act regulations (ESG, 1994).

Mercury and organohalogen compounds (OHCs), including PCBs, polybrominated diphenyl ethers (PBDEs), and pesticides (e.g., dichlorodiphenyltrichloroethane (DDT), chlordanes (CHLs), hexachlorocyclohexane (HCH)) can biomagnify to high levels in top Arctic predators (Muir et al., 2000; Braune et al., 2015). Many of these top predators (e.g., ringed seals, beluga whales) are a staple in the diet of many Inuit, so exposure to these contaminants is a severe health concern. Since the early 1990s, temporal trends of OHC concentrations in upper–trophic level marine mammals in the BBDS region have generally decreased for most compounds. These declines are a consequence of past national and regional bans and restrictions on uses and emissions in circumpolar and neighboring countries, which began in the 1970s for chlorinated pesticides and PCBs (Muir and de Wit, 2010). In contrast, global emissions of mercury continue to rise, which will likely result in increased mercury concentrations in wildlife.

The largest circumpolar data set for OHCs and mercury in biota is for ringed seals. Thus, this species has provided the best spatial resolution for contaminant trends in top predators across the circumpolar Arctic. Spatial trends for PCB and DDT concentrations in ringed seals tend to increase from the western Canadian Arctic to the eastern Canadian Arctic and across Greenland, with the highest levels reported in east Greenland, Svalbard, and the Russian Arctic (Muir et al., 2000). HCH concentrations, on the other hand, increase from east to west, with Canadian Arctic levels higher than levels in west and east Greenland (Muir et al., 2000; Vorkamp et al., 2008). The highest HCH levels are reported in the western Canadian Arctic, reflecting the greater use of HCH in Asia and atmospheric and oceanic transport to the western Arctic (Muir et al., 2000).

Mercury concentrations in ringed seals tend to increase westward from east Greenland to west Greenland and across the Canadian Arctic, with the highest concentrations in the western Canadian Arctic (Rigét et al., 2005; Brown et al., 2016). Within the Canadian Arctic, mercury concentrations in ringed seals tend to be higher in the west than the east, which is largely due to both natural geological differences and diet variability among the regions. Cadmium concentrations in ringed seals tend to be higher in the east than in the west, largely due to their dietary preferences (Brown et al., 2016). For trace metals in Greenland biota, there is a tendency for the highest cadmium concentrations to be found in central West Greenland, with the highest lead and mercury concentrations in the east (Rigét et al., 2000). Chapter 3 describes contaminants in wildlife and humans in the BBDS region in more detail.

2.3. Priority issues

The BBDS region encompasses a variety of human interests and concerns regarding economic, social, and political development in the region. To describe adequately the priority issues within this transnational region is therefore a challenging task. Because the regional governments of Nunavut and Greenland play a key role in setting the development agenda in the BBDS region, the objective

Ashley Cooper/Alamy Stock Photo

A football match in Ilulissat, Greenland

of this section is to list the priority issues they have identified in the form of strategies and policies. In addition, concerns and perspectives from BBDS stakeholders consulted in the Adaptation Actions for a Changing Arctic (AACA) project (see Chapter 1) will be included, as they have guided the focus of this report. The government strategies presented here reflect the communal concerns of different groups in the region. However, additional and competing perspectives and concerns have most likely been identified within local communities, just as important formal or informal strategies are undoubtedly being pursued by individual communities and local administrations. The importance of such perspectives and initiatives is recognized, but these additional considerations are not systematically included in this section.

2.3.1 Priority issue: health

There is a great disparity between health in the North versus the rest of Canada and the Kingdom of Denmark, as manifested in the lower life expectancy among Inuit. Serious health issues of the region include cancer, suicide, chronic illness, and infectious disease. Some of the priority health concerns for youth in the region include suicide and teenage pregnancy. The health challenges in the region are related to social and economic inequalities, socio-economic distress, crowded and poor-quality housing, high unemployment, limited access to health services, food insecurity, and behavioral and environmental factors. Furthermore, the region has struggled and continues to struggle with historical trauma (Government of Nunavut et al., 2010). In both Nunavut and Greenland, it has been argued that health should be addressed in a holistic manner, including considerations of what is considered "a good life" and addressing a broad range of social determinants for achieving "the good life" (see Chapter 4).

The Inuit Health Survey, *Qanuippitali?* (meaning "How Are We?"), was conducted across the Canadian Arctic over two summers in 2007 and 2008. This survey included the major Inuit communities on the Canadian side of the BBDS region. The survey data are compatible with, and contribute to, the International Inuit Health in Transition study, which includes Inuit communities in Greenland.

During the ArcticNet Integrated Regional Impact Study (IRIS) regional science meeting in November 2012 (see details in Chapter 1), we learned that the Inuit Health Survey has produced and continues to produce a large number of scientific publications. These publications cluster around two major themes: (1) the emergence of chronic diseases, such as obesity and diabetes, and the quest to understand their metabolic pathways; and (2) changes in diet and nutritional status, including food insecurity, as well as specific deficiencies such as iron and vitamin D. Issues presented at the meeting and discussed by participants included the following:

1. Self-rated health: A useful index of overall health is a respondent's self-rating of health. Only a small minority (7%) of Health Survey respondents rated themselves as being in poor health. Studies have shown that there is strong correlation between a person's self-rated health and their long-term health outcomes such as premature mortality and hospitalization.
2. Health-related behaviors: One of the most important risk factors for a variety of diseases is smoking. Among adults that participated in the Health Survey, 73% were current smokers. Exposure to environmental smoke was almost universal in homes – 89% of households had at least one smoker, and the proportion was even higher (91%) among households with children.

3. Diet and nutrition: The Inuit Health Survey provides a detailed description of the diet and food intake of Inuit today, with a special interest in the role of traditional foods obtained from hunting, trapping, and fishing. Not surprisingly, compared to a decade ago, there was a significant decrease in the proportion of daily energy intake from traditional foods and a corresponding rise in "market foods," especially potato chips, pasta, and sugar-sweetened beverages.

4. Environmental effects: Questions were raised about the compounding factors of climate change, resource development, and country food contamination on Inuit health and how these emerging environmental issues need to be monitored and mitigated wherever possible to protect Inuit health. ("Country food" is food that comes from local resources – e.g., plants, fish, wild game).

2.3.1.1 Nunavut strategies for human health and health services

Food security

Access to healthy and affordable food has been a challenge for Nunavummiut (residents of Nunavut) for many years and is now a particularly urgent public health issue for the region. At the IRIS Regional Science Meeting (IRIS-RSM) in Iqaluit (6–8 November 2012), we heard from the Territorial Food Security Coordinator for the Government of Nunavut that for Canadian Inuit, the right to food extends far beyond basic physical and economic accessibility, as country food is integral in providing social cohesion and identity. The Inuit Health Survey reported that nearly 70% of Inuit households in Nunavut are food insecure. In 2009, the Government of Nunavut released a statement of priorities, *Tamapta: Building our Future Together*, which emphasized the importance of meeting the basic needs of Nunavummiut, including affordable healthy food (Nunavut Food Security Coalition, 2014). As a part of these priorities, the Government of Nunavut agreed to prepare and implement a poverty reduction strategy titled "The Makimaniq Plan: A Shared Approach to Poverty Reduction." The Nunavut Food Security Coalition and strategy were derived from this public engagement process, reflecting over two years of collaborative effort (2014–2016). The strategy outlines the actions that need to be taken to improve food security in Nunavut. For example, the objectives of the food security strategy are to (1) promote country food as a foundational food for Nunavummiut; (2) support a food supply chain that promotes the availability and affordability of store-bought foods that maximize nutritional and economic value; (3) explore and promote the potential for local food production in the region; (4) support efforts to increase the ability of Nunavummiut to improve their own food security by gaining and utilizing life skills, including language, literacy, and numeracy; (5) support community efforts that improve access to food for those who are most vulnerable to hunger; and (6) advocate for a strong social safety net that promotes food security through policy and legislative measures (Nunavut Food Security Coalition, 2014).

Maternal and newborn health care strategy

Nunavut has the country's highest teenage pregnancy rate, with 24% of live births being to mothers under the age of 19 years (compared to 5% for the rest of the country) (Government of Nunavut, 2009). Young mothers are at an increased risk of delivering preterm babies. Young mothers are also more likely to smoke and to drink alcohol and are less likely to breastfeed. Nunavut's maternal and newborn health care strategy was developed in 2009 to guide the Department of Health and Social Services in delivering its mandate to improve the health of Nunavummiut and to provide quality maternal and newborn health care to its residents. This long-term plan includes the following major components: (1) a vision for maternal and newborn health care; (2) guiding principles for maternal and newborn health care; (3) an action plan: specific goals and priority actions; and (4) key measurable outcomes for a 5-year period and beyond. This strategy builds on *Developing Healthy Communities: A Public Health Strategy for Nunavut, 2008–2013* (Government of Nunavut, 2008a) and provides the broader policy framework for the Midwifery Profession Act. This act was passed in September 2009 by the Government of Nunavut to assure high-quality and safe midwife-assisted births in the region.

Suicide prevention strategy

Nunavut has a suicide rate that is 10 times that of the national average. Inuit boys aged 15–19 years, in particular, have a high rate: 40 times higher than that of their peers in the rest of Canada. Suicide prevention is an urgent issue for the region. The *Nunavut Suicide Prevention Strategy* was developed in 2010 and is the result of a partnership approach that began in 2008 between the Government of Nunavut, Nunavut Tunngavik Inc., the Embrace Life Council, and the Royal Canadian Mounted Police (Government of Nunavut et al., 2010). The strategy was presented in the Nunavut Legislature in October 2010, and the subsequent strategy action plan outlined steps to achieve the vision for Nunavut in which the rate of suicide is the same as the rate for Canada as a whole or lower. This plan envisions a region where youth grow up in a safer and more nurturing environment that provides the skills needed to overcome challenges, make positive choices, and enter into positive relationships. Despite the strategy having been put into place in 2010, the suicide rate remains particularly high in the region. Action continues to be taken, however, as Inuit Tapiriit Kanatami (ITK) recently developed a suicide prevention plan for the entire Inuit Nunangat (ITK, 2016).

Housing and homelessness strategy

Nunavut is experiencing a housing crisis, with many Nunavummiut crowded into substandard housing and with the number of homeless individuals and families rising. The Government of Nunavut, through the Nunavut Housing Corporation, subsidizes more than 80% of all housing, with the cost of public housing and staff housing programs occupying nearly one-sixth of the government's budget. The framework for the Government of Nunavut's *Long-term Comprehensive Housing and Homelessness Strategy* (Nunavut Housing

Corporation, 2013) provides 4 strategic directions: (1) increase Nunavut's housing stock, (2) improve collaboration within the government and with external stakeholders, (3) identify gaps in Nunavut's housing continuum, and (4) instill self-reliance to reduce dependence on government.

Other health frameworks

In 2007, the Government of Nunavut published a *Nutrition in Nunavut* action plan (Government of Nunavut, 2007c), which provides rationale, goals, and objectives to assist the Department of Health and Social Services in supporting Nunavummiut in achieving and maintaining healthy eating to promote optimal health and well-being.

In 2011, the Government of Nunavut released a *Nunavut Tobacco Reduction Framework for Action* (Government of Nunavut, 2011). Nunavut has the highest rate of smoking in Canada: more than half of Nunavummiut smoke, compared to approximately 21% for the rest of Canadians. Nunavummiut are at increased risk of experiencing sickness, disability, or premature death as a result of tobacco use. The framework builds on what is already being done to address tobacco use in Nunavut and makes use of existing resources. In addition, it sets a course for new directions in tobacco control.

In 2012, the Government of Nunavut developed the *Nunavut Sexual Health Framework for Action* (Government of Nunavut, 2012) to ensure that a coordinated plan is in place to improve and maintain sexual health in the territory. The sexual health framework is aligned with the priorities outlined in *Tamapta*, which seeks to build healthy families and communities, with an emphasis on improving health through prevention and helping those at risk. The sexual health framework is a 5-year plan that describes key elements to address priority issues. Four critical themes are identified in the action plan: (1) health promotion, (2) health protection, (3) knowledge and evaluation, and (4) leadership, capacity, and collaboration.

2.3.1.2 Greenland strategies for human health and health services

In 2012, the Greenland government launched its strategies and goals for human health, 2013–2019, emphasizing that health is more than the absence of disease and also including the goal of "a good life" (Government of Greenland, 2012a). The strategies focus on lifestyle practices that have major effects on the population, including alcohol and hash abuse, smoking, physical activity, and eating habits. Existing programs initiated under the previous government strategy (Inuuneritta II) for pregnant families and suicide prevention will be continued. In 2013, the Greenland government launched its national strategy for suicide prevention, as well as an action plan for the alcohol problem in Greenland, 2013–2019. In 2013, the government also launched its strategy and action plan against violence, 2014–2017 (Government of Greenland, 2014b).

In 2014, the Greenland government furthermore launched a National Health Service strategy (Government of Greenland, 2014c). The strategy presents 6 political goals: (1) the citizen at the center, (2) good living conditions, (3) health technology to bring health services to citizens, (4) the health services as an attractive career, (5) efficient use of resources, and (6) research and monitoring. This strategy, which also describes status and challenges for health services, covers 11 areas, including the consolidation of the recent health reform; patient counselors; prevention within the areas of cancer, suicide, and sexual health; coherent clinical pathways; dental treatment; recruitment; telehealth; economy; extractive industries and preparedness; and monitoring and evaluation.

2.3.1.3 Other priority issues: climate change and health

The AACA stakeholder consultations (see Chapter 1) also pointed to some climate change–related risks to human health. Circumpolar health issues with traditional food and food security are a priority area of the Inuit Circumpolar Council (ICC), which has raised concerns about the mobilization of contaminants. Furthermore, the Arctic Council's working group on international circumpolar disease surveillance has identified three health challenges related to climate change: (1) new vector-borne diseases, (2) the appearance of a disease, like tetanus, that does not currently pose a challenge (in Greenland at least) but could appear as a result of permafrost thawing, and (3) drinking water problems where surface water from lakes is used.

2.3.2 Priority issue: contaminants

Inuit living in the eastern parts of the Canadian Arctic and in Greenland have higher concentrations of certain POPs and mercury than do populations from other Arctic regions (AMAP, 2009, 2014; see also Subchapter 3.2). Although POP concentrations in the Canadian Arctic are approximately 10–50 times lower than in temperate, more industrialized areas, their presence in the country foods of Inuit people has driven national and international government policies (Dewailly and Furgal, 2003).

The Northern Contaminants Program (NCP), funded by the Government of Canada, was established in 1991 to address concerns about human exposure to elevated levels of contaminants in wildlife species that play an important role in the traditional diets of Inuit in the Canadian Arctic. Research under NCP is often conducted in collaboration with communities, and an important focus of the program is on the meaningful incorporation of traditional knowledge. Results generated through phases NCP-I, NCP-II, and NCP-III were synthesized and published in 1997, 2003, and 2013, respectively, in the *Canadian Arctic Contaminants Assessment Report* (CACAR). The NCP's strategy is to fund northerners and scientists to research and monitor long-range contaminants in the Canadian Arctic. The data generated by the NCP is used to (1) assess ecosystem and human health, (2) address the safety and security of traditional country foods, and (3) inform decision-makers in the federal government as they consider policies and regulatory actions related to the presence of contaminants in Inuit country foods.

The Greenlandic Nutrition and Advisory Council has, since its development in the mid-2000s, provided advice and recommendations regarding diet and lifestyle related to contaminants, with a focus on marine mammals, and the general change toward Western food. Hansen et al. (2008) gave a comprehensive description of the "Greenlandic Dilemma" of balancing the "good" and "bad" of consuming traditional food. Monitoring programs for long-range contaminants in air, biota, and humans were initiated in the mid-1990s in both Greenland and Canada. These programs have continued to contribute to the Arctic Monitoring and Assessment Programme.

2.3.3 Priority issue: transportation and infrastructure

The Government of Nunavut released its transportation strategy in 2008. The strategy examines the current transportation infrastructure, which primarily supports air and ship traffic plus a minor road network (Government of Nunavut, 2008b). This system delivers essential core transportation services to communities, including the movement of people and perishable goods by air and of heavy or bulky commodities by sealift. The strategy focuses in part on maintaining the stability, viability, and increased efficiency of this system through the support of existing infrastructure, operational improvements, and workforce training, as well as policy changes. If plans for increased oil and gas and mining exploration and development progress, then new transportation infrastructure will be necessary. For example, the strategy identifies key actions – such as improving air links, developing strategic deep-water ports, connecting communities to resources, and responding to the effects of climate change – that will facilitate access to economic opportunities and put Nunavut on an equal footing with the rest of Canada. Participants at the 2012 IRIS regional science meeting heard about plans for potential new deep-water ports for Iqaluit and Qikiqtarjuaq, but currently only Iqaluit has had funding (partial funding) approved by the federal government. The financing of Nunavut's transportation needs may ultimately require some combination of federal government funding, private sector investment, and private–public partnerships.

Experts at the IRIS meeting stressed that permafrost degradation is a serious threat to existing infrastructure in Nunavut and that this degradation must be integrated into future design and maintenance plans for community, industry, and transportation infrastructure. For example, some Nunavut communities are directly affected by permafrost degradation triggered by extreme weather events (e.g., the thermo-erosion of river banks, bridges, and roads from flooding in Pangnirtung; see details in Chapter 10) or anthropogenic disturbance (e.g., slope failures in Arctic Bay). Other communities are indirectly affected by changes in the permafrost thermal regime, through changes in lake drainage or potable water quality. Construction practices during community expansion may accelerate the impact of climate change on thawing permafrost, especially if infrastructure is developed over areas with highly sensitive permafrost properties, such as ice-rich soils (for example, the Iqaluit airport) or if the natural drainage network is altered during site development.

The IRIS-RSM participants also highlighted the award-winning Plateau Subdivision in Iqaluit as an example of best practices for building a new housing area based on sustainable development principles. The city council and the residents of Iqaluit integrated perspectives on the sensitive physical environment, the high costs of energy and construction, and the impacts of climate warming in order to design and develop their community in a more sustainable way (Figure 2.12).

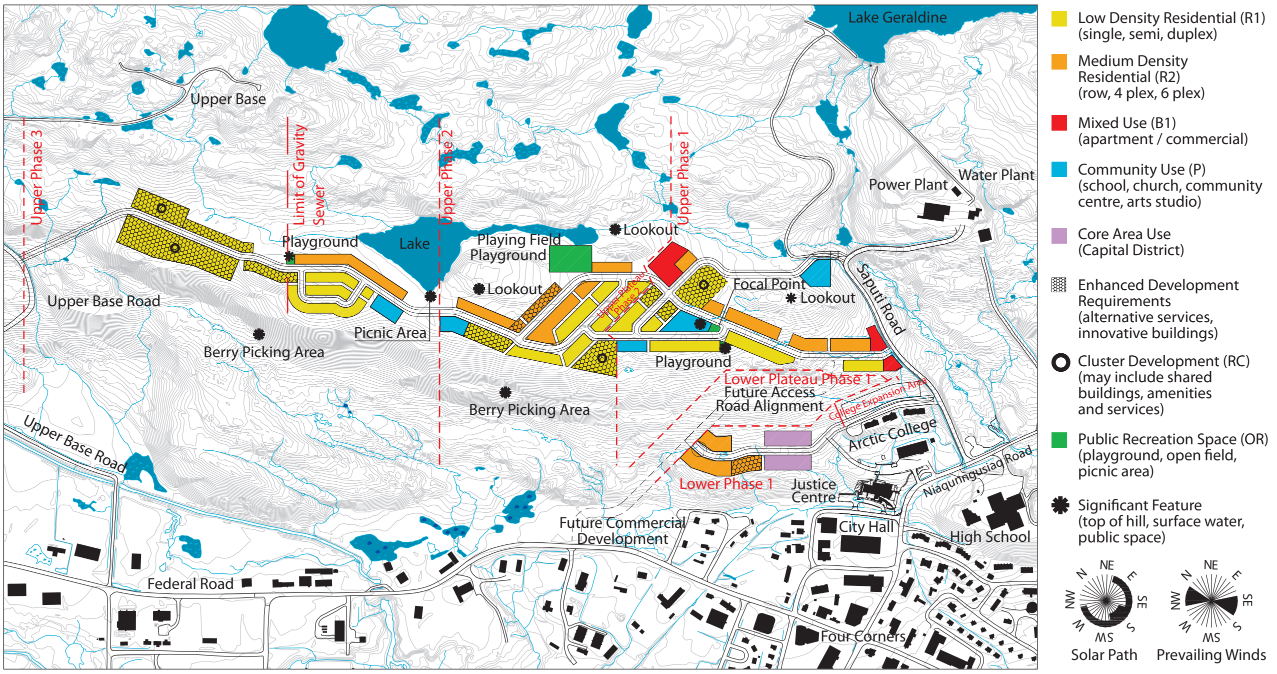

Figure 2.12 Concept plan for the Plateau Subdivision in Iqaluit, Nunavut. The plan incorporates development practices to build a more sustainable neighbourhood while also considering community needs and values, available resources, and climate. For example, the subdivision includes a variety of lot sizes, including smaller, more affordable lots; road and lot orientations that minimize snow drift and maximize solar exposure, as well as views of Frobisher Bay; and a mixture of land uses that support the community's cultural and socio-economic diversity. (Source: City of Iqaluit and FoTenn Consultants, 2012).

Mining infrastructure must also accommodate a changing climate – whether considering tailing pond dams that rely on the permafrost thermal regime to maintain their integrity or ice roads that provide economical land transportation routes to supply mine sites. At the IRIS meeting, infrastructure developed at the coast was also identified as potentially vulnerable to flooding from rising sea level, increased storminess, and erosion from increased open-water wave action and onshore sea-ice pile-ups.

In 2009, the just-established Greenland Self-Government set up a transport commission in recognition of the critical role that the transport sector plays in supporting the long-term goal of a self-sustaining Greenland economy. The Transport Commission of 2011 (Government of Greenland, 2011a) provided recommendations on specific infrastructure projects (airports, harbors, and conveyance) as well overarching transport-related political issues (Government of Greenland, 2011b). The transport commission classifies projects according to their negative or positive contributions to the national economy and recommends their continuation or discontinuation accordingly. The commission recommended to move the Atlantic airports from Kangerlussuaq and Narsarsuaq to Nuuk and Qaqortoq, respectively; build a new container harbor in Nuuk (a project now initiated); extend the airstrip in Ilulissat; establish simple airstrips in Nanortalik and Paamiut; close the Qaanaaq airport and have the Thule airbase run all services in the Qaanaaq district; replace helicopter transport by boat transport during the open water season in South Greenland; and establish a combined road and boat connection between Qaarsut and Uummannaq, as well as between Nanortalik and Paamiut (Government of Greenland, 2011b).

A sector plan released for Greenland's ports in 2015 (Government of Greenland, 2015d) recommends a new prioritization of the harbor facilities. Emphasizing the need to consider current demographic trends and coordinate with existing planning and policy initiatives, the sector plan recommends the following priorities in a two-level hierarchical order: (1) different types of harbor expansions or developments in Ilulissat, Tasiilaq, Kangerlussuaq, and Sisimiut, and (2) establishment of a new port facility on the Qaqortoq peninsula, renovation of the port in Narsarsuaq, and coastal protection in Uummannaq and Upernavik. A sector plan for airport investments is underway (Government of Greenland, 2015a).

During the Greenland AACA consultation on climate change–related challenges (see Chapter 1), the maintenance and expansion of built infrastructure emerged as a problem relevant to the current work or the predicted everyday work of planners and technicians in Greenland municipalities. These challenges include the following: (1) the protection of cultural heritage, including the protection of wooden buildings and the protection of ruins from coastal erosion; (2) mold in buildings; (3) problems with roads and buildings due to changes in permafrost; (4) changing uses of open land, including the establishment of new trails for dogs and snowmobiles; (5) increased snow load on buildings; (6) drainage of increased meltwater and rainwater; (7) the identification of areas suitable for building new infrastructure in the context of permafrost melt; (8) an increased need for gritting and snow clearing; and (9) impaired transport opportunities when sea ice is unstable. Royal Greenland, which runs many of Greenland's fish factories, also noted that melting permafrost and increased storms and precipitation would increase the risks of damage to buildings.

Chapter 10 discusses specific issues associated with infrastructure in the BBDS region.

2.3.4 Priority issue: development of the mineral sector and the oil and gas sector

The Government of Nunavut, Nunavut Tunngavik Inc. (NTI), and Indigenous and Northern Affairs Canada (INAC) completed a review of the future economic outlook for Nunavut in 2001. Two years later (2003), a vision for Nunavut's economic future, with the focus being on quality of life, was created. The strategy states: "We believe that Nunavummiut need strong community and territorial economies to attain the goal all societies seek: 'a high and sustainable quality of life.' " (Sivummut Economic Development Strategy Group, 2003, p. i). In the vision statement of the Government of Nunavut, *Pinasuaqtavut 2004–2009*, the government sets out to develop Nunavut's economy, private sector, and job market by aggressively implementing its focus on mining, along with other important sectors (Government of Nunavut, 2004).

Since 1999, mineral exploration investment in Nunavut has increased fivefold, and the territory is now the northern leader in exploration investment. The *Parnautit Mineral Exploration and Mining Strategy* was established in 2006 (Government of Nunavut, 2006). The overarching goal of the strategy is to "create the conditions for a strong and sustainable minerals industry that contributes to a high and sustainable quality of life for all Nunavummiut" (Government of Nunavut, 2006, p. 5). The strategy rests on 4 pillars: (1) jurisdictional framework, which aims to provide a good foundation for legislation, regulation, and policies to facilitate the development of the mining industry; (2) community benefits, with a focus on allowing Nunavummiut to become full participants in the minerals economy; (3) infrastructure development, to improve and build infrastructure that provides broad benefits throughout other economic sectors; and (4) environmental stewardship, aimed at recognizing the importance of protecting the environment and ensuring that the environmental effects of mining are minimized. Under the 4 pillars, 16 policy positions and 22 action items were identified to be carried out by 2010.

The Nunavut Oil and Gas Summit held in Iqaluit in January 2015 posed the question, "*Is Nunavut ready for oil and gas development?*" (Croal, 2016, p. 2). The participants shared information and attempted to identify issues, concerns, and gaps that need to be addressed to develop a consensual path forward for future oil and gas exploration and possible development in the region. In the end, they concluded that Nunavut stakeholders need more information and discussion through continuous engagement before Nunavut's readiness for oil and gas activities can be properly determined. Five broad themes that surfaced many times during the summit were:

1. A strategic environmental assessment (SEA) would be a very useful decision-support and community-engagement tool for identifying issues that must be addressed before

oil and gas exploration could be considered in the BBDS region of Nunavut.

2. More education on overlapping jurisdictional and transboundary issues concerning the federal and Nunavut governments, including links to land claims, must be offered.
3. The potential impacts from seismic surveys and the potential benefits to communities must be better identified and explained to Nunavut communities.
4. Communities, including youth, must be fully involved in all aspects of the debate concerning the potential for oil and gas exploration and development in Nunavut.
5. *Inuit Qaujimajatuqangit* (IQ; Inuit social values) must be respected and used in decision-making with respect to oil and gas activities in Nunavut.

During the 2012 IRIS regional science meeting, experts and participants raised concerns about the impacts of mining developments on a broad range of aspects of community well-being, such as food security and health, culture and language, and family and social life. Although some communities have found ways to effectively participate in the economic benefits of mining – through Inuit Impact and Benefit Agreements – the pace and magnitude of anticipated development may overwhelm some communities. There is an immediate need to help establish governance structures and monitoring programs to ensure that economic change does not undermine community adaptability and resilience. Debate is ongoing regarding the risks of relying on nonrenewable resources for economic development, and the important long-term planning challenges associated with mine closure remain an open issue in Nunavut. Operating mines are not necessarily economically secure, given global economic conditions and the cost of extracting ore in Arctic environments. Therefore, managing the transition to a post-mining economy will present vulnerability challenges to communities as significant as those associated with climate change.

The impacts of seismic surveys on marine wildlife were specifically raised as a real community concern, and the RSM participants challenged scientists to conduct more research on the issue and to incorporate Inuit observations and knowledge in their findings.

To the Government of Greenland, the oil and mineral sector offers one of several possibilities for securing wealth and well-being for Greenland's society through increased income and employment. The government has formulated a strategy for Greenland's oil and mineral development for the period 2014–2018 (Government of Greenland, 2014a), in which the goal is to promote the possibilities for discovering a commercially sustainable oil deposit. In addition, 5 to10 mines shall always be active in Greenland. The strategy is meant to support the opening of 3 to 5 mines during 2014–2018 and the presence of 1 to 2 offshore oil drilling projects every second year (Government of Greenland, 2014a). In 2013, the Greenland government lifted a previous ban on uranium mining. This decision has met with significant protest within Parliament, the public, and civil society (i.e., nongovernmental organizations and associations) (see also Subchapter 3.3).

Sermersooq Municipality has developed a strategy for the sustainable development of the mineral sector within the municipality. Its three focus areas are "a participating (Greenlandic) business community," "a competent workforce," and "sustainable development" (Kommuneqarfik Sermersooq, no date).

During the Greenland AACA stakeholder consultations (see Chapter 1), a variety of concerns were raised regarding the possible consequences of mineral and oil projects. The Inuit Circumpolar Council emphasized the need for environmental standards, local involvement, and free prior consent in the development of the mineral sector. Furthermore, ICC foresees a need to secure Inuit minority rights in national legislation regarding scenarios of large-scale worker immigration. The adaptation capacity of local people and government is also a priority issue for the international oil industry, which has emphasized the importance of understanding how change will affect the people and the governments they work with. The fishing sector remains concerned with oil and gas development because such development may affect local and commercial fisheries negatively (e.g., causing ecological disturbances, pollution, damage to the region's fish-product image, and increasing competition for labor).

2.3.5 Priority issue: energy

Nunavut relies exclusively on imported fossil fuels for its energy needs. Almost all electricity is produced through diesel combustion; however, a small amount of renewable energy generation is gaining ground (www.nunavutenergy.ca). In Greenland, 60% of the electricity and heat supply comes from 5 hydropower plants that supply 6 of the largest towns. The remaining 40% comes from diesel. Due to the fossil fuel needs of the transportation sector, 85% of Greenland's overall energy consumption is still based on fossil fuels. (See also Chapter 7.)

Ikummatiit, the Government of Nunavut's Energy Strategy, was put into place in 2007 to provide guiding principles through the year 2020 and to enable Nunavut to reduce its dependence on imported fossil fuels. The objectives of the strategy include diversification of the energy supply to include clean, alternative energy and domestic energy sources and also the provision of business and employment opportunities as the territory increases its energy efficiency and increasingly uses renewable and domestic energy sources (Government of Nunavut, 2007b). More emphasis is to be put on hydroelectric energy, existing diesel-generation facilities, solar water heating, and energy from municipal wastes. Under this strategy, all key policies for energy impacts will be reviewed and modified to encourage the promotion of energy efficiency and alternative energy sources. In 2006, prior to the establishment of the Nunavut energy strategy, Qulliq Energy Corporation launched the Nunavut Energy Centre to provide advice to Nunavummiut about energy efficiency and alternative energy.

A Greenland strategy and action plan for the energy sector (2008–2015) was launched in 2007 (Government of Greenland, 2007), containing a strong focus on hydropower and establishing climate change as a context for new industrial opportunities. The strategy presented 4 goals: (1) a coherent energy supply, including large-scale industries; (2) energy savings and efficiency; (3) renewable energy, with hydropower playing a key role in the future; and (4) reorganization of the sector, with an emphasis on achieving the advantages of large-scale production. A new strategy is scheduled to be issued in 2017.

2.3.6 Priority issue: arts and crafts

Arts (e.g., visual, singing, dancing) have been a central part of Inuit culture for thousands of years and can be considered as an expression of identity, a way of sharing history, and a component of spirituality. The arts have played an important role in Nunavut's economy for more than fifty years. Currently, the sector contributes tens of millions of dollars to the Nunavut economy, with the variety of produced art including carvings in stone, ivory, bone, and antler; fine art prints, drawings, and paintings; woven tapestries; wall hangings; basketry; contemporary fashions; traditional clothing; ceramics; jewelry; and metal (Government of Nunavut, 2007d). The region is witnessing considerable entrepreneurship associated with the arts, where modern and traditional elements are being combined (e.g., modern fashion design with Inuit symbols or animal products). The art reflects the knowledge, stories, history, and skills that have been passed down from generation to generation and is an integral part of Inuit culture. The art products also reflect creative adaptation skills in a modern context. For example, connecting to culture through traditional arts and crafts has been identified as an important protective factor for the mental health and well-being of Inuit youth, and this connection can be used to enhance resilience and adaptive capacity (MacDonald et al., 2015).

Twenty percent of Nunavut's workforce over the age of 14 is employed through the arts sector. To support the arts economy in the region, the Government of Nunavut's Department of Economic Development developed *Sanaugait: A Strategy for Growth in Nunavut's Arts and Crafts Sector* (Government of Nunavut, 2007d). The strategy focuses on arts best described by the Inuktitut word *sanaugaq*, which means "things made by hand." The first meeting to implement the strategy took place in 2005, with the intent to guide development of the arts sector through 2013. Seven goals were identified and implemented for the strategy: to increase the quality of Nunavut art; maximize artists' profits through participation in the value-added chain; secure market share through the protection of intellectual property rights; secure market share through international brand recognition; expand international market share; provide current and accurate information about the arts sector; and promote and celebrate the contribution of Nunavut's arts to global society.

In Greenland, arts and crafts are prioritized as a cultural activity, but no formal national strategy has been formulated with a focus on economic growth in this particular sector. The Greenland government wishes to contribute to a "continuous production of different types of cultural expressions with the goal of developing a rich, diverse and dynamic arts- and cultural life with deep roots in the Greenlandic history" (Ministry of Education, Culture, Research and the Church, 2016). The municipalities have overall responsibility for creating a local framework for cultural activities, including arts and crafts. Sermersooq Municipality developed a cultural strategy for 2010–2013, focusing on 5 themes: artistic quality, cultural diversity, children's access to culture, culture in public spaces, and the capital as a cultural center (Kommuneqarfik Sermersooq, 2010). A sector plan for culture, arts, and the church is being developed (Government of Greenland, 2015a).

This BBDS report does not contain a detailed section on arts and crafts, but the subject is touched upon in Subchapter 3.3 and Chapters 4 and 8.

2.3.7 Priority issue: tourism

Tourism is a critical element of the Nunavut economy, with tourism-related businesses generating more than CAD 40 million in revenue and representing 3.2% of overall Nunavut annual GDP in 2011. Of total travelers to Nunavut in 2011, an estimated 84% visited the Qikiqtaaluk region and the remaining 16% visited the Kitikmeot and Kivalliq regions (Government of Nunavut, 2013). The Government of Nunavut released its tourism strategy, titled *Tunngasaiji*, in 2013. The strategy focuses on achieving sustainable growth by supporting the creation of quality tourism products and services, increasing education and training for tourism operators, supporting community business development, and strengthening the legislative and regulatory environment (Government of Nunavut, 2013). The strategy also identifies specific 5-year goals and actions for developing a strong tourism sector in Nunavut. For example, a 2013–2018 revenue growth target for Nunavut tourism is 2.2% to 4.0% per year, such that by the end of the 5-year period, the total revenue generated by the tourism sector would be CAD 49 million. This level of growth would represent a 23% increase in total revenue generated by tourism. Most growth is expected in business travel, leisure travel, cruise ships, and travel for the purpose of visiting family and friends. Business travelers account for the majority of travelers to Nunavut.

The discussion on tourism at the 2010 IRIS regional science meeting focused almost exclusively on cruise ship traffic. It was argued that cruise ship tourism could be a potential and growing economic and social development tool in Nunavut; however, the Canadian Arctic areas most frequented by cruise vessels are natural and historical sites. Most cruise ships stop at two or three established communities, where tourists experience local performances and craft displays. There are a handful of preferred communities for these cruise ship stops, primarily those with some tourism infrastructure and those where access is safe and reliable. Community members from smaller hamlets voiced frustration with the unpredictability of cruise ship stops and the disruption of local lifestyle to accommodate brief appearances of large numbers of tourists, with little benefit realized.

In Greenland, the goal of the government is to further the development of tourism as one of the pillars of the economy. At the time of this writing (March 2016), the government is in the process of formulating a renewed tourism strategy. The goal of the government's tourism policy is to support the "great potentials for growth in tourism by focusing on improvements of framework conditions of the tourism industry and by promoting investments on necessary infrastructure." The draft strategy suggests that the Greenland government for the first time allocate "significant means" to a broad effort within tourism – not only with a large marketing budget but also with improvements to infrastructure and an expansion of the experiences and activities offered to tourists (Government of Greenland, 2015e). During the Greenland AACA consultations (see Chapter 1), municipal and self-government officials supported a focus on the region's tourism potential, as the changing climate has resulted in increased interest in the entire Arctic area.

2.3.8 Priority issue: education and learning

The greatest challenge for the educational systems in the BBDS region is improving the low graduation rates across all education levels. This challenge is discussed in detail in Subchapter 3.3 and Chapter 5. The Greenland government aims to ensure that Greenland, to a larger extent than today, will educate its own population so that the country can fill positions in all sectors and give individuals better opportunities to provide for themselves and their families. The overall goal for the education sector is for 70% of the students within each year group leaving elementary school to obtain a qualifying education (that is, education beyond the 10-year elementary education; Boolsen, 2017) before they turn 35 (Government of Greenland, 2015b).

Under the 2015 educational strategy, the Greenland government has selected 10 focus areas for the education sector: (1) more children in preschool, (2) strengthening of elementary school, (3) earlier start of youth-level and higher education, (4) more skilled workers, (5) higher completion rates, (6) better guidance and counseling/psychological therapy, (7) more information to youth about the possibility and freedom to choose education and apprenticeships abroad, (8) increased information and communication technology skills, (9) management training, and (10) optimal use of resources and impact assessment. The educational strategy is accompanied by an action plan (Government of Greenland, 2015c).

In Nunavut, a number of recent reports, such as the *Nunavut Economic Development Strategy* (SEDS Group, 2003), have highlighted the need to improve literacy levels and the delivery of adult education and training. The success of Nunavut depends on respect for values and traditions and the ability of Nunavummiut to take an active role in the economic opportunities in their region. However, the challenge remains to provide the training, education, and skills that individuals require to fill these roles. The *Nunavut Adult Learning Strategy*, which was available for public consultation and input between November 2005 and March 2006, presents a framework for improving the delivery of adult learning activities in Nunavut over the next 20 years (Government of Nunavut, 2005).

The *National Strategy for Inuit Education*, initiated by Mary Simon, former President of Inuit Tapiriit Kanatami, Canada's national Inuit organization, was developed and launched by the National Committee on Inuit Education in June 2011 (ITK, 2011; see also Chapter 5). This strategy is the first national effort to improve outcomes in Inuit education. The national strategy identifies 3 broad goals: (1) providing support for children to stay in school and graduate, (2) offering bilingual curricula and culturally relevant resources, and (3) increasing the number of Inuit educational leaders and bilingual educators in schools, through key investments such as improving success in post-secondary education and establishing a university in Inuit Nunangat. The ten recommendations of the strategy highlight the need for ongoing support for parents, students, and educators; focused development of Inuit educational leadership; improved academic standards; improved access to higher education for Inuit; and support for Inuit educational research by Inuit scholars. Discussion at the IRIS regional strategy meeting recognized that while steps are being taken in these directions, there is a great deal of work required at the federal and territorial government levels, as well as in local communities and schools, for these goals to be met.

In Greenland, during the AACA stakeholder consultations (see Chapter 1), ICC Greenland noted the ongoing transition from a subsistence economy to a monetary economy and the fact that modern education does not take into account knowledge from traditional hunting. As a result, the use of dog sleds has diminished and people are increasingly investing in new modern-day equipment such as boats, engines, and snowmobiles. Further, the Greenland Ministry of Education, Church, Culture and Equality has expressed its concerns regarding the potential loss of traditional and local knowledge due to climate change. Despite the continued transitions, there are, however, examples in the region of informal training and mentorship programs for activities such as arts and crafts and hunting. The priority area of education and learning is strongly connected to building adaptive capacity and resilience in the region.

2.3.9 Priority issue: living resources

In 2005, the Government of Nunavut and Nunavut Tunngavik Inc. formulated the Nunavut fisheries strategy (Government of Nunavut and NTI, 2005). The vision of this strategy was "*To see fisheries emerge as a driving economic catalyst for Nunavut resulting in increasing prosperity for current and future generations of Nunavummiut recognizing the principles of sustainable use and Inuit Qaujimajatuqangit (IQ)*,"– i.e., Inuit social values (Government of Nunavut and NTI, 2005, p. 13). According to the Government of Nunavut, the strategy "*served as a blueprint for Nunavut's fisheries development and contributed to significant growth in the industry*" (Government of Nunavut, 2014). In 2014, the Government of Nunavut was in the process of renewing the strategy in consultation with a number of Nunavut communities to identify "*new opportunities that help Nunavut's sustainable fisheries industry continue to prosper*" (Government of Nunavut, 2014).

At the Nunavut IRIS regional science meeting, much of the interest revolved around inshore and coastal fisheries, including char for subsistence and small-scale commercial fisheries; there was also some discussion of offshore fisheries in Baffin Bay. The difference in the sizes of the commercial fisheries on the opposite sides of the BBDS region was discussed, including the relation of this difference to the pattern of marine primary productivity. Low primary productivity values characterize much of the Baffin side (Figure 6.3), with productivity levels in this area generally close to those of a "biological desert" (see further in Subchapter 6.2)

In 2009, Greenland's (Home Rule) Fishery Commission formulated a range of recommendations on how to restructure the fishery with an emphasis on biological sustainability, profitability, and efficiency (Government of Greenland, 2009). A broad range of fishery stakeholders participated in the commission, which provided the overall recommendation to consolidate the fisheries further, to increase profitability, and to prioritize this profitability over employment concerns. In practice, the strategy has been only partly implemented due to competing interests in the development of the fishery sector (Jacobsen and Raakjær, 2014). In contrast to the recommendations of the Fishery Commission, the 2015 employment strategy of the Greenland Government now includes the fishery under its "initiative 13," with a focus on strengthening employment in the fisheries (Government of Greenland, 2015f). This strategy focuses on investigating possibilities for raising the cod quota, increasing the volume of local products, increasing the degree of processing, strengthening local supply, providing noncommercial fishers an opportunity to trade in fish, and bringing back home fish industry workplaces that have moved abroad. Several of these initiatives have already been implemented. The 2015 employment strategy furthermore identifies a need to finance the replacement and modernization of agricultural machinery to increase domestic production and employment within agriculture. Sector plans for fishing, hunting, and agriculture have not yet been fully formulated in Greenland, but the development of such plans may be underway (Government of Greenland, 2015a).

Understanding how these industries can adapt to climate change impacts has been a priority issue for the Greenland government, which has initiated adaptation analyses for the fishing and hunting sector (Government of Greenland, 2012b) and the agriculture sector. AACA consultation with Greenland stakeholders within the fishing and hunting sector (see Chapter 1) confirmed that climate change is a significant threat, that adaptation is already ongoing, and that a range of uncertainties remain regarding the socio-economic effects of different adaptation strategies.

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3. Drivers of regional change

Northern residents are currently living through a period of profound change in Arctic climate, environment, and society. This chapter explores the various drivers of change in the Baffin Bay/Davis Strait (BBDS) region: climatic (Subchapter 3.1), environmental (Subchapter 3.2) and socio-economic (Subchapter 3.3). An attempt to synthesize across these diverse fields is provided in the four framework scenarios presented in Subchapter 3.4. These scenarios are designed as narrative tools to sharpen our understanding of the ranges of possible futures, choices, and actions and to facilitate our exploration of adaptation options.

Robert Landau / Alamy Stock Photo

Aerial view of Nuuk, Greenland

3.1 Climatic drivers

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Key messages

- ***The Earth's climate is warming due to anthropogenic greenhouse gas emissions, and warming will continue throughout this century.*** *Climate models are the central tool for constructing physically based scenarios of the future.*
- ***Climate models do not provide one single projection for the future but rather a range of likely outcomes.*** *This range arises from differences in imposed greenhouse gas emissions, model structures and processes, and outcomes of natural climate variations. For the Baffin Bay/Davis Strait (BBDS) assessment, medium- and high-emissions scenarios were used for the climate projections.*
- ***Continued BBDS warming is projected.*** *Mean near-surface winter air temperatures are projected to increase (relative to 1986–2005) by about 1 to 4°C by 2030 and 1.5 to 10°C by 2080. Summer temperatures are projected to increase by about 0.5 to 2°C by 2030 and 1 to 5°C by 2080. Projected changes tend to be largest in the northwestern part of the region. For the high-emissions scenarios, thawing-season lengths increase by about 1–2 months by the end of the century.*
- ***An increase in precipitation is generally projected for the BBDS region.*** *For winter, mean total precipitation is projected to change by about -10% to +25% by 2030 and -10% to +70 % by 2080. For summer, the projected change is about -5% to +15% by 2030 and 0% to +35% by 2080. The projected change is generally toward increasing precipitation, with the largest relative changes being in winter and over the northwestern parts of the region.*
- ***Mean BBDS near-surface wind speeds are projected to change within ±5% by 2030 and ±10% by 2080 for all seasons.*** *There is little information on projected changes in prevailing wind direction.*
- ***Projections of weather extremes show increases in minimum and maximum temperatures and also heavy precipitation.*** *Annual minimum temperatures are projected to increase by 2–6°C by 2081–2100 under medium emissions and >6°C under high emissions. Annual maximum temperatures increase somewhat less. Both quantities increase more on the Nunavut side of the region than on the Greenland side. Projections show more wet days, shorter dry spells, and more precipitation during very wet days.*
- ***Projections of snow-cover duration for the late 21st century show a decrease of approximately 40–60 days, mainly due to later snow onset.*** *Reductions are most pronounced in coastal regions. The results are quite sensitive to imposed emissions—e.g., with stabilization after decline under medium emissions and accelerating decreases under high emissions. Large reductions in May–October snowpack are projected.*
- ***BBDS permafrost is projected to warm the most in the region's coldest areas and to thaw considerably in the warmest areas.*** *Ellesmere Island is an example of a cold area that is projected to experience pronounced permafrost warming. Southwestern Greenland is an example of a relatively warm area that is projected to experience pronounced permafrost thawing.*
- ***The Greenland Ice Sheet is projected to lose mass during the 21st century, with the primary mechanisms being increased freshwater runoff (up to a doubling or tripling) and glacier calving.*** *Year-to-year variability in freshwater runoff is projected to increase. The Canadian Arctic glaciers and ice caps are similarly projected to lose mass due to increased runoff.*
- ***Projections for lake ice in 2050 indicate a 10–15 day earlier break-up and a 5–10 day later freeze-up, with a 10–30 cm decrease in maximum ice thickness.*** *Lake-ice response to warming is influenced by lake morphology (size and depth) and local changes in snow accumulation.*
- ***Freshening and warming of the Baffin Bay surface layer (about 0.2°C per decade over the next 50 years) is projected under the high-emissions scenario.*** *Models project an increased inflow of warm Atlantic-origin water into the bay, a decrease of cold Arctic water flow through the Canadian Arctic Archipelago, and an intensification of the Baffin Bay counterclockwise circulation. The duration of ice bridges in Nares Strait, and thus the duration of the North Water Polynya, will likely decrease.*
- ***Climate models project the largest decreases in sea ice cover to occur in the autumn (15–20% reduction by 2080) due to later freeze-up, with smaller decreases in the spring (10–15% reduction) due to earlier ice break-up.*** *Winter ice thickness is projected to decrease by about 20–30 cm, with the largest decreases in more northerly regions. The timing of the changes varies considerably across models. For the foreseeable future, multi-year ice is likely to remain a hazard for shipping in the Canadian Arctic Archipelago.*
- ***Relative sea level in the BBDS region is projected to fall at nearly all locations, due mainly to crustal uplift in response to past and projected ice mass decreases.*** *For the year 2100 in the high-emissions scenario, projected median relative sea-level changes across the region range from approximately -90 cm to +10 cm.*

Introduction

The climate of the BBDS region is undergoing a period of rapid change linked to global warming (Overland et al., 2017) and natural climate variability (Way and Viau, 2014). The increase in atmospheric concentrations of greenhouse gases is significantly affecting the climate of the region, which in turn drives changes in ecosystem services and the populations that rely on these services (see AMAP, 2017b, and Chapter 6 of this report in particular). Climatic drivers are dealt with in this subchapter, which discusses aspects of ongoing and projected climate change relevant for the BBDS region. Section 3.1.1 consists of a general discussion of changes in the global climate system, explaining how such knowledge is obtained and how it must be interpreted. Sections 3.1.2 through 3.1.6 discuss changes taking place specifically in the BBDS region, with each section discussing trends of the recent past, as well as future scenarios for the atmosphere, terrestrial cryosphere, ocean, sea ice, and sea level. The climatic components are discussed separately for convenience, but they are closely interconnected (Hinzman et al., 2013; Overland et al., 2017).

The main role of this subchapter is to provide a synthesis of published information on observed and projected climate change over the BBDS region. However, the authors recognize that traditional and local knowledge (TK) is an important complement to the larger-scale portrait provided in the scientific literature: TK provides the link between large-scale climate change and local impacts. One of the challenges of incorporating TK into scientific assessments is that the observations are anecdotal, are fragmentary in time and space, and are usually not published in citable literature. However, efforts to consolidate TK across Arctic communities reveal a fairly consistent picture of some of the most important climate and environmental changes affecting local communities. From the Gaden and Stern (2015) compilation of traditional climate and environmental observations made by Inuit in the western and central Canadian Arctic, the changes most consistently reported across the 12 communities were the following: warmer summers and/or more extreme warm summer temperatures, more variable and unpredictable weather, a longer ice-free season, thinner ice, earlier snow melt, lower freshwater levels, and the presence of new plant/animal/insect species. These observations are the local footprint of the large-scale climate changes documented in this subchapter.

Reliable information about the future evolution of climate is needed by decision-makers for a wide range of applications (Mote et al., 2011; Huard et al., 2014). The process of providing this information requires a detailed understanding of local needs and the climate sensitivities contained, for instance, in TK, which is difficult to incorporate into decision-making processes (Cuerrier et al., 2015). Making this connection is beyond the scope of this subchapter; the aim here is to present the larger-scale changes in regional climate as documented in the published literature. However, it should be noted that Cuerrier et al. (2015) propose a novel mix of qualitative and quantitative methods to translate TK into evidence for decision-making and for developing environmental policy.

3.1.1 Global and Arctic climate change

The vast majority of climate scientists agree that human activities have put Earth's climate on a warming path (Oreskes, 2004; Cook et al., 2013; IPCC, 2013a), which is amplified in the Arctic by various processes (Pithan and Mauritsen, 2014; Barnes and Polvani, 2015; Overland et al., 2017). This section briefly explains the scientific background on global warming and provides information on the limitations and interpretation of climate scenarios. The processes responsible for Arctic amplification are presented in the supplementary material for this subchapter (Langen et al., 2016).

3.1.1.1 Climate change scenarios

The Earth's climate is warming due to anthropogenic greenhouse gas emissions, and this warming will continue throughout this century. Climate models are the central tool for constructing physically based scenarios of the future.

A steady global climate is the result of an equilibrium between Earth's energy input (solar radiation) and output (infrared radiation). Because greenhouse gases (e.g., carbon dioxide, methane) and aerosol particles (e.g., sulfates, black carbon) affect these radiative fluxes (Arrhenius, 1896; Twomey, 1977; Blanchet and List, 1983), the climate system responds to modifications in the atmospheric concentrations of these constituents. Basically, greenhouse gases (GHGs) absorb a part of the infrared radiation that would normally escape to space, and then reemit it back toward the Earth's surface, resulting in a warming effect. Anthropogenic aerosols have a variety of effects, summing up to a cooling that is insufficient to compensate for the anthropogenic GHG warming. The amplitude of the net response has been assessed with detailed, physically based models, and the results show that human GHG emissions have forced the climate toward a warmer state. Moreover, it is practically certain that this warming process will continue throughout this century and into the next one, at a rate that depends on both past and future emissions (IPCC, 2013a).

Here, we operate with the concept of a *climate scenario*, which is, in essence, one plausible trajectory for one or more climate variables, among many other plausible trajectories. Although there are a number of methods for constructing scenarios (see Mearns et al., 2001, for a discussion of the various methods and their advantages and disadvantages), climate models remain the central tool for scenario construction. These models provide a large ensemble of physically based, plausible responses to the increasing concentrations of greenhouse gases in the atmosphere. Climate model–based scenarios assume external forcings, such as an anthropogenic emissions scenario, as well as a certain level of solar and volcanic activity. The output may take the form of a time series (e.g., one value for the average temperature at Nuuk, Greenland, for each day from here to 2100) or of a climatic change (e.g., the percent change in mean annual total precipitation over Baffin Island between the 1986–2005 reference period and the 2081–2100 future period). As emphasized next, a climate scenario cannot be interpreted as a prediction, and a large ensemble of different scenarios is necessary for developing robust adaptation plans (Charron, 2014).

3.1.1.2 Limitations and interpretation

Climate models do not provide one single projection for the future but rather a range of likely outcomes. This range in climate projections arises from differences in imposed greenhouse gas emissions, different model structures and processes, and different outcomes of natural climate variations. For the Baffin Bay/Davis Strait assessment, climate model projections were used for two scenarios: medium emissions and high emissions.

Considerable progress has been made over the past 30 years in climate modeling. However, this progress does not allow scientists to *predict* the exact future climatic trajectory, because of at least three important sources of uncertainty (Rowell, 2006; Hawkins and Sutton, 2009): (1) uncertainty in future human (and natural) forcings, (2) imperfections in the models' formulations of the physical, chemical, and biological processes that determine the climate, and (3) natural variability in the climate system. The first point refers mainly to the fact that future decisions related to GHG emissions (and land use) cannot be foretold exactly. The second point refers to the fact that different models indicate different responses to assumed external forcings: no single best model can be identified, since each one has its own strengths and weaknesses in representing the climate system. Finally, the third point refers to interannual and interdecadal variations that superimpose on the long-term warming signal. In brief, there exist many plausible combinations of anthropogenic emissions scenarios, model formulations, and natural variability phenomena – which implies many plausible climate scenarios.

The emissions scenarios called "RCP4.5" and "RCP8.5" (van Vuuren et al., 2011) have been adopted as plausible lower and upper bounds for future emissions pathways for this report ("RCPs" refer to representative concentration pathways but are discussed here in terms of emissions, for convenience.). This adoption follows a recommendation to standardize scenarios across the Snow, Water, Ice and Permafrost in the Arctic (SWIPA) report (AMAP, 2017b) and the Adaptation Actions for a Changing Arctic (AACA) reports. The low-emissions RCP2.6 scenario was not considered (this scenario requires drastic reductions in carbon dioxide emissions); the RCP6.0 scenario is covered by the spread between RCP4.5 and RCP8.5. The model outputs used are representative of the large ensemble of simulations from the Coupled Modeling Intercomparison Project Phase 5 (CMIP5; Taylor et al., 2011), which was used by the Intergovernmental Panel on Climate Change (IPCC) for its fifth assessment report (AR5), published in 2013 (IPCC, 2013a).

Due to computing limitations, global climate model simulations are currently produced at horizontal and vertical resolutions of approximately 100–300 km and 1 km, respectively (the atmosphere's horizontal scale is much greater than its thickness). Processes occurring at a finer scale – such as wind channeling effects in fjords (Maxwell, 1981; Seidel, 1987) and katabatic "piteraq" events (Moore et al., 2015) – cannot be fully represented, which limits the direct utility of such model simulations for many local applications. Various downscaling techniques have been developed to overcome this limitation and produce meaningful local scenarios (Maraun et al., 2010; Hewitson et al., 2014).

It is important to emphasize that climate scenarios inform on what *could happen* on Earth and not what *will happen*. To account for the various plausible responses, climate scenarios may be presented, for example, as confidence intervals or as probabilities of occurrence (Kandlikar et al., 2005). Scenarios presented as multi-model averages have the advantage of synthesizing a vast amount of information. However, these types of scenarios must be interpreted carefully because the averaging procedure smooths out natural variability and between-model variability. A future change represented by a multi-model average often represents a fairly likely outcome among many others, and its sign is generally that of the majority of the models. However, multi-model averages are often misinterpreted as "robust predictions." Finally, spatial averages over the entire BBDS domain may mask geographical differences.

The following climate projections are generally based on multi-model assessments for the entire BBDS region. In addition to this set of assessments, the Danish Meteorological Institute (DMI) has prepared a series of reports specifically for Greenland, based on downscaling with the DMI climate model system (Christensen et al., 2015). However, because the DMI work relies on a single regional model and a single driving global model and because it covers only a portion of the BBDS region, the DMI results will be used only occasionally throughout the following discussion. The full reports (in Danish) may be downloaded from the DMI website (DMI Scientific Report 15-04, www.dmi.dk/laer-om/generelt/dmi-publikationer/videnskabelige-rapporter/).

3.1.2 Atmosphere

In this section, scenarios are presented for 21st-century changes (relative to the reference period 1986–2005) in near-surface air temperature, precipitation, and wind speed. Expectations related to meteorological extremes are also discussed. The figures represent new calculations that are based on published CMIP5 model results but are specific to the BBDS region (see land and sea boundaries in Figure 2.1). The results are discussed in light of other recent results published in the scientific literature.

3.1.2.1 Temperature

Continued warming is projected for the BBDS region. Mean near-surface winter air temperatures are projected to increase by about 1 to 4°C by 2030 and 1.5 to 10°C by 2080 (relative to 1986–2005). Summer temperatures are projected to increase by about 0.5 to 2°C by 2030 and 1 to 5°C by 2080. Projected changes tend to be largest in the northwestern part of the region and smallest in the southeast. For the high-emissions scenarios, thawing-season lengths increase by about 1–2 months by the end of the century.

Observed trends

Air temperature data from climate stations in the region indicate a slight cooling from 1950 to about the mid-1990s; at that time, a period of rapid warming began, culminating with 2010 as likely the warmest annual mean temperature in the instrumental record. Annual mean near-surface air temperatures in the region warmed at rates of approximately 1°C per decade over this period (Brown et al., 2018), with the greatest warming occurring over more northerly areas (Hamilton and Wu, 2013). The spatial pattern of this recent warming is characterized by a maximum over the eastern Canadian Arctic, with the seasonal pattern showing the greatest warming in the autumn and early winter period (Rapaić et al., 2015). Near-surface air temperatures indicate regional cooling since 2010, mainly in the winter. This cooling is consistent with a return to more positive values of the North Atlantic Oscillation, which exhibited large negative anomalies in 2010.

Projected changes

In this subsection, temperature-change scenarios based on the CMIP5 ensemble are presented and discussed. A particular focus is placed on natural variability – namely, the year-to-year and decade-to-decade fluctuations that cause the climate to vary around the long-term warming trajectory.

During the current century, average near-surface air temperatures in the BBDS region are expected to increase, with a very high likelihood. However, the magnitude of this warming cannot be exactly predicted due to the reasons stated above, in the discussion of model limitations and interpretation. Figure 3.1 shows the evolution of observed warming (black lines) and projected warming (colored envelopes) for the BBDS region for each season (land area only). Observed interannual variability is much larger in winter than in the other three seasons. The green and red bands summarize the 20-year moving averages of regionally averaged temperature projections from 95 CMIP5 simulations (56 and 39 simulations for the RCP4.5 and RCP8.5 emissions scenarios, respectively). The simulation results show that much larger warming is expected for winter than for the other seasons. At approximately 2035, the RCP4.5 and RCP8.5 envelopes start diverging. Over time, each envelope widens, reflecting model-related uncertainty (primarily) and natural variability (secondarily) (Hawkins and Sutton, 2009).

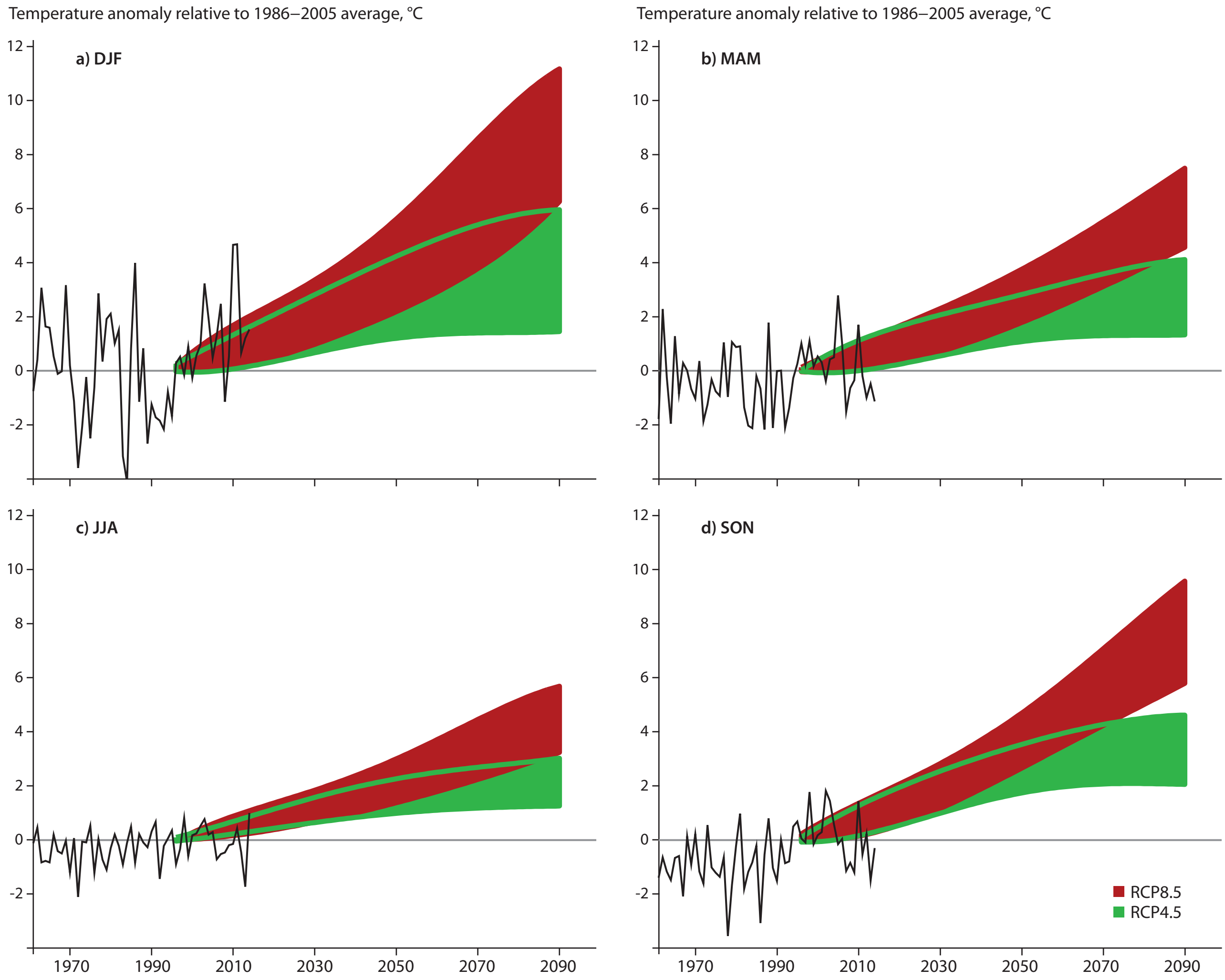

Figure 3.1 Observed and projected anomalies in 2-meter air temperature averaged over the land portion of the BBDS region, relative to the 1986–2005 average. The black lines represent observations (specifically, the CRU TS 3.23 tmp observational product) (Harris et al., 2014). The colored envelopes represent the likely evolution of the 20-year averages up to 2090 under the RCP4.5 (green) and RCP8.5 (red) emissions scenarios, based on CMIP5 simulations for (a) winter (December-January-February, DJF), (b) spring (March-April-May, MAM), (c) summer (June-July-August, JJA), and (d) autumn (September-October-November, SON). The CRU data are presented up to 2014. Average anomalies for each simulation are first calculated for each year and then averaged over 20-year blocks from 1986–2005 (attributed here to the year 1996) through 2080–2099 (attributed to 2090). For each attribution year, the 10th and 90th percentiles among the simulations are next calculated; fourth-order fits on these two percentile times series define the envelope boundaries.

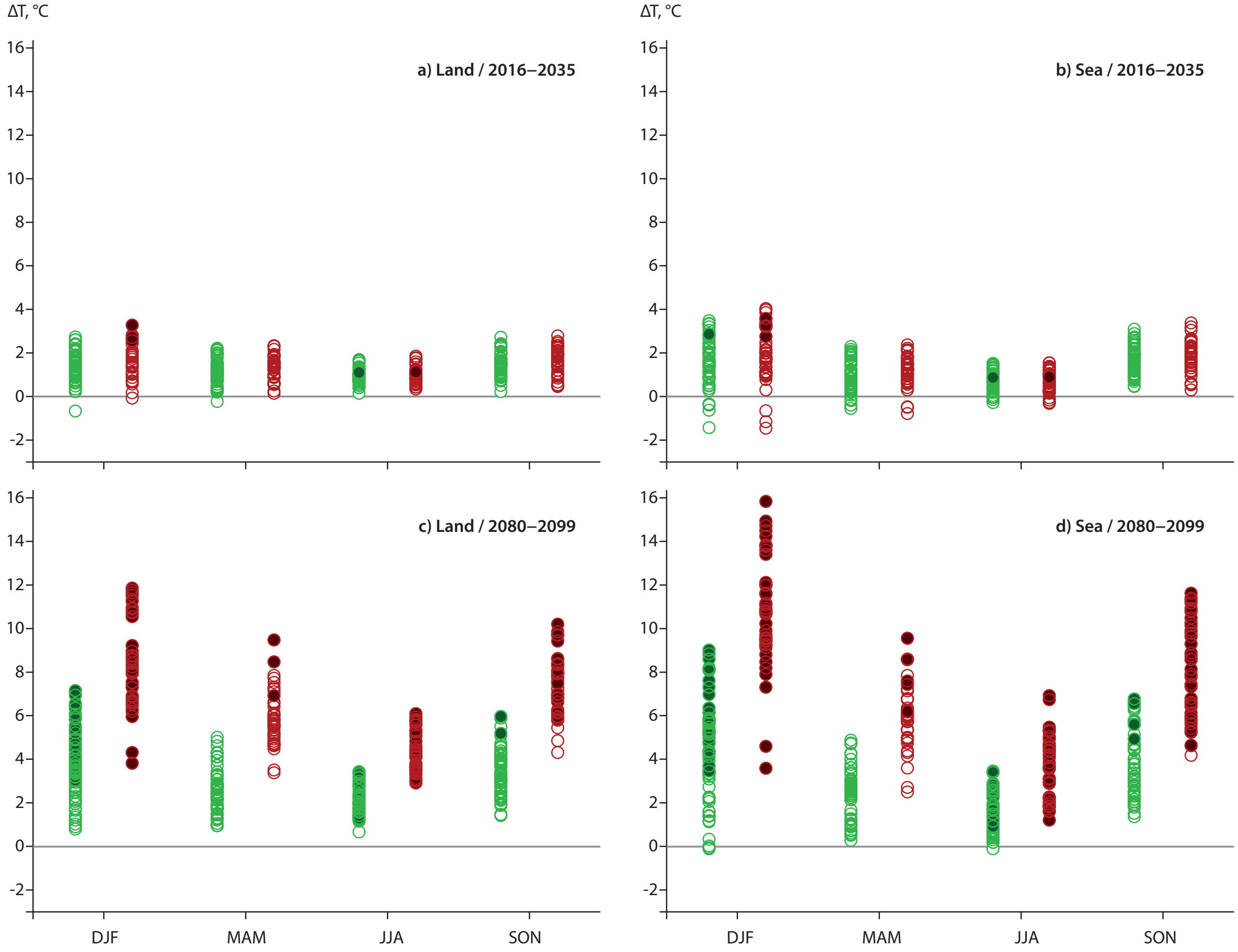

Figure 3.2 Average 2-meter air temperature anomalies (ΔT) relative to 1986–2005 for the BBDS region: (a) land areas for 2025 (2016–2035), (b) sea areas for 2025, (c) land areas for 2090 (2080–2099), and (d) sea areas for 2090. Each circle represents one simulation. A filled circle indicates that the anomaly is larger than the 1986–2005 standard deviation in that same simulation. A total of 95 CMIP5 simulations are used: 56 for RCP4.5 (green) and 39 for RCP8.5 (red).

The expected amount of warming can also be presented as intervals (Figure 3.2). The model results show that a few simulations project negative temperature anomalies for 2016–2035, whereas for 2081–2099 such cases are rare (only for RCP4.5 and only over the sea). The inter-simulation spread in anomalies is larger over sea than over land. Anomaly results for minimum and maximum daily temperature (not shown) are similar to those for average temperature (Figure 3.2).

The spatial pattern of projected temperature change is shown in Figure 3.3, in terms of the 25th, 50th and 75th percentiles for annual mean air temperature. This way of visualizing the spread in the range of changes projected by the climate model ensemble is recognized by the IPCC as "*a simple, albeit imperfect, guide to the range of possible futures (including the effect of natural variability)*" (IPCC, 2013b, p. 1313). (See also the introductory discussion above, regarding limitations and interpretation of climate models.) Overall, the projected warming shows a gradient of greatest warming toward the northwest. This pattern is associated with general Arctic amplification and the gradual disappearance of sea ice in the region. The corresponding seasonal maps for winter and summer reveal similar patterns but with larger amplitudes during winter (see Langen et al., 2016). Although large-scale patterns emerge in these figures from the model ensemble, it is important to note that the actual climate evolution may turn out to have a significantly different pattern (just as with any single model version) (Deser et al., 2014).

Due to natural variability, which occurs at various timescales, temperatures are not expected to change as smoothly as depicted in the multi-model averages. Natural variability is strong enough that temporary local cooling trends, with durations of up to 25 years or more, can be expected with significant probabilities (Grenier et al., 2015). Figure 3.4 illustrates these concepts by presenting three plausible RCP8.5-based climate scenarios for winter temperature at Clyde River (Baffin Island, Nunavut) over 2011–2035 (following observations over 1962–2010). Each scenario (a, b, and c) is based on a different global climate model (GCM). Successive 15-year trends are represented by the red (warming) and blue (cooling) lines. The FIO-ESM scenario (Figure 3.4a) presents a marked cooling phase centered on ~2020, with average winter temperatures around 2030 being no different than what has been observed in the past. The MIROC-ESM scenario (Figure 3.4b) also presents a temporary cooling centered on 2020, followed by pronounced warming. The GFDL-CM3 scenario, on the other hand, continues the sustained warming observed during 1990–2010 (Figure 3.4c).

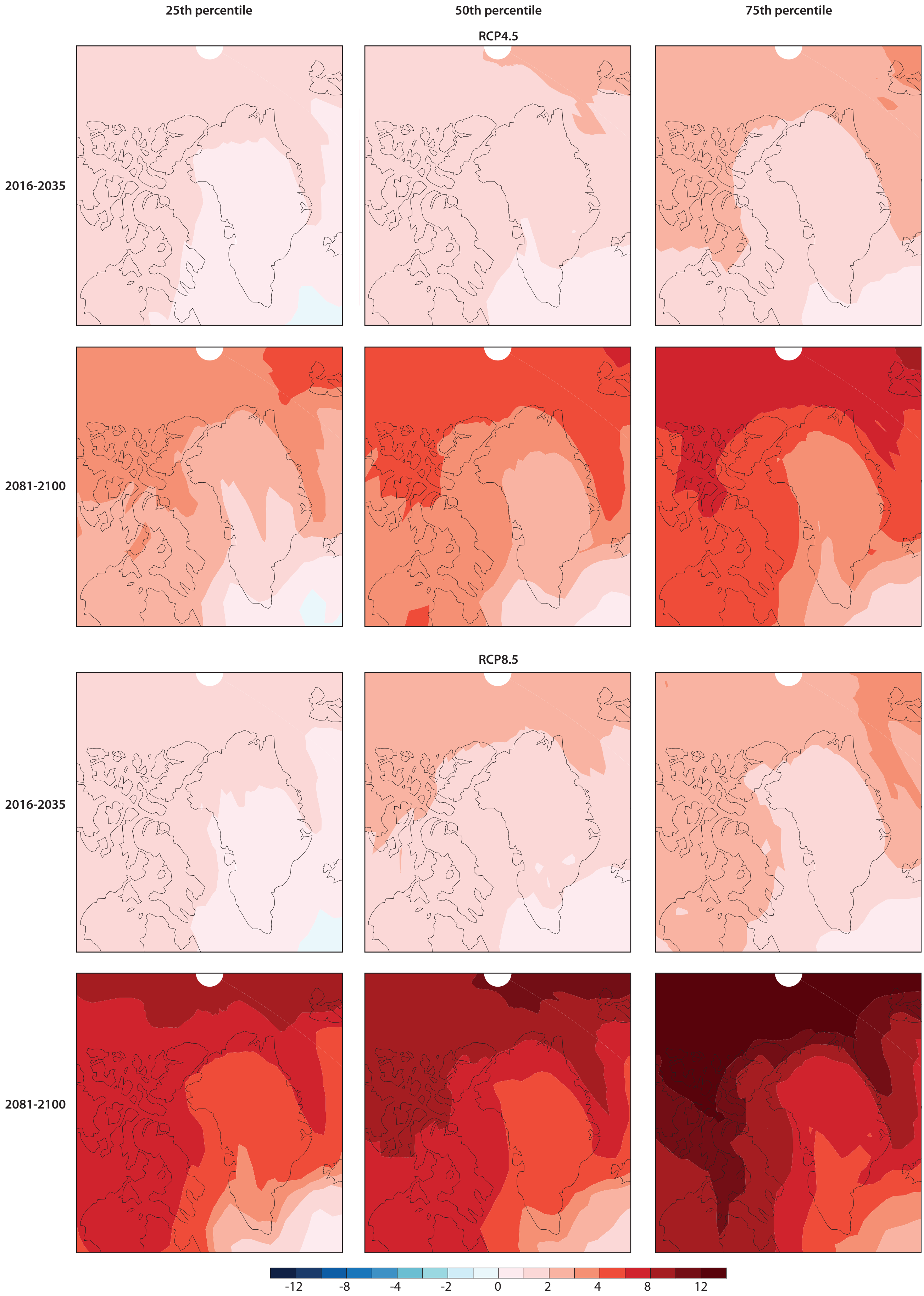

Figure 3.3 Changes in annual mean near-surface air temperature (°C) for RCP4.5 and RCP8.5 for the time periods 2016–2035 and 2081–2100 (relative to 1986–2005): 25th, 50th, and 75th percentiles. The 50th percentile corresponds to the median value, and the 25th and 75th percentiles correspond to the values dividing the distribution of projected changes into the coldest 25% and warmest 25% of models, respectively. (Data source: IPCC, 2013b.)

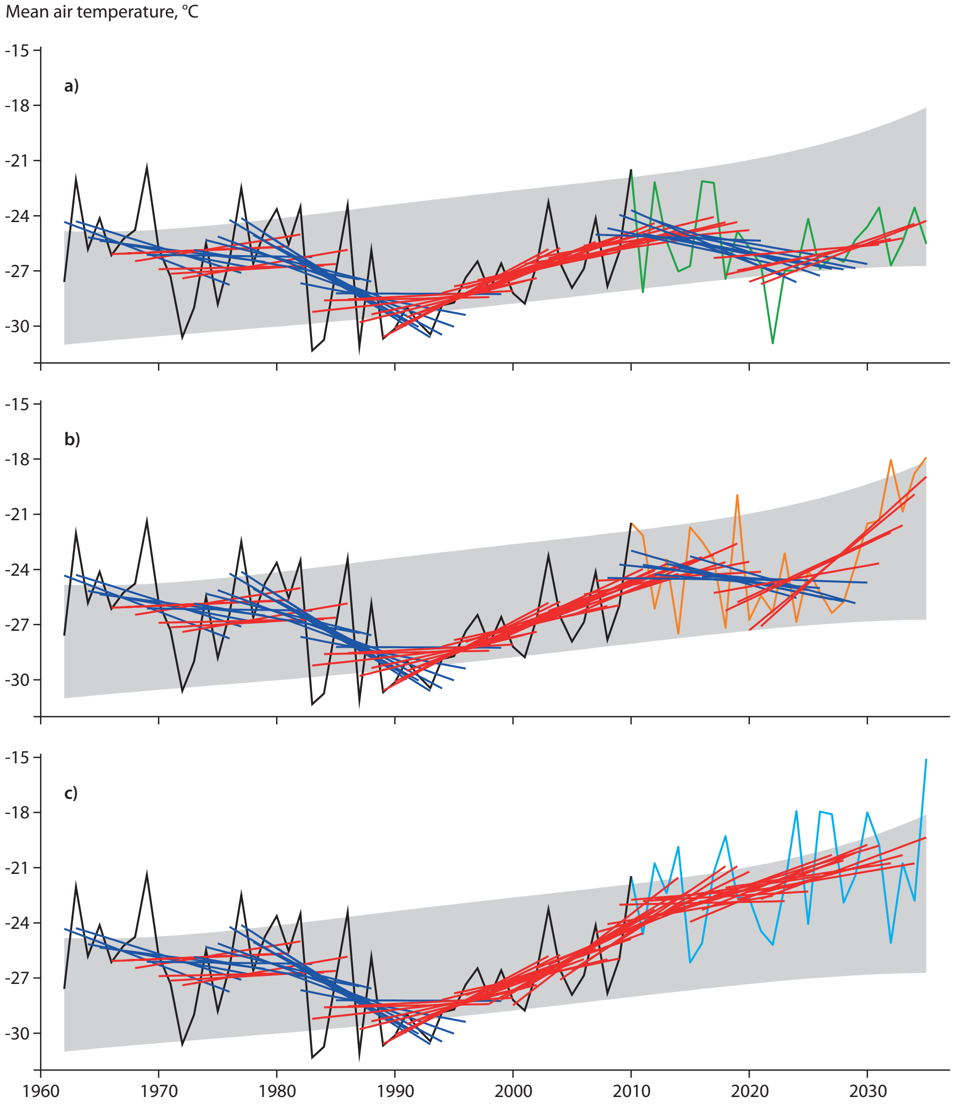

Figure 3.4 Selected winter climate scenarios for Clyde River in Nunavut (70°28'26" N, 68°35'10" W), based on the r1i1p1 member of the RCP8.5 experiment performed with the following global climate models: (a) FIO-ESM (green), (b) MIROC-ESM (orange), and (c) GFDL-CM3 (cyan). Gridded (10×10 km) data from Natural Resources Canada (Hopkinson et al., 2011) are used as observations over 1962–2010 (black line). Climate scenarios over 2011–2035 are obtained by statistically adjusting the simulations with a procedure termed quantile mapping (Grenier et al., 2015). Linear trends over 15-year segments are represented in red when positive and blue when negative. The gray envelope represents the time-smoothed 10th and 90th percentiles for yearly values in an ensemble of 15 RCP8.5-based climate scenarios (comprising the three presented here).

With changing annual and seasonal average temperatures, many temperature-derived climate indicators are also projected to change. For example, the Arctic summer length (defined here as the time between melt onset in spring and freeze onset in autumn) is projected by the CMIP5 RCP8.5-based simulations to increase by ~40 days over land and ~80 days over sea ice during the 21st century, with substantial differences among models (Mortin et al., 2014). Sillmann et al. (2013b) report consistent decreases in the number of frost days between the time periods 1981–2000 and 2081–2100, with decreases varying across the domain (land only) by about 0 to 30 days under RCP4.5 and about 5 to 70 days under RCP8.5. For Greenland, Christensen et al. (2015) found thawing season increases of approximately 45 days by 2081–2100 for RCP8.5 (~15 days for RCP4.5), using the HIRHAM5/EC-Earth climate model at 5 km resolution. Other indicators, such as the frequency of freeze–thaw cycles, could change monthly but not necessarily annually, as reported for other northern regions such as Nunavik and Nunatsiavut (Allard and Lemay, 2012). For Greenland, results from the HIRHAM5 model showed marked regional differences but an overall increase in the number of freeze–thaw cycles with projected warming (Christensen et al., 2015). Analysis of the frequency of winter thaw days over Baffin Island showed only small increases projected for 2050 (Barrette, 2013).

3.1.2.2 Precipitation

An increase in precipitation is generally projected for the BBDS region. For winter, mean total precipitation (liquid and solid) is projected to change by about -10% to +25% by 2030 and -10% to +70 % by 2080 (relative to 1986–2005). For summer, total precipitation is projected to change by about -5% to +15% by 2030 and 0% to +35% by 2080. The projected change is generally toward an increase in precipitation, with the largest relative changes being in winter and over the northwestern parts of the region.

Observed trends

Estimating trends in precipitation over the BBDS region is a particular challenge, for a number of reasons: precipitation is notoriously difficult to measure in Arctic environments, the surface station network is sparse and biased to coastal locations, there is strong interannual variability in precipitation time series, data sets are rarely homogeneous, and satellite sources do not always provide long enough periods of data for reliable trend analysis. Nevertheless, Mernild et al. (2014) analyzed trends in Greenland precipitation data (derived from coastal meteorological stations and ice cores) for various 30-year periods during

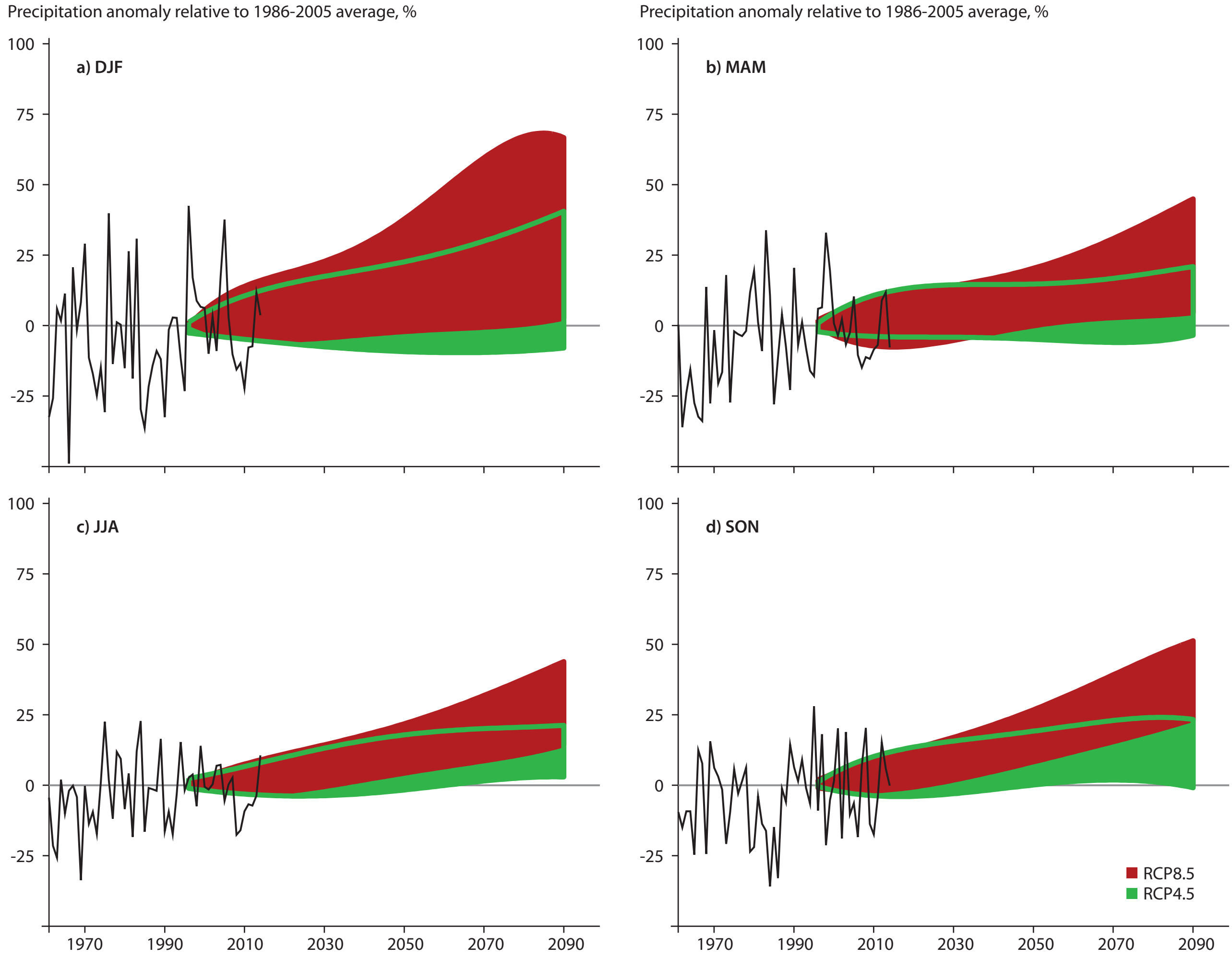

Figure 3.5 Same as Figure 3.1, but for anomalies in total (liquid and solid) precipitation. Changes are expressed as percentage differences with respect to the 1986–2005 average. The observational product is CRU TS 3.23 (pre), and the simulations are the same as those used for Figure 3.1.

1890–2012. While statistically significant trends were found, the results were spatially heterogeneous with both increasing and decreasing precipitation trends, even for sites a relatively short distance apart. None of the analyzed normal periods exhibited large-scale simultaneous agreement on positive or negative precipitation trends. Analysis of adjusted climate station precipitation data over the Canadian sector of the BBDS region from Mekis and Vincent (2011) shows evidence of statistically significant increases in precipitation over the 1950–2010 period: 5% per decade for rainfall and 3% per decade for snowfall (Brown et al., 2018). However, Rapaić et al. (2015) found that trends computed using the adjusted Mekis and Vincent (2011) station data were about two times larger than those obtained from a multi–data set estimate. They concluded that while there was strong evidence of long-term increases in precipitation over the Canadian Arctic, there were large uncertainties in the magnitude of the change. Hamilton and Wu (2013) reported a statistically significant trend of about +10 mm per decade from the 60-year precipitation record at Alert. The observed long-term increases in precipitation over the region are a response to both warming (warmer air can hold more water vapor) and loss of sea ice (Kopec et al., 2016; Thomas et al., 2016).

Projected changes

Precipitation is expected to increase over the BBDS region in response to warming and reductions in sea ice cover (Kattsov et al., 2007; Zhang et al., 2012; Bintanja and Selten, 2014; Kopec et al., 2016; Thomas et al., 2016). However, the climate change signal for precipitation is less marked than for air temperature.

Figure 3.5 shows the projected range in precipitation changes for the BBDS region (land only). The range of the RCP4.5 scenarios (green) is consistent with no change for some seasons. As with temperature, recent past interannual variability, as well as the range of future changes, is much larger in winter than in summer. RCP-related uncertainty becomes considerable around 2050, and both envelopes show ranges that widen with time due to model-related uncertainty and natural variability. It must be stressed that large relative changes can occur with small absolute changes for areas of the High Arctic where total precipitation amounts are low – e.g., the mean annual precipitation is only about 200 mm at Resolute in the Northwest Territories (Mekis and Vincent, 2011). Projections for changes in other variables of the atmospheric branch of the water cycle are discussed in the supplementary materials provided for this subchapter (Langen et al., 2016).

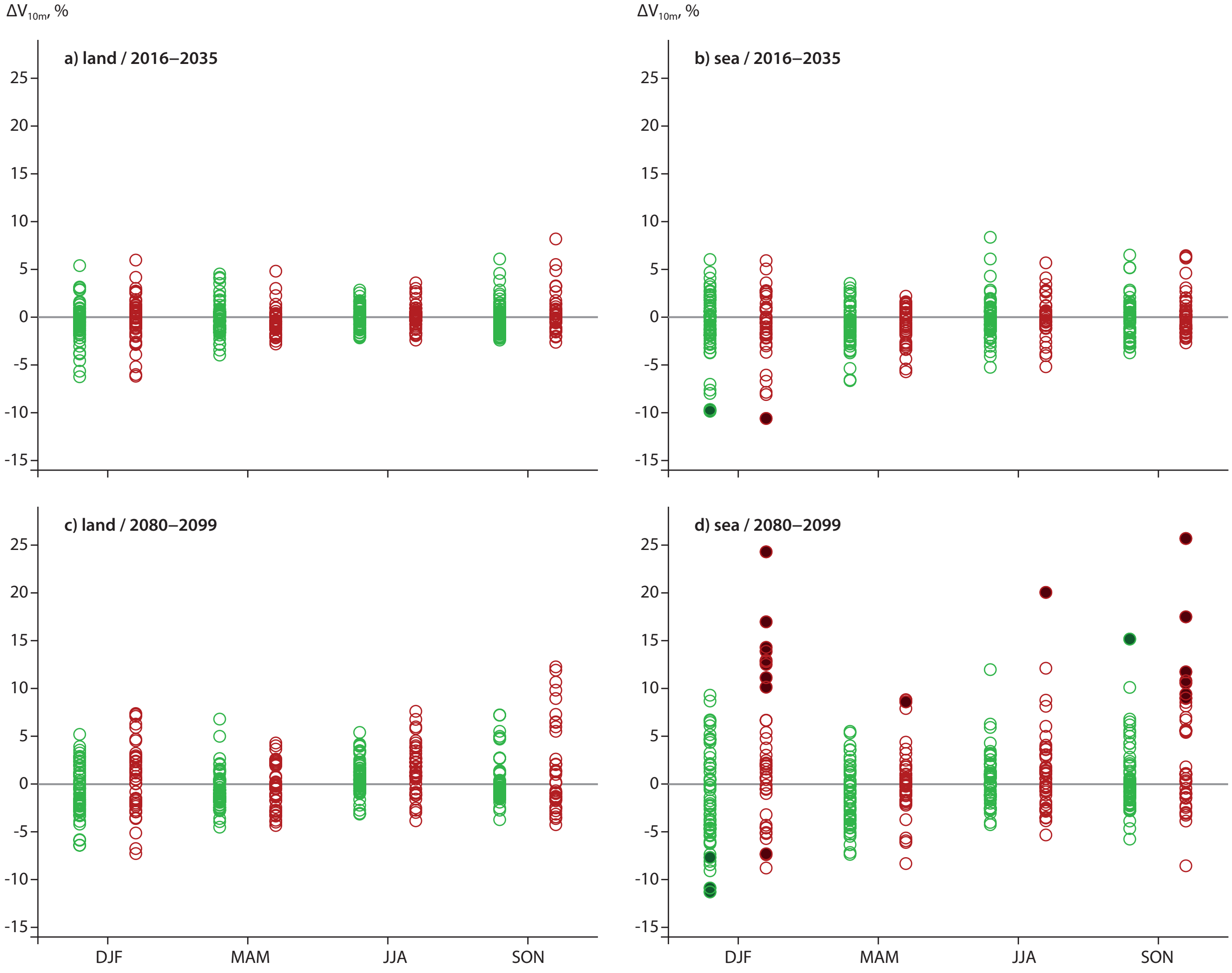

Figure 3.6 Same as Figure 3.2, but for anomalies in mean wind speed (ΔV_{10m}), expressed as percentage differences with respect to the 1986–2005 average.

3.1.2.3 Wind

Mean BBDS near-surface wind speeds are projected to change within ±5% by 2030 and ±10% by 2080 for all seasons. There is little information on projected changes in prevailing wind direction.

Observed trends

It is difficult to reach clear conclusions about wind-speed trends in the BBDS region. Trend analysis of surface wind speed observations is complicated by strong interannual variability and by the sensitivity of these observations to instrumentation (anemometer type and height) as well as the location and exposure of the observing site. There are relatively few studies of trends in wind speeds in the BBDS region. Wan et al. (2010) presented wind speed trend analysis results for homogenized wind speed records at a number of Canadian stations in the BBDS region over the period 1953–2006. The results show increasing wind speeds at Alert and Resolute but decreases at stations on Baffin Island. The observed increase in annual mean wind speed at Alert over the 1954–2011 period was +0.33 m/s per decade (Hamilton and Wu, 2013). Trends in geostrophic winds (the wind speed derived from surface pressure observations) indicate decreasing wind speeds over most of the BBDS region (Wan et al., 2010). Stopa et al. (2016) report increasing over-water wind speeds in Baffin Bay for the recent 1992–2014 period (from the Climate Forecast System reanalysis).

Projected changes

During the current century, average near-surface wind speeds in the BBDS region are likely to remain close to the reference value. There are relatively few studies of projected changes in wind direction (e.g., McInnes et al., 2011; Gorter et al., 2014), and this aspect is not further discussed here.

Dynamical phenomena involved in future wind regime and storm activity changes are complex, not fully understood, and some of their effects work in opposite directions (Bengtsson et al., 2006; Harvey et al., 2013; Gorter et al., 2014). Hence, the sign of the sum (net) impact on surface winds at the scale of relatively small regions, such as the BBDS, is not consistent from one model to another. This inconsistency means that weak, positive, and negative 21st century changes all represent plausible outcomes. Figure 3.6 shows near-surface (10-meter) 20-year average wind speed anomalies relative to the period 1986–2005 for a large ensemble of CMIP5 simulations. This figure suggests that adaptation plans should consider ±5% changes in mean wind speed for the period 2016–2035 and ±10% changes for 2080–2099.

Examples of CMIP5 global models that project positive trends in surface wind speeds include EC-Earth; indeed, Dobrynin et al. (2012) find increases on the order of 0–10% over the maritime portion of the BBDS region from the mid–19th century to the end of the 21st century (with RCP4.5 and RCP8.5 emissions scenarios). Using an ensemble of CMIP3 models, McInnes et al. (2011) also obtained no consensus among models regarding the sign of the signal in mean wind speed over the BBDS region from 1981–2000 to 2081–2100. However, for some maritime parts of the BBDS region, at least two-thirds of the CMIP3 simulations do agree on a 0–10% reduction in winter wind speed.

3.1.2.4 Extreme events

Projections of weather extremes for the BBDS region show an increase in annual minimum and maximum temperatures and an increase in heavy precipitation. Annual minimum temperatures are projected to increase by 2–6°C in the medium-emissions scenarios and more than 6°C in the high-emissions scenarios by 2081–2100, relative to 1981–2000. Annual maximum temperatures increase somewhat less. Both quantities increase more on the Nunavut side of the region than on the Greenland side. Projections show large (40–150%) increases in the amount of precipitation during very wet days, as well as increases in the number of wet days and decreases in the length of dry spells. Projected changes in extreme winds have different signs across the region.

In climatology, an *extreme event* is the occurrence of a value near the lower or upper range of the distribution of all observed values (IPCC, 2012). Because extreme events occur only rarely, their frequency in observational records may not be representative of their true probability of occurrence, and theoretical assumptions must compensate for the small sample size (Coles, 2001; Katz, 2013). This consideration poses an additional difficulty for obtaining reliable scenarios for the distribution extremes (Wehner, 2013), whose climatic change is not necessarily the same as that of the distribution mean (Kunkel, 2003; Katz, 2010). Extreme atmospheric events manifest in different forms, and each application requires specific indicators. Several global studies have focused on indices for extreme temperature and precipitation, discussing observed recent trends (e.g., Alexander et al., 2006), the performance of global models during the recent past (e.g., Sillmann et al., 2013a), and model projections for the 21st century (e.g., Tebaldi et al., 2006; Orlowsky and Seneviratne, 2012). Extreme winds have been investigated somewhat less.

Observed trends

Analysis of surface stations (Peterson et al., 2008; Donat et al., 2013; Wang et al., 2014) shows the BBDS region following trends similar to those of the rest of the Arctic – toward significant warming of temperature-extreme indices, particularly for indices based on daily minimum temperatures. Matthes et al. (2015) find most of the BBDS experiencing significant increases (decreases) in the duration of winter warm (cold) spells over the 1979–2013 period (in the ERA-Interim reanalysis). Trends in precipitation extremes vary greatly among stations; hence there is no clear regional pattern of change in extreme-precipitation indices over the region.

Projected changes

An analysis of CMIP5 simulations by Sillmann et al. (2013b) indicates that over the BBDS region (land only), between 1981–2000 and 2081–2100, the multi-model median of the average annual minimum temperature (index "TNn") changes by about +2 to +6°C under RCP4.5 and by more than +6°C under RCP8.5. For the multi-model median of the average annual maximum temperature ("TXx"), the projected changes are about +0 to +4°C under RCP4.5 and +1 to +7°C under RCP8.5 (the ranges represent differences across the region). For both TNn and TXx, increases are larger on the Canadian side than on the Greenland side of the region. On a seasonal basis, increases in TNn are more pronounced for winter than summer. Sillmann et al. (2013b) also report decreases in cold spell duration indices and increases in warm spell duration indices. Regarding precipitation extremes over the BBDS region (land only), their study indicates that the multi-model median of the annual amount of precipitation falling during very wet days (index "R95p") changes between about +40% and +100% under RCP4.5 and between +70% and +150% under RCP8.5. Also, the multi-model median of the annual number of days with precipitation above 10 mm ("R10mm") increases by 0.5 to 4 days (RCP4.5) and by 0.5 to 10 days (RCP8.5), whereas the multi-model median of the length of the longest dry-day sequence ("CCD") decreases by about 1 to 10 days (under both RCP4.5 and RCP8.5). For the CCD index, these results are not statistically significant over southern Greenland.

Only a few studies examine future wind extremes for the BBDS region. Using an ensemble of scenarios based on eight CMIP3 global climate models, Cheng et al. (2014) found that the annual number of hours with wind-gust speeds exceeding specific thresholds (28, 40, 70, and 90 km/h) is likely to increase at Resolute, Nunavut. The percentage increases are approximately 5–85% for 2046–2065 and approximately 15–170% for 2081–2100 (reference period 1994–2009; higher percentage increases associated with higher gust thresholds). Seasonal results for the 70 km/h threshold in 2081–2100 indicate a larger percentage increase in summer than in other seasons, partly due to lower summer values during the reference period. Wind-gust scenarios from Cheng et al. (2014) also indicate increases at Eureka, Pond Inlet, Clyde River, Hall Beach, and Iqaluit, though not in all seasons (a decrease is projected for Hall Beach in winter). Assuming that 850 hPa winds co-vary with near-surface winds, the results from Gastineau and Soden (2009) indicate geographical differences in 21st century changes in the annual frequency of extreme daily winds: a decrease over Davis Strait, an increase over the Canadian archipelago, and a relatively weak change over Baffin Bay. No equivalent multi-model results have been found for the Greenland side.

It is important to note that the reliability of scenarios for precipitation and wind extremes is tightly connected with the ability to model cyclones (McCabe et al., 2001; Pfahl and Wernli, 2012). In the BBDS region, these storms often enter from the south (Maxwell, 1981). Evaluating the cyclone climatologies of climate models in this region is a challenge because estimates of the relative frequency of cyclones vary widely depending on which study periods, reanalysis data sets, and storm tracking algorithms are used (e.g., Zhang et al., 2004; Serreze and Barry, 2005; Vavrus, 2013; Tilinina et al., 2014). Models are found to perform well at capturing the spatial pattern and seasonal variations in cyclone frequency but with large between-model differences in the numbers of cyclones (Vavrus, 2013; Zappa et al., 2013). Topographically driven wind extremes, such as the katabatic piteraq events of southern Greenland, require high-resolution models (Moore et al., 2015) and cannot be represented in global climate models.

3.1.3 Terrestrial cryosphere

3.1.3.1 Snow

Projections of snow-cover duration for the end of the 21st century show a decrease of approximately 40–60 days. This change is mainly due to later snow onset, with reductions being most pronounced in coastal regions. The results are quite sensitive to the imposed emissions scenario – e.g., with stabilization by 2100 under the medium-emissions scenario and with accelerating decreases under the high-emissions scenario. Annual maximum snow depth shows little response to warming, but for the May–October period, large relative reductions in snowpack are projected.

Seasonal snow is present over most of the BBDS region from early October to mid-June, with permanent or semipermanent snow cover over higher elevations. Changes in snow cover timing and amount have important implications for living and non-living resources (see Chapters 6 and 7; Bokhorst et al., 2016; Brown et al., 2017). Such changes also influence the Arctic climate system and cryosphere due to the reflective and insulating properties of snow. For example, the timing and amount of snow accumulation on sea ice is an important control on ice cover formation and growth (Barber et al., 2017). Snow accumulation varies considerably in space and time, with several variables exerting strong influences on maximum snow accumulation at regional to local scales: proximity to moisture sources, elevation, surface topography (exposure to wind), and prevailing vegetation. The regional patterns of snow cover duration (SCD) and of mean annual maximum snow accumulation (Figure 3.7) highlight the strong coastal gradients in snow cover around Baffin Bay.

Observed trends

The longest available satellite-based information for estimating trends in annual snow cover duration over the BBDS region is the U.S. National Oceanic and Atmospheric Administration (NOAA) climate data record (Estilow et al., 2015), with complete data since 1972. The utility of this data set is limited by its coarse resolution (190.5 km) and an absence of information over Greenland. However, the regionally averaged annual SCD series from NOAA agrees well with estimates obtained from in situ observations over the Canadian side of the BBDS (see Langen et al., 2016). The two series combined provide evidence of a decrease of approximately 3 weeks in the duration of snow on the ground since 1950. Station data show that most of the decrease is related to a later start to the snow cover season, which reflects the enhanced warming observed in autumn over the region (Rapaić et al., 2015).

There are large uncertainties in documenting trends in annual snow accumulation because of the sparse network of in situ measurements and the fact that snow-depth observations made at climate stations in open terrain may not be representative of snow conditions in the prevailing land cover. According to the available Canadian in situ snow-depth data, maximum snow depths have decreased over the Canadian side of the BBDS by an average of about 20% since 1950 (Brown et al., 2018).

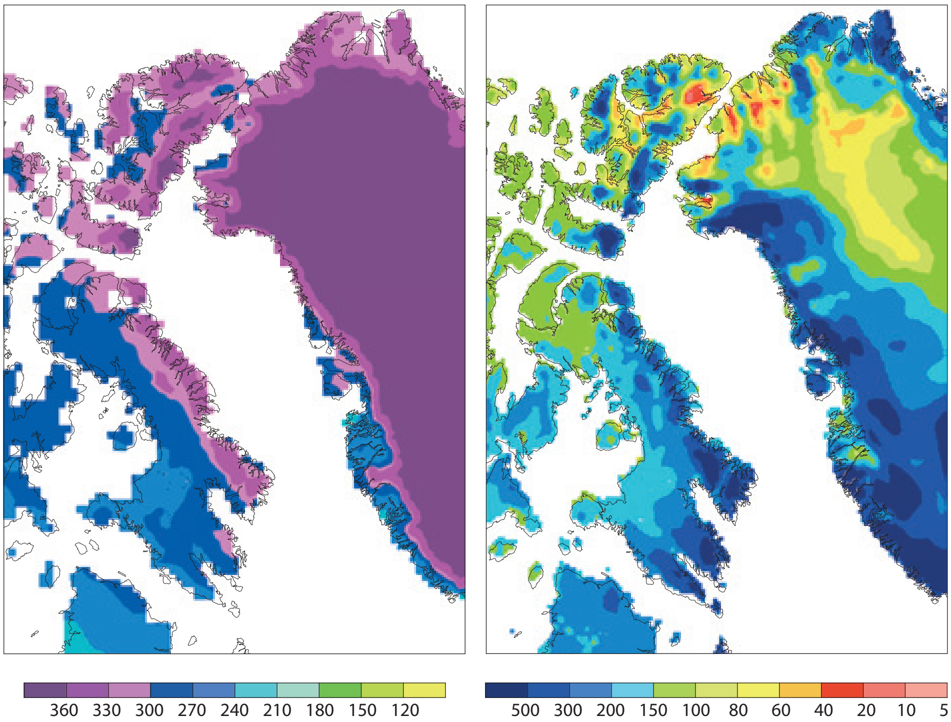

Figure 3.7 Left: Mean annual number of days with snow on the ground (snow cover duration, SCD) from the NOAA IMS 24 km daily snow cover analysis (Helfrich et al., 2007) over snow seasons 1998/99 to 2013/14. Right: Mean annual maximum snow water equivalent (SWE) (mm) over the 1979/80 to 2008/09 snow seasons, from the snow cover reconstruction of Liston and Hiemstra (2011).

Estimates of trends in maximum annual snow water equivalent (SWEmax) from other sources, such as passive microwave satellite data (GlobSnow; Takala et al., 2011) and the reanalysis-driven reconstruction of Liston and Hiemstra (2011), do not agree on the sign of change over the BBDS region in spite of evidence that precipitation is increasing over the region (AMAP, 2011; Lindsay et al., 2014; Vincent et al., 2015).

Projected changes

Projections of snow cover change for the BBDS region were obtained from the SWIPA 2017 report (Brown et al., 2017), which examines monthly snow cover and snow water equivalent (SWE) output from 16 independent CMIP5 models for 3 sets of experiments: historical (1986–2005), RCP4.5 (2006–2099), and RCP8.5 (2006–2099). Maps of relative change in annual snow cover duration and annual maximum SWE over Arctic land areas were generated for three 20-year scenario windows: near-term (2016–2035), mid-term (2046–2065), and long-term (2081–2100), all expressed with respect to the 1986–2005 reference period (shown in Langen et al., 2016). SCD was also computed for the first half of the snow season (August–January) and the second half (February–July), to capture changes in snow cover onset and snow-off (end of spring melt) dates. Regionally averaged results were computed over non-glacier gridpoints in the BBDS domain (approximated by the latitude/longitude box of 60–85°N, 45–95°W). The following general points can be made from the CMIP5 model results:

- Annual maximum SWE shows little response to warming in the BBDS region (-10 to +15% range by 2100 for RCP8.5) and is relatively insensitive to emissions scenario (Figure 3.8, left panels). However, large relative reductions in SWE are projected to take place in the May–October period (Figure 3.8, right panels).
- Annual snow cover duration shows strong sensitivity to warming (Figure 3.9, top panels), with decreases of 15–25% projected by 2100 for RCP8.5. These percentage changes correspond to decreases of approximately 40–60 days, based on the mean annual SCD (255 days) observed at Canadian communities in the BBDS region (see Langen et al., 2016). SCD is also sensitive to emissions scenario: the RCP4.5 results indicate a stabilization of snow cover duration toward the end of this century, at levels about 5% lower than today, while the RCP8.5 results indicate accelerating reductions in snow cover throughout the century.
- Snow cover duration is projected to decrease more rapidly in the start of the snow season than at the end of the snow season (Figure 3.9, bottom panels). This feature is also found in snow cover trends from in situ observations and in high-resolution regional RCP4.5 and RCP8.5 model projections for Greenland (Christensen et al., 2015).

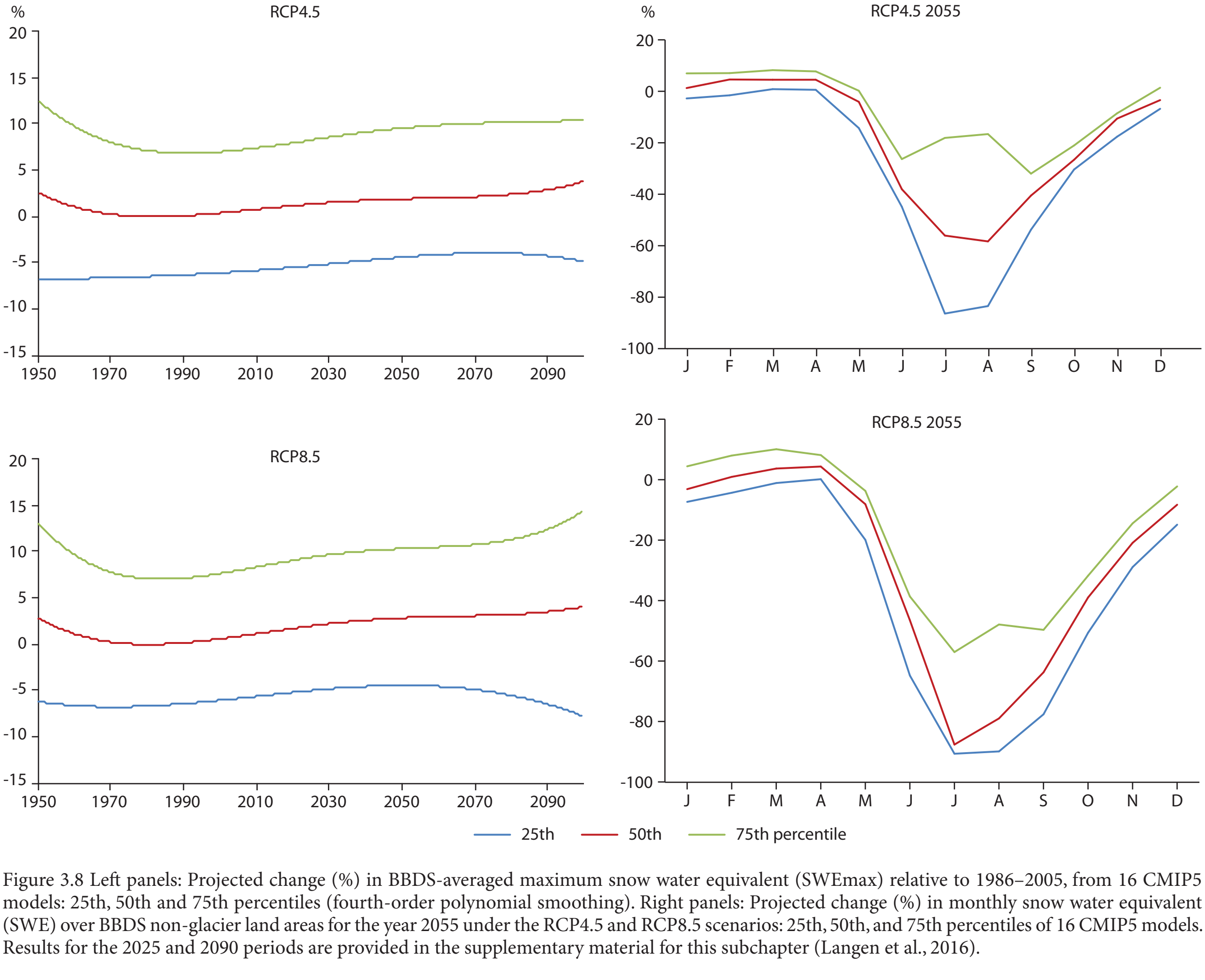

Figure 3.8 Left panels: Projected change (%) in BBDS-averaged maximum snow water equivalent (SWEmax) relative to 1986–2005, from 16 CMIP5 models: 25th, 50th and 75th percentiles (fourth-order polynomial smoothing). Right panels: Projected change (%) in monthly snow water equivalent (SWE) over BBDS non-glacier land areas for the year 2055 under the RCP4.5 and RCP8.5 scenarios: 25th, 50th, and 75th percentiles of 16 CMIP5 models. Results for the 2025 and 2090 periods are provided in the supplementary material for this subchapter (Langen et al., 2016).

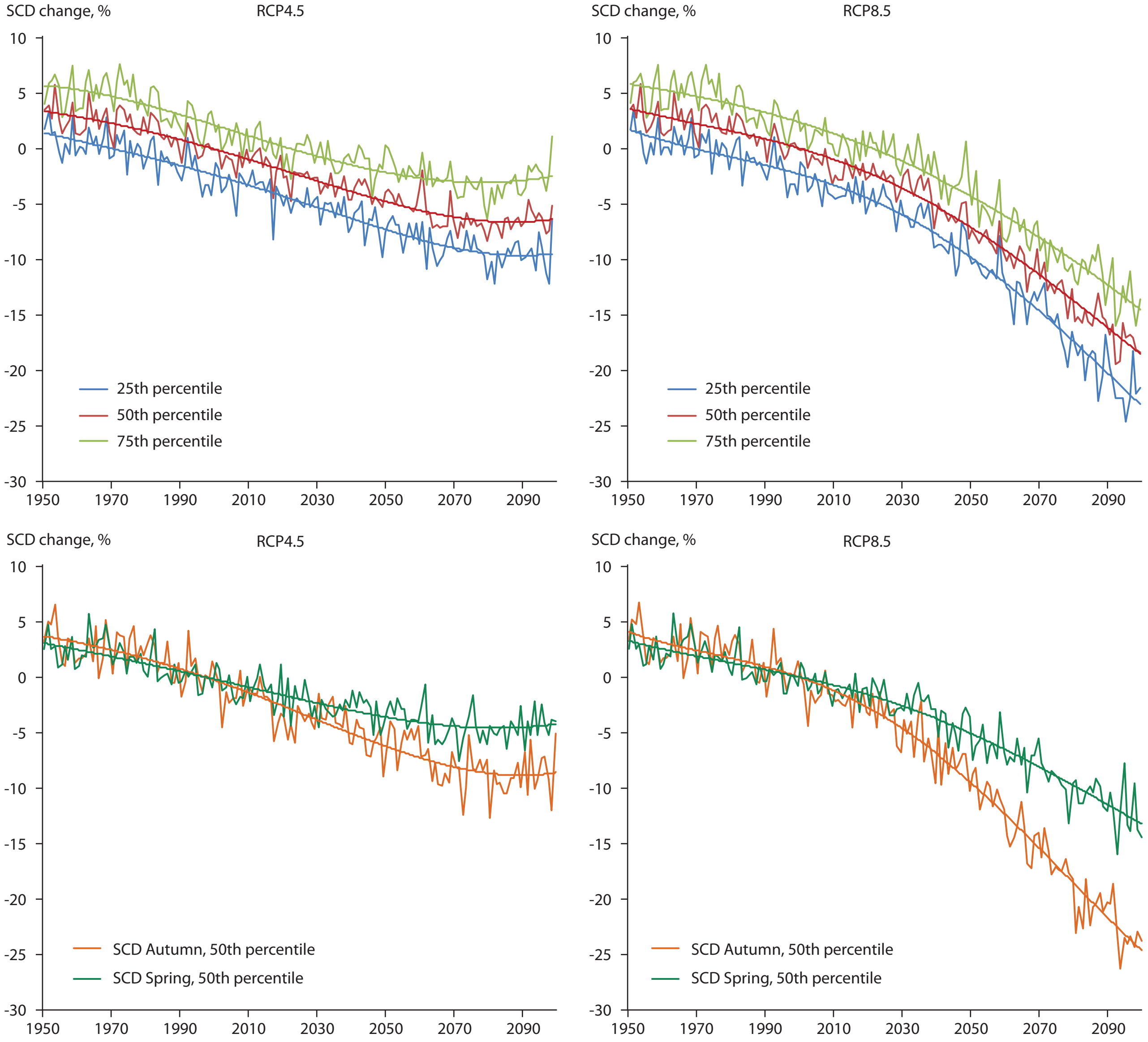

Figure 3.9 Top panels: Projected change (%) in annual snow cover duration relative to 1986–2005, averaged over non-glacier land points in the BBDS region, from 16 CMIP5 models: 25th, 50th, and 75th percentiles. Bottom panels: Projected change (%) in snow cover duration over the first half (SCD Autumn) and second half (SCD Spring) of the snow season, relative to 1986–2005, from 16 models: 50th percentiles.

More detailed information on the spatial pattern of projected snow cover changes from the CanRCM4 regional climate model (0.22° Arctic CORDEX experiment, run 1) (Scinocca et al., 2016; see Langen et al., 2016) shows evidence of strong coastal gradients in SWEmax change in several areas (e.g., southern Baffin Island, southwestern Greenland, Ellesmere Island), with decreases along the coastal margins and increases over higher elevations farther inland. The stronger climate response of snow cover in coastal regions is consistent with the conclusions of Brown and Mote (2009) regarding the higher climate sensitivity of snow cover in marine areas. This greater sensitivity is related to the warmer cold season temperatures and higher precipitation in these areas.

3.1.3.2 Permafrost

BBDS permafrost is projected to warm the most in the region's coldest areas and to thaw considerably in the warmest areas. Ellesmere Island is an example of a cold area that is projected to experience pronounced permafrost warming. Southwestern Greenland is an example of a relatively warm area that is projected to experience pronounced permafrost thawing.

The thermal state of the ground is closely linked to climate – particularly air temperature and precipitation, which are the main drivers influencing thermal-state variability and temporal and spatial changes. Other local environmental drivers – such as wind, snow drift dynamics (Stieglitz et al., 2003; Zhang, 2005), vegetation cover growth (Lantz et al., 2012), drainage, and subsurface material properties (including ice/moisture content) – greatly influence ground temperature and its spatial and temporal variability. In such contexts, trends in shallow ground temperature can be sensitive to short-duration variations and regional comparisons can be challenging. Deeper ground temperatures reflect longer-term trends in climate. A recent review of changing Arctic permafrost and the impacts of these changes is provided in Chapter 3 of the SWIPA update (Romanovsky et al., 2017).

Observed trends

Figure 3.10 shows permafrost temperatures for several sites in the BBDS region. On the Canadian side, the mean annual ground temperatures generally decrease with increasing latitude, ranging from about -5°C in the southern portion of Baffin Island to about -15°C at the northernmost sites of Ellesmere Island (e.g., Smith et al., 2010; Smith et al., 2013). On Baffin Island, the thickness of the active layer (the seasonally thawed surface layer above permafrost) ranges from less than 1 m to about 2 m (Ednie and Smith, 2010; Ednie and Smith, 2011); limited observations indicate thicknesses generally less than 1 m for the northernmost sites. Since the 1980s, permafrost temperatures at Alert have increased at rates of about 0.5 and 0.3°C per decade at depths of 15 and 24 m, respectively (Figure 3.11 and Table 3.1), which is consistent with air temperature trends (Smith et al., 2012; Romanovsky et al., 2015). Higher rates of permafrost warming were observed in the period 2000–2014, with a warming of 0.7 to 1°C per decade at 24 m depth and 1.3°C per decade at 15 m depth. Record-high permafrost temperatures were observed at Alert in 2012, with mean annual ground temperatures in the upper 25 m reaching more than -11°C at one site (Romanovsky et al., 2015). Shallow (<5 m) permafrost temperatures recorded in Iqaluit show warming rates of about 0.2°C per year between 1993 and 2004 (Throop et al., 2010). The shorter time series records (4–5 years) at 10 to 15 m depth at other sites on Baffin Island and the surrounding islands show warming patterns similar to those recently observed at Alert. These patterns are part of a consistent pan-cryospheric response to warming (Derksen et al., 2012).

Table 3.1 Change in permafrost temperature over time for selected sites in the BBDS region (Smith et al., 2012; Romanovsky et al., 2015; Throop et al., 2010; Ednie and Smith, 2015; plus updates).

Site (and measurement depth)	Time period	Rate of temperature change (°C per year)
Alert BH1 (24 m)	1978–2014	0.03
	2000–2014	0.07
Alert BH2 (24 m)	1978–2014	0.03
	2000–2014	0.10
Alert BH5 (15 m)	1978–2014	0.05
	2000–2014	0.13
Resolute (15 m)	2008–2012	0.33
Eureka (10 m)	2009–2012	0.29
Arctic Bay (15 m)	2008–2013	0.18
Pond Inlet (15 m)	2008–2013	0.15
Iqaluit (5 m)	1993–2004	0.20

On the Greenland side of the BBDS region, permafrost temperatures are relatively warm (close to 0°C) in coastal zones and south of the Arctic Circle; inland and farther north, temperatures are colder. Data from four shallow boreholes covering the period 2007–2009 (Figure 3.10) indicate that mean

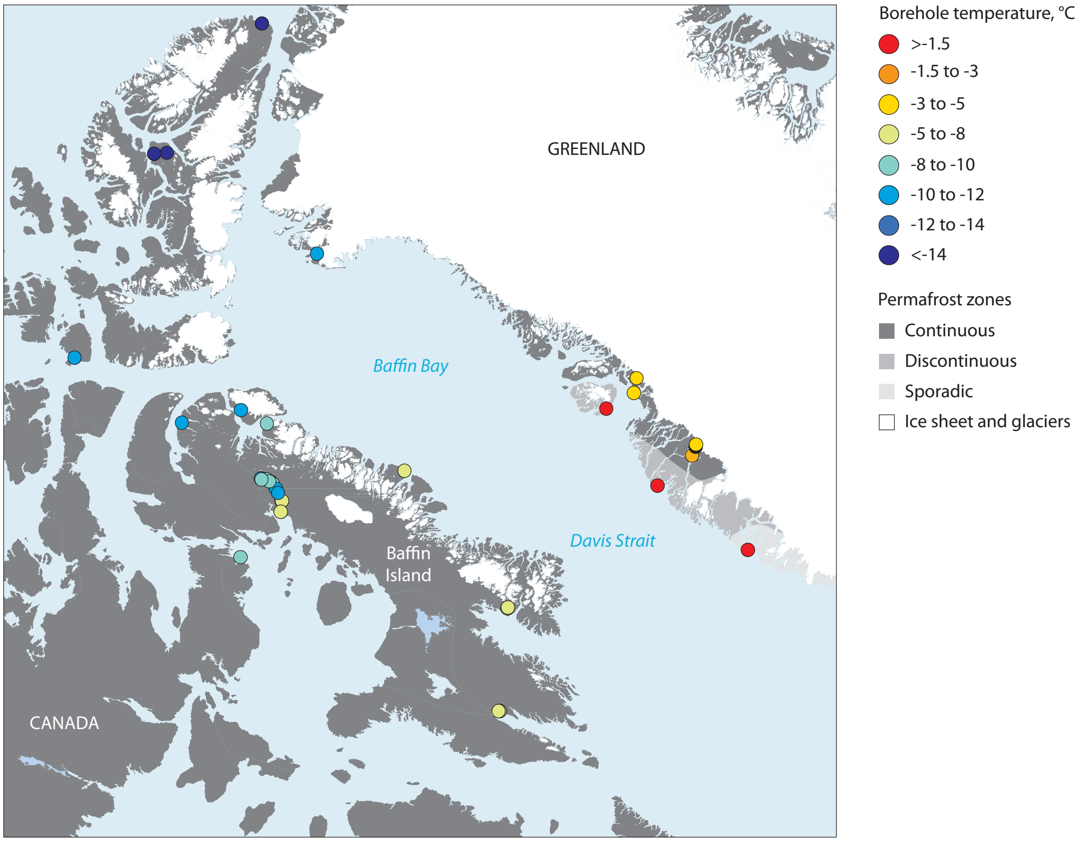

Figure 3.10 Permafrost temperatures (derived from Christiansen et al., 2010; Smith et al., 2013) and permafrost zones (from the map of Brown et al., 2014). The temperatures represent mean annual ground temperature at the depth of zero annual amplitude (the depth below which there is no significant seasonal variation in ground temperature) or at the depth of the closest measurement. The data were generally collected since 2008. The permafrost zone categories, indicated by the dark-to-light gray shading, are continuous (90–100% cover), discontinous (50–90% cover), and sporadic (10–50% cover).

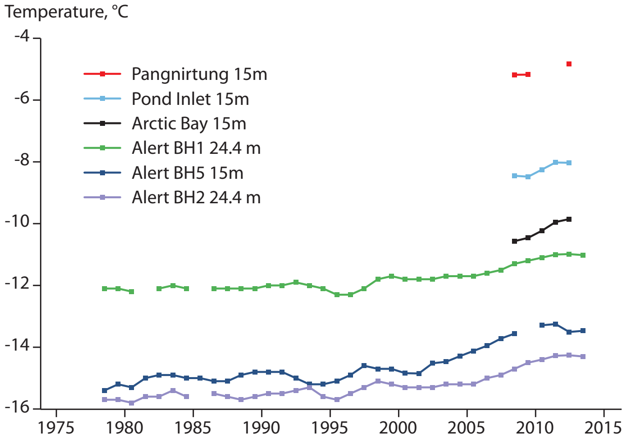

Figure 3.11 Permafrost temperature (annual mean) time-series records (reproduced from Smith et al., 2015) for Canadian Forces Station (CFS) Alert, at depths of 15 and 24 m (updated from Smith et al., 2012, and Romanovsky et al., 2015) and three communities on Baffin Island (data from Ednie and Smith, 2015, and Romanovsky et al., 2015). Alert BH1 is located near the coast and has greater snow cover than the other two Alert sites. (This figure is a copy of an official work published by the Government of Canada. This reproduction has not been produced in affiliation with or with the endorsement of the Government of Canada.)

annual ground temperatures at depths near 4 m range from 0.2°C at Nuuk (sporadic permafrost) to -3.4°C at Ilulissat (continuous permafrost) (Christiansen et al., 2010). The Ilulissat borehole is located in a fine-grained marine deposit with a residual salinity that increases with depth. The resulting depression of the freezing point (relative to zero-salinity conditions) means that permafrost at this site is relatively close to thawing (Ingeman-Nielsen et al., 2010). In the northernmost part of West Greenland, a borehole at Thule has a mean annual ground temperature of -10°C (Bjella, 2012). These observed values are in agreement with simulation results obtained from the Geophysical Institute Permafrost Lab (GIPL; University of Alaska, Fairbanks) model forced using year 2005 data from the Climate Research Unit 3.1 database (CRU-3.1).

Projected changes

The recent CMIP5 generation of climate and earth system models shows a wide range of abilities in the simulation of current permafrost distribution and active-layer characteristics. Most models are not designed to simulate deep ground temperatures. Computed temperatures are sensitive to soil layer and lithologic discretization, realistic representation of surface snowpack and organic soils, realistic treatment of heat and water flow in soils, and the numerical precision of the computer running the climate model (Paquin and Sushama, 2015). In addition, Slater and Lawrence (2013) found that some models had significant air temperature and snow depth biases that adversely affected their ability to simulate realistic permafrost conditions.

It is therefore practical to employ a dedicated permafrost model driven by climate model output. Figure 3.12 shows the result of one such experiment (using the model GIPL2; Marchenko et al., 2008). Under RCP4.5 (Figure 3.12, upper panels), the simulated permafrost temperatures at 5 m depth show warming of about 2–4°C over large areas of the cold permafrost regions on the Canadian side of the region by the years 2081–2100. The Greenland side also shows ground temperatures increasing by up to 2–4°C. This warming results in degradation of the permafrost, especially in the southern part of the region (Gent et al., 2011). Under RCP8.5 (Figure 3.12, lower panels), the largest increase in the 5 m temperature could reach 8–10°C by the 2081–2100 period; most of the permafrost on the Canadian side could warm by about 6–8°C. On the Greenland side, where the permafrost is already fairly warm (between 0 and -5°C), large areas are projected to have temperatures cross the 0°C threshold by 2081–2100. These results, which reflect only one model (GIPL2) and do not account for local variability, may not accurately correspond to site-specific observations.

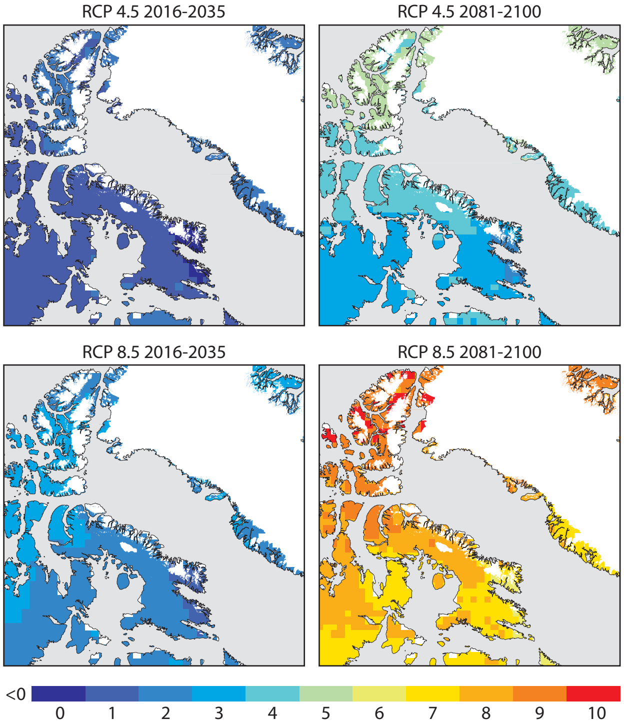

Figure 3.12 Projected change for BBDS permafrost, expressed as the change in average temperature (°C) at 5 m depth for the periods 2016–2035 (left panels) and 2081–2100 (right panels). The results are based on the GIPL2 transient permafrost model forced with the CCSM4 GCM and emission scenarios RCP4.5 (upper panels) and RCP8.5 (lower panels). Changes are computed relative to the reference period 1986–2005.

3.1.3.3 Land ice

The Greenland Ice Sheet is projected to lose mass during the 21st century, with the primary mechanisms being increased freshwater runoff (up to a doubling or tripling) and glacier calving. Year-to-year variability in freshwater runoff is projected to increase. The Canadian Arctic glaciers and ice caps are similarly projected to lose mass due to increased runoff.

The BBDS region encompasses ice sheets and glaciers in both Greenland and the Canadian Arctic Archipelago. Ice sheets and glaciers gain mass through precipitation, and they lose mass primarily through meltwater runoff, iceberg calving, and melting in direct contact with ocean water. The difference between the mass gain and loss is called the total mass balance. The surface mass balance is the difference between accumulation from precipitation and mass loss from surface ablation (sublimation, drifting snow erosion, and runoff of meltwater). The loss of mass through iceberg calving and melting in direct contact with the ocean is termed the dynamical mass loss. An Arctic-wide perspective on observed and projected changes in land ice is provided in Chapter 4 of the SWIPA update (Box et al., 2017).

Observed trends

According to a reconstruction by Box (2013), meltwater runoff from the Greenland Ice Sheet as a whole increased 63% over the 1840–2010 period. This reconstruction suggests that the ice sheet surface mass balance had an insignificant decreasing trend due to nearly equal increases in accumulation and runoff rates. In the early 1990s, the surface mass balance started to decrease, due almost entirely to increased melting and runoff, with changes in accumulation being small (Sasgen et al., 2012; Vernon et al., 2013). The increase in melting is driven by regional warming that is associated with both anthropogenic changes (e.g., Fyke et al., 2014b) and prevailing atmospheric circulation patterns that are favorable for melting (e.g., Fettweis et al., 2013).

The ice sheet changes led to 20–50% increases in freshwater input to the seas adjacent to Greenland between 1992 and 2010 (Bamber et al., 2012). Mernild and Liston (2012) modeled regional changes in the magnitude and timing of runoff since 1960. Runoff increase is attributed mainly to an increase in areal melt extent, with smaller contributions from an increase in melt duration and a countering decrease in melt rates. The length of the simulated discharge season was longest in the south (about 4–6 months) and shortest in the north (about 2–3 months). The length of the discharge season increased between 1960–1969 and 2000–2010, with changes ranging from 11 days in the north to 27 days in the south and southwest. The mass loss and ocean freshwater input from increased runoff has been augmented by an increased iceberg calving flux since the early 1990s from southern and western Greenland (Bigg et al., 2014).

Reconciliation of results from various methods estimating the total mass balance of the Greenland Ice Sheet (e.g., Shepherd et al., 2012) has documented a sharp increase in the total mass loss over recent decades. The IPCC's AR5 (IPCC, 2013a) reports an acceleration from 0.1 mm sea-level equivalent per year (1992 –2001) to 0.6 mm per year (2002–2011). According to Enderlin et al. (2014), the relative contribution of dynamical mass loss to the total loss decreased from 58% before 2005 to 32% between 2009 and 2012. In the southwest, recent mass loss has been mainly through surface mass balance, while in the west and northwest, surface mass balance and dynamical mass loss contribute approximately equally. The majority of the current Greenland total mass loss (about 60%) is attributed to West Greenland (Andersen et al., 2015).

Outside the ice sheets of Greenland and Antarctica, the Canadian Arctic Archipelago (CAA) contains the largest area of land ice (~150,000 km^2) on Earth. Recent estimates of mass loss identify the CAA as the single largest land ice contributor to sea level rise outside the two ice sheets (Gardner et al., 2011; Sharp et al., 2011; Gardner et al., 2013; Sharp et al., 2014). Observations show that most of the land ice in the CAA has lost mass, thickness, and area over the past half century as a result of climate warming. Since 2007, more intense and sustained melt has occurred in response to a trend toward more frequent summer anticyclonic circulation over the region (Overland et al., 2012; Gascon et al., 2013; Sharp et al., 2014; Bezeau et al., 2015). The CAA mass losses are dominated by melt and runoff, with iceberg calving playing a varying but apparently minor role (Williamson et al., 2008; Van Wychen et al., 2014). Floating ice shelves at northern Ellesmere Island have also been strongly affected by the recent warming, with some fjords in the region now ice free for the first time in over 3,000 years (Sharp et al., 2014; White et al., 2014).

Projected changes

Although snowfall accumulation is projected to increase in the future (Krasting et al., 2013), all studies indicate that the Greenland surface mass balance will continue to decrease because projected increases in runoff are greater than projected increases in accumulation (Church et al., 2013a). Rae et al. (2012) compared regional climate models over Greenland, driven by different global models. Depending on the model combinations employed, projected runoff rates increase by about a factor of 2–3 over the 21st century in the A1B scenario (which lies between the RCP4.5 and RCP8.5 scenarios). In a single-model experiment using the RCP8.5 scenario, Fyke et al. (2014a) found an approximately 50% increase in year-to-year variability in surface mass balance; this increase was dominated by increased variability in runoff.

Increasing dynamical ice loss has been linked to the arrival of warm ocean water (Holland et al., 2008; Straneo et al., 2010, 2012) and a reduction of ice in the fjord ahead of a glacier terminus, thus increasing the calving rate (Amundson et al., 2010). As noted by Church et al. (2013a), 19 coupled global atmosphere–ocean climate models show a warming of about 2°C in scenario A1B around Greenland over the 21st century (Yin et al., 2011), indicating that the increased outflow may be expected to continue into the future. We do not currently have three-dimensional models of iceberg calving and energy exchange at the ice–ocean interface, but flowline modeling by Nick et al. (2013) suggests speed-ups of up to 70% for a suite of four major outlet glaciers. These speed-ups tend to occur mainly in the early part of the 21st century; after that, the speeds level out.

Model projections of future mass loss components were synthesized by Church et al. (2013a), and the projected Greenland Ice Sheet contribution to sea level rise is given in Table 3.2. The median total contribution is found to be about 10 cm of sea level, with an upper range of about 20 cm.

Table 3.2 Projected Greenland Ice Sheet contribution to sea level rise (in meters) by 2081–2100, relative to 1986–2005: median values [and likely ranges] (Church et al., 2013a).

	Surface mass balance (m)	Dynamical mass loss (m)	Total (m)
RCP4.5	0.04 [0.01 to 0.09]	0.04 [0.01 to 0.06]	0.08 [0.04 to 0.13]
RCP 8.5	0.07 [0.03 to 0.16]	0.05 [0.02 to 0.07]	0.12 [0.07 to 0.21]

As with the Greenland Ice Sheet, the indications are that the currently observed trend of CAA glacier mass loss will continue into the future, as enhanced meltwater runoff is not sufficiently compensated by increased snowfall (Lenaerts et al., 2013). However, it should be stressed that there is considerable model variability in the sign, magnitude, and timing of projected changes in snowfall and accumulated snow mass over the region; in addition, most climate models do not represent local moisture sources such as the North Water Polynya, which is an important contributor to the mass balance of the Manson and Prince of Wales ice fields (Boon et al., 2010). Radic et al. (2013) used downscaled output from 14 different global climate models forced by emissions scenarios RCP4.5 and RCP8.5 to drive a glacier mass balance model. For the period 2006–2100, they found glacier volume reductions of 10–60% in the Queen Elizabeth Islands and 20–100% in the Baffin/Bylot region. The glaciers of the Queen Elizabeth Islands have a relatively low sensitivity to the first 2°C of warming, but their sensitivity increases as warming increases beyond that point. Relative to other regions, the CAA has a relatively low sensitivity of mass balance to climate warming, but this still results in large projected mass losses due to the relatively large warming projected over this region.

3.1.3.4 Freshwater ice

Projections for lake ice in 2050 indicate a 10–15 day earlier break-up and a 5–10 day later freeze-up, with a 10–30 cm decrease in maximum ice thickness. Lake-ice response to warming is influenced by lake morphology (size and depth) and local changes in snow accumulation.

The following material is taken largely from the ArcticNet Eastern and Central Canadian Arctic Integrated Regional Impact Study (IRIS) report (Stern and Gaden, 2015) and the Eastern Canadian Arctic IRIS report (Brown et al., 2018).

Lake and river ice are integral components of the northern environment, and they influence a wide range of related climate-sensitive ecosystem services and numerous ecological and water quality characteristics (Beltaos and Prowse, 2009; Prowse et al., 2011a). Ice is also a critical component of cold-region hydrologic systems, affecting extreme floods and low winter flows (Beltaos and Prowse, 2009). Ice cover formation, melt, and dynamics are sensitive to a variety of meteorological variables, and changes in any of these variables can influence ice composition, thickness, and stability, as well as the complex interactions among hydrodynamic, mechanical, and thermal processes (Beltaos and Prowse, 2009). Lake and river ice regimes also respond to non-climatic controls such as lake morphology and depth (Brown and Duguay, 2010) and changes in the terrestrial hydrologic regime (Prowse et al., 2011a, 2011b).

Compiling information on trends in lake and river ice cover is a challenge. Few in situ records exist, and satellite observations have a variety of limitations related to resolution, frequency, consistency, and duration of coverage. Latifovic and Pouliot (2007) used Advanced Very High Resolution Radiometer (AVHRR) satellite imagery to analyze lake freeze-up/break-up trends over the period 1985–2004, including four lakes distributed across the Canadian side of the BBDS region. Their analysis showed evidence that these lakes were part of a consistent Canadian Arctic–wide trend toward later freeze-up and earlier break-up. The average change observed over the four lakes for the 20-year period was a 15-day later freeze-up and a 24-day earlier break-up. Lake Hazen, near Alert, exhibited the largest trends and also the only statistically significant trends. Paquette et al. (2015) provided evidence of recent significant changes at Ward Hunt Lake on northern Ellesmere Island, from analysis of field records, aerial photographs, and satellite imagery. These records show that the summer perennial ice regime was relatively stable from 1953 to 2007 but then experienced rapid thinning in 2008 and became ice free in 2011. Further evidence of rapid lake ice changes over the region was provided by Surdu (2015), who observed widespread decreases in lake ice cover over the Canadian Arctic Archipelago from analysis of RADARSAT data for the 1997–2011 period. There is also evidence that some lakes may be transitioning from perennial to seasonal ice regimes (Mueller et al., 2009), which has major consequences for freshwater ecosystems and related ecosystem services (Vincent et al., 2012).

A variety of methods are used to generate scenarios of projected change in river and lake ice because these quantities are typically not resolved in global climate models. Recent studies have applied lake ice models to estimate the responses of lake ice characteristics to changes in temperature and precipitation: lake ice freeze-up/break-up, ice thickness, and the potential for white ice formation (Brown and Duguay, 2011; Dibike et al., 2011, 2012). White ice results from the incorporation of melted surface snow into the ice. Over the BBDS region, these studies project a 10–15 day earlier break-up and a 5–10 day later freeze-up for 2050. These numbers are comparable to an estimated decrease in river ice duration over most of Canada of approximately 20 days by 2050, provided by Prowse et al. (2007), based on the observed temperature sensitivity of river ice. Ice thickness is projected to decrease by 10–30 cm, with only small increases in the amount of white ice formation. These model simulations are based on an "idealized lake" of fixed depth. In reality, lake response will vary with lake morphology (size and depth) and local changes in snow accumulation, as shown by Brown and Duguay (2011).

3.1.4 Ocean

A freshening and warming of the Baffin Bay surface layer (about 0.2°C per decade over the next 50 years) is projected under the high-emissions scenario. This change is expected to reduce convection depth during winter and increase water column stability during the ice-free months. Models project an increased inflow of warm Atlantic-origin water into the bay, a decrease of cold Arctic water flow through the Canadian Arctic Archipelago, and an intensification of the counterclockwise circulation in Baffin Bay. Under these projected changes, the duration of ice bridges in Nares Strait, and thus the duration of the North Water Polynya, will likely decrease.

3.1.4.1 Physical oceanography of the region

Baffin Bay connects the Arctic Ocean with the western North Atlantic through three narrow CAA passages (Nares Strait, Jones Sound, and Lancaster Sound). Depth-averaged summer temperature and salinity over the upper 100 m (Figure 3.13) displays an east–west difference that reflects the relatively warm and salty West Greenland Current flowing northward along the west Greenland slope and the cold and fresh Arctic water flowing southward through the CAA and along the western side of Baffin Bay and Davis Strait. The relatively fresh water nearshore on the west Greenland shelf is a continuation of the East Greenland Coastal Current, which rounds the southern tip of Greenland to then flow northward, hugging the western Greenland coast; ice sheet runoff further freshens this water as it travels northward.

Vertically, Baffin Bay has a three-layer structure consisting of cold and fresh Arctic water in the top 300 m, a warm and salty middle layer from about 300 to 800 m, and a cold and slightly fresher deep layer (Tang et al., 2004). A similar three-layer structure is observed in Davis Strait (Figure 3.14) to the south, although the deep layer in the strait, in contrast to the bay, is not fresher than the middle layer. The winter mixed layer depth, resulting from wind mixing and sea ice formation, reaches about 100 m (Tang et al., 2004). In the summer, a strong, shallow pycnocline develops, reducing the mixed layer depth to about 10–30 m (e.g., Harrison et al., 1982; Jensen et al., 1999).

A summary of observation-based mean freshwater inputs and outputs for Baffin Bay is shown in Figure 3.15. The data upon which many of the numbers are based are extremely limited, and they do not reflect the strong interannual variability observed at locations where measurements have been taken long enough to identify lower-frequency variability as an important feature of these Arctic Ocean exports.

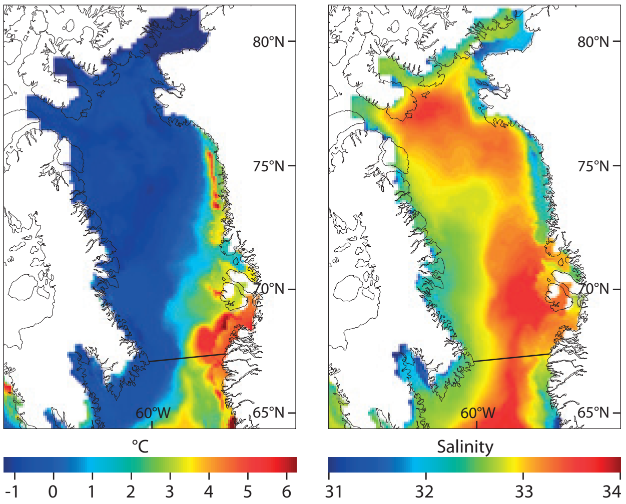

Figure 3.13 Summer (August to October) temperature (left panel) and salinity (right panel) in the upper 100 m of the Baffin Bay/Davis Strait water column. Derived from available archived data between 1910 and 2009. The transect line indicates the location of the cross-sections shown in Figure 3.14. (Modified from Hamilton and Wu, 2013; see their report for data-set details. © Her Majesty in Right of Canada, as presented by the Minister of Fisheries and Oceans.)

There are three principal inputs of fresh water to Baffin Bay: the CAA passages, the East Greenland Coastal Current extension, and the Greenland Ice Sheet. Combining estimates from the CAA passages (Melling et al., 2008; Munchow and Melling, 2008; Rabe et al., 2012; Peterson et al., 2012; Hamilton and Wu, 2013; see Langen et al., 2016, for Barrow Strait/Lancaster Sound time series) gives a mean volume transport through the entire CAA of about 1.5 Sv (1 Sv = 1 million m^3 per second) and a freshwater transport of 81 mSv. These inputs show strong seasonal variability (with summer transport being 2–3 times larger than winter transport) and strong interannual variability (up to a factor of 4). Along West Greenland, Curry et al. (2014) derived northward mean volume transports of 0.4 Sv on the shelf and 0.7 Sv on the slope (Irminger Sea water) and a freshwater transport of 24 mSv. For the western half of Davis Strait, they reported a southward mean volume transport and freshwater transport in the Baffin Island Current of 2.9 Sv and 117 mSv, respectively. Glacial freshwater (solid and liquid) also enters Baffin Bay, principally off the Greenland Ice Sheet but also from glaciers on Baffin and Ellesmere islands. According to Bamber et al. (2012), 80% of the total Greenland discharge enters the ocean on the western and southeastern coasts. The rate of freshwater discharge from these glacial sources is increasing (Rignot et al., 2011; Bamber et al., 2012).

3.1.4.2 Observed trends

Hamilton and Wu (2013) used archived summer temperature and salinity data from 1950 to 2005 to derive trends in Baffin Bay and Davis Strait. Although interannual variability was high, particularly in the upper ocean, some significant trends were observed:

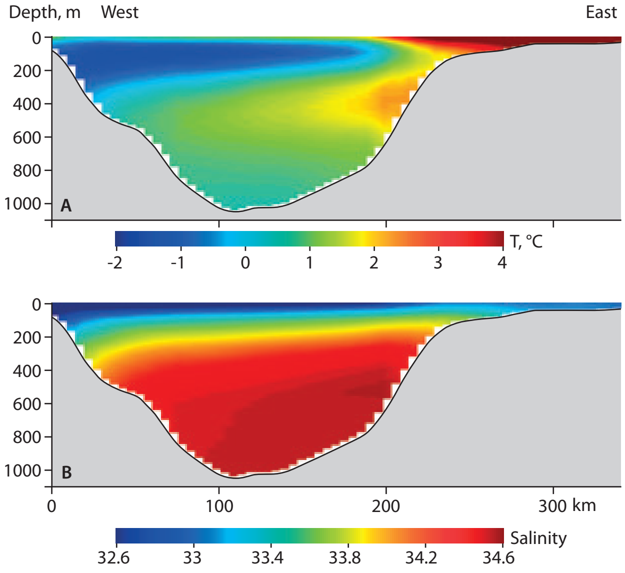

Figure 3.14 Davis Strait cross-sections of mean summer temperature (T, top) and salinity (S, bottom). Derived from available archived data between 1910 and 2009. The three-layer structure of Baffin Bay is also reflected in these Davis Strait data. The location of the cross-sections is indicated by the black transect line in Figure 3.13. (Reproduced from Hamilton and Wu, 2013; see their report for data-set details. © Her Majesty in Right of Canada, as presented by the Minister of Fisheries and Oceans.)

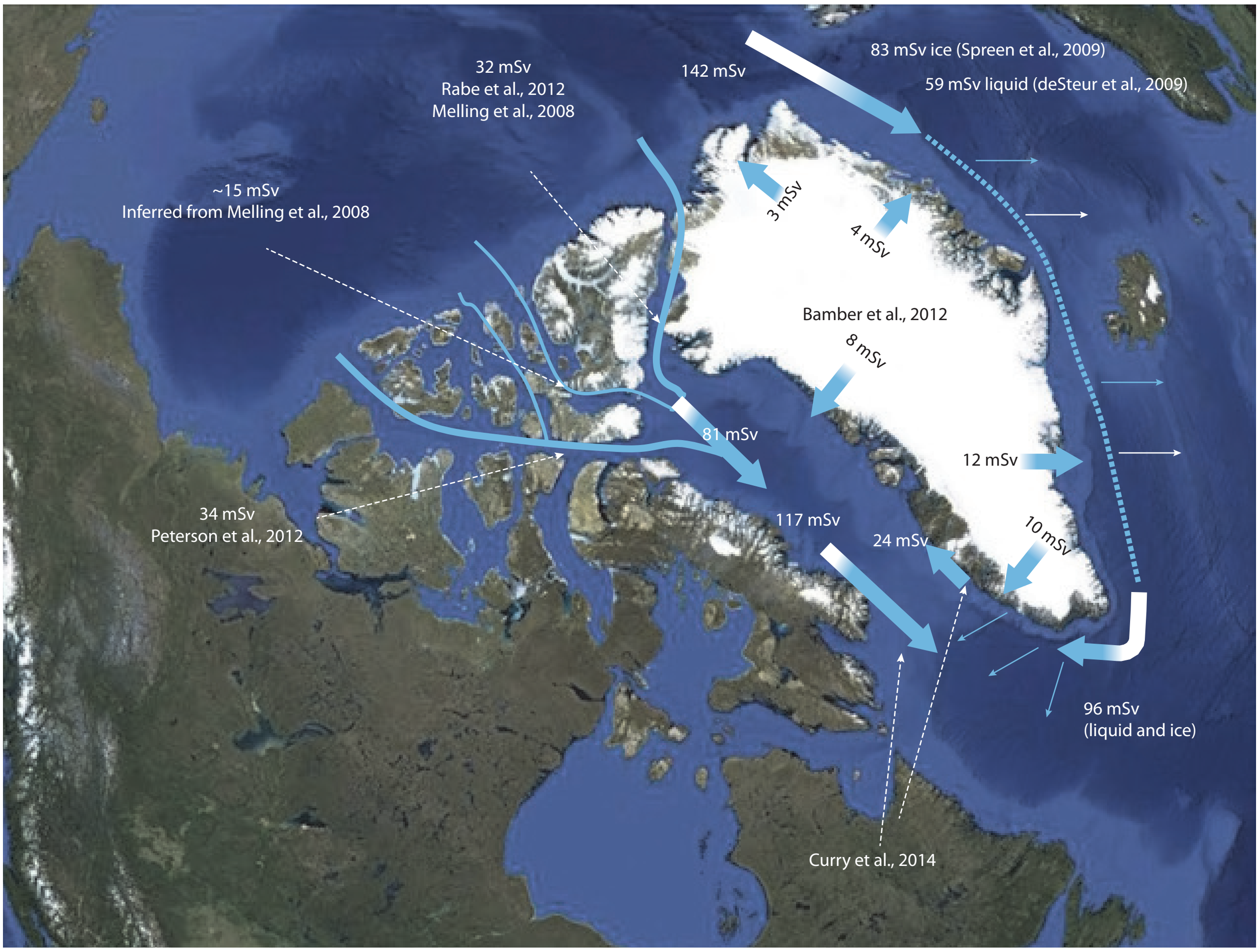

Figure 3.15 Mean freshwater fluxes (mSv) into Baffin Bay, based on observations reported by the referenced investigators. The coloring of the block arrows denotes the portion of the flux that is liquid (blue) versus ice (white).

- Freshening on the Baffin Island shelf (-0.06 psu per decade [psu is practical salinity unit]). This rate is similar to the findings of Zweng and Munchow (2006), who computed a freshening trend of -0.086±0.039 psu per decade using data from 1916 to 2003. Most of the change occurred in the 1980–2005 period. Hamilton and Wu (2013) excluded data from the top 50 m, using data only within the 50–200 m interval because inclusion of the highly variable surface data masked the trend.
- Highly significant warming over the 600–800 m depth interval: 0.13°C per decade over the last 50 years (Hamilton and Wu, 2013). This observed warming trend is consistent with the finding of Zweng and Munchow (2006), who give 0.11±0.06°C per decade for warming of the intermediate layer of Baffin Bay.

According to Vaughan et al. (2013), the rate of Greenland Ice Sheet mass loss during the decade 2002–2011 was 215 Gt/yr (7 mSv). Rignot et al. (2011) found this loss rate to be increasing at 0.76 mSv/yr (based on an 18-year record). This increase in rate is corroborated by Bamber et al. (2012), whose results further indicate that between 1992 and 2010, direct discharge along the shores of Baffin Bay, the Labrador Sea, and the Irminger Sea increased by 22%, 48%, and 49%, respectively.

3.1.4.3 Projected changes

Circulation

As noted in Section 3.1.1, projections of regional-scale changes are typically associated with large uncertainties, and ocean circulation changes are no exception, especially in the Northwest Atlantic/Baffin Bay region (e.g., Loder et al., 2015). Due to their coarse resolution, global models generally lack an adequate representation of the CAA channels, which, as mentioned above, are one of the main Arctic freshwater flux pathways (see the discussion above, regarding the region's general physical oceanography). Moreover, in these models, runoff from the Greenland Ice Sheet is often distributed uniformly over a large region of the northern North Atlantic, rather than close to the Greenland coast. Jahn et al. (2012) showed that a realistic representation of the CAA channel configuration, sea ice thickness, and local ice sheet runoff appears necessary to obtain consistent projections of circulation and freshwater flux changes in Baffin Bay.

High-resolution regional models, on the other hand, have a better representation of the CAA but do not necessarily include all forcings, such as changes in wind stress, large-scale sea surface height, and Greenland Ice Sheet melt. Nevertheless,

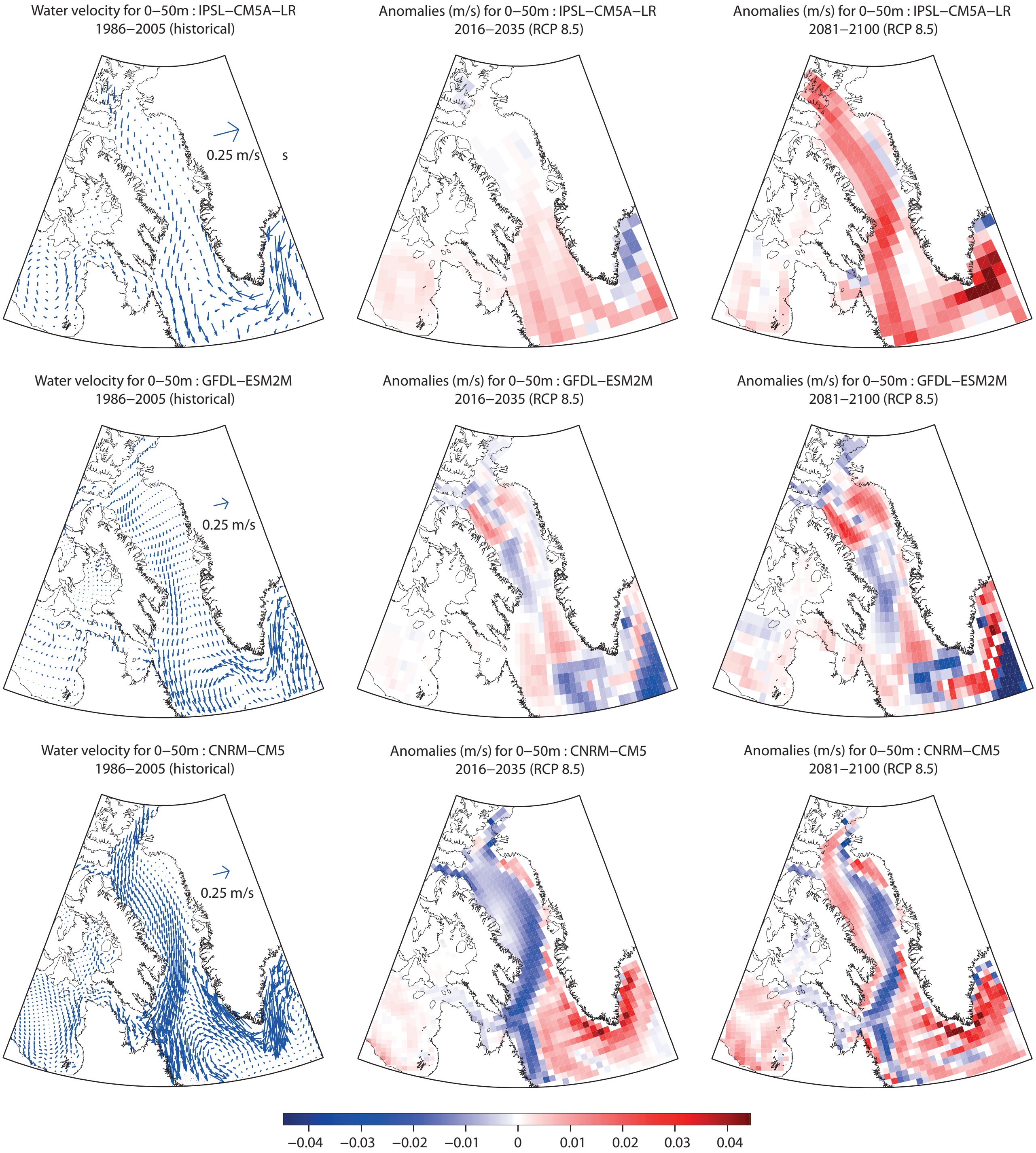

Figure 3.16 Labrador Sea/Baffin Bay mean near-surface current velocities (0–50 m) over the reference period (1986–2005), plus projected changes for the periods 2016–2035 and 2081–2100 under the RCP8.5 scenario. The projected changes are expressed as differences between the future period and the historical period. Each row shows the output of a different model.

some common trends do emerge when considering results from a few global and regional models.

Figure 3.16 shows projected changes in the strength of near-surface currents for the two periods 2016–2035 and 2081–2100 (relative to 1986–2005) for the RCP8.5 scenario for three global models (see Langen et al., 2016, for the RCP4.5 case). Of the seven available models that incorporated biogeochemistry at the time the Lavoie et al. (2013) study was initiated, these three provided a reasonable representation of the counterclockwise circulation in Baffin Bay (Figure 3.16, left column). In the projections of future conditions, this basic circulation pattern generally persists across the different models. The strength of the circulation is the characteristic that changes.

As illustrated in Figure 3.16, the disagreement among the three global models in projected changes in current strengths is comparable in magnitude to the changes themselves. The models all include a representation of ice calving (Swingedouw et al., 2009; Dunne et al., 2012; Voldoire et al., 2013) but only in the GFDL-ESM2M model (Figure 3.16, middle row) is the meltwater distributed close to the ice sheet. This characteristic may explain the GFDL model's better agreement with the following regional model results.

Several regional model studies project a decrease in the flow of cold Arctic water through the CAA due to an increase in sea surface height in Baffin Bay, an intensification of the counterclockwise circulation, and an increased transport of freshwater along the west Greenland coast (Hu and Myers, 2014; Castro de la Guardia et al., 2015; Lique et al., 2015).

Mixed layer depth

Considering the different water masses flowing into Baffin Bay, the uncertainty in future circulation changes, and the low horizontal and vertical resolution of the global models, confidence in the details of projected mixed layer depth changes are low. However, based on recent and projected near-surface air temperature trends (Loder and van der Baaren, 2013; Steiner et al., 2015) and surface layer freshening (see below), some conclusions can be drawn.

The global models analyzed by Lavoie et al. (2013), as well as the regional North American Arctic–Nucleus for European Modelling of the Ocean (NAA-NEMO) model of Hu and Myers (2014), project a mean warming of the surface layer of about 0.2°C per decade over the next 50 years under the RCP8.5 scenario (see Steiner et al., 2015). A freshening trend of the sea surface layer is also projected by these models, although with a greater uncertainty. The multi-model ensemble mean trends calculated by Lavoie et al. (2013) are -0.12 (±0.12) and -0.19 (±0.12) psu per decade for RCPs 4.5 and 8.5 (with ± indicating model spread). The regional NAA-NEMO model projects a freshening of about half that rate (i.e., -0.09 psu per decade; Steiner et al., 2015).

Warming and freshening of the surface layer is expected to stabilize the surface layer, reduce convection depth in winter, and increase water column stability during the ice-free months. The subset of models used by Lavoie et al. (2013) does project a modest decrease of the monthly maximum mixed layer depth. The multi-model ensemble mean trends are -0.7 (±0.6) m per decade for RCP4.5 and -1.0 (±0.6) m per decade for RCP8.5. The mean mixed layer depth trend is associated with an even higher uncertainty than the monthly maximum mixed layer depth. The projected shallowing is of only 2–3 m over the next 50 years. Warming and freshening of the surface layer thus appears to have a greater impact on stratification below the mixed layer, with strengthening stratification potentially resulting in reduced vertical mixing and a reduction of heat loss from the warm subsurface layer. A warming of the intermediate layer has indeed been simulated in different studies (e.g., Castro de la Guardia et al., 2015; Lique et al., 2015; and references therein).

Projections examined by Holland et al. (2007) consistently showed increased freshwater storage in the Arctic Ocean and increased freshwater export into the North Atlantic in response to increased precipitation, river runoff, and melting. However, the magnitude of these projected changes is highly uncertain. Possible changes in the relative importance of the pathways for freshwater export, i.e., Fram Strait versus CAA, are also unclear. The future impact of increased freshwater input on mixing and circulation in the North Atlantic will depend on whether future conditions favor one pathway over the other.

3.1.4.4 The North Water Polynya

The North Water Polynya is one of the Arctic's largest and most productive polynyas (Deming et al., 2002; see also Chapters 2 and 6). The polynya forms seasonally under the action of strong northerly winds that push sea ice southward, away from an ice bridge that forms in Nares Strait/Smith Sound (at the constriction point between Greenland and Ellesmere Island), thus leaving behind an area of open water (Melling et al., 2001; Dumont et al., 2010). Once the polyna is open, upwelling of warm water along the Greenland coast contributes to its maintenance (Melling et al., 2001; Dumont et al., 2010).

Arctic waters, advected through Nares Strait, and Atlantic waters, advected with the West Greenland Current, are both present in the North Water Polynya (Melling et al. 2001; Lobb et al., 2003). Arctic waters cross the polynya as a southward flow, while the West Greenland Current, entering through Melville Bay, splits and then recirculates into the southward flow at different locations (Melling et al., 2001; Dumont et al., 2010). During northerly wind events, upwelling can occur both along the Greenland coast and along the landfast ice edge (ice bridge), depending on the ice configuration (Dumont et al., 2010). The warm upwelled waters, rich in nutrients, contribute to the high primary production reported for this area (Tremblay et al., 2002).

The presence of an ice bridge is necessary for the formation of the polynya (Melling et al., 2001). With the observed and projected changes (e.g., warming, freshening, thinning of sea ice; more mobile sea ice), the duration of ice bridges in Nares Strait/Smith Sound – and thus the duration of the North Water Polynya – will likely decrease. The existence of the North Water Polynya could be at risk in the future, with significant consequences for primary production (Michel et al., 2015). An important reduction in primary production in the polynya was indeed observed in the last decade and was attributed to freshening and increased stratification resulting from fresher Arctic water flowing through Nares Strait and from increased Greenland glacier melt (Bergeron and Tremblay, 2014). The changes in the ice bridge (i.e., its shorter duration) have also led to an increased advection of multi-year ice through Nares Strait and along the western side of Baffin Bay in recent years (Barber and Massom, 2007; Michel et al., 2015).

3.1.5 Sea ice

Climate models project the largest decreases in sea ice cover to occur in the autumn (15–20% reduction by 2080) due to later freeze-up, with smaller decreases in the spring (10–15% reduction) due to earlier ice break-up. Winter ice thickness is projected to decrease by about 20–30 cm, with the largest decreases in more northerly regions. The timing of the changes varies considerably across models. For the foreseeable future, multi-year ice is likely to remain a hazard for shipping in the Canadian Arctic Archipelago.

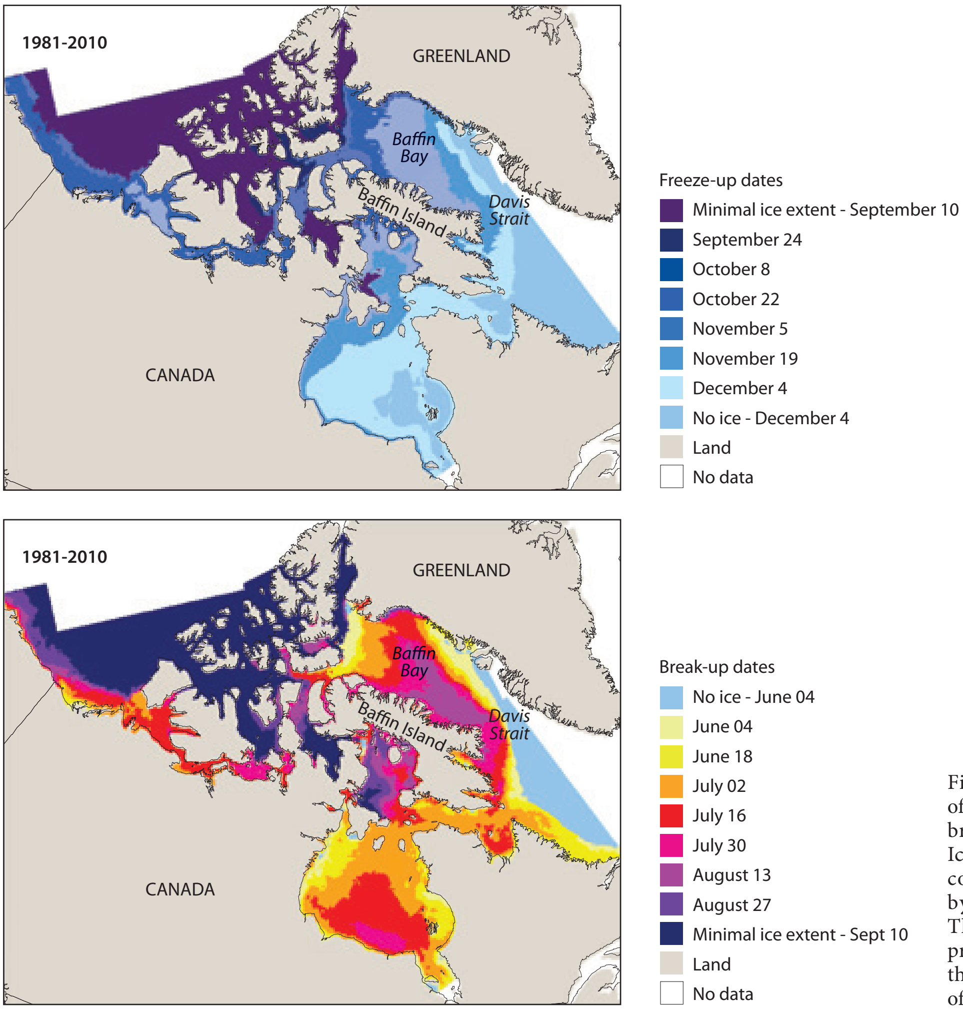

Figure 3.17 Mean dates (1981–2010) of sea ice freeze-up (upper panel) and break-up (lower panel) (Canadian Ice Service, 2011b.) (These maps are copies of official works published by the Government of Canada. These reproductions have not been produced in affiliation with or with the endorsement of the Government of Canada.)

The sea ice season in the BBDS region extends from approximately October to July (Figure 3.17), with seasonal concentration and thickness responding to the combined influences of air temperature, atmosphere and ocean circulation (winds, currents, sea surface temperatures), leads and polynyas, and, when ice is compressed against the west side of Baffin Bay, ridging and rafting. The influence of the North Water Polynya is clearly visible in the Figure 3.17 break-up plot (lower panel), with northern Baffin Bay being the first area to be ice-free. Break-up dates range from June to mid-August, with some northern areas of the region remaining ice covered for most of the year (e.g., Nares Strait, Kane Basin, and the northern coast of Ellesmere Island) (Tivy et al., 2011). On the Greenland side of the region, ice conditions are much lighter due to the influence of the relatively warm, north-flowing West Greenland Current. The ice cover in West Greenland is seasonal even in regions that receive imports of advected multi-year ice.

Only a small amount of multi-year ice enters Baffin Bay from Nares Strait and Lancaster Sound, and it is mainly restricted to the western side of the bay (Tang et al., 2004; Kwok et al., 2010). Sea ice is transported down the western side in the southward-flowing portion of the Baffin Bay gyre at speeds of up to 20–30 km/day (Canadian Ice Service, 2011a). The average ice drift velocity from northern Baffin Bay to the southern Labrador Sea is typically about 10–15 km/day but can exceed 20 km/day with variations in wind speed serving to speed up or slow down this motion (Kwok, 2007; Canadian Ice Service, 2011a).

Ice thickness can vary considerably over the region. For example, ice formed in newly opened leads is typically <0.5 m thick, whereas ice formed at the start of the winter season can eventually reach thicknesses of approximately 1.5 m (Tang et al. 2004). When the pack is compressed against the coastline, ridging and rafting can generate ice thicknesses of over 3 m. Weekly landfast ice thickness measurements made at Canadian coastal communities around Baffin Bay during the 1961–1990 period (Canadian Ice Centre, 1992) show average maximum ice thicknesses ranging from approximately 1.5 m around southern Baffin Island to over 2 m for Alert and Eureka on Ellesmere Island.

3.1.5.1 Observed trends

The BBDS region experienced a 20% loss in July–November sea ice extent over the period 1981–2014 (see Langen et al., 2016), with most of the change occurring in the time after 1998. The year 2006 had the lowest ice cover seen in the period of regular satellite observations. Analysis of trends in ice extent from passive microwave satellite data (Figure 3.18) shows decreases in nearly all months in the BBDS region, with Baffin Bay, Hudson Strait, and Davis Strait experiencing some of the largest Canadian Arctic decreases in summer total sea ice area and multi-year sea ice area (Howell et al., 2009; Tivy et al., 2011). Stroeve et al. (2014), using passive microwave satellite data, examined trends in the dates of first melt and first freeze-up of sea ice over the Baffin Bay region. For the 1979–2013

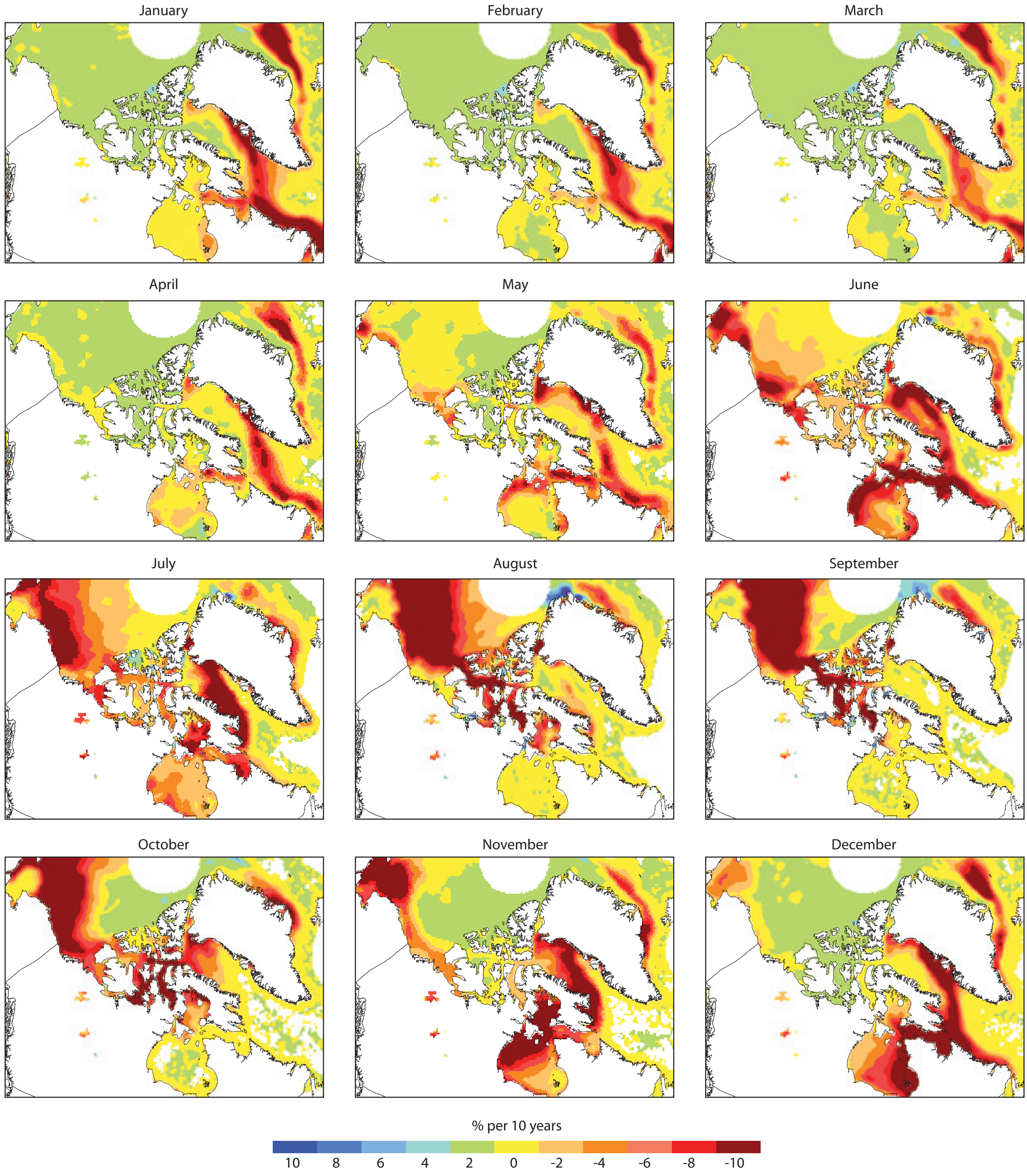

Figure 3.18 Trends in monthly average ice concentration (%) over the Canadian Arctic and adjacent waters, 1979–2012, expressed as percent change per decade (based on the passive microwave satellite data set of Cavalieri et al., 1996, updated to 2012).

period, they found a statistically significant trend to earlier melt onset, of 4.6 days per decade. There was also evidence of a trend to a later freeze-onset date of 0.8 days per decade, but this trend was not statistically significant. This Baffin Bay finding contrasts with the case of the CAA, which was dominated by significant trends to later freeze-up, of 2.2 days per decade. The larger changes in the freeze-up period over the CAA are consistent with recent temperature trends over the region, which show the strongest warming in the October–December season (Rapaić et al., 2015). These ice changes are a reaction to (and in turn provide positive feedbacks to) the increasing air and sea surface temperatures and changes in atmospheric circulation (Overland et al., 2012; Sharp et al., 2014) that are driving the rapid rates of climate change observed over the region in the past decade.

Analyses of U.S. National Ice Center weekly sea ice charts from 1976 to 2007 by Yu et al. (2014) show that landfast ice extent around the Arctic Basin was relatively extensive from the early to mid-1980s but then declined in many coastal

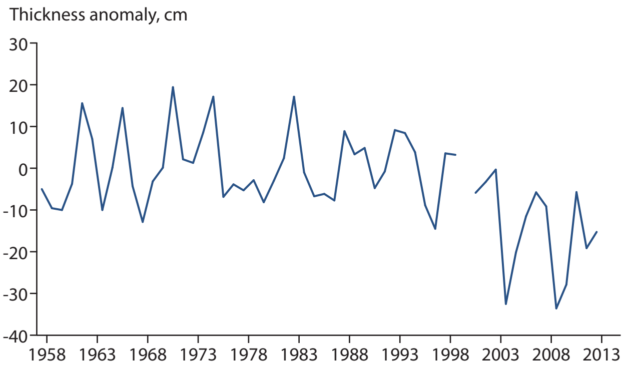

Figure 3.19 Regionally averaged annual anomalies in maximum ice thickness, 1958–2013 (with respect to a 1959–1987 average) from six Canadian BBDS stations with long-term weekly ice thickness measurements. (Ice thickness data were obtained from the Canadian Ice Service, www.ec.gc.ca/glaces-ice/.)

regions of the Arctic, particularly after the early 1990s. Yu et al. (2014) documented a 4.5% per decade decrease in winter landfast ice area over Baffin Bay over the 1976–2007 period, but this trend was not statistically significant. However, their Baffin Bay regional time series of winter landfast ice area (see Langen et al., 2016) shows a reduction of ~50% in landfast ice extent over the period 1994–2005. Analysis of Canadian landfast ice conditions with Canadian Ice Service digital charts from 1983 to 2009 by Galley et al. (2012) showed significant decreases in landfast ice cover duration over the CAA from later ice onset and/or earlier breakup. The study highlighted major reductions in landfast ice cover duration for most of Baffin Bay's coastal regions. Three BBDS communities (Arctic Bay, Pond Inlet, and Clyde River) were identified as being located in areas that were most affected by decreasing landfast ice duration. In the interior of the Northwest Passage, landfast sea ice duration was not observed to have undergone any statistically significant change over the period analyzed. These observed decreases in landfast ice duration are consistent with Inuit community observations of thinner ice and a shorter ice season (observations summarized by Gaden and Stern, 2015). The impacts of the changing ice regime on Inuit hunting are discussed in Section 6.5.2.

Analyses of weekly ice thickness data from six Canadian coastal BBDS communities with long-term weekly ice thickness measurements (since the late 1950s; Brown et al., 2018) show that maximum ice thicknesses experienced an abrupt decrease of approximately 20 cm after 2000. This decline represents about a 10% reduction in maximum thickness (Figure 3.19). The regionally averaged date of annual maximum ice thickness advanced by approximately 3 weeks over the same period in response to earlier melt.

3.1.5.2 Projected changes

CMIP5 models project a continuation of observed trends to a shorter ice season and thinner ice but with a large spread in the rate and timing of sea ice changes (Stroeve et al., 2012). Projected changes in autumn and winter ice concentration and ice thickness for RCP4.5 are shown in Figures 3.20 and 3.21, respectively. (Results for all seasons and for the RCP2.6 and RCP8.5 scenarios are shown in Langen et al., 2016.) The largest decreases in sea ice concentration (15–20% by 2080) are projected for the autumn (SON) season, related to a later freeze-up. Decreases of 10–15% are projected over most of the region in the summer (JJA), in response to earlier break-up. Winter ice thickness is projected to decrease by approximately 20–30 cm, with the largest decreases occurring in more northerly regions. A large spread in model-projected changes is evident over Baffin Bay and Foxe Basin.

It should be noted that the temporal evolution of simulated Arctic sea ice cover is strongly influenced by internal variability (Jahn et al., 2012; Stroeve et al., 2012) and that averaging over a model ensemble will smooth out the influence of those models that show early rapid ice loss events (Döscher and Koenigk, 2013). Wang and Overland (2012) determined a model consensus for nearly ice-free Arctic summers by the 2030s, using a subset of models that best represented the observed sea ice regime and historical trends. However, most of these models do not resolve the CAA and the regional ice dynamics that involve the import of multi-year ice from the Arctic Ocean (Howell et al., 2008, 2013). Sea ice change scenarios from a high-resolution coupled ice–ocean model for the Canadian Arctic (Hu and Myers, 2014) do not show completely ice-free summers in the CAA before 2100, in agreement with Sou and Flato (2009). The future response of multi-year ice in the CAA depends on other factors in addition to air temperature (Derksen et al., 2012). For the foreseeable future, ice is likely to remain a hazard for shipping (Haas and Howell, 2015). Additional simulations from high-resolution coupled ice–ocean models driven with a range of climate model outputs are needed to reach robust conclusions about the projected magnitude and timing of changes in BBDS sea ice cover in coastal waters.

3.1.6 Sea level

Relative sea level in the BBDS region is projected to fall at nearly all locations, despite projected global sea level rise. The BBDS pattern is mainly due to crustal uplift in response to past and projected ice mass decreases. For the high-emissions scenario, the projected median relative sea-level change (at 2100, relative to 1986–2005) ranges over the region from a fall of nearly 90 cm to a rise of nearly 10 cm.

3.1.6.1 Observed trends

Global sea level rose at a mean rate of 1.7 (±0.2) mm/yr between 1901 and 2010 (Church et al. 2013a; IPCC, 2013a), with considerable decadal-scale variability of the average rate of rise during the 20th century (Church and White, 2006). Between 1993 and 2010, sea level rose at a faster rate of 3.2 (±0.4) mm/yr (Church et al., 2013a).

Relative sea level, in contrast to global mean sea level, is the sea level experienced at a single fixed location on the earth's solid surface. Changes to relative sea level are the net effect of a combination of changes in global sea level, local vertical crustal motion, and other factors described below. If the land is rising, then (all else being equal) relative sea level is lowered; if the land is sinking, then relative sea level is increased. Vertical land

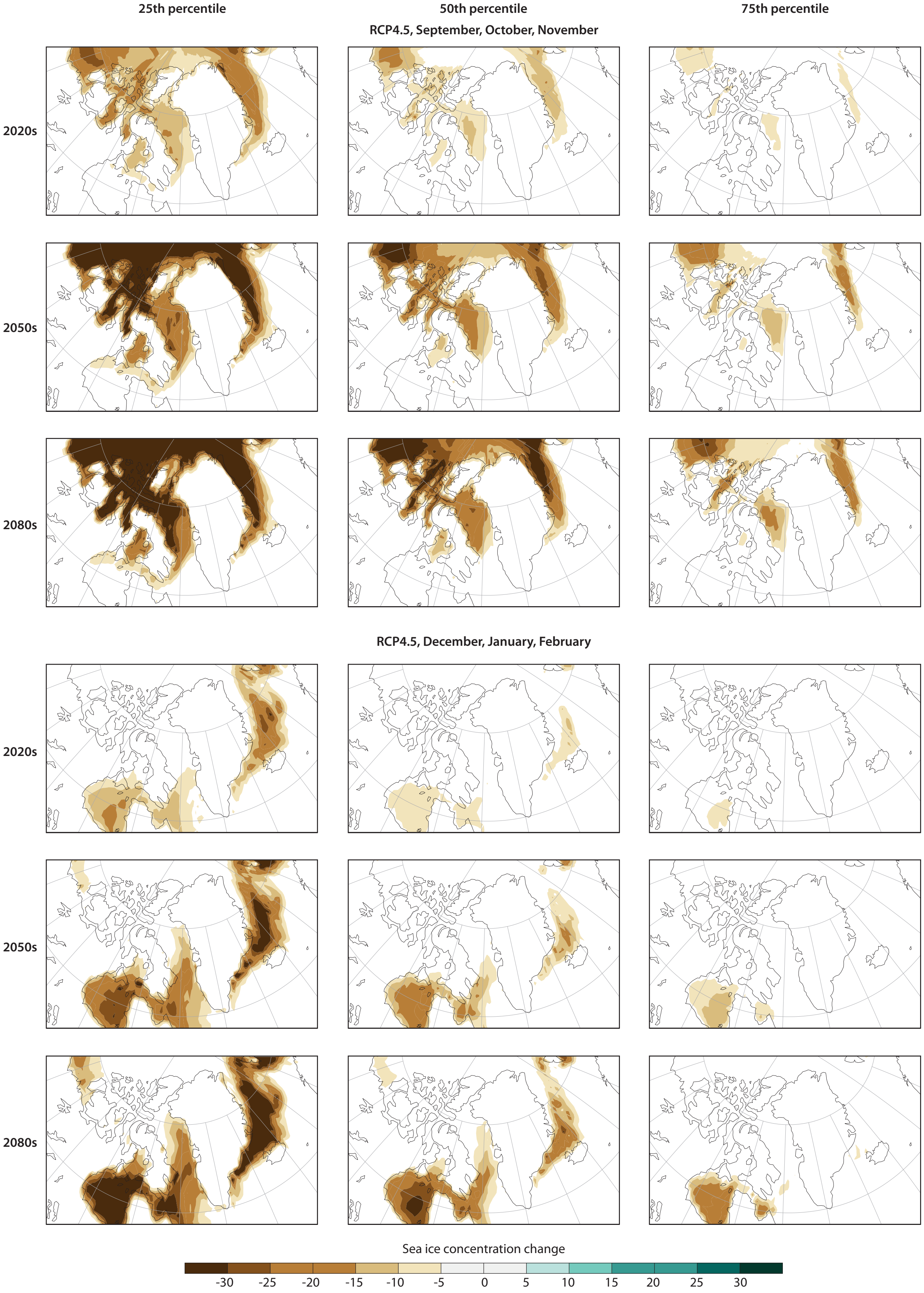

Figure 3.20 Projected change in autumn (SON) and winter (DJF) sea ice concentration (change in percent concentration relative to the 1986–2005 average) for the RCP4.5 scenario, according to a 29-member CMIP5 multi-model simulation. Results are shown for three periods in the future: 2016–2035 (labeled 2020s), 2046–2065 (labeled 2050s), and 2081–2100 (labeled 2080s). The figures illustrate the 25th, 50th, and 75th percentile changes projected by the CMIP5 models. For a list of the 29 models, see Table 4.1 of AMAP (2017a).

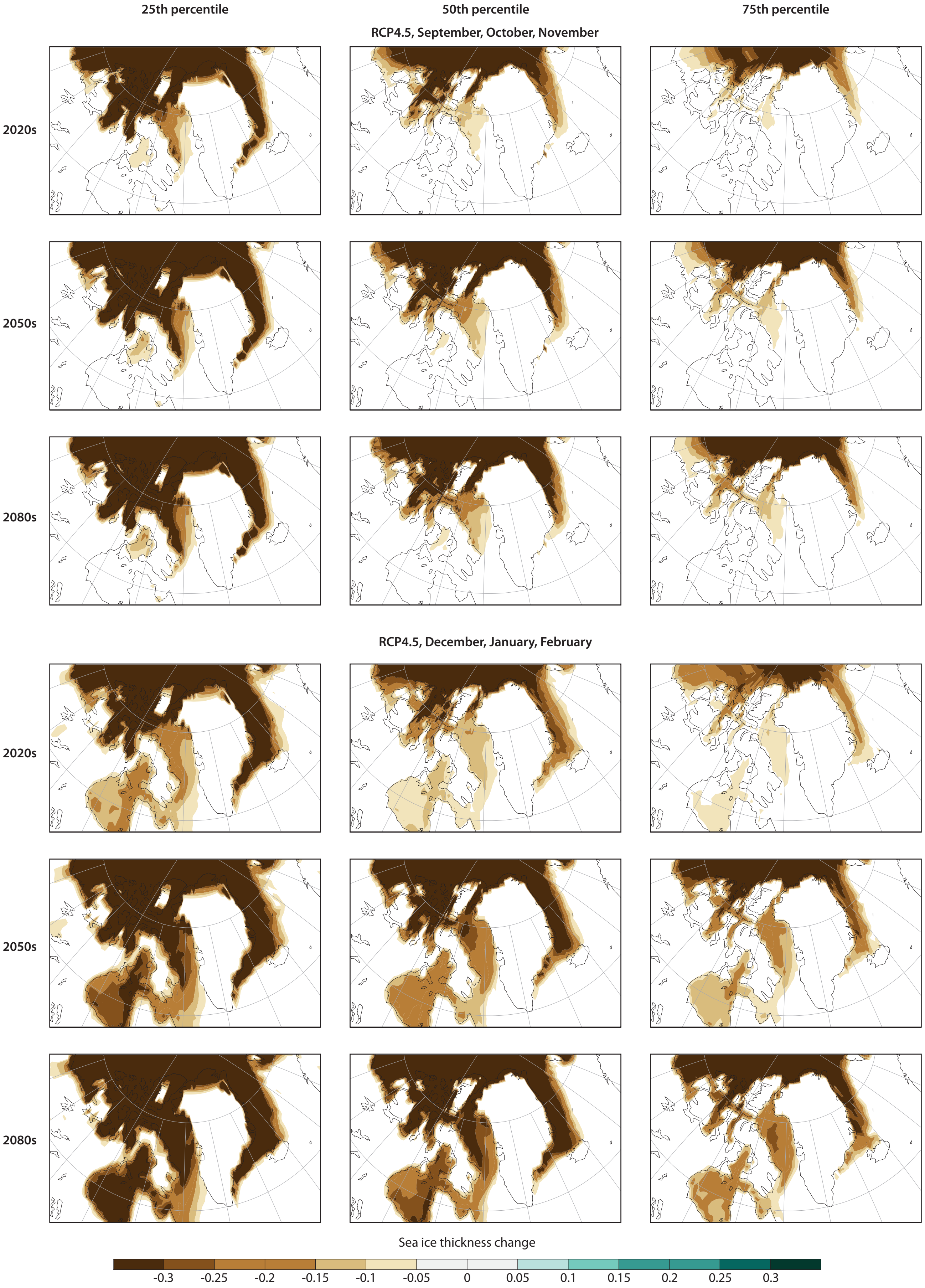

Figure 3.21 Projected change in autumn (SON) and winter (DJF) sea ice thickness (change in meters relative to the 1986–2005 average) for the RCP4.5 scenario, according to a 29-member CMIP5 multi-model simulation. See Figure 3.20 for an explanation of the panels.

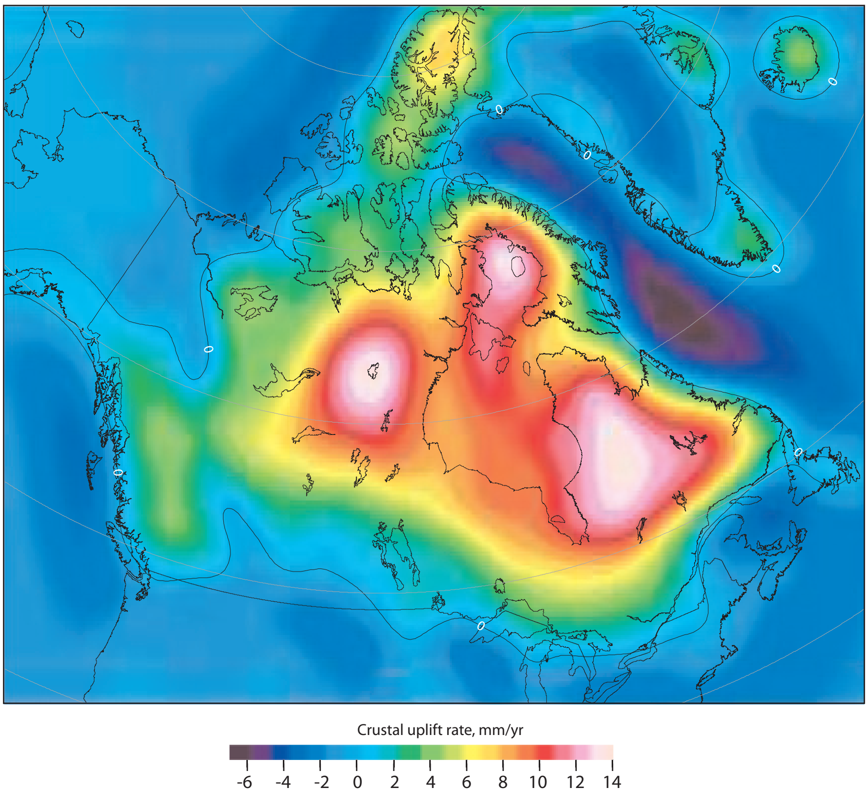

Figure 3.22 Present-day vertical crustal motion estimated by the ICE-6G glacial isostatic adjustment (GIA) model (described in Peltier et al., 2015). Regions of large uplift (warm colors) indicate former centers of the Laurentide Ice Sheet; subsiding regions (cool colors) were close to the ice-sheet margin or were peripheral to the ice sheets. In Greenland, the modest amounts of crustal uplift and subsidence are largely due to modeled changes in the Greenland Ice Sheet.

motion exerts a strong control on relative sea level changes in the Arctic region (Figure 3.22).

Glacial isostatic adjustment, also known as postglacial rebound, is the response of the solid earth to changes in glaciers and ice sheets. During ice ages, the glaciated surface of Earth is depressed beneath large ice sheets. At great depths within the planet, mantle material is displaced through slow, viscous flow. When glacial ice masses shrink and retreat, such as over much of Canada, the surface loading on the earth's surface is reduced. The earth responds, and areas that were depressed due to the weight of the ice begin to rise toward their previous elevations. This gradual process continues for thousands of years after ice loads have diminished. In regions that were once at the margins of the great ice sheets or were peripheral to the great ice sheets, the land rose during glaciation. Following deglaciation, these marginal and peripheral regions subside.

In areas such as Greenland and portions of the northern and eastern CAA, which are still glaciated, the solid earth also responds to past ice mass changes. Superposed on this viscous response to past ice mass changes is a faster elastic response of the solid earth to present-day ice mass changes. Close to ice masses that are presently undergoing large changes, this elastic crustal response can be large – up to a few millimeters per year. This response can provide a dominant contribution to observed or projected relative sea-level change.

Other factors that contribute to relative sea-level change, introducing additional spatial variability, include dynamic oceanographic effects, which add 15–20 cm to projected BBDS sea level rise by 2100 in the RCP8.5 scenario (e.g., Yin et al., 2010; Yin, 2012). The gravitational response of the ocean to ice mass changes (Mitrovica et al., 2001) is very important close to large masses of ice that are undergoing large changes or are projected to undergo large changes. The reduced Greenland Ice Sheet, for example, now causes less gravitational upward "pull" of the surface of the ocean. Tide gauge records are sparse for the Arctic, but an intermittent record at Alert, at the northern tip of Ellesmere Island, indicates that sea level there has been falling at an average 1.5 mm/yr since the mid-1960s (Atkinson et al., 2016). In contrast, a tide gauge on the southwestern coast of Greenland at Nuuk indicates that relative sea level at that location has been rising at about 2 mm/yr for the time range 1958–2002 (Spada et al., 2014) – more slowly than the 1993–2010 global average of 3.2 mm/year (IPCC, 2013a).

3.1.6.2 Projected changes

Climate projections using the RCP scenarios (see Section 3.1.1) in the IPCC's AR5 (IPCC, 2013a) include global mean sea level change. Global sea level at 2100 is projected to be higher by 36–71 cm (RCP4.5) to 52–98 cm (RCP8.5), relative to 1986–2005 (Table 13.5 in Church et al., 2013a). In the BBDS region, relative sea-level projections depart strongly from global values and site-specific projections are required.

Relative sea-level projections have been generated for the Canadian side of the BBDS region (James et al., 2014, 2015). These projections utilized regional sea-level projections provided by the AR5 (Church et al., 2013b), incorporated vertical crustal motion from global positioning system (GPS) observations (James et al., 2014), and included regional dynamic oceanographic effects and the elastic crustal and gravitational effects of changing ice masses.

Under the high-emissions scenario (RCP8.5), relative sea level by 2100 is projected to fall at nearly all locations in the region

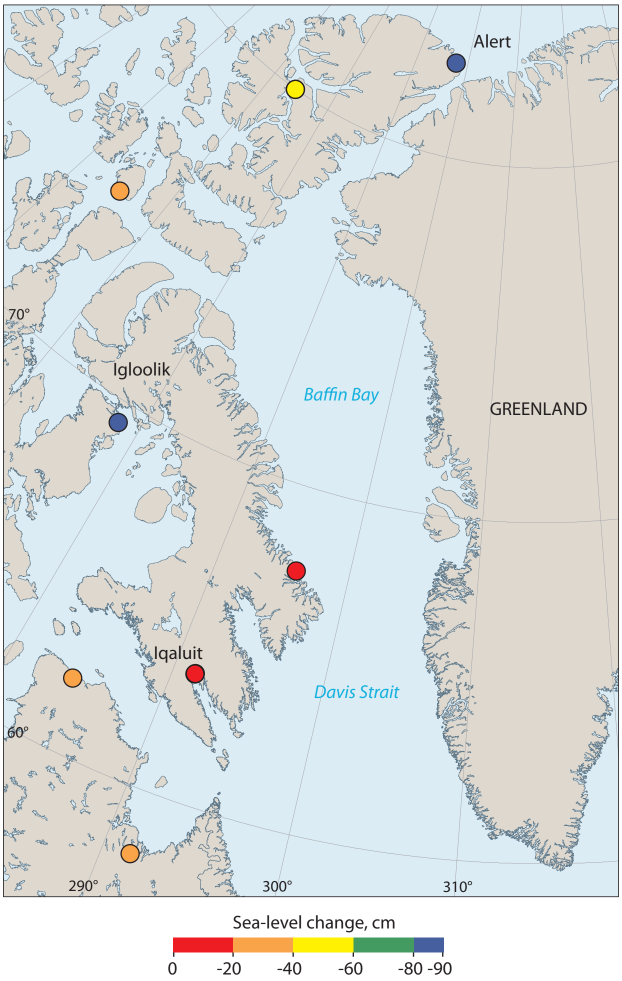

Figure 3.23 Projected relative sea-level change at the year 2100 (in cm) for the median RCP8.5 value at coastal locations in the Canadian sector of the Baffin Bay/Davis Strait region (after James et al., 2014). Values range from −84 cm to −1 cm and are relative to 1986–2005. Locations mentioned in the text are labeled.

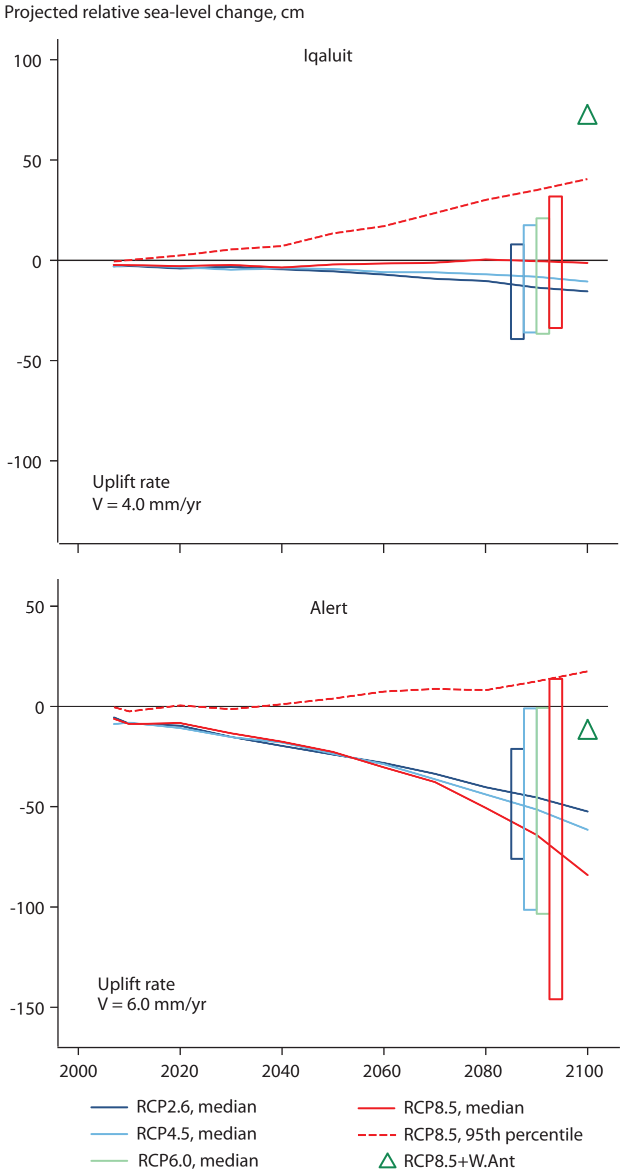

Figure 3.24 Projected relative sea-level change for Iqaluit and Alert (after James et al., 2014), based on the IPCC AR5 (Church et al., 2013a, 2013b) and also vertical crustal motion (uplift rate, given to nearest 0.5 mm/yr) derived from GPS observations. Projections are given through the century for the RCP2.6, RCP4.5, and RCP8.5 scenarios. The rectangles show the 90% confidence interval (5% to 95%) of the average projection for the period 2081–2100 for each of those three scenarios and also RCP6.0. The dashed red line gives the 95th percentile value for RCP8.5. The projected value at 2100 is also given for a scenario in which West Antarctica contributes an additional 65 cm of global sea level rise, added to the median projection of RCP8.5 (RCP8.5+W.Ant; green triangle).

(Figure 3.23), even though mean global sea level will have risen significantly by then. The projected sea level fall results from the combination of large amounts of crustal uplift at some sites, due to glacial isostatic adjustment (for example, Igloolik is measured to be rising at about 11.5 mm/yr, generating large projected sea level fall) and proximity to the Greenland Ice Sheet, which is projected to lose mass through the 21st century (Section 3.1.3). This latter effect is particularly strong at Alert, which is close to the Greenland Ice Sheet and has large values of projected sea level fall. Although proximity to the changing ice sheet makes detailed relative sea-level projections for sites on the Greenland coast less accurate under the present analysis, sea-level projections for western Greenland are also strongly negative (Church et al., 2013a).

Projections through the 21st century for Iqaluit (Figure 3.24, upper panel) show that the RCP8.5 projected relative sea level is higher (more positive) than the RCP4.5 case, similar to global projections in which larger emissions scenarios give larger projected global sea level rise. This correspondence is generally expected and projected at most locations. An exception is seen at Alert (Figure 3.24, lower panel), where the largest emissions scenario (RCP8.5) has the largest amount of projected relative sea-level fall. Here, the elastic crustal response to projected shrinking of the ice sheet gives larger amounts of crustal uplift for larger scenarios, thus leading to larger amounts of projected sea level fall. This phenomenon is also expected for western Greenland.

For Iqaluit, uncertainties are such that sea level rise or fall on the order of 40 cm is possible for all RCP scenarios; at Alert, sea level fall is favored. A scenario that considers the effect of an additional 65 cm contribution to global sea level rise from partial collapse of the West Antarctic ice sheet, added to the median projection of RCP8.5, provides larger amounts of projected sea level rise or reduced amounts of sea level fall (green triangles in Figure 3.24).

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3.2 Environmental drivers

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Key messages

- ***Mercury concentrations will likely increase in the Baffin Bay/Davis Strait (BBDS) environment and wildlife.*** *Long-term monitoring of mercury in wildlife from the BBDS region, including seals, seabirds and land-locked char, has shown a continued increasing trend in recent decades.*
- ***Concentrations of persistent organic pollutants (POPs) that are subject to national and international regulations will likely decrease.*** *Monitoring results show that the concentrations of most POPs that are regulated under the Stockholm Convention have been decreasing in Arctic air and wildlife over the past decade. Some POPs have been declining since the 1990s, at which time many of the original Stockholm Convention POPs had already been banned by most industrialized nations.*
- ***Chemicals of emerging Arctic concern will likely be found in the environment for the first time or will be found to increase in the environment.*** *Arctic monitoring programs are constantly expanding their analytical protocols to include new chemicals whose characteristics (physical/chemical properties) suggest the potential for them to contaminate the Arctic environment. Arctic monitoring data is critical for a new chemical to be classified as a POP under the Stockholm Convention.*
- ***The possibility of a catastrophic oil spill in the marine environment is the greatest concern related to oil and gas activities.*** *The cold Arctic climate retards the natural degradation of spilled oil, prolonging negative effects on ecosystems. Harsh weather and the presence of sea ice will affect the distribution and fate of spilled oil and may also hinder an effective oil spill response or even make an effective response impossible.*

Guiding question

What are the trends of contaminants in Arctic wildlife and humans, and will contaminants be a significant driver of environmental, socio-economic, and cultural change in the BBDS region?

3.2.1 Introduction

Recent levels of mercury and, in particular, of persistent organic pollutants in top predators in the Arctic – including the Baffin Bay/Davis Strait, East Greenland, and Svalbard areas – are believed to exceed thresholds for biological effects in some species (Letcher et al., 2010; AMAP, 2011; NCP, 2013). It is also recognized that assessing the effects of contaminants on Arctic wildlife must be placed in the context of other environmental, ecological, and physiological stressors (both anthropogenic and natural). Such assessments will require a multi-stressor approach to ecological risk assessment in the future (NCP, 2013). This recognition is particularly important in light of the magnitude and variety of anticipated changes in the Arctic over the coming decades. It is important to emphasize that there exists minimal evidence of current contaminants having widespread direct effects at the population level, such as has been previously seen, for example, in raptors of Scandinavia and North America, where population declines were related to eggshell thinning caused by the use of the pesticide DDT.

Humans in the Arctic are exposed to contaminants such as mercury and POPs by consumption of traditional food, especially marine mammals. A significant proportion of people from communities in the eastern Canadian Arctic and Greenland, including women of childbearing age, have exhibited blood mercury levels that exceed the health guidelines of the United States of America (USA) and Canada (AMAP, 2011). Also, the levels of POPs in humans from the eastern Canadian Arctic and north and east Greenland can affect the health of people (AMAP, 2009). POPs and heavy metals can be transferred through the placenta, thereby exposing the fetus to these compounds and possibly influencing child development (Long et al., 2015). However, it is important to stress that threats from environmental contamination must be weighed against the many health benefits that are derived from the harvesting, consumption, and sharing of traditional foods.

3.2.2 Heavy metals

Heavy metals in the environment, such as mercury (Hg), cadmium (Cd), and lead (Pb), are derived both from anthropogenic sources to the atmosphere and from natural sources. There are three main anthropogenic sources of heavy metals to the atmosphere: fossil fuel combustion, nonferrous metal production, and waste incineration (AMAP, 2005). The total amount of Hg released to the atmosphere in 2010 from human sources was estimated at 1,960 tonnes (UNEP, 2013) with a further 3,000 to 4,000 tonnes released either from natural sources or as re-emissions of Hg previously deposited on surfaces. Re-emissions may be associated with, for example, volatilization, fires, dust, and sediment resuspension (AMAP, 2011). In the case of Cd, the largest source of atmospheric emission derives from nonferrous metal production (73%) (AMAP, 2005). Natural emissions to the atmosphere (e.g., volcanic releases) account for 30–50% of total emissions (AMAP, 2005). For atmospheric Pb emissions, combustion of leaded or low-leaded gasoline is still the major source (AMAP, 2005).

Mercury is deposited from the air mostly in inorganic forms. In the environment, inorganic Hg can be transformed into methylmercury (Me-Hg). Methylmercury, which is also one of the most toxic forms of Hg, is easily taken up at the base of the food chain, where it biaccumulates over time and biomagnifies with each step of the food chain. Therefore, the highest Hg concentrations are found in top predators in long marine food chains. Comparing Hg levels in Arctic wildlife between preindustrial times and the present day (in hard tissues such as teeth, hair, and feathers), researchers found the human-made contribution to be above 92% (Dietz et al., 2009). Over the last 30 years or so, no generally consistent Arctic-wide temporal trend of Hg in Arctic wildlife has been evident in the long-term monitoring data (Rigét et al., 2011). However, in the BBDS region, a number of time series records of Hg in biota (ringed seal in northwest Greenland, seabirds on Prince Leopold Island, sea-run Arctic char from Pangnirtung, and landlocked Arctic char from Char Lake) show significant increases during that period (Rigét et al., 2011; Braune et al., 2015a). In general, levels of Hg in human tissues are declining in the Arctic. However, Inuit who consume marine mammals still have high blood Hg levels, often exceeding health guidelines. This pattern is especially prominent in parts of Greenland and Arctic Canada where consumption of marine mammals is relatively high (AMAP, 2009). Prenatal exposure to mercury has been associated with neurodevelopmental effects in Inuit from Nunavik (just south of the BBDS region). Public health authorities in and around the BBDS region have issued advisories describing the risks associated with mercury exposure and providing advice on how to reduce this risk by limiting the consumption of certain traditional foods. For example, the Nunavik Regional Board of Health and Social Services (2011) issued dietary advice for pregnant women and women of childbearing age, including a recommendation to reduce consumption of beluga (white whale) meat, which is known to be a major dietary source of Hg. Similarly, in Nunavut, pregnant women and women of childbearing age have been advised to avoid consumption of ringed seal liver in order to reduce Hg-related health risks (Nunavut Department of Health and Social Services and Nunavut Tunngavik Incorporated, 2012).

Cadmium also bioaccumulates in wildlife, with highest levels found in the livers and kidneys (Sadiq, 1992) and in some cases exceeding threshold values for potential organ dysfunction (AMAP, 2005). The highest concentrations of Cd in the Arctic are found in the livers and kidneys of marine mammals. In terms of geographic distribution, the highest levels are found in marine mammals from the eastern Canadian Arctic and northwestern Greenland (AMAP, 2005). In caribou across the Canadian Arctic to West Greenland, Cd levels decrease from west to east, which probably reflects the geochemical environment rather than anthropogenic gradients (AMAP, 2005). Industrial Cd sources do not appear to have resulted in increasing levels of Cd in the most remote areas of the Arctic, and Cd levels in Arctic biota are either stable or declining (AMAP, 2005). The main source for human Cd exposure is smoking (AMAP, 2003). Although marine mammal livers and kidneys have high Cd concentrations and are important human food items in the Arctic, it appears that the accumulation of cadmium from Greenlanders' marine diet is very low (Johansen et al., 2006a).

The atmospheric deposition of lead has been reduced dramatically in Arctic regions, where the use of leaded gasoline was banned during the 1970s and 1980s by many countries (AMAP, 2005). Lead from lead shot used during hunting appears to be an important source of human Pb exposure (Johansen et al., 2006b). However, the use of lead for hunting game birds was banned in 1999 in Canada and in 2012 in Greenland.

3.2.3 Persistent organic pollutants (POPs)

Persistent organic pollutants have a long lifetime in the environment and therefore have the potential to be transported over long distances. Most of the total quantity of POPs found in the Arctic environment is derived from distant sources (AMAP, 2004). POPs are transported to the Arctic mainly by atmosphere and ocean currents. POPs bioaccumulate and biomagnify in Arctic food chains. Most POPs are lipophilic and are found in highest concentrations in fatty tissues. Top predators in the marine food chain (e.g., polar bear, toothed whales), as well as birds of prey, have the highest levels of POPs (AMAP, 2004).

The use of several POPs has been banned or restricted for decades, and international actions have been established to reduce emissions and releases to the environment. Examples include the United Nations Environment Programme (UNEP) 2001 Stockholm Convention on Persistent Organic Pollutants (entered into force in 2004) and the 1998 Protocol on Persistent Organic Pollutants to the 1979 Convention on Long-range Transboundary Air Pollution. However, the levels of many POPs in Arctic biota are still high enough that certain species, including many top predators, may be at risk for biological effects from these compounds (Letcher et al., 2010; NCP, 2013). The nature of potential effects includes impacts on reproductive, endocrine, and immune systems (NCP, 2013).

Most POPs that have been banned for an extended period of time in developed countries – e.g., drins (aldrin, endin, and dieldrin), polychlorinated biphenyls (PCBs), and chlordanes – show declines in Arctic air, including at the monitoring station at Alert, Nunavut (AMAP, 2014). Declining concentrations of these POPs are also seen in Arctic biota (AMAP, 2014), including seabirds from Prince Leopold Island, ringed seals from Lancaster Sound and east Baffin Bay, beluga from Cumberland Sound (NCP, 2013), and ringed seals from central West Greenland (Rigét et al., 2013a). The organochloride compound β-hexachlorocyclohexane (β-HCH) is an exception, as increasing amounts have been found in ringed seals and seabird eggs from the Lancaster Sound region (NCP, 2013). Amounts have been declining in West Greenland ringed seals (Rigét et al., 2008). Inuit living in the eastern parts of the Canadian Arctic and in Greenland have 2- to 10-fold higher concentrations of certain POPs compared to populations from other Arctic regions (AMAP, 2014). However, a recent assessment suggests that human concentrations have decreased in both Nunavik and West Greenland (AMAP, 2014). Declining blood levels of POPs have also recently been reported for West Greenland Inuit (Long et al., 2015).

The use of polybrominated diphenyl ethers (PBDEs), a type of brominated flame retardant (BFR), was phased out in North America (USA and Canada) and the European Union in the mid-2000s. In 2009, the technical mixtures PentaBDE and OctaBDE were included in the Stockholm Convention. Levels of PBDEs in both animals and humans are much lower than other previously regulated POPs. For example, PBDE-47 concentrations (6 µg/kg lipid weight, lw, in blood plasma) in Inuit from Nunavik in 2004 was 30- to 75-fold lower than PCB-153 (158–189 µg/kg lw) and DDE (461–467 µg/kg lw) (AMAP, 2014). PBDE concentrations increased in seabird eggs and

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Scientist sampling ringed seal, Qaanaaq, Greenland

ringed seals from the Lancaster Sound region between the early 1990s and about 2003/2005, after which concentrations either decreased or stabilized (NCP, 2013). The same pattern is seen in ringed seals and polar bears in central East Greenland (Rigét, 2016; Dietz et al., 2013), but in ringed seals from central West Greenland, PBDE concentrations appear to still be increasing (Rigét, 2016). Air concentrations of PBDEs at the Canadian Arctic station Alert remained more or less unchanged from 2002 to 2011, while at Pallas (Finland) and Zeppelin (Svalbard), concentrations declined from approximately 2007 to 2011. The concentrations at Alert were generally higher than at the European stations, which may reflect the higher historical usage of these compounds in North America in general (AMAP, 2014). Hexabromocyclododecane (HBCD), another flame retardant, has shown increasing trends – for example, in ringed seals from Lancaster Sound and belugas from Cumberland Sound (NCP, 2013). However, air concentrations of HBCD declined at Zeppelin (Svalbard) (mid-2006–2012); at Alert, air concentrations have been very low, with no apparent increase or decrease in trend (2002–2012) (AMAP, 2016).

Perfluorinated alkylated substances (PFASs) constitute another group of compounds that is very persistent in the environment. In wildlife and humans, PFASs bind to blood proteins – in contrast to most other POPs, which are lipophilic. PFASs therefore bioaccumulate mainly in the liver, kidneys, and bile secretions. Perfluorooctane sulfonate (PFOS) is usually found in much higher concentrations than other fluorinated compounds in Arctic wildlife. In 2000, the largest producer of PFOS, the 3M Company (USA), announced it would phase out production. In June 2008, PFOS was banned in the European Union, and in 2009, it was included in the Stockholm Convention on POPs. In seabird eggs from Prince Leopold Island, PFOS concentrations increased after 1975, but recent measurements (2009–2011) suggest that concentrations of PFOS are now declining (NCP, 2013). In ringed seals from east Baffin Island and Lancaster Sound, PFOS concentrations peaked in the early 2000s, which was also the case for beluga from Cumberland Sound (NCP, 2013). In ringed seals from West Greenland, PFOS concentrations peaked around 2006 (Rigét et al., 2013b). For women of childbearing age in Nunavik, PFOS concentrations have appeared to decrease; this decline is in contrast to an increasing trend in Nuuk, West Greenland, in the period 1998–2005 (AMAP, 2014). At Zeppelin (Svalbard), PFOS in air remained more or less constant from 2006 to 2012. On the other hand, the PFOS precursors methyl and ethyl perfluorooctane sulfonamido ethanol (MeFOSE and EtFOSE), which can transform or degrade to PFOS in the environment, were found to be unchanging and declining, respectively, in air at Alert.

New organic compounds are being regularly developed and produced by the chemical industry and introduced to global markets for a variety of applications. If new compounds that are similar to POPs in their physical–chemical properties are emitted to the environment, it is likely they could cause new Arctic problems. Several initiatives in environmental policy deal with the identification of potentially problematic compounds, listing compounds to be phased out, monitored, or studied further. A number of novel flame retardants that replaced some of the banned BFRs are found in Arctic biota, although at low levels (NCP, 2013; Vorkamp et al., 2015). Examples include the compounds bis(2-ethylhexyl)tetrabromophthalate (BEH-TEBP or TBPH); 2-ethylhexyl-2,3,4,5-tetrabromobenzoate (EH-TBB or TBB); 1,2-bis(2,4,6-tribromophenoxy)-ethane (BTBPE); decabromodiphenyl ethane (DBDPE); and 2,3-dibromopropyl-2,4,6-tribromophenyl ether (TBP-DBPE or DPTE). The compounds BEH-TEBP, EH-TBB, and BTBPE have been found in air at Alert, at concentrations similar to PBDEs (Xiao et al., 2012).

3.2.4 Currently used pesticides (CUPs)

A number of pesticides that are still being produced and used for a variety of applications have been found in the Arctic. Compounds such as lindane, endosulfan, chlorpyrifos, chlorothalonil, dacthal, diazinon, methoxychlor, and trifluralin have been consistently detected in the Arctic (Muir and de Wit, 2010). The levels of these currently used pesticides (CUPs) are often low, but their presence shows that they can travel over long distances and potentially accumulate in the food web (Muir and de Wit, 2010). Air concentrations of CUPs measured at Alert are mostly low compared to other POPs. Seasonal differences in air concentrations observed in the Arctic atmosphere are likely related to application patterns and subsequent long-range transport to the Arctic (NCP, 2013). There are very limited data for CUPs in Arctic biota and humans.

3.2.5 Petroleum hydrocarbons and polycyclic aromatic hydrocarbons (PAHs)

Petroleum hydrocarbons and polycyclic aromatic hydrocarbons (PAHs) have natural sources (seeps) and anthropogenic sources (e.g., oil and gas activities, shipping, combustion of fossil fuels) in the Arctic. Concentrations in the Arctic are generally low compared with other areas of the world (AMAP, 2010a, 2010b). Most organisms, such as fish, birds, and mammals, can metabolize and excrete PAHs.

The biggest concern related to oil and gas activities in the Arctic is the possibility of a catastrophic oil spill in the marine environment (AMAP, 2010b; see also Chapter 7 of this report). The probability of such an incident is low, and the global trend in volumes of oil spilled is decreasing (Schmidt-Etkin, 2011). Nevertheless, the probability of a spill does exist, and the environmental impacts from a large spill can be severe and long lasting, particularly in an Arctic environment such as the Baffin Bay region.

Several factors increase the potential for severe impacts from a large oil spill in the BBDS assessment area. Owing to the Arctic climatic conditions (particularly low temperatures), the degradation rate of oil is reduced, thus prolonging potential effects. Harsh weather conditions and the occurrence of ice during winter and spring may influence the distribution and fate of spilled oil and may also hinder an effective oil spill response or even make an effective response impossible.

The journal *Science* has published a synthesis of 14 years of oil spill studies in Prince William Sound, conducted after the 1989 *Exxon Valdez* spill (Peterson et al., 2003). This synthesis concludes that delayed, chronic, and indirect effects of the oil spill have occurred. According to an AMAP oil and gas assessment, tankers are the primary potential source for a spill in Arctic waters (AMAP 2010a, 2010b). Another potential source would be a blowout during drilling. This type of spill, in contrast to a tanker spill, is continuous and can last for days, weeks, or even months. The 2010 deep-water blowout of the Macondo well in the Gulf of Mexico, for instance, lasted 87 days before it was stopped by the drilling of a relief well.

3.2.6 Climate change effects on contaminant trends

Global warming and related environmental changes will affect contaminant pathways and biological systems. In the physical environment, some POPs, such as hexachlorobenzene and PCBs, have shown increasing trends in air at certain Arctic locations. These trends may be related to revolatilization of these substances from the open ocean due to reduced sea ice coverage or from melting glaciers associated with the Arctic warming of recent years (AMAP, 2014). New POPs emissions from human activities related to climate change can also be expected – e.g., increased shipping emissions in the North (see Chapters 8 and 9) and the use of pesticides in northern agricultural practices (Pacyna et al., 2015). In order to better predict the environmental impact of contaminants in a changing Arctic, it is necessary to better characterize primary and secondary sources and to more accurately quantify current and future releases of POPs (Pacyna et al., 2015).

Further, climate change will influence food web structures and affect contaminant cycles. The relatively long time series that are available for Arctic species make it possible to examine probable linkages to climate change variables. Time series of POPs in eggs of thick-billed murre from Coats Island in northern Hudson Bay and Prince Leopold Island in Lancaster Sound are examples. A lowering of these birds' trophic position on Coats Island and an upward shift on


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Core samples from an oil exploration vessel docked at Ilulissat, Greenland

Prince Leopold Island has occurred, as indicated by stable isotope ($\delta^{15}N$) studies. These shifts have in turn affected the concentrations of POPs in eggs at the two locations, where the decreasing trend was either slowed, in the case of Prince Leopold island, or accelerated, in the case of Coats Island. This example illustrates the complex linkages between climate change, food web processes, and contaminants (Braune et al., 2015b). Another example is seen in ringed seals from central West Greenland, where several POPs have exhibited a positive relation with the winter Atlantic Oscillation Index, probably caused by enhanced transport of air masses from industrial regions when the index is high (Rigét et al., 2013a). The concentrations of several POPs have also been related to the number of sea ice days or the timing of ice break-up: a longer period of sea ice coverage during the winter (later break-up) coincides with lower POP concentrations in the seals (Gaden et al., 2012). Changes in feeding ecology connected to climate change have also been found to affect the levels of contaminants in other areas of the Arctic – e.g., in polar bears from western Hudson Bay (McKinney et al., 2009) and East Greenland (McKinney et al., 2013).

3.2.7 Future concerns for contaminants

Without improved pollution controls or other actions to reduce mercury emissions, global Hg emissions to the air and thereby deposition in the Arctic will likely be substantially higher in 2050 than today (UNEP, 2013). Once implemented, however, the Minamata Convention on Mercury will hopefully bring about a reduction in global emissions that will eventually translate into lower levels of Hg in the Arctic environment. Both Canada and Denmark became signatories of the Convention on October 10, 2013. This event expresses the willingness of Canada and Denmark to continue the treaty-making process, qualifies them to proceed to ratification, and creates an obligation for them to refrain from acts that would defeat the object and purpose of the treaty. Continued monitoring will be required to assess the effectiveness of the Convention. In the meantime, if Hg levels continue to increase, the consumption of traditional/local food, without dietary restrictions, may lead to increased human health risks in the region. The levels of most persistent organic pollutants that are under national and international regulation are declining. If contaminant monitoring (including screening studies for emerging chemicals) continues in the Arctic, it is likely that new and emerging chemicals of Arctic concern will be discovered and actions will be initiated – e.g., through international regulation of long-range transported contaminants.

The future development of BBDS infrastructure (Chapter 10), shipping (Chapter 9), and mining and oil and gas activities (Chapter 7) can result in local point sources of contaminants. However, it should be possible with proper management to limit or minimize environmental impacts from such activities. The threat level of any form of environmental contaminant must also be coupled with other health determinants such as smoking and general nutrition, and any threats from environmental contamination of traditional foods must also be weighed against the health benefits of their consumption.

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3.3 Socio-economic drivers

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Key messages

- ***New international governance gaps continue to emerge in the Baffin Bay/Davis Strait (BBDS) region.*** *Among the scenarios for future climate change and oil and gas exploration, the more extreme ones will make those gaps more problematic. Governance will exert a very strong influence on the outcome of most change processes in the region.*
- ***The region shows a very clear trend of more localized governance.*** *Regional governments are increasingly becoming key players for domestic development and are increasingly empowered to enact policies aimed at offsetting negative trends affecting the region's population.*
- ***Dependence on outside workers in various sectors, including service and public administration, is a current fact, with slightly different trends in Nunavut and Greenland.*** *If the region's population is to take an increasingly active part in governing and in benefiting from the changes to come, adequate access to relevant education and training will be required. This need will become particularly acute with industrial development and increasing devolution of governance.*
- ***Development of the formal economy is seen by many decision-makers as an important driver for societal development as well as independence in the region. A significant trend is the continued economic, social, and cultural importance of the subsistence ("land-based") economy.*** *Fishing, hunting, and gathering activities are a key part of the region's mixed economy, with the subsistence economy and the cash economy supporting each other. However, this interdependence is sensitive to changes in policy and climate. Although elements of a formal economy are required to underpin the subsistence economy, it is likely that tension between the two economies will increase as nonrenewable resource exploitation and associated activities affect local environments. Because of the social and cultural values embedded in the subsistence economy, changes to this economic system will have substantial impacts on Indigenous peoples in the region.*
- ***The strength of the Inuit language shows different trends within the region.*** *Kalaallisut remains strong in Greenland. Inuktitut is widely used on the Nunavut side of the BBDS region but shows signs of erosion, especially in younger generations. Language is closely linked to issues of identity, well-being, governance, and education.*
- ***The BBDS region is still quite isolated (more so in Nunavut than in Greenland), but both areas show trends of increasing connectivity within and outside the region.*** *Physical infrastructure improvements are a key driver of connectivity of various sorts, with implications for security, health, education, and various economic sectors.*

Guiding questions

What are the ongoing and future trends – within economy, demography, governance, education, and culture – that may potentially drive development in the Baffin Bay/Davis Strait region? How do these trends interact?

3.3.1 Governance

The colonial history of the Baffin Bay/Davis Strait region provides an overall context for the social and economic dynamics in the region. The colonization of the region was tightly connected to the exploitation of Arctic resources, from the early fur trade and whaling of the 17th and 18th centuries to the fishing and mining of the 20th century (Nuttall, 1992). Colonial administration played out differently in Nunavut and Greenland. In Greenland, for example, the Danish administration was characterized as being paternalistic up until World War II (Nuttall, 1992), with Inuit being somewhat economically and culturally "protected" – and isolated – from the outside world. In Nunavut, in contrast, the Canadian administration was more directly informed by Euro-Asian market demands (Nuttall, 1992). After World War II, the administration of both Denmark and Canada could be termed as a "welfare colonialism" (Paine, 1977), in which it became important to improve the living standard of the Indigenous population by means of "modernization." This modernization was implemented with great speed. The result was not only rapid social, economic, and cultural change that continues through today, but also historical and social trauma.

3.3.1.1 International cooperation and competition in the region

The Arctic is portrayed by actors within as well as outside the region as a vulnerable ecosystem, a climate change "canary in the coal mine," a last frontier for resource exploitation, and a revived sphere of geopolitical interest. To Inuit living in the region, it is simply home, whether they were transported to the area within living memory (like the people of Resolute, Grise Fiord, and Qaanaaq) or have lived there for many generations. Based on emerging images of the Arctic, international competition and cooperation have evolved and are continuously evolving, with implications for the overall governance framework for the Baffin Bay/Davis Strait region.

Trends of international competition that are affecting development in the BBDS region include the rush to establish rights to emerging resources, be they continental rights or rights to new fish stocks entering the region. There may well be competition also for quotas of marine mammals that are projected to become increasingly limited in population size, such as narwhals and belugas. Quota levels are already viewed as unnecessarily restrictive by local hunters (Ford and Goldhar, 2012; Rodon 2014b).

A major trend of international cooperation includes the establishment of the Arctic Council and its scientific working groups on natural and human development, as well as the established regional organizations that coordinate the governance of the living marine resources harvested by the industries and people of the region (e.g., the International Council for the Exploration of the Sea, the North Atlantic Marine Mammal Commission, the North East Atlantic Fisheries Commission, the Northwest Atlantic Fisheries Organization, the North Atlantic Salmon Conservation Organization). Most recently, the five Arctic Ocean coastal states have begun engaging in scientific dialogue on the living marine resources of the central Arctic Ocean, in discussions that have expanded to include Iceland and some observer states (Danish Ministry of Foreign Affairs, 2015). Meetings in the spring of 2016 between the heads of state of Canada and the United States of America (USA) and between the Nordic countries and the USA have added more commitments to international cooperation in the Arctic, including commitments to conservation, sustainable development, and the inclusion of traditional knowledge in setting policy (Government of Canada, 2016; White House, 2016).

New governance gaps continue to emerge, as environment, policy, and society change. One type of governance gap that could potentially affect the region is created by the new exploration activities of the extractive industries. When Cairn Energy was drilling for oil off Greenland (2010–2011), there were concerns in Canada about potential spills entering Canadian waters. A 1983 treaty exists between Canada and Denmark on cooperation relating to the marine environment (Agreement between the Government of Canada and the Government of the Kingdom of Denmark for Cooperation Relating to the Marine Environment, 1983), but it covers only consultation on such developments. The treaty does not establish a process for managing the shared body of water. Without such an agreement, continued industrial development that affects marine resources could be a driver of conflict.

Bilateral cooperation across the Greenland/Canadian borders within the BBDS region is generally increasing. Bilateral agreements exist between Canada and Greenland in relation to the governance of shared fish resources (e.g., shrimp and Greenland halibut) and marine mammals (e.g., polar bears in the McClintock Channel). Increased scientific cooperation between Greenland and Canada is another significant trend.

Increasing cooperation between the regional governments is also emerging. For example, Greenland and the Government of Nunavut signed, in 2000, a memorandum of understanding on cooperation. This memorandum prioritizes cooperation for the sustainable management of polar bears and fisheries in waters common to Greenland and Nunavut.

The Inuit Circumpolar Council (ICC), which was established in 1977 (as the Inuit Circumpolar Conference), remains a vital player in pan-Arctic cooperation to enhance Inuit rights and perspectives in decision-making relevant to the region. ICC promotes Inuit rights and perspectives in international bodies such as the Arctic Council and the United Nations and also functions as a forum for Inuit in Canada and in Greenland to share information and formulate collective positions. An emergent ICC-sponsored body is currently considering the future of the Pikialasorsuaq/North Water Polynya, an important ice-free region in Baffin Bay (see Section 3.1.4 and Subchapter 6.2). As a newer trend, ICC Greenland is also making itself heard in relation to Greenland's discussions of participatory decision-making within Inuit self-governance.

3.3.1.2 Localizing governance in the region

The shift toward more powers for governments in the region has been a long-term trend in the Canadian Arctic and in Greenland (see also Chapter 2).

The creation of the Nunavut Territory in 1999 is a clear example of this trend. The Nunavut government has quasi-provincial powers, with the exception of land and nonrenewable resources management. Inuit of Nunavut express their rights to self-government through the public Government of Nunavut. Inuit make up 85% of the Nunavut population (Statistics Canada, 2011a, 2011b) and also protect their Indigenous rights through co-management boards (boards designed to allow Indigenous peoples' participation in decisions about land and wildlife) (White, 2008; Rodon, 2014b). Without the revenue of resource development, the territorial government has limited financial autonomy. At this point, 98% of its revenues are transferred from the Canadian government (Rodon, 2014a). The creation of the Nunavut territory was layered onto the 1993 Nunavut Land Claim Agreement (Agreement between the Inuit of the Nunavut Settlement Area and Her Majesty the Queen in Right of Canada, 1993) that confirmed Inuit ownership of more than 350,000 km^2 of land (of which about 10% also includes mineral rights) and also created Inuit institutions to safeguard Inuit rights on those lands and elsewhere within the Nunavut Settlement Area.

The Canadian territories are also negotiating powers on land and resources. A recent example is the 2013 devolution agreement between the Canadian government and the government of the Northwest Territories (Northwest Territories Lands and Resources Devolution Agreement, 2013), following a similar deal in the adjacent Yukon Territory. The Government of Nunavut is currently negotiating its own devolution deal. It should be noted, however, that this process will likely take several years if it follows the pattern of the previous two devolution agreements. Devolution of lands and resources would theoretically allow the Government of Nunavut to become less financially dependent on the federal government but would also likely increase pressure on the territorial government to promote more resource development in order to maintain or increase government revenues.

Thierry Rodon

Nunavut Legislative Assembly building

In Greenland, decolonization began in the 1970s, with international opinion and the ethno-national movement of Greenland's elite laying the foundation for the devolution process that started with the establishment of Greenland Home Rule in 1979 (Dahl, 1986). In 2009, Greenlanders voted, in a national referendum, in favor of further independence in the form of Greenland Self-Government. This new arrangement transferred to Greenland the full rights to its underground resources as well as the possibility to "take home," whenever the Greenland Self-Government decides, some of the remaining fields of responsibility that are still placed within Danish institutions. Other fields of responsibility can be transferred only when Greenland decides to be an autonomous state (Lov om Grønlands Selvstyre, 2009; see also "The Greenland Home Rule scheme," www.stm.dk/_a_2566.html).

Throughout Greenland history, mineral resources have been exploited for their economic potential (Rosing et al., 2014), but these resources have received renewed attention since the commencement of Greenland Self-Government in 2009. While welfare and well-being through economic growth is often presented as a goal in itself, economic dependence on Denmark remains a key concern within the Greenland government. An annual block grant from Denmark accounts for one-third of Greenland's gross domestic product (GDP), and leading politicians have been explicit about the connection between their aspirations for increased independence from Denmark and their choice of an active mineral resource extraction policy. However, a report by a panel of academics from Greenland and Denmark (Rosing et al., 2014) suggests that mineral development is unlikely to cover the costs of full independence plus the incremental costs associated with demographic issues (e.g., more elders, fewer young people, and increased social expenditures). In 2013, the Greenland government explicitly allowed for the mining of radioactive materials in Greenland.

Devolution has proved to be a challenge in terms of capacity, and the Greenland Home Rule government has depended on Danish labor immigration in, for example, administration, hospitals, and schools. Greenland still needs foreign labor, though the picture is slowly changing as more and more Greenlanders are taking secondary, vocational, and higher education.

The Government of Nunavut also has trouble filling its positions (25% of government positions were unfilled in 2014) (Government of Nunavut, 2014). If Inuit access to education is not improved and if other barriers to Inuit participation in the bureaucracy are not lowered, then devolution might foster the need for more administrators from southern areas. This situation may create an in-migration and would lower the percentage of Inuit employees in the government, thus making it harder to fulfill the Nunavut Land Claim Agreement (NLCA) obligation (Article 23) to have a representative bureaucracy (meaning 85% Inuit; the current percentage in the government administration is only 50%).

3.3.1.3 Shifting paradigms for natural resource management

Various concerns for ecological, economic, and social sustainability have gradually emerged to shape natural resource governance paradigms in the region. Competing policy goals are shaping governance design, including decision-making procedures, planning practices, design of access rights, and monitoring arrangements. In turn, these governance institutions have different impacts on the state of the natural resources, on local societies, and on both the formal and subsistence economies of the self-governed polities.

In the BBDS region, there is also an ongoing epistemological debate that has a direct bearing on resource management. National and regional governments are increasingly taking into account traditional ecological knowledge (TEK) when making management decisions (CEAA, 2015). Increasingly, holders of traditional ecological knowledge are questioning the scientific knowledge that constitutes the other significant knowledge input to decision-making (Dowsley and Wenzel, 2008). When the two types of knowledge disagree, the lack of consensus has the potential to delay decision-making, to repeatedly change the course of management (e.g., in the Greenland coastal fisheries; Jacobsen and Raakjær, 2012), or to increase tension over the decisions made, depending on which sort of knowledge is held to have prevailed in determining policy. Finding a way to truly integrate these epistemologies could be a valuable contribution to future adaptive management.

The natural resources can be divided into living and non-living resources, for which different trends are observable (see also Chapters 6 and 7).

3.3.1.4 Living resources

Fisheries are already the most regionally important living resource in terms of economic value and employment, and they may well become even more important as economically important new species move northward into the region and more investment is put into the industry. The weight of the industry is more apparent in Greenland than in Nunavut. In Greenland, the fisheries industry creates over half of the region's service and goods export (57% of 4.2 billion Danish kroner, DKK, in 2011, or approximately 469 million Canadian dollars, CAD), and the fishery sector has been estimated to create employment corresponding to 3,500 full-time jobs (Copenhagen Economics, 2013). In Nunavut, federal government figures for 2013–2014 showed the total market value of Nunavut's fishery was CAD 86 million (CanNor, 2015; see also Chapter 6 of this report), with 370 people employed seasonally in the offshore and inshore fisheries. (The CAD 86 million value accrues largely to out-of-territory ships and crews, mostly from Newfoundland and Labrador.)

Since the 1980s, the total allowable catch (TAC) paradigm within living resources management has increasingly balanced ecological sustainability concerns against the more immediate economic and employment concerns of those groups in society that are directly dependent on fishing. TAC policy is a hot topic in the region, as quotas are often perceived as constraints imposed by central governments or even international opinion. The scientific knowledge base for TAC decision-making is often contested. A recent but seemingly significant trend is the influence of Marine Stewardship Council (MSC) certification on fishery policy-making; the certification requirements tend to favor more restrictive TAC policies in the Greenland fisheries (Jacobsen and Raakjær, 2012).

Trends of consolidation and privatization are other significant and perhaps even more profound governance drivers in relation to living resources. In Greenland (Jacobsen and Raakjær, 2014) and the northwest Atlantic in general (Holm et al., 2015), trawler profitability, privatization, and consolidation are increasingly being promoted as a counterweight to previous policies that emphasized the need to sustain local settlements based on arguments of regional development or cultural identity alongside overall economic growth. The individual transferable quotas (ITQ) reform of the coastal Greenland halibut fishery in 2012 is the latest example of this development (Jacobsen, 2013).

The expected impacts of consolidation include increased competitiveness on the international market for the consolidated seafood companies, as well as increased taxable incomes to fund Greenland's welfare state (Government of Greenland, 2009). Fishing access closure through consolidation, privatization, and a more restrictive TAC policy critically affects fishery-dependent families and communities that have few options other than fisheries and hunting to earn the cash income that also covers the running costs of subsistence activities. In economic terms, the closure of fisheries access affects the gross national product (GNP) when income alternatives are lacking because municipal social welfare budgets will then have to compensate for the loss of local income by increasing expenditures on public welfare (Delaney et al., 2012; Hendriksen, 2013).

In Nunavut, the value of commercial fisheries has risen over the past few years, particularly along the east coast of Baffin Island. There is momentum behind these fisheries, as well as interest in exploring other fishing opportunities off Nunavut. In early 2015, government agencies and Inuit organizations combined to invest more than CAD 7 million in several exploratory fisheries and in research on existing fisheries (Government of Canada, 2015).

With fisheries perhaps expanding as a resource, especially in the context of climate change and the arrival of new species, this sector has the capacity to increase employment options for Inuit communities that presently have few such options. Still, any expansion of fisheries resource use will also be determined by the governance arrangements in place. Under the land claims agreement in Nunavut, all Inuit have the right to hunt/fish and sell without any license or reporting, but the governments of Nunavut and Canada contend that this right does not extend to commercial harvesting for the specific purpose of selling outside of Nunavut. Thus, commercial harvesting requires a permit. In Greenland, commercial hunting and fishing is regulated with quotas and a license system. With few exceptions, only persons or companies holding a commercial license are allowed to market their catch nationally and internationally. In both Nunavut and Greenland, support programs for hunters and fishers will probably also play a role in the biologically, economically, and socially sustainable expansion of the fisheries.

Other living resources (particularly seals, walrus, whales, and caribou/reindeer) make up a substantial portion of diets in the region, with a replacement value of millions of dollars (ITK and ICC Canada, 2012; Jeppesen, 2012). There are indications that the combination of climate change and socio-economic factors – such as equipment issues, cost of gas, and tensions between the wage economy and the subsistence economy – are reducing access to these traditional foods. Organizations in Nunavut cite this situation as exacerbating food insecurity. There is also value in the byproducts of subsistence hunting, such as walrus and narwhal tusks. There are indications of growth in the market for these products, particularly in China (Cooper, 2015).

Living resources in the BBDS region are further discussed in Chapter 6.

3.3.1.5 Non-living resources

On the Nunavut side of the BBDS region, the federal and Nunavut governments are investing millions of dollars in geoscience to further investigate the mineral and petroleum potential of the land and the seabed (CanNor, 2014). Both the Nunavut government and the land claims organization Nunavut Tunngavik Incorporated (NTI) support efforts to attract increased investment in the sector. Despite this enthusiasm, the only viable development at the time of this writing is the Mary River iron mine, which recently started production on northern Baffin Island.

There is some local concern about resource development, as communities fear that aspects of that development may compromise their ability to harvest the animals on which they rely and may also more generally affect their livelihood in negative ways. In 2014, a court challenge was launched by the community of Clyde River, together with the community's mayor and the local organization representing hunters and trappers, against a decision by Canada's National Energy Board to authorize seismic testing in Baffin Bay and Davis Strait. The challenge was rejected in the Federal Court of Appeal, but the hamlet has been granted leave by the Supreme Court of Canada to appeal the decision. Hearings were held in November 2016, and the Court is expected to rule on the case in the spring of 2017 (Rodon, 2018). Opposition to seismic testing in the region has also been voiced by many Inuit organizations, and NTI and the Nunavut Marine Council have proposed a moratorium on seismic testing in Baffin Bay. The federal government has refused to consider a moratorium before it conducts a strategic environmental assessment (Nunatsiaq News, 2014; Indigenous and Northern Affairs Canada, 2014). That assessment has now been contracted through the Nunavut Impact Review Board for delivery in 2019. Environmental and conservation organizations are active in the region. The WWF has offices in Iqaluit and Nuuk and runs various projects mostly centered on the "Last Ice Area," the area of projected resilient summer sea ice. Oceans North has also funded work in the region, and Greenpeace helped to support the Clyde River court case.

Nunavut land use plans are drafted by the Nunavut Planning Commission, a co-management board established by the Nunavut Land Claim Agreement. These plans are intended to set the template for where development is allowed and encouraged and for where traditional land uses and conservation will be prioritized. Only two plans have been approved by the federal government (North Baffin and Keewatin); work on a Nunavut-wide land use plan (which would supersede the regional plans) has been delayed by a lack of funding. Public hearings on the draft plan are now scheduled to take place in 2017.

In Greenland, applications for extractive industries have been regulated under the Greenland Bureau of Minerals and Petroleum since 1998, with the governance framework being gradually adjusted since that time. Within the recent years of Greenland Self-Government (since 2009), the trend has been to continue and even intensify an active strategy for mineral and oil extraction. In 2012, the Greenland Parliament passed the Large-Scale Projects Act, which provides a framework for large-scale projects (defined by total construction costs exceeding DKK 5 billion, or almost CAD 1 billion). In 2013, the subsequent parliament lifted a previous ban on uranium mining.

The mandatory use of environmental impact assessments (EIAs) and social impact assessments (SIAs) is a prominent trend, though still in its early stages. It is notable that, due to a variety of reasons, including political will, EIAs have in fact proven efficient in influencing industry planning (Hansen, 2010).

The recent increase in project activity and planning has been met with an equally increased demand for public involvement and public access to information. A second trend in the governance of extractive resources is thus the expansion of governance discussions to include a strong focus on public participation, as well as social impacts. In 2014, a nongovernmental organization (NGO) for better citizen participation in extractive industry projects was created – uniting the Inuit Circumpolar Council, ICC Greenland, Transparency Greenland, and KNAPK (Association of Fishermen and Hunters in Greenland) with international, national, and local environmental NGOs (e.g., WWF and Friends of Nuuk Fjord). The confluence of interests and the emergence of joint projects among international environmental NGOs and Inuit fisher/hunter interests seems to represent a third trend in the natural resource governance landscape of the BBDS region (NGO Koalitionen for Bedre Borgerinddragelse, 2014).

Non-living resources are further discussed in Chapter 7.

3.3.2 Demography

3.3.2.1 General population growth

In terms of population growth, the BBDS region shows different tendencies on the Greenland and Nunavut sides. The population of Nunavut's Qikiqtaaluk Region (formerly called the Baffin Island region) is 19,498 (Nunavut Bureau of Statistics, 2015), with a growth rate of 7% from 2006 to 2011 (Statistics Canada, 2011a, 2011b). This growth is explained by a high fertility rate and lately by a positive migration rate. In 2015, the population of Greenland was 55,984 (52,515 within the BBDS part), with a negative growth rate (Statistics Greenland, 2015). In 2015, the Greenland population fell below 56,000 for the first time since 1997.

It is difficult to predict future population trends in the Nunavut portion of the BBDS region. Nunavut has a very young population, with a median age of 24.1 years (Statistics Canada, 2011a, 2011b). For many years, people have expected a drop in fertility rate, but there is no sign yet of a drop. The current numbers show a fertility rate of just under 3 births per woman. Because replacement value is considered to be 2.1, the present fertility rate suggests a continuation of the Nunavut trend of a young and rapidly growing population. This population growth rate is both an opportunity and a challenge. The growing population will continue to put pressure on education, health, and housing services and on both the traditional and wage economies to create employment. However, if these numerous challenges are met, this young population could prove to be an asset for Nunavut.

The population impact of resource development in Nunavut is for the moment quite moderate. The impact statement for the fly-in/fly-out Mary River project (where most employees fly in for a two-week shift and then fly back home for two weeks off) states that, "*The potential for the Project to cause non-Inuit migration into communities, as well as the potential for Inuit to move out of the communities as a result of the Project was assessed. Neither of these possibilities is identified as significantly affecting the composition and numbers of the North Baffin populations or the community social fabric*" (Baffinland Iron Mines Corporation, 2012, p. 17). Because the transportation infrastructure in Nunavut is so limited, it is likely that future developments would also be fly-in/fly-out, thus minimizing the impact on permanent immigration (see Chapters 7 and 10).

For Greenland, the 2014 prognosis from Statistics Greenland is for a decline in the population. If fertility, mortality, and migration alone influence population size, then based on past and current trends, the total population can be expected to fall to 54,800 by 2030. A current trend is for net migration to be negative and for emigration to exceed the birth surplus (Statistics Greenland, 2015).

3.3.2.2 Urbanization

Iqaluit, the capital of Nunavut, has witnessed a steady increase in population (8.3% increase between 2006 and 2011, according to Statistics Canada), and this trend is likely to continue. The community will most likely see an increase of population associated with resource development projects because all of the regional services are located here.

Greenland, too, shows trends of urbanization and concentration. Overall, the number of residents living in settlements and small towns has been declining, particularly within the last 15 years. Since 1999, the number has declined by almost one-third, from just below 10,000 to about 7,500 (Statistics Greenland, 2015). As a result of this concentration process, the age composition is very different across the country, with relatively more elderly in settlements and smaller towns. This trend will become even stronger as the population ages.

Still, there are nuances to the Greenland trend. Some settlements (e.g., in the Upernavik district) have not experienced this decline in population. This difference may be due to local opportunities for earning income from the local catch, sale, and production of Greenland halibut (Hendriksen, 2013).

3.3.2.3 Migration out of the region

For Nunavut, the latest statistics show a rapid growth of the number of Inuit living in the south (Morris, 2016). Reasons for moving south are varied; they include opportunities for health treatment and education and employment (Patrick and Tomiak, 2008) but also the escape of bad circumstances and poor living conditions in Nunavut (Morris, 2016).

The outmigration seems to be greatest from western Nunavut, but we see an increase of Inuit in southern Canada (Statistics Canada, 2006, 2011b). At this time, the outmigration is offset by the very high fertility rate in Nunavut. The fly-in/fly-out practice associated with resource development could also increase outmigration by encouraging northern workers to relocate to big centers where flights are available and where there is better and cheaper access to housing and services.

In Greenland, despite relatively high fertility rates (compared to, e.g., Denmark), the population has remained fairly constant in recent decades due to net outmigration. Accompanying this net outmigration is, more recently, some "brain drain," as an increasing number of young Greenlanders are not returning to Greenland after completing their education abroad, primarily in Denmark. Identified drivers of this phenomenon include a lack of student housing and trainee positions within Greenland, as well as concerns for the availability of housing and daycare and the quality of children's school education upon return (Government of Greenland, 2015b; Sermitsiaq News, 2015).

3.3.2.4 Worker immigration

In Nunavut, the trend of increased worker migration will affect mostly Iqaluit. Resource development and a localization of government would bring more southern workers to the capital, thus affecting the balance between Inuit and non-Inuit. Already, the Iqaluit population is 50% non-Inuit. The effect on the composition of the Nunavut population outside Iqaluit should be quite small because this population is 85% Inuit.

As noted above, an increase of government workers from outside Nunavut may be expected if a devolution agreement covering lands and resources goes ahead in Nunavut. In Greenland, a similar increase was seen in the 1980s in regard to Danish immigration, but this trend has since reversed. The trend might, however, change again if mineral exploitation creates a new demand for migrant workers. Danes currently make up approximately 10% of the population in Greenland. In the period from 2008 to 2013, the immigration of citizens from outside Denmark doubled, but in 2015, the total immigration was still only 974 persons.

In the resource extraction sector, the established trend on the Canadian side of the BBDS region is to use fly-in/fly-out. This pattern of employment has been shown to be corrosive to family relationships and to cultural continuity (Gibson and Klinck, 2005). Due to this fly-in/fly-out model, only a small immigration of labor is forecasted on the Canadian side, even in the scenarios of high resource development (see Subchapter 3.4 for a description of the scenarios considered in this BBDS assessment). In Greenland, the immigration changes might be more dramatic, and the prospect has already caused much debate – e.g., about social dumping and pressure on the health infrastructure.

As noted above, Inatsisartut (the Greenland Parliament) passed the Large-Scale Projects Act in 2012. This act facilitates the influx of foreign labor while also attempting to prevent the payment of low wages to foreign workers. International investors have estimated a need for 2,000–2,250 migrant workers (primarily Chinese) for a planned aluminum smelter to be constructed and operated by Alcoa in the vicinity of Maniitsoq (north of Nuuk). The estimated need for a planned iron mining project to be constructed and operated by London Mining (the so-called Isua project, close to Nuuk) is 1,000–3,000 workers (primarily Chinese) (London Mining Greenland A/S Isua, 2012). These


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levels of foreign labor would make every tenth citizen in Greenland a Chinese worker, as fly-in/fly-out has not been presented as a relevant option for Greenland. Instead, plans have been to accommodate workers in camps outside the towns.

In the service sector, the whole BBDS region can expect an increase of outside workers in the scenarios of high resource development (see Subchapter 3.4 for scenario descriptions).

The Inuit Circumpolar Council has noted that a dramatic increase of worker immigration in connection with large-scale projects could make Inuit a minority in the region and would call for the specification of Inuit rights in the legislation of the self-governing territories (Adaptation Actions for a Changing Arctic, AACA, stakeholder consultation. See Chapter 1 for a description of the AACA consultation process.) ICC International furthermore states that, "*The pace of resource development has profound implications for Inuit. A proper balance must be struck. Inuit desire resource development at a rate sufficient to provide durable and diversified economic growth, but constrained enough to forestall environmental degradation and an overwhelming influx of outside labour*" (ICC, 2011, p. 1).

3.3.3 Economy

3.3.3.1 Formal economy

According to the *2013 Nunavut Economic Outlook*, Nunavut is "*set to embark on a prolonged period of economic growth*" (Impact Economics, 2013, p. 17). The following trends are observed:

- Government is still the main economic sector and could increase with devolution.
- Mining is the biggest hope for major capital investment, job creation, and business opportunity, but at this time the industry is quite small.
- Infrastructure projects will also be important: CAD 100 million federal transfer for public housing, the Iqaluit international airport project, the Nanisivik Naval Facility, and the Mary River Project. In a future scenario with a high level of mining development (see Subchapter 3.4), this sector would become very important in the Baffin Island economy.
- Nunavut fisheries has been the sector with most growth in recent years, with more quota allocations and investments in equipment and research. This trend might continue, but climate change and ocean acidification could have major impacts on this industry because fish and feed stocks are sensitive to changes in water temperature and acidity. The types and timing of fisheries activities will change with climate change. For Greenland halibut, for instance, the inshore ice-based fishery will experience a decrease in available season, while the offshore fishery from boats will experience a longer season.
- The regulatory environment could also affect the fisheries industry (through agreements with Greenland, for example, but also through competition with southern-based fisheries). Nunavut still lacks a deep-water port.
- Tourism has a potential for growth. In 2011, more people were employed in the tourism industry than in mining (Impact Economics, 2013). The arts sector has always been strong in Nunavut but could be affected by the development of other sectors, as with few exceptions, employment in the arts is less lucrative.

In Greenland, the current national economic situation is dismal. The growth rate has been negative for a couple of years, and growth prospects are dim. This situation is reflected in various economic indicators, including unemployment and also net migration.

Public finances are under pressure not only in the short run but also in the medium to long run due to an aging population. Experts (Økonomisk Råd, 2014) warn that unchanged policies are simply not an option and that significant reforms are needed to ensure both fiscal sustainability and a more dynamic and growing economy.

In recent years, the economy has benefited from increasing prices for seafood (particularly shrimp). This price increase is masking falling catches, and the biological advice indicates declining stocks. Falling quotas are thus part of the scenario. Fishing has benefited from the recent appearance of mackerel, but the medium-term implications are still uncertain.

Previous enthusiasm surrounding oil and mining has waned. A ruby mine is under construction in Qeqertarsuatsiaat, south of Nuuk, and a few other projects are being planned. The exact impact of oil and mining projects on the economy in the near future is highly uncertain.

Exploitation of natural resources can play an important role in the future to ensure a process toward a more self-sustaining economy. This trajectory also requires that these projects be used to create activities and employment for domestic enterprises and workers; if not, the social and financial gains from the projects would be limited.

There is scope for increasing value added in fisheries and tourism, but these activities are not likely in themselves to have a decisive growth impact. The Arctic tourism industry in the BBDS region is, however, a means to diversify the region's historical reliance on the resource industry. Tourism is often promoted as having an important role in economic development and diversification, and this sector may contribute to curbing the negative impacts of a boom–bust cycle in areas where resource-based economies are in decline or in flux, such as in the BBDS region. Tourism also enables local people to be employed on a seasonal basis while also allowing time to engage in traditional and cultural activities (see Chapter 8).

Logistics remain an important challenge, with a small population scattered across a large country and difficult and expensive options for domestic and international transport. So-called small-scale disadvantages pose a challenge in many areas and constitute a potential cost driver and an impediment to economic development.

Social and economic inequalities are relatively large, and a number of indicators point to poor living conditions for a substantial part of the population. Shortage of housing is also an issue (Skatte- og Velfærdskommissionen, 2010; Government of Greenland, 2015b; see also Chapters 4 and 10).

3.3.3.2 Informal economy

The economy of Arctic societies is characterized by the significance of the mixed economy, in which the formal and informal economies interact (Wenzel, 1981; Quigley and McBride, 1987; Usher and Weihs, 1989; Usher et al., 2003). Thus, the trend is for the formal and informal economies to be each other's prerequisites rather than each other's competitors. As the Survey of Living Conditions in the Arctic (SLiCA) concludes, *"A combination of traditional activities and cash employment, the mixed economy of the Arctic, is the prevailing lifestyle of Arctic indigenous peoples. It takes money to pursue traditional activities; households with higher incomes can, and do, choose to spend income on these activities"* (Poppel, 2015, p. 55).

The informal economy includes harvesting activities (hunting, fishing, trapping, and gathering) and also artistic activities (such as carving and sewing). Not all of these cultural activities are "traditional"; many are adaptations by younger artists who use elements of traditional culture but incorporate them into new fashion designs, television shows, or new musical forms. Harvesting activities are still very prominent in the BBDS region, especially in the smaller communities but also in towns like Nuuk and Iqaluit. The informal economy is thus contributing greatly to food security. For instance, a study of extended families in the Baffin Island community of Clyde River concluded that country foods contributed about 20% of the families' total income (Harder and Wenzel, 2012; see also Chapter 4).

After public outcry, a moratorium on Baffin Island caribou hunting was changed in 2015 to an annual quota of 250, but it is clear that hunting pressure is affecting the sustainability of the practice of hunting that population. Human population growth and other factors, such as the growth of informal markets for wild foods, are also increasing the pressure on wildlife resources, especially around larger communities (see Chapter 6).

There are large differences between the country food markets in Greenland and Nunavut. In Greenland, local food markets date back to colonial times, when they served Danish non-hunters. Today these markets serve all people but are most prevalent in larger towns. In Iqaluit, Nunavut, a local country food market has developed through a public market held twice a year and also through a Facebook page. Commercialization of country food is one component of addressing food insecurity issues in Nunavut (Ford et al., 2016). As the SLiCA survey (Poppel, 2015) also showed, informal sharing is still prevalent in the Arctic.

The development of extractive industries could have contradictory impacts on subsistence ("land-based") activities. Such development could, on the one hand, provide more financial means, thus allowing people to buy better equipment and gain better access to wild foods. However, work schedules – especially long shift work – could also negatively affect land-based (subsistence) activities (Rodon and Lévesque, 2014). The enclosure of work sites is another potential issue. Even at an early resource-exploration stage, local hunters from Nuuk have already experienced exclusion from common lands where they once hunted caribou. At the moment, little research has been conducted, and the few available results are inconclusive. There are also concerns about seismic work and mining-related shipping potentially having a negative impact on the availability or accessibility of marine resources (DFO, 2012).

Warming may initially affect some Arctic species positively (see Subchapter 6.3), but climate change has already negatively affected land-based activities because of the stresses created for some species and because of the greater difficulty of traveling on land and sea ice for hunting, fishing, trapping, and gathering. This consideration was indeed a main concern that ICC, KNAPK, and Qaanaaq community members expressed in the AACA consultations (see Chapter 1).

The carving sector could also be affected by the development of extractive industries. In a low-development scenario (see Subchapter 3.4), carving could continue. In a high-development scenario, however, many of the carvers would probably be employed in a different sector. This shift could lead to lower carving production but also better-quality production (Impact Economics, 2013).

3.3.4 Education and culture

3.3.4.1 Formal education

Education is also an economic driver in the BBDS region, through public investment and also through the increase in human capital. Better access to formal education would diminish the outmigration of students who, at this time, must go south or go abroad to study. Education is a priority issue for the BBDS region, as discussed in Chapter 5.

The Nunavut side of the BBDS region offers the whole range of primary and secondary education, but at this time there is no university in the Canadian Arctic. Nunavut Arctic College is a community college that provides training programs and also delivers two university programs accredited by southern universities (teacher training and nursing). A law program was offered in Iqaluit through a southern university from 2001 to 2005 and will be offered again in 2017 through a different university.

School graduation rates in Nunavut are slowly increasing but are still the lowest in Canada. An improvement in graduation rates and the creation of a local university would help to reverse the trend of increasing proportions of southern workers in public administration and service jobs.

Greenland offers a range of secondary, college, and university educational options. In 2005, the educational aim of the Greenland Parliament was to increase the share of citizens with a qualifying education (that is, education beyond the 10-year elementary education; Boolsen, 2017) from one-third to two-thirds. The 2015 educational plan of the Government of Greenland states that the overall goal is for 70% of a year group leaving elementary school to obtain a qualifying education before the age of 35 (Government of Greenland, 2015a). Educational performance is currently unsatisfactory in terms of these stated aims. In 2013, 34% of men over 16 held a secondary or higher degree; for women, the proportion was 37% (Statistics Greenland, 2013). Many people leave public school (10th grade) with insufficient proficiency in subjects such as Greenlandic, Danish, and mathematics – and with a lack of motivation for continuing their education. Half of today's cohort does not receive an education relevant for the existing labor market.

The Greenland trend, however, is in the direction of improving educational levels. From 2003 to 2013, the number of persons with a completed education above primary school (i.e., above grade 10 or 11) increased by 6%, to 15,105 persons in 2013 (34% of the population).

3.3.4.2 Inuit education

On both sides of the BBDS region, traditional education is informal and still occurs today within traditional cultural practices, mixed economies, and traditional systems such as food systems (Poppel, 2015).

In the Canadian Arctic, some researchers contend that the Western system of education has eroded Inuit culture without allowing the people to fully participate in the new economy (Irwin, 1989; NTI, 2007), and many people in Nunavut are concerned that Nunavut youth are not adequately prepared in either form of education – Inuit or Western (Impact Economics, 2013).

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Ilimmarfik University of Greenland, Nuuk

This situation could be changed by two initiatives. The first one is exemplified by the new Piqqusilirivvik Inuit Cultural Learning Centre in Clyde River. This facility is dedicated "*to enabling the transfer of traditional culture and knowledge, taught in the Inuit language and based on the guiding principles of Inuit Qaujimajatuqangit*" (Nunavut Arctic College, 2017; see also Chapter 5). The second initiative, the creation of an Inuit Nunangat university, is being discussed. The establishment of such an institution could greatly improve access to a knowledge economy but still contribute to maintaining the core elements of Inuit values and culture.

In West Greenland, formal education has been considered a key driver in the modernization process that began in the 1950s. The resulting educational system has provided access to the knowledge economy, as Greenlanders are increasingly taking on key positions and functions in institutions such as schools, hospitals, and government agencies.

Today, concerns about threats to Inuit knowledge in Greenland are being raised regarding climate change and the resulting challenges to subsistence activities (comments from ICC Greenland and the Greenland Ministry of Education, Church, Culture and Equality, in the AACA stakeholder consultation; see Chapter 1). ICC Greenland recommends that the teaching of Inuit knowledge be incorporated within the formal educational system (ICC Greenland).

3.3.4.3 Inuit language

Maintaining Indigenous languages is generally considered by the Indigenous peoples of the Arctic as being important for the identity of the individual as well as cultural continuity (Poppel, 2015).

In the Qikiqtaaluk region, the Canadian census shows that between 2001 and 2011, the proportion of respondents who reported using Inuktitut most often at home declined from 68% to 64% (Statistics Canada, 2001, 2011b). Qikiqtaaluk Region nevertheless remains the Nunavut region where Inuktitut is the strongest.

In order to understand the trend in Inuktitut usage in the Qikiqtaaluk region, one must distinguish between Iqaluit, where more than 50% of the inhabitants are non-Inuit, and the other communities, where Inuit constitute a strong majority. Figure 3.25 shows this difference, with 45% of Iqaluit inhabitants having Inuktitut as a mother tongue compared to 92% of residents in the other communities of Baffin Island. These numbers clearly show that Inuktitut is much stronger outside of Iqaluit – a city where Inuktitut is threatened by the prevalence of non-Inuktitut speakers and where 38% of Inuktitut speakers don't speak it at home.

Another indicator of the erosion of Inuktitut is the important difference between people having Inuktitut as their mother tongue (74%) and the people speaking Inuktitut most often at home (64%) (Statistics Canada, 2011b). In Iqaluit, although 45% of Iqalummiut (residents of Iqaluit) have Inuktitut as a mother tongue, only 28% speak it as their primary language at home. The other communities of Baffin Island report 92% of the people having Inuktitut as their mother tongue and 87% speaking it most often at home. These gaps suggest a significant erosion in Inuit language use between generations.

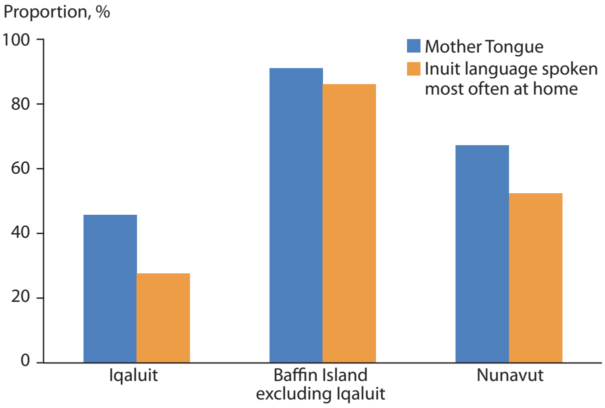

Figure 3.25 Proportion of Inuktitut (Inuit language) speakers in different parts of Nunavut (data compiled from Statistics Canada, 2011b).

Resource development and devolution would certainly reinforce these language trends, by bringing more non-Inuit speakers to Iqaluit. In the communities, resource development could also have an impact through employment because mines require their employees to speak English.

On the other side of the BBDS region, based on various experts' subjective evaluations, Greenlandic (Kalaallisut) is estimated to be the mother tongue of 70% of Greenland's people, with the remainder having Danish as their mother tongue (15%) or being naturally bilingual (15%) (Langgaard, 2001). Based on these numbers and the historical evolution of language in Greenland, Kalaallisut is judged to be a thriving mother tongue language in Greenland today and is expected to remain so for many decades to come (Langgaard, 2001).

For the Greenlandic language, the question is no longer one of language survival but rather of how to develop the language into one that is essential to society and complete in covering all domains of present-day life and all levels of abstractions. The quality of Greenlandic language education is a critical driver in this process.

The digitalization strategy of the Greenland Self-Government has prioritized the development of language technology, which has taken off at a considerable speed and could be considered one trend supporting the development of the Greenlandic language. A second supportive trend could be the emergence of new literature (e.g., Korneliussen, 2014) that takes as a point of departure the interests and concerns of the young generations. A third possible trend is the growth of the Internet, with its potential for building international language proficiency. This trend, however, is currently counterbalanced by high Internet prices, which make Internet access unavailable to many (Langgaard, 2015).

Both strengths and weaknesses are connected to the continuing use of Indigenous languages, including those of the BBDS region: Inuktitut and Kalaallisut (Greenlandic). The *Arctic Human Development Report* (Larsen and Fondahl, 2015) points out that language retention is connected to the concepts of cultural vitality and fate control (i.e., controlling one's own destiny), which contribute to well-being. The report also points out that in Greenland, mastery of only Greenlandic (and not also Danish) is a limiting factor in accessing post-secondary education.

3.3.4.4 Connection with the rest of the world

At this time, the Nunavut side of the BBDS region is poorly connected to the rest of the world, with no deep-water port in the communities and only one regional airport able to accommodate large jets (see details in Chapter 10). Mobile phone service is available only in Iqaluit. Internet access is provided by satellite and is very slow and unreliable, but since 2005 all Nunavut communities have at least been able to access broadband Internet through a government-sponsored program.

Internet in parts of the Nunavut side of the region could become much faster if the Arctic Fibre project goes forward. A submarine fiber-optic Internet cable is planned to link China directly to Europe, but the project offers also the possibility (for a substantial fee) to connect the southern Baffin Island communities to the main cable. This connection would provide access to high-speed Internet, thus allowing the development of an Internet-based economy and giving access to telehealth systems and online education.

Internet access is also used to connect families who live scattered across the region (and the entire Arctic), to coordinate events ranging from political participation (e.g., demonstrations in Greenland and Nunavut) to food sharing (e.g., the "Feeding My Family" Facebook page in Nunavut), and to express Inuit culture and engage in Inuit activism (e.g.,'Sealfies' in which people post pictures of themselves wearing seal products).

A greater availability of Internet access will also likely increase opportunities for both the formal and informal economies. Already, a thriving Internet-based market exists for arts and crafts producers and harvesters from the region to sell their wares in Nunavut and beyond (Nordicity Group and Uqsiq Communications, 2010)

Greenland also shows trends of increasing connectivity. In 2009, Nuuk and Qaqortoq were connected to the Internet through a fiber-optic cable running to Iceland and Canada. The remainder of the west coast is connected to the Internet through a 1,410 km chain of radio stations. For the east coast and the northern part of the west coast, Internet connections are via satellite.

Obviously, the Internet comes cheaper, faster, and more reliably to residents in Nuuk and Qaqortoq than anywhere else in Greenland. The reason most often provided by citizens in Greenland for not having an Internet connection is the associated costs (including the purchase of a computer). Notwithstanding these considerations, 72% of the population has in-home access to the Internet. Internet penetration is greatest among town dwellers, with an occurrence of 75% compared to 53% in small settlements (HS Analyse, 2013).

A PhD study of online distance teaching in Greenland schools (Øgaard, 2016) shows that distance teaching has been perceived as a technical solution to the problem of inadequate access to professional teaching. The most prominent example in Greenland shows how a village school, through the Internet, has been connected to professional teachers from a town school. In this way, the teaching obtains legitimacy among parents, teachers, and students. To date, distance teaching has been about establishing a traditional school situation, even though distance teaching for primary school children holds strong progressive potentials for pedagogical development toward self-governance, cooperation, and the solid acquisition of functional academic skills (Øgaard, 2016). This study implies that distance teaching is gaining support and legitimacy but has not yet realized its potential for progressive pedagogical development.

Greenland currently plans to expand the capacity of its only deep-water harbor in Nuuk. Three airports in the BBDS part of Greenland can accommodate jets. The costs of air and boat travel in Greenland are generally high. As a result, these costs constitute a negative driver for, in particular, the ability of private persons to physically connect with each other and the rest of the world. Tourism (fully addressed in Chapter 8) is also known to be sensitive to the cost of transport (Andrew, 2014).

The development of extractive industries in the region could also improve connections to the rest of the world. The Baffinland mining company, for example, has built a jet airstrip to support the Mary River mine. However, these types of facilities are often not situated close to communities, so local benefits are limited.

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3.4 Regional framework scenarios

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Scenario thinking can be a useful tool to reflect on possible futures, choices, and actions in the context of uncertainty. It is highly difficult to predict with any certainty how the climatic, environmental, and socio-economic drivers presented in Subchapters 3.1–3.3 will interact and affect Arctic lives, environments, and economies – the topics covered in the later chapters of this Baffin Bay/Davis Strait (BBDS) report (Chapters 4–10). Scenarios offer a tool for visualizing possible impacts and contemplating on adaptation actions in the context of uncertainty.

Four framework scenarios are presented here to assist in reflecting on possible future impacts of change in the Baffin Bay/Davis Strait region. In order to spur reflections on *possible* future impacts, two macro-drivers – potential "game changers" – were selected for consideration: *climate change* and the *development of extractive industries* (oil/gas and hard minerals) in the region. The framework scenarios offer a way to think about possible trajectories of future climatic change (moderate to dramatic) and industrial change (modest to intense) by the years 2030 and 2080. These scenarios will be discussed in several of the following thematic impact chapters (Chapters 4–10).

> *"Climatic, environmental, and socio-economic drivers may interact and amplify the difficulty in making decisions in an unpredictable and rapidly changing Arctic. Cumulative changes may increase existing pressures in the Arctic, while others may bring new opportunities."* – AMAP, "Adaptation Actions for a Changing Arctic" (AACA) informational brochure

This problem statement has defined the AACA-C project (see Chapter 1), and the great challenge of this project is to synthesize existing knowledge across disciplines and present it in a way that can facilitate adaptation actions. Indigenous communities, stakeholders, and the scientific community can identify relevant drivers and connections among these drivers, but they can offer little in terms of certainty when drivers collide. Where certainty ends, scenario thinking can be useful. As a tool, scenarios can spark our imaginations and creative capacity; through them, we can formulate narratives of what could happen if we go in one or the other direction. As tools of reflection about the future and where we want to go, these narratives can sharpen our understanding of the range of possible futures, choices, and actions.

The regional integration team of the Baffin Bay/Davis Strait (BBDS) region therefore composed a simple scenario model in order to stimulate, within the following impact-related chapters (Chapters 4–10), discussions of possible future scenarios. The model is described in this subchapter.

In discussing possible scenarios, Inuit knowledge is complementary to Western knowledge. The impact chapters therefore include a variety of sources and perspectives, including Indigenous knowledge and inputs from the ArcticNet Integrated Regional Impact Study (IRIS) and AACA stakeholder consultation processes (see Chapter 1).

3.4.1 The scenario framework model

3.4.1.1 Choosing the macro-drivers

We selected two macro-drivers for the scenario framework: *climate change* and the *development of extractive industries* (oil/gas and hard minerals) in the region (Figure 3.26). Climate change is selected because it has the potential to alter living conditions dramatically and because climate has been a starting point for Arctic change discussions. Development

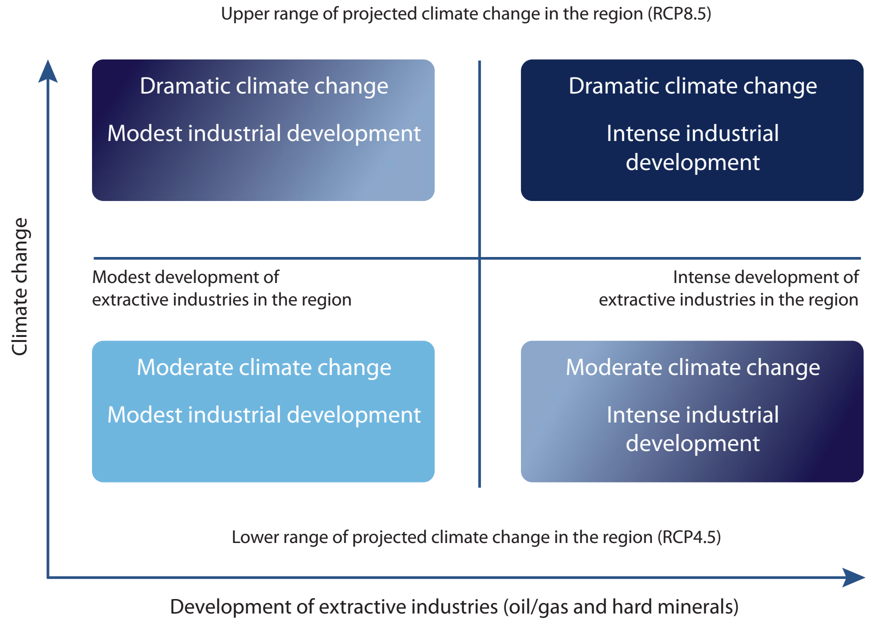


Figure 3.26 The BBDS scenario framework formulated by the AACA Baffin Bay/Davis Strait regional integration team. The two macro-drivers are *climate change* and the *development of extractive industries* (oil/gas and hard minerals) in the BBDS region. Each scenario is to be considered in terms of two timeframes: through the year 2030 and also the year 2080.

of the mineral extractive industries is selected as the other defining driver (among several candidates) because it has the potential to be a "game changer" in the BBDS region, drastically changing the economy, geopolitics, and living conditions. We imagine that these drivers will amplify and interact with other local drivers in the region, creating cumulative effects. In order to frame the discussions in the thematic chapters that follow (Chapters 4–10), four BBDS framework scenarios are constructed using these two macro-drivers (Figure 3.26), with the projection timeframes of 2030 and 2080:

- Scenario 1: Upper range of projected climate change + modest development of extractive industries
- Scenario 2: Upper range of projected climate change + intense development of extractive industries
- Scenario 3: Lower range of projected climate change + modest development of extractive industries
- Scenario 4: Lower range of projected climate change + intense development of extractive industries

Constructing "lower"- and "upper"-range climate change scenarios from RCPs

The climatic scenarios, which are based on representative concentration pathways (RCPs), are adopted directly from Subchapter 3.1. In terms of projected physical climatic changes for the 2030 timeframe, there is little difference between the high (RCP8.5) and medium-low (RCP4.5) emissions scenarios considered by the Intergovernmental Panel on Climate Change (IPCC) in the Fifth Assessment Report (IPCC, 2013). The effects of the two scenarios do, however, begin to diverge noticeably by 2050 (Figure 3.27). Only toward the end of the century (2080 and beyond) do the differences manifest themselves strongly. The climate model ensemble employed by the IPCC (CMIP5) generates a range of climate responses for each scenario, as summarized in the colored bars of Figure 3.27.

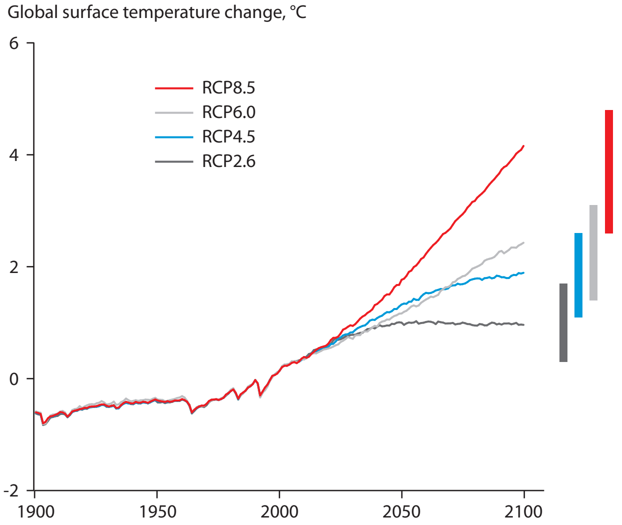


Figure 3.27 Global mean temperature (relative to 1986–2005) for the four RCP scenarios considered in the Fifth Assessment Report of the IPCC (modified from Collins et al., 2013). The vertical bars indicate the corresponding likely ranges for global temperature change by the end of the 21st century. The BBDS framework scenarios consider the cases of high emissions (RCP8.5; red) and medium-low emissions (RCP4.5; blue).

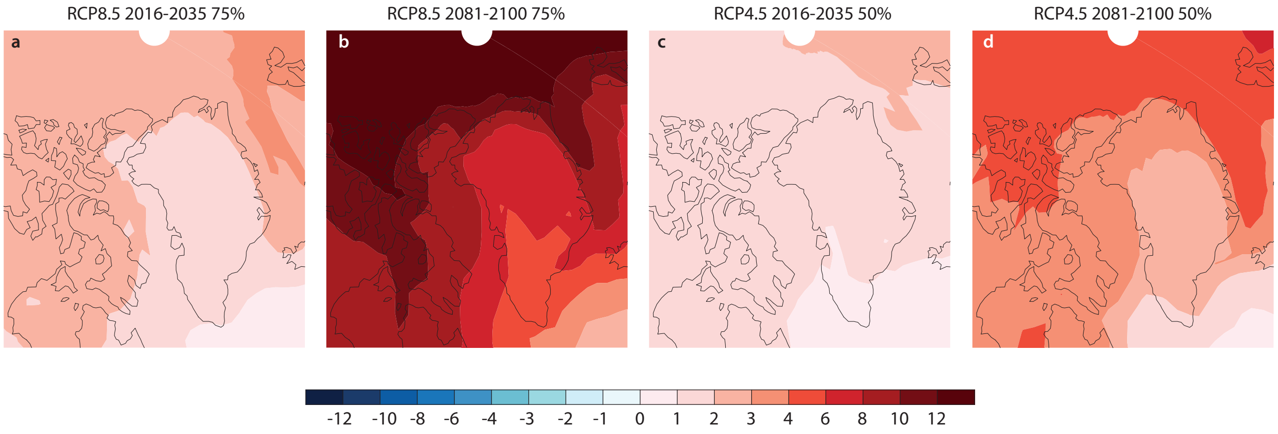
The RCP8.5 (red) scenario assumes a continued increase in greenhouse gas emissions until the end of the 21st century. The RCP4.5 (blue) scenario assumes a stabilization of greenhouse gas emissions by the middle of the 21st century, followed by a sharp decrease.

The Figure 3.28 maps illustrate the differences between the two scenarios in short-term (2016–2035) and long-term (2081–2100) projections. The figure shows that the differences in near-surface air temperature become larger through time and that the long-term RCP8.5 scenario (upper right panel) implies a very drastic temperature increase for the BBDS region.

3.4.2 Macro-driver axis: Climate change

Upper range of projected climate change in the region defined:

For the upper-range (RCP8.5) emissions scenario, global annual mean temperatures (relative to the 1986–2005 reference climate period) are projected to increase by about 1°C by 2030 and about 4°C by 2080. In terms of 75th percentile changes in the BBDS


RCP8.5 2016-2035 75%

RCP8.5 2081-2100 75%

RCP4.5 2016-2035 50%

RCP4.5 2081-2100 50%

Figure 3.28 Projected annual mean near-surface air temperature changes (°C, relative to 1986–2005) in the (a, c) near-term future, 2016–2035, and (b, d) long-term future, 2081–2100 (based on data from IPCC, 2013). a, b: Upper range (RCP8.5, 75th percentile). c, d: Lower range (RCP4.5, 50th percentile).

region, the 2030 (2080) temperatures are projected to increase by about 1.5°C (4.5°C) for the summer season, 3.5°C (10°C) for winter, and 2.5°C (7.5°C) for the annual means. Precipitation is projected to increase by 10% (30%) for the summer season, 20% (50%) for winter, and 10% (40%) for the annual mean[1].

Model-projected changes in annual snow cover duration from the 16 CMIP5 models show consistent decreases across all models, with regionally averaged changes ranging from 0% to -10% for 2030 (with an average value of -3%) and -5% to -30% for 2080 (average = -11%). Projected changes in regionally averaged annual maximum snow accumulation show much greater model spread, ranging from -8% to +5% in 2030 (average = -1%) and -17% to +17% in 2080 (average = -3%), with no model consensus on the sign of the projected change apart from increased snow accumulation appearing in 2050 (and beyond) over the Canadian Arctic Archipelago.

Summer sea ice extent is projected to decrease somewhat by 2030, with some summer sea ice left in the northern part of Baffin Bay. By 2081–2100, the region is projected to be largely free of ice in the summer, with remaining patches in the Nares Strait and north of Greenland. Winter sea ice extent is essentially unchanged in 2030, with some small reductions by 2081–2100.

Lower range of projected climate change in the region defined:

For the lower-range (RCP4.5) emissions scenario, global annual mean temperatures (relative to the 1986–2005 reference climate period) are projected to increase by about 1°C by 2030 and about 2°C by 2080. In terms of 50th percentile changes in the BBDS region, the 2030 (2080) temperatures are projected to warm by about 0.9°C (2°C) for the summer season, 2°C (5°C) for winter, and 1.6°C (3°C) for the annual means. Precipitation is projected to increase by 5% (10%) for summer, 10% (20%) for winter, and 5% (15%) for the annual means.

Model-projected changes in annual snow cover duration from the 16 CMIP5 models show mostly decreases across all models, with regionally averaged changes ranging from 0% to -8% for 2030 (average = -3%) and +2% to -15% for 2080 (average = -5%). Projected changes in regionally averaged annual maximum snow accumulation show much greater model spread, ranging from -12% to +7% in 2030 (average = -1%) and -10% to +9% in 2080 (average = -1%), with little model consensus on the sign of the projected change apart from some evidence of increasing snow accumulation by 2080 over the Canadian Arctic Archipelago.

Summer sea ice area is projected to decrease somewhat by 2030, with some sea ice left in the northern part of Baffin Bay. By 2081–2100, much of the summer sea ice is gone, but some will likely remain in the Canadian Arctic Archipelago. Winter sea ice extent is essentially unchanged by 2030 and by 2081–2100.

3.4.3 Macro-driver axis: extractive industries (oil/gas and hard minerals)

“Modest” development of extractive industries in the region defined:

Under this scenario, 1 or 2 large mines will be operating within the Baffin Bay/Davis Strait region in 2030 and 2 to 3 mines will be operating in 2080. In Greenland’s Large-Scale Projects Act, large-scale projects are defined as those with construction costs of more than 5 billion Danish kroner (approximately 1 billion Canadian dollars). Currently, only the Isua and Kuannersuit/Kvanefjeld projects (see Chapter 7) fall into this category. In the modest-development scenario, transport and reloading would be taking place, as well as greater local ore processing using hydropower. On the Nunavut side of the BBDS region, the Mary River project would maintain a moderate production.

No oil or gas is produced in this “modest” scenario, based on the fact that although oil and gas companies hold licenses in the region, there are no commitments to exploratory drilling. The high cost of infrastructure is one potential barrier to the development of hydrocarbon fields. Oil and gas production could also be hampered by a successful local challenge to seismic testing in Baffin Bay (e.g., the court challenge launched by the Clyde River community).

Possible background drivers for this scenario are to be found in global resource demand, resource prices, and regional priorities. Global developments in population, affluence, and technology would turn out not to be significant drivers for investment. Within the region, decision-makers would not have been able to attract foreign investors, and the desire for more regional autonomy and economic development would not have been sufficiently potent to make resource development more attractive to foreign investors. Decision-makers may also, in this future scenario, have chosen a multi-pronged approach to economic development, with support for a variety of sectors. In this scenario, a governance environment characterized by high-regulation/low financial incentive/high-royalty regimes makes the region less attractive to investors than other jurisdictions.

“Intensive” development of extractive industries in the region defined:

Under this scenario, 3 to 5 large mines are operating within the Baffin Bay/Davis Strait region in 2030 and in 2080. Local ore processing and refining would be taking place. Offshore, 2 oil/gas production fields would be under construction in 2030; in 2080, production would be steady at 2 million m^3/year.

Global developments in population, resource prices, affluence, and technology would foster, in this scenario, an increased interest from outside the region and within the region. Within the region, the desire for more regional autonomy and economic

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[1] These quantities were estimated by taking averages over the area 95°W–45°W, 60°N–85°N on the 75th percentiles from the RCP8.5 AR5 Annex I files. Because 2030 does not have its own slice in these annexes, the short-term quantities were estimated as a 5/6 and 1/6 weighted average between the 2016–2035 and 2046–2065 slices. The long-term (2080) quantities were estimated as a weighted average of 5/7 of 2081–2100 and 2/7 of 2046–2065.

development would turn out to be a potent driver for making resource development more attractive to foreign investors. The governance regime surrounding resource extraction is, in this scenario, governed by a low-regulation/high financial incentive/low-royalty regime, thus making the region more attractive than other jurisdictions. In this scenario, Arctic reserves of metals and oil and gas are heavily exploited by international companies in cooperation with national companies.

3.4.4 Application of the scenarios

The four scenarios described above were considered by all of the technical author teams that compiled the thematic chapters (Chapters 4–10). However, the relevance of the scenarios differs across the thematic areas, so each author team has treated the scenarios differently.

A key effect of introducing the scenarios to the writing teams was that the process challenged the sector-specific focus that specialist teams may tend to have. This process also stimulated imaginative thinking about how a broad range of factors – socio-economic as well as climatic – may influence people and society in the BBDS region over the coming decades, thus helping the teams to develop suggestions for adaptation options.

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4. Health and well-being

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Key messages

- ***Residents across the Baffin Bay/Davis Strait (BBDS) region have experienced common challenges in relation to rapid development and changes in living conditions, and they continue to adapt to the legacy of colonization.*** *However, there are still significant symptoms of social problems and mental vulnerability. The strong relation to nature and the importance of artistic creativity and cohesion remain central to the life of Inuit. These factors are of great importance for mental health and well-being.*
- ***The BBDS health service systems are widely spread out and dependent on central hospitals and medical professionals.*** *As a result, innovative adaptation options for delivering care are of critical importance.*
- ***The health challenges experienced in BBDS communities require a holistic approach, beyond the dominant narratives on the origins of health equities.*** *Health must be viewed outside the traditional model of solely describing disease and negative health outcomes, and health programs must build on community strengths.*
- ***On the Nunavut side of the BBDS region, socio-economic distress and social exclusion have been identified as main factors associated with the high rate of suicide in male youth.*** *Recognizing the impacts of colonization and of changing roles in society and supporting communities to address intergenerational trauma are critical in promoting well-being.*
- ***There is an acute shortage of affordable and adequate housing in the BBDS region.***
    - *Respiratory illness is a major health issue for children in the BBDS region. Such illnesses are directly associated with overcrowded and poor housing conditions.*
    - *The housing shortage is leading to homelessness (both visible and hidden) across the circumpolar North.*
    - *Addressing housing shortages, overcrowding, and inadequate housing is a prerequisite to foster Inuit health and well-being and also to sustain community social and economic development across the Arctic.*
- **In Nunavut, food insecurity has been identified to be at crisis levels. In Greenland, some children also experience food insecurity. Food security is affected by climate change through its impacts on food availability, accessibility, quality, and use.**
    - *Climate change is affecting the availability of food as a result of shifts in biodiversity as well as changes in the ranges and abundances of animal and plant species important to communities (e.g., berries).*
    - *Thinner ice, later ice freeze-up, earlier ice break-up, more variable snowfall, unpredictable weather, warmer temperatures, and more frequent and intense storms have direct impacts on access to traditional and healthy foods.*
    - *Food quality is being affected by (1) a general decrease in wildlife health and (2) the substitution of store-bought food for traditional foods, resulting in higher consumption of nutrient-poor and high-fat foods.*
    - *Climate change affects the development of traditional knowledge and land skills by reducing the ability of young Inuit to engage in land-based (i.e., subsistence) activities. The disruption of traditional mechanisms of knowledge learning and exchange, including meat storage and preparation, has direct implications for how communities interact with the impacts of climate change on the food system, now and in the future.*
    - *Because the production, preparation, and consumption of food are central cultural BBDS activities that provide social cohesion and identity, the availability of traditional food is a core issue regarding food security.*
- ***Projected changes to water availability for communities and residents can potentially alter water quality, with immediate and long-term health risks to residents.*** *The current relatively low frequency of testing for bacteriological and chemical characteristics may not be sufficient to detect seasonal and relatively short-term changes in water quality. Inevitably, a warmer climate will necessitate more careful and frequent treatment and more frequent deliveries from central sources to residents in order to keep potentially harmful bacterial pathogens out of drinking water.*

4.1 Introduction

Human health and living conditions in the Arctic are rapidly changing (Kral et al., 2011; Virginia and Yalowitz, 2011). There is a close interrelationship between the human environment, the natural environment, and climate (Marmot, 2005; AMAP, 2009). Health, or the absence of health, is determined by an individual's circumstances and the environment in which the person lives. Accordingly, impacts on the natural environment of the Arctic may potentially influence human health, both directly and indirectly (Bjerregaard, 2011).

The state of the environment influences the health of individuals and communities in the Arctic, both positively and negatively, through environmental changes (e.g., warming temperatures and melting sea ice and thawing permafrost soils), the spread of


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Hospital pathology laboratory, Ilulissat, Greenland

environmental contaminants, and transportation difficulties and geographical remoteness (Virginia and Yalowitz, 2011; see also Chapters 3, 6, and 10). Complex interactions among the various factors are causing cumulative impacts on the environment and on the people living in the Arctic (AMAP, 2011a).

Multiple causal factors are related to health status, such as where people live, their genetics, income and education level, relationships with friends and family, and the effects of colonial legacies on social institutions. The development of extractive industries also has considerable derived impacts on health in the Arctic (Hansen et al., 2016). Therefore, when assessing health, the underlying determinants of health – such as physical environments, health services, education, and coping – should also be considered (ICMM, 2009; WHO, 2013a). To fully capture this holistic perspective, discussions of health and well-being should not be framed strictly as deficits but should instead be focused on the circumpolar context and the indicators important to northerners – asking ourselves, given the changing environment, what is the state of our communities and what are the opportunities for enhancing health and well-being in our communities?

Discussion of the social determinants of health underscores the need to understand health beyond illness and wellness beyond absence of disease. In particular, given that Inuit are the main population in the Baffin Bay/Davis Strait region, the importance of land to culture and of culture and land to health should not be missed (NCCAH, 2016). This interconnection will also be an important parameter when considering a community's vulnerability and hence adaptation capacity.

Given the potential future climatic impacts on the environment, this chapter later explores the influence of climate change on community well-being as it is linked to land and culture. Further, the chapter highlights areas potentially subject to change due to cumulative impacts. The issues are food security, water security, access to health services, and community well-being. This chapter presents an assessment of the key impacts on the health and well-being of residents in the Baffin Bay/Davis Strait region and of sensitivity to the drivers described in Chapter 3 (climatic, environmental, and socio-economic drivers). The chapter considers both cumulative and interactive consequences of change and potential impacts in the future.

4.2 Social determinants of health

The World Health Organization (WHO) defines the social determinants of health as "*the conditions in which people are born, grow, live, work, and age, including the health system. These circumstances are shaped by the distribution of money, power and resources at global, national and local levels, which are themselves influenced by policy choices*" (WHO, 2013b).

In 2014, Inuit Tapiriit Kanatami, Canada's national Inuit organization, released a paper titled *Social Determinants of Inuit Health in Canada* (ITK, 2014). This discussion paper was first submitted to the World Health Organization in 2007. The updated paper focuses on the need to take a more holistic outlook on the overall health status of Inuit, in contrast to the commonly referenced indicators that focus on health deficits such as the higher rates of infant mortality, suicide, infectious disease, and so forth. Drawing from current data sources and consultation with Inuit land claim organizations, including Nunavut Tunngavik Inc., and governments, the paper highlights the key social determinants of health that are most relevant to Inuit in Canada, including the following eleven factors:

- Quality of early childhood development
- Culture and language
- Livelihoods
- Income distribution
- Housing
- Personal safety and security
- Education
- Food security
- Availability of health services
- Mental wellness
- Environment

In Greenland, too, where Inuit constitute the majority of the population (approximately 90%), the need to understand and investigate health conditions from a more holistic perspective has been emphasized by experts (see, e.g., Bjerregaard, 2001; Niclasen et al., 2007). In 2015, The Ministry of Health in the Government of Greenland published a report titled *Folkesundhed i Grønland 2014* [*Public Health in Greenland 2014*] (Government of Greenland, 2015). The report presents findings from a public health monitoring program, Inuuneritta II. The authors emphasize that health is to be understood and approached from the perspectives of what is considered "a good life" and of determinants of health as related to the opportunity to have "quality of life." The Inuuneritta program includes 56 indicators – for example, economic inequity and perceived quality of life, as well as more traditional indicators such as food security and infant mortality.

Many of the health indicators utilized at the national levels, as described in the previous paragraphs, reflect challenges currently affecting the health of residents in the BBDS region. Life expectancy in Inuit Nunangat (the collective Canadian Inuit homeland) is below the Canadian average: 70.8 years in Inuit Nunangat compared to 80.6 years for all Canadians (Statistics Canada, 2012a). The figures are almost the same in Greenland: there, the life expectancy is 71.1 years (Statistics Greenland, 2015), compared to 80.8 in Denmark (Statistics Denmark, 2015).

Another indicator reflecting a poor health outcome is the high number of youth suicides in Nunavut (Statistics Canada, 2012b). Death by suicide is reflective of socio-economic distress and is a strong manifestation of social exclusion, particularly for male youth between the ages of 15 to 24, the group for which suicide is most prevalent in Inuit society in Canada. One-half of all deaths of young people in Inuit Nunangat are suicides, compared with approximately one-tenth in the rest of Canada (Statistics Canada, 2012c). Between 2004 and 2008, children and teenagers (ages 1–19) in Nunavut were more than 30 times more likely to die by suicide than were children and teenagers in the rest of Canada (Statistics Canada, 2012b). In Nunavut, between 2008 and 2012, suicide was second only to cancer as a leading cause of death (Statistics Canada, 2015).

Further, a growing body of literature documents high rates of chronic illness and infectious diseases among Inuit. For example, one study in Nunavut found that 306 out of 1,000 infants were hospitalized for bronchiolitis and other respiratory tract infections (Banerji, 2001). Similarly, the Inuit Health Survey 2007–2008 found that 42% of Inuit children had sought medical attention during the previous year for respiratory illness (Egeland et al., 2010c). Collectively, these studies link many health problems to crowded and poor-quality housing (highlighted also in Chapter 10), unemployment, marginal access to health services, and food insecurity, as well as behavioral and environmental factors. The prevalence of these conditions in Inuit communities reflects deeper social and economic inequalities that are causing serious daily distress, as evidenced in the high rate of death by suicide.

In Greenland, the past traditional Inuit culture has, within a few generations, changed into a modern, Western-inspired community; the society has gone from being a Danish colony to being governed by a self-rule government (see Chapter 2 and Subchapter 3.3). Health conditions are often heavily influenced when living conditions in communities change in such a rapid manner (Bjerregaard et al., 2003). This influence is particularly pronounced among various Indigenous peoples who, despite great differences in history and culture, have experienced common challenges in relation to rapid development and changes in living conditions. These challenges include epidemics of newly introduced infectious diseases, such as measles and hepatitis, and also more profound psychosocial problems. The term *psychosocial* refers to the influence of social factors on an individual's mind or behavior and to the interrelation between mind/behavior and social factors (Martikainen et al., 2002). There is an overrepresentation of a number of social problems associated with poverty, marginalization, lack of education, sexually transmitted diseases, suicide, alcohol and tobacco abuse, addiction, and consequent neglect of children and families. Indigenous communities are likewise hit hard by the global epidemics of overweightness and diabetes (AMAP, 2015a). These social problems also affect the population in Greenland, even while Inuit there, in contrast to many other Indigenous peoples, constitute the majority of residents in the country (PAARISA, 2004; Nielsen et al., 2004). Greenlanders have largely managed to adapt to life in a modern society, but there are significant symptoms of social problems and mental vulnerability, as in Canada (Galloway and Saudny, 2012). Still, the population in Greenland upholds a strong relation to nature, and singing, artistic creativity, and cohesion are factors of great importance for mental health (Bjerregaard et al., 2003).

To understand and capture health condition in these complex social environments, a holistic approach is needed. Such an approach does not merely consider physical indicators related to epidemiology or access to health services but also encompasses indicators related to the linkages among individuals, families, nature, built environment, natural environment, and more. Housing, food safety, infant care, culture and language, education, income distribution, safety, mental health, and availability of healthcare are all examples of important features relevant to the condition of general health and well-being. Housing, access to health services, water security, food security, and mental wellness were identified as issues of concern to the stakeholders involved in the Adaptation Actions for a Changing Arctic (AACA) consultations conducted during the initiation of this report (see Chapter 1). These issues are addressed in greater detail in the following sections.

4.2.1 Looking forward: social determinants of health

A changing biophysical environment interacts with the determinants listed above. Consideration of all the determinants is key when evaluating the impact of these changes on human health. Beyond the physical changes to environment and landscape, the significance of homeland to health cannot be underestimated, given the cultural and spiritual connections that exist (Reading and Wein, 2009). Demonstrably, BBDS residents have been engaged in significant efforts to improve socio-economic conditions in their communities. There is still much work to be done in this area, however, to address the conditions that lead to high rates of suicide, respiratory tract infections, and other ailments. Notably, ITK (2014) states that "*the most effective actions will be those that can address the driving forces behind socio-economic conditions*" (p. 38) and "*increasing and improving data collection on Inuit health must be a major focus for Inuit governments and organizations*" (p. 38). The latter point builds on the fact that accurate information is the foundation of the health planning process (Elliott and Macaulay, 2004). Through increased investment and collaboration between Inuit organizations and all levels of government, coordinated, holistic, and innovative approaches must be taken to address those factors influencing human health in the BBDS region.

4.3 Food security

The loss of sea ice has had a major influence on marine and terrestrial ecological dynamics, with the impacts of a changing climate already documented to be affecting the health, abundance, and migration timing of a variety of species (Hovelsrud et al., 2008; Huntington, 2009; Sharma et al., 2009; Post et al., 2013; Meier et al., 2014; see also Subchapter 3.1 and Chapter 6). Climate change effects have thereby also affected human systems, with Arctic populations being identified as highly sensitive (Larsen et al., 2014; Ford et al., 2015). As described in Chapter 3, climate models project that the Arctic will experience the world's most rapid and extreme warming this century, at least double the global average. This change is expected to have substantial impacts. Food systems are expected to be disrupted, with effects on the access, availability, quality, and use of both traditional food (country food) and store food (store-bought food) (Furgal and Séguin, 2006; Ford, 2009; Council of Canadian Academies, 2014; Ford et al., 2014; Loring and Gerlach, 2015).

4.3.1 The Inuit food system and food security in the BBDS region

A food system comprises "*dynamic interactions between and within the biogeophysical and human environments which result in the production, processing, distribution, preparation and consumption of food*" (Gregory et al., 2005, p. 2, 141). Communities in the BBDS region can be characterized as having dual food systems composed of both traditional and store foods (Hansen et al., 2008; Goldhar and Ford, 2010).

The traditional Inuit diet in the BBDS region was based mainly on marine mammals, birds, fish, and land-based (terrestrial) animals. In Nunavut, a mix of more than 300 species of marine and land mammals, birds, and plants are still consumed, with ringed seal, caribou, Arctic char, and beluga among the most common (Chan, 2006; Beaumier et al., 2014). Similar traditional foods are consumed in Greenland, in addition to other locally harvested animals such as whales, muskoxen, reindeer, hares, birds, and fishes (Goldhar et al., 2010; Niclasen et al., 2013). However, a rapid dietary transition took place when Greenland shifted to a more modern economy during the last century. The transition has caused competition between traditional food consumption and a more westernized diet. Today the diet in Greenland comprises a mixture of traditional and imported foods. In 2013, imported foods provided 75–80% of the energy consumed in adult Greenlanders (Niclasen et al., 2013). Most of the fresh food consumed today still comes from wild animals (Bjerregaard and Dahl-Petersen, 2008). Greenland has a small production of lamb and a small supply of vegetables, but most produce and processed foods are imported from other countries. Domestic foods (country foods) are often self-supplied.

Store-bought foods are important to communities in the BBDS region. In Greenland, a variety of imported foods are available at government-subsidized prices that are relatively uniform across the country, but still with variations between the larger towns and the smaller settlements (Blanchet et al., 2002; Niclasen et al., 2013). In Nunavut in general and in some of the settlements in Greenland, store foods, while subsidized, still have high prices, tend to be of poor nutritional quality (with high sugar, carbohydrate, salt, and fat contents), and are often described as lacking variety, accessibility, and freshness, with inconsistent and unreliable availability (Mead et al., 2010; Niclasen et al., 2013; Sheehy et al., 2015).

Because food is increasingly imported to Nunavut and Greenland in fabricated forms, the type and quality of nutrition in the diet is changing (Ford and Beaumier, 2011; Niclasen et al. 2013). Along with this shift, public health may be affected and the social and cultural aspect of preparing and eating meals may be affected (Bjerregaard and Dahl-Petersen, 2008). The traditional diet is very important to the population both culturally and financially, in addition to being of importance in order to provide sufficient nutrients. The production, preparation, and consumption of food are central cultural activities in the BBDS region, as in any community. These activities are important to the individual and are also important in terms of the ways that people come together. In the BBDS region, language and diet are found to be the most important cultural markers. The availability of traditional food is therefore a core issue regarding food security.

The World Food Summit of 1996 defined food security as existing "*when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life*" (FAO, 1996). Food insecurity therefore exists when these conditions are not met. In acknowledgement of the dual food system characteristic of the BBDS region, food security additionally entails the continued and predictable availability of and access to traditional foods (Paci, 2004; Council of Canadian Academies, 2014). This definition of food security stresses the importance of the traditional food system from a social perspective and recognizes that the traditional diet of country food is not only a vital source of nourishment but also an integral part of emotional, spiritual, and cultural well-being (Wenzel, 2009; Cunsolo Willox et al., 2012; Wenzel, 2013). For Inuit, the right to food extends beyond basic physical and economic accessibility, as country food is integral in providing social cohesion and identity (Dahl, 2000; Damman et al., 2008; Sejersen, 2009; Harder and Wenzel, 2012). Inuit livelihoods have historically been, and continue to be, defined by a close relationship to the environment and the resources it provides.

Numerous criteria are used to identify food security, with four main components recognized in the context of Inuit food systems: *availability* (sufficient quantities available consistently), *accessibility* (enough resources to obtain food), *quality* (adequate nutritional and cultural value), and *use* (required knowledge of how to utilize food) (Ford, 2009; Ford and Berrang-Ford, 2009; Loring and Gerlach, 2015). In Nunavut, food insecurity has been identified to be at crisis levels, with among the highest rates of food insecurity documented in the published literature (Egeland and Johnson-Down, 2009; Egeland et al., 2010a, 2010b, 2010c; Huet et al., 2012; Guo et al., 2015). Recent studies have found that some children in Greenland also experience food insecurity. A report from the Greenland Self-Rule Government states that 11% of Greenland schoolchildren aged 11–17 years report that they "often" or "always" go to bed hungry (Government of Greenland, 2015). Hunger is generally considered a severe type of food insecurity and is hence an important factor to consider when identifying adaptation actions. The relations among traditional food insecurity, food consumption, and socio-economic factors are, however, complex. There are indications that food insecurity in children in Greenland is connected to a high consumption of

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Seal and narwhal preparation

traditional foods combined with a high level of junk food and soda. This somewhat contradictory situation can be explained with reference to socio-demographic conditions because high consumption of both traditional foods and less healthy foods is associated with living remotely in the smaller settlements and being less wealthy.

When identifying adaptation strategies related to food security in Greenland and Nunavut, a central issue to consider, related to quality of food, is also the high level of long-range transported contaminants in the natural environment, as described in Subchapter 3.2. Several emerging contaminants have been detected in Arctic biota. High levels of organic contaminants are found in people, and the pollution has reached a level that is of concern to health experts. The food supply strategy and the potential replacement of traditional food by substandard, imported food therefore need careful consideration (Deutch et al., 2004). Except for sea mammals and some seabirds, fresh food in the region generally has a low level of contaminants. Local fish products, especially, are highly recommended by the health authorities; land mammals and new local food products are similarly highly recommended. Berries, seaweeds, herbs (e.g., angelica), vegetables, and fungi (e.g., mushrooms) are all healthy local products.

Access to sufficient, safe, and local fresh food depends on many interconnected factors, including education and food preferences, poverty, unemployment, household crowding, food costs, harvesting costs, and environmental conditions. In turn, these factors need to be considered in the context of transformations in livelihoods and socio-economic conditions, colonial history, and land dispossession. These conditions provide the underlying context for many of the challenges facing northern Indigenous food systems today (Smith and Wright, 1989; Wenzel, 2000; Richmond, 2009; Wenzel, 2009; Council of Canadian Academies, 2014; Loring and Gerlach, 2015).

4.3.2 Effects of climate change on food security in the BBDS region

As further described in Chapter 6, the scientific literature and the observations of communities in the BBDS region indicate a number of pathways through which climate change is already affecting food systems and could have future impacts.

Food security, as noted above, is affected by climate change through impacts on food availability, accessibility, quality, and use. Climate change is affecting the *availability* of food as a result of shifts in biodiversity as well as in the ranges of animal and plant species important to communities (Meier et al., 2014; Laidre et al., 2015). Many of these impacts are occurring in the context of resource development activities (extractive industries), with few studies examining potential cumulative effects (Frid and Dill, 2002; Boulanger et al., 2012; Cameron, 2012; McDowell and Ford, 2014). Few studies have examined what climate change might mean for berry picking, an important activity in many communities (Lévesque et al., 2012; Bunce, 2015). Worth noting, store food is also susceptible to climatic conditions. The majority of store food items are imported to communities over long distances via air transportation. Thus, weather hazards, including high winds and blizzards, can delay air access to communities and limit the availability of fresh food stocks in local stores. In addition, infrastructure is likely to be increasingly affected by permafrost thawing as the climate continues to warm (e.g, airport runways) (Ford and Goldhar, 2012; Council of Canadian Academies, 2014; see also Chapter 10). Planning and logistics may be relevant adaptation options in this regard. This aspect is further described in Chapter 10.

Food access refers to the ability to procure the foods that are available (including physical and logistic access to the locations where foods can be procured), the affordability of foods, and how food allocation mechanisms work (Council of Canadian Academies, 2014). Access to traditional foods is being affected by climate change, with thinner ice, later ice freeze-up, earlier ice break-up, more variable snowfall, unpredictable weather, warmer temperatures, and more frequent and intense storms documented across the BBDS region (see Subchapter 3.1). These changes are disrupting the semipermanent ice- and snow-based trails used to access hunting and fishing areas, compromising access to other communities and the ability to conduct inter-community trade, and affecting the safety of using boats in the open water (Gearheard et al., 2006; Sejersen, 2009; Gearheard et al., 2010; Holm, 2010; Gearheard et al., 2011; Ford and Goldhar, 2012; Ford et al., 2013; Hansen and Larsen, 2014; McDowell and Ford, 2014; Statham et al., 2015). The lengthening of the open water season in summer has also created new opportunities, extending the period of time available for commercial and subsistence fishing (Ford et al., 2015).

The *quality* of food can also be affected by environmental conditions. A number of studies, mostly in Nunavut, have noted a general decrease in the health of some wildlife species concurrent with observed climate change, including reduced animal size and physical deformities, as well as variations in meat taste and other sensory qualities (Chan et al., 2006; Furgal and Séguin, 2006; Nickels et al., 2006; Holm, 2010). Because traditional foods are often transported and stored outdoors using traditional practices – and are also aged to make speciality and highly prized foods – rising temperatures may also increase the risk of food-borne disease (Furgal et al., 2008; Parkinson and Evengard, 2009; Simon et al., 2011; Harper, 2014; Harper et al., 2015; Loring and Gerlach, 2015). Sensitivity to such diseases is increased by the consumption of raw sea-mammal meat. Food quality may also be affected if substitution for traditional foods, as a result of climate change, results in higher consumption of nutrient-poor, high-fat store foods.

The accumulation of contaminants, as described in Subchapter 3.2, in wildlife consumed by BBDS residents has also emerged as a major concern for food quality, with potential impacts of climate change on contaminant transport pathways (Kuhnlein and Chan, 2000; Van Oostdam et al., 2005; Donaldson et al., 2010). Studies have highlighted that snowmelt is a major source of mercury contamination in Arctic freshwater systems, for example, and this source could increase with future climate change (Dommergue et al., 2003; Gantner et al., 2010; Prowse et al., 2011). Other research has found that climate change may lead to increased bioaccumulation of contaminants in the food chain (Hare et al., 2008; Kuzyk et al., 2010; Macdonald and Loseto, 2010; Pacyna et al., 2015), although these types of studies are in their infancy. The quality of store food and its links to climate change has been examined less, although the quality of such food depreciates when inclement environmental conditions result in delays that may cause spoilage of perishable food items (Furgal and Séguin, 2006; Statham et al., 2015).

Food *use* concerns the knowledge that is needed for preparing and consuming country and store foods. Climate change has been observed to be affecting the development of traditional knowledge and land skills by reducing the ability of young Inuit to engage in land-based (subsistence) activities, thereby disrupting traditional mechanisms of knowledge learning and exchange (including meat storage and preparation) (Takano, 2004a, 2004b; Ford et al., 2006; Furgal and Séguin, 2006; Ford et al., 2008; Wenzel, 2009; Dowsley et al., 2010; Pearce et al., 2015). This disruption is compounding the effects of societal changes – affecting knowledge transmission to younger generations, with implications for how communities will interact with and respond to future impacts of climate change on the food system (Ford et al., 2013; Pearce et al., 2015). Warmer conditions are also resulting in a shift from traditional food storage practices to newer and potentially unsafe storage and preparation practices and methods, such as the use of plastic containers (Council of Canadian Academies, 2014).

4.3.3 Looking forward: food security

The impacts that climate change is having, and will have, on individuals, households, and communities are not equal across the BBDS region. The differences partly reflect different sensitivities to climate impacts. The locations of some communities with respect to animal migration patterns and access to hunting areas, for instance, will exacerbate impacts related to long transportation distances and ice-dependent access routes. Those community members and communities who obtain a greater portion of their food from traditional sources are also at greater risk to disruption of this component of the food system.

Adaptive capacity to manage climate change impacts on the food system will also differ, affected by knowledge of environmental conditions, the existence of alternative sources of income, social networks, economic status, diversity and flexibility in harvesting, and institutional context (Sejersen, 2009; Ford, 2012). Presently, communities are responding to climate change impacts in a variety of ways to maintain access to hunting and fishing areas, with varying levels of success. Coping mechanisms to maintain food security include using new harvesting equipment, modifying hunting and fishing locations, developing alternative transportation routes, changing the times at which certain species are harvested, enhancing food sharing, and switching foods. The ability to respond to change, however, is challenged by a variety of pressures. Harvest regulations and quotas, for example, constrain the ability to switch species harvested or to alter the timing and location of resource-use activities in response to changing conditions (Ford et al., 2006; Sejersen, 2009; Wenzel, 2009). The ability to manage the impacts of climate change on food systems at an individual and household level is negatively affected by poverty, which affects options for adapting to changes in access to traditional foods – e.g., traveling longer distances to hunting areas or investing in boats to take advantage of the longer periods of open water (Ford et al., 2010; Loring and Gerlach, 2015). Studies have also documented a weakening of the social networks through which traditional foods are shared in communities (Sejersen, 2001, 2004, 2009; Ford and Beaumier, 2011), thus increasing vulnerability to projected future changes in climate. The potential long-term success of adaptation actions, how they may shift impacts to other regions or communities, and how they will affect pressures on ecological systems is not yet known.

4.4 Water security

Access to water and water-related socio-economic and ecosystem services are key components of water security; collectively, these elements constitute a primary sensitivity of BBDS communities to climate change. In particular, changing access to water can generate substantial limitations in communities, add costs to daily living, affect health, and impose the need for longer-term planning, particularly in cases where informal water collection has sufficed in the past. In more structured water management systems (for instance, community water supplies or hydroelectric developments), changing water availability, particularly on a seasonal basis, introduces further challenges. Changes in water quality have similar dimensions – with existing or informal systems of water supply potentially being unable to adequately adapt to external changes – with implications for human health. In a related way, changes to historical hydrological conditions may represent a hazard that requires communities and individuals to assess and plan for risk differently. Finally, the strong cultural connection of Inuit to the land and its ecosystem services represents an additional dimension of water security in the BBDS region.

4.4.1 Current status

Surface water is abundant across the BBDS region in the form of lakes, ponds, rivers, and streams. With the exception of the small populations of Iqaluit and Resolute Bay, where water is supplied through above-ground piping, communities on the Nunavut side of the BBDS region utilize storage tanks and trucked water delivery to meet residents' needs (Daley et al., 2014; NCCEH, 2014). Where water is pumped to a central holding reservoir, the water is chlorinated before delivery to residents for domestic use (i.e., indoor household use). Aside from chlorination, the water does not typically receive any chemical or physical filtration treatment to remove contaminants (Daley et al., 2014). Infrastructure is typically limited to individual tanks in buildings and a delivery truck that pumps water from the community source. Tank maintenance is the responsibility of individual building occupants and may be irregular in the case of residences. In Greenland, water is led through pipelines to central reservoirs where it is cleaned and treated before being passed on to consumers (Government of Greenland, 2016). In some of the smaller settlements with no other alternatives, seawater is desalinated to provide clean drinking water.

Water supply is typically from nearby lakes with access by all-season roads. Generally, these sources of water are adequate to meet the limited demand of small community populations. Iqaluit maintains a water distribution system to many parts of the city through a network of pipes and pump stations, as is the case in the towns and larger settlements in West Greenland. The Iqaluit water supply reservoir is located above the community (i.e., at higher elevation) and is supplied by a protected watershed. In all cases, potable water is untreated at the source. Broader use of water on the Nunavut side is limited. Several mines operate and utilize surface-water supply and delivery systems similar to those of communities. Hydroelectricity, while contemplated in the Iqaluit region, has not been developed there yet. Hydroelectricity is a major source of energy in Greenland, where micro-hydropower facilities are also emerging on South Greenland sheep farms (Subchapter 6.6 and Chapter 7).

Although the community of Coral Harbour (Southampton Island, Nunavut) is not within the BBDS boundaries, a case study from that community characterizes water use in the region, showing that household water use is one-third of the Canadian household average. This relatively low quantity of water is adequate for some families, but some households experience water shortages that limit their ability to follow public health standards and that negatively affect their overall well-being (Daley et al., 2014).

In Nunavut, water quality practices are guided by the Public Health Act, which specifies recommended minimum frequencies for public water sampling (up to 7 times monthly, depending on population) and also indicates maximum amounts of specified water pollutants (Public Health Act, 1990). Other water quality characteristics, such as turbidity, color, and odor, are required to be monitored daily. The chemical characteristics of drinking water are required to be monitored at a frequency determined by the Chief Medical Health Officer, but no more often than once every two years (Public Health Act, 1990). Although clear regulations ensure that water quality monitoring is carried out and that records are maintained, these records are not readily accessible or regularly reported to the public, unless a "boil water" advisory is issued.

4.4.2 Impacts of climate change and development on water quantity and quality

Climate projections indicate the likelihood of substantial changes in surface water conditions in Nunavut. In particular, warmer air temperatures will lead to longer thaw periods, particularly in the autumn (see Subchapter 3.1). Given that most river and stream flows in the region are only seasonally active, the lengthening of the thaw season suggests the potential for greater runoff to support water supplies (AMAP, 2011b). Similarly, model projections indicate increased precipitation, in the form of both snowfall and summer rainfall (Chapter 3). In a simple sense, the increase in water should increase the availability of water supplies, and modeling in the region (e.g., Lewis and Lamoureux, 2010) indicates that increased runoff and prolonged baseflow in the summer and autumn periods are likely. However, several factors can alter water availability and all are important to consider. Most importantly, increased snowfall has not uniformly resulted in increased runoff in Arctic settings, and a number of factors appear to alter the timing and magnitude of runoff (Shi et al., 2015; also discussed in Section 6.3.3).

Changes in the seasonal distribution of precipitation have important implications for the management of both the quantity and quality of water. Warmer spring air temperatures will lead to earlier snowmelt discharge and thus replenishment of reservoirs, although earlier ice-off will increase the potential for evaporative losses from reservoirs over the summer (AMAP, 2011b). Similarly, increases in summer and late autumn rainfall stand to be beneficial from the perspective of replenishing reservoir levels ahead of winter.

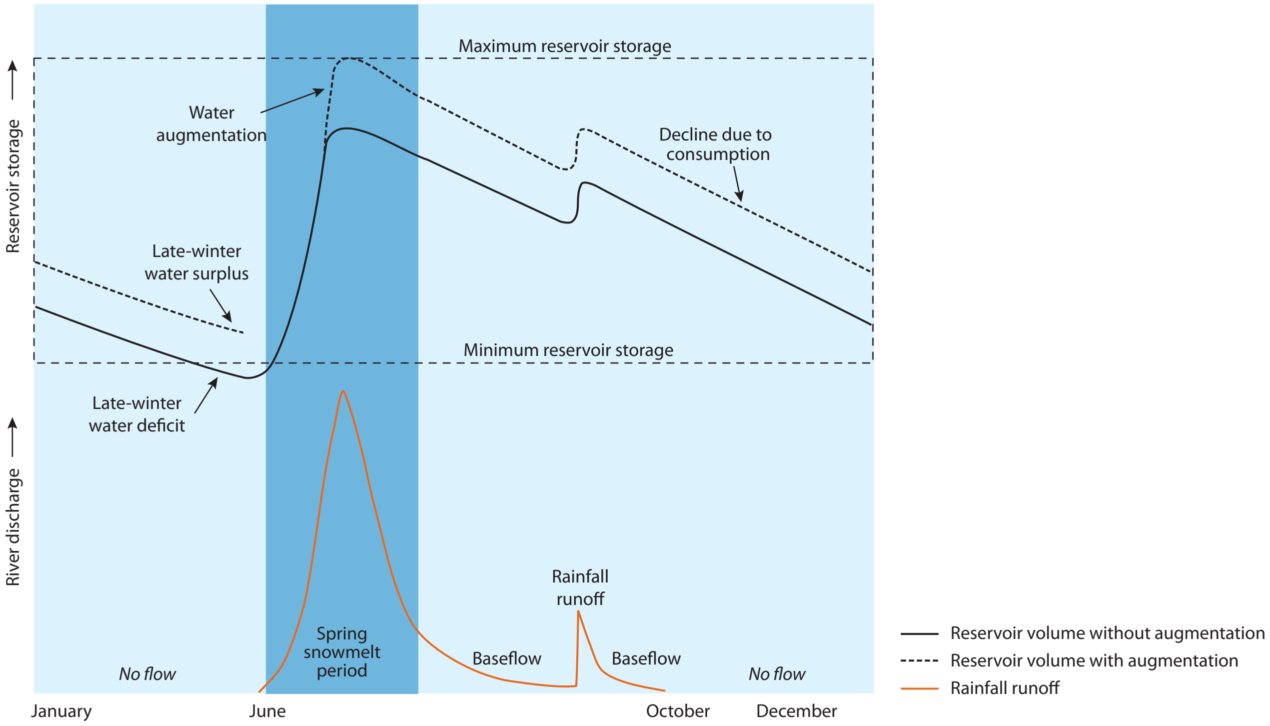

Figure 4.1 An illustration of the challenges of managing water supply in a reservoir in Nunavut. The upper panel indicates total water storage in a reservoir throughout the year. The lower panel shows a typical river runoff hydrograph. Most of the water is available during the spring snowmelt period, but consumption in a community is relatively constant throughout the year. To maintain adequate water supply for the entire winter period, then, water managers need to consider augmenting water supply during the spring snowmelt period (to yield the greater reservoir quantities indicated by the dashed line). Summer rainfall alone is rarely adequate to accomplish a year-round supply and is, moreover, unpredictable. (Source: S. Lamoureux)

The timing of snowmelt and rainfall contributions represents an important challenge in some water supply settings on the Nunavut side of the BBDS region. Given the important role of spring snowmelt to resupplying reservoirs and lakes, the sporadic and unpredictable delivery of summer rainfall runoff, and the long winter period when supplies cannot be replenished, water supply management requires planning forward for much of the water year to anticipate needs (Figure 4.1). Water shortages are also likely to occur when summer and autumn runoff is reduced and where ongoing drawdown of water supply results in low reservoir levels as winter approaches and alternative sources may be limited.

Many water supplies on the Nunavut side are sufficiently large to avoid this type of water limitation. Still, the Geraldine Lake reservoir system that serves Iqaluit is vulnerable to end-of-autumn water limitations; the critical time for refilling occurs during the short interval earlier in the year when water supplies are abundant during snowmelt. Similar concerns regarding sufficient water supply are important for many resource industries that currently contribute to the Nunavut economy (e.g., mineral processing) or that hold promise for future economic growth (e.g., fish processing). Additionally, a hydroelectric power project has been proposed at a site near Iqaluit; maintaining reservoir levels there would pose similar challenges.

Projected changes to water availability for communities and residents hold the potential for altered water quality, with immediate and long-term health risks to residents. As indicated above, Nunavut water quality practices are guided by the Public Health Act, which specifies recommended minimum frequencies for public water sampling (up to 7 times monthly, depending on population) and also indicates maximum amounts of specified water pollutants. In Greenland, protection zones are defined for the rivers and lakes used for water supply. Activities such as traveling by motor vehicle, constructing buildings, keeping animals, and operating businesses are restricted in these zones; polluting activities are not allowed.

The current climate change projections also imply impacts to surface hydrology. Increased snowmelt or rainfall runoff will enhance erosion and sediment transport. Greater sediment transport can in turn alter river and lake channel environments, sometimes impeding access within aquatic ecosystems, particularly for fish during spawning. Other water quality parameters (e.g., bacteria, dissolved organic matter, nutrients) may also change in ways that are important to aquatic ecosystem functions. It should be noted that the relatively low frequency of testing for bacteriological and chemical characteristics may not be sufficient to detect the seasonal and relatively short-term changes in water quality that could result from seasonal changes in snow and rainfall.

Water quality changes are of particular importance given the limited water treatment in BBDS communities and the use of water from other sources by residents carrying out traditional land-based activities. The biological productivity of microorganisms is expected to increase with increasing temperatures (AMAP, 2011b). Although little is known about how climate change is likely to influence the production of most pathogens and toxic algal blooms, there is evidence that the increases in temperatures projected for the Arctic could result in an increase in the abundance of toxin-producing algae and an increase in the levels of toxins produced by existing species (Kleinteich et al., 2012). Inevitably, a warmer climate will require more careful and frequent treatment and delivery of water to residential storage tanks, in order to keep potentially harmful bacterial pathogens out of drinking water.

Permafrost is found in most of the BBDS region (see Section 3.1.3 and Chapter 10); warmer temperatures will increase the depth of active layer development and will lead to permafrost degradation (AMAP, 2011b). (The active layer is the top layer that is subject to annual thawing and refreezing.) Combined with increases in summer rainfall, deeper active layer development and permafrost thaw is projected to lead to increases in the incidence of permafrost disturbances such as slumps, active layer detachments, and the destabilization of permafrost in ice-rich regions (Lamoureux et al., 2014; see also Chapter 10). These changes will have important implications for water quality, as such disturbances have been shown to dramatically increase sediment and nutrient loads in rivers for many years following the disturbance (Lafrenière and Lamoureux, 2013; Lamoureux et al., 2014; Louiseize et al., 2014). Further, deep thaw of the permafrost has been shown to lead to increases in solute and nutrient fluxes, even in the absence of physical disturbance (e.g., slumps or slides) (Lafrenière and Lamoureux, 2013).

4.4.3 Looking forward: water security

Climate change will influence water security in the BBDS region in several key areas. Firstly, the net effect of climate change on runoff volumes and seasonality is still largely unknown: increases in thaw may increase water in the short-term storage of snow and rain in soils and groundwater but could reduce overall discharge. Alternatively, discharge may increase due to additional rain or snow precipitation (Subchapter 3.1). More late-season rainfalls may be beneficial for replenishing reservoir volumes, so long as these events are not also accompanied by negative impacts on water quality.

In addition, projected changes to the seasonality and amounts of rainfall (timing and intensity) have potentially both positive and negative effects on water quantity and quality. The unpredictable and sporadic nature of rainfall runoff events – more extreme events – presents serious challenges to managing reservoirs and monitoring water quality, especially in cases where residents may use rivers as informal water sources.

The precise impact of climate warming on water quality in residential storage tanks and other informal water systems found in Nunavut and Greenland is unclear, although negative impacts due to enhanced biological activity is a likely outcome. Also, permafrost degradation and related land disturbances generate important impacts on water quality. These changes can occur suddenly and have lasting effects. In Nunavut BBDS communities, these changes are further complicated by housing pressures that may increase the density of residents in buildings, thus taxing water supply delivery and potentially limiting water access for domestic needs, with potential consequences for resident health.

4.5 Housing

Access to adequate housing has been a social, ecological, and health problem in Inuit communities in Canada and Greenland since the movement toward sedentary living began. Housing shortages, overcrowding, and poor-quality housing are commonplace in many communities across Inuit Nunangat and are compromising peoples' health and communities' capacity for social and economic development (Knotsch and Kinnon, 2011).

4.5.1 Housing conditions: a brief overview

In Nunavut, the latest housing needs survey (conducted in 2009–2010) inventoried 8,550 dwellings occupied by "usual residents." Public housing (i.e., subsidized rented dwellings managed by the Nunavut Housing Corporation and made available to Nunavut residents who meet certain eligibility requirements) made up the majority of the housing stock (4,400 dwellings; 51%). This proportion reaches 67% when some of the larger communities (i.e., Rankin Inlet, Cambridge Bay, and Iqaluit) are excluded; in these communities, the proportion of owner-occupied and government-staff housing is higher (Statistics Canada, 2010). In the Qikiqtaaluk region (formerly called the Baffin region), public housing accounts for 45% of the housing stock overall and for 67% when Iqaluit is excluded. Tenants rent their houses from the Nunavut Housing Corporation (NHC) through local housing organizations, paying monthly rent on a geared-to-income basis. Nunavut still receives funding from the federal government, and across the region the Government of Nunavut (via NHC) is the primary homebuilder (NHC, 2013).

In Greenland, despite the increasing share of private ownership, the majority of dwellings are owned by public organizations, e.g., by the Government of Greenland, the municipalities, or by large companies (Hansen et al., 2013). Historically, small houses designed by non-Inuit accommodated large households. Despite improvements in dwelling size and quality and a decrease in household sizes over time, household crowding remains a concern in Greenland, especially in small remote settlements (Bjerregaard et al., 2008; see also Chapter 10).

Adequacy and suitability are concepts used to assess the quality of housing. *Adequacy* identifies whether a dwelling has properly functioning basic housing services such as heat, water, electricity, and shelter from the elements. *Suitability* refers to whether a dwelling is crowded, based on the space available and the number of people in the dwelling. In Nunavut, the housing needs survey (NHC, 2013) reported that 23% of the dwellings were considered inadequate (i.e., needed major repairs) and 35% were overcrowded according to Canadian National Occupancy Standards. In the Qikiqtaaluk region, these proportions were 20% (major repairs) and 30% (overcrowding). At the 2006 Canadian census, 39% of the population in Nunavut reported living in houses with more than one person per room, versus 3% of non-Indigenous Canadians (Statistics Canada, 2008b). Overall, in Nunavut and in the Qikiqtaaluk region, 49% and 44% of dwellings, respectively, are below housing standards – they are either inadequate and/or crowded. For public housing specifically, 63% of the dwellings in Nunavut are below housing standards; in the Qikiqtaaluk region, 59%.

For Greenland, information regarding housing adequacy and suitability is not systematically available – not for the nation as a whole nor for specific communities. Results from the Survey of Living Conditions in the Arctic (SLiCA, 2015) conducted in Greenland indicated that 40% of housing required major repairs in 2004–2006. Results from the 2005–2010 Inuit Health in Transition Greenland Survey reported that 40% of residents lived in houses with more than one person per room (Riva et al., 2014b).

4.5.2 Housing and health

The housing shortage and poor housing quality in the Arctic are compromising people's health and communities' capacities for social and economic development (Knotsch and Kinnon, 2011). It is now acknowledged that, in addition to individuals' biological and genetic constitution and behavioral risk factors, a range of socio-environmental factors also influences health and health inequalities. Among these factors, housing conditions have been identified as a key determinant of Indigenous health (Bailie and Wayte, 2006; Gracey and King, 2009; Reading and Wien, 2009). A large body of evidence indicates strong (mostly cross-sectional) associations between poor housing and poor health (Shaw, 2004; Thomson et al., 2013). This research is, however, mostly based on non-Indigenous populations. The literature synthesis below presents results from selected studies, with a particular focus on studies conducted among Inuit and other Indigenous populations.

There is strong and consistent scientific evidence that poor indoor environmental quality is harmful to human health (Samet et al., 1987). Among Indigenous populations, research on housing conditions has focused mainly on respiratory health, especially among children (Kovesi et al., 2007; Banerji et al., 2009; Bailie et al., 2010) and on high rates (and transmission) of tuberculosis (Clark et al., 2002). An epidemiological study in Canada showed increased tuberculosis (TB) incidence in First Nations communities characterized by higher household crowding (Clark et al., 2002). In Australia, household overcrowding has been associated with the development of ear infections in Indigenous children, potentially compromising their development and school achievement (Australian Government, 2013). Indoor environments can be contaminated by chemical, organic, and particulate matter pollutants such as environmental tobacco smoke. Exposure to mold and bacteria and their components also affect human health (Fisk et al., 2007). Exposure to environmental tobacco smoke was identified as a risk factor explaining an elevated incidence of lower respiratory tract infections among young children (Kovesi et al., 2007). The latest information on smoking prevalence in Nunavut indicates that 62% of the population reported smoking daily (Statistics Canada, 2015). Although this information does not indicate whether people smoke indoors or whether there are house rules against smoking inside the house, it is likely that exposure to environmental tobacco smoke in houses in Nunavut is a risk factor for respiratory health.

In Nunavik, 49% of the population reported living in overcrowded households (i.e., in houses with more than one person per room; Statistics Canada, 2008a). In crowded dwellings, the lack of privacy and the impossibility of withdrawing from (unwanted) social interactions may limit the ability to control one's home situation (Dickerson and Kemeny, 2004) and lead to "over-arousal," possibly eliciting physiological stress responses (Johnston-Brooks et al., 1998; Evans, 2003; Evans et al., 2007) and mental ill-health (Lepore et al., 1991a; Fuller et al., 1996; Evans et al., 2003). In Nunavik, a recent study showed that living in crowded dwellings was associated with elevated (physiological) stress levels among adults, especially among women (Riva et al., 2014a). Among Inuit of Greenland, a recent study shows higher prevalence of poorer mental well-being in crowded households, especially among women (Riva et al., 2014b). Research further suggests that other structural conditions of dwellings, such as housing type, are important – e.g., that multi-dwelling housing is associated with adverse psychological health impacts (Evans et al., 2003). Noise within and outside the house is associated with annoyance and sleep disturbance (Passchier-Vermeer and Passchier, 2000). Whether housing type and noise influence health in the Arctic remains to be established.

A recent study reported a higher risk of food insecurity among Inuit families that had school-aged children living in overcrowded households (Ruiz-Castell et al., 2015); food insecurity is a risk factor for poor physical and mental health, as well as suboptimal child development. Household crowding also influences early childhood development (Evans, 2006; Leventhal and Newman, 2010) and success in school (Goux and Maurin, 2005). Associations between physical and psychosocial housing characteristics and physical and mental health outcomes of Inuit children aged 2 to 5, across Inuit Nunangat, were recently examined using data from the 2006 Aboriginal Children's Survey (Kohen et al., 2015). Although this study covers a broad geographic area and different Inuit populations, the results are relevant to the Qikiqtaaluk area. Structural housing conditions, such as overcrowding and major repairs needed, and the presence of a smoker in the house were both related to the physical and mental health of children, as reported by their parents. When psychosocial factors such as homeownership and parental satisfaction with housing conditions were considered, many of the associations between structural housing conditions and children's health disappeared (Kohen et al., 2015). In 2006, a study was conducted in Kingait (Cape Dorset, Nunavut) to examine housing conditions in relation to a range of physical and mental health symptoms among 91 participants. The structural conditions of their houses were perceived by the participants as having repercussions on their well-being and as contributing to physical ill-health (Tester, 2006).

These results lend support to arguments suggesting that housing conditions may influence health through psychosocial pathways. Housing studies have examined a range of psychosocial factors (PSF), including satisfaction with the house (Dunn, 2000); control and powerlessness, with consequences for self-efficacy (Evans et al., 2003; James, 2008); identity and self-esteem (Evans et al., 2003; James, 2008); risk and insecurity, with consequences for anxiety and fear (Evans et al, 2003); lack of privacy and reduced neighborliness (James, 2008); and social support (Lepore et al., 1991b; Wells and Harris, 2007). There are few studies on housing conditions and PSF or on PSF and health among Inuit populations. However, studies have discussed the design of the "Euro-Canadian" house in the Arctic as not being conducive for traditional lifestyles and not reflecting cultural identity (Dawson, 2006; see also Chapter 10). Studies have also discussed crowding in relation to social problems (Tester, 2006). The cultural relevance of indicators of crowding, such as persons per room (PPR) and, in Canada, the National Occupancy Standard (NOS), has been questioned for research among Inuit populations (Lauster and Tester, 2010; Memmott et al., 2011), suggesting that the subjective experience of crowding might be a more culturally appropriate measure (Tester, 2006; Memmott et al., 2011). Studies have yet to examine the coherence of indicators of objective versus perceived crowding and of differential associations with physical and mental health outcomes.

In this section, the focus has been on housing conditions, and especially overcrowding, in relation to health and well-being. Yet the acute shortage of affordable and adequate housing in the BBDS region is leading also to homelessness (both visible and "hidden" homelessness) across the circumpolar North and also in capital cities and other large "southern" cities (e.g., Ottawa, Montreal, Copenhagen). Experiencing homelessness or inadequate housing can significantly affect one's health, exacerbate pre-existing medical conditions, impede treatment and recovery, and increase the risk of both infectious diseases and mental health issues (Frankish et al., 2005).

4.5.3 Looking forward: housing

On the Nunavut side of the BBDS region, pressures for the construction of new housing are exacerbated by the young and rapidly growing population, the high cost of materials, and the short construction season. (For example, half the Nunavut population is aged under 25 years, and population numbers increased by 8.3% between 2006 and 2011, compared to 5.9% for Canada; Statistics Canada, 2011.) Climate change and shifting permafrost pose additional challenges to housing construction and community development across the Arctic (see Chapter 10). Although efforts are being made to encourage home building and private ownership, the high cost of building and maintaining a house (e.g., water, electricity, heating) makes homeownership unattainable for even those families with high income and long-term income and employment. Addressing the housing shortage, overcrowding, and inadequate housing is a prerequisite not only to fostering Inuit health and well-being but also to sustaining community social and economic development across the Arctic.

4.6 Access to health services and information

4.6.1 Health services in Canada – Baffin (Qikiqtaaluk)

In northern Canada, primary healthcare services and public health services are delivered within a collaborative model of care (Chatwood and Marchildon, 2012). In general, primary care services deal with immediate responses to health concerns while public health activities tend to focus on the prevention of disease and injury and the promotion of well-being (Government of Nunavut, 2014).

Prior to the 1950s, formal governmental healthcare services were almost nonexistent in northern Canada. Healthcare services were provided by the federal government until 1967, when they were devolved to the Northwest Territories and then to Nunavut when Canada's third territory was formed in 1999 (Government of Canada, 1993; Government of the Northwest Territories, 2015). The Nunavut government has a Department of Health, which is responsible for administering a range of health and healthcare services – in particular, medically necessary hospital and primary care services that are defined as "insured services" under the Canada Health Act (Marchildon, 2005). In total, 25 aspects of health and care, such as emergency care, public health, dental services, and more, are administered by the Nunavut Department of Health, and such services are provided free to all residents (Chatwood and Marchildon, 2012).

Primary care services on the Nunavut side of the BBDS region are accessed through community-based health clinics. Primary care clinics are commonly known as community health centers and have been built on the nursing stations and outposts initially established by the federal government in the 1950s. The community health centers are staffed by community health nurses, community health representatives, and other support staff such as interpreters and translators.

The majority of nursing staff are registered nurses (RNs), supplemented in some communities by nurse practitioners (NPs) who have advanced practice standing (Chatwood and Marchildon, 2012). The scope of practice for community health nurses (CHNs) is much more broad than for their southern counterparts, and they deliver a diverse range of health services in geographically isolated conditions (Roberts and Gerber, 2003; RNANTN, 2010). CHNs provide basic 24-hour, 7-day-a-week emergency care and primary care services, as well as some public health services. Consultations with physicians, either in the regional centers or in the south, are done through community visits by the physician or by telephone. The number of CHNs in any given community health center is a function of the community's population size and its overall health needs relative to surrounding communities.

Community health representatives (CHRs) provide public health programming in every community. The role of the CHR is to work with a variety of health professionals in the prevention of disease and maintenance of health and the protection of individuals and communities from harmful exposure to disease and disability (Government of Nunavut, 2015). The responsibilities of the CHR include working with members of the health promotion team and other community program staff, such as nurses, social workers, and other organizations (e.g., shelters and elders' centers), in promoting health to all staff and the general public. CHRs are often bilingual in English and Inuktitut, able to offer public health programming in both languages.

In remote communities, patients access care through the nurses located in the health centers. In the large community of Iqaluit and in large communities outside the BBDS region (e.g., Rankin Inlet, Arviat, and Cambridge Bay), patients are serviced by family physicians who play a major role in the

Figure 4.2 Health service network and the typical referral pathways that serve Nunavut communities. (Source: Government of Nunavut, Department of Health.)

delivery of primary care (see Figure 4.2 for typical referral pathways in Nunavut).

Qikiqtani General Hospital in Iqaluit provides a broad range of secondary services, birthing services, emergency services, day (ambulatory) surgeries, and pediatric care through a diverse staff of physicians, as well as health professionals providing medical imaging and laboratory services. Physiotherapy, occupational therapy, and speech therapy are available through referral to a rehabilitation services clinic that is also located in Iqaluit. Mental health and wellness counseling is available through a referral process to the mental health division of the Department of Health; advanced psychiatric support and addiction treatment are referred out of the territory. A family practice clinic, serviced by nurse practitioners, also operates in Iqaluit.

4.6.2 Health services in Greenland

The healthcare service in Greenland offers, for free, a wide range of treatments and preventive measures for all of its residents. In addition, all prescription drugs are free. However, not all therapies are offered and medication is usually carefully selected and distributed. The objective is to provide the best possible treatment to all residents in Greenland, while also taking into account the economy and the availability and quality of medical resources. The healthcare system is generally considered to be well functioning. However, limited economic resources, rapid epidemiological changes, and difficulties in recruiting professionals challenge the system. The biggest challenge is supplying healthcare services of high quality under extreme conditions, in order to serve the geographically dispersed population that lives in remote areas where the extreme climate also affects logistics.

A structural reorganization of the healthcare system – establishing larger healthcare regions – was initiated in Greenland in 2010 to address the challenges mentioned above. The initiative included the implementation of a program focusing on health promotion and disease prevention, as well as educational initiatives to upgrade local staff qualifications and improve recruitment. A fundamental component of the program aims to connect all parts of the healthcare system through telemedicine and, in the future, to implement a joint electronic patient file system. The effects of the new system have not been evaluated yet, but healthcare in many areas in Greenland has proved flexible and adaptable, due partly to the small size of the system and the relatively small number of patients.

From 2002 to 2012, approximately 80% of all Greenlanders annually had at least one contact with primary healthcare (Pedersen et al., 2012). Women use healthcare slightly more than men. Most contacts were primarily for in-person patient consultations, with the most frequent problems due to musculoskeletal diseases, followed by skin and respiratory problems. Among young children, the most frequent problems are related to respiratory and ear infections. Consumption of medicine in Greenland is generally much lower than in the other Nordic countries such as Norway and Sweden. The reasons may be associated with the lower life expectancy in Greenland, as older people generally receive a larger proportion of medicine than other age groups. The limited availability of specialized healthcare, cultural factors, and disease patterns may also be part of the explanation.

4.6.3 Looking forward: health services and information

The BBDS health service systems are widely spread out and are dependent on central hospitals and medical professionals. As a result, innovative adaptation options for delivering care are of critical importance.

Healthcare systems can and should mirror the values of the people they serve, and such systems should promote healthcare models that are grounded in Inuit ways of knowing and understanding wellness. As the health system evolves and adapts to meet the needs of the growing population of the region, innovative governance models can serve as examples for enhancing healthcare and governance in the future. The health challenges experienced in northern communities require a holistic approach, beyond the dominant narratives on the origins of health equities.

4.7 Concluding remarks

This chapter provides an important foundation for understanding the health context of the BBDS region – specifically, the multitude of causal factors (i.e., drivers) that influence health outcomes. Health-related issues, often framed from a place of health deficit, must be approached from a place of developing sound and vibrant communities to ensure a more holistic understanding of health. Health must be viewed outside the traditional model of solely describing disease and negative health outcomes, and health programs must build on community strengths. It is apparent, based on projections from this and other chapters (e.g., Chapter 3), that there will be a need to monitor for new diseases in both humans and animals. Culturally, Inuit health is closely connected to the health of the animal populations that individuals and communities depend upon. It is abundantly clear that new stressors on the health system must be anticipated. There is also a strong sense that projected changes due to climate change will have a significant impact on people's connection to the land and marine environments. This consideration is important because that connection is viewed as incredibly important from a cultural perspective (NCCAH, 2016). Climate change will require individuals and communities to draw upon resilience as a means to cope with changing external conditions – the impacts will be felt beyond environmental changes, affecting livelihoods in the modern and traditional economies.

While it is difficult to project shifts in health status over the next twenty to thirty years, the following is an overview of projected changes and adaptations, based on the findings of this chapter and the BBDS assessment and on understandings of the health system and applicable drivers:

- **Technology**: Elements of the present-day medical system provide some space for projection into the future. Advances in the field of tuberculosis and latent tuberculosis diagnosis in Nunavut (Oxlade et al., 2016) and in Greenland (de Colombani et al., 2011) would suggest that health technologies will play a greater role in positively affecting health outcomes through quicker diagnosis, treatment, and contact tracing, thereby reducing the burden of disease. Further, it is anticipated that technologies like telehealth will be expanded and advanced upon and connectivity will increase as a result of access to fiber-optic services (see Subchapter 3.3 and Chapter 12). Improvements in the design of housing are also anticipated to positively affect respiratory health; currently, rates of respiratory illness, particularly among children, are high (Banerji et al., 2009; see also Chapter 10).
- **Population growth**: The Inuit population in Canada is young and is the fastest-growing segment of the Canadian population (see Chapter 2 and Subchapter 3.3). It is projected that population growth will create new pressures for the health system as well as infrastructure (Chapter 10). In addition to an increasing Inuit population in Canada, it is anticipated that in-migration will increase as the region becomes more accessible due to climate change and infrastructure development. In-migration is projected to be driven by resource extraction activities in the region (Subchapters 3.3 and 3.4 and Chapter 7). In Greenland, the population is not predicted to increase even with anticipated in-migration (Statistics Greenland, 2016).
- **Resilience**: Inuit resilience is frequently described in relation to one's ability to be persistent, to be resourceful, to endure, and finally to have the innate ability to adapt in the face of the extremes of the Arctic environment (but see Chapter 11 for further elaboration). It is projected that the resilience described in today's literature will be essential in adapting to societal and environmental change in the future. While resilience has historically been described in relation to environment, future resilience will be essential in adapting to the extreme shifts in society that may result from multiple drivers, such as climate change and continued rapid societal transition.
- **Contaminants**: Currently the Arctic is a sink for contaminants, and if global weather patterns remain largely unchanged, then long-range contaminants will remain an ongoing concern. This concern is further complicated by the ongoing development of new chemicals and the identification of new contaminants found in the Arctic (AMAP, 2015b). The emergence of new contaminants is of particular concern because these compounds are not yet fully understood from a human health perspective (Subchapter 3.2). In addition, increased development in the BBDS region – in particular, the development of the industrial sector (e.g., mining and oil and gas) – increases the likelihood of there being local sources of contaminants in the environment (Chapter 7).

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5. Education

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Key messages

- ***Education has become the key factor for adapting to new changes in the environment and in society at large.*** *Education is always an investment for the future, whatever the content might be.*
- ***Postsecondary education clearly contributes to regional and local capacity building, and there is a strong link between postsecondary education and community development.***
- ***A significant development in northern higher education is the trend toward thinking in terms of "circumpolarity."*** *This includes more exchange programs for students and the sharing of teaching material with an Arctic focus.*
- ***Inuit access to the knowledge economy is limited by complex and interrelated factors.*** *Colonial legacies, systemic challenges of disengagement from school, high levels of staff turnover, and struggles to implement bilingual education continue to limit the ability of Inuit to participate fully in the knowledge economy and to prepare for the impact of climate change on Inuit society.*
- ***Inuit cultural and social values should be at the core of educational programs.*** *Language programs on both sides of the Baffin Bay/Davis Strait (BBDS) region require strengthening.*

5.1 Education in Greenland and Nunavut

Offering a formal education[2] in the sparsely populated areas and small communities of the Arctic is challenging. Long distances, housing problems, lack of infrastructure, impacts of colonialism, lack of cultural relevance, and lack of resources in terms of both economic and human capital are basic obstacles for completing a degree at a local place called home. With new technological developments, some opportunities have become available as online courses and distance-learning opportunities have arrived in the Arctic, but there are still some problems because not everyone has reliable access to the Internet (Johansson et al., 2004; see also Subchapter 3.3).

The educational system in Greenland is very much based on the Danish system, due to a long colonial past. As a result, Greenland's system follows the welfare model, where education is free for everyone and primary school is mandatory from first to ninth grades. Greenland as a nation has developed at a rapid pace over the decades, and education has become one of the most important cornerstones of the society. There are various educational institutions, from primary school to the university level. The primary school has been improved, and much attention has been given to the "good school" strategy of elementary school reform (Landstingsforordning nr. 8 af 21. maj 2002 om folkeskolen). However, improvements are being demanded. Numerous vocational training and higher-level educational programs have been developed over the years. Various policies to prevent low graduation rates – one of the largest problems to date – have been implemented at every level of education but with no viable effect. Another problem is the difficulty of retaining talent within the country. Many students are going abroad, often to Denmark, to continue their education, and then they never return to Greenland. The result is a huge "brain drain," which is a problem for not only Greenland but also other small communities around the world.

In Canada, even less than a hundred years ago, Inuit knowledge that had been honed over millennia was passed on by parents, grandparents, extended families, and elders. This practice shaped Inuit society. The younger generation learned life skills and values appropriate to their culture and context. In the colonial period, 1950–1970, missionary schooling, including the use of residential schools, emerged in the communities, along with day schools. The effects of colonial control, social disruption, and loss of culture from this period are still being felt in the educational system. In the years since the early 1970s, Nunavut has struggled to reshape formal education in a way that better reflects Inuit culture, language, and values, while also striving to offer students a high standard of Canadian mainstream education so that high school graduates can access post-secondary education. The creation of divisional boards of education in the 1980s and 1990s met with some success (McGregor, 2010). However, dissolution of the boards took place when Nunavut was created in 1999 and regional operations offices, reporting to the Department of Education, were established. The divisional boards created a structure that represented all the communities in the three regions of Nunavut, thus enabling Inuit parents and representatives to make collaborative decisions about education. The Coalition of Nunavut District Education Authorities (CNDEA) now represents parents and community members in all three regions.

The Nunavut Land Claims Agreement, signed in 1993, led to the establishment of a public government in the territory of Nunavut in 1999 but largely overlooked the matter of education. Following public consultation, legislators took several years to develop the Education Act, which was given assent in 2008. This act formally grounds education in Nunavut in the principles of *Inuit Qaujimajatuqangit* (IQ), Inuit social values, and bilingualism (Inuit languages and English). The IQ principles are based on Inuit knowledge and values (Lévesque, 2014).

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[2] It is important to distinguish between *transmission of knowledge* (the higher-level concept of learning), *education* (the dominant Western form of knowledge transmission), *Indigenous knowledge transmission* (based on learning by experience and observation and transmission of values), and *training* (a limited transmission of technical knowledge for skill development).

In a 2006 report submitted to the federal government as part of the Nunavut Land Claims Agreement implementation process, Justice Thomas R. Berger argued for the need to have more highly educated, bilingual Inuit to fill leadership positions in government to meet Article 23 of the agreement. This article requires representative numbers of Inuit employment (85%) in Nunavut's public sector by 2020 (Berger, 2006). He identified the problem as one of supply, not demand, as there are insufficient numbers of qualified Inuit to fill the professional positions available in Nunavut. Berger highlighted the need to increase high school graduation rates and improve bilingual education in order to address this challenge. In 2012, Statistics Canada reported the high school graduation rate in Nunavut to be 57%, the lowest in Canada – though greatly improved over the 13 years since Nunavut was created. However, the policy of "social promotion" adopted by the Government of Nunavut (aimed at not failing students) explains this improvement (Nunavut Legislative Assembly, 2015). High school graduation levels are linked to university access and are fundamental in addressing the shortage of highly skilled and professionally qualified Inuit. Unlike every other circumpolar country, there is no university in Canada's Arctic region. Access to credit-based university programs in Nunavut currently requires partnerships with educational institutions in southern Canada. Several successful partnerships address the need for college- and university-educated Inuit in Nunavut, but many more are necessary if significant change is to take place.

This chapter elucidates challenges and opportunities associated with education in Greenland and Nunavut. First, a short historical background provides an introduction to the themes for both areas. Secondly, statistics, reports, strategies, policy documents, and other official documents are used to highlight the development of the current situation. Most of the themes are based on previous research, and supplementary new perspectives are included. While the educational systems of Greenland and Canada differ from each other, some similarities as well as dissimilarities are outlined in this chapter.

5.2 Brief historical overview: Greenland

Greenland became a formal colony in 1721 as a consequence of the activities of the Norwegian missionary Hans Egede, who came to the island. Christianity brought literacy and, with it, an early schooling system (Gaviria, 2013; Lennert, 2015). Greenlandic catechists, working as both local teachers and preachers, were trained in Danish and German as early as the 18th century. In 1845, a catechist seminary was established in Nuuk. In 1900, the German Herrnhut mission left Greenland, as their activities became integrated into the Greenlandic church (Bærenholdt, 1999). In 1905, the Greenland Church and School Act was passed to establish a public school system and the church in Greenland, and a building for teacher training was constructed. Today this building is the main building of Ilinniarfissuaq (the Greenlandic teachers' training college in Nuuk), which opened in 1907 (Bærenholdt, 1999). Formal education became more common in the second half of the 19th century, after the establishment of two teacher training colleges (Gaviria, 2013). Starting with higher learning to reach the wider population, Greenland became self-sufficient not only in providing teachers for the educational system but also ensuring that a great majority of Greenlanders were able to read and write (Gaviria, 2013).

The 1905 act was implemented to reform and enlarge teacher training colleges, resulting in the introduction of the first high school curricula. During this period, it was also possible for Greenlanders to complete an education in Denmark (Gaviria, 2013). In 1925, the Danish parliament decided that compulsory teaching of Danish for all children ages 7–14 was to be introduced in the Greenlandic schools (Gaviria, 2013). From 1925 to 1979, compulsory school was required for seven years; after the 1979 introduction of Home Rule, the requirement was changed to nine years (Lennert, 2015).

With the *Danization* policies of the 1950s and 1960s, substantial change took place in post-secondary education in order to bring the educational content in line with Danish standards. During this period, teacher training moved to Denmark and the college in Nuuk was downgraded to provide a basic level of education (for grades one and two) (Gaviria, 2013). Under the Home Rule system, the need for teachers grew due to the introduction of high schools and the University of Greenland (Bærenholdt, 1999).

In 1963, legislation to provide and control apprenticeships was introduced, and a technical school was inaugurated in Nuuk in 1965. However, a full-fledged dual vocational training system equivalent to the Danish system was not implemented until 1976 (Gaviria, 2013).

During the 1970s, nationalism along ethnic lines inaugurated a *Greenlandization* period, which eventually led to the establishment of Ilisimatusarfik, the University of Greenland. This university was originally established as the Inuit Institute in 1983, as part of a strategy to consolidate the Home Rule achieved in 1979 (Gaviria, 2013). Mandated by act of legislation, the aim of this first university was to pursue research and education in Greenlandic culture. The Inuit Institute offered two-year study programs in Greenlandic grammar, Greenlandic literature, Greenlandic history, and social sciences within a Greenlandic framework. With professors and lecturers imported from Denmark, though, the Inuit Institute was in fact shaped after the Danish model (Gaviria, 2013). The structure of the educational system today is such that every Greenlander with ambitions of higher education must learn Danish and English. The three high schools and the University of Greenland are dominated by Danish teachers and Danish standards (Bærenholdt, 1999).

In 1987, a new act established the current Ilisimatusarfik/University of Greenland. Still following the Danish model, this new university focused on the humanities and social sciences in order to avoid duplicating programs that were already available to Greenlanders in Denmark. In the subsequent decades, additional university acts were introduced, mirroring Danish university acts. In 1996, the terms of Ilisimatusarfik's collegial governance and institutional autonomy were expanded and decentralized decision bodies were introduced, similar to the reforms of the Danish University Act of 1993 (Gaviria, 2013).

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Children play outside a primary school, Sisimiut Holsteinsborg, Kitaa, Greenland

In 1994, a new reform within the primary school system was introduced, with the goal of integrating Danish-speaking and Greenlandic-speaking children. Previously, Danish speakers and Greenlandic speakers had been in separate classes, but now all students were to be in the same classroom (Skydsbjerg, 1999). As a result of this policy, a language center was established in Sisimiut in 1997 to provide an opportunity for people to enhance their language skills in Danish, Greenlandic, and foreign languages (Skydsbjerg, 1999).

In 2005, the Greenland parliament passed an education plan with the aim of strengthening the educational sector, both quantitatively and qualitatively. In 2005, one-third of the population on the labor market had an education beyond elementary school (i.e., through grades 9 or 10). The aim of the education plan was to increase this figure to two-thirds by 2020 (Boolsen, 2008a, 2009a, 2009b, 2009c, 2010a, 2012).

The plan of 2005 was developed into a strategy titled the *Greenland Education Programme (GEP) 2006–2020*. Greenland asked the European Union for cooperation to implement this program. The first phase of the program (2006–2012) targeted primary school graduation rates and unskilled/unemployed workers under 50 years of age. Higher education was meant to be the focus of the second phase (2013–2020). In 2007, a new university building was opened in Nuuk to facilitate the majority of the higher education programs (Gaviria, 2013).

As of 2012, the reform of 2005 had not produced the desired results – the level of education among the targeted labor force had not increased with the desired speed (Boolsen, 2012, 2013) – and a second reform was developed, midway through the planned evaluation period. The title of the new reform was political in that it did not reflect the fact that the original plan was not working: *Education for the Future - Education for All*. This plan's goal, which outlined more preschool education, was less ambitious than the earlier goal. Transitions from the educational arena into the workforce were not touched upon. Instead, the focus changed to the period before school (preschool institutions) and thus the transition *into* the school system. The rationale for the reform was primarily financial, with the administration's perspective being influenced by static economic evaluation models.

In 2014, a third educational reform was proposed: *Equal Educational Opportunities for All* (Government of Greenland, 2014). A few years had passed with very limited success; education continued to be for a few instead of the majority. Again, the title of the reform did not reflect the reality of the situation. The aim of the 2014 reform was further reduction, to provide less ambitious educational opportunities. The focus moved from what happens after education (i.e., transition from education to employment) to what happens before starting school (i.e., transition into education). The means for realizing the goals of the reform plan were expressed in economic models and static evaluation models (Boolsen, 2013).

Another important institution – by size and completion of studies – is Piareersarfik, which was one of the important dimensions from the reform of 2005. The focus was on students above 30 years of age with very limited or poor elementary school education, who wanted an education within various professions. As of 2016, the institution of Piareersarfik had grown considerably. The age of the students has decreased, and – best of all – completion has increased (Boolsen, 2016).

The current educational system consists of the following schools: several elementary schools in larger towns and settlements around Greenland; branch schools in Qaqortoq, Narsaq, Paamiut, Nuuk, Maniitsoq, Sisimiut, and Ilulissat; high schools in Aasiaat, Nuuk, Sisimiut, and Qaqortoq; one university, Ilisimatusarfik, in Nuuk; and the Arctic Technology Centre in Sisimiut, a joint program with the Technical University of Denmark. Branch schools provide basic education beyond elementary school, including various forms of craftsmanship and business programs. There is also a police school in Nuuk (Statistics Greenland, 2014), and the Greenland Maritime Centre, Imarsiornermik Ilinniarfik, offers basic and advanced courses in navigation, fisheries, and other topics in Paamiut, Nuuk, and Uummannaq. In other words, the educational sector has grown appreciably in recent decades. The number of institutions has increased, and diversity within the educational system continues to grow.

5.3 Brief historical overview: Nunavut

Before World War II, the attitude of the Canadian government toward the education of Inuit was ambiguous at best. On the one hand, the federal government provided financial assistance to church congregations so they could build day schools and residential schools that allowed them to give basic education to Inuit children throughout the Canadian Arctic. On the other hand, school was not mandatory and many bureaucrats in Ottawa wondered "*why should the government squander public money on dotting the Arctic with well-equipped primary schools that will give the children of Eskimo fur-trappers the same education as white children receive, when these Eskimo children will themselves become mere fur-trappers as they grow up*?" (Jenness, 1964, p. 43).

After World War II, the Canadian government changed course and decided that it had the responsibility to educate Inuit and provide them the same opportunities as other Canadians to participate in the life and activities of the country (Lesage, 1955), meaning that schooling was now mandatory for Inuit children. In 1949, the first three Eastern Arctic federal schools providing elementary education were opened in Kimmirut (formerly called Lake Harbour), in the BBDS region, and Kugluktuk (formerly called Coppermine, in Kitikmeot Region) and Coral Harbour (in Kivalliq Region), outside the BBDS region. In 1955, a residential school was established in Chesterfield Inlet (Kivalliq Region), where a Catholic mission school had existed for decades. The following year, a federal school was opened in Cape Dorset (Weissling, 1991). In subsequent years, additional schools were opened: Frobisher Bay (Iqaluit), Arctic Bay (Ikpiarjuk), and Resolute Bay (Qausuittuq) in 1959; Clyde River (Kanngiqtugaapik) and Igloolik in 1960; Grise Fiord (Aujuittuq) and Padloping Island in 1962; Lake Harbour (again) in 1963; and Hall Beach (Sanirajak) in 1967 (Damas, 2002).

During this period, high school education was also available to young Inuit, but not locally. Inuit students had to leave home and go to residential schools in Yellowknife (founded in 1958), Inuvik (founded in 1959), or Churchill, Manitoba (founded in 1964). These residential schools were clearly aimed at assimilating Inuit; all education was provided in English and was based on a Western curriculum. In addition, physical and sexual abuse were rampant in many residential schools (Truth and Reconciliation Commission of Canada, 2015). Between 1951 and 1961, the number of Inuit students attending schools in communities rose from 245 to 2,600. The proportion of young Inuit who were going to school also increased, from 10% in 1951 to 63% in 1961. By 1966, there were 61 schools in the Northwest Territories (which at that time included Nunavut).

For the Canadian government, education was considered a means to prepare Inuit to participate in the development of the resources of the Northwest Territories; thus, the schools gave the students "*an education that would lead to vocational training and prepare them for work 'in the white man's economy'* "(King, 1999, p. 42). Accordingly, vocational programs began to be offered in the 1960s through Frontier College, which sent adult educators to northern communities to teach English and civic literacy courses. In 1968, the Adult Vocational Training Centre (which later became Arctic College and then, in 1999, Nunavut Arctic College) was created to provide vocational programs and courses to Inuit at the local level (Dalseg, 2015).

In the 1960s and 1970s, training for the managers of the cooperative stores was also offered to Inuit in communities across the Northwest Territories as part of an attempt by government to educate northern Indigenous peoples about democracy and local self-government.

In 1979, one of the most long-standing northern programs – the Eastern Arctic Teacher Education Program (EATEP) – was established. In 1981, through support from the Donner Canadian Foundation, the two-year program began offering a Certificate in Native and Northern Education provided by McGill University's Faculty of Education. In 1985, EATEP became part of the newly established Arctic College, and by 1996, a Bachelor of Education program was offered (Aarluk Consulting Inc., 2005). Elsewhere, too, the number of vocational training programs increased during this time as communities began to prepare for major resource development projects and increases in community infrastructure.

By the 1980s, Arctic College had expanded to include six community learning centers. The number of courses and programs proliferated at this time and reflected many of the labor force needs. For example, in 1985, Arctic College ran 81 programs in 30 communities across the Northwest Territories, and the government provided more than 95 training and professional development courses to over 1,200 employees. Inuit were also able to attend vocational programs offered in southern Canada.

In the 1990s, there was a surge of business and office administration programs offered by the government and colleges in eastern and western Northwest Territories, in preparation for the division of the territory (i.e., the establishment of Nunavut). After 2000, there was a rapid development of initiatives in post-secondary education, stimulated by the need for well-educated personnel to staff the new Government of Nunavut and also beneficiary organizations. These initiatives were, for the most part, requested and funded by the Government of Nunavut and were offered either through accreditation by university or college programs in the south (e.g., the University of Manitoba's Inuit Language and Culture Program) or through the delivery of courses locally, online, or in a hybrid version (e.g., the University of Victoria's Akitsiraq Law Program; the University of Prince Edward Island's Master of Education in Nunavut; the University of the Arctic and Carleton University's Certificate in Nunavut Public Service Studies; Athabaska University). Unfortunately, these initiatives were offered only on a one-time basis or for a special cohort.

5.4 Recent development of education in Greenland

From 1973 to 2004/06 – a span of over 30 years – considerable educational development occurred in Greenland. In 1973, 28% of the population had taken a formal degree beyond primary school; by 2004/06, the number has risen to 47% (Lennert, 2015).

Major investments in education took place during the 1980s. The Greenland government and administration assumed authority of both primary schools and vocational training due to the implementation of the Home Rule Act in 1979 (Lennert, 2015). As a result of the commitment to take over the educational system, vocational training institutions and trade schools were established in all major towns throughout Greenland (Lennert, 2015). Even though the political ambition was to give young people education in the vocational training areas, graduation rates remained low – averaging about 30% in the 1980s and increasing to 43% in the mid-1990s (Lennert, 2015).

A statistical snapshot of the educational career for a young person leaving elementary school in 2010 shows the probability of continuation into post-secondary education to be less than 50%. Young Greenlanders who embark upon an educational career after elementary education are more likely to leave the system and are less likely to complete their post-secondary education (Boolsen, 2013).

During the period 2003–2013, a total of 3,606 students completed their studies at the vocational training level; during the same period, 2,408 students completed high school. The mean graduation age in 2013 was 26 years for vocational training schools and 20 years for the high school level. In 2013, 497 individuals started a university (Bachelors of Arts level) education: 41% in profession-based programs and 30% in academic programs. A majority of those students were female (63%, or 315 individuals) (Statistics Greenland, 2014).

In 2014, a third of Greenland's population over 16 years of age had enrolled in education beyond elementary and secondary school – an increase from previous years. The high schools and the profession-based schools have also seen an increase in student graduation (*Sermitsiaq*, 2016).

The system of post-secondary education includes shorter, medium-range, and longer educational programs. The shorter educational programs are 2 to 3 years in duration, medium-range programs last for 3½ to 4½ years, and the longer university programs require 5 to 6 years (Bachelor of Arts level for 3 years and then Master of Arts level for 2 more years) (*Sermitsiaq*, 2016).

Figure 5.1 provides information about educational volume over time (2003–2012), showing that more students are entering the educational sector, more students never take a degree, and more students receive a degree. In terms of completion rates, improvements are evident, but non-graduates (dropouts) still represent the majority. From the perspective of the educational reforms (2005, 2012, and 2014), it is highly problematic that the completion rates are lower than the dropout rates throughout the period of observation. Because the relation between the individual factors (completion and non-graduation) is relatively

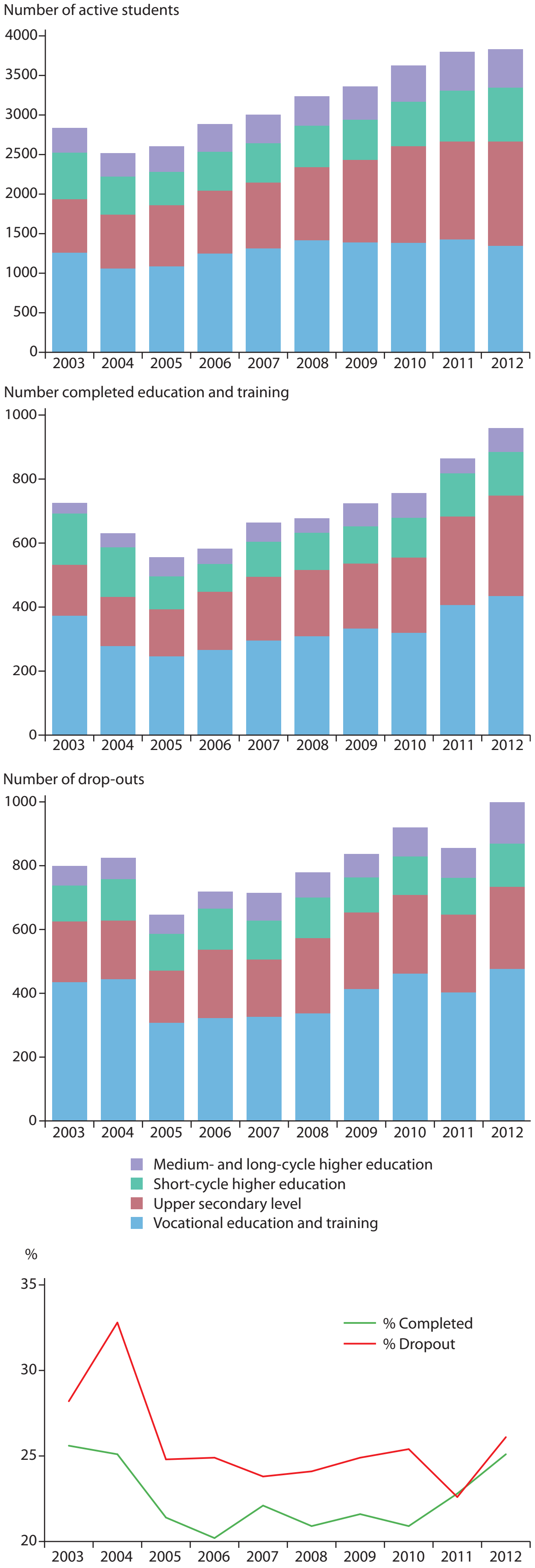

Figure 5.1 Students involved per year in various types and levels of educational activities in Greenland, 2003–2012 (Designed by the editor on the basis of data from Statbank Greenland, bank.stat.gl, 2014). Percentages are expressed relative to number of active students.

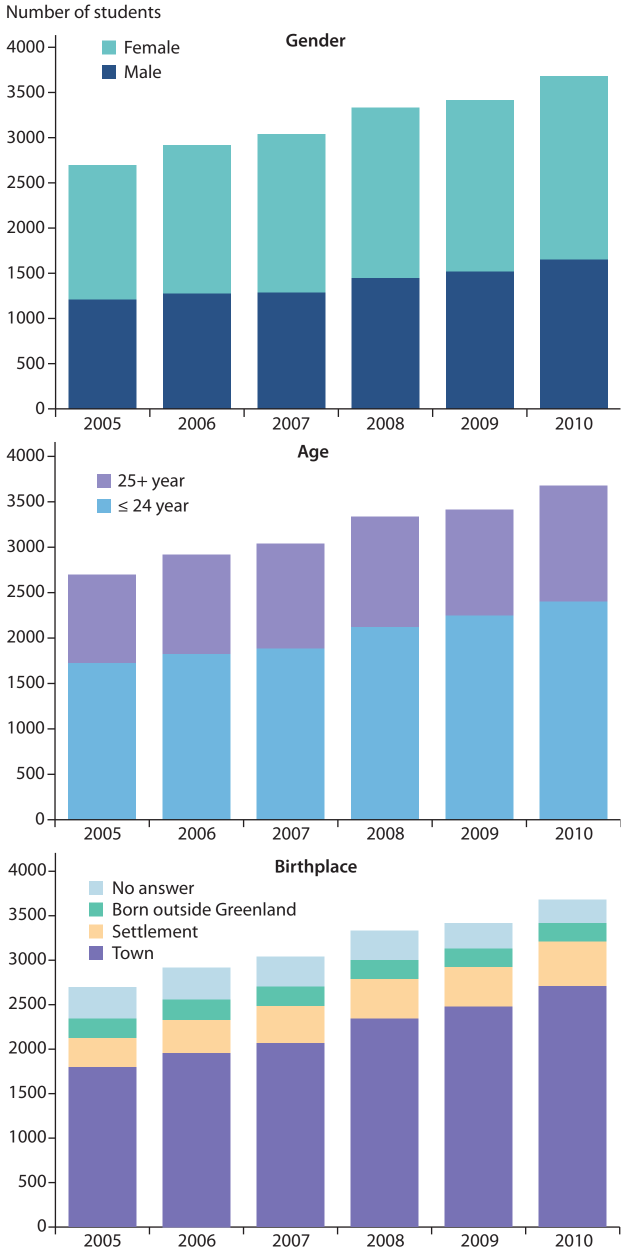

Figure 5.2 Student demographics in Greenland, 2005–2010 (Designed by the editor on the basis of data from Statbank Greenland, bank.stat.gl, 2014). (Note that the "no answer" fraction of the responses is large enough that it may affect the validity of the other figures.)

stable, it is concluded that the education sector increased in size during this period (as measured by number of students) without becoming more efficient (Boolsen, 2013, 2016).

Figure 5.2 shows temporal trends in students' gender, age, and birthplace. With regard to gender, the data (not shown here) indicate that young men and women take different educational programs, following common sex-role patterns. A more important difference is that the women acquire higher educational levels than the men.

All three educational reforms (2005, 2012, and 2014) focused on the low graduation (completion) rate, which is important and serious because more students leave the educational sector as dropouts than as degreed graduates. The explanations for this situation and its consequences varied with each reform. In 2005, the low graduation figures were explained in terms of sociological and demographic variables. Change, it was said, would be produced through (a) more qualified student counseling and (b) more financial help to students who were geographically far from schools and other educational institutions. In 2012, the non-graduation numbers were considered to be evidence of individual problems, and the means for reducing non-graduation rates was consequently also individualized. This approach produced the idea that children must be screened before entering the educational system. In 2012, then, it was recommended that children enter preschool institutions, where screening would occur. In 2014, the tendency to explain low graduation rates as being symptomatic of individual problems continued, and it was suggested that the need for psychological assistance and help at the individual level must be revealed through screening in the preschool institutions. Economic analysis (Boolsen, 2016) shows that educational funding shifted according to the focus and goal of each successive educational reform – from 2005, when the focus was on structural and demographic factors, qualified teachers, qualified student/academic counseling, and the transition from the educational system to the labor market, to 2014, when the focus turned to individual psychological factors and a child's transition into preschool activities, where individual screening could occur.

5.4.1 Future trends and challenges in Greenland

The education plans and discussions about educational development presented above are characterized by good intentions but very little success, when we look at what has taken place in this century.

In Greenlandic materials – reports, papers, plans, and discussions – the Danish influence is obvious. The strategies may be characterized as "Danish." The focus has been on statistical measures within the field of education, such as numbers of students by grade level, numbers of graduates, and numbers of dropouts from programs. Therefore, the educational sector focuses on factors that are not so meaningful to Greenland's population. At the same time, governmental departments focus less on those factors that are important to the common Greenlander (Boolsen, 2008b, 2008c, 2010b).

The educational system is an ever-changing field, with reforms always taking place. What has been seen in recent years is that the Greenland government is working toward diversifying the range of available educational programs, with proposals coming from not only from the government but also the various educational institutions. Within the educational sector, there is an effort to adapt to the drivers addressed in this report, by offering new programs in these areas – e.g., climate change (Chapter 3), natural resources (Chapters 6 and 7), tourism (Chapter 8), and the like. Within tourism, for instance, a new initiative has been launched at Campus Kujalleq to train students to become adventure guides. At the high schools, more specialization has been introduced, to prepare students for university studies within their specific fields of interest.

At Ilisimatusarfik/University of Greenland, an initiative is underway to launch a natural sciences program in cooperation with the Greenland Institute of Natural Resources. In the autumn of 2015, universities within the Nordic Atlantic Cooperation region collaboratively launched a master-level program in West Nordic Studies. Another initiative is a new bachelor-level program in business, also started during the autumn of 2015. Education has become the key factor or key driver for adapting for changes in the environment and in society at large. Education, whatever its content, is always an investment for the future.

However, there will always be challenges to overcome. One major challenge for Greenland is to acknowledge traditional knowledge in order to have it integrated into the educational system. This knowledge is somewhat neglected today, and it could even disappear in the future. Some educational areas such as language issues and language learning need to be prioritized ahead of other disciplines in the future (Subchapter 3.3). Attention should be directed also toward other basic disciplines over all grade levels and educational institutions. The primary school still needs improvement, and there should be more focus on the transition from primary school into higher levels of education.

5.5 Overview of the state of education in Nunavut

Overall, high school (secondary school) graduation rates within Nunavut showed improvement over the past decade, but the last 4 years have seen a decline (Figure 5.3; Nunavut Bureau of Statistics, 2016). The rate grew from 21% in 1999 to 36% in 2010, then declined to 31% in 2015. In the Qikiqtaaluk region (formerly called the Baffin region), the percentage grew from 25% in 1999 to 40% in 2010, then declined to 28% in 2015 (Nunavut Bureau of Statistics, 2016).

Such fluctuations can be attributed to many factors. First, many Inuit students take longer to complete high school and this can affect the numbers because they are not graduating at age 17 or 18, which is what the rate is based on. There may also be a cohort effect amongst some student groups that encourages attendance and supports graduation in particular years but not others, leading to important yearly variations (McGregor, 2017).

A study conducted amongst Nunavut Inuit high school dropouts showed that parental and peer influence are the key factors associated with school perseverance (O'Gorman and Pandey, 2015). Here again, the negative impacts of the residential-school legacy could explain the lower level of support for education from Inuit parents.

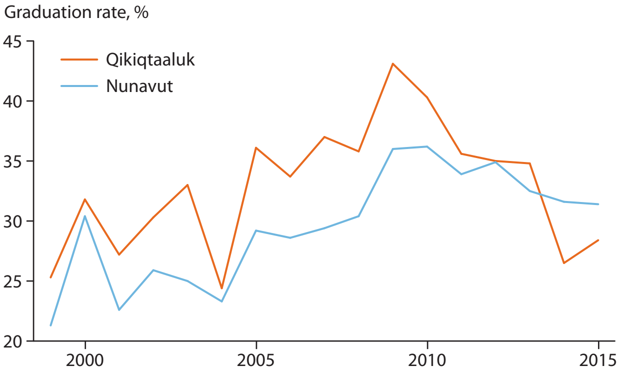

Figure 5.3 High school graduation rates in Nunavut and in the Qikiqtaaluk region, 1999–2014 (data source: Nunavut Bureau of Statistics, 2016).

Whatever the cause, Nunavut high school graduation rates remain the lowest among Indigenous populations in Canada (Richards, 2008; Canadian Council on Learning, 2009). In terms of highest levels of educational attainment, the Qikiqtaaluk region shows the highest levels among the three regions of Nunavut (Table 5.1). Among Qikiqtaaluk residents aged 25–64, 42% do not have any kind of diploma; in the Kivalliq and Kitikmeot regions (both outside BBDS), the numbers are 51% and 50%, respectively. The percentage of Nunavummiut (residents of Nunavut) with an apprenticeship or trade certificate also differs among the regions: 13% in the Kitikmeot region but dropping to 11% in the Kivalliq and 9% in the Qikiqtaaluk regions. The percentage of people holding a university certificate or college diploma is highest in the Qikiqtaaluk region (Statistics Canada, 2011). This difference among the regions can be explained by the fact that Iqaluit, the capital of Nunavut, is situated in the Qikiqtaaluk region and has an important, well-educated non-Inuit population.

As the Nunavut Bureau of Statistics points out, there is a huge discrepancy in educational attainment between Inuit and non-Inuit Nunavummiut. Inuit are far less likely to graduate from high school than their Nunavummiut non-Inuit peers. According to

Table 5.1 Highest level of educational attainment for the population aged 25–64 in Nunavut and its three administrative regions: 2011 counts and percentage distributions (Statistics Canada, 2011).

	No certificate, diploma, or degree	High school diploma or equivalent	Apprenticeship or trades certificate or diploma	College or other non-university certificate or diploma	University certificate or diploma below bachelor level	University certificate, diploma, or degree at bachelor level or above
Nunavut	6565	1770	1425	2420	230	1855
	46%	12%	10%	17%	2%	13%
Qikiqtaaluk	3420	1060	710	1480	155	1240
	42%	13%	9%	18%	2%	15%
Kitikmeot	1275	260	325	400	35	250
	50%	10%	13%	16%	1%	10%
Kivalliq (Keewatin)	1875	455	395	540	45	365
	51%	12%	11%	15%	1%	10%

the bureau's 2013 report (Nunavut Bureau of Statistics, 2013), as of 2011, 60% of Nunavut Inuit aged 25–64 had not completed a high school diploma, compared with 5% for their non-Inuit counterparts. Moreover, 47% of non-Inuit adults had a university degree, compared with only 2% of Inuit adults.

Inuit who graduated from high school and pursued post-secondary education studied primarily in the fields of education, business, and construction. According to the Nunavut Bureau of Statistics (2008, p. 4): "*In 2006, about one third of postsecondary graduates aged 25 to 64 in Nunavut studied in the field of Business or Education. Amongst university graduates in Nunavut, about one in three had a degree in Education. Also, one third of adults with a trades certificate in Nunavut were qualified in Construction Trades, the highest proportion of all provinces and territories.*"

This brief overview suggests three main conclusions regarding the state of high school and post-secondary education in Nunavut:

- High school graduation rates increased between 1999 and 2010 but have since decreased (Figure 5.3); graduation rates remain the lowest among the Indigenous population in Canada.
- Inuit are less likely to graduate and undertake post-secondary education than non-Inuit.
- Most Nunavummiut who undertake post-secondary education do so in one of these three fields: education, business, or the construction trades.

5.5.1 High school education in Nunavut

The systemic challenges of disengagement from school, high levels of educational staff turnover, and struggles to implement bilingual education continue to limit the ability of Inuit to participate fully in the knowledge economy and prepare for the impact of climate change on Inuit society (Berger, 2006).

However, recent territorial and national legislative and policy developments bring hope and provide a framework for change, creating opportunities for Inuit to build a school system based on Inuit language, culture, and values (McGregor, 2010). After the creation of Nunavut in 1999, Inuit set a number of priorities for the new territory, including making Inuktitut the official working language of the territory by 2020 and increasing the proportion of Inuit in the government's work force to 85% (Government of Nunavut, 1999). The Government of Nunavut has passed legislation to create an environment favorable to change, including an Education Act (Government of Nunavut, 2008a), an Inuit Language Protection Act (Government of Nunavut, 2008b), and an Official Languages Act (Government of Nunavut, 2008c), all based on the principles of *Inuit Qaujimajatuqangit*.

This legislation and the policies now being implemented across communities and schools in Nunavut call for innovation in the ways that curriculum and Inuit languages are taught in schools. The new vision for Inuit education in Nunavut also includes an enhanced role for parents through locally elected education committees, district education authorities (DEAs), and the Coalition of Nunavut District Education Authorities. Inuit Tapiriit Kanatami (ITK), the Inuit national organization, has organized a series of strategic, policy-based, Inuit-led actions to foster parental engagement and build a school system based on IQ. As Mary Simon, recently retired National President of ITK argued in 2009, "*We need to get Inuit children into the classroom, and we need them to be successful, and to do this we must focus on innovative strategies that will fundamentally transform our education system*" (University of Prince Edward Island, 2017). Under Simon's leadership, an Inuit Education Accord was signed in April 2009, creating for the first time a National Committee on Inuit Education (NCIE), which represents the four Inuit regions and has developed a National Strategy on Inuit Education (National Committee on Inuit Education, 2011) focusing on strategic priorities for change.

The National Strategy on Inuit Education argues that "*there is almost no data or evidence supporting any of the major policy shifts in Inuit education*" (National Committee on Inuit Education, 2011, p. 90). Research from the ArcticNet project "Inuit Qaujimajatuqangit and the Transformation of High School Education in Nunavut" provides findings related to increasing student success in high schools in Nunavut. This project involved research funded by ArcticNet from 2010 to 2015. Researchers from the University of Prince Edward Island (UPEI) Faculty of Education and Inuit graduates of the UPEI Master of Education program worked in partnership with the Nunavut Department of Education and the Coalition of District Education Authorities of Nunavut to identify factors contributing to improved educational outcomes for Inuit students. Case studies of high schools in Pangnirtung, Clyde River, Rankin Inlet, and Kugluktuk provided data related to high school education across Nunavut based on analyses of interviews with youth, teachers, staff, principals, DEA members, parents, and community members. The findings indicate that high school students want to learn about their language and culture, as well as obtain an education that prepares them for post-secondary education. Support from families, including grandparents – as well as Inuit principals, teachers, and staff – were named as key influences promoting academic and personal success as students complete their education to the grade 12 level. Ten-year historical and statistical analyses of data from the four high schools were completed for the period from 2000 to 2010 (McGregor, 2014). Two documentary videos were produced: *Going Places: Preparing Inuit High School Students for a Changing, Wider World* and *Alluriarniaq Stepping Forward: Youth Perspectives on High School Education in Nunavut*.

Key findings included:

- Student engagement improves when parents, teachers, administrators, and district education authority members work together to provide personal and academic support as high school students complete their educations.
- Grounding education in IQ contributes to a stronger sense of identity and confidence among youth, increasing student engagement in high school.
- Strong Inuit leadership in schools and communities provides positive role models for Inuit youth and promotes pride in Inuit culture and identity, encouraging students to complete a high school education.

- Including IQ-based curriculum in high schools, as well as improving overall academic standards, will contribute to raising graduation levels in Nunavut.

5.5.2 Vocational and post-secondary education in Nunavut

Hundreds of adult education and post-secondary courses and programs have been offered to Inuit across Nunavut (previously a part of the Northwest Territories) since the 1960s. At first glance, it might seem that students who completed high school have had many opportunities to pursue vocational training or post-secondary education inside and outside of their territory. However, despite these initiatives, access to relevant and sustainable post-secondary education in Nunavut has remained extremely limited for most Inuit in Nunavut, and long-term accessibility to high-quality, diversified post-secondary education has been problematic. Although Inuit have made noticeable gains at the high school, college, and trade levels since 1981 (ITK and Research Analysis Directorate, 2006), the percentage that completes a university degree has remained quite low (increasing from 1.6% in 1981 to 2.7% in 2006). More significantly, the gap between non-Inuit and Inuit has increased because the percentage of non-Inuit who completed a university degree during that same period increased from 6.4% to 16.5% (Poelzer, 2009).

The lack of progress at the post-secondary level can be explained by many interrelated factors:

- The absence of a university in the North (Poelzer, 2009; Rodon et al., 2015) forces most students wishing to pursue post-secondary education to move away from home – a step many are not ready to take.
- The quality of high school education in Nunavut does not always prepare Inuit students adequately for the requirements of post-secondary education in a southern university (Hicks, 2005).
- Post-secondary programs, especially vocational and training programs, have been designed to mirror the political and economic events and priorities of their times, as a means of building a workforce in a wage economy. These programs have thus tended to focus on skills development and on improving the employability of Inuit in the wage-economy labor force (in both the private and public sectors). For this reason, their scope, numbers, and long-term relevance can be limited.
- Few of the initiatives developed by southern universities have proven to be sustainable over long periods of time. Most have suffered from not being coordinated in long-term partnerships with government or other agencies in Nunavut, as well as offering programs in only a few specific fields of study (e.g., in education and health, plus one program in public policy and one in law) and being available only in limited locations (mostly in Iqaluit). These initiatives have also proven costly and have required a strong commitment from the various partners over a long period of time, which is difficult to establish and maintain (Kennedy Dalseg et al., 2015).
- Online courses have been developed to overcome some of these shortcomings, but most are not well adapted to the needs of Nunavut students, who often require extensive support to succeed (ITK, 2008). Curricula in these programs may not be adapted to Nunavut realities (Silta Associates, 2007).
- Moreover, Inuit still lack confidence as a result of the loss of control their communities have experienced since the 1950s. This loss of control affects community wellness, which in turn has a negative impact on post-secondary educational success as defined in the south (Rodon, 2008).
- Another factor to consider is the fact that Inuit students' educational paths, as well as their specificity from a sociological and cultural perspective, differ from normative models found in southern Canada. For example, Inuit post-secondary students are generally part of one of two distinct groups: (1) mature adults who are returning to school after being away for an extended period of time or (2) young adults who have recently completed high school. In order to succeed, Inuit adults need access to educational programs that also offer transition and access programs (ITK, 2008) and that reflect their needs as parents and family members, as well as their cultural specificities (Berger, 2001; Hicks, 2005).

There are no easy remedies for the limited access of Inuit students to post-secondary and university education. This is why the Government of Nunavut is currently trying to develop a strategy to ensure the provision of "*consistent, accessible, quality post-secondary education opportunities to all northerners*" (Government of Nunavut, 2011).

Two recent surveys conducted with Inuit students have begun to shed some light on these issues. Rodon et al. (2015) studied the experiences of post-secondary Inuit students outside Nunavut. The researchers found that despite the challenges associated with pursuing post-secondary education in the south, most respondents perceived their experience to be positive. Lack of access to sufficient and equitable funding was perceived by respondents to be a significant barrier, as was the lack of readily available information for prospective students from Inuit Nunangat.

Another survey (Rodon et al., 2014), conducted amongst 372 Nunavut Inuit with post-secondary education, showed the individual and collective value of post-secondary education for Nunavut. Most respondents were satisfied with their post-secondary educational experience but, more importantly, also reported that post-secondary education had greatly improved their income and job outcomes. Finally, post-secondary education clearly contributes to capacity building: half of the respondents work in their communities, and a majority of the respondents who are not in their communities would like to work there. Post-secondary education and community development are strongly linked. However, some issues need to be addressed by policy-makers – the most notable being gender inequality in terms of job status, systemic discrimination against Inuktitut speakers in the educational system, and the need to provide more access to post-secondary education. A vast majority of the survey respondents expressed a wish to go back to school. Funding should also be examined, since it is the second most important factor explaining non-completion of a post-secondary program.

5.6 Comparative outlook

In both Greenland and Nunavut, the historical heritage within education stems from missionary, church, and colonial education. In Greenland, Danish influences have shaped the educational system. Since the introduction of Home Rule in 1979, a new development toward creating a more Greenland-founded educational system has been in the forefront. Today, Greenland has a full-fledged educational system, from the elementary level up to the university level. In Nunavut, the educational system is not yet fully developed, and in spite of recent discussions about a university in Nunavut (Kennedy et al., 2015), there is still no independent post-secondary institution in the territory.

In Nunavut, schools can be found in communities that range from 200 to 7,000 in population size. In smaller communities, school grades are often combined to make greater use of limited resources (Johansson et al., 2004). Although a teacher training program has been in place in Iqaluit since 1979, the availability of teachers has been a major challenge in Nunavut. This shortage of teachers is explained mainly by the competing need for well-trained Inuit in other professions, induced by the establishment of the Government of Nunavut. Many Inuit who were trained as teachers in Nunavut are now employed in the senior level of territorial government administration.

A significant development in northern higher education is the trend toward thinking in terms of "circumpolarity." Another is the increased interest in using information and communication technology and open learning networks. These trends are reflected the programs of the University of the Arctic and the Northern Research Forum (Johansson et al., 2004).

5.7 Challenges and opportunities

Educational challenges are similar in Greenland and Nunavut. In both areas, the largest problem is how to achieve a higher level of completion of the various educational programs. The high level of non-completion and dropout remains a significant problem. The influence of cultural and social values among Inuit peoples should be respected and considered when developing educational programs.

Language programs also require strengthening in both areas. It is not enough to have an educational system with only one language or a system in which students are taught in their second or third language, which might be the case in some areas. In Greenland, there is a wide range of Greenlandic and Danish language skills. In Nunavut, English is gaining ground despite a focus on Inuktitut.

Another challenge relates to the quality of teaching at the elementary school levels, due to a shortage of curriculum resources in Inuit languages. Because the skills learned at this level have an impact on the rest of a student's educational path, recent initiatives to address literacy levels in Inuit languages and in English may positively affect skill levels. At the high school level in smaller communities, high rates of teacher attrition and turnover affect the consistency of program delivery. Opportunities for various schools to work collaboratively might be a way forward, in both Greenland and Nunavut. In Greenland, however, the focus has very much been toward Denmark, which does not always move Greenland priorities forward. The lack of a university in Nunavut is, of course, a drawback for that area in terms of its ability to prosper and develop. A university campus gives a region additional possibilities for developing educational programs and can also support the labor environment in various directions. The future could involve working toward more opportunities to collaborate within the circumpolar area and to exchange experiences with respect to what is working and what is not. Lessons learned from both Nunavut and Greenland could support improvements in the educational systems in both areas.

Apart from the key messages and ideas proposed above, this chapter does not specifically formulate adaptation options (e.g., in a special chapter section) because an education strategy is currently being developed for Nunavut (see also Section 3.3.4). This strategy will include suggestions for ways to adapt educational options/programs/curricula to the broad range of changes affecting the Arctic, and it will include elements applicable to the BBDS region.

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6. Living resources

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6.1 Introduction

In the Baffin Bay/Davis Strait (BBDS) region, living resources are a central part of Inuit culture because they provide nutrition (Chapter 4), clothing, and artistic expression (Subchapter 3.3) in coastal communities. Communities also derive revenue from the sale of harvested goods and from visiting tourists drawn by the unique Arctic fauna (Chapter 8). In addition, living resources maintain other essential ecosystem services such as carbon storage and nutrient recycling. The BBDS region stretches over a vast north–south axis and includes disconnected land masses (Greenland and the Canadian islands), with its eastern and western sectors exposed to highly contrasting ocean currents. These features maintain a high diversity of temperature, ice, and moisture regimes; influence the distribution and dispersal of marine and terrestrial species; shape the seasonal timing and magnitude of plant food production; and affect the life history and population size of harvested animals, both on land and in the sea. Species that compose the marine and terrestrial food webs of the BBDS are therefore susceptible to changes of the physical environment caused by extreme weather events and climate oscillations or change, either directly or through biological cascades resulting from a response of their predators or prey. The paucity of long-term monitoring data and the multiplicity of intervening factors precludes a clear assessment of the impact of climate change on biodiversity and the population status for several species. For other species, recovery from overexploitation, changing harvest or management practices, or responses to climate oscillations is regarded as the main driver of population size, possibly obscuring concurrent responses to the environment.

This chapter summarizes the current state of knowledge regarding living resources in marine and terrestrial ecosystems of the BBDS region, with an emphasis on harvest through fishing and hunting. Agriculture, farming, and herding are considered only for Greenland because these activities have not been developed on the Canadian side. The subchapters on marine and terrestrial ecosystems (Subchapters 6.2 and 6.3) are provided as a fundamental introduction to ecosystem dynamics and functions, to illustrate how basic conditions for harvested resources might change. All subchapters consider the main environmental drivers of change, both past and future, as well as their known or anticipated consequences on ecosystem status, harvestable resources, and northern communities. Each subchapter begins with one or more guiding questions and key messages (listed below), and each concludes with a discussion of adaptation options (also summarized below).

The practical details of the adaptation options differ among ecosystems or activities but follow similar principles – advocating that the optimal use of living resources will benefit from the best management practices and conservation measures supported by heightened capacities for the surveillance of ecosystem status and function, the monitoring of key species, and education and cooperation among the different socio-economic sectors and actors involved. The integration of traditional knowledge with Western science is an important component of increasing surveillance capacity within the BBDS region.

6.1.1 Guiding questions and key messages from Subchapters 6.2–6.6

6.1.1.1 Marine ecosystems (Subchapter 6.2)

Guiding questions

What is the distribution of primary productivity and marine biological hotspots across the BBDS region, and how is this distribution conditioned by the physical environment?

How does primary productivity change or fluctuate over time, and what are the main driving factors?

Is there any evidence for a link between the productivity of the lower food web and population trends for avian predators and marine mammals?

Key messages

- ***In the BBDS region, marine hotspots and a subset of ecologically and biologically significant areas (EBSAs) have been identified as possible priority areas to be included in a regional integrated management plan or in strategies for the implementation of marine protected areas****. The identified areas include:*
    - *Entrance to Hudson Strait and the nearby Hatton Basin*
    - *Southwestern end of Baffin Bay, just north of Davis Strait*
    - *Lancaster Sound*
    - *Smith Sound (Pikialasorsuaq/North Water Polynya)*
    - *Greenland shelf from Uummannaq to Melville Bay (Qimusseriarsuaq)*
    - *Disko Bay*
    - *Store Hellefiskebanke*
    - *Maniitsoq area and Fyllas Bank*
- ***Spatial patterns of marine productivity across the BBDS are highly consistent with the spatial heterogeneity in physical and chemical drivers (ice cover, stratification, and nutrient supply).*** *This heterogeneity results from both local and remote processes. The establishment of any monitoring program should incorporate local and regional sampling elements.*
- ***Annual primary productivity exhibited contrasting temporal patterns in different areas of the BBDS region during the period 1998–2014.*** *Interannual variability was high, and the data suggest the presence of cyclic phenomena that would be consistent with climate oscillations. Existing time series should be prolonged in order to confirm this possibility.*

- ***Between 2005 and 2014, the central Labrador Sea experienced an overall decline in productivity, whereas the chronically unproductive waters of central Baffin Bay became slightly more productive.*** *In the historically productive North Water Polynya, productivity declined during the first decade of the century but then increased in more recent years. The West Greenland shelf from Maniitsoq to Fyllas Bank experienced an overall increase in productivity, especially during the year 2014. Areas with contrasting responses could be used as monitoring sites to track and understand the impacts of environmental change*
- ***Historical data on benthic diversity indicate stability for the period 1976–2009 in terms of total species observed in high-productivity areas.*** *Future monitoring of benthic diversity in these areas therefore offers a powerful means to detect continued resilience or ecological tipping points in the face of multiple environmental drivers and stressors.*
- ***Increases in temperatures (air and water) in recent years have made the coastal zone of high-latitude areas more susceptible to changes in climate, hydrography, and ecology.*** *This temperature change, together with increases in Arctic shipping activity (resulting from reduced sea ice and increased resource exploitation) will possibly augment the risks of harmful algal blooms and aquatic invasive species introductions in the BBDS. Monitoring programs could be implemented in ports (and possibly also communities) to provide early detection/warning for invasive species.*
- ***Data deficiencies preclude robust assessments of the response/resilience of the population size of most seabirds and marine mammals to environmental change.*** *Significant observed changes have been attributed to human exploitation or a combination of factors.*

6.1.1.2 Terrestrial ecosystems (Subchapter 6.3)

Guiding questions

What are the characteristics of terrestrial biodiversity in the BBDS region?

How resilient/vulnerable is the biodiversity of the terrestrial BBDS region as compared to other parts of the Arctic?

What are the most pronounced changes that can be expected within the 21st century in the terrestrial BBDS region as a result of climate change and other human-caused perturbations?

How will these changes affect living conditions for human populations?

What are the management options to mitigate adverse effects on human living conditions and biodiversity assets?

Key messages

- ***The terrestrial ecosystems of the BBDS region may possess greater resilience to climate change than terrestrial ecosystems elsewhere in the Arctic.*** *The BBDS region has a much larger north-to-south geographic extent of Arctic habitat than any other part of the circumpolar Arctic. Furthermore, the region is one of the Arctic's most mountainous areas. These characteristics, in combination with the modeled expectation that multi-year sea ice may persist longest in the northernmost part of the BBDS region, may confer this greater resilience. The many deep and wide water bodies isolating the region's islands may also limit the northward expansion of less mobile southern species that could threaten indigenous Arctic species.*
- ***There will likely be both positive and negative impacts of climate change on terrestrial ecosystems.*** *Initially, some Arctic species may benefit from earlier snowmelt, warmer summers with enhanced productivity, and milder winters. But in the longer term, negative effects – such as increased competition from the northward expansion of more competitive species – may be more important. Further, many species may suffer from the drying of tundra areas due to reduced irrigation from perennial snowbanks and altered hydrology (resulting from reduced permafrost, including a deeper active layer in summer) or from a change in food availability, if different trophic levels do not respond in synchrony to climatic changes. Additionally, the effects of an increased occurrence of extreme weather events, such as rain on snow (creating ice layers that are impenetrable to foraging species like caribou), may have population-level impacts.*
- ***The most serious limitation to our ability to forecast climate change effects on terrestrial ecosystems is a lack of appropriate climate models, together with an insufficient understanding of species and ecosystem functioning.*** *Existing climate models lack adequate spatial resolution and weather variables.*
- ***Human impacts on BBDS terrestrial ecosystems are currently limited in geographic extent.*** *However, the local effects of hydrocarbon and mineral extraction, as well as the introduction of potentially invasive nonnative species, may have risks and effects that will necessitate serious regulation, preparedness, and prevention measures.*
- ***The multitude of biodiversity changes in the BBDS region will, taken together, affect the living conditions of local people in a variety of ways.*** *There will be new possibilities and challenges. Among the challenges may be intensified fluctuations in the abundance of caribou, the most important terrestrial resource. Such changes may result in a need for intensive management.*

6.1.1.3 Sustainable fisheries (Subchapter 6.4)

Guiding questions

What is the general current state of the fisheries in the BBDS region?

How will projected changes in the marine ecosystem affect the fisheries?

How will socio-economic drivers affect the fisheries?

How will the fisheries develop in the short-, mid-, and long-term future?

What are possible adaptation options to ensure the future sustainability of the fisheries?

What are the main knowledge gaps hindering an improved advisory process and a deeper general ecosystem understanding?

Key messages

- ***Fisheries are of great importance to local communities in the BBDS region.*** *Fishing and consumption of local foods contribute to food security, cultural identity, well-being, employment, income, and mixed economies.*
- ***The fisheries are also of great importance to the economies of Nunavut and, in particular, Greenland.*** *Exports from Greenland's state-of-the-art fisheries play a key role in financing the emergent welfare state and in supporting national independence. For Nunavut, Greenland halibut is the third most important export good.*
- ***Greenland halibut and northern shrimp resources are currently upholding most of the export value in the region.*** *These fisheries are considered to be biologically sustainable but sensitive to environmental regime shifts.*
- ***Stocks of the major BBDS fisheries exhibit significant differences in current trends.*** *Greenland halibut stocks are currently considered stable and in good condition, West Greenland cod stocks are gradually rebuilding, and northern shrimp stocks are generally on a downward trend.*
- ***New fisheries based on emerging species or on an increased abundance of local species may develop, facilitated by the shift to a warmer BBDS marine ecosystem.*** *In particular, production of Atlantic cod and Greenland halibut, two species that are at or near the northern limits of their distribution, is expected to increase.*
- ***Although the effects of warming on BBDS fisheries are difficult to forecast, predictions can be made based on changes observed in adjacent systems to the south.*** *Off the northeast coast of Newfoundland, for example, shrimp populations are rapidly declining and finfish stocks are increasing.*
- ***Forage fish species in the region (capelin, sand lance, Arctic cod) are currently unexploited commercially and could potentially become the object of new fisheries.*** *Given the key role of forage fish in transferring energy from secondary producers to higher trophic levels within the BBDS marine ecosystem, the potential impacts of forage fish exploitation on groundfish fisheries should be given particular consideration.*
- ***Most commercial and recreational fisheries of the BBDS region are considered biologically sustainable.*** *However, some coastal stocks (crab, Greenland halibut) are, due to socio-economic pressures, currently fished at levels above the scientific advice. The implementation of management plans to ensure the long-term sustainability of these vulnerable resources is essential.*
- ***Some issues regarding the economic and social sustainability of some coastal fisheries remain unresolved.*** *Such issues are most typically resolved in the short term by overriding the biological recommendations, while in the longer term, individual transferable quotas (ITQs) are introduced.*
- ***With individual transferable quotas, new challenges are likely to follow.*** *One example is the concentration of fishing quota into fewer hands and fewer fishing communities. Lack of access to commercial small-scale fisheries can have negative impacts on the well-being of affected individuals, families, and communities.*
- ***Expected changes in species distributions and quota allocations will likely result in the relocation of some processing activities.*** *Such relocations would lead to new opportunities for some communities and new vulnerabilities for others.*
- ***Key knowledge gaps exist for all BBDS fisheries species of commercial interest.*** *Key knowledge gaps also exist regarding the trophic linkages among these species within the BBDS marine ecosystem.*
- ***Even in the short term (i.e., between now and 2030), projected environmental changes are expected to result in a variety of changes in fish stock distribution and productivity.*** *Given the complexity and interrelatedness of environmental drivers and their effects, it is not possible to predict the development of fisheries over longer time periods. This forecast limitation applies to both local and emerging species. Also, the effects of management initiatives will modulate species and ecosystem responses, thus making predictions even more difficult.*
- ***The ability to both plan and engage in a flexible fishery or processing industry is key to adapting to change.*** *Both management plans and the development of multispecies fisheries have been proposed by the stakeholders of the region.*
- ***The oil and gas and mining sectors are most commonly perceived as having competing interests with the fishing sector.*** *This perception is due to concerns that that new marine activities (exploring, drilling, shipping) may compromise ecosystem health, resource availability, and the international image of the region's seafood products.*
- ***In order for communities and decision-makers to address issues of socio-economic sustainability in the fisheries, it is important to understand how long-term changes in access to resources occur and how such changes may affect specific communities and the society at large.*** *Such long-term changes can result from environmental or political regime shifts.*
- ***Securing local community access to fish quota and diversifying fishing and other livelihood options could help to reduce the economic vulnerability of communities.*** *Many communities are already highly dependent on only a few fish resources for well-being, income, and employment. The availability of these resources may be compromised by both environmental and climatic change as well as socio-economic factors such as fishing policy. In this context, securing access and promoting diversification may be a relevant principle in fishery adaptation actions.*
- ***The potential harvest of new species would have not only economic but also cultural implications.*** *Some of the hunted species that are important to communities as a source of nutrition and in relation to cultural practices, social networks, health, and well-being are at risk as a result of severely declining populations (e.g., caribou in Nunavut). One possible adaptive response is to shift preferences – and therefore harvesting pressure – to other sources of country food.*

6.1.1.4 Hunting (Subchapter 6.5)

Guiding questions

From a human use perspective, what are currently the key living resources in the BBDS region, how are they important, and how is accessibility to these resources expected to change in the future?

How will the expected changes in occurrence and accessibility of living resources interact with socio-economic developments in the region?

How can we adapt to the expected changes in the region if we want to continue benefiting from the use of the living resources but at the same time ensure sustainable wildlife populations?

Key messages

- ***Hunting is important throughout the BBDS region, although traditions, dependence on, and access to living resources vary greatly within the region.*** *Harvest relates to many aspects of BBDS hunting traditions – traditional diet and food security; the use of down or skins products; cultural, physical, and spiritual well-being; and contributions to a mixed economy.*
- ***Key hunting resources are marine mammals, seabirds, and caribou.*** *However, hunting levels have declined for several species of seabirds and marine mammals due to management regulations, urbanization, and occupational changes. Residents in some larger communities increasingly rely on nontraditional wage economy employment and recreational activities other than hunting.*
- ***Climate warming has already affected hunters' access to species associated with sea ice.*** *Examples include hooded seal, harp seal, ringed seal, polar bear, and narwhal. Changes in access are expected to continue into the future.*
- ***For some hunted species, accessibility is expected to decrease due to changes in distribution (e.g., beluga) or abundance (e.g., thick-billed murre) or due to limitations in hunters' ability to travel (e.g., due to thinner ice or more frequent storms).***
- ***For open water–dependent species (e.g., orcas), hunter access may increase due to a wider distribution of the animals, longer ice-free periods, and faster motorboats.***
- ***For some species, less hunting is expected in the future due to a combination of less demand, current or future population declines, and more regulation due to international resource management.*** *Examples include thick-billed murre, polar bear, beluga, and narwhal.*
- ***New hunting/harvest opportunities are expected to emerge for certain goose species, common eider, northern gannet, some species of baleen whales, and, in some areas, caribou.***
- ***Despite an overall regional decline, hunting is expected to remain important for the foreseeable future, especially in smaller and more isolated communities.*** *However, for the traditional Inuit hunter, local adaptive responses may conflict with non-Inuit attitudes about wildlife conservation, sustainability, and environmental management.*
- ***The effects of climate change may be obscured by the fact that a number of marine mammal stocks are still recovering from depletion due to previous unsustainable harvests.*** *The history of harvest within the BBDS region includes centuries of commercial whaling and hunting by foreign actors.*
- ***The potentially intensive future development of extractive industries in the region would increase the risk of cumulative impacts on hunted species.*** *Currently, there is concern for cumulative impacts on some species (e.g., polar bear, narwhal, and thick-billed murre), related to hunting, climate change, oil pollution, seismic activity, and contaminants.*
- ***In terms of social impacts of change, the people and communities that rely heavily on traditional resource uses would be the most sensitive.*** *Some coping mechanisms cost money. Thus, the capacity to adapt to climate change is negatively affected by poverty.*

6.1.1.5 Agriculture, farming, and herding (Subchapter 6.6)

Guiding question

How will fundamental changes in the terrestrial ecosystem affect current and future agriculture, farming, and herding in the BBDS region, and how will these impacts interact with socio-economic development?

Key messages

- ***Within the BBDS region, agriculture, farming, and herding are important only in South Greenland.*** *Sheep farming is the single most important of these activities.*
- ***New farming and herding opportunities are expected to accompany the changes in climate.*** *These expectations include additional space for newly farmed species (e.g., cattle) and new types of vegetables (e.g., cabbage).*
- ***More developed infrastructure and adaptive planning can assure more lasting and better coordinated distribution of products.*** *Developing infrastructure includes better Internet access as well as better (gravel) roads and improvement of transportation by sea. These initatives can improve access to currently isolated areas.*
- ***Increased use of green energy can reduce the carbon dioxide footprint and the cost of agricultural production.*** *The result is more viable farming and better usage of cultivated areas.*
- ***Better technical solutions to handle the challenges of more extreme weather events can increase and stabilize crop production.*** *Improved irrigation systems, for example, could help to handle the challenges of drought and flooding.*
- ***Changing the terms and conditions associated with purchases of abandoned and indebted estates could help ensure that all prepared farming areas are utilized.*** *Today several previously farmed areas lie fallow and could be relatively easily recultivated.*

6.1.2 Adaptation options summarized from Subchapters 6.2–6.6

6.1.2.1 Marine and terrestrial ecosystems (Subchapters 6.2–6.3)

Wise ecosystem management is one of the key ingredients for strengthening the adaptive capacity and resilience of the BBDS region toward climate change and other external stressors, and thus, also the potential for ecosystem services. Management should build on robust knowledge, combining Western science and traditional knowledge about harvested or sensitive species and their ecosystems, and should take into consideration the following principles (also considered in many of the criteria for EBSA and marine protected area (MPA) networks):

- International agreements for nature and biodiversity conservation should be implemented.
- Eco-regional representation, connectivity, critical areas for various life stages (breeding, feeding, roosting, molting), "biodiversity hotspot" analyses, and maintenance of the most productive or resilient areas should be taken into account. For the marine environment, this process has already started – e.g., the work of the Protection of the Arctic Marine Environment working group and the work associated with the Arctic Marine Shipping Assessment's Recommendation IIC) – and continuation should build on this work.
- Biodiversity hotspots should be viewed from the perspective of safeguarding unique Arctic species and regional endemics – not just areas with many species. Areas that are merely species-rich may be dominated by species already common south of the BBDS region, and these southern species may constitute a threat to genuine Arctic species by displacing them through climate-driven northward expansion. Thus, the protection of areas with many unique Arctic species should be given high priority.
- When identifying unique hotspots in the BBDS region, it is essential to consider important polynyas, coastal shelves and fjords, areas of perennial sea ice, large river deltas, lake systems, hot springs and cold seeps, and seasonally important areas for reproduction, molting, and fattening of many birds, fishes, and mammals.
- Given the scale of forecasted changes that could result in substantial habitat displacements in the Arctic, it is important that protected areas be (1) sufficiently large or flexible (i.e., to be adjusted as core habitats and populations may shift) to safeguard critical habitat for target populations, (2) strategically selected (i.e., forming ecological networks of sites), and (3) actively managed in coordination with other approaches that support the overall resilience of regional ecosystems and species.
- The identification of key species for ecosystem well-being, followed by targeted management of populations and the habitats of such species, is essential for success in the sustainable management of living resources.

Adapt or develop indicators specific to the BBDS region, to allow for periodic and comparative assessments of marine and terrestrial ecosystem status (productivity, biodiversity, function) in the future. These indicators should also address broader ecosystem services (e.g., carbon storage, nutrient recycling).

Establish and maintain long-term programs to monitor the response of marine mammal and seabird populations to human activity (navigation, harvest, coastal development), extreme weather events, climate oscillations, and climate change.

Develop codes of conduct for tourists and operators to reduce impacts on wildlife, enhance the quality of wildlife watching, and preserve environmentally or culturally sensitive sites.

6.1.2.2 Sustainable fisheries (Subchapter 6.4)

Develop management plans in collaboration with scientific advisers, local communities, and stakeholders to accommodate changes in resource abundance and distribution, with consideration of social and economic impacts at local and regional scales. Stakeholders include Inuit communities, elders, leaders, hunters, and youth.

Ensure that management actions promote sustainability and are based on well-established scientific advice and possibly provide a basis for eco-certification of the resource, which in turn increases the value of the fisheries.

Including Inuit participation, establish a joint Greenland–Canada strategy and guidelines for developing and managing fisheries based on emerging species that are expected to move into the BBDS region following its warming. The guidelines of Fisheries and Oceans Canada could provide a starting point but should be explicitly tailored to the characteristics of each individual species or fishery.

Adapt the bilateral fisheries management system in the BBDS region to accommodate the different governance structures, including land claims agreements, of Greenland and Canada, to enable managers to more efficiently reach agreement on mutual commitments.

Establish a "new-fisheries working group" as soon as a new fishery emerges or is expected to emerge, to discuss and suggest relevant management initiatives. The working group's agenda should be clearly defined in terms of participation, mandate, and working principles.

Increase fisheries research capacity to identify environmental drivers of stock dynamics and the role of commercially important species in local food webs.

Survey the distributions and abundances of pelagic forage fishes (capelin, sand lance, and Arctic cod), which constitute a critical link between plankton production and fishery resource abundance and distribution.

Identify biological and fishery hotspots that will require protection in the context of future development of the oil and gas and mining sectors and the rapidly increasing tourism industry.

Prioritize, promote, and support flexibility in the fisheries – for example, by adapting the management system to multispecies fisheries.

Consider both the formal economy and the subsistence economy and alternative livelihood options when changes in fishery access rights are introduced.

Support community resilience by developing a broader range of livelihood options that are considered culturally relevant and locally appropriate.

Support small-scale entrepreneurial activity through "research and development centers," funding, and legislation that facilitates marketing options.

Strengthen cooperation among communities, industry, and multiple scientific disciplines on knowledge gaps directly relevant to communities and industry.

Work toward consensus building regarding the overall societal goal of the fisheries, in order to coordinate adaptation measures.

6.1.2.3 Hunting (Subchapter 6.5)

To maximize the adaptive capacity of harvested populations of mammals and birds, allow the species to achieve and maintain healthy population levels that meet sustainable harvest goals.

Assign high priority to the development of management plans for depleted populations, to ensure that current harvests do not delay population recovery.

Provide case-based courses for managers and researchers regarding the development of wildlife management plans, including the aspects of integrating traditional knowledge and addressing potential conflicts between conservation and harvest.

Maintain viable populations by, for example, regulation of the take itself and harvest methods, as well as the use of spatial management (e.g., establishing protected zones for reproduction, molting, and feeding). The establishment of sufficiently large no-disturbance zones can improve hunting conditions in surrounding areas.

To secure long-term use, take into consideration that some species are more vulnerable to environmental change or human use than others, and manage such species with caution. Examples include ice-associated marine mammals and slowly reproducing seabirds. This approach may require that certain areas or regions be fully protected from human use, despite strong local traditions of harvest. Such options highlight the need to make management decisions collaboratively among users, managers, and researchers.

Invest in better monitoring and research of hunted species to fill in knowledge gaps that currently make it difficult to estimate maximum sustainable use.

Facilitate cooperation among researchers, managers, and local users, and support local involvement in monitoring (e.g., through community-based monitoring programs).

Integrate the use of cost-efficient, high-tech solutions in monitoring, such as automated camera surveillance, electronic tracking devices, and gene technology.

Encourage greater international cooperation in the management of shared seabird resources to ensure the benefit of sustainable harvests on a population scale, as is currently practiced for some marine mammals and commercial fish species.

Consider reserving more hunting quotas for trophy hunting as a supplementary income source for hunters, and consider allowing the hunting of more species. Trophy hunting is currently more widely practiced on the Nunavut side of the BBDS region, and Greenland may benefit from this experience.

Enhance communication about the status of declining or vulnerable species and the impact of climate change on the distribution and behavior of animals. Also, communicate information about new hunting opportunities (e.g., some geese species) or alternative uses of living resources.

Facilitate alternative uses of living resources (e.g., eider down collection, macroalgae or mussel cultivation, wildlife watching or other tourist activities) as an alternative to traditional ecosystem services (e.g., hunting).

6.1.2.4 Agriculture, farming, and herding (Subchapter 6.6)

Take advantage of future possibilities for agricultural development, but prior to new investments, investigate implications and solutions related to:

- Increased variability due to climate change (e.g., drought issues).
- Logistical bottlenecks caused by limited infrastructure (e.g., roads).

Increase the use of renewable energy, such as micro hydropower plants and solar panels.

Combine occupations within farming and herding with alternative services, such as tourism and the manufacture of handicrafts.

Facilitate cooperation among farmers to maximize the use of infrastructure and technical aid.

Increase agricultural research in order to increase the production of fodder and vegetables while simultaneously being aware of the increasing possibility of introducing alien invasive species (plants as well as pest species, from both agriculture and horticulture).

6.2 Marine ecosystems

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Key messages

- ***In the Baffin Bay/Davis Strait (BBDS) region, marine hotspots and a subset of ecologically and biologically significant areas (EBSAs) have been identified as possible priority areas to be included in a regional integrated management plan or in strategies for the implementation of marine protected areas.*** *The identified areas include:*
    - *Entrance to Hudson Strait and the nearby Hatton Basin*
    - *Southwestern end of Baffin Bay, just north of Davis Strait*
    - *Lancaster Sound*
    - *Smith Sound (Pikialasorsuaq/North Water Polynya)*
    - *Greenland shelf from Uummannaq to Melville Bay (Qimusseriarsuaq)*
    - *Disko Bay*
    - *Store Hellefiskebanke*
    - *Maniitsoq area and Fyllas Bank*
- ***Spatial patterns of marine productivity across the BBDS are highly consistent with the spatial heterogeneity in physical and chemical drivers (ice cover, stratification, and nutrient supply).*** *This heterogeneity results from both local and remote processes. The establishment of any monitoring program should incorporate local and regional sampling elements.*
- ***Annual primary productivity exhibited contrasting temporal patterns in different areas of the BBDS region during the period 1998–2014.*** *Interannual variability was high, and the data suggest the presence of cyclic phenomena that would be consistent with climate oscillations. Existing time series should be prolonged in order to confirm this possibility.*
- ***Between 2005 and 2014, the central Labrador Sea experienced an overall decline in productivity, whereas the chronically unproductive waters of central Baffin Bay became slightly more productive.*** *In the historically productive North Water Polynya, productivity declined during the first decade of the century but then increased in more recent years. The West Greenland shelf from Maniitsoq to Fyllas Bank experienced an overall increase in productivity, especially during the year 2014. Areas with contrasting responses could be used as monitoring sites to track and understand the impacts of environmental change*
- ***Historical data on benthic diversity indicate stability for the period 1976–2009 in terms of total species observed in high-productivity areas.*** *Future monitoring of benthic diversity in these areas therefore offers a powerful means to detect continued resilience or ecological tipping points in the face of multiple environmental drivers and stressors.*
- ***Increases in temperatures (air and water) in recent years have made the coastal zone of high-latitude areas more susceptible to changes in climate, hydrography, and ecology.*** *This temperature change, together with increases in Arctic shipping activity (resulting from reduced sea ice and increased resource exploitation) will possibly augment the risks of harmful algal blooms and aquatic invasive species introductions in the BBDS. Monitoring programs could be implemented in ports (and possibly also communities) to provide early detection/warning for invasive species.*
- ***Data deficiencies preclude robust assessments of the response/resilience of the population size of most seabirds and marine mammals to environmental change.*** *Significant observed changes have been attributed to human exploitation or a combination of factors.*

Guiding questions

What is the distribution of primary productivity and marine biological hotspots across the Baffin Bay/Davis Strait region, and how is this distribution conditioned by the physical environment?

How does primary productivity change or fluctuate over time, and what are the main driving factors?

Is there any evidence for a link between the productivity of the lower food web and population trends for avian predators and marine mammals?

6.2.1 Introduction

Arctic marine ecosystems provide numerous benefits and services of economic, societal, and ecological value, including the provision of food and the maintenance of the diversity of habitats and species that sustain the health, well-being, culture, and tradition of Inuit, as well as coastal livelihoods, economies, and tourism (further discussed in Chapters 3, 4, and 8). These benefits and services can be either enhanced or reduced by direct local impacts, including habitat modification, commercial harvest, navigation, and the exploitation and transport of oil and gas, or by indirect impacts, through the cumulative effects of global human activities on climate. This subchapter provides an overview of the current state and characteristics of marine ecosystems in the Baffin Bay/Davis Strait region, the known and possible responses of lower food webs to climatic and oceanic drivers of change or variability, and possible scenarios for the future.

6.2.2 State and characteristics of marine ecosystems in the BBDS region

The marine BBDS is a hub where massive flows of water, sea ice, and glacial ice transit and connect. Biodiversity and the structure and function of ecosystems are therefore shaped by a combination of local and remote processes operating at different scales of time and space. In this regard, latitudinal gradients of temperature and light availability, as well as longitudinal differences in major ocean currents, sea ice dynamics and glacial melt, maintain large spatial contrasts in ecosystem dynamics. The western BBDS collects relatively cold and fresh waters (hereafter referred to as "Arctic Outflow") that spend nearly a decade transiting the Arctic. These waters are conditioned by remote events occurring in the Pacific Ocean, on shallow shelves, and in boreal river watersheds (Figure 6.1). The eastern BBDS connects to the North Atlantic via the West Greenland Current, which carries relatively warm and salty water northward along southwest Greenland. This general configuration makes the eastern BBDS particularly susceptible to the northward spread of temperate Atlantic species, while the western BBDS is susceptible to the spread of boreal species from the Pacific to the Atlantic sectors of the Arctic (McKeon et al., 2016).

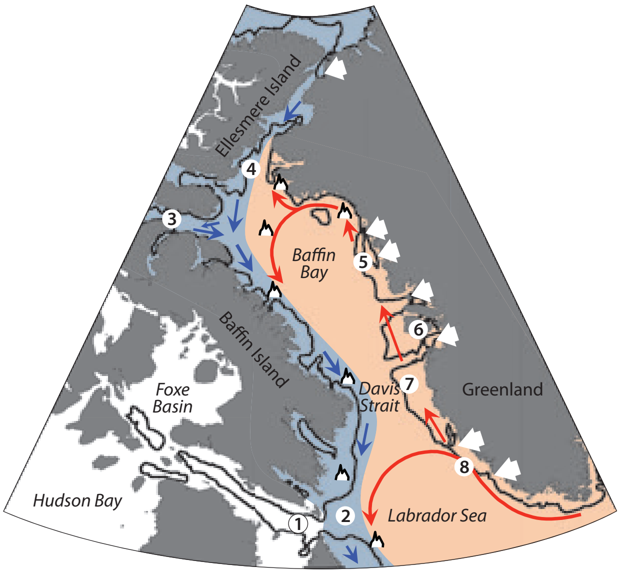

Figure 6.1 Map of the two major ocean current systems in the BBDS region (Pacific-derived = blue arrows and blue shading; Atlantic water = orange arrows and orange shading). Marine biological hotspots and EBSAs discussed in the text are shown by the numbered circles: (1) Hudson Strait, (2) Hatton Basin, (3) Lancaster Sound, (4) Smith Sound, (5) the Greenland shelf from Uummannaq to Melville, (6) Disko Bay, (7) Store Hellefiskebanke, and (8) the Maniitsoq area and Fyllas Bank. The white block arrows denote inputs of fresh water and icebergs from the Greenland Ice Sheet. The solid lines near the coasts mark the 250-meter isobath that delineates shelf areas. (Base map generated using Ocean Data View; Schlitzer, 2016.)

6.2.2.1 Nutrient loading as a determinant of biological productivity

The primary production that supports food webs in seasonally ice-covered areas ultimately depends on nutrient supply (Tremblay and Gagnon, 2009). In the BBDS, this supply has a horizontal component associated with major currents and a vertical component related to upper ocean dynamics. When nutrient concentrations are maximal, prior to the seasonal onset of phytoplankton blooms, coastal Greenland and the Arctic Outflow have similar surface concentrations of nitrate but differ greatly with respect to phosphate and silicate (Table 6.1). These two nutrients are much higher in the eastern BBDS (Pacific-derived) because the Arctic Outflow is enriched by the upwelling of deep nutrient-rich waters in the North Pacific Ocean and, for silicate, by the added contribution of river discharge (Torres-Valdés et al., 2013). Denitrification, a bacterial process that removes nitrate from seawater in the oxygen minimum zones of the North Pacific and in the shallow sediments of the western Arctic, explains why nitrate is not likewise elevated. Without this remote sink, nitrate concentrations and biological productivity in the Arctic Outflow through Nares Strait and Lancaster Sound could be nearly twice as high (Tremblay et al., 2015).

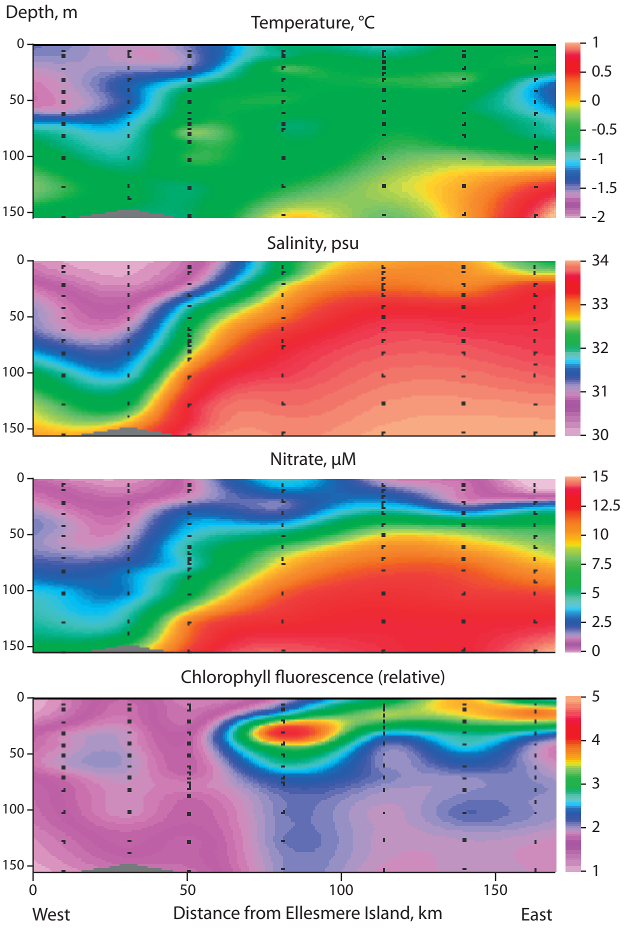

Figure 6.2 East–west cross-sections of selected ocean properties in Smith Sound (North Water) between Ellesmere Island and Greenland, 0–150 m: temperature, salinity, nitrate concentration, and relative chlorophyll fluorescence (an index of phytoplankton biomass) (data from the 2005 ArcticNet expedition).

Table 6.1 Pre-bloom concentrations of major nutrients, nitrogen deficiency factor (N_{def}), and silicate:nitrate ratio (Si:N) for Pacific-derived (Smith Sound) and Atlantic-derived (Nuup Kangerlua) surface waters in the BBDS.

	Silicate (μM)	Phosphate (μM)	Nitrate (μM)	N_{def}[3]	Si:N
Pacific-derived (Northeast Smith Sound)[1]	25.1	1.43	11.34	2.0	2.2
Atlantic-derived (Outer Nuup Kangerlua)[2]	4.8	0.59	9.95	1.0	0.5

[1] Average concentrations in the upper 50 m on 7 June 1998 at 78.33°N, 74.66°W, obtained during the International North Water Polynya Study.

[2] Average concentrations in the upper 50 m for the month of January, 2006–2012 (from Juul-Pedersen et al., 2015).

[3] The nitrogen deficiency factor (N_{def} = phosphate × 16/nitrate) indicates the potential multiplicative increase in productivity that would result from complete phosphate use by the phytoplankton (i.e., potential productivity = N_{def} × actual productivity).

Vertical nutrient supply depends on the physical forces that pull nutrient-rich deep waters toward the surface (upwelling) or that stir the ocean (mixing and turbulence). Inverse relationships have been observed between the strength of stratification, which opposes mixing, and primary production (Ardyna et al., 2011; Ferland et al., 2011). As a case in point, Figure 6.2 shows extremely low surface concentrations of nitrate and chlorophyll fluorescence (an index of phytoplankton biomass) in the cold and relatively fresh Arctic Outflow, where stratification (i.e., vertical salinity gradient) is strongest. In this post-bloom setting, nitrate has been consumed farther north (i.e., "upstream") and is not being replenished from depth due to the strong stratification. A sharp increase in fluorescence occurs toward Greenland, where the West Greenland Current is less stratified and where bathymetric features are conducive to upward nutrient supply at shelf breaks and within fjords (Arendt et al., 2010; Kjellerup et al., 2015). Tidal mixing is an important replenishment mechanism for nutrients in these areas, especially where tidal currents interact with lateral constrictions (narrow straits) or vertical obstacles (sills). Tidal mixing can be particularly vigorous over the shallow sills and shallow banks of the southwest Greenland shelf. In Greenland fjords with marine-terminating glaciers, subglacial discharge of meltwater from the Greenland Ice Sheet rises near the glacier front and entrains nutrient-rich water, lifting it up to the surface or to the depth of neutral buoyancy (Mortensen et al., 2011; Straneo and Cenedese, 2015). This process has been related to a second (post-spring) primary production bloom that characteristically occurs in the Nuup Kangerlua (formerly Godthåbsfjord) each August (Juul-Pedersen et al., 2015).

6.2.2.2 Ecological implications of ocean acidification

The potential consequence of ocean acidification for living organisms can be assessed using the saturation state of aragonite (Ω_{arg}). Aragonite is a form of calcium carbonate that constitutes the hard shells of pelagic pteropods, bottom-dwelling mollusks, and cold-water corals. When Ω_{arg} decreases, the water becomes more corrosive and may eventually reach a state where spontaneous dissolution of shells can occur (Orr et al., 2005; Fabry et al., 2008). In the BBDS, the lowest-Ω_{arg} water is associated with the Arctic Outflow (Azetsu-Scott et al., 2010) and is shallow enough to affect corals along Baffin Island. Large areas of Baffin Bay are colonized by cold-water corals, especially within large gorgonian coral forests (Kenchington et al., 2010) that provide refuge for many species of fish and invertebrates (Edinger et al., 2007b). Corals' aragonite skeletons make them vulnerable to acidification (Wisshak et al., 2012). While cold-water corals may continue to produce skeletons under acidified conditions, this production proceeds at an increased metabolic cost that may adversely affect overall fitness (McCulloch et al., 2012). In a Greenland fjord, carbon dioxide (CO_2) uptake by primary producers and especially benthic macroalgae has been shown to create localized niches of high pH that potentially offer refuge to calcifiers, suggesting that productive coastal systems may prove resilient to acidification (Krause-Jensen et al., 2015). For the BBDS, the long-term impact of acidification in conjunction with other stressors (warming, increased stratification) remains unclear, as does the flexibility that organisms may have in adjusting to decreasing Ω_{arg} (i.e., resilience) (AMAP, 2013).

6.2.2.3 Sea ice as a habitat and determinant of biological timing

Sea ice and the associated snow cover is a habitat for several mammals, as well as microalgae that produce the first new source of food for herbivorous copepods and benthic organisms during spring. Polar bears depend on sea ice for foraging, mating, and, in some regions, denning (Stirling and Derocher, 2012). Four of the 19 known subpopulations of bears use the BBDS, including Kane Basin, Baffin Bay, Lancaster Sound, and Davis Strait. The timing of key events in the life history of polar bears is coupled with that of their primary prey, the ringed seal. When there is no sea ice, polar bears come onshore and fast until the sea ice returns in the fall. While polar bears can occur anywhere on land within their range, there are known summer retreat areas (e.g., Cape Churchill, northeast Bylot Island). When the sea is covered by ice, the marine environment becomes an extension of the habitat for some tundra wildlife predators, such as the Arctic fox. Sea ice plays an important role in the foraging ecology and genetic population structure of this species (Tarroux et al., 2010).

Sea ice also constrains the productivity of the marine ecosystem by reflecting and absorbing the light required for photosynthesis. In this regard, the retreat of the sea ice determines the timing of phytoplankton blooms and affects ambient water temperature. In general, annual ice clears from the southeastern BBDS long before the western BBDS. Moreover, the southern edge of winter ice retreats northward by several hundred kilometers during years when the North Atlantic Oscillation is negative (Heide-Jørgensen et al., 2007).

The phytoplankton bloom on the southern West Greenland shelf typically begins in April (Wu et al., 2008), resulting in a much longer growth season here than in the western and northern BBDS, where ice persists until July (see ice cover images in Figure 2.6). Models of the pelagic food chain show that the timing of the sea ice break-up is critically important for the successful consumption of the spring bloom by upper trophic levels (Heide-Jørgensen et al., 2007). Copepods ascend from dormancy during early spring, and a match with the timing of the spring bloom is essential to maintaining the pelagic food web. Studies show that a substantial part of the spring bloom also sinks and fuels the benthic community (Sejr et al., 2007; Dünweber et al., 2010). The arrival of thick-billed murres at their breeding colonies is strongly correlated to latitude and the timing of ice recession in West Greenland (Laidre et al., 2008). Pre-breeding feeding of little auk on calanoid copepods requires open water; when the edge of the landfast ice is distant from the colony, the birds spend more energy on feeding forays (Heide-Jørgensen et al., 2013).

6.2.2.4 Impacts of icebergs and ice islands on pelagic and benthic habitats

Iceberg scouring of the seafloor and the sedimentation of particles associated with glacial meltwater both disturb the benthic communities (Conlan et al., 1998; Sejr et al., 2010) that supply food to several species of fish and marine mammals. Scouring removes late-succession organisms, creates opportunities for colonizer species, and releases nutrients into the water column. Following a scouring event, full recolonization of a benthic community can take more than nine years (Conlan and Kvitek, 2005). On the Baffin Island shelf, scouring can trigger the release of oil (seeps) and gas (vents), potentially affecting marine organisms and the air–sea exchange of methane, a highly potent greenhouse gas (Levy and Ehrhardt, 1981; Judd, 2003). Although the ecological impacts of icebergs have not been studied in detail in the BBDS, drifting icebergs in the Southern Ocean show elevated concentrations of chlorophyll on their walls and in their wake, which is attributed to the release of micronutrients having a positive effect on algal growth and accumulation (Smith et al., 2007; Schwarz and Schodlok, 2009). The elevated productivity attracts zooplankton and marine birds and is quantitatively significant at the regional scale (Smith et al., 2007). In the Arctic, the upward supply of macronutrients caused by the mixing effect of breaking waves or the upwelling of subsurface meltwater (Jenkins, 1999) potentially stimulates primary production (Stern et al., 2015).

6.2.2.5 Effects of glacier melt on seawater chemistry

In addition to the impact of meltwater on local nutrient supply and regional stratification (discussed above), melting at the ocean terminuses of Greenland Ice Sheet glaciers also modifies the properties of the seawater it dilutes. The meltwater itself contains bioavailable carbon (Lawson et al., 2014) and a host of viruses and bacteria that were previously preserved in the ice. The input of terrestrial carbon from meltwater has a limited impact in productive subarctic systems but may exceed primary production in unproductive Arctic fjords (Sejr et al., 2014). Finally, meltwater affects the seawater carbonate system, with impacts on the trajectories of CO_2, pH, and ultimately ocean acidification. Glacial meltwater has been identified as an important driver of the high uptake of atmospheric CO_2 in Greenland fjords (Meire et al., 2015).

6.2.3 Marine hotspots and habitat use in the BBDS region

Satellite-based estimates of annual primary production in ice-free BBDS waters range from 5 to 100 g C/m^2/yr, on average, for the period 1998–2014 (Figure 6.3). Very low productivity levels (purple in Figure 6.3), analogous to those of an ocean "desert," characterize most of Baffin Bay. Higher values are often observed along the Greenland coast, but the Baffin Island shelf exhibits low coastal productivity across its entire latitudinal extent. This pattern is consistent with the prevalent southward flow of strongly stratified, nutrient-depleted surface waters in the west. Against this backdrop, some areas stand out as being more productive, including the northern tip of Baffin Bay (North Water), Lancaster Sound, eastern Hudson Strait, Disko Bay, and shallow banks of the west Greenland Shelf, such as Store Hellefiskebanke and Fyllas Banke, as well as fjords with strong tidal mixing and marine-terminating glaciers. These hotspots and many others have been formally identified as "ecologically and biologically significant areas" (EBSAs) in Canada (DFO, 2011; see also Chapter 2, Figure 2.3). No areas in Greenland are formally identified as EBSAs, but based on international criteria (including the EBSA criteria) and national priorities, ecologically and biologically valuable

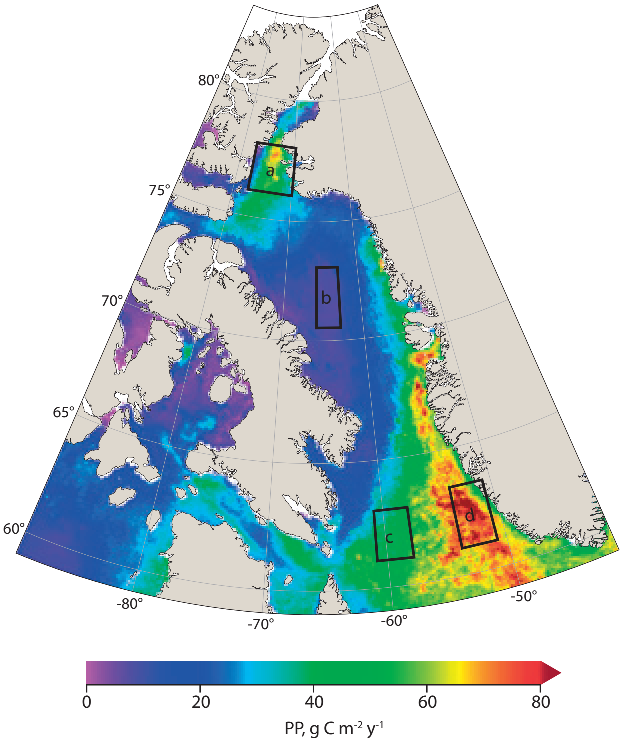

Figure 6.3 Satellite-based estimates of annual primary production (PP) in open (ice-free) waters of the BBDS, averaged over the period 1998–2014. The black boxes indicate the four areas considered for the analysis of temporal trends presented in Figure 6.4.

areas have also been identified here (Christensen et al., 2012, 2016). Based on the International Maritime Organization (IMO) criteria for identifying "particularly sensitive sea areas" (PSSAs), seven areas are identified along Greenland's west coast. Of these, the North Water, Disko Bay, and Store Hellefiskebanke areas stand out and get the highest-ranked priority (Christensen et al., 2012).

Overall, the Labrador Sea is more productive than Baffin Bay (Figure 6.3) due to the deep convection and mixing that occurs in this sea during winter.

In addition to the production of phytoplankton, which occurs everywhere in the BBDS, coastal areas also support the production of benthic microalgae and kelp, which are not routinely included in productivity estimates. These plants provide a direct food source for benthic consumers and create habitats that foster biodiversity. Data from the Greenland coast indicate that kelp beds are widely distributed there. On the outer coast not directly affected by runoff from land, a 50% kelp cover is found (Boertmann et al., 2013).

Among the EBSAs, Hudson Strait (Figure 6.1) is a major seasonal migration route for marine mammals such as beluga, narwhal, and bowhead (DFO, 2011). This area includes walrus haul-out sites, orcas, and overwintering bowhead and beluga and is of prime importance for marine mammals that are feeding and nursing. Many seabird nesting and feeding areas are found on the northern and southern shores. A portion of the Canadian shrimp fishery occurs in eastern Hudson Strait, which also marks the western extent of Greenland halibut habitat (Cobb, 2011). At the entrance to Hudson Strait and in Hatton Basin to the east (Figure 6.1), strong currents and elevated primary production help to sustain thriving populations of invertebrates, fishes, and marine mammals. This area is fished commercially for shrimp and Greenland halibut and is the most important site for deep-sea corals and sponges on the western side of the BBDS (Edinger et al., 2007a; Kenchington et al., 2011; Knudby et al., 2013). Fisheries-related damage to benthic habitats (ablation of epibenthic fauna by bottom trawls) and the associated by-catch of coral is higher here than at any other location in the Canadian Arctic (Edinger et al., 2007b), which presumably has an adverse effect on the abundance of these long-lived organisms. To the north, the southwestern end of Baffin Bay (just north of Davis Strait) is the more southerly of two overwintering areas for narwhals. This location coincides with deep-sea coral aggregations; large catches of the bamboo coral (*Keratoisis grayi*) have been recorded in this area, and abundant other coral species, such as black corals and sea pens, have been reported in fisheries by-catch (DFO, 2007; Wareham, 2009).

Lancaster Sound and Smith Sound (Figure 6.1) harbor two major polynyas (the Lancaster Sound Polynya and the North Water Polynya), and their contiguous domain has been identified as a "super EBSA" (Speer and Laughlin, 2011). Lancaster Sound is a major migration corridor for marine mammals, and it supports a high abundance, biomass, and diversity of benthic fauna (DFO, 2011). The sound is also used as a walrus haul-out site and a feeding area for the highest density of polar bears anywhere in the Arctic (DFO, 2011). The North Water Polynya, long deemed the Arctic's largest and most productive polynya, has historically supported unusually early and intense phytoplankton blooms (Klein et al., 2002), creating one of the most productive food webs in the Arctic (Stirling, 1980; Dunbar, 1981; Deming et al., 2002). This polynya provides shelter for large numbers of marine mammals, including walruses, seals, and polar bears, which feed at the ice edge until spring break-up (Heide-Jørgensen et al., 2013). Tens of millions of seabirds, mostly little auk but also thick-billed murre, fulmar, kittiwake, and ivory gull, use the polynya for feeding and breeding (Egevang et al., 2003; DFO, 2011; Christensen et al., 2012; Heide-Jørgensen et al., 2013; Christensen et al., 2016). Second only to the Bering Sea, the Greenland side of the North Water Polynya supports one of the largest aggregation of seabirds in the northern hemisphere.

Farther south along the Greenland coast, the northwest shelf and ice edge from Uummannaq to Melville Bay (Figure 6.1) have been identified as important habitat for whales and seabirds, both as a migration route and as breathing and resting areas (Christensen et al., 2012, 2016). Still farther south, the Disko Bay area in general – and more particularly West Disko and Store Hellefiskebanke (Figure 6.1) – are especially productive areas. The Disko Bay and Store Hellefiskebanke area has also been identified as a "super EBSA" (Speer and Laughlin, 2011). Here, complex oceanographic regimes drive tidal mixing and upwelling that sustain productive pelagic and benthic food webs, with sand lance and capelin as important prey for whales and seabirds (Christensen et al., 2015). Christensen et al. (2015) demonstrate that five smaller areas within the Disko Bay/Store Hellefiskebanke area are, based on a set of international criteria and national priorities, identifiable as the biologically most important areas. Other productive areas are found along the shelf near Maniitsoq (Figure 6.1), just south of the northern edge of winter sea ice. Fyllas Bank, in particular, is highly productive and serves as an important feeding ground and winter habitat for seabirds (Christensen et al., 2012, 2016). This area also functions as an entrance for migrating whales and seabirds moving into the Baffin Bay area from the south. For West Greenland in general, large-scale patterns of productivity are reflected in the annual productivity of bivalves, sea urchins, and kelp, with a decreasing trend toward the north, which is interpreted as a negative response to prolonged ice cover. Latitudinal studies in Greenland show that the impact of sea ice coverage on annual light availability influences both the maximum depth limits and annual growth rates of kelps (Krause-Jensen et al., 2012).

6.2.4 Drivers and dynamics of productivity in different EBSAs

In Baffin Bay as a whole, the ice season has been contracting at the mean rate of eight days per decade since 1979 (Markus et al., 2009), permitting a longer productive season for the marine ecosystem. In the past few years, the onset of seasonal ice melt in the western Labrador Sea and in eastern Baffin Bay north of Davis Strait occurred nearly two months earlier than the long-term average for 1979–2014; a smaller change was observed in western Baffin Bay (NSIDC, 2014). This change in ice melt is consistent with the increase in annual primary production

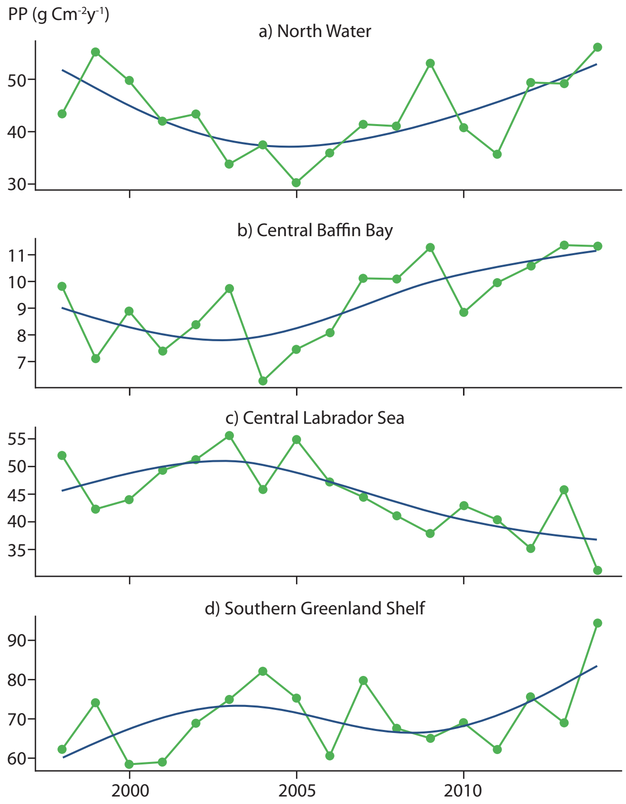

Figure 6.4 Temporal trends in satellite-based primary production, 1998–2014, in open waters of (a) Smith Sound (North Water), (b) central Baffin Bay, (c) the central Labrador Sea, and (d) the southwest Greenland shelf. The locations of these four areas are shown in Figure 6.3. The dark blue lines are moving averages adjusted to the data.

documented by remote sensing for central Baffin Bay over the past decade (Figure 6.4) (Bélanger et al., 2013; Arrigo and van Dijken, 2015) and implies a positive influence of greater light availability on biological production. The secondary autumn bloom of phytoplankton that was previously confined mostly to southwest Greenland and the North Water area has begun to occur more frequently in Baffin Bay (Ardyna et al., 2014), spreading the production of plant food over a longer portion of the year.

Sea ice is not a limiting factor for productivity in the Greenland shelf areas bordering southern Baffin Bay and the Labrador Sea. Other drivers, such as upward nutrient supply, are likely to be more relevant in this region, which shows the highest increases in productivity across the BBDS (Bélanger et al., 2013); in 2014, a strong positive anomaly in productivity was observed in the Maniitsoq–Fyllas Bank area (Figure 6.4d). This increase agrees with the results of a 20-year ship-based survey of the AR7W transect between Labrador and South Greenland (Li and Harrison, 2014), which documented a particularly important rise of chlorophyll-*a* concentrations on the Greenland shelf and slope between 1994 and 2013. Within the BBDS, this is the area that is most influenced by anthropogenic drivers such as commercial fishing, oil and mineral exploration, and marine traffic in general. Historical data show that variation in the inflow of Atlantic water can also drastically alter the ecosystem. During the 1920s and 1930s, there was a dramatic increase in ocean temperatures in the North Atlantic (Drinkwater, 2006). Along the west coast of Greenland, increasing temperatures resulted in the arrival of new boreal species, while Arctic species retreated northward and several commercial fish species increased recruitment and growth (Jensen, 1949). Since the 1980s, the number of humpback whales frequenting the coast of West Greenland on a seasonal basis has been increasing steadily.

Historically, the opening of the North Water Polynya has been contingent on the formation of an ice arch in Kane Basin (approximately 78.6°N), which prevents southward-moving ice from entering the western BBDS. A detailed analysis of the arch reveals that break-up (i.e., end of the polynya) occurred at week 31 (±3 weeks) prior to 1994 and at week 27 (±3 weeks) after 1994 – a one-month advance. The arch has also failed to form in Kane Basin at least 6 times since the early 1990s. A pronounced concomitant drop in satellite-based primary production (-25%) occurred in the North Water between 1998 and 2005 (Figure 6.4a), which was confirmed by direct estimates of seasonal nutrient consumption (Bergeron and Tremblay, 2014). This decline was particularly pronounced on the western side of the North Water, where Pacific-derived Arctic waters flow south (Bergeron and Tremblay, 2014). Tentatively, the decline has been ascribed to enhanced vertical stratification resulting from the freshening of Canada Basin source waters in the west (Yamamoto-Kawai et al., 2009) and accelerated melt of the Greenland Ice Sheet in the east (Harig and Simons, 2012). A concurrent increase in productivity in Kane Basin, north of the North Water, suggests that the productivity zone shifted northward, possibly because reduced ice cover there allowed the phytoplankton to deplete surface nutrients before the southbound waters entered Smith Sound (Bélanger et al., 2013). An analogous situation developed in Lancaster Sound, where productivity decreased in the east but increased "upcurrent" in the western part of Lancaster Sound (Bélanger et al., 2013). An updated analysis shows that productivity in the North Water has been increasing again in recent years (Figure 6.4a), possibly following a cyclical pattern that cannot yet be resolved given the short span of the time series. Maximum departures from the mean for the period 1998–2014 are substantial (approximately ±31%), indicating that primary production is highly sensitive to environmental conditions in the area.

6.2.5 Links between primary productivity and population trends for avian predators and marine mammals

The actual impacts of variability, change, and possible cyclicity in primary productivity on trophic coupling (i.e., zooplankton grazing and the transfer of organic matter up the food web) remain elusive. The BBDS is on par with the Barents Sea in having the highest number of resident marine mammal species ($n = 9$ out of 11 possible) of all Arctic regions (CAFF, 2013), but the response of these populations to changes in the lower food web is largely unknown. According to a recent review by Laidre et al. (2015), there is insufficient data to assess population trends for narwhal, beluga, ringed seal, and bearded seal across the BBDS. Notable exceptions exist for walrus, whose populations are considered stable or increasing, and bowhead whale, whose abundance has apparently increased

Yvette Cardozo/Alamy Stock Photo

Young male polar bear rests and hunts nesting seabirds on rocky cliff of Coburg Island, Northwest Passage, Nunavut

across the BBDS and in the Disko Bay area in particular (Heide-Jørgensen et al., 2007; Laidre et al., 2015). These increases are attributed to recovery from past overexploitation, and they may potentially mask the effects of habitat loss and changing marine productivity in the short term (Laidre et al., 2015). On the West Greenland shelf north of Store Hellefiskebanke, beluga whales shifted their distribution westward, tracking the eastern edge of winter pack ice as it receded to the west after the 1980s. For polar bear, the Kane Basin and Baffin Bay populations are likely declining, the Davis Strait population appears stable, and the status of the Lancaster Sound population is unclear due to a data deficiency (Laidre et al., 2015).

Links between seabird population sizes and changes or fluctuations in the productivity of the lower food web are tenuous for the BBDS, due to a lack of long-term monitoring data, the prevalence of other drivers, or a multiplicity of concurrent factors (CAFF, 2013). Clear declines in thick-billed murre populations in central West Greenland have been attributed to heavy harvesting (but see additional information in Subchapter 6.5). Decreasing ivory gull numbers have been linked to multiple causes, including harvest, mercury contamination, and changing sea ice conditions (CAFF, 2013). Meanwhile, the populations of common eiders have increased dramatically since 2001 as a result of reduced hunting pressure, both on the Nunavut side of the BBDS and in West Greenland (Chaulk, 2009; Merkel, 2010). At present, the strongest environmental pressures on seabird populations seem to associated not with long-term warming but with changes or fluctuations in the seasonal timing of sea ice retreat and with abrupt temperature shifts associated with climate oscillations (e.g., Irons et al., 2008). As an example, Descamps et al. (2013) were able to link a decline of thick-billed murre populations in Svalbard to a warming episode that resulted from a weakening of the subpolar gyre. This phenomenon possibly also affects West Greenland colonies. With regard to sea ice, its impact on fitness or colony size (e.g., thick-billed murre) so far seems to result primarily from its effect on the temporal overlap between predator and prey rather than on the magnitude of marine productivity (CAFF, 2013). However, given the secular association between large colony size and productive marine areas, it is likely that sustained decreases in primary production, should they occur, would have a negative impact in the long run.

Louise Murray/Alamy Stock Photo

Cracks and leads form in the sea ice as the spring melt/break-up proceeds; meltwater runs off into these cracks or leads

6.2.6 Future of marine ecosystems and knowledge gaps

Climate scenarios for the BBDS region forecast local summertime air temperature increases of 1 to 4°C by 2030 and 1.5 to 10°C by 2080 (relative to 1986–2005), corresponding to an average surface water warming of 0.2°C per decade over the next 50 years (Subchapter 3.1). It is noteworthy that for 2012 alone, sea surface temperature anomalies of 2–3°C (relative to the 1982–2006 mean) were observed in August (Timmermans et al., 2013). By 2080, total precipitation is expected to change by 10 to 70% during winter and by 0 to 35% during summer (Subchapter 3.1). In combination, warming and freshening will increase the buoyancy of surface waters flowing through the area, with the change expected to be greatest in the Arctic water that flows through the western BBDS. This buoyancy increase will be augmented by the ongoing melting of Nunavut glaciers and the Greenland Ice Sheet, as well as by remote events that affect the increasing supply of low-salinity Pacific water across the Bering Strait (Woodgate et al., 2012), river discharge, precipitation, and the retention of fresh water within the Beaufort Gyre (Timmermans et al., 2013). In 2012, melting of the Greenland Ice Sheet attained a record high (Nghiem et al., 2012). Climate models project sea ice cover decreases of 15–20% in the fall and 10–15% in the spring by 2080, with the largest change occurring in the northern BBDS (Section 3.1.5).

In combination, these events are likely to augment vertical stratification and curtail nutrient supply, thus slowing or stopping the recently observed productivity increase over most of the BBDS. Under these conditions, an increasingly large fraction of pelagic primary production is likely to take place under the ice or within subsurface phytoplankton layers that cannot be monitored from space. However, runoff events from the Greenland Ice Sheet during mid-summer have been shown to boost local primary production in fjord environments (Juul-Pedersen et al., 2015). Clearly, the physical interactions and consequences of ablating of the Greenland Ice Sheet on the marine environment and its productivity are not yet fully understood.

In the northern BBDS, the shift of elevated productivity zones toward the north (Kane Basin) or the west (inner Lancaster Sound) in some years implies that nutrients are being stripped from surface waters before flowing into Smith Sound and eastern Lancaster Sound (Bélanger et al., 2013). At the larger scale, the continued existence of productive zones inside Lancaster Sound and Nares Strait, whatever their exact position, constitutes a “nutrient trap” whereby phytoplankton strip the surface waters of the nutrients provided by mixing in the narrow channels and over the shallow sills of the Canadian Archipelago and Nares Strait. Once the organic matter has sunk, strong stratification in the Arctic Outflow limits the subsequent reintroduction of mineralized nutrients into the surface layer. This particular setting is expected to maintain the productivity of western and central Baffin Bay at a relatively low level in the future. However, unexpected changes could result from remote events – for example, altered upwelling or denitrification in the source regions that feed the Arctic Outflow or reduced vertical stability of the outflow, which could result from reduced landfast ice in the Arctic interior (Itkin et al., 2015) or changing ice-bridge/polynya dynamics in Nares Strait and Lancaster Sound.

Sea ice loss may also increase benthic productivity in coastal areas where macroalgae and kelp contribute substantially to annual primary production. Due to their bottom-dwelling location, benthic primary producers are less prone to nutrient limitation than are phytoplankton. This influence implies a potential for northward kelp expansion and increased productivity with further sea ice loss. Moreover, the distribution of eelgrass in the subarctic appears to be limited by water temperature (Olesen et al., 2015), indicating that warmer coastal waters may result in the northward expansion of this unique habitat-forming primary producer. Kelp is a part of the Inuit diet and is a source of iron, magnesium, folate, and fiber. The northward expansion and possibly greater productivity of kelp in the BBDS region may help commercialization efforts to bring revenue to some coastal communities.

Changes in the timing of algal production could potentially result in a mismatch between primary and secondary producers, with negative consequences for the herbivorous food web that supports harvestable resources (Wassmann and Reigstad, 2011, and references therein). Conversely, a protracted growth season may create more opportunities for episodic nutrient subsidies arising from storms and upwelling (e.g., the new fall blooms reported by Ardyna et al., 2014), thus creating multiple feeding opportunities over time (Tremblay et al., 2011). Warming may also compensate for the potentially negative effect of an early phytoplankton bloom by speeding up the development rates of grazers. Prior studies of the North Water, where the main bloom formerly began as early as April, revealed a particularly efficient transfer of primary production toward grazers and top predators (Tremblay et al., 2006; Tremblay and Smith, 2007). Recruitment of the dominant copepods *Calanus glacialis* and *Calanus hyperboreus* in the Arctic was shown to be highly flexible and to synchronize with the main diatom bloom from late April to mid-July (Ringuette et al., 2002). While it cannot be assumed that a future BBDS with early-opening waters or a greater incidence of under-ice blooms will reproduce the strong trophic coupling observed in polynyas, studies of these systems suggest a high resiliency of pelagic herbivorous food webs to a changing phenology of primary production.

Trophic mismatches could also result from a shift in the type of phytoplankton that dominates primary production in surface waters. The reasons for such shifts are not fully understood, but coccolithophores and harmful algal blooms (HABs) are typically favored under strongly stratified, nutrient-impoverished conditions (Sabine and Tanhua, 2010). The northern edge of their boreal extent will possibly expand with warming (Walsh et al., 2011), reaching into the eastern BBDS. Coccolithophores have already replaced diatoms in portions of the coastal Bering Sea, with dire consequences for food webs (Macklin et al., 2002). An intriguing possibility is that cold temperatures presently guard nearshore waters from HABs. At lower latitudes (e.g., the North Sea), the incidence of these HABs has been positively linked to human population growth and the release of nutrient-rich effluents in the coastal zone (Heisler et al., 2008). It would be prudent to anticipate these effects as warming progresses and coastal villages and infrastructures develop.

The impact of environmental changes on the production of phytoplankton biomass and the quality of this biomass may have direct impacts on Inuit health and well-being by altering the local marine foods (e.g., seals, beluga, fish, walrus) that they consider essential for a healthy spirit, mind, intellect, and body (ITK and ICC, 2012; see also Chapter 4). Inuit make food choices according to their preferences but also with consideration of the accessibility, abundance, appearance, and nutritional value of marine foods. These four characteristics are strongly tied to the quality and quantity of algal biomass, which is the main entry point for energy, numerous vital or health-enhancing molecules, and contaminants into the food web (e.g., Bjerregaard and Mulvad, 2012; Lemire et al., 2015).

Lipids are the densest form of chemical energy through which light energy is “stored” in marine algal biomass (Parrish, 2013) and then passed on to higher trophic levels, marine foods, and Inuit. Among the lipids, long-chain polyunsaturated fatty acids (especially omega-3s) are essential for reproduction, immunity, membrane function, vision, optimal cardiometabolic function, healthy neurodevelopment, and the prevention of neuropsychiatric and neurodegenerative disorders (e.g., Lemire et al., 2015). Lipids are also a solvent and absorption carrier for carotenoids and vitamins A, D, E, and K (Parrish, 2013). Carotenoids are strong antioxidants that enhance immune responses against cancer and contaminants; they also provide the dark orange-red coloration that Inuit associate with healthier and tastier Arctic char, the central fish species for subsistence and culture in many communities of the BBDS region. Unfortunately, mercury and lipophilic contaminants (i.e., endocrine disruptors such as polychlorinated biphenyls and some new persistent organic pollutants) are also concentrated in the food web, implying a trade-off between the positive and negative effects of a marine diet on health (see Subchapter 3.2). Studies conducted at lower latitudes suggest that the content of health-enhancing substances in algae responds to changes in light availability, temperature, nutrient supply, and/or pH (e.g., Hixson and Arts, 2016); this responsiveness is likely to occur in the Arctic as well. Devising sustainable adaptation strategies in this context will require an assessment of how the rapidly transforming Arctic Ocean may further affect Inuit local food systems and security in the BBDS region.

6.2.7 Adaptation options

The pressures of climate change cannot be prevented by local protection measures, but conservation actions can help mitigate their impacts by minimizing the diversity of stressors acting simultaneously on a system. A synthesis of biological changes occurring within 124 marine reserves in temperate regions around the world has shown that fishes, invertebrates, and seaweeds typically grow bigger and become more abundant inside marine reserves (Lester et al., 2009); biodiversity is also considerably higher in reserves than adjacent areas. Whether these benefits would also apply to eventual reserves in cold Arctic waters remains to be determined.

Adaptation options are perhaps few when it comes to fundamental changes in marine ecosystems. However, marine protected areas (MPAs) are one of the possible approaches for protecting biodiversity and productivity in the BBDS region. Within a legal framework, MPAs permit the regulation of human activities, including harvest, tourism, and commercial navigation. The latter two activities are expected to intensify in the future. This intensification may bring economic benefit to coastal communities, and it may also affect marine fauna through habitat perturbation, the introduction of invasive species, noise pollution, and accidental spills (see Chapters 8 and 9). Most MPAs are zoned such that some activities are permitted in some locations, while other activities are restricted or prohibited. Some marine protected areas include no-take zones, in which all fishing and other resource extraction activities are prohibited. In Canada, traditional cultural uses of marine renewable resources are permitted in MPAs. Given the possibility of future shifts in the locations and sizes of hotspots of productivity and habitat use by marine fauna, some flexibility could be built into the spatial delineation of MPAs or other conservation areas. Such an adaptive delineation could rest on a combination of observational approaches, including the synoptic monitoring of primary productivity by remote sensing (e.g., Figures 6.3 and 6.4) coupled with local knowledge and observations.

On the whole, protecting an area of the sea from resource extraction, including fishing at any scale, safeguards the habitat, the populations of organisms that would normally be exploited, and those organisms' natural predators. Industrial fishing in particular can damage habitats, especially those where plants and corals create structure and refugia for other marine plants and animals (Norse and Crowder, 2013). Examples of such habitat-forming plants and animals in the BBDS region include seaweeds, calcareous red algae, cold-water corals, sponges, and bryozoans (Buhl-Mortensen et al., 2010).

There is a clear need for fundamental research on coastal marine areas in the BBDS, as well as long-term environmental monitoring based on meaningful indicators of coastal ecosystem health; such indicators have yet to be developed for cold Arctic waters. These elements are essential to support decision-making and to define adaptation options with respect to Inuit health and well-being. Some options may need to be adjusted for regional differences in governance and social structure between Greenland and Canada.

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6.3 Terrestrial ecosystems

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Key messages

- ***The terrestrial ecosystems of the Baffin Bay/Davis Strait (BBDS) region may possess greater resilience to climate change than terrestrial ecosystems elsewhere in the Arctic.*** *The BBDS region has a much larger north-to-south geographic extent of Arctic habitat than any other part of the circumpolar Arctic. Furthermore, the region is one of the Arctic's most mountainous areas. These characteristics, in combination with the modeled expectation that multi-year sea ice may persist longest in the northernmost part of the BBDS region, may confer this greater resilience. The many deep and wide water bodies isolating the region's islands may also limit the northward expansion of less mobile southern species that could threaten indigenous Arctic species.*
- ***There will likely be both positive and negative impacts of climate change on terrestrial ecosystems****. Initially, some Arctic species may benefit from earlier snowmelt, warmer summers with enhanced productivity, and milder winters. But in the longer term, negative effects – such as increased competition from the northward expansion of more competitive species – may be more important. Further, many species may suffer from the drying of tundra areas due to reduced irrigation from perennial snowbanks and altered hydrology (resulting from reduced permafrost, including a deeper active layer in summer) or from a change in food availability, if different trophic levels do not respond in synchrony to climatic changes. Additionally, the effects of an increased occurrence of extreme weather events, such as rain on snow (creating ice layers that are impenetrable to foraging species like caribou), may have population-level impacts.*
- ***The most serious limitation to our ability to forecast climate change effects on terrestrial ecosystems is a lack of appropriate climate models, together with an insufficient understanding of species and ecosystem functioning.*** *Existing climate models lack adequate spatial resolution and weather variables.*
- ***Human impacts on BBDS terrestrial ecosystems are currently limited in geographic extent.*** *However, the local effects of hydrocarbon and mineral extraction, as well as the introduction of potentially invasive nonnative species, may have risks and effects that will necessitate serious regulation, preparedness, and prevention measures.*
- ***The multitude of biodiversity changes in the BBDS region will, taken together, affect the living conditions of local people in a variety of ways.*** *There will be new possibilities and challenges. Among the challenges may be intensified fluctuations in the abundance of caribou, the most important terrestrial resource. Such changes may result in a need for intensive management.*

Guiding questions

What are the characteristics of terrestrial biodiversity in the Baffin Bay/Davis Strait region?

How resilient/vulnerable is the biodiversity of the terrestrial BBDS region as compared to other parts of the Arctic?

What are the most pronounced changes that can be expected within the 21st century in the terrestrial BBDS region as a result of climate change and other human-caused perturbations?

How will these changes affect living conditions for human populations?

What are the management options to mitigate adverse effects on human living conditions and biodiversity assets?

Introduction

The topography of the terrestrial environment on both sides of the Baffin Bay/Davis Strait region is mountainous, with decreasing alpine relief to the south and west on the Canadian side. Climatically, the two sides of the region are very different. The Canadian islands are predominantly High Arctic[3] (Figure 2.2; Table 2.1), with only the southern part of Baffin Island being Low Arctic.[4] On the Greenland side, there is a much stronger north–south climatic gradient due to the branch of the warm Irminger Current that flows from south of Iceland and northward along the southwest coast of Greenland (Figure 2.4). This current keeps the sea of southwest Greenland largely free of sea ice (but not icebergs) year-round. The Baffin Island Current, in contrast, brings heavy sea ice southward along the Canadian side most of the year (see Subchapter 6.2). As a result of these ocean influences, the southernmost part of Greenland has a markedly milder climate than its latitudinal

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[3] The High Arctic is characterized by vegetation of very low stature and a July mean temperature of less than 5–6°C.

[4] The Low Arctic is the zone between the High Arctic and the treeline, which is equivalent to a July mean temperature below 10–12°C. Here, the vegetation is often knee-high, but there are no trees.

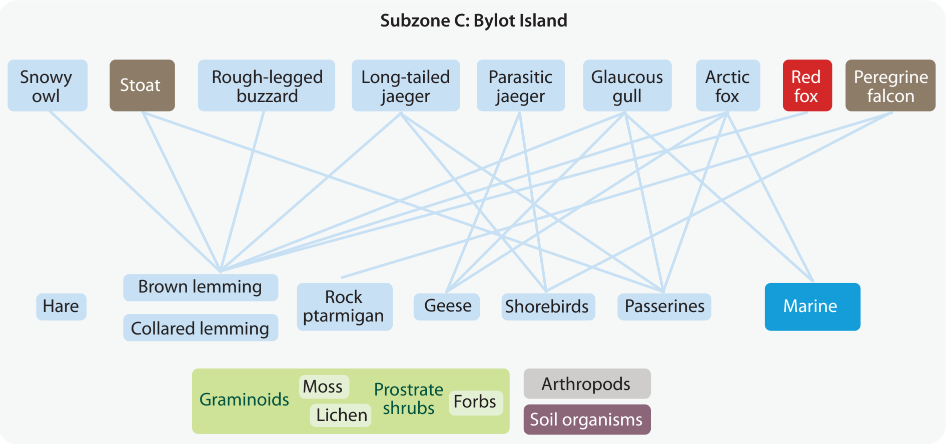

Figure 6.5 Generalized terrestrial food web. The lines represent major trophic relationships. The species shown in red is mainly boreal, those shown in pale blue are typically Arctic, and those in brown are widespread boreal and Arctic. "Subzone C" is one of five Arctic bioclimate subzones. (Figure from Ims and Ehrich, 2013.)

counterpart on the Canadian side – i.e., it is Subarctic[5] rather than Low Arctic (Figure 2.2). Similarly, the coastal land from south Greenland northward to Melville Bay is only Low Arctic, rather than High Arctic (CAVM Team, 2003; Meltofte, 2013).

These climatic and physical differences are the main reasons why the Inuit population on the Greenland side of the region is three times larger than the population on the Canadian side (see Subchapter 3.3). Virtually all settlements are located on the outer coasts because the primary resources used by the people are marine (see further below). Agriculture, primarily sheep farming, is practiced in Subarctic Greenland (see Subchapter 6.6).

Terrestrial ecosystems in the BBDS region – including the land, lakes, and rivers – range from those experiencing warmer climates adjacent to open seas in southern Greenland, where deeper soils support agriculture, to the most barren landscapes of the far north, surrounded by sea ice (CAVM Team, 2003). Between these extremes, tundra ecosystems of moss layers and a shrub or herbaceous overstory (CAVM Team, 2003) form the foundation of a food web that supports relatively few invertebrate, avian, and mammalian species, compared to warmer, wetter climates (Figure 6.5; see also Ims and Ehrich, 2013). There appears to be little redundancy and less competition here than in more diverse ecosystems, but also likely less resilience when a species is lost or decimated – e.g., due to overharvest by humans or other factors such as disease outbreaks, often in combination with negative environmental conditions or catastrophic weather events such that the population crashes (Chapin et al., 1997). Freshwater lakes and rivers in the region may support just a few resident species, yet likely play an important role in facilitating nutrient inputs to terrestrial ecosystems through anadromous fish (Wrona and Reist, 2013) and migratory birds (Blais et al., 2005). Prior to industrialization, human distribution in the region largely reflected access to marine resources and, in some instances, caribou (Meldgaard, 1986).

6.3.1 General status and trends

For biodiversity, the marked climatic and physical gradients – from north to south and from coast to inland – result in clear differences in species composition along the gradients. Vegetation on the Greenland side of the BBDS region ranges from tall, closed-canopy shrub forests in the Subarctic south to polar barrens in the north; most bioclimatic zones described for the circumpolar Arctic can be found here (Böcher, 1979; CAVM Team, 2003). On the Canadian side, the moist, low-shrub tundra dominated by gray willow (*Salix glauca*) >40 cm tall (facilitating the growth of other tree species) is not found. In general, graminoid tundra and various prostrate shrub tundra are more common here, although limited pockets of erect dwarf shrub tundra are reported on Baffin Island (CAVM Team, 2003). The gradient in diversity is particularly strong in Greenland, from the more diverse and warmer continental inland areas to the cooler coastal areas (Bay, 1992; Fredskild, 1996). On the Canadian side, there is a greater variety of bedrock types, and the western and northern islands tend to have sparse and less diverse vegetation. Overall, polar oases with high plant cover and diversity are more abundant in the southern part of the region; in the northernmost parts, such oases are sparse yet biologically very important (Bliss and Matveyeva, 1992; Freedman et al., 1994).

The two sides of the BBDS region are also very different in other respects. First of all, on the Greenland side, there are no lemmings (*Dicrostonyx* spp. and *Lemmus* spp.) south of Melville Bay. This lack stands in sharp contrast to lemmings' widespread occurrence and prominent ecosystem role on the Nunavut side (Krebs, 2011; Legagneux et al., 2012). Caribou (*Rangifer tarandus* spp.) and muskoxen (*Ovibos moschatus*) are found on both sides. Muskoxen are indigenous to High Arctic Greenland and the northernmost Canadian islands. They were never present in West Greenland before the 1960s introduction of 27 muskoxen to the Kangerlussuaq (Søndre Strømfjord) area. Seven additional translocations followed to other sites along the west coast. Productivity was initially exceptional but has since dropped to more moderate levels. Today, the harvest of muskoxen is of high economic value to commercial, sport, and trophy hunting, as well as the creation of muskox fiber (qiviut) products; opportunities for tourism also exist (see Section 6.5.1 for more details).

Historically, caribou have constituted the single most important terrestrial resource for human populations on both sides of the BBDS region. Other important terrestrial resources are geese (particularly snow geese, *Chen caerulescens*, on the Nunavut side), ptarmigan (*Lagopus* spp.), hare (*Lepus* spp.), berries (mostly blueberry, *Vaccinium* spp., and crowberry, *Empetrum* spp.), and

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[5] The Subarctic is the northernmost part of the boreal zone, where forests are intersected by tundra patches and the trees are not suitable for timber.

angelica (*Angelica archangelica*). In the past, Arctic foxes (*Vulpes lagopus*) were also valuable (specifically, their pelts). Arctic char (*Salvelinus alpinus*) is still important in rivers and lakes.

Rapid climate-related changes to the landscape have already occurred (ACIA, 2005; Cuerrier et al., 2015) – for example, increased shrub growth (Hill and Henry, 2011; Myers-Smith et al., 2011; Boulanger-Lapointe et al., 2014; Hollesen et al., 2015) together with an expansion of shrubs into new areas. Although this pattern varies among regions, it is generally attributed to a longer growing season, resulting from earlier snowmelt, warmer soils, and changes in hydrology. This seemingly simple change in vegetation has the potential to alter the food web and provide a positive feedback to climate warming (Ims and Ehrich, 2013; Myers-Smith et al., 2015). This is because an increase in plant biomass can cause lower albedo, thereby accentuating the Arctic amplification of climate change at the global scale (Sturm et al., 2005).

Among terrestrial mammals, a large decline of the Peary caribou herd on Ellesmere Island has been attributed to severe icing episodes (COSEWIC, 2004), and the frequency and severity of such episodes may be increasing as a result of climate change. In present-day Greenland, caribou and muskoxen have not suffered similar impacts at a population-change scale. Although the West Greenland caribou have been through two cycles of major fluctuating abundance since 1721 (Vibe, 1967; Meldgaard, 1986), almost all populations have exhibited a sustained high abundance since the 1970s (Cuyler et al., 2007; Cuyler et al., 2011). Greenland management actions taken since 2000–2001 have aimed to halt further growth in caribou numbers, so as to avoid a third cycle of peak abundance. These actions have also reduced populations in regions where caribou density exceeded the recommendation of approximately 1.2 animals per km^2, which appears to sustain both maximum caribou production and vegetation regeneration following grazing (Cuyler et al., 2016).

In 1952, Norwegian semi-domestic reindeer (*Rangifer tarandus tarandus*) were introduced to the Itivnera/Kapisillit area in Nuup Kangerlua (Godthåbsfjord) in West Greenland (Cuyler, 1999); later, some individuals were translocated to seven other sites (C. Cuyler, unpublished data). Of the eight populations, two remain domestic, two are extirpated, and four are well-established wild populations that are genetically mixed with the indigenous wild caribou (Jepsen et al., 2002; Cuyler et al., 2016). Today, the caribou/reindeer harvest remains a cultural event for all hunters, and it provides considerable income to commercial hunters and the service industries underlying boating and hunting.

The nonmigratory Baffin Island caribou have declined precipitously – from between 110,000 and 340,000 individuals in the late 1980s (Ferguson and Gauthier, 1992) to just 4,652 in 2014 (95% confidence interval: 3,462–6,250) (Campbell et al., 2015). These numbers represent a decline of approximately 95%, but the earlier estimate was based on limited data (i.e., not an island-wide survey). The decline is thought to be associated with a natural population cycle of 60–90 years periodicity, in combination with the exacerbating factors of hunting, increased efficiency of harvest, and the cumulative effects of mine and road development, which has given hunters' year-round access to the herds (DoE, 2015). Potential effects from climate change are also suspected, through an increased occurrence of the icing events that impede the animals' access to forage (DoE, 2015). Baffin caribou remain an important food source for 60% of Nunavummiut (i.e., residents of Nunavut) in the Baffin area.

Berries are another local resource of strong cultural relevance to Inuit. As food, berries are also important to animals. Berry picking is an activity often practiced with friends and family, and berries represent an excellent source of vitamins and antioxidants. Berry plants are less common or absent in the northern portion of the BBDS study area, but most other communities are near berry-producing areas. Berries are often exploited opportunistically by people while traveling or hunting. The natural variability of berry productivity in time and space remains poorly understood. Little is known of the impact of present-day warming on competing shrub growth, pollinating insects, or berry productivity in general (Lévesque et al., 2012).

Little is known also about the status and trends for fresh waters in the region (Wrona and Reist, 2013; Wrona et al., 2016). Baseline information collected for mining projects can provide a snapshot of current conditions but not insight into how things are changing. The absence of regional predictive climate models and the difficulty of monitoring precipitation and water flow in remote, cold environments also make it difficult to develop estimates. For many rivers, data are not available for even resident or anadromous fish populations. Arctic char is found in most rivers and have always been important to humans (see Subchapter 6.4).

6.3.2 Key drivers and dynamics for terrestrial ecosystem change

So far, human impacts on terrestrial ecosystems in the BBDS region have been modest. If not for caribou hunting, almost all terrestrial activities for Inuit would be concentrated around communities and river outlets with fishing and berry-picking possibilities in summer. Unlike seabird colonies, walrus (*Odobenus rosmarus*) haul-out sites, and other concentrated resources in the marine environment, terrestrial fauna species generally do not concentrate in large numbers at particular sites. Instead, they spread out over large expanses of land, making them much less vulnerable to hunting and other disturbance. The exceptions are muskoxen, which are easy to round up with dogs or motorized vehicles, and molting waterfowl that are flightless for about four weeks in summer, when they are dependent on safe and undisturbed sites (Ganter and Gaston, 2013). In certain places, overharvest of Arctic char may also be an issue (Christensen et al., 2016).

Climatic fluctuations have had – and will increasingly have – profound impacts on ecosystems and living conditions in the BBDS region (ACIA, 2005; Meltofte, 2013). Projections for the circumpolar North indicate that major impacts from climatic change in the region will likely include a decrease in nearshore sea ice, a higher amount of snowfall in a shorter winter, an increase in the frequency of freeze/thaw and rain-on-snow events, an increase in the summer thaw depth of soils, and changes in lake and river hydrology (associated with increased glacier melt and decreased summertime river flow from non-glacial lakes and rivers, which are in turn associated with higher temperatures, earlier onset of snowmelt, and increased evapotranspiration) (see Subchapter 3.1). These climate-induced changes may result in the loss of important habitat for some species, as well as the spread of pathogens into additional layers of the food web (Meltofte et al., 2013; Wauchope et al., 2017).

In terms of biodiversity conservation, the northward expansion of more competitive Subarctic species is one of the potentially greatest climate change–related threats to native Arctic species (Meltofte et al., 2013). This threat includes even Low Arctic species expanding into the present-day High Arctic, thus displacing unique species and ecosystems. In parallel, the deliberate introduction of nonnative species, some of which are potentially invasive, exerts a permanent threat, particularly due to horticulture, afforestation, tourism, and the general transfer of materials from southern areas into the Arctic (Lassuy and Lewis, 2013; Normand et al., 2013; Pauchard et al., 2016). In addition to direct competition, the influx of new species may permit increased predator density and exposure to "new" pathogens (diseases and parasites).

The increasing human demand for minerals and hydrocarbons from the region is an additional consideration. Oil, iron, zinc, lead, nickel, rare earth elements, and many other mineral resources are under active exploration along the west coast of Greenland and in several locations on the Nunavut side of the region. A major iron ore mine in the Mary River region of north Baffin Island has been operating since September 2014 (see details in Chapter 7).

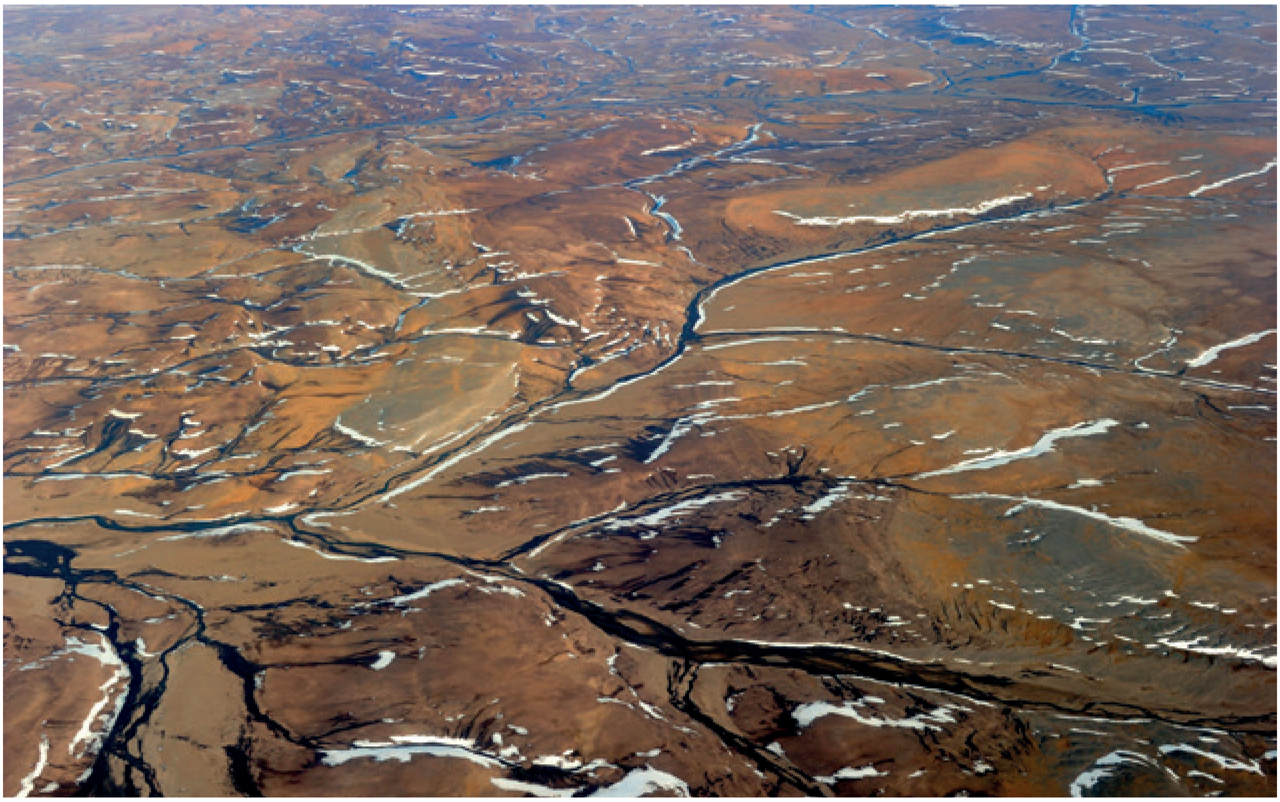
6.3.3 Short- and long-term expected changes

The most likely scenario for climate change impacts on the BBDS terrestrial environment is one of increased vegetation growth and the spread of species northward and to higher elevations, facilitated by earlier snowmelt and warmer summers (Meltofte, 2013; see also Heide-Jørgensen and Johnsen, 1998). The loss of species that are seeking (and failing) to find climatic conditions similar to those they experience today is expected to be moderate, at least during the initial phases of warming. The BBDS region has a large potential capacity to accommodate latitudinal and elevational shifts in distribution – provided that the species can redistribute fast enough. Indeed, the north-to-south extent of the terrestrial Arctic zone is larger here than anywhere else in the circumpolar Arctic, and the area is among the most mountainous (CAVM Team, 2003). Furthermore, the opportunity for southern terrestrial species to move northward, displacing native Arctic species, is hampered by the fact that the BBDS region includes a large number of islands separated by large expanses of ocean. The isolation of these islands from mainland North America is expected to act as a dispersal barrier for less mobile species (Meltofte et al., 2013). Investigation of changes to tundra food webs in the region, although currently limited, has not yet indicated drastic changes (Rautio et al., 2011; Gauthier et al., 2013).

Climate change alters terrestrial habitats via changes in temperature and moisture (i.e., the balance between water inputs from precipitation and outputs due to evaporation and plant transpiration losses) (Ims and Ehrich, 2013). When these two factors change to a state outside their historical range of variation ("extreme events") for even a relatively short period, they can have a greater impact on ecosystems than the progression of "average" climate change itself (Parmesan et al., 2000). For the soils and vegetation types in the BBDS region, increases in shrubs appear to be likely for all but the most barren tundra habitats (CAVM Team, 2003; Ims and Ehrich, 2013). Locally, shrub expansion may result in fewer habitats for herbivorous geese and lemmings, which favor grasses and sedges; this change would alter the structure and function of food webs (Ims and Ehrich, 2013). Similarly, modeling of Arctic wader habitat shows that climatically suitable breeding conditions could shift, contract, and decline over the next 70 years, with 66–83% of species losing the majority of currently suitable area (Wauchope et al., 2017). While caribou, muskoxen, and even lemmings (Olofsson et al., 2009) may help to keep shrub biomass in check, high densities of the large grazers may tip that balance, with a potential for overgrazing. This circumstance would affect not just shrubs but also other forage sources – e.g., the overgrazing of lichens (Ferguson et al., 2001) when caribou herbivore populations expand too rapidly (Henry and Gunn, 1991).

Initially, global warming may benefit many Arctic species that can take advantage of earlier snowmelt, warmer summers, and milder winters (see Subchapter 3.1). However, these same species are at risk later from the expansion of more competitive species from the south or from lower elevations (Meltofte et al., 2013). Further, many species' productivity may suffer from the drying of tundra areas (due to reduced irrigation from perennial snowbanks), altered hydrology (due to reduced permafrost, including a deeper active layer in summer) (Hodkinson, 2013; see also Section 3.1.3), and likely increased insect harassment. The timing of phenological events may also be altered, and mismatches among trophic levels may be expected if some trophic levels respond more quickly to warming than others. See Subchapter 6.5 for examples of mismatch.

Another significant change that may be observed in terrestrial ecosystems is increased river flows from melting glaciers and possibly decreased summertime river flows from non-glacial lakes or rivers, which may become drier due to earlier snowmelt, a deeper active layer, or increased evapotranspiration by plants (Kane et al., 1992; Nilsson and Svedmark, 2002; Smol and Douglas, 2007). Increased water flow at snowmelt causes rapid erosion of sensitive periglacial landscapes (e.g., tundra polygons) and disturbs the surface hydrology, thereby leading to the drainage of wetlands and a reduction of wet sedge habitat for herbivorous grazers (Godin et al., 2016; Perreault et al., 2016; see also Subchapter 4.4). Drying would have the greatest negative impacts on freshwater species, especially spawning fish and the migratory birds that forage in wetlands (Hilborn et al., 2003; Massé et al., 2001; Alisauskas et al., 2012; Perreault et al., 2016; van Gils et al., 2016). In both cases (i.e., increased and decreased river flows), human movements may be affected and so may be the transport of water and sediment to lakes and ultimately to the sea (Lamoureux et al., 2014). Also, changes in permafrost integrity or a loss of perennial or semi-perennial ice cover may affect freshwater quality and aquatic ecosystem processes (Paquette et al., 2015; Vonk et al., 2015; Subchapter 4.4).


Nature Picture Library/Alamy Stock Photo

Aerial view of High Arctic Devon Island, Nunavut, Canada, June 2012

Outbreaks of animal and plant pathogens (e.g., bacteria, viruses, and invertebrate parasites) have cascading impacts on food webs and ecosystem functioning (Hoberg and Kutz, 2013). Just outside the BBDS region, on Banks and Victoria Islands in the Canadian Arctic, bacteria have been responsible for high summer mortality of muskoxen since 2010, possibly as a result of a warmer environment that favors bacterial pathogens and causes physiological stress for the muskox hosts (Kutz et al., 2015). Changes in animal migration – including both range contraction, with more animals concentrated into smaller areas (Poole et al., 2000), and range expansion (MacPherson, 1964; Alisauskas et al., 2012; Burnham et al., 2012; Burnham et al., 2014) – can expose wildlife to more pathogens. In addition, pathogens are spreading due to their own northward advance (Wardle et al., 2011). Plant pathogens and insect outbreaks can also reduce the productivity of important forage species (Mordecai, 2011; see also Franke et al., 2016). Such outbreaks may serve to counter other climate-induced changes, such as species expansion (Wardle et al., 2011). Further, an increase in the number of predators could have dramatic impacts on prey species in the region, including migratory birds (McKinnon et al., 2010). These combined processes can have net positive or net negative impacts on wildlife populations. As a result, aside from the increased likelihood of population fluctuations in game species, it is currently difficult to predict impacts to northerners.

The direct and indirect impacts of industrialization, coupled with the cumulative effects of climate change, can have impacts that affect ecosystems at scales relevant to communities and governments, even though any one project may not have a significant impact beyond the local scale (NRC, 2003). Multiple local impacts in a subregion can add up to significant, broader-scale impacts – a phenomenon referred to as "death by a thousand cuts" (Johnson and St-Laurent, 2011). For example, mining projects may create infrastructure (ports, roads, worker camps) that may in turn facilitate additional industrial development and greater access for non-mining activities – e.g., roads that open human access to new areas for activities such as hunting, recreation, and tourism (NRC, 2003; see also Chapter 7). Indirectly, increases in individual economic resources and cultural changes among rural residents may result in increased human activities across a larger area – e.g., as new means of transportation can be afforded or as the amount of time available for travel on the land changes (Gunn et al., 2011). Tourism can also be expected to have predominantly local effects that most often would be relatively easy to manage (Nellemann et al., 2000; Meltofte et al., 2013; see Chapter 8). Understanding which BBDS areas provide essential ecosystem services (e.g., habitat for caribou calving, goose molting, and fish spawning), will augment the possibilities for reducing the cumulative impacts of industrial development and climate change on terrestrial ecosystems in the region.

6.3.4 Resilience, adaptation, and knowledge gaps

As stated above, climate change holds a number of opportunities as well as challenges for the terrestrial environment. On a positive note, agriculture in South Greenland may profit from an earlier and longer growing season, and the possibilities for agricultural development may extend farther north than at present (see Subchapter 6.6 and Chapter 12). Over the long term, sheep farming could benefit and perhaps the emerging honey-production industry could expand to other areas. Tourism could also gain from a longer summer season, possibly developing into one of the region's major industries, provided that infrastructure and "adventure" possibilities including rich wildlife are secured (see Chapter 8).

Because few terrestrial biotic resources are exploited by humans in the BBDS region, concerns for the region's biodiversity are related to conservation in general and to caribou in particular. From a biodiversity point of view, the High Arctic desert of the far north is probably the most vulnerable habitat. This zone is at risk of disappearing altogether because it is being squeezed between the Arctic Ocean to the north and expanding vegetation zones from the south (Ims and Ehrich, 2013). An increase of only 1–2°C in High Arctic mean July temperatures would permit the establishment of woody dwarf shrubs, sedges, and other species that are currently generally absent in this subzone but are common just to the south (Walker et al., 2016).

The least vulnerable areas may be the continental inland areas close to the Greenland Ice Sheet – specifically, those areas that are also in a precipitation rain-shadow (Cuyler et al., 2011). If true, this circumstance would be rather fortunate for Greenland, which has several such areas where relatively high densities ($1.2/km^2$) of caribou (and muskoxen) may persist (Cuyler et al., 2011, 2016). Coastal areas may be more vulnerable to climate variability. Milder winters combined with ice-free coastal waters may give rise to increased snow depths or more incidents of winter thaw and rain-on-snow or ground ice, all of which could reduce forage availability to caribou and other wildlife (Ims and Ehrich, 2013). Even just one region-wide severe thaw–refreeze icing or extreme deep snow event can abruptly and drastically decimate caribou numbers across all age classes (Miller, 1990; Jacobsen and Wegener, 1995).

Still, such projections are not much more than educated guesses at this point. The simulation models designed to project future climatic changes currently lack the level of detail required to make predictions possible on a local scale. Further, our understanding of the basics of Arctic ecosystem functioning is still limited. Thus, the delineation of certain segments of the BBDS region as "areas of exceptional ecosystem resilience," worthy of designation as priority conservation areas, remains highly subjective. The most obvious way forward is to focus on areas that are currently particularly rich in *unique Arctic biodiversity* and to adjust regulations as changes become apparent, affecting conditions for humans and wildlife (Meltofte et al., 2013).

Current knowledge regarding the physiology and genetics of the BBDS species is inadequate to allow for predictions of their long-term potential for adapting to climate change or increased anthropogenic disturbance. With few exceptions, the species currently among the region's resident terrestrial fauna also occur in warmer tundra habitats, which may indicate an ability to tolerate a change in climate and its cascading effects. On the other hand, migratory birds come to the Arctic to nest and molt, likely in response to the unique conditions of low predation and disturbance pressure, the extensive tundra habitat that allows for large numbers in the Arctic, and also the timing of when their preferred forage is emergent and most nutritious (McKinnon et al., 2010; Gauthier et al., 2011; Gilg et al., 2012; Doiron et al., 2015). These species may be less resilient and also more susceptible to competition from non-Arctic avian species that may move into the area as a result of range expansion.

A number of species and subspecies largely endemic to the region need special attention in conservation planning. Among these are at least 14 plants[6] (Bay, 1999; E. Lévesque, unpublished data) and 7 birds,[7] most of which leave the area in winter (Godfrey, 1986; Boertmann, 1994). In addition to these species endemic to the region, a large number of species endemic to the Arctic in general must be considered in conservation planning in relation to climate change. Finally, one of the most unique Arctic habitats – polar cryptogamic crusts (biodiverse micro-communities) – also deserves much greater attention from conservation efforts in the face of global warming and increased local human activity (Pointing et al., 2015).

6.3.5 Adaptation options

In order to promote resilience and give species in terrestrial ecosystems sufficient time and space to adapt to climate change and increasing human development, the following three options for adaptation should be considered:

- An *expanded system of protected areas or protective measures for essential habitat* should be established to ensure connectivity of seasonal habitats, based on current understanding and predictive modeling of land use and land cover change. Protected landscapes should represent the climatic and geomorphic diversity of the region – including coverage of unique (endemic) Arctic species and ecosystems, not just the most productive or those with the most species – to allow for physiological diversity and to account for uncertainty in how the landscape will change.
- *Strategic, cooperative land management plans* for areas around communities or subregions can help reduce cumulative impacts on terrestrial ecosystems. Such plans are especially useful where recreation, hunting, tourism, shipping, and industrial exploration and exploitation are likely to co-occur. In these areas, regulation of the introduction of potentially invasive alien species (e.g., in relation to horticulture and afforestation) may also be necessary.
- A *species distribution and abundance monitoring program* (see, e.g., Gauthier et al., 2013) for key species at the subregional scale should be developed and implemented. Such programs are designed to also test alternative hypotheses regarding the mechanisms that drive changes. Regional monitoring for pathogens may help prevent population-level outbreaks. The results should be used to adapt management strategies, based on observed changes (see Figure 6.6).

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[6] *Calamagrostis stricta* ssp. *inexpansa* (northern reedgrass), *Calamagrostis purpurascens* (purple reedgrass), *Elymus trachycaulus* ssp. *virescens* (Greenland wildrye), *Festuca groenlandica* (Greenland fescue), *Puccinellia groenlandica* (Greenland alkaligrass), *Puccinellia nuttalliana* (Nuttall's alkaligrass), *Sisyrichium groenlandicum* (Greenland blueeyed grass), *Potamogeton groenlandicus* (Greenland pondweed), *Antennaria affine*, *Antennaria hansii*, *Antennaria alpina* (alpine pussytoes), *Hieracium mumorum* (Arctic hawkweed or wall hawkweed), *Hieracium umbellatum* (umbellate hawkweed), and finally the special hybrid between *Rhododendron tomentosum* and *Rhododendron lapponicum* (*Rhododendron X vanhoeffeni*), which appears as an accepted species.

[7] Greenland white-fronted goose (*Anser albifrons flavirostris*), greater snow goose (*Anser caerulescens atlanticus*), mallard ssp. (*Anas platyrhynchos conboschas*), rock ptarmigan sspp. (*Lagopus mutus rupestris* and *L. m. saturatus*), Thayer's gull (*Larus thayeri*), and Iceland gull (*Larus glaucoides*).

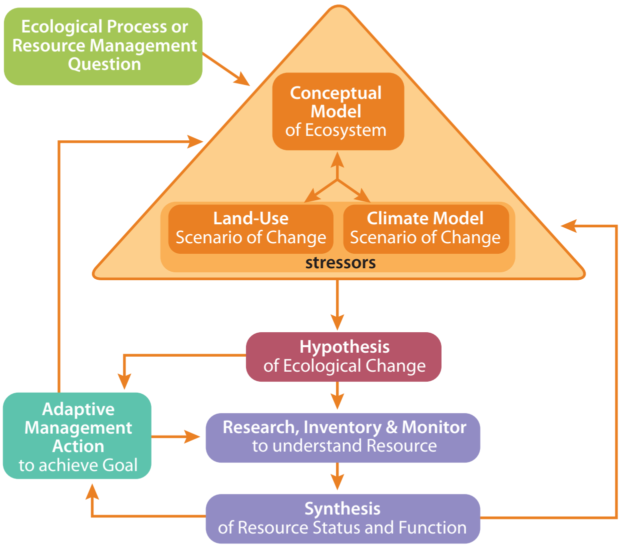

Figure 6.6 Conceptual model for science-based management of natural resources that face climate and development/land-use impacts. The process begins with a conceptual model of the key drivers affecting the resource or ecosystem of interest, such as breeding habitat. Projected changes and impacts from climate change and development are incorporated based on local observations/expert knowledge, modeled projections, or examples from similar ecosystems elsewhere to develop a hypothesis of how the resource might change. A research, inventory, and/or monitoring plan designed to understand the most important drivers of future changes is designed and implemented to track the actual changes that occur over time. As sufficient data are collected, scientists, managers, and communities adapt their management choices to better mitigate the impacts as they are understood. Ongoing long-term monitoring is needed to continue to examine the resiliency of the resource or ecosystem in response to ongoing climate and land-use changes. (Figure by W.M. Loya.)

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6.4 Sustainable fisheries

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Key messages

- ***Fisheries are of great importance to local communities in the Baffin Bay/Davis Strait (BBDS) region.*** *Fishing and consumption of local foods contribute to food security, cultural identity, well-being, employment, income, and mixed economies.*

- ***The fisheries are also of great importance to the economies of Nunavut and, in particular, Greenland.*** *Exports from Greenland's state-of-the-art fisheries play a key role in financing the emergent welfare state and in supporting national independence. For Nunavut, Greenland halibut is the third most important export good.*

- ***Greenland halibut and northern shrimp resources are currently upholding most of the export value in the region.*** *These fisheries are considered to be biologically sustainable but sensitive to environmental regime shifts.*

- ***Stocks of the major BBDS fisheries exhibit significant differences in current trends.*** *Greenland halibut stocks are currently considered stable and in good condition, West Greenland cod stocks are gradually rebuilding, and northern shrimp stocks are generally on a downward trend.*

- ***New fisheries based on emerging species or on an increased abundance of local species may develop, facilitated by the shift to a warmer BBDS marine ecosystem.*** *Production of Atlantic cod and Greenland halibut, species at or near the northern limits of their distribution, is expected to increase.*

- ***Although the effects of warming on BBDS fisheries are difficult to forecast, predictions can be made based on changes observed in adjacent systems to the south.*** *Off the northeast coast of Newfoundland, for example, shrimp populations are rapidly declining and finfish stocks are increasing.*

- ***Forage fish species in the region (capelin, sand lance, Arctic cod) are currently unexploited commercially and could potentially become the object of new fisheries.*** *Given the key role of forage fish in transferring energy to higher trophic levels, the potential impacts of forage fish exploitation on groundfish fisheries should be given particular consideration.*

- ***Most commercial and recreational fisheries of the BBDS region are considered biologically sustainable.*** *However, some coastal stocks (crab, Greenland halibut) are, due to socio-economic pressures, currently fished at levels above the scientific advice. The implementation of management plans to ensure the long-term sustainability of these vulnerable resources is essential.*

- ***Some issues regarding the economic and social sustainability of some coastal fisheries remain unresolved.*** *Such issues are most typically resolved in the short term by overriding the biological recommendations, while in the longer term, individual transferable quotas (ITQs) are introduced.*

- ***With ITQs, new challenges are likely to follow.*** *One example is the concentration of fishing quota into fewer hands and fewer fishing communities. Lack of access to commercial small-scale fisheries can have negative impacts on the well-being of affected individuals, families, and communities.*

- ***Expected changes in species distributions and quota allocations will likely result in the relocation of some processing activities.*** *Such relocations would lead to new opportunities for some communities and new vulnerabilities for others.*

- ***Key knowledge gaps exist for all BBDS fisheries species of commercial interest.*** *Key knowledge gaps also exist regarding the trophic linkages among these species.*

- ***Even in the short term (between now and 2030), projected environmental changes are expected to result in changes in fish stock distribution and productivity.*** *Given the complexity and interrelatedness of environmental drivers and their effects, it is not possible to predict the development of fisheries over longer time periods. The effects of management initiatives make predictions even more difficult.*

- ***The ability to both plan and engage in a flexible fishery or processing industry is key to adapting to change.*** *Both management plans and the development of multispecies fisheries have been proposed by the stakeholders of the region.*

- ***The oil and gas and mining sectors are most commonly perceived as having competing interests with the fishing sector.*** *This perception is due to concerns that new marine activities (exploring, drilling, shipping) may compromise ecosystem health, resource availability, and the international image of the region's seafood products.*

- ***In addressing socio-economic sustainability in the fisheries, it is important to understand how long-term changes in access to resources occur and how such changes may affect specific communities and the society at large.*** *Such long-term changes can result from environmental or political regime shifts.*

- ***Securing local community access to fish quota and diversifying fishing and other livelihood options could help reduce the economic vulnerability of communities.*** *Many communities are highly dependent on only a few fish resources for well-being, income, and employment. The availability of these resources may be compromised by environmental and climatic change as well as socio-economic factors such as fishing policy.*

- ***The potential harvest of new species would have not only economic but also cultural implications.*** *Some hunted species that are important to communities are at risk, with severely declining populations (e.g., caribou in Nunavut). One possible adaptive response is to shift preferences – and therefore harvesting pressure– to other sources of country food.*

Guiding questions

What is the general current state of the fisheries in the Baffin Bay/Davis Strait region?

How will projected changes in the marine ecosystem affect the fisheries?

How will socio-economic drivers affect the fisheries?

How will the fisheries develop in the short-, mid- and long-term future?

What are possible adaptation options to ensure the future sustainability of the fisheries?

What are the main knowledge gaps hindering an improved advisory process and a deeper general ecosystem understanding?

6.4.1 State and characteristics of fisheries in the region

In the Baffin Bay/Davis Strait region, fisheries are an integral part of the subsistence activities that hold great social and cultural value to the Indigenous peoples. Fishing, processing, distributing, and consuming local fish link people to their history and their present cultural settings. These activities maintain individual well-being and social relationships and help to define a sense of family and community (Nuttall, 2005; see also Chapter 4). The cultural role of these activities also pertains to people living in towns and people working outside the fishery sector. Additionally, access to local fish is important for food security and health. Due to the mixed character of the region's economy (see Subchapter 3.3), small-scale commercial sales of fish are pursued ad hoc to cover expenses connected with fishing, hunting, and gathering for subsistence and cultural purposes (Delaney et al., 2012; Hendriksen and Jørgensen, 2015).

BBDS fisheries play a significant role in the economies of the region. In Greenland, commercial fisheries produce over half of the total service and goods export value (57% of 4.2 billion Danish kroner in 2011) (Copenhagen Economics, 2013). The shrimp fishery constitutes over 50% of the fishery in terms of volume and value. Commercial fisheries are rapidly expanding in the waters off the Canadian territory of Nunavut, with an increase in total value from 38 million to 86 million Canadian dollars (CAD) during the period 2006–2014 (Standing Senate Committee on Fisheries and Oceans, 2009; CanNor, 2015). In 2012, Greenland halibut was the third most important export good for Nunavut (Lambert-Racine, 2013).

In the BBDS region, very little fishery takes place north of 72°N. The descriptions provided in this subchapter deal primarily with the area from Cape Farewell to 71°N on the Greenland side and with similar latitudes in Canadian waters. The fishing fleets of the BBDS region engage in economically and biologically significant offshore fisheries outside this region (e.g., for Greenland halibut, redfish, and pelagic species off east Greenland and cod, saithe, and haddock in the Barents Sea).

The offshore fisheries of the BBDS region are currently dominated by bottom trawling for Greenland halibut and northern shrimp. Previously, West Greenland cod supported the most important fishery, with annual landings exceeding 400,000 tonnes (t) in the prime years in Greenland, but following collapse of the stock in the 1980s, catches have been negligible in all but a few years. In Greenland, the coastal commercial fisheries are composed of a mosaic of harvesting activities. In the inshore region, Greenland halibut, shrimp, and cod are the most important target species of commercial interest, but the fishery for lumpfish is also important during a brief period in spring. The harvesting cycle of coastal fishers may also include Atlantic halibut, wolffish, Arctic char, salmon, marine mammals, birds, caribou, and muskox. These animals are fished or hunted primarily for subsistence use or local and national marketing. In Nunavut, inshore commercial fisheries are largely limited to Arctic char and, in Cumberland Sound, Greenland halibut.

6.4.1.1 Offshore Greenland halibut (*Reinhardtius hippoglossoides*) fishery

Fishing in Davis Strait began in the mid-1960s by the Union of Soviet Socialist Republics (USSR), German Democratic Republic, Faroe Islands, Norway, and Japan (DFO, 2014a). Since the early 1980s, after the implementation of the Third Convention of the Law of the Sea, Greenland halibut quotas have been shared by Canada and Greenland. Following concerns that the stock had begun to decline in the early 1990s, the first comprehensive assessment of Greenland halibut in Northwest Atlantic Fisheries Organization (NAFO) Division 0B and Subarea 1 was conducted in 1994, leading to the recommendation for a decrease in total allowable catch (TAC) from 25,000 t to 11,000 t (see NAFO areas in Figure 2.8). In 1996, a first exploratory license was granted to Nunavut interests in NAFO Division 0A, and in 2000, the NAFO Scientific Council recommended additional TAC in NAFO Divisions 0A and 1A (offshore) (DFO, 2014a).

Overall, Greenland halibut offshore TAC and landings have gradually increased during the past 20 years and now account for approximately 30,000 t annually. The offshore resource is assessed by NAFO at the request of Canada and of Denmark on behalf of Greenland. The quota is set in accordance with the scientific advice and is divided equally between Canada and Greenland. The fishery in Greenland waters has for the past decades been concentrated in relatively small areas (Figure 6.7) and is conducted almost exclusively by bottom trawl, except for a very small and irregular fishery with longlines. In Canadian waters of the BBDS region, about 25% of the catches are taken by gillnets, which are prohibited in the offshore fishery in Greenland. Stock indicators show a stable or slightly positive trend (Jørgensen, 2014; Jørgensen and Treble, 2014), and the stock is considered to be in good condition and fished at a sustainable level.

6.4.1.2 Inshore Greenland halibut (*Reinhardtius hippoglossoides*) fishery

With the exception of a longline fishery in Cumberland Sound, Nunavut, the inshore Greenland halibut fishery takes place primarily in northwest Greenland, in three main areas: Disko Bay, Uummannaq, and Upernavik (listed south to north, all

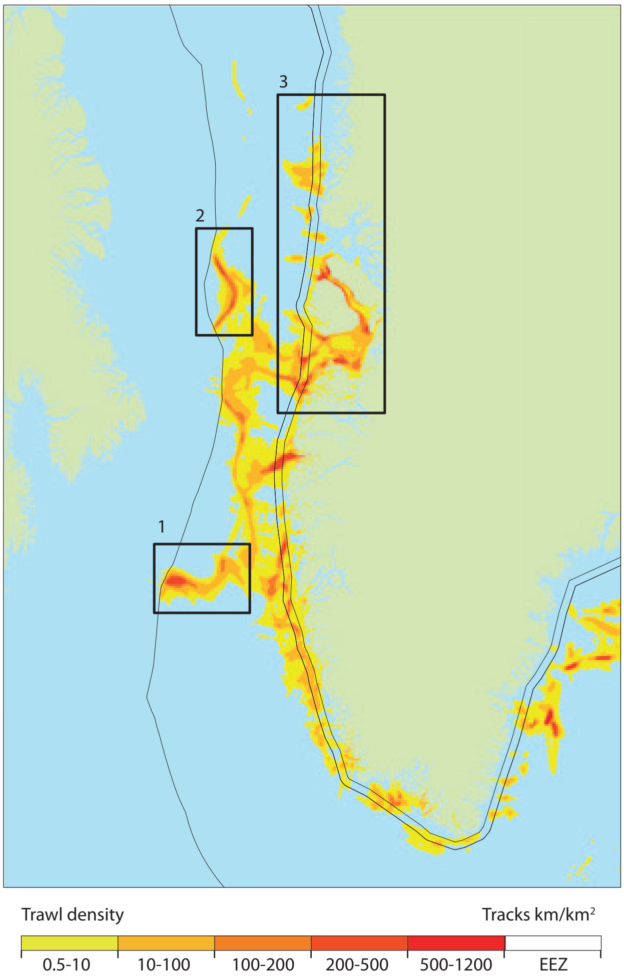

Figure 6.7 Distribution and intensity of the trawl fishery in West Greenland waters, 1999–2013, based on logbook information. Boxes 1 and 2 indicate the traditional Greenland halibut fishing grounds in West Greenland, while box 3 shows the area of inshore Greenland halibut fishery. The remaining fishery in West Greenland is aimed at shrimp. The trawl intensity is graduated from low (yellow) to high (red), with the sailed distance (km/km^2) being summed over all years. The thin lines show the 3–, 12–, and 200–nautical mile zones. (GIS analysis by Karl Brix Zinglersen, GINR. Analogous data were not available for the Nunavut side).

within box 3 on Figure 6.7). The three areas as a whole are considered a sink for offshore-spawned fish that settle in the inshore region, where they remain but do not spawn (Boje, 2002; Simonsen and Gundersen, 2005). There is limited migration between the three areas, and each one is managed separately with individually set quotas. The nature of the system entails that it cannot be overfished in the traditional sense, as new recruits will continue to arrive irrespective of the inshore stock size. Overfishing in these areas is relevant only in terms of growth overfishing. If the stock is persistently overfished (i.e., if growth cannot compensate for mortality), then the average fish size and stock size will decline, which will in turn lead to an increased fishing intensity if quotas remain at the same level. Given the slow growth of Greenland halibut (Treble et al., 2008), a collapsed stock would take considerable time to recover.

Both gillnets and longlines are used in the Greenland inshore fishery, but >75% of the catches are taken by longlines. At present, total annual landings in the area are approximately 20,000 t, with fairly even distribution among the three areas. This pattern has been stable for the last 20 years with little variation. Most notably, the Disko Bay landings peaked in the early 2000s at 12,000 t but have since returned to the previous levels of approximately 8,000 t per year. The 2015 quotas were set at record-high levels in all three areas – 28,000 t in total. However, the quota was not fully exploited in any of these areas and the total landings were 23,000 t, which was slightly above the scientific advice (20,300 t).

Stock indicators for these areas show that recruitment is good from the offshore region (Nygaard, 2014). In the two northernmost areas (Uummannaq and Upernavik), there are no indications that the stock is suffering negative consequences of the fishery, but in the Disko Bay region, the average fish length has declined considerably over the past decade. This observation led to a recent reduction in the scientific advice, from 9,000 t to 8,000 t per year. Based on the available data, the fishery appears to be sustainable although the trend of declining size in the Disko Bay region is of concern.

There is also a minor inshore fishery for Greenland halibut in some of the southwest Greenland fjords. Of these, the fishery in Nuuk Fjord is the most important, with landings of around 1,000 tons in some years.

In Nunavut waters, a winter longline fishery through the ice cover started in 1986 in Cumberland Sound (eastern coast of Baffin Island) with a 500 t quota (DFO, 2014a). The use of gillnets is prohibited in this inshore fishery. Catches peaked at 430 t in 1992 and then strongly declined in the mid-2000s, primarily due to deteriorating ice conditions. In 2005, the Cumberland Sound Turbot Management Area was created and since then, the 500 t quota has been able to be fished year-round. Since 2008, the Cumberland Sound turbot (Greenland halibut) fishery has been treated as commercial. Greenland halibut in Cumberland Sound are thought to be a combination of resident fish, which settle in the inshore and do not migrate back into Davis Strait, alongside migrant fish, which actively move between the inshore and offshore areas (Treble, 2003). Whether spawning takes place in Cumberland Sound is currently unknown. Exploratory fisheries, both through the ice and in the summer open water period are ongoing in many areas of Nunavut; the communities of Grise Fiord (Jones Sound), Arctic Bay (Admiralty Inlet), Qikiqtarjuaq, Pond Inlet, and Clyde River are investigating their inshore turbot resources. A quota of 100 t is reserved for inshore turbot exploration around Nunavut (DFO, 2014a).

6.4.1.3 **Northern shrimp (*Pandalus borealis*) and striped shrimp (*Pandalus montagui*) fishery**

Northern shrimp in NAFO Division 0A and Subarea 1 (Figure 2.8) is a joint Greenland–Canada fishery assessed annually as a single stock by the NAFO Scientific Council. There is no sharing formula for the offshore portion of this stock, and both Canada and Greenland set autonomous quotas for the stock. The inshore fishery takes place along the entire west coast of Greenland from Cape Farewell to 72°N (Figure 6.7) but is currently concentrated north of 66°N at depths between 250 and 350 m (Hemmeken Arboe, 2014). Total annual catches (inshore + offshore) peaked in

2005 and 2006 at 157,000 t but have steadily decreased since then to approximately 90,000 t in 2014, in accordance with declining quotas. The quota for 2015 was set at 73,000 t.

The Canadian portion of this fishery occurs in NAFO Division 0A. Despite previous annual catches of approximately 7,000 t, catches declined to 5 t in 2012 (Hammeken Arboe and Kingsley, 2013; DFO, 2015a), with limited reports of harvesting in the following years. Annual trawl surveys carried out in NAFO Subarea 1 and NAFO Division 0A east of 60°30' W show declining trends for various stock indicators, including biomass, which in 2014 reached its lowest level since 1997 (Burmeister and Kingsley, 2014). There was, however, a biomass increase in 2015, partly due to increased recruitment. Nevertheless, the stock is believed to be fished at a sustainable level (Kingsley, 2014).

There is a separate Canadian fishery occurring in NAFO Division 0B and into Hudson Strait and Ungava Bay to the west. This fishery, which is managed within six subareas, targets both *P. borealis* and *P. montagui*. In 2014, catches of *P. borealis* totaled 8,100 t, with an additional 5,700 t catch of *P. montagui* (DFO, 2015a). The main fishing effort in this area is concentrated to the southeast of Resolution Island.

6.4.1.4 Atlantic cod (*Gadus morhua*) fishery

Four Atlantic cod stocks with distinct spawning areas are present in the BBDS region, and all of them occur in Greenland waters: West Greenland offshore, West Greenland inshore, East Greenland/Iceland offshore, and Iceland inshore. All four stocks use the BBDS region as a nursing area, but they display distinct homing behavior (Storr-Paulsen et al., 2004; Bonanomi et al., 2015).

West Greenland offshore cod fishery

The West Greenland offshore stock suffered a decline following a very large fishery between 1950 and 1980; the stock has not since recovered to any significant level. Cod eggs and larvae drift from East Greenland/Iceland to West Greenland when suitable environmental conditions coincide with a spawning event. This occurrence is unpredictable, but the West Greenland offshore fishery currently relies on this input. When year classes of eastern origin reach maturity at age 4–6, they migrate out of the West Greenland offshore area and back toward East Greenland/Iceland waters. This migration was last observed with the 2003 year class, and a similar event is expected to take place for the 2009 year class, though with a smaller proportion of the biomass leaving the West Greenland area (ICES, 2014a). There are indications that the West Greenland offshore stock is beginning to rebuild, but it is still at a low level (ICES, 2014a). In both fisheries and survey data, it is often difficult to disentangle the proportional contributions from the different stocks.

West Greenland inshore cod fishery

The West Greenland inshore stock size and distribution have fluctuated, often as a response to temperature regime (Hansen and Hermann, 1953; Hovgård and Wieland, 2008); nevertheless, the stock has yielded annual catches of 10,000–20,000 t for more than 80 years. In the early 1990s, catches declined drastically to below 1,000 t but have increased again in the last ten years. In 2014, the catch exceeded 18,000 t – the largest catch since 1991. The 2015 quota is set at 25,000 t. Unlike during colder periods, the fishery is now distributed all along Greenland's west coast, although only small amounts of cod are caught in southwest Greenland and north of Upernavik. The main gear is pound net, but gillnet and jig also contribute and are becoming increasingly important. The majority of the catches is taken by small vessels.

The stock indicators show an increase in stock size over the past decade. However, recent recruitment index values have been declining, and there is a large discrepancy between the scientific advice (12,000 t; ICES, 2014a) and the set quota (25,000 t). Nevertheless, the stock has increased considerably in the last decade and the fishery must have been at a sustainable level during this period. Further, the area sporadically receives larval inflow from the East Greenland/ Iceland region, and these fish grow to a fishable size before homing to their spawning grounds (Therkildsen et al., 2013). This phenomenon can cause elevated catches for a short period without increasing the fishing mortality. These inflow events are unpredictable, and no formal procedure is in place to detect the proportional contribution from the different stock components.

6.4.1.5 Deepwater redfish (*Sebastes mentella*)

Deepwater redfish occur in the BBDS region. Even though they have never been subjected to a commercial fishery, they are regularly caught as bycatch of the Greenland halibut and northern shrimp fisheries. From the main survey index in NAFO Divisions 0A and 0B (Figure 2.8), stock size is estimated to be approximately 150,000 t (DFO, 2014b).

6.4.1.6 Arctic char fishery

Arctic char provide a small but lucrative fishery on the Nunavut side of the BBDS region. Commercial landings in Nunavut were 62 t in 2013, with a landed value of CAD 223,000 (DFO, 2015b). This species is fished with gillnets or weirs during downstream and upstream migrations. This species is also the target of extensive subsistence fishing. The majority of Nunavut's char fishery happens around the area of Cambridge Bay, west of the BBDS region. However, active fisheries also exist along the east coast of Baffin Island, near Pangnirtung and Qikiqtarjuaq. There is increasing interest in expanding the char fishery along the eastern coast of Baffin Island. Multiple attempts have been made to develop commercial fishing near Iqaluit, the capital of Nunavut, but these efforts resulted in decreasing fish sizes and catch per unit effort (CPUE), thus leading to subsequent closures (VanGerwen-Toyne et al., 2013). Current fisheries are believed to be operating at a sustainable level, with little risk of overexploitation predicted for the next 10 years (DFO, 2013, 2015c). However, accurate assessments of population size and structure do not exist for most char stocks in Nunavut.

6.4.1.7 Small-scale subsistence/recreational fisheries

The only small-scale fisheries of commercial and ecological importance are the lucrative spring lumpfish fishery and the snow crab fishery. Other small-scale/recreational fisheries target redfish, Arctic char, Atlantic salmon, wolffish, capelin, whelk, clams, inshore shrimp, and Atlantic halibut. Landings in all of these latter cases are negligible from a fish-mortality (population-scale) point of view but are still significant for individual fishers and local communities.

The lumpfish fishery has increased in importance over the last 15 years, and landings peaked in 2013 with 2,100 t roe. In 2014, landings declined due to a combination of factors (e.g., ice, prices), and in 2015, a newly implemented management plan set quota on this previously unregulated fishery. The fishery has gradually expanded northward, and lumpfish are now caught as far north as Upernavik (73°N). Little is known about the species' biology and stock status, and no scientific advice was available prior to 2014. There is no survey of the population, and all stock indicators developed in 2014 are based on commercial data; they all suggest that the stock is not overexploited. However, the almost exponential increase in landings between 1995 and 2013 raised concerns, and, following the scientific advice, the 2015 quota (1,500 t roe) was significantly reduced from the peak 2013 landings.

The snow crab fishery developed quickly after its inception in 1995 to become a 15,000 t fishery in 2001. The stock was, however, unable to support this level of harvest, and landings have decreased rapidly since then, to levels currently below 2,000 t. The stock shows no sign of rebuilding (GINR, 2015).

6.4.2 Consequences of change for fisheries

6.4.2.1 Effects of environmental change on key target species and other species

Expected environmental changes (see Chapter 3) can have both direct and indirect effects on the marine ecosystem. The direct effect of warming temperatures is a concurrent increase in the metabolic demand of organisms, which in turn leads to increased growth rates if the supply of prey is sufficient to sustain these higher rates (see Subchapter 6.2). This phenomenon has already been observed in juvenile Greenland halibut (Sünksen et al., 2009), and the same is expected for cod (Drinkwater, 2005). The increase in BBDS water temperatures (all else being equal) is expected to result in a parallel increase of the overall productivity of fish stocks and of the potential harvests they can support. Such growth holds great potential for positive economic, social, and cultural impacts in the fishery-dependent region. Precisely how this growth will benefit different groups and communities, though, will eventually depend on how the oft-competing biological, economic, and socio-cultural interests are weighed against each other in the fishery policies of the region. A growth in productivity can mean many things: improved fishing opportunities in the short and long term, increased company profits and tax revenues, increased employment in the fishery sector and related businesses, increased livelihood options in local communities, and so on. How to prioritize or balance the various interests is a political decision (Holm et al., 2015).

Both Atlantic cod and Greenland halibut occur in the BBDS region at or near the northern limit of their distributions. With the expected further warming of the Northwest Atlantic, the

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Arctic Char Fishing in Nunavut, Canada northern boundaries of the stocks may shift northward. In this event, production for those species in the BBDS region would be expected to increase. A temperature increase in BBDS waters is likely to cause a northward expansion of Atlantic cod populations into areas north of Disko Bay. Early signs of this expansion have already been observed (ICES, 2014a), and similar latitudinal responses to warming in fish communities in general are well documented (e.g., Perry et al., 2005).

Predicting the extent of these possible changes in distribution is difficult, as other factors such as commercial fisheries and possible shifts in the ecosystem (e.g., prey and predator dynamics) also exert an influence. Prior to 1990, the Greenland shelf ecosystem was dominated by cod but then, following the cod collapse under a cold period in the late 1980s and early 1990s, shifted to being dominated by shrimp. This rapid shift from groundfish to shrimp in the BBDS region extended along the northeast coast of Newfoundland and Labrador and reached as far south as the Flemish Cap (NAFO 3M, east of the Grand Banks, Newfoundland).

The Flemish Cap provides an extreme example of temperature-driven shifts between Atlantic cod and shrimp. Like several other Atlantic cod stocks, Flemish Cap cod collapsed during the cold period of the early 1990s (NAFO, 2014). Simultaneously, shrimp biomass increased rapidly and supported a fishery until the mid-2000s (Casas, 2013). The onset of the current warm period throughout the Northwest Atlantic in the mid-2000s corresponded to the start of a new regime dominated by cod. The recovery of Flemish Cap cod occurred over a period of 7 years, while the once-flourishing shrimp population collapsed over a period of 4 years and has remained at low levels since then (Casas, 2013; NAFO, 2014). Similarly, the northeast coast of Newfoundland (NAFO 2J3KL) was characterized by high shrimp biomass following the early 1990s collapse of the stock of northern cod (DFO, 2014c). Under the warming conditions since the mid-2000s, shrimp biomass has experienced a rapid decline and has returned to pre-1990s levels (DFO, 2014c). Concurrently, finfish populations, including northern cod, have been increasing since the late 2000s, and even though it is not possible to predict a timeline to recovery at this point, the northeast coast of Newfoundland is expected to eventually revert to a finfish-dominated system (DFO, 2014c).

Given the shifting dynamics observed in these systems adjacent to the BBDS region, the continued warming of BBDS waters is expected to favor the recovery of West Greenland cod to the detriment of shrimp populations. In addition to increasing cod biomass, a northern expansion of cod is another likely outcome, as has been observed in other warm periods (Hovgård and Wieland, 2008) and for other stocks (Perry et al., 2005). Subject to the uncertainties inherent in the climate projections, a temperature increase as described in Subchapter 6.2 could be expected to probably result in an increase of cod biomass and a shift in the northern boundary of cod somewhere in the range of 200–400 km by 2050 (Drinkwater, 2005; Perry et al., 2005)

An increase of temperature may also have indirect effects on the BBDS marine ecosystem. For instance, a prerequisite for species presence and productivity is prey availability, especially during the larval stage for fish species – a period when starvation risk is maximal (Hjort, 1914; Houde, 2008; Robert et al., 2014). The importance of an overlap in time and space between larvae and prey (the match–mismatch hypothesis; Cushing, 1990) becomes increasingly important with increasing latitude, due to an increasingly shorter growth season (Kristiansen et al., 2011). Batch-spawning fish such as cod, which are characterized by a protracted spawning season, will probably benefit from increasing temperatures, since reduced sea ice will result in an earlier spring bloom and a larger window of opportunity for their larvae to find adequate prey. However, for deep-spawning species such as Greenland halibut, larval growth environments will likely not experience the same level of temperature increase and the benefit may be limited. For most fish stocks, the timing of spawning is not expected to change much, so a rapid shift in the timing of peak primary production could result in a mismatch situation that leads to high larval mortality and low recruitment and productivity for a given stock (also reported in Subchapter 6.2). These examples highlight the complexity of predicting the overall effect of climate change and, generally, the net effect of climatic change (i.e., temperature) on metabolic demands, prey availability and quality, predator abundance, and trophic interactions. In addition, potential changes in ocean currents are so complex that our ability to predict the overall impact of environmental changes on fisheries is limited.

Unlike key target fish species, shrimp are expected to respond negatively to increasing water temperatures. As in other areas of the Northwest Atlantic, shrimp stock size in the BBDS region has been declining for the past 10 years and the fishery is moving northward (Kingsley, 2014). The negative effect of increasing temperatures on recruitment has been shown to occur through reduced larval survival (Jónsdóttir et al., 2013). However, the actual agent of change may be a derivative of temperature (e.g., predation) and the effect may not be similar across different areas and seasons. Indirect factors are also important, as predators of adult shrimp (i.e., cod and Greenland halibut) are expected to react positively to a warming environment, which may lead to increased predation on shrimp (Worm and Myers, 2003). The relative importance of the causal agents driving the current shrimp biomass decline (direct or indirect) may be in question (Aschan et al., 2006), but the future level of catches will most likely be lower than what was seen in the early 2000s. Because a stock's response is the integrated effect of multiple interrelated factors on different life stages, the magnitude of the response cannot be predicted. However, based on observed trends in shrimp distribution and biomass, it is likely that shrimp biomass will decline even further and that the stock's potential habitat will be further reduced as water temperatures continue to rise.

Under the conditions of the expected environmental trends, fisheries species composition would change in the BBDS region. This change includes shifts in the relative importance of different species and also the introduction or disappearance of species (Møller et al., 2010; Wisz et al., 2015). Recently, the unpredicted emergence of an East Greenland–based mackerel fishery demonstrated the potential for "new" species to generate highly productive and lucrative fisheries. In the BBDS region, a similar phenomenon has not yet been observed, but the presence of unfished pelagic species (e.g., capelin, sand lance, herring) and the increased occurrence of "warm water" benthic species (e.g., saithe) (Hedeholm, 2016) could suggest future potential for currently unfished species.

The potential harvest of new species has not only economic but also cultural implications. Some of the hunted species that are of great importance to communities as a source of nutrition and in cultural practices, social networks, and health and well-being are at risk, with severely declining populations (e.g., caribou in Nunavut). One response could be to try and shift preferences – and thereby harvesting pressure – to focus on other sources of country food.

6.4.2.2 Effects of socio-economic drivers on sustainable fisheries

The region's commercial fisheries are being increasingly submitted to TAC governance in order to balance economic development with biological sustainability in the most commercially important fisheries (see also Subchapter 3.3). So far, the subsistence fisheries are not subject to TAC governance in either of the two BBDS countries, but these fisheries are in some cases subject to closure seasons (e.g., salmon in Greenland). The yearly TAC policies are therefore not directly affecting regulatory access to subsistence fishing. However, subsistence fishing may of course be affected by the overall management of the stocks, just as access to commercial TAC quota may have an indirect impact on the ability to fund subsistence activities in local communities.

In the TAC governance system, scientific knowledge and institutions play a defining role in formulating the scientific advice, and Inuit traditional knowledge has not yet been meaningfully incorporated. With respect to some species, TAC policy and its supporting scientific knowledge base can be highly contested by industry and harvesters. The final TAC quota is a political decision, which is often reached following a negotiation of competing interests between stock assessment and industry and/or community requirements (Jacobsen and Raakjær, 2012). Regarding the key target species, the scientific advice is currently followed for offshore Greenland halibut and shrimp (using an adaptive management approach) but not for cod (inshore or offshore) or inshore Greenland halibut (all three management areas, Figure 6.7). Regarding the smaller-scale commercial fisheries, the scientific advice is followed in the lumpfish fishery but not the snow crab fishery.

Regional demographics also play a role. Nunavut has Canada's youngest and fastest-growing population, whereas Greenland's population is declining slightly (Chapter 2). Any substantial pressure on fish stocks in the BBDS region is most likely to occur in the context of commercialization and export and not from subsistence fishing. However, urbanization/concentration patterns in the region could increase local competition and translate into increased pressure on coastal TACs in the commercial fishery. Customary use rights for subsistence fishing (e.g., Arctic char) out of larger towns may also be challenged by local population growth. One relevant adaptation measure could be to introduce newcomers to any customary, but unwritten, management principles; another measure could be to include these principles in formal management plans. For issues relevant to the livelihoods and integration of families new to a local area, it may also be appropriate for "old" and "new" users to negotiate the adaptation of existing management principles in order to maintain efficiency and legitimacy.


Ashley Cooper/Alamy Stock Photo

Baiting lines for catching Greenland halibut in Ilulissat, Greenland

The eco-labeling of fisheries is a global trend that is also influencing fisheries in the BBDS region (see Subchapter 3.3). Obtaining Marine Stewardship Council (MSC) certification has been perceived by the fishing industry as a way to gain access to premium international markets. This certification requires scientifically based advice and a management scheme (management plan) that complies with the advice. The continued observance of scientific advice and other conservation measures may thus have a positive impact on stock status and on the fishery-based economy under this new marketing paradigm. However, the stricter observance of scientific advice is contested in many of the coastal fisheries as it may also result in short-term negative socio-economic impacts.

The coastal fisheries in Greenland are managed by licenses to "Olympic" fisheries without area restrictions, meaning that fishers are in internal competition with each other until the overall TAC is fished. This situation typically results in competition between the smaller local vessels and the larger and more mobile vessels from outside the TAC district, which leaves local vessels at a disadvantage. This in turn can increase local communities' pressure on the TAC policy. Furthermore, an Olympic-style race for fish can result in fishers taking

Knud Falk

The harbor of Ilulissat, West Greenland, is crowded with commercial vessels of all types taking their catch to sell to the processing plants for national and global markets

greater risks in order to secure a larger part of the TAC before it is fished up, thereby potentially affecting their health and safety. A move away from Olympic fisheries was initiated in 2012 with a quasi-privatization of fishing rights (through individual transferable quotas, ITQs) and the closure of new access to the Olympic coastal Greenland halibut fishery. ITQ management can theoretically optimize the economic yield of a stock by allowing fishers to plan their fishery and target optimal fish sizes and/or seasons to increase outtake without increasing fishing pressure on the stocks. An ITQ system could also reduce health-related risks to harvesters and secure a more stable supply to subsistence production. ITQs will most likely change the composition of the fleet toward fewer and financially stronger participants. This consolidation may make fishery access financially challenging in the future for most local people. Lack of access could undermine the mixed economy of the region and create local unemployment in rural areas unless the economic barriers for local access are addressed or alternative income opportunities are created (Hendriksen and Jørgensen, 2015).

A structural change in the fleet, caused by the consolidation of fishing quotas and the purchase of larger fishing vessels, may furthermore change geographical fishing patterns. Larger vessels could cover larger areas, thus minimizing effects on local stocks (if present) but possibly increasing pressure on stocks farther away. With their greater mobility, larger vessels could also contribute to increased competition over local TACs in areas with less mobile fisheries (Hendriksen and Jørgensen, 2015).

The land-based processing of fishery products (i.e., the establishment, continuation, or closure of land-based processing facilities) has been contentious since the early development of the Greenland fishery (Gullestrup et al., 1976), and the topic remains contested today. While the offshore fishery has been allowed to process its catches at sea, the regulatory obligation of the coastal fisheries to land 100% of their catches to processing plants is rooted in a policy aiming to create regional employment. This obligation has been contested recently (Fiskerikommissionen, 2009), but so far the Greenland Self-Government has decided to maintain it (Jacobsen and Raakjær, 2014). Local processing facilities (Figure 2.8) have a significant local impact in terms of employment and local development. Similarly, the political decision to allow in "buyer vessels" (vessels that buy the catch from fishers and produce the fish onboard or elsewhere outside the community) is often viewed positively by fishers but negatively from the perspective of local production and employment (Delaney et al., 2012). After a years-long trend of having fish processing move out to sea and abroad, a new trend within the Greenland Self-Government and the government-owned Royal Greenland company is toward debate and investigation regarding the further development of local/domestic land-based production (e.g., Royal Greenland, 2015). These topics are of high socio-economic impact, and they tend to stir much debate. Policy development in this arena is difficult to predict, as it reflects the changing dynamics of stakeholder power (Holm et al., 2015).

In Nunavut, land-based fish processing has seen limited development, with four processing plants across the territory; processing in the BBDS region is concentrated in Pangnirtung

(Figure 2.8). The processing of fishery products is limited to Arctic char and Greenland halibut catches from the inshore fishery. Due to the lack of deep-water ports (Figure 2.8), all offshore fisheries catch must be landed outside of Nunavut, largely in Greenland, thus limiting the current potential for increased processing in Nunavut. This lack of marine infrastructure (see details in Chapter 10) has been cited as the most significant impediment to the development of Nunavut's fishing industry (Fisheries and Oceans Canada (DFO) and the Nunavut Department of Community Development and Transportation, 2005).

Oil/gas and mineral development (exploration and exploitation) is another expected driver of change in fisheries. An oil spill would adversely affect marine resources, through both direct contamination and long-term integrated effects that influence recruitment and trophic interactions (Merkel et al., 2012). The Association of Fishermen and Hunters in Greenland (KNAPK) officially opposes the development of an offshore oil industry because of its potential for damaging the fisheries that still represent 90% of the goods export economy and also because they are concerned about the observed effect of seismic activities on marine mammals.

Oil and gas development and shipping development (see Chapters 7 and 9, respectively) may also affect the market conditions of the fisheries industry. Royal Greenland, a Greenland Self-Government–owned seafood company that exports fish and shellfish to Europe and Asia, brands its products as originating from the "crystal clear waters" of the region. Similarly, Nunavut's Arctic char brand, Truly Wild, markets its fish as coming from "the cleanest and coldest Northern waters." Royal Greenland points to the risk that an oil spill in the region (e.g., from a ship or an oil well) may negatively affect consumers' and buyers' perceptions of their products. Furthermore, the fishing industry identifies a risk of "losing" employees to emerging and more attractive sectors.

The habitat integrity of Arctic char, including connectivity to the sea, may also be negatively affected by the development of hydropower projects in the region (see Subchapter 2.3 and Chapter 7).

6.4.3 Future development of fisheries

Under both climate change scenarios outlined in Subchapter 3.4, BBDS fisheries will most likely be affected through changes relating directly to the fish resources. Even in the short term (2030), expected environmental changes will result in a variety of changes in fish stock distributions and productivity. The first indications have already been observed, as described above. Given the complexity and interrelatedness of environmental drivers and their effects, it is not possible to predict the development of fisheries (for either local or emerging species) over longer time periods. Also, the effects of management initiatives will modulate any ecosystem responses, thus making predictions even more difficult.

Empirical evidence from an already-warming North Atlantic – including the BBDS region – suggests that the region's fishery should be prepared to shift or expand to new fishing grounds farther north and can expect to see shifts in the importance of current key target species, as well as the invasion of boreal species. In this process, the nature of the ecosystem should be kept in mind. Arctic and Subarctic species tend to be slow growing compared to more southern populations (e.g., Drinkwater, 2005), and rapidly developing fisheries could quickly deplete stocks that would then require considerable time to rebuild to a commercially sustainable level. This effect has been observed in snow crab, redfish, Greenland halibut in some southwestern Greenland fjords, and Atlantic cod to some extent. For this reason, a precautionary management approach to fisheries would ensure higher long-term yields by reducing the risk of exploited stock collapse.

In relation to emerging fisheries, the offshore fishing industry has stated that their decision of whether to start fishing a new species is primarily market driven. If a new species is economically viable, a fishery will rapidly develop, as was seen in the case of East Greenland mackerel. The same principle applies for declining species, such as northern shrimp. Even though shrimp stocks and landings have been declining for several years, the industry is still able to generate adequate profit due to higher market prices. For communities, the decision to harvest new species is also rooted in culture, and shifts in available fish resources would probably have significant impacts (e.g., on food security, resilience, and so on).

Emerging fisheries require the development of technology and the training of employees. Royal Greenland, which owns many of the land-based fish factories, is expecting that changes in species distributions will pose adaptation challenges to existing factory equipment. Changes in the distribution of resources and fishery structure also imply risk for the local population. While new factories may open in some communities, existing factories can also close down in others.

Changes in sea ice cover and reliability have already altered conditions for the fishing and hunting activities that take place on the ice or at the ice edge. During the Adaptation Actions for a Changing Arctic (AACA) stakeholder consultations (see Chapter 1), representatives from KNAPK and WWF (formerly World Wildlife Fund), planners from Qaasuitsup Municipality, and locals from Qaanaaq all highlighted changes in the sea ice as a major challenge to ice-edge fishing and hunting. The ice has become very unreliable, and this complicates ice-edge travels (AACA stakeholder consultation). The community of Qaanaaq, for example, has experienced increased difficulty in hunting from the edge of the sea ice and today residents must often use motorboats. In addition, they can no longer hunt polar bears from the sea ice but must instead travel across Inglefield Land (AACA stakeholder consultation).

In a worst-case scenario, the northernmost BBDS fisheries that rely on permanent ice will likely disappear as early as 2030 (e.g., in the Disko Bay area); farther north, winter ice will continue to support both commercial and subsistence-based fisheries (e.g., in the Qaanaaq area). In Pangnirtung (Nunavut), unpredictable ice conditions have already affected the inshore Greenland halibut fishery that operates primarily in the winter through the ice (DFO, 2014a). The cultural and social effects of sea ice changes are a major concern for Inuit in the region, and this topic connects fisheries impacts with questions of food security, safety, culture, well-being, identity, knowledge, and education (AACA stakeholder consultation; see Chapter 1 and also Krupnik et al., 2010). For this reason, adaptation options for small-scale fisheries cannot be too sector-specific in focus but should recognize that small-scale fisheries in the region currently serve a variety of needs within the Inuit population.

As also mentioned by various stakeholders, diminishing ice cover could result in greater open water access and longer open water fishing seasons. The industry may be able to pursue new opportunities in new fishing areas. On the other hand, changes in ice and weather could also mean prolonged seasonal transition periods in areas where even open water fishing has generally become more difficult. As Royal Greenland noted (AACA consultation), an increased frequency of storms and precipitation is expected to increase the risks inherent to fishing in the area. Furthermore, the infrastructure of the fishing sector (e.g., factories) could also experience additional pressures.

6.4.4 Adaptation options and knowledge gaps

6.4.4.1 Adaptation options

To secure food security and to meet cultural needs for fishing and hunting activities in the region, local communities could work toward shifts of preferences, and thereby shifts of harvesting pressure, to focus on new sources of country food where existing ones are declining.

To ensure that the BBDS region's fisheries are conducted sustainably, the management system must be set up to accommodate changes. To this end, management plans developed in collaboration among communities, industry, scientific advisers, and local, regional, or national governance institutions should be in place. This approach will ensure transparency for the fisheries and will avoid "day-to-day" decisions on how to manage a given fishery. In addition to setting quotas on targeted species, such management plans could include multispecies considerations. For instance, capelin is considered a key mediator of energy flow (Hedeholm, 2010), and it constitutes a major prey resource for a multitude of species, including Atlantic cod and Greenland halibut (Carscadden and Vilhjálmsson, 2001). Therefore, capelin's important role in the food web should be considered prior to any implementation of a new commercial capelin fishery. This consideration would also respond to KNAPK's identification of the need for more research on different populations of capelin in order to establish whether there is competition between an offshore fishery on capelin and a coastal fishery on species that feed on the incoming capelin.

Multispecies considerations are already implemented in other North Atlantic regions, such as the Barents Sea (ICES, 2014b), and such considerations are potentially of great value to the fisheries. In some years, targeted species will be in good condition due to high prey availability, and if such events can be predicted in advance, the outtake from the stock can be larger than if the scientific advice were based simply on average values. This approach would require knowledge of the dynamics of several trophic levels – i.e., knowledge not limited to just the targeted species.

In order to prepare for potential new fisheries, guidelines on how to proceed would be helpful. In Canada, such guidelines already exist (DFO, 2008, 2010) and could serve as a starting point, though such guidelines would need to be specific to each individual case. In this context, it would also be useful to consider a joint strategy for the Arctic Ocean, given its overall increasing accessibility with diminishing ice cover, which in turn results in increasing potential for new fisheries opportunities (Wisz et al., 2015). Such a strategy should ideally be multilateral, but at a minimum, Greenland and Canada should agree on the management of joint stocks. Efficient bilateral agreements between Canada and Greenland would need to consider the different management systems of the two countries, including different traditions of stakeholder participation.

In the context of adaptation to environmental change and the management of fishing pressure, the organizations representing industry and fishers and hunters in Greenland emphasize their members' needs for flexibility. KNAPK recommends multispecies licenses that enable fishers and companies to invest in new types of gear and target seasonal species – including new pelagic ones. According to KNAPK, this type of license would facilitate the implementation of new fisheries and could also play a key role in achieving a more sustainable conservation policy (e.g., TAC), as fishers would be able to shift to other species instead of depending exclusively on, and exercising pressure on, just a single species (AACA stakeholder consultation, 2 June 2013; interview with KNAPK, 19 May 2015). The current license administration system, however, constitutes a bottleneck for implementing multispecies licenses (AACA stakeholder consultation, 5 February 2016). This situation indicates that flexibility-enhancing adaptation measures should focus on barriers in the governance system too. The Greenland Business Association, which represents the offshore fishery, reported that it is currently possible for their members to conduct a flexible fishery and that the decision of whether or not to invest in such a flexible fishery is determined by questions of profitability.

Another significant adaptation option identified by stakeholders concerns the choice of how to organize the production. The possibility and profitability of more local/national processing is a major topic of discussion in Greenland, where most fish are currently being exported as whole frozen fish. The option of reopening closed factories is being raised by municipal stakeholders in South Greenland municipalities, together with the option of developing new products. Nunavut communities have expressed interest in expanding processing capabilities through the development of new processing facilities and in increasing wharf infrastructure to allow for the landing of offshore catches within the territory. The processing of fish products will need new investments, especially if new products are to be developed based on new species. However, because emerging fisheries are unpredictable, stakeholders do recognize that the associated investment opportunities are relatively risky. Furthermore, stakeholders emphasize that local initiatives to exploit new fishery resources should be carefully planned and coordinated. A relevant adaptation option for Nunavut could be to explore whether lessons learned in Greenland might inform decision-making in Nunavut as the territory seeks to expand its processing capabilities. Greenland may also find inspiration in any "new" models that Nunavut has to offer.

The expansion of livelihood opportunities is also relevant to discussions of adaptation to change. This major theme was brought to the table by stakeholders during AACA consultations: how to develop other industries and professions, and how to prioritize among them. It must be noted that the question of how to diversify the Greenland economy is an ongoing discussion in Greenland, but now with the prospect of climatically derived changes, the subject receives renewed attention from the region's stakeholders. Furthermore, efforts to diversify livelihoods could be downscaled to local levels, as small communities are often hugely dependent on one local buyer or factory.

The expansion of local livelihood opportunities also includes the development of new seafood products. Various stakeholders in Greenland (AACA consultation, 2–5 February 2016) suggested "research and development," "pilot centers," and "food research environments" as interesting adaptation options that could promote new businesses. If the offshore industry partners with the Greenland society and smaller-scale actors, these initiatives could serve the society's economy at multiple scales. Certain bottlenecks exist today for the sale of seafood products produced at the small-scale level, the most significant of which may be the current food production regulations. Adapting the Danish legislation to suit the region's context may be a concrete and relevant adaptation option to start with.

In general, the "catalog" of other potential industrial/business developments in the region is very broad, including tourism, energy, mineral extraction, scientific research, socio-cultural events, biotechnologies, and macroalgae production (see, for example, Aalborg University, 2014). A discussion of all of these potential developments is beyond the scope of this chapter, but Subchapter 6.2 supports the notion of new potential in the marine environment, noting that macroalgal growth rates are increasing and that these algae will probably expand northward. Macroalgae can be directly consumed, and they can also be used as bioenergy fuel and as a source of extracts for industrial products (e.g., food and cosmetics) (Wegeberg and Feldby, 2010). Tourism in combination with fishing and hunting as a cultural activity could be included in discussions of possible options (Chapter 8), as could the development of extractive industries (Chapter 7).

In discussions of alternative livelihood options and economic diversification, debate and a clarification of societal goals for the fishery could be helpful in assessing the extent to which planning efforts in the fishery sector could and should expect the development of economic alternatives to replace or supplement fishing. For example, if fishing and hunting on smaller scales is to continue to contribute to local employment, cash income, and food security in the future, it may be necessary to address the current trend toward the consolidation and privatization of fish quota, as promoted by the ITQ system. If, on the other hand, fisheries consolidation continues because it is deemed to contribute more to the national economy than does the unconsolidated fishery, then long-term alternatives to fishing and hunting for income and food security will, in time, need to be made available to the region's citizens and local communities.

6.4.4.2 Knowledge gaps

With the goal of optimizing the scientific advice procedure, several knowledge gaps can be identified for the key target species as seen from a biological perspective. For northern shrimp, the drivers influencing stock dynamics are not fully understood. This situation indicates a lack of ecological understanding of the system, and future research should focus on predation, in particular, as a determinant of recruitment success. Such studies would require a multidisciplinary approach, including research into both primary production and other key species such as Atlantic cod and Greenland halibut. For Greenland halibut, the main knowledge gaps concern insufficient data on feeding preferences, growth patterns, drivers of recruitment success, and links between inshore and offshore areas. Also, the abundance of fish in unsurveyed and mostly unfished areas could be better described. The mixed-stock nature of cod fisheries is problematic from an advisory perspective. In addition to making it difficult to know the origin of a given cod, this characteristic also makes it difficult to know which stocks are being targeted by the fishery. Developing a simple approach for stock delineation would be helpful. Elsewhere, otoliths and morphometrics are being used for that purpose (Stransky et al., 2008).

For all fish species, prey availability and prey quality are paramount to recruitment success and stock productivity. Primary production in the BBDS region is to a large extent made available to predatory fishes by key forage fishes (e.g., capelin, sand lance, Arctic cod), which play a vital role in so-called wasp-waist ecosystems (Cury et al., 2000). Forage fish prey on lower trophic levels (zooplankton), thereby converting the biomass of secondary producers to fish biomass, which is in turn predated upon by commercial predatory fishes and other higher trophic levels. Forage fish have been given little attention in the BBDS region, but because they contribute greatly to driving predator dynamics, this area of research should be given high priority. Forage fish research should include not only basic parameters such as stock size but also investigation into how environmental effects might indirectly affect higher trophic levels through shifts in trophic interactions and cascading effects (Frank et al., 2005).

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6.5 Hunting

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Key messages

- ***Hunting is important throughout the Baffin Bay/Davis Strait (BBDS) region, although traditions, dependence on, and access to living resources vary greatly within the region.*** *Harvest relates to many aspects of BBDS hunting traditions – traditional diet and food security; the use of down or skins products; cultural, physical, and spiritual well-being; and contributions to a mixed economy.*
- ***Key hunting resources are marine mammals, seabirds, and caribou.*** *However, hunting levels have declined for several species of seabirds and marine mammals due to management regulations, urbanization, and occupational changes. Residents in some larger communities increasingly rely on nontraditional wage economy employment and recreational activities other than hunting.*
- ***Climate warming has already affected hunters' access to species associated with sea ice.*** *Examples include hooded seal, harp seal, ringed seal, polar bear, and narwhal. Changes in access are expected to continue into the future.*
- ***For some hunted species, accessibility is expected to decrease due to changes in distribution (e.g., beluga) or abundance (e.g., thick-billed murre) or due to limitations in hunters' ability to travel (e.g., due to thinner ice or more frequent storms).***
- ***For open water–dependent species (e.g., orcas), hunter access may increase due to a wider distribution of the animals, longer ice-free periods, and faster motorboats.***
- ***For some species, less hunting is expected in the future due to a combination of less demand, current or future population declines, and more regulation due to international resource management.*** *Examples include thick-billed murre, polar bear, beluga, and narwhal.*
- ***New hunting/harvest opportunities are expected to emerge for certain goose species, common eider, northern gannet, some whale species, and, in some areas, caribou.***
- ***Despite an overall regional decline, hunting is expected to remain important for the foreseeable future, especially in smaller and more isolated communities.*** *However, for the traditional Inuit hunter, local adaptive responses may conflict with non-Inuit attitudes about wildlife conservation, sustainability, and environmental management.*
- ***The effects of climate change may be obscured by the fact that a number of marine mammal stocks are still recovering from depletion due to previous unsustainable harvests.*** *The history of harvest within the BBDS region includes centuries of commercial whaling and hunting by foreign actors.*
- ***The potentially intensive future development of extractive industries in the region would increase the risk of cumulative impacts on hunted species.*** *Currently, there is concern for cumulative impacts on some species (e.g., polar bear, narwhal, and thick-billed murre), related to hunting, climate change, oil pollution, seismic activity, and contaminants.*
- ***In terms of social impacts of change, the people and communities that rely heavily on traditional resource uses would be the most sensitive.*** *Some coping mechanisms cost money. Thus, the capacity to adapt to climate change is negatively affected by poverty.*

Guiding questions

From a human use perspective, what are currently the key living resources in the Baffin Bay/Davis Strait region, how are they important, and how is accessibility to these resources expected to change in the future?

How will the expected changes in occurrence and accessibility of living resources interact with socio-economic developments in the region?

How can we adapt to the expected changes in the region if we want to continue benefiting from the use of the living resources but at the same time ensure sustainable wildlife populations?

6.5.1 State and characteristics of hunting in the BBDS region

Hunting is the activity of pursuing birds and mammals for food, limited local commercial sale, or recreation. Subsistence hunters depend on the products of the hunt to supplement their food supply; local commercial hunting has the sale of products as its main goal; and recreational hunting is conducted mainly for sport. However, the lines separating these categories are difficult to draw. Recreational hunting contributes to the informal household economy, and in Greenland, both subsistence and recreational hunters can sell some of the products of their hunt (see Subchapter 3.3). In Greenland, there are three types of hunting permits – for full-time hunters (those who make a living from hunting and fishing; i.e., >50% of their income), recreational hunters, and outfitters. Outfitters are permitted to guide trophy hunters for caribou (*Rangifer tarandus*), muskoxen (*Ovibos moschatus*), birds, smaller terrestrial mammals, and seals.

The Greenland full-time hunters are similar to subsistence hunters in Nunavut, as the basic needs of both groups depend on the harvest or the income generated by the harvest. However, hunting rights differ between Nunavut and Greenland. In Nunavut, Inuit hunting rights stem from traditional use and land claim rights, and these rights differ from those of other residents and non-residents. In Greenland, there are no land claim rights because all land is government property and there is no distinction between Inuit and other residents (distinctions are made for non-resident foreigners). However, in some cases, certain quotas are earmarked for certain hunters or certain hunting methods.

As used here, the term *harvest* covers all types of use of living resources – i.e., hunting, egg collection, down collection, fishing, and berry picking. In this chapter, hunting is the main focus.

6.5.1.1 General importance of harvest

The harvest of wildlife is culturally important throughout the BBDS region because it forms the basis of the traditional food system that is still common in contemporary diets. For many Indigenous peoples, the traditional diet is not only a vital source of nourishment, closely tied to food security, but also a fundamental aspect of their emotional, spiritual, and cultural well-being (see Section 4.3.2 for a more detailed description of the Inuit food system and food security in the BBDS region). To varying degrees, this is also the case for many non-Indigenous residents of the BBDS region. Harvesting contributes directly to hunter income through the sale of food items (e.g., meat, whole birds) and byproducts (e.g., polar bear hides, seal skins, and walrus and narwhal ivory). Hunting also contributes indirectly to income, through barter and the savings associated with being partially self-sufficient. Full-time hunters in West Greenland are allowed to sell byproducts as well as meat at local markets or to the government-owned shop, which distributes food products to other parts of Greenland. This arrangement contributes to a mixed economy (see Subchapter 3.3), which is especially important for smaller, isolated communities where there are few occupational alternatives. In addition, because hunting is an outdoor activity requiring physical effort, many people, particularly recreational hunters, see hunting as a way to uphold aspects of a traditional lifestyle and maintain a healthy lifestyle with reduced stress.

Traditional food sources include terrestrial and marine mammals, birds, and fish. Among these, the marine mammals are of greatest significance foodwise, materially, and, to a degree, also socio-culturally. Data collected by the Nunavut Wildlife Management Board for the period 1996–97 to 2000–01 show that all sources of wild foods (including fish) conservatively contributed an average annual mass of 1,525,568 kg (320 g per person daily) to the food system of the ten communities of Qikiqtaaluk Region (Priest and Usher, 2004). Directly comparable figures are not available from West Greenland. However, recent studies show that intake from local traditional food there corresponds to 12–15% of total energy intake in the south (Narsaq and Nuuk) and up to 26% in the north (Uummannaq, Qaanaaq) (Deutch et al., 2007; Hansen et al., 2008). Similarly, the amount of meat obtained from local marine mammals was smallest in the south (approximately 20 g per person per day in Narsaq and Nuuk) and highest in the north (approximately 100 g per day in the Qaanaaq area). The intake of local fish and caribou was highest in the south (Hansen et al., 2008). An older study carried out in the Uummannaq district showed that traditional food then (1976) constituted 41% of the total energy intake (59% by weight) (Deutch et al., 2007).

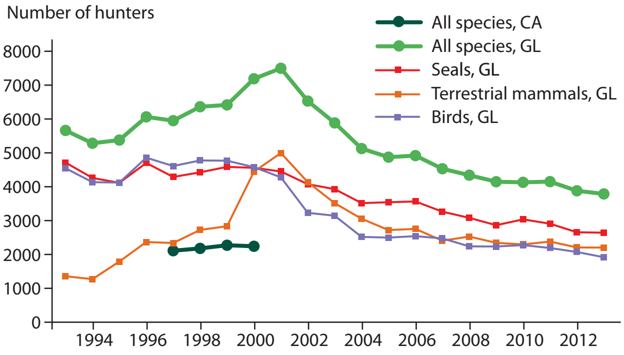


Figure 6.8 Numbers of hunters reporting harvest of at least one species within a species group in West Greenland (GL) and the Canadian (CA) Baffin area (Arctic Bay, Clyde River, Grise Fiord, Iqaluit, Kimmirut, Pangnirtung, Pond Inlet, Qikiqtarjuaq, Resolute Bay, and Cape Dorset). The distinct peak in the harvest of terrestrial mammals in West Greenland in the early 2000s reflects a spike in caribou hunting. (Canada data from Priest and Usher, 2004; Greenland data from Piniarneq, 2014.)

A tight link between hunters and the marine environment continues to exist throughout the BBDS region, but regional differences grew more pronounced over the second half of the 20th century (for a more detailed account, see Subchapter 4.3). The importance of locally harvested food, especially from the marine environment, as a food source and as the basis for a mixed economy, remains high in communities in Nunavut and northwest Greenland; in other parts of West Greenland, fisheries have grown more important as a source of fundamental monetary income (see Subchapter 6.4). At the same time, there has been a tendency for small communities in West Greenland to become even smaller due to urbanization, especially within the last 15 years (see Section 3.3.2); this trend coincides with a gradual decrease in the number of hunters in West Greenland (Figure 6.8), both commercial and recreational (disregarding a caribou-related spike in the early 2000s). One plausible explanation for this development might be that hunters who move to the larger towns (e.g., Nuuk or Ilulissat) engage to a greater extent in nontraditional, wage-economy employment and in recreational activities other than hunting. Furthermore, educational levels are increasing in the urban areas (see Section 3.3.4 and Chapter 5), making it possible for members of the younger generation to choose a nontraditional lifestyle. The costs associated with harvesting, as well as external factors beyond the control of BBDS hunters, may also be important (e.g., collapse of the European sealskin market, increased fuel costs for longer travels, increasing costs for safety equipment) (Wenzel et al., 2016). Due to these factors, plus stricter management regulations for several species, overall hunting levels in the BBDS region have declined considerably for several species of seabirds and marine mammals, at least on the Greenland side (Table 6.2). However, despite this overall decline, it should be emphasized

Table 6.2 Annual mean numbers of marine birds and mammals reported harvested on the Canada (CA) and Greenland (GL) sides of the BBDS region. The CA data represent the ten Qikiqtaaluk Region communities (Priest and Usher, 2004); the GL data represent all of West Greenland (Piniarneq, 2014).

	Canada		Greenland	
	1996/97– 2000/01	2004–2014	1993–2003	2004–2014
Marine birds				
Thick-billed murre	289		184,640	70,977
Thick-billed murre, eggs	2,601			
Common eider	2,506		61,014	25,438
Black-legged kittiwake			42,084	7,685
Little auk			49,568	20,624
Little auk, eggs			2	1,641
Black guillemot	25		21,191	12,795
Larger gulls, eggs				3,877
Marine mammals				
Polar bear	120	134	112	93
Beluga	127		547	201
Narwhal	222		642	311
Bowhead whale				1[a]
Fin whale			12	10
Minke whale			148	168
Humpback				8[b]
Harbor porpoise			1,849	2,566
Pilot whale			96	283
White-beaked dolphin				103
Orca			4	15
Ringed seal	18,765		68,071	61,303
Harp seal	436		72,751	76,874
Hooded seal	56		4,766	2,313
Bearded seal	328		1,817	1,110
Harbor, common seal	5		225	121
Walrus	98		317	130

[a] Covers only the period 2008–2014.
[b] Covers only the period 2010–2014.

that recreational hunting is still an important activity for hunters residing in urban centers; for the remaining hunters in nonurban areas, the importance of subsistence hunting is largely unchanged. On the Nunavut side of the region, the data are insufficient to show whether there has been a similar decline in the number of hunters (Figure 6.8). Urbanization, at least, seems to be less pronounced on the Nunavut side of the region, due to a higher birth rate (and lower emigration rate) compared to West Greenland (see Section 3.3.2).

In the BBDS region, the dependence on terrestrial wildlife has been and still is less profound than the dependence on marine wildlife. The hunting of caribou, however, remains important throughout the region (Table 6.3), even though caribou populations have fluctuated widely through the ages and, consequently, so has hunting availability (see Subchapter 6.3 and below). In Greenland, muskoxen have become increasingly important for food security.

6.5.1.2 Key species harvested from marine environments

The Canadian Eastern Arctic and West Greenland share several stocks of marine mammals, including polar bears (*Ursus maritimus*), walruses (*Odobenus rosmarus*), seals, bowhead whales (*Balaena mysticetus*), narwhals (*Monodon monoceros*), and belugas (*Delphinpterus leucas*, also known as white whales). The migrations of these species follow the formation and melting of sea ice, generally moving from west to east and north to south as the sea surface freezes in winter and from

Table 6.3 Annual mean numbers of terrestrial birds and mammals reported harvested on the Canada (CA) and Greenland (GL) side of the BBDS region. The CA data represent the ten Qikiqtaaluk Region communities (Priest and Usher, 2004); the GL data represent all of West Greenland (Piniarneq, 2014).

	Canada		Greenland	
	1996/97–2000/01	2004–2014	1993–2003	2004–2014
Terrestrial birds				
Snow goose	4,233			
Snow goose, eggs	2,373			
Canada/cackling goose	754			295
Barnacle goose				55
Goose spp.			913	55
Duck eggs	7,702			
Ptarmigan	11,141		34,081	17,664
Terrestrial mammals				
Caribou	6,620		6,620	13,587
Muskox	28[a]		712	2,269
Arctic fox	274		2,254	2,007
Red fox	45			
Arctic hare	570		3,346	2,408
Gray wolf	63			

[a] Covers the period 1991–2011.

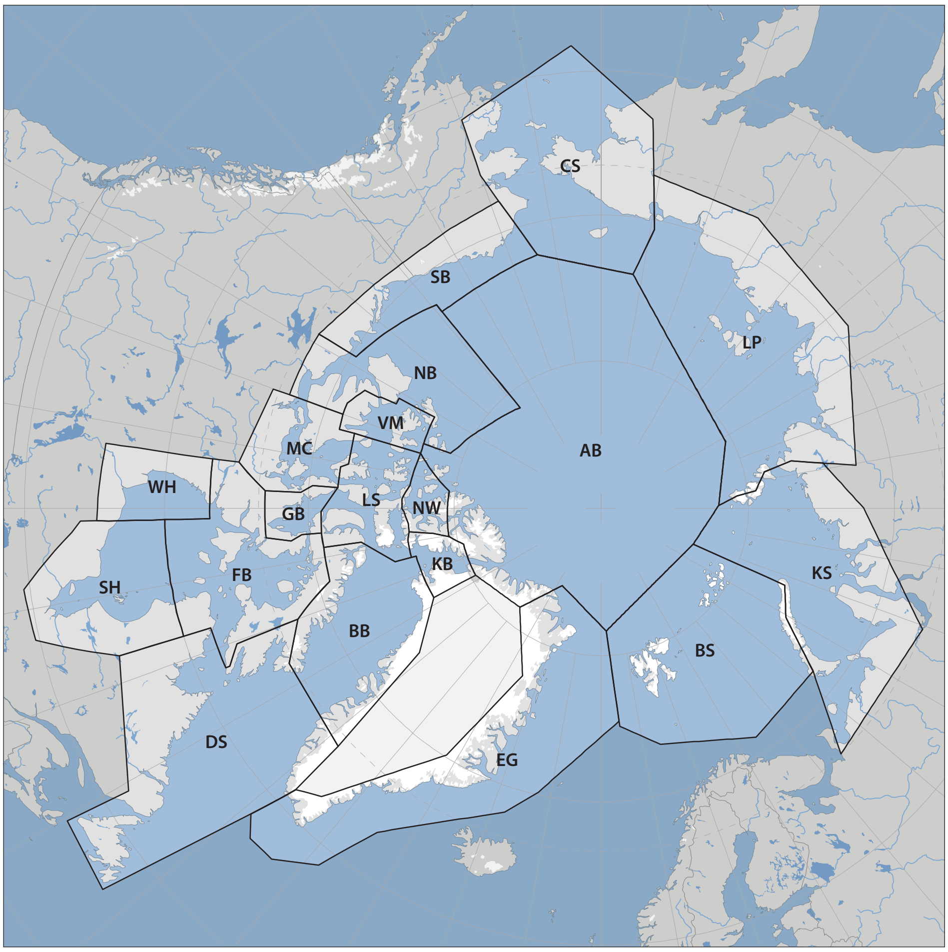
east to west and south to north as the sea ice melts in the spring and early summer (Heide-Jørgensen et al., 2012a; Laidre et al., 2012; Wiig et al., 2014; Nielsen et al., 2015).

Polar bears

The polar bear is the most iconic species in the Arctic, used as a poster child for conservation groups, hunters, and governments alike, often with conflicting messages and interests. For inhabitants of the BBDS region, polar bears have cultural importance, as seen in the banners of the governments of Greenland, Nunavut, and a number of municipalities. There are six subpopulations of polar bears in the BBDS region, three of which are shared between Greenland and Canada (Figure 6.9). The shared populations are in Davis Strait, Baffin Bay, and Kane Basin. Populations specific to Canada inhabit Lancaster Sound, the Gulf of Boothia, and Foxe Basin.

For subsistence hunters, polar bears provide meat, skin, and extra income. However, until recently it had not been possible to document the sustainability of the combined harvest in Greenland and in Canada in Baffin Bay and Kane Basin (Figure 6.9) (Born and Ugarte, 2007). Therefore, negative CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) non-detriment findings (NDFs) prevent hunters from Greenland and Canada from exporting hides, claws, or other products originating from the Baffin Bay and Kane Basin subpopulations, thus limiting the economic value of harvesting the bears. Export bans for products derived from polar bears were implemented in 2007 for all polar bear subpopulations in Greenland and in 2010 for the subpopulations of Baffin Bay and Kane Basin in Canada (Hunt, 2010). In Canada, the export ban prevents local hunters from earning money from the trophy hunting of polar bears from these two subpopulations. However, trophy hunting of polar bears from other subpopulations is an important source of income in Canadian communities within the BBDS region. Trophy hunting of polar bears is not allowed in Greenland. The Scientific Working Group to the Canada-Greenland Joint commission on Polar Bear (SWG) delivered an updated harvest advice for Baffin Bay and Kane Basin in summer 2017 (Regehr et al., 2017). The new advice is based on updated population estimates that are higher than the previous estimates and takes into account the potential effects of climate change. The advice triggered negotiations about harvest levels between Canada/Nunavut and Greenland, which may in turn result in updated CITES non-detriment findings. Hunters as well as the Government of Nunavut have indicated their intention to lobby the Canadian government for a positive CITES-NDF.

The International Union for Conservation of Nature (IUCN) Polar Bear Specialist Group (PBSG, 2017b) has listed the subpopulations of Davis Strait, Foxe Basin, Lancaster Sound, and Gulf of Boothia (Figure 6.9) as stable, although the statuses of the Lancaster Sound and Gulf of Boothia populations are uncertain due to the long period of time since the last surveys (conducted in 1997 and 2000, respectively). The Kane Basin population increased between 1997 and 2013, probably due to a combination of ecological changes and reduced harvest (SWG, 2016). Trends of the Baffin Bay population are unknown, but compared to the 1990s, the population shows several signs of stress due to climate change, including a reduction of the



AB	Arctic Basin
BB	Baffin Bay
BS	Barents Sea
CS	Chukchi Sea
DS	Davis Strait
EG	East Greenland
FB	Foxe Basin
GB	Gulf of Boothia
KB	Kane Basin
KS	Kara Sea
LS	Lancaster Sound
LP	Laptev Sea
MC	M'Clintock Channel
NB	Northern Beaufort
NW	Norwegian Bay
SB	Southern Beaufort
SH	Southern Hudson Bay
VM	Viscount Melville
WH	Western Hudson Bay

Figure 6.9 Geographic delineation of polar bear populations in Canada and Greenland. Within the BBDS region: FB = Foxe Basin, GB = Gulf of Boothia, LS = Lancaster Sound, KB = Kane Basin, BB = Baffin Bay & DS = Davis Strait. (Figure reproduced from PBSG, 2017a.)

animals' range; a shift northward; increased isolation from neighboring populations; total disappearance of sea ice habitat during summer; an increase from 60 to 90 days on average of the open water season, when the polar bears wait on land with limited access to food; increased frequency of swims longer than 100 km when the ice melts during summer; shorter maternity denning periods for reproductive females; increased elevation of maternity dens; worse physical condition; and reduced reproductive rates (SWG, 2016).

Population sizes have been estimated at 2,158 (95% confidence interval, CI: 1,833–2,542) for the Davis Strait population in 2007 (Peacock et al., 2013); 2,585 (95% CI: 2,096–3,189) in Foxe Basin in 2010 (Stapleton et al., 2015); 2,541 (95% CI: 1,759–3,323) in Lancaster Sound in 1997; 1,592 (95% CI: 870–2314) in the year 2000 in the Gulf of Boothia (Taylor et al., 2009); 357 (95% CI: 221–493) in Kane Basin in 2014, and 2,826 (95% CI: 2,059–3,593) in Baffin Bay in 2015 (SWG, 2016). Local Inuit knowledge indicates that polar bears remain abundant in the whole area, and populations are stable or increasing.

The combined Canada and Greenland historical (5-year mean) annual take for the period 2010–2014 (including the harvest, illegal hunting, and killing of problem bears) was 5 bears for Kane Basin, 143 for Baffin Bay, and 109 for Davis Strait (PBSG, 2017b). Harvests in Kane Basin are mainly from Greenland; in Davis Strait, mainly from Canada; and in Baffin Bay, from both jurisdictions. Mean annual harvests for the same period from the Lancaster Sound, Gulf of Boothia, and Foxe Basin subpopulations were 87, 60, and 106 individuals, respectively. Statistics for the three Canadian subpopulations include harvest in areas of Nunavut outside the BBDS region. See also Table 6.2 for mean annual harvest for the Qikiqtaaluk region of Nunavut and for all of West Greenland.

Cetaceans

Two species of small cetaceans, beluga whales and narwhals, are especially important for communities on both sides of the BBDS region. For eastern Nunavut communities, 1996–2001 data from the Nunavut Wildlife Harvest Study (Priest and Usher, 2004) indicate that the mean annual narwhal harvest was 222 and the beluga whale harvest was 127 (Table 6.2). In West Greenland, annual catches in the 1990s were up to approximately 800 narwhals and 700 belugas per year. This level of harvest was considered unsustainable by the Canada/Greenland Joint Commission on the Conservation and Management of Narwhal and Beluga, and a quota system was implemented in 2004, reducing the mean annual catches substantially (Table 6.2). The catch of belugas actually decreased prior to the introduction of quotas, probably because this species is associated with the edge of the pack ice and decreasing ice cover shifts the ice edge and the whales offshore. This phenomenon has been observed in Greenland: with increased distance from central West Greenland settlements to the eastern edge of the pack ice, there is a reduced number of whale catches (Heide-Jørgensen et al., 2010b). Quotas for West Greenland in the period 2015–2018 are 424 narwhals and 320 belugas per year (Government of Greenland, 2015). It should be noted that an aggregation of belugas that previously wintered in the area around Nuuk was extirpated by the 1920s due to excessive hunting (Heide-Jørgensen, 1994).

Recently, after a nearly 75-year ban on bowhead whale hunting, the harvest of 2 bowhead whales per year was permitted in the Qikiqtaaluk region of Nunavut. Hunters from West Greenland can take 2 bowhead whales, 164 minke whales (*Balaenoptera acutorostrata*), 19 fin whales (*B. physalus*), and 10 humpback whales (*Megaptera novaengliae*) per year. These quotas have been used only partly (Table 6.2). In addition, there is an increasing catch of small cetaceans in West Greenland, with harbor porpoise (*Phocoena phocoena*), pilot whale (*Globicephala melas*), white-beaked dolphin (*Lagenorhynchus albirostris*), and orca (*Orcinus orca*) being the most important species (Table 6.2).

Seals and walruses

Among seal species, the ringed seal is harvested throughout the year and provides the greatest share by weight to the food system in Nunavut's Qikiqtaaluk region (Table 6.2). On the Greenland side, the harvest of ringed seals (*Pusa/Phoca hispida*) is even higher, outnumbered only by harp seals (*Pagophilus groenlandicus*), which migrate into Davis Strait and Baffin Bay waters in large numbers after whelping on ice floes off Newfoundland during spring. Prior to the European Union seal import ban in 2009, harp seals were also harvested in large numbers on the Canadian side, mainly south of the BBDS region. Other pinnipeds in the BBDS harvest inventory are hooded seal (*Cystophora cristata*), bearded seal (*Erignathus barbatus*), and walrus (Table 6.2). Harbor seals (*Phoca vitulina*) were caught in West Greenland until 2010, when they became totally protected because they had become critically endangered (Government of Greenland, 2010).

Catches of walruses in Greenland were previously considered unsustainable, but the introduction of a quota system in 2006 resulted in a substantial reduction of catches and the depleted stocks seem now to be recovering (Ugarte, 2015). Currently, about 140 animals are shot each year in West Greenland (Table 6.2), which corresponds to approximately one-third of the previous harvest level. Estimated population sizes are 2,544 walruses (95% CI: 1,513–4,279) wintering in the eastern side of the North Water Polynya (assumed to include the majority of the Northern Baffin Bay population) (NAMMCO, 2013) and 1,408 walruses (95% CI: 922–2,150) wintering in West Greenland (a portion of the Davis Strait/Southern Baffin Island stock) (Heide-Jørgensen et al., 2013a). Parts of these stocks are shared between Greenland and Canada (Wiig et al., 2014). Hunters from Qaanaaq (Greenland) reported landing 67 walruses in 2014 (from a quota of 86); in the three Nunavut locations where this population is harvested (Grise Fiord, Craig Harbour, and Resolute Bay), the average annual take over the period 2007–2011 was 7 (NAMMCO, 2013). The harvest in 2014 from the West Greenland/Southern Baffin Island stock was of 52 walruses in Greenland (from a quota of 69). Catches from this stock in the Nunavut settlements of Qikiqtarjuaq, Iqaluit, and Pangnirtung averaged 16 walruses per year in the period 1977–2009, based on rough estimates (Currie, 2009; NAMMCO, 2010; Ugarte, 2015). In Greenland, the walrus quota is earmarked for full-time hunters (subsistence hunters); in Nunavut, for subsistence hunting and trophy hunting.

Seabirds

Traditionally, seabirds have been of major importance in West Greenland, especially in southwest Greenland, which constitutes an important wintering area for seabirds breeding in the North Atlantic (Boertmann et al., 2004). Thick-billed murres (*Uria lomvia*), little auks (*Alle alle*), common eiders (*Somateria mollissima*), black guillemots (*Cepphus grylle*), and black-legged kittiwakes (*Rissa tridactyla*) constitute the most important species and are hunted in relatively large numbers (Table 6.2), although shorter hunting seasons have reduced hunting levels over the past two decades (Merkel and Christensen, 2008; Merkel et al., 2014). Common eiders, thick-billed murres, and black guillemots are also hunted in Nunavut (Chardine et al., 2008), but in contrast to southwest Greenland, the numbers are small and hunting occurs mainly during spring, summer, and autumn because most birds migrate out of Nunavut for the winter (similar to northwest Greenland). Communities where seabird hunting is significant in Nunavut are Kinngait (Cape Dorset), Kimmirut (Lake Harbour), Mittimatalik (Pond Inlet), and Pangnirtung; in all of these communities, seabirds are a part of the traditional diet. Large-scale seabird hunting in Canada, similar to the winter hunt in southwest Greenland, occurs only south of the BBDS region (e.g., the murre hunt in Newfoundland and Labrador) (Chardine et al., 2008).

6.5.1.3 Key species harvested from terrestrial environments

Caribou

Caribou is by far the terrestrial mammal most commonly hunted for food in the BBDS region (Table 6.3 and see also Section 6.3.1). In central West Greenland, a decade of restricted caribou hunting in the 1990s (shorter hunting seasons) resulted in a considerable population increase. Subsequently, relatively high hunting pressure was allowed (Table 6.3), with the aim of reducing the population to a target level of approximately one caribou per square kilometer. Since 2014, the Government of Greenland has again reduced the length of the hunting season for two of the three larger stocks, as the density of caribou has approached target levels. In Nunavut, due to the significant population decline on Baffin Island (see Section 6.3.1), hunters now have limited access to this important food source. In 2014, an interim moratorium on harvest was implemented, and in 2015, a "bulls only" quota of 250 animals was instituted, to remain in effect indefinitely.

Muskoxen

In Canada, the impact of unrestricted muskox harvest by early explorers in the region is thought to have been significant (Barr, 1991), bringing numbers to very low levels. The Canadian government responded in the early 1900s and legislated protection of the species (Barr, 1991; Gunn and Forchhammer, 2008). Starting with the 1990/91 hunting season, muskox harvest data have been collected annually, with 558 known individuals harvested as of 2011. There are indications that the actual harvest may be under-represented due to unreported take (DoE, 2011). Within the northern part of Qikiqtaaluk Region (muskoxen are absent from Baffin Island), there are six muskox management units, where harvest for domestic use constitutes more than half the reported harvest (54%) and sport/trophy hunting accounts for about a third (34%).

In Greenland, muskoxen are native only to East Greenland and the northernmost part of the BBDS region. However, a group of 27 animals was introduced from East Greenland into the Kangerlussuaq area of West Greenland in the 1960s. In 1992, quota-managed hunting was introduced in West Greenland for both recreational and full-time hunters. The introduction of muskoxen in West Greenland was rather successful, and by 2005, the population had grown to about 24,489 (95% CI: 18,410–30,568), estimated from incidental sightings during caribou surveys (Cuyler et al., 2009). Despite being hunted during two seasons (August–October and January–March), the population is still growing and is expanding its range. There are now regular sightings in the area around Maniitsoq and Nuuk, approximately 275 km south of the introduction site. Muskoxen from Kangerlussuaq have also been exported to establish stocks in five other locations of West Greenland. In these locations, they are now well established and their harvest is regulated by quotas and hunting seasons. Muskoxen in West Greenland are popular game for subsistence (full-time) hunters, as well as recreational hunters and trophy hunters.

Furbearers

In Nunavut, Arctic gray wolf (*Canis lupus arctos*), Arctic fox (*Vulpes lagopus*), red fox (*Vulpes vulpes*), and Arctic hare (*Lepus arcticus*) are the main species of small mammals harvested. Most furbearers are hunted for their fur. According to the Nunavut Wildlife Harvest Study (Priest and Usher, 2004), the numbers harvested annually in the Qikiqtaaluk region of Nunavut, 1996–2000, were rather small (Table 6.3). Although these estimates are minimum estimates due to the under-reporting of harvests for various reasons, they provide a good indication of the rather limited effort devoted by most hunters toward these species. Arctic fox and Arctic hare are also harvested in West Greenland, with approximately 2,000 and 3,000 animals, respectively, reported shot annually over the past two decades (Table 6.3). Considering the much larger number of hunters in West Greenland than in Canada (Figure 6.8), these estimates also suggest a moderate hunting effort toward fur-bearers. In Greenland, the Arctic wolf is fully protected and occurs mainly in northeast Greenland. However, in 2015 and 2016, several individuals were observed in the Qaanaaq area. It is not known whether these wolves originated from Nunavut or from northeast Greenland.

Terrestrial birds

Greater snow goose (*Chen caerulescens atlantica*) is the main terrestrial bird species harvested on the Canadian side of the BBDS region. The total number of snow geese harvested annually in the communities of Arctic Bay, Clyde River, Grise Fiord, Kimmirut, and Pond Inlet averaged 1,045 from 1979 to 1984 (Reed et al., 1998) and 1,077 from 1996 to 2000; in the recent period, a large number of snow geese were also harvested in Cape Dorset (3,156; Table 6.3). Although the total greater snow goose population increased 5-fold during 1979–2000 (Calvert et al., 2007), the harvest did not increase as much. The harvest by Inuit hunters in Nunavut is very small compared to the total harvest of greater snow geese by sport hunters in southern Canada and the northern United States of America (USA), where harvests averaged 80,000 birds annually during 1979–2000 and, in recent years, has exceeded 150,000 due to the special conservation measures introduced to control this overabundant population (Calvert et al., 2007). In West Greenland, the snow goose population is small and mainly limited to the north (Reed et al., 1998). Hunters report steadily increasing numbers, but this species cannot be legally hunted at present. The main goose hunting in West Greenland is on the Canada goose (*Branta canadensis*), which replaces the cackling goose (*Branta hutchinsii*) east of Baffin Island (Scribner et al., 2003). The reported Canada goose harvest in West Greenland is small (Table 6.3)

Rock ptarmigan (*Lagopus muta*) is harvested throughout the year in most communities of the BBDS region. During the period 1996–2000, an average of 11,141 ptarmigans were harvested annually on the Canadian side, with the highest numbers in the communities of Iqaluit, Kimmirut, Cape Dorset, Pangnirtung, and Clyde River. Although no recent information is available, the harvest is believed to have remained stable. In West Greenland, the harvest varies between about 10,000 and 49,000 birds per year (1993–2014) and is very popular among recreational hunters from the larger cities – i.e., Nuuk, Sisimiut, and Ilulissat (Piniarneq, 2014). However, the harvest has declined considerably in recent years (Table 6.3).

Eggs

The harvest of bird eggs is important in some communities. Over the period 1996–2000, the number of snow goose eggs harvested annually in the Baffin Island region averaged 2,373, with the highest numbers near Pond Inlet. Duck egg harvest was significant in the communities of Cape Dorset, Pangnirtung, and Iqaluit (3,241, 2,274, and 1,294 eggs annually, respectively; 1996–2000). Among seabirds, only thick-billed murre eggs were harvested in significant numbers, primarily in the community of Pond Inlet (2,601 eggs annually; 1996–2000) (Table 6.2). In West Greenland, egg harvest was rather extensive for common eider, Arctic tern (*Sterna paradisaea*), thick-billed murre, little auk, and kittiwake prior to the 1990s but has gradually been forbidden over the past three decades. Egging is still allowed for little auk in the Qaanaaq area of northwest Greenland. However, elsewhere in West Greenland, egging is limited mainly to the larger gull species (glaucous gull (*Larus hyperboreus*) and great black-backed gull (*Larus marinus*)), with annual mean numbers of 3,877 eggs reported (2003–2014) (Table 6.2).

6.5.1.4 Current harvest regulation

In Canada/Nunavut, a number of species are subject to formal regulation by federal, territorial, or provincial agencies. The principal regulatory tool in much of the BBDS region is the setting of total allowable harvests (TAHs) for certain species within designated management zones. The TAH for the zone is then allocated as community-designated quotas among communities exploiting the zone. In Nunavut, the allocation of TAHs among communities is co-managed by the Nunavut Wildlife Management Board, regional wildlife organizations, and hunter and trapper organizations. In Greenland, the TAHs are decided by the Ministry of Fisheries and Hunting after consultation with relevant organizations, including the Association of Fishermen and Hunters in Greenland (KNAPK), the organization of the municipalities (KANUKOKA), and the Greenland Institute of Natural Resources. Currently, there are TAH/quotas in Greenland for polar bear, walrus, narwhal and beluga, as well as minke, fin, humpback and bowhead whales. Hunting of muskox and reindeer is regulated by a license system and hunting seasons. There are also hunting seasons for Arctic hare and fox. No hunting limits are set for seal species, except for harbor seal and gray seal (*Halichoerus grypus*), which are protected from all hunting. Harbor porpoise, pilot whale, white-beaked dolphin, and orcas can also be caught year round without quotas in Greenland. In Canada, zone TAHs and community quotas are in force for polar bear, walrus, narwhal, beluga, and bowhead whale and, in Baffin Island, muskox and recently also caribou.

Management advice for narwhals and belugas is given by the Canada/Greenland Joint Commission on the Conservation and Management of Narwhal and Beluga (JCNB). Similarly, the Canada/Greenland Joint Commission on Polar Bear gives advice for the harvest of polar bears in Baffin Bay and Kane Basin. Greenland receives advice on walrus and marine mammals in general from the North Atlantic Marine Mammal Commission (NAMMCO). Quotas for large whales in Greenland are given by the International Whaling Commission (IWC). Canada withdrew its IWC membership in 1982. In Canada, Inuit have been authorized to hunt bowhead whales in the Nunavut Settlement Area since 1996; the Nunavut Wildlife Management Board has since increased the harvest, now allowing up to 4 individuals annually in Nunavut.

Bird hunting by non-Inuit in Nunavut and by residents of West Greenland is regulated by open and closed seasons and by daily limitations on the number of birds shot. For certain seabird species, less restrictive rules apply to the most northern communities in the Qaanaaq area. In Nunavut, there are no restrictions on bird hunting by Inuit.

6.5.2 Consequences of change for hunting

6.5.2.1 Changes related to governance within and outside the region

The mixed economy in the BBDS region has been facilitated by the external demand for particular products produced locally in association with harvesting. The most important, in terms of underpinning the monetary sector, has been the market for sealskins (Malouf, 1986; Rosing-Asvid, 2010). On the Canadian side, most seals have been hunted outside the BBDS region (harp seals from Newfoundland and the Gulf of St. Lawrence). However, the European sealskin market incorporated ringed seal pelts from Nunavut communities, as well as substantial quantities of harp seal and ringed seal pelts from West Greenland. This market was severely undermined in the beginning of the early 1980s due to a European boycott of Canadian seal products, along with nongovernmental organization (NGO) campaigns aimed at preventing the commercial killing of baby seals (Malouf, 1986; Wenzel, 1991). This limited the sale of ringed seal and other seal species products from BBDS hunters on the Canadian side to less than 10,000, and the price received by hunters dropped from an average of approximately 20 Canadian dollars (CAD) per skin to less than CAD 2. On the Greenland side, the prices paid to hunters remained stable, primarily due to government subsidies, and trade continued in relatively large numbers of seal pelts (50,000–70,000 per year) throughout the 1980s and 1990s (Rosing-Asvid, 2010). In 2009, the European Union passed a law banning the promotion of imported seal products and once more the hunters in the BBDS region suffered financially – this time also on the Greenland side. In 2015, the restrictions on seal imports to the European Community were modified by the introduction of an Inuit exemption, which allows Nunavut and Greenland to export to the European Union. However, the Inuit exemption is not functioning as aimed, and the level of sales is not increasing in Greenland (Jessen, 2016). The sealskin industry in Greenland, even with government subsidies, has undergone major changes in an effort to survive.

The management of quotas for several species of marine mammals through NAMMCO or IWC (see above) further illustrates the influence of multilateral management of shared resources. For narwhals, belugas, and walruses in Greenland waters, the reduction of hunting, in accordance with NAMMCO's advice, led to the recovery of previously depleted populations (NAMMCO, 2013). Commercial whaling from industrialized nations depleted global stocks of bowhead whales in the 19th century and of other baleen whales during the 20th century. Large-scale commercial whaling had ceased by the 1980s when an IWC global moratorium took effect (for bowhead whales, large-scale whaling ceased in 1931). Subsistence hunting of humpback whales stopped in Greenland in 1986. In more recent years, the stocks of fin whales, humpback whales, and bowhead whales in the BBDS region have shown clear signs of recovery (Heide-Jørgensen et al., 2007, 2010a, 2012b). Greenland was able to resume subsistence hunting of humpback whales in 2009.

In September 2015, the polar bear range states (USA, Russia, Norway, Greenland, and Canada) approved a Circumpolar Action Plan, identifying key threats to polar bears as being climate change, human-caused mortality, mineral and energy resource exploration and development, contaminants and pollution, shipping, tourism-related activities, and disease and parasites. The plan has a number of objectives aimed at securing the long-term persistence of polar bears in the wild (PBRS, 2015). The circumpolar plan is to be followed by national action plans. Both Canada and Greenland have scheduled the publication of their action plans in the coming years.

A good example of significant impact on harvest caused by governance within the region is the management of seabirds in Greenland. The large decline in seabird hunting levels that occurred over the period 1993–2014 in Greenland (Table 6.2) was to a large extent caused by a general shortening in 2001 of the hunting season. Other changes in the harvest regulation have since been implemented but with less impact on the harvest.

6.5.2.2 Direct and indirect impacts of climate change

It is evident that a number of environmental changes related to climate shifts have already taken place in the BBDS region, especially in the last two to three decades. The change that is most visible and most remarked upon by local residents is the earlier break-up of sea ice in spring and the delayed freezing of the sea in autumn. As a result of these changes, hunters are now experiencing a longer open water season throughout the area than in the 1970s and 1980s (Wenzel, 2009; Born et al., 2011; Adaptation Actions for a Changing Arctic, AACA, stakeholder consultations). For instance, in the 1970s, break-up along the middle portion of Baffin Island rarely occurred before early to mid-August; today, the onset of break-up is typically mid-July and is preceded by ice conditions that limit, if not inhibit, over-ice travel as early as late June. Other reported effects are reduced ice thickness, reduced extent of landfast ice, and the appearance of cracks and leads in unexpected places. In the period 1979–2013, the duration of the open water season increased by 16–20 days per decade in Davis Strait and by 10–12 days per decade in Baffin Bay (Laidre et al., 2015).

Changes in the length of the open water season and in the safety of the sea ice for transportation during winter clearly affect the way marine mammals are hunted. For instance, in Greenland, hunters reported that the number of polar bears taken from skiff has increased relative to the numbers taken using dog sleds as transport (Born et al., 2011). Similarly, the spring hunt of walrus in Qaanaaq (northwest Greenland) used to be mainly over the sea ice at the edge of the North Water Polynya. However, with the reduction of sea ice, hunters are increasingly using skiffs to hunt walruses resting on ice floes (Egevang, 2015). As mentioned above, increased distance to the sea ice has resulted in a reduction of belugas taken in West Greenland (Heide-Jørgensen et al., 2010a).

The prolonged periods of open water have been accompanied by changes in the marine biological subsystem (see Subchapter 6.2). While the climate change literature has focused primarily on potentially negative climate impacts – such as a reduction in polar bear access to key spring season prey and possible disruption to the ecology of ice-loving (pagophilic) pinnipeds – the effects on hunters are mixed. For example, BBDS polar bears now come to land up to a month earlier than “normal,” and in some Qikiqtaaluk communities, summer polar bears are considered a public safety issue. Similar safety issues are emerging in East Greenland (especially in Ittoqqortoormiit), and the number of polar bear–human interactions is increasing in West Greenland as well. Sightings of polar bears in Nuuk were once rare – about once a decade until 2009. From 2009 to 2015, 8 polar bears were seen close to Nuuk: 3 were legally hunted, 3 were killed by wildlife officers or police for security

age fotostock/Alamy Stock Photo

Inuit hunter driving snowmobile with Qamutik Inuit sled on sea ice, Arctic Bay, Baffin Island, Nunavut, Canada reasons, 1 was illegally hunted, and 1 survived, despite passing close to the city. Changes in the distribution, abundance, and movements of bears also indirectly affect human access to common eiders on the Canadian side. With less sea ice available for polar bears to hunt marine mammals, bear depredation on colony-nesting common eiders has increased dramatically and the eiders have responded by nesting in a more dispersed manner (Iverson et al., 2014).

Several Qikiqtaaluk communities have attributed an inability for hunters to access seals during the open water season to the presence of orcas. Indeed, local residents and scientists have observed orcas feeding on marine mammals in Nunavut waters (Steltner et al., 1984; Campbell et al., 1988; Laidre et al., 2006; Higdon and Ferguson, 2009). Orcas may be an important predator of seals, belugas, narwhals, and bowheads, as indicated by the behavioral responses of these animals to the presence of orcas (Campbell et al., 1988; Laidre et al., 2006). DFO is working with Nunavut's hunters and trappers organizations (HTOs) to gather information on orca abundance and distribution, in order to evaluate the whales' impact on marine mammals (Higdon and Ferguson, 2009; Matthews et al., 2011; Ferguson et al., 2012). Orcas could alter the marine ecosystem through a top-down effect of predation. If orca predation increases with the loss of sea ice, then their possible predator–prey relationships with seals, belugas, narwhals, and bowheads may result in distributional changes of prey and changes to the marine food web. On the Greenland side, orcas are hunted as food for humans and sled dogs in North Greenland and also as unwanted competitors for the harvest of marine mammals. Interestingly, the observations (and catches) of orcas in West Greenland have not increased. In East Greenland (Tasiilaq), however, orcas, pilot whales and white beaked dolphins are replacing minke whales as the main cetacean game species during summer (GINR, 2016).

Climate warming affects not only accessibility to the harvest but also potentially the quality of the food (negatively). Traditional practices of storing and aging the harvest outdoors are affected by the rising temperatures, which increase the risk of food-borne diseases. Also, especially in Nunavut, reports of reduced animal size, physical deformities, and greater variation in the taste of the harvest have been connected to climate change (see Subchapter 4.3 and references herein).

As noted above, hunters may also benefit from climate warming (Wenzel, 2009). Hunters from the east coast of Baffin Island indicate that narwhal are now available for longer periods (although hunters also note the possible negative influence of orcas scaring away seals). In addition, the increased abundance of bowhead whales has meant the lifting of a hunting ban and the implementation of a limited quota hunt for Qikiqtaaluk communities and (if negotiated with Nunavut) for Nunavik. Furthermore, harp seals have appeared along the Baffin Bay coast north of Cumberland Sound in greater numbers than in the 1970s and 1980s. Hunters also report that members of the species now appear within fjord systems, whereas earlier they were mainly observed on the outer coast (Wenzel, 2009). In northwest Greenland, hunters report increased occurrences of polar bears in coastal areas due to reduced sea ice coverage. As a benefit of the longer boat season, hunters note that a boat has a larger range (compared to a sled) and can cover more ground faster, resulting in more hunting opportunities, including polar bear hunting (Born et al., 2011).

In a study comparing seven Arctic and four Subarctic marine mammal species, Laidre et al. (2008) assessed the sensitivity of the species to climate change by using a quantitative index based on population size, geographic range, habitat specificity, diet diversity, migration, site fidelity, sensitivity to changes in sea ice, sensitivity to changes in the trophic web, and maximum population growth potential. They found that marine mammals dependent on sea ice (e.g., hooded seal, polar bear, and narwhal) appear to be most sensitive to climate change. However, the effects of climate change on marine mammals are obscured by the fact that several stocks are still recovering from depletion due to previous unsustainable harvests, including hunting by foreign commercial whalers (see above).

Seabirds in the BBDS region typically depend on large, energy-rich zooplankton and small forage fish and are likely to be negatively affected by increasing temperatures and decreasing ice cover. Changes in the extent and timing of sea ice cover over the past several decades, for example, have led to changes in the phenology and reproduction of thick-billed murres in Canada, with adverse consequences for nestling growth (Gaston et al., 2005). A circumpolar study of the population change of thick-billed murres and common murres (*Uria aalge*) showed that both species tended to decline following major changes in sea temperature (Irons et al., 2008). More temperate piscivorous species may benefit from increasing temperatures and decreasing ice cover (Kitaysky and Golubova, 2000). In the southern part of the BBDS region, it is likely that the breeding population of the partly planktivorous thick-billed murre will be gradually replaced by its sibling species, the piscivorous common murre (Gaston and Irons, 2010). However, due to pronounced site fidelity for murres, this replacement will probably be a very slow process. Another important planktivorous species is the little auk, for which the northern BBDS region is home to about 33 million breeding pairs (Egevang et al., 2003). This species is speculated to be highly vulnerable to changes in the sea ice–associated prey of the North Water Polynya, especially the large lipid-rich zooplankton species *Calanus hyperboreus* (Frandsen et al., 2014).

In general, the timing of spring migration and breeding of most bird species is likely to change substantially in the coming decades. Within the BBDS region, the phenology has already changed for common eider and thick-billed murre (Aarhus University and GINR, 2016) but not for some long-distance migratory birds such as snow geese (Gauthier et al., 2013). Changing breeding conditions (e.g., phenology, prey availability, or available breeding habitats) may also lead to changing numbers of wintering birds within the BBDS region.

As discussed in Subchapter 6.3, climate warming will initially benefit many herbivore species in the terrestrial environment via increased plant growth. However, through time, there is a potential risk for the development of a mismatch between the peak of resource demand by reproducing herbivores and the peak of resource availability. In a study from central West Greenland, Post and Forchhammer (2008) documented a case of trophic mismatch for caribou. As mean spring temperatures rose by more than 4°C over the period 1993–2006, the researchers observed increasing caribou offspring mortality and a 4-fold drop of offspring production. In this case, the problem appears to relate to the fact that the timing of the caribou's seasonal migration to the summer ranges, where calves are born, is cued by changes in day length, whereas the onset of the plant-growing season on the same ranges is cued by local temperatures. A similar case of trophic mismatch has been documented for greater snow goose on Bylot Island. Doiron et al. (2015) found that the geese were only partially able to adjust their breeding phenology to compensate for interannual changes in the timing of the availability of high-quality food plants, leading to mismatches of up to 20 days between the two. As a result, gosling body mass and structural size at fledging were reduced when mismatch was high.

Finally, as discussed in Subchapter 4.3 in connection with food security, it is important to note that the impacts of climate change and the necessity to adapt to a changed harvest situation are not equal for all communities within the BBDS region. Those communities that rely more heavily on traditional resources, due to historically favorable harvest conditions or due to limited alternative sources of income, are more sensitive to changes. Further, some of the mechanisms of coping with change cost money – such as purchasing and using new harvesting equipment, purchasing and using alternative transportation means, or traveling longer. Thus, the capacity to adapt to climate change is negatively affected by poverty (see references in Subchapter 4.3).

6.5.2.3 Framework scenarios, vulnerability, and cumulative impacts

Among the four framework scenarios outlined in Subchapter 3.4, the scenario that combines dramatic climate warming with intensive development of the mineral extractive industries (Figure 3.26) clearly has the largest potential impact on hunting in the BBDS region. All else being equal, the direct and indirect impacts of climate change (see above) will occur at a higher speed and over a larger area if climate warming exceeds average expectations (see Subchapters 3.1 and 3.4). These impacts may also interact with the potential environmental impacts or socio-economic drivers associated with intensive development of mineral extractive industries (see Chapter 7). The risk of such interactions occurring and potentially leading to cumulative effects depends on multiple conditions, such as the spatial planning of industrial activities, the vulnerability of the hunted species or their habitats, the management options chosen for implementation, and the risk of accidental events (e.g., an oil spill). The most likely outcome for the communities and the local hunters, in terms of their harvest of living resources, is that hunting will need to be managed more conservatively and flexibly to account for the potential risk of cumulative effects caused by climate warming and a larger presence of mineral extractive industries (see details below).

With respect to vulnerability, birds are generally considered extremely vulnerable to oil spills in the marine environment (Schreiber and Burger, 2002). Birds that rest on or dive from the sea surface, such as auks, seaducks, cormorants, and divers (loons), are more exposed to floating oil than are birds that spend more time flying and on land. Oil soaks easily into the plumage, destroying its insulating and buoyancy properties. Therefore, oiled seabirds readily die from hypothermia, starvation, or drowning – the main causes of seabird losses following an oil spill. Birds may also ingest oil by cleaning their plumage or feeding on oil-contaminated food, which can cause sublethal and long-term effects. Because many seabirds aggregate in small and limited areas for certain periods of their life cycles, even small oil spills in these areas may cause very high mortalities. Further, many seabird species have a low reproductive capacity and a corresponding long average lifespan (low population turnover), which makes them particularly vulnerable to additive adult mortality caused, for example, by an oil spill (Boertmann and Mosbech, 2011; Merkel et al., 2012).

Marine mammals are more robust and can generally survive short periods of fouling and contact with oil, except for polar bears and seal pups, for which even short exposures can be lethal. Seal pups are very sensitive to direct oiling, because they have not yet developed an insulating blubber layer and are dependent on their natal fur for insulation (St. Aubin, 1990). Within the BBDS region, hooded seals are particularly sensitive in this respect because their whelping patches are located on the eastern edge of the Davis Strait pack ice. For the polar bear, too, contact with oil means the loss of the insulating properties of the fur. Polar bears can pick up oil when they swim between ice floes, and they may also unavoidably ingest oil as a part of their grooming behavior. Both types of exposure can be lethal (Boertmann and Mosbech, 2011; Merkel et al., 2012).

Although difficult to predict in time and space, the simpler cumulative effects are those associated with events that lead to a direct and sudden mortality of the hunted species, such as a major oil spill. The consequences in terms of instant mortality can be very high, and in some cases there will also be long-lasting environmental impacts (see Chapter 7). However, the risk of such events is usually very low (but increases with increasing activity). The risk can be even further reduced by following best available techniques and practices during the exploration and extraction phases (see Chapter 7) and by implementing sensible regulation standards for shipping (see Chapter 9).

More difficult to detect are the cumulative impacts potentially caused by routine activities within the extractive industries. Typically, these activities are insignificant if carried out only once, but the cumulative effects from the same activity carried out at many sites at the same time or at a single site over an extended period can be significant (see Chapter 7). In 2012, hunters expressed great concern about the potential cumulative impact of multiple marine seismic survey activities on marine mammals in Baffin Bay. The hunters were particularly concerned about Melville Bay narwhals, which are also subject to local subsistence hunting. Therefore, studies were carried out in 2012 and 2014 to examine the possible effects of seismic noise on narwhals and narwhal hunting in Melville Bay (Heide-Jørgensen et al., 2013b; Hansen et al., 2015; Nuttall et al., 2015; Wisniewska et al., 2015). The studies concluded that the measured noise levels were potentially high enough to affect the narwhals and that the seismic noise may have caused the narwhals to prefer a more central part of Melville Bay in 2012, compared to previous observations. However, subsequent aerial surveys (conducted in 2014) suggested that clumping of narwhals in the central part of Melville Bay is a long-term trend that is unrelated to seismic exploration. Still, concern remains with regard to seismic surveys among the hunters, who reported nervous swimming by the narwhals and altered migration routes (Nuttall et al., 2015). Concern has also been raised regarding the effects of noise (and potential fuel spills) from increased shipping within the region. To date, there has been very little winter icebreaking activity in the area, but in the future, such ice-breaking may be needed through Baffin Bay for the year-round support of industrial facilities and transport of mining supplies and ore shipments (e.g., from the Mary River iron mine).

Cumulative impacts caused by the combination of hunting and climate change are also of concern for some species. Polar bears and narwhals, for example, are among the species that are more sensitive to climate change and they are also, in some areas, now more accessible to hunters (see above). One way to lessen impacts is to reduce the hunting quota, but for polar bear, this solution is partly hindered by the necessity to shoot more bears for safety reasons. Another cumulative-impact concern is for the thick-billed murre. A long-term population decline in West Greenland was previously ascribed to unsustainable harvest levels and oil pollution (Kampp et al., 1994; Wiese et al., 2004; Merkel et al., 2014). However, despite a subsequent large reduction in both hunting and oiling mortality, the rate of population decline has not slowed, and it now appears that changes in oceanographic conditions are also contributing to the decline (Descamps et al., 2013; Merkel et al., 2016).

6.5.3 Future development of hunting and adaptation options

In general, a greater focus on sustainable use and an increasing reliance on bilateral (Greenland/Canada) and international cooperation in resource management is having a significant impact on all harvest practices in the BBDS region. So far, the effects are most pronounced for the management of marine mammals and commercial fish species (Subchapter 6.4), but in the future, these trends will likely become more widespread and will likely include more species (e.g., shared seabird species). In the near future, the result may be smaller quotas for some species, but in the longer term, international cooperation will lead to better management and greater potential for a sustained harvest.

The possibility of improving the management of shared resources is enhanced by increased scientific cooperation between Greenland and Canada, along with an increased focus on Arctic research in general (e.g., PAME, 2009; AMAP, 2011, 2013; CAFF, 2013), leading to a significant boost in knowledge and thus a better basis for shared management. Greater awareness of the importance of integrating local knowledge and observations will add to the knowledge gained.

Among seabirds, the thick-billed murre breeding population in the BBDS region is a good example of a situation where a solid international knowledge base is needed. During winter, the BBDS population is mixed with breeding populations from countries in the eastern North Atlantic, but hunting is currently managed only on a national scale. Although information on status and potential threats are shared among countries, the current management approach is proving to be inadequate to secure a sustainable harvest. As mentioned above (Section 6.5.2), the population appears to be negatively affected by the cumulative impacts of hunting, oil pollution, and oceanographic conditions. Only with a very detailed knowledge about migration patterns and timing for all major breeding populations (e.g., Frederiksen et al., 2016) is it possible to evaluate which threats are affecting which populations. In addition, the thick-billed murre exhibits the typical life-history characteristics of seabirds, including very limited reproductive capacity – a confounding factor that makes this species less resilient to hunting. Consequently, the prospects for murre hunting in the BBDS region in the future are probably waning. In Greenland, the murre decline has already resulted in a significantly shorter hunting season.

On a more positive note, common eiders are now recovering in Greenland from the unsustainable harvest practices of the past (Merkel, 2010; Burnham et al., 2012). This recovery has already resulted in slightly longer hunting seasons in some areas. The increasing number of large eider colonies in Greenland also provides a large potential for eider down collection – something that is currently practiced in only a few places in Canada, mainly south of the BBDS region (Bédard et al., 2008). In general, down collection and hunting do not go well together, but if wisely managed, the harvest of eider down could represent a unique and highly sustainable resource. The down has a very high market value and also provides an opportunity to locally produce high-quality down products (thus providing local income and livelihood diversification). In addition, there is substantial experience in harvesting eider downs from maritime Canada and Iceland (Bédard et al., 2008; Carlsen, 2013). Eider colonies have also increased on the Canadian side of the BBDS region (Chaulk et al., 2005), but the potential for down collection from these colonies is perhaps more uncertain due to increasing egg predation by polar bears (see above) and the emerging epidemics of avian cholera in colonies bordering the Nunavut area. Both of these trends represent a threat to the viability of the Canadian breeding population (Descamps et al., 2012; Iverson et al., 2014).

The BBDS region also holds the potential for increased goose hunting in the future. Cackling geese currently constitute a negligible proportion of the local harvest on Baffin Island (Priest and Usher, 2004) due to their low abundance. However, there is evidence that the cackling goose population is increasing and expanding its range northward (Canadian Wildlife Service Waterfowl Committee, 2016; G. Gauthier, 2016; reports by local hunters) and thus could eventually become more important in the local harvest. Hunters in West Greenland frequently argue for more hunting opportunities on goose species, and with the apparent population increase of greater snow goose and Canada goose, this increased hunting might be a possible scenario. For the greater snow goose, however, an additional consideration is its status in the south. Because the greater snow goose is considered overabundant in eastern North America, liberal hunting regulations in the USA and southern Canada are aimed at reducing its population (Lefebvre et al., 2017). Therefore, future hunting of this species in the BBDS region might depend on the outcome of this North American regulation.

H. Mark Weidman Photography/Alamy Stock Photo

Butchering a freshly killed caribou at a remote campsite, Cumberland Sound, Baffin Island, Nunavut, Canada

The current northward expansion of the Atlantic mackerel (*Scomber scombrus*) may lead to new foraging opportunities for seabirds and marine mammals. Mackerel now occur in large numbers in East Greenland waters and the southern part of the BBDS region (Subchapter 6.4), and this abundance may in turn lead to a northwestern expansion of the northern gannet (*Morus bassanus*). In the long term, these shifts may lead to a new hunting opportunity on northern gannets in the BBDS region. A correspondence in the range expansions of mackerel and northern gannet has been observed in other areas (Montevecchi and Myers, 1997).

As indicated, ice-dependent marine mammals, such as polar bears and ice seals, are potentially threatened by the shorter duration of the sea ice season and the smaller spatial extent of summer ice. Earlier ice break-up and later ice formation can affect these species by extending the period of minimal food intake for polar bears (i.e., longer duration of open water season) and by disrupting critical life history events for the ice seals (i.e., loss of ice for pups in spring). Predictions indicate an increased risk of declines in marine mammal populations over the next few decades (Laidre et al., 2015), leading to reductions in hunting quotas and seasons. Nevertheless, a number of populations of narwhal, beluga, and walrus are currently increasing because they are recovering from previous overharvesting. Interspecies competition is expected to increase as temperate species expand northward into marine areas that were once exclusive to Arctic-adapted marine mammals. Negative health and demographic effects of disease and contaminants may also increase with climate change, affecting ice whales and seals.

Among the larger whales, the humpback whale, fin whale, bowhead whale, and sei whale are recovering from previous overexploitation (e.g., Heide-Jørgensen et al., 2012b), and these species have the potential to support an increased harvest. This potential may be enhanced by the expected increase of prey fish species such as mackerel and herring.

Species such as pilot whales, white-beaked dolphins, and orcas may become more common as their distributions shift northward with the warming waters. An increase in orcas has already been documented on the Canadian side of the BBDS region (Higdon et al., 2012). An increase in orcas also seems to be the case in southeast Greenland, where the harvest of this species has increased since 2010 (GINR, 2016).

High levels of contaminants in some marine mammals are a major concern for Inuit health (e.g., Dietz et al., 2015; see also Chapter 4), and concentrations of mercury are expected to increase to even higher levels in the future (see Subchapter 3.2). The health issue may cause the harvest demand for human food to decrease at some point in the future, but in the near future, strong cultural traditions and a concern for food security are probably more important for the individual hunter (see also Subchapter 4.1). Problems with contaminants may escalate because marine mammals may be increasingly affected by contaminants as they experience longer periods of starvation (thus releasing contaminants from fat deposits) due to climatic changes (e.g., polar bears).

Regarding the terrestrial mammals, the near-future prospects for caribou hunting on Baffin Island are poor for the reasons previously mentioned (Subchapter 6.3). However, a caribou co-management committee has been established and management initiatives are being implemented (see above) to lessen the decline and prevent the potential extirpation of Baffin caribou. This harvest management, which will perhaps be accompanied by a more positive phase of natural population fluctuation, will hopefully improve the long-term prospects for caribou hunting on Baffin Island. In West Greenland, the current and near-future basis for caribou hunting is more promising (see above). Over a longer time span, West Greenland may be able to support larger populations of caribou in continental inland areas due to a warmer climate (as discussed in Section 6.3.4). The more coastal caribou habitats may be at risk for deeper snow depths and more incidents of winter thaw, resulting in icing events. Populations of introduced muskoxen in West Greenland are healthy and expanding, giving good prospects for continued and increasing sustainable hunting in the future.

Traditionally, hunted birds and mammals have provided good potential for creating alternative income through tourism, including both trophy hunting and nature viewing. The existence of a local workforce with an intimate knowledge of the species and their habitats is a resource the tourism industry could promote by incorporating hunters into their tour operations (see Chapter 8). Trophy hunting is a good example of a potentially high-value activity for local hunters; management of this activity is currently quite diverse within the region. Consequently, there is much to gain by sharing experiences among the management bodies within the BBDS region. As an example, trophy hunting of polar bears is an important source of money for Inuit on the Canadian side, while trophy hunting of polar bear is not allowed on the Greenland side. In 2004, 10 polar bear trophy hunts at Clyde River brought approximately CAD 225,000 into the community, altogether more than twice the income that entered the community from four years of hikers, skiers, kayakers, and other ecotourists (Wenzel, 2009). For the Government of Greenland to allow such an activity, a CITES positive non-detriment finding (i.e., a finding of no negative impact on the polar bear population) and a suitable, safe organization and infrastructure would be first required (AACA stakeholder meeting, Nuuk, February 2016; see Chapter 1). Trophy hunting on the domestic reindeer stock in South Greenland already takes place (Subchapter 6.6). In other cases, the coexistence of tourism and hunting can be problematic, as exemplified by the divergence of interests associated with whale watching and whale hunting in Nuuk. There, 6 seasonally resident humpback whales were responsible for 50% of the whale sightings in the period 2007–2012 (Boye et al., 2014); since the 2009 reintroduction of humpback whale quotas, 3 of those 6 humpback whales have been shot.

Research in the BBDS region and elsewhere in the Arctic has contributed to a better understanding of the distribution, abundance, habitat use, trophic connections, and vulnerabilities of the living resources. This information is essential when assessing the risks of population declines and unsustainable harvests of important resources in the region. The risks can be minimized through a continued effort to better understand the relations between wildlife populations and their environments. The local communities of the BBDS region are literally residents of this environment and are firsthand witnesses to the ongoing changes. It is important to build on the residents' observations through community-based monitoring programs or similar collaborations. Such programs would assist in connecting the co-management groups, to effectively help Arctic wildlife conservation into the future and to guide Nunavummiut (residents of Nunavut) and Greenlanders in adapting to a changing Arctic. However, it should be emphasized that the challenge to understand the direct and indirect effects of climate change and the cumulative impacts of human stressors on the Arctic environment has just begun and will require an ongoing scientific effort as well as an adaptive management approach.

As a final notion, and as seen from a broader socio-cultural viewpoint, it should be noted that future challenges for the traditional Inuit hunter may extend far beyond the need to adapt to changing wildlife abundances caused by climate change or by federal, national, or international management decisions. Wenzel (2009) argues that these transitions will be only minor compared to the real adaptive challenge that will confront Inuit – i.e., clashes with non-Inuit attitudes. As worldwide concerns about the impacts of climate change grow – especially among Europeans, Americans, and southern Canadians – Inuit may find that their many effective local-level adaptive responses will conflict with non-Inuit attitudes about wildlife conservation, sustainability, and environmental management. Wenzel (2009) concludes that in the future, communication and negotiation will be among the most important tools in the adaptive toolkit of traditional Inuit hunters.

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6.6 Agriculture, farming, and herding

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Key messages

- ***Within the Baffin Bay/Davis Strait (BBDS) region, agriculture, farming, and herding are important only in South Greenland.*** *Sheep farming is the single most important of these activities.*
- ***New farming and herding opportunities are expected to accompany the changes in climate.*** *These expectations include additional space for newly farmed species (e.g., cattle) and new types of vegetables (e.g., cabbage).*
- ***More developed infrastructure and adaptive planning can assure more lasting and better coordinated distribution of products.*** *Developing infrastructure includes better Internet access as well as better (gravel) roads and improvement of transportation by sea. These initatives can improve access to currently isolated areas.*
- ***Increased use of green energy can reduce the carbon dioxide footprint and the cost of agricultural production.*** *The result is more viable farming and better usage of cultivated areas.*
- ***Better technical solutions to handle the challenges of more extreme weather events can increase and stabilize crop production.*** *Improved irrigation systems, for example, could help to handle the challenges of drought and flooding.*
- ***Changing the terms and conditions associated with purchases of abandoned and indebted estates could help ensure that all prepared farming areas are utilized.*** *Today several previously farmed areas lie fallow and could be relatively easily recultivated.*

Guiding question

How will fundamental changes in the terrestrial ecosystem affect current and future agriculture, farming, and herding in the Baffin Bay/Davis Strait region, and how will these impacts interact with socio-economic development?

6.6.1 State and characteristics of agriculture, farming, and herding in the BBDS region

In the Canadian part of the BBDS region, there is no current or past tradition of agriculture, farming, or herding. There, as in the northern part of Greenland, Inuit have relied on wildlife hunting, fishing, and the gathering of plants and berries. These areas have not been appealing for agriculture. There is no vast area of grassland, such as that which has promoted ranching and herding in the western part of Canada.

Farming has not been an integral part of Inuit life in Greenland either. The practice of farming was first introduced to Greenland by the Norse and then again more recently by the Icelanders. The first records of Greenland farming date back to the year 1000 (Arneborg et al., 2012). The Norse period of more or less intensive farming lasted for 400–500 years. The reasons for its ending are still unclear, but climate change and unsustainable land use have been proposed among the main reasons (Arneborg et al., 2012).

There is no evidence that farming was adopted by the indigenous people of Greenland during the Norse period (Gulløv, 2008). Present-day farming developed from the introduction of Icelandic sheep, which were brought to South Greenland in 1915 to supplement fishing and hunting. Since then, a mixed culture of Nordic and Inuit origins has been associated with the running of farms in southern Greenland (Jensen, 1958). Today, the Greenland way of farming is closely connected to the Icelandic way of farming, as many of the young farmers obtain a portion of their education in Iceland. Most farmers devote all of their time to farming and do not supplement their income by hunting wildlife – unlike most non-farmers. However, fishing is still an integral part of farm life (e.g., for Arctic char and cod). The original idea of farming as a supplement to hunting and fishing (Jensen, 1958) has reversed, so that it is now the other way round: for established farmers, fishing is a supplement to farming. Thus, a different culture has developed in South Greenland.

Farming constitutes a small part of the Greenland economy. The sector is heavily subsidized by the government, in the amount of approximately 40 million Danish kroner in 2013 and 23 million in 2014 (Government of Greenland, 2014a), because only a few farmers are able to provide for themselves at the present standard of modern living. However, the Greenland government has a vision of some future level of self-sustainable production of foodstuff in Greenland and supports farming in that light (Government of Greenland, 2014b). Independent farmers can apply for government funding in certain circumstances – for example, in times of unexpected natural events (drought, flood) or when machinery needs replacement. In severe winters, farmers can also apply for funding to buy extra fodder for livestock (Government of Greenland, 2014a).

Products from agriculture, farming, and herding are sold primarily on the home market. Exports from farming – mainly sheep and reindeer meat – make up about 0.1% of the total national export (Statistics Greenland, www.stat.gl).

Greenland's farms are located in South Greenland (Narsaq, Qaqortoq, and Nanortalik) and are mainly single-family estates. Over the past 10 years, the number of farms declined steadily – from 60 in 2001 to 43 in 2013 and 37 in 2016. However, the total area of farmland increased during the same period – from just under 8 km^2 to 11 km^2 (Table 6.5). The majority of farmland (99%) is used for the production of winter fodder for sheep (Agricultural Consulting Services, 2016).

Table 6.5 Number of farm animals and annual production in Greenland, 2002 and 2013. (Data source: Statistics Greenland, www.stat.gl.)

	2002	2013	
	Number	Number	Meat (kg)
Stock			
Mother sheep	18,967	19,994	
Cattle	12	125	
Reindeer	3,100	3,000	
Annual production			
Sheep	1,958	1,522	34,734
Lambs	19,082	20,344	293,691
Cattle		19	2,660
Reindeer	1,072	~ 900	

6.6.1.1 Farming and herding

In the following discussion, we distinguish between farming and herding. *Farming* refers to agricultural landholding specialized in raising sheep and cattle. *Herding* refers to the practice of bringing individual animals together into a group and moving the group between summer and winter habitats without agriculture or supplementary feeding. Thus, in Greenland herding relates exclusively to reindeer.

In Greenland, intensive sheep farming first arose in the 1920s and then increased until the mid-1960s, when the stock of sheep reached 48,000 head (Jensen, 1958; Kristiansen, 1966). Sheep farming relied on extensive grazing for most of the year, and the production of winter fodder was negligible. This approach allowed farmers to expand the stock of sheep in periods of mild climate. However, this system was highly vulnerable to the vagaries of weather and many animals died during harsh winters. During the winter of 1948–1949, more than 10,000 sheep died and the stock was reduced by half (Jensen, 1958; Kristiansen, 1966). In the mid-1960s, more than 60% of the stock (approximately 28,000 animals) died of starvation because of snow and ice (i.e., thawing/freezing events during winter). This event resulted in a legal change that obliged all farmers to keep all livestock in stables during the winter, thereby also creating a need for fodder production (Westergaard-Nielsen et al., 2015).

During the 1980s, sheep farming changed to a more intensive form (Egede, 1982). Keeping sheep in stables and fed during the winter stabilized the sheep stock but at the same time increased operating costs for farmers – and the Greenland society. During the past 40–50 years, Greenland farmers have depended on government subsidies and loan capital as stated above. Most sheep farms have approximately 400 ewes but would need more than 500 to be economically viable (Government of Greenland, 2014a).

Since the 1990s, there have been approximately 40,000 sheep on grass during summer and 20,000 in stables during winter. At the time of writing, Greenland has a mean size of ewe stock of more than 540 ewes. The first decade of the 21st century was the most productive in the history of Greenland sheep farming. However, the load of grazing in many areas has reached a maximum, which is reflected in the quality of sheep meat. The farmers' association has helped to regulate the number of sheep according to the carrying capacities of the pastures, which are typically smaller than the capacities of the stables. For this reason, many farmers do not use the full available capacity of their winter stables.

6.6.1.2 Reindeer herding

Like sheep farming, reindeer herding was introduced from outside of Greenland (Rasmussen, 1992). In 1952, approximately 300 animals were introduced to West Greenland. However, unlike present-day sheep farming in South Greenland, reindeer herding is free-ranging and extensive, with no supplemental feeding and no production of winter fodder (Rasmussen, 1992; Nymand, 2004).

Two semi-domestic reindeer herds exist in South Greenland, at Isortoq and on the island of Tuttutooq. The Isortoq herder has in some years had up to 5,000 reindeer in the winter stock (Nymand, 2004); however, in the autumn of 2015 there were fewer than 2,000 reindeer (GINR, 2015). The Tuttutooq herder has no more than 300 reindeer (Kommune Kujalleq, 2013). This latter herder has an arrangement with the Narsaq abattoir (slaughterhouse) for culling, whereas the Isortoq herder has established its own on-site abattoir, which can process 800–1,000 reindeer per year (Magnusson, 2005). The Isortoq station is authorized to receive trophy hunters (Magnusson, 2005).

The Isortoq reindeer herd was established in 1973, when approximately 100 individuals were relocated from the population originally introduced in 1952 (Rasmussen, 1992). The area used by this free-ranging herd has gradually increased from 170 km^2 (Rasmussen, 1992) to the present 1,500 km^2 (Magnusson, 2000). The Tuttutooq herd was established in 1992 when reindeer were introduced to the island; the herd now occupies an area of 221 km^2. Some issues have arisen regarding the compatibility of the area's previous uses (hunting and fishing) with today's primary use (herding) (Kommune Kujalleq, 2013). Areas that are now used for grazing are also used for hunting (e.g., of Arctic hare and ptarmigan), and the herders argue that the hunting severely disturbs the grazing reindeer. Also, the introduction of hiking tourists has been an issue (Kommune Kujalleq, 2013) for herders, who argue that this activity disturbs reindeer at a sensitive period.

6.6.1.3 Agriculture

Farmed area in Greenland was 4.6 km^2 in 1990 and almost 10 km^2 in 2003 (Westergaard-Nielsen et al., 2015; Agricultural Consulting Services, 2016). The main effort is devoted to growing crops for fodder in order to feed the sheep during winter when they are in stables.

Most vegetables are grown outdoors (e.g., cabbage, potatoes); however, some are grown in greenhouses (e.g., lettuce). Greenland has been known for having very little to no need for pesticide treatment, but a viable vegetable production

Cindy Hopkins/Alamy Stock Photo

Sorting potatoes, Tunulliarfik, Itelleq near Qassiarsuk

demands a lot of fertilizer (Agricultural Consulting Services, 2016). This need is met in some part by sheep manure but mostly by imported commercial products.

Until recently, vegetables were produced mainly for home use or the local market, but in the last few years, production has expanded. The potato crop increased to 108 tonnes in 2012 (more than double the production of previous years), and for a couple of farmers this crop has become their main income.

In 2012, a new locally owned company was established to enable the distribution of vegetables, thus enhancing the possibility that vegetables produced in South Greenland can be sold in other areas of Greenland.

6.6.2 Consequences of change for agriculture, farming, and herding

History shows that subarctic farming is very sensitive to changes and variability of temperature and, in particular, snow and rainfall. A study by Christensen et al. (2016) analyzed the impact of climate changes in southern Greenland and concluded that for the near future (present to 2035), existing climate models are unable to provide clear answers regarding the magnitude of the effects of climate change. However, in line with Subchapter 3.1, Christensen et al. (2016) expect climate change to result in higher temperatures and increased winter precipitation, as well as more frequent and harsher extreme weather incidents toward the end of this century. Depending on the levels of greenhouse gases in the atmosphere, the authors also expect a number of secondary effects, such as changes in the period of snow cover and length of growing season.

A higher mean temperature means better living conditions for plants and animals. Increasing temperatures also mean that the ongoing recession of the inland ice margin will continue to expose new areas potentially suitable for farming. This trend implies better possibilities for farming in Greenland. However, the thawing of permafrost is expected to give rise to soil erosion and increased leaching of potentially bioavailable nutrients from the soil (Subchapter 3.1 and Chapter 10).

An increase in precipitation can have both positive and negative effects. In areas with few natural sources of water, more precipitation may increase potential crop yields. On the other hand, greater precipitation may also increase the leaching of already sparse nutrients from the soil and may increase the risk of fungal infections and other diseases in crops and livestock. The magnitude of the impacts will depend on the timing of the precipitation (spring versus autumn; Chapter 3).

Lehmann et al. (2016) discuss opportunities for climate change adaptation in the Greenland agricultural sector. They conclude that the amount of water available for plants will decrease due to increased evaporation following temperature increases. Farmers state that periods of drought during the growing season already result in lower-quality crop (e.g., lower protein content in grain). Dry summers in 2007, 2008, and 2015 were detrimental to farming – especially for the production of fodder. As a consequence, and in order to stabilize the production of coarse fodder, new irrigation systems have been established and more are forthcoming. Furthermore, training in irrigation and irrigation systems is offered to farmers in order to reduce the impacts of drought periods. Lehmann et al. (2016) suggest that initiatives regarding soil improvement schemes are being initiated as this will increase the water household capacity and eventually the soil fertility.

Aurora Photos/Alamy Stock Photo

Slaughterhouse in Narsaq, Greenland

6.6.3 Future development of agriculture, farming, and herding

The current capacity of approximately 20,000 sheep year-round and 40,000 during the summer is close to the estimated carrying capacity for the pasture areas presently in use. Therefore, increasing the number of sheep within the existing range is not a sustainable option under current conditions. However, a study forecasting the dry biomass production available for sheep over the next 85 years found that existing farmers in South Greenland can expect to see an increase in above-ground biomass production (Subchapter 6.3) and thus a decreasing need to buy additional winter fodder (Westergaard-Nielsen et al., 2015).

Today in South Greenland, some farms (fewer than 10) are abandoned (Kanuthsen, 2016). New farmers are reluctant to take over these abandoned farms because of the lack of debt-relief possibilities – i.e., the current system transfers the indebtedness of the estates to those who buy them. Changing the economic system with respect to debt relief may increase the use of these abandoned fields, which have already been prepared for farming.

The potential for introducing sheep farming outside its existing range depends heavily on infrastructure development and on distance to a town or settlement. According to one model (Westergaard-Nielsen et al., 2015), this dependence is more important than a temperature deviation of ±2°C. The most promising area for expansion is the inner part of Nuup Kangerlua (Godthåbsfjorden), where farms were located during the Norse period a thousand years ago. In some of this area, a resumption of sheep farming was recently attempted but without success. Sheep farming will, however, be initiated again in 2019. The contemporary potential for sheep farming in this area is estimated to be about 50% or more of the current capacity in South Greenland – i.e., 10,000 sheep or more in winter, if appropriate infrastructure is established.

Westergaard-Nielsen et al. (2015) conclude that if neither water nor nutrients become major limiting factors for plant growth, the future climate in Greenland will probably improve the preconditions for sheep farming. The real restriction to the expansion of sheep farming seems to be the limited number of settlements and, as a result, a limited possibility for the in- and outflow of people and goods. Urbanization predictions (Subchapter 3.3) state that more people will likely abandon remote settlements to move into larger towns. This shift will pose an additional challenge for the creation of more infrastructure for farms and farm products.

6.6.4 Adaptation options and knowledge gaps

A priority for today's Greenland government is that farming and herding be ecologically and economically sustainable. The latter is a challenge.

In order to optimize the self-sufficiency of farms, the area of farmed land must be increased and infrastructure – especially roads from pastures to buildings – must be developed. An estimated 100 km of gravel road is needed in addition to the existing 200 km, so that more farms can be connected via land routes, thus increasing interactions among them. Many stables are more than 30 years old and need to be replaced.

The changing climate (i.e., higher temperatures and longer growing seasons) will probably allow for the use of new fields in South Greenland and an expansion of farming toward southwestern Greenland. However, the quality of areas already in cultivation must be improved by the assessment and administration of optimal amounts of supplemental nutrients and chalk. An increasing risk of drought will increase the need for watering systems (see also implications summarized in Chapter 12). It may be possible to "regrow" some previously farmed areas, while also being mindful of the potential for conflict with a recent application for Norse farming land in South Greenland to be included (and thereby protected) on the United Nations Educational, Scientific and Cultural Organization (UNESCO) list of World Heritage Sites.

In recent decades, several farmers have offered "bed and breakfast" services for small-scale ecotourism, as well as other services (e.g., horseback riding and semi-guided tours between farms; Blue Ice Explorer, 2016). The recent rapid increase in the numbers of pleasure crafts and ship-based tourists (Chapter 8) can make this kind of tourism viable, given that tourists board the ships in South Greenland (after arriving by airplane). People who stay extra days before or after a cruise can make a large difference for the communities. If access to Greenland is improved via Iceland, including more flights also in wintertime, then the need for offerings from local farmers will increase and so will the market for locally manufactured products (honey, handicrafts, tours). However, some complaints have been put forward regarding the use of reindeer-calving areas for tourism (e.g., trekking, camping; Blue Ice Explorer, 2016; Tasermiut South Greenland Specialists, 2016). To avoid or minimize such conflicts, careful planning and the involvement of stakeholders are essential.

Power and water are important factors in farming. Virtually all farms are placed near a stream, river, or lake – providing an ideal situation for the production of renewable energy. In recent years, many farmers have been able to establish their own micro hydropower plants because of the lowering of costs associated with this technology. If hydropower production can increase, the cost of farming can be reduced and self-sustainability can be increased. This scenario may be a realistic one for the future because climate models project more or less the same amount of precipitation as now for the 2030 scenario and more precipitation than now for the 2080 scenario.

To date, little work has been been done on analysis of adaptation to climate changes specific for Greenland agriculture, farming, and herding (Lehmann et al., 2016). Additional thorough analysis is needed.

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7. Non-living resources

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Key messages

- ***Commodity prices, together with extraction prices and technology development – not climate change effects – are the main drivers of change in the Baffin Bay/Davis Strait (BBDS) non-living resources sector.*** *The commodity prices of mineral resources are expected to decline in the coming years.*
- ***However, opportunities for new mining and petroleum projects may arise as a result of retreating ice****. A longer seasonal time window and new routes for shipment are expected to open up due to climate change.*
- ***It is unlikely that oil and gas activity will result in a producing BBDS site within the coming decade(s).*** *The number of exploration wells in Greenland is still very low and a commercial oil discovery has yet to come.*
- ***Most likely, the region's workforce will be able to meet the labor demand for larger mining projects only to a limited extent.*** *Limited skills training is one of several reasons.*
- ***In rapidly changing Arctic conditions, the cumulative impacts of increased activities need, in general, ecosystem-based management****. In addition, integrated risk management may be required, so that assessments analyze not only a project's effect on the environment but also the environment's (climate's) impact on the project over long time scales.*
- ***Unused hydropower potentials are available for the "green" development of mines and other industries.*** *Wind power may, with technology development, be feasible on a local scale. Solar energy is expected to have significant potential at a local scale.*

Guiding questions

What is the most important driver for resource exploration/extraction development in the Baffin Bay/Davis Strait region?

Will the BBDS region experience increased mineral development and oil and gas development?

Regarding capacity building and skills development: will the local workforce meet the labor demands of the mining and petroleum industries?

Could the value chain from production to consumers be reduced to an extent that mining potentials would be more viable?

Should there be more investment in the maturation of licenses in general and in strategic environmental impact assessments on land, to promote and enhance the basis for evaluating mining projects?

Could public/private cooperation be further developed?

Will technological developments related to extraction processes make it more cost-effective to locate ore-processing facilities in the BBDS region?

Should governments focus on exploiting only those deposits with high income potential and minimal social and environmental implications?

Are "green" energy potentials (hydropower, wind power, and solar energy) real alternatives as energy resources in the BBDS region?

Can the BBDS region maintain a reputation as a "pollution-free" zone (for example, in relation to fisheries) and at the same time develop its extraction industries?

Will there be a risk for demographic asymmetry in the local societies as a result of extraction (e.g., mining) projects?

Introduction

This chapter looks closely at the current state of the non-living resources of the Baffin Bay/Davis Strait region. The objective is to describe the major potential influences on the development of the region, as well as the potential outcomes of these developments in so far as the adaption of the region is concerned.

It should be pointed out that the term "non-living resources" is rarely used in the academic or political literature. The terms "extractive resources" or "nonrenewable resources" are more commonly used. In essence, we are discussing those resources that are finite and that cannot be reproduced. The two extractive industries relevant to the BBDS region are (1) hard minerals and (2) oil and gas. Both sectors are seen by many, both inside and outside the region, as possible sources of development with the potential – even though they are finite – to enhance the sustainability of communities in the region. Indeed, of all potential drivers of change, the extractive industries are seen by many in the region as the sector most likely to bring a general increase in the well-being and sustainability of the region. At the same time, many people also fear potential negative impacts on the environment (Chapter 6) and more directly on the communities themselves. Given this situation, it is important to examine closely the role these sectors could play in the future of the region.

In this chapter, we first examine the current state of non-living resources in the BBDS region. This brief overview includes a discussion of current activities in both the mineral sector and the oil and gas sector, as well as possible future activities. We then examine the major factors influencing these activities – i.e., in terms of the decisions made on whether to undertake or continue these developments. Finally, we look at what these developments mean for the region. We also outline potential impacts on the environment, as well as the more direct potential socio-economic impacts.

7.1 Status and trends in mineral and hydrocarbon activities

This section lists the mineral and hydrocarbon exploration and extraction activities in the region – initiated, planned, or prospected.

7.1.1 Mineral extraction

As noted in Subchapter 3.3, interest in mineral development in the region has increased substantially over the past few decades. While mineral development in Greenland began over a hundred years ago, development in the Canadian Arctic is a more recent trend. Some political actors and academics have attributed this increased interest in mining to climate change; however, industry representatives tend to highlight a decrease in the availability of more accessible resources and increases in commodity pricing (Southcott, 2014). The added cost of developing mineral resources in the BBDS region means that industry becomes interested only when pricing for the commodity is higher than would typically be required in more accessible regions (Huskey and Morehouse, 1992).

7.1.1.1 Greenland

Mining in the West Greenland portion of the BBDS region started in the mid-19th century and became important with the opening of the Ivittuut cryolite mine in the 1860s. Indeed, during the last part of the 19th century and the first part of the 20th century, this mine financed most state activities in Greenland (Sinding, 1992). After World War II, the expenses of the state surpassed the revenue coming in from mining, but the Ivittuut mine continued to contribute until the 1980s. A lead–zinc mine opened at Maarmorilik in the 1970s and operated until 1990. The Nalunaq gold mine was in production from 2004 to 2013, when it was closed due to falling gold prices. Recently, the mining sector has been the subject of much debate in Greenland (Areddy and Bomsdorf, 2013).

Currently, three mines are being developed. Greenland Ruby A/S has completed the infrastructure for a ruby mine near Fiskenæsset in West Greenland, and started production. Hudson Resources Greenland A/S received an exploitation license for anorthosite (a feldspar-containing rock) in 2015. Currently, the company is concluding the approvals process for its exploitation and abandonment (closure) plans; infrastructure development and the commencement of production are expected for 2017. Ironbark A/S received an exploitation license for lead and zinc in December 2016. The company is expected to start production within the next 5 years.

The Greenland government encourages mining developments, but the commodity price declines of recent years have been unfavorable for mining operations (World Bank Group, 2016). The most promising projects are shown on the map of Figure 7.1, which also indicates the current stage of development of each project as of May 2016. In Greenland, the lack of infrastructure and the difficult logistics associated with harsh climatic conditions are major challenges for the mining industry. This is also the case on the Nunavut side of the BBDS region.

The Greenland oil and mineral strategy (Government of Greenland, 2014) states, based on global mineral demand, that iron ore, copper, zinc, rare earth elements (REEs), gold, and gemstones are the most important minerals. In Greenland, there are large amounts of all of these. Greenland will continue to map and assess the geographical distribution of mineral occurrences and the potential and size of new occurrences. The zinc potential in northern Greenland is one example.

The strategy mentions the following as the most important parameters for mineral investment:

- Geological potential and prospects (metals and minerals)
- Mineral legislation
- Fiscal conditions
- Institutional factors and framework conditions
- Political stability

In accord with the previous oil and mineral strategy, effort has been devoted to the accumulation of general geological knowledge and also specific knowledge about promising geological areas of mineral deposits in Greenland. Exploration activities have been at a relatively high level since 2007 (Figure 7.2).

In the coming years, the government's survey programs will focus on:

- Iron ore, copper, and zinc
- Rare earth elements
- Gold
- Uranium
- Gemstones
- Anorthosite
- Small-scale mining

In 2013, the Geological Survey of Denmark and Greenland (GEUS) established an office in Nuuk. This office provides consultancy and scientific knowledge regarding minerals and climate in order to strengthen the exchange of knowledge between Denmark and Greenland. A background paper for the Committee for Greenlandic Mineral Resources to the Benefit of Society (Borch, 2013) states that missing or weak infrastructure, high salaries, and strict environmental requirements are factors that negatively influence the profitability of a given mineral resource. Distance to consumers is also a negative factor for most of Greenland – probably the only factor subject to change due to climate change. Reduced ice cover may result in easier accessibility to parts of Greenland where ice currently hinders ship traffic. However, safety issues due to to glacial surges and an increased occurrence of icebergs are also likely (see Subchapter 3.1). The effects of the various negative influences on mining development may be somewhat alleviated by the potential high-grade quality of mineral commodities in Greenland.

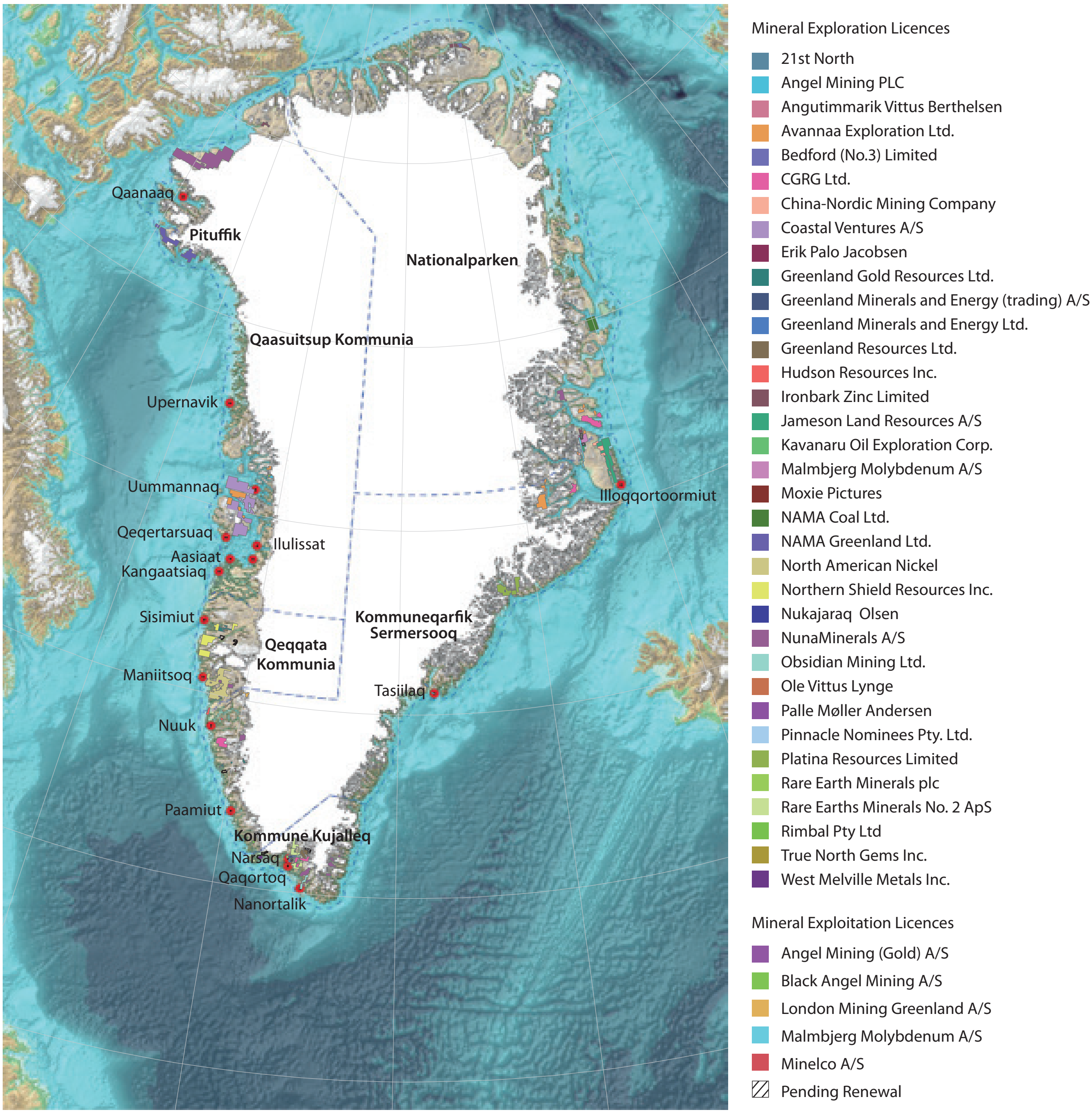

Figure 7.1 Overview map of mineral licenses and major mining projects in Greenland, as of 2014 (from Government of Greenland, 2016a). Up-to-date information about current licenses can be found on the Minerals and Petroleum Licence Map of the Government of Greenland: licence-map.bmp.gl/

The costs associated with shipping mineral concentrate from a mine to a smelter are considerable, and the companies therefore try to reduce these costs by ensuring the shortest possible transport route. If future climate change allows for the regular and safe sailing of ore carriers in northeastern BBDS waters and the Northwest Passage, then very large areas of the Arctic – including North Greenland – will be of heightened interest to the mining industry (see Chapter 9 for further discussion of shipping).

A number of mining projects have now reached a stage at which exploitation of the mine deposits has been permitted by Greenland's self-government. Other projects are at an earlier stage, with companies conducting environmental analyses and preparing environmental impact assessment (EIA) reports for potential mining projects. Some of the current mining projects are described in more detail below.

In recent years, there has been a high level of interest in small-scale mining, and the Mineral License and Safety Authority (MLSA) is in the process of issuing new standard terms for small-scale licenses.

Projects with exploitation permission

Rubies and sapphires at Aappaluttoq, east of Qeqertarsuatsiaat/Fiskenæsset. Greenland Ruby A/S officially opened its ruby and pink sapphire mining operation in Aappaluttoq in May 2017. The mine is located east of Qeqertarsuatsiaat/Fiskenæsset (Fisher's Inlet) in southwest Greenland, between Nuuk and Paamiut (Figure 7.1). The company's EIA describes the expected environmental impacts, which overall are regarded as small (Government of Greenland, 2013). The environment will be monitored.

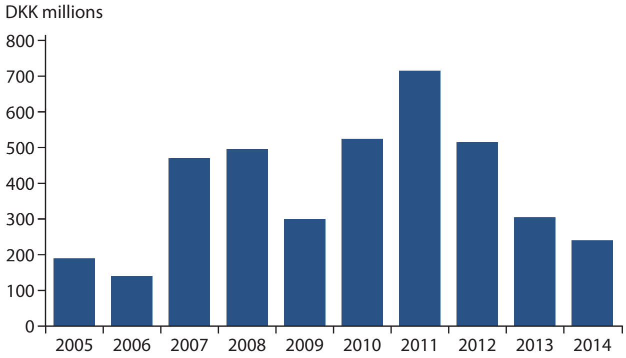

Figure 7.2 Mineral exploration expenditures in Greenland, 2005–2014, in DKK millions (from Government of Greenland, 2014). (As of 5 June 2017, 1 Danish krone = 0.20 Canadian dollar.)

The rubies are found on and under a lake peninsula approximately 230 m above sea level and approximately 3 km from the river Tasiusaa. Quarrying will take place in an open quarry. Near the mine, there will be crushing, sieving, leaching, and grading activities to convert the ore to a raw concentrate that can be shipped to Nuuk for further refining. The lake will undergo changes: firstly, the water surface will be lowered, and secondly, the tailings will be deposited in a predefined part of the lake. The most important environmental aspect of the project is associated with the changes of the lake. The EIA concluded that the lake is expected to slowly regain its original lake dynamics and clarity after the mine closes. The water level will be restored within 2–3 years of the refilling of the outlet trench (a drainage outlet dug for the purpose of lowering the lake water level). In addition, during the purification process in Nuuk, hydrofluoric acid will be used. This chemical is extremely corrosive, and thus there will be strict rules related to its disposal after use.

Anorthosite at Naajat – "White Mountain" in west Greenland. A large deposit of anorthosite, which consists of 90–100% calcium feldspar, is located approximately 80 km southwest of the Kangerlussuaq airport. The company Hudson Resources Greenland A/S received an exploitation license for this deposit in 2015 (Figure 7.1). The project involves the creation of a quarry, a road, and port facilities at Kangerlussuaq. The project will extract the ore from an open pit mine by drilling and blasting. Approximately 30 full-time positions are expected to be required at the mine site during operation. The mine will supply the fiberglass industry with feed material as a replacement for kaolin. This material also has the potential to replace bauxite in the production of alumina and to provide solutions for the very large mineral filler/extender market. The environmental effects are overall considered relatively small. As of February 2018 the company is establishing infrastructure and expects to start production in 2018.

Iron at Isukasia. In 2013, the company London Mining Greenland A/S was granted an exploitation license for iron extraction near the inland ice north of the inner part of the fjord Nuup Kangerlua (Figure 7.1). The occurrence of iron here is significant. The project is currently pending, while the company seeks financing to initiate the extraction. Isukasia is a good example of a project that is suffering from the effects of declining commodity prices.

Zinc and lead in Citronen Fjord in northern Greenland. In December 2016, the company Ironbark A/S was granted an exploitation license for the minerals sphalerite (a zinc-ore mineral) and galena (a lead-ore mineral). The company is expected to start production within the next 5 years. However, the company must first obtain the Government of Greenland's approval of an exploitation and closure plan. The company submitted an application for this in 2017.

Rare earth metals and arfvedsonite in Kringlerne, near Narsaq. The Australian-owned company Tanbreez has applied for an exploitation license for a site near Narsaq in south Greenland. The Government of Greenland is currently reviewing the application documents.

Projects at an advanced stage but without exploitation permission

Rare earth metals and uranium in Kuannersuit (Kvanefjeld) near Narsaq. Kvanefjeld, near Narsaq in south Greenland, contains a large number of rare elements in higher concentrations than Earth's crust generally holds. During the period from the 1950s to the beginning of the 1980s, studies were conducted to clarify the possibilities for exploitation here, especially of uranium. Evidence of rare earth metals, in particular, gave rise to a huge interest. The Kvanefjeld deposit's association with uranium has raised concerns locally, as well as in the rest of Greenland and Denmark. In December 2015, the Australian-owned company Greenland Minerals and Energy Ltd. submitted a draft version of the environmental impact assessment and social impact assessment (SIA) for the project. Currently, the EIA and SIA are undergoing review by the Government of Greenland.

7.1.1.2 Nunavut

The area that is now Nunavut has had a number of mines since the 1950s, starting with the Rankin Inlet nickel and copper mine in 1957. In the portion of Nunavut covered by this BBDS study, there have been two commercial mines: the Nanisivik lead–zinc mine, which ran from 1976 to 2002, and the Polaris zinc mine, which ran from 1981 to 2002. Since then, the only mine in the BBDS region of Nunavut to go into production is the Baffinland iron mine at Mary River on northern Baffin Island (Figure 2.11). Recent commodity price decreases have resulted in scaled-down operations from what was initially envisaged. As in other areas of the BBDS region, exploration activity has increased substantially in Nunavut over the past 10 years and several new projects are being considered. This activity includes a promising diamond site. At the same time, recent commodity price decreases have meant a decrease in exploration expenditures, as seen in Figure 7.3.

Mining is seen by the Government of Nunavut as a key part of its future economic development. In this regard, the government works closely with the land claims organization, Nunavut Tunngavik Inc. (NTI). The importance of mining was elaborated on in the first Nunavut Economic Development Strategy, which was developed as a joint effort in 2003. This strategy clearly stated the need for a sustainable economy

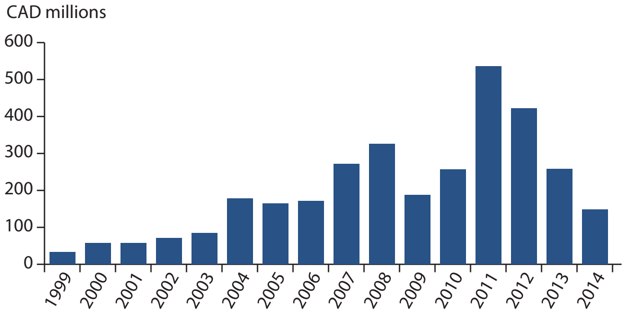

Figure 7.3 Mineral exploration expenditures in Nunavut, 1999–2014, in CAD millions (data for 1999–2008 are from Natural Resources Canada, 2009; data for 2009–2012 are from AANDC, 2015a). (As of 5 June 2017, 1 Canadian dollar = 4.90 Danish kroner.)

in the region and noted also the need for Nunavut to access natural resources through activities such as mining in order to provide the territory with the capital required to develop a sustainable economy (SEDSG, 2003). More recently, working once again in partnership with NTI and other organizations, the Government of Nunavut developed the 2006 Nunavut Mineral Exploration and Mining Strategy (Nunavut Department of Economic Development and Transportation, 2006).

While public-sector expenditures currently represent the most important sector of the Nunavut economy (32% percent of Nunavut's gross domestic product), mining is now – following the 2010 opening of the Meadowbank gold mine (Kivallik Region) and the 2014 opening of the Baffinland iron mine (Qikiqtaaluk Region) – the second most important sector (Nunavut Bureau of Statistics, 2015). Mining continues to be seen as one of the most important sectors for growth in the territory. In 2014, mining represented 18% of Nunavut's gross domestic product. Construction, some of it related to mining, represented an additional 16% of GDP. Exploration expenditures have increased substantially over the past 15 years, as seen in Figure 7.3.

Projects in production

Mary River mine, Baffin Island. The Mary River Project is currently the only mining project in production on the Nunavut side of the BBDS region. Production started in 2014, and the first load of iron ore shipped to Europe in August 2015. Though this mine is in production, it was hit hard by falling commodity prices in the autumn of 2013. The mining company's original (2010) plan called for the company to build a 149 km railroad from the mine site in the interior of northern Baffin Island to an all-season port at Steensby Inlet (Baffinland Iron Mines Corporation, 2010; see also Chapter 10). A total of 21 million tons per annum were to be produced at the mine for a period of at least 21 years. Of this amount, 18 million tons were to be shipped out of Steensby Inlet on a year-round basis. A northern port at Milne Inlet, with an existing road from an earlier development, was to be used to ship an additional 3 million tons a year but only during the three-month open water season. The fall of commodity prices has meant that Baffinland has been unable to secure financing to build the railroad and is instead planning to ship ore only from Milne Inlet. The company has a permit to do so for the 3 ice-free months of the year and would now like to to extend the shipping season to 9 months so that enough ore can be shipped to attract investments for the original plan. This proposal has met with opposition in northern Qikiqtaaluk Region (formerly called Baffin), due to concerns about the impacts of ice-season shipping on the local wildlife necessary for subsistence harvesting (see Subchapter 3.3 and Chapter 6).

How potential future conflicts regarding geographically overlapping areas of competing interests will play out remains difficult to assess. However, previous instances of locally expressed concerns about disturbances to sea ice and wildlife habitats may shed some light. When the Canadian-based company Greenex A/S operated the Black Angel mine in the municipality of Uummannaq (Greenland), a conflict arose in the early 1970s between the company's transport ship *Sigyn* and the local subsistence hunters who used the annual winter sea ice during the spring harvesting season. The heart of the matter was the disturbance caused by the ship breaking through otherwise stable ice, thus severely hampering the local harvest and endangering fishermen who were farther out on the ice (i.e., seaward of the ship's ice-breaking path). The takeaway message from this case was that the dispute between the local stakeholders and the company was settled at the municipal (not national) level, with the mutual signing of the so-called Uummannaq agreement, which clearly outlined restrictions on the timing of the shipping of ore in local waters (see Dahl, 1976).

Others with permits. The Mary River mine is the only project in the Nunavut portion of the Baffin Bay/Davis Strait study region with a production permit.

Projects at an advanced stage

Five other projects are listed as "active" in the Qikiqtaaluk region, according to the federal and territorial government (AANDC, 2015b). These projects are still in the exploratory phase. MMG Limited is listed as having an exploration project at its Borden base metal site on the northern end of Baffin Island. Vale Canada is listed as having an active nickel–copper exploration project at its West Melville site on the Melville Peninsula. A more active base metal exploration project exists at the Storm site of Ashton Bay Holdings Ltd. on Somerset Island.

Recently, diamond exploration on Baffin Island has attracted new attention. Diamond mining is somewhat less negatively affected by current commodities pricing, and as a result, diamond exploration projects are seen as being more likely to result in productive mines. In particular, the Chidliak project on southern Baffin Island, run by Peregrine Diamonds Ltd., is creating the most interest (AANDC, 2015b). Another diamond project on southern Baffin Island, the Mel site, is being examined by North Arrow Minerals Inc.

7.1.2 Oil and gas exploration and extraction activities

7.1.2.1 Greenland

The most comprehensive hydrocarbon drilling campaign to date in Greenland was conducted by the Scottish oil company Cairn Energy PLC in 2010 and 2011. In 2010, 3 wells were drilled in the license block Sigguk, Disko West. In 2011, 5 wells were drilled: 3 in the license blocks Atammik and Lady Franklin in the Davis Strait, and 1 each in the license blocks Eqqua and Napariaq, in the northern part of the Disko West area. The oil company encountered minor quantities of oil and gas but not enough for commercial exploitation. For further details, see Government of Greenland (2012).

Before the Cairn Energy drilling campaign, 6 other offshore exploration wells were drilled in 2 areas during the years 1976–2000: at Store Hellefiskebanke (1 well by ARCO Greenland Inc.) and in the Davis Strait (1 well by Chevron Petroleum Co. of Greenland, 1 by Total Grønland Olie A/S, 1 by Statoil A/S, and 2 by Mobil Exploration Greenland Inc.).

In 1996, a single onshore well was drilled on the Nuussuaq peninsula by GrønArctic Energy Inc. Three slim holes drilled at the same site were not further developed due to the presence of shallow gas formations (GrønArctic, 1997), although traces of hydrocarbons were encountered.

For more details about the history and current exclusive licenses for oil exploration drilling in Greenland, please consult the website of the Government of Greenland (www.govmin.gl/petroleum).

In *Greenland's Oil and Mineral Strategy 2014-2018* (Government of Greenland, 2014), the strategy was to continue issuing and maturing blocks for future oil exploration (in "mature" areas, the geology is well known, technical challenges are few, and infrastructure is well developed or planned; Norwegian Petroleum Directorate and Norwegian Ministry of Petroleum and Energy, 2017). The strategy is presently under revision for the next time period.

7.1.2.2 Nunavut

Oil and gas exploration and extraction in the Qikiqtaaluk region differs from mining exploration and extraction in that oil and gas are not seen as being an imminent potential benefit to the region. Unlike the situation with mining, the role of Nunavut in oil and gas development is not well defined. Instead, all oil and gas activity is regulated by the federal government (INAC, 2016). The main recent activity has been a 5-year offshore seismic survey program in Baffin Bay and Davis Strait, approved by the National Energy Board (NEB). Unlike the Mary River mine project, this survey activity provoked a great deal of opposition from communities in the area and a recent court challenge by the community of Clyde River (Goodman, 2014; see also Chapter 6). As a result, there has been no recent seismic survey activity.

Compared to mining, little recent attention has been paid to oil and gas development in Nunavut, but there is a history of oil and gas exploration and production in the area. Starting in the late 1960s, significant exploration was undertaken in the Sverdrup Basin, north of the Qikiqtaaluk region of Nunavut (MacIsaac, 2015). Although there has been little activity over the past 20 years, this basin is still considered to be a potential future production site. At the southern margin of the Sverdrup Basin is the Cameron Island Bent Horn site, which produced a high-quality oil from 1985 to 1996. Crude oil was shipped from there to be refined in Montreal. The unrefined oil was used at Little Cornwallis Island's Polaris zinc mine and also in generators in Resolute Bay.

Oil and gas activity in the Canadian North is divided into several oil and gas provinces (OGPs). For the Qikiqtaaluk region, the Eastern Arctic OGP is the most relevant. This offshore province has a history of 5 wells drilled, including 1 discovery (AMAP, 2010). AMAP's 2007 assessment of oil and gas activities in the Qikiqtaaluk region noted that recent exploration in this OGP had been minimal and that further development in this particular subregion remains a "distant possibility" (AMAP, 2010, p. 2_90).

The Qikiqtaaluk region is also linked to two areas of the Hudson Platform OGP: Foxe Basin and Hudson Strait. One well was drilled in Hudson Strait in 1969 and one in Foxe Basin in 1970 (AMAP, 2010). Both were unsuccessful, and there is no current activity in this region.

While little exploration activity is currently taking place on the Nunavut side of the BBDS region, the oil and gas industry has expressed an interest in the Eastern Arctic area of Nunavut, which includes most of the Qikiqtaaluk region. It is suggested that this region contains ultimate initial marketable gas estimated at 16.7 trillion cubic feet (Tcf) and ultimate recoverable oil estimated at 0.8 billion barrels (Barnes, 2015). As a result, a consortium of companies has wanted to conduct a 5-year program of seismic surveying off the coast of Baffin Island. This desire for a survey has been tempered lately by community concerns relating to the protection of Lancaster Sound and the surrounding areas and to ongoing discussions about a national marine conservation area.

In the Nunavut part of the BBDS region, as throughout the Arctic, there is a great deal of concern about offshore oil and gas developments and their potential environmental impacts. Compared to onshore developments, offshore developments are seen as being potentially more damaging to the subsistence activities of local Indigenous communities. In addition, the communities feel that they have not been properly consulted or told how they will benefit from oil and gas developments (Varga, 2014b). Similar observations have been noted in coastal communities on the northwest coast of Greenland, in the districts of Upernavik and Disko Bay (Hansen and Tejsner, 2016).

While current, low energy (oil) prices and high infrastructure costs make the likelihood of oil and gas development in the near future unlikely (Varga, 2014b), there is a recognition that oil and gas could eventually be of benefit to Nunavut (Varga, 2014a) and that there is a need for Nunavut to develop a strategy to guide this potential development. In this respect, Nunavut officials and residents are extremely interested in what is happening with oil and gas development in Greenland (Bell, 2010).

7.1.3 Status of socio-economic impacts

This section describes the income, employment, and infrastructure considered to derive from existing exploration and production activities and hence provides an estimate of their relative importance to local and regional value creation.

7.1.3.1 Exploration impacts

Greenland

The Government of Greenland requires that companies undertake and document social impact assessments (SIAs) and negotiate impact and benefit agreements (IBAs) as part of the application process for permission to undertake extraction-related activities (Bureau of Minerals and Petroleum, 2011; Business and Growth Ministry and the Government of Greenland, 2015). For mining projects, there is no obligation to negotiate IBAs in relation to exploration work. As part of the exploitation permission, though, an IBA agreement is negotiated between the Government of Greenland, the municipality, and the company. For oil and gas projects, the three-party IBA must be negotiated prior to exploration.

The objectives of SIAs and IBAs are, in general, to ensure informed decision-making, to ensure that companies consider mitigation measures for negative impacts, and to enhance the possibility of local benefits in cooperation with communities before activities are carried out (Hansen et al., 2015). Public participation is an integral part of the SIA process. IBAs are negotiated with the purpose of accessing local knowledge, enabling the local people to adapt to industry-related changes, and encouraging connections between the companies and the local people (Olsen and Hansen, 2014). IBA negotiations among a mining company, the Government of Greenland, and the local municipality follow the granting of an exploitation license for hard minerals. The intent of the IBA process is to promote cooperation between the licensee and the Greenland authorities in developing the project as a viable, sustainable, and integrated part of Greenland society. Because IBAs are not required for the exploration phase of mining projects, the only income from mineral exploration activities is through taxation of the local companies and their workers.

An example of a negotiated IBA is the one signed in September 2011 in association with the Cairn Energy exploration drilling license. For this IBA, the associated promised expenditure was 505 million Danish kroner, DKK (about 98 million Canadian dollars, CAD) in 2010 and a further DKK 800 million (about CAD 157 million) in 2011. A substantial proportion of these amounts (about 30%) covered normal local procurement within Greenland, while 8% was related to contractors' expected expenditures in Greenland. Less than 1% related to the cost of training staff. Normal tax payments to the Government of Greenland amounted to DKK 53 million (about 7% of the total figure), and payments to the government shareholding entity, Nunaoil, amounted to DKK 430 million (about 54%). Finally, the IBA promised to contribute DKK 380,000 (about CAD 75,000) to a community development fund (Hansen et al., 2015).

Nunavut

In Nunavut, analyses of socio-economic impacts typically occur only in association with applications for production permits. The socio-economic impacts of the preceding exploration activities are therefore much harder to describe. The mineral exploration expenditures shown in Figure 7.3 are not all spent in the territory. Most of these expenditures are for services and wages that end up outside Nunavut. Still, the territory does receive direct economic benefit from exploration activities. Local firms often provide food, transportation, accommodation, and other logistical services. Local workers are sometimes hired to work on exploration projects. Little research has attempted to measure these economic benefits.

Negative impacts can sometimes occur due to the nature of exploration activities. While the permitting system results in a general knowledge of these activities by federal and some territory-level organizations, local communities are often not as effectively consulted or informed. Lack of local knowledge about the exploration activities can sometimes result in community stress and opposition.

7.1.3.2 Production impacts

Greenland

An example of production impacts can be found in the social impact assessment of the Greenland Ruby A/S project (previously the True North Gems project) (Figure 7.1). The assessment report states that corporate tax is expected to be approximately DKK 90 million over the 30-year mine life span covered by the exploitation permit. Income taxation of personnel is estimated to be between DKK 6 and 12 million per year. The Greenland oil and mineral strategy (Government of Greenland, 2014) states that the revenue may rise substantially if the company succeeds in selling rough rubies rather than polished rubies (True North Gems and Grontmij, 2013).

The IBA agreement with True North Gems Greenland (now LNSGG) includes the provision that the company shall at the start of the anticipated production annually allocate DKK 1,000,000 to educational funds and DKK 250,000 to social and cultural funds. These yearly contributions are to continue until the mine is decommissioned. Further, the company shall reimburse the municipality's costs related to IBA negotiations, up to DKK 150,000 per year.

Education and capacity building of the local work force is key to further economic development in Greenland (see Chapter 5). The larger the proportion of local workers in the mining industry, the larger the income contribution to the Greenland economy.

As described in the SIA of Hudson Resources Greenland A/S (Hudson Resources, 2015) for their anorthosite (feldspar) mine (Figure 7.1), mining projects may have a small but positive effect on education levels locally and across Greenland. The potentially higher household incomes in the vicinity of an active mine may enable children to remain in school or seek further education instead of entering the workforce to support their families. The skills improvement associated with professional worker retraining may apply to only a small proportion of Greenland's population. This limited impact is due to the fact that extraction projects are likely to attract workers who are already employed in mining or in related sectors (Hudson Resources, 2015). Nevertheless, such projects may indirectly create opportunities for skills development and jobs for unemployed workers in Greenland.

Clive Tully/Alamy Stock Photo

Truck at Seqi olivine mine, Greenland

Based on the Hudson SIA (Hudson Resources, 2015), it is expected that local revenue will accrue primarily during the operations phase rather than the construction phase of the mine. Most of the construction material for this particular project will be sourced from Europe and North America and will be brought to the project site by ship. The operations-phase revenue to the government and Greenland communities and residents will come partly from labor and partly from supply services.

Cooperation between public and private enterprises may serve to enhance the local benefits of mining projects, in terms of both revenue generation and capacity building. Such cooperation can be encouraged and promoted by the advisory company Greenland Business A/S (a subsidiary of Greenland Holding A/S), which aims to promote and develop national businesses in close cooperation with the municipalities.

In connection with the Hudson project, it is also possible that people with the appropriate professional skill set may relocate to the area of mining activity as new residents. However, the project-induced in-migration is expected to be limited. A large fraction of the workforce will be foreign but will fly-in/fly-out (FIFO) for each extended shift. It is not expected that this workforce will come to permanently reside in Greenland; hence, the project is not expected to lead to substantial demographic changes in the local population profile (Hudson Resources, 2015).

In-migration can affect local societies by increasing demand for housing and infrastructure (Chapter 10). In assessing the impacts of mining production, the potential for increased crime, health problems, and disputes over benefits (Hansen, 2013) must also be considered.

Nunavut

The environmental impact statement provided by Baffinland in order to obtain a production permit for the Mary River iron mine on Baffin Island (Figure 2.11) (Baffinland Iron Mines Corporation, 2010) listed a large number of positive socio-economic impacts. The report noted that the cost of building the mine and accompanying infrastructure would be CAD 4.1 billion. According to the company, the mine will help Nunavut meet its needs for infrastructure, training, and sustainable economic development. The Inuit Impact and Benefit Agreement (IIBA) between Baffinland and the Qikiqtani Inuit Association will ensure that benefits flow to the Inuit communities in close proximity to the mine. The mine is expected to provide 21,080 person years of employment. In addition to the financial benefits agreed upon in the IIBA, more than CAD 1.6 billion in taxes is expected to be paid to the Government of Nunavut and more than CAD 1.9 million in royalties is expected to be paid to Nunavut Tunngavik Inc. over the proposed life of the mine. The mine is expected to strengthen the economy of Nunavut, thus decreasing economic instability.

These estimated financial impacts are based on an estimated yearly production of 21 million tonnes. Under current conditions, though, unless a permit is approved for Baffinland to increase its Milne Inlet shipping season to 9 months instead of 3, the limiting of yearly production to 3 million tonnes will result in considerably fewer benefits until and unless capital is secured to build the railroad to Steensby Inlet.

Despite the size of the Mary River project and the large number of potential impacts, the project did not face a great deal of opposition. Concerns on a variety of issues were expressed at the hearings of the Nunavut Impact Review Board (NIRB), but these concerns did not lead to a large-scale movement against the development.

The risk that demographic asymmetry might develop in the local societies as a result of, e.g., mining projects, was also considered as a part of this BBDS study. For the Qikiqtaaluk region, the demographic differences are assessed not to be particularly significant because all ongoing and planned work is to be fly-in/fly-out.

There is currently no oil or gas production in Nunavut.

7.1.4 Present environmental regulation, impact, and mitigation

Greenland

In connection with all projects and activities assessed to potentially significantly affect the Greenland environment, the permit applicant must conduct an environmental impact assessment (EIA). The EIA scoping document goes through preliminary consultations between the company, the Self-Government's Environmental Agency for Mineral Resources Activities (EAMRA) and EAMRA's scientific advisors. This pre-consultation of 35 days is followed by public consultation regarding the draft EIA before the Government of Greenland makes a decision regarding EIA approval. In the EIA, the applicant must explain all relevant environmental conditions and must document that the principles of best available technique (BAT) and best environmental practice (BEP) are being applied. EIA must be based on actual environmental studies in the area. If the Mineral Resource Authority concludes that there is insufficient information about potential environmental impacts and the technologies to be used, it may request that the company undertake additional studies.

A number of guidelines and threshold values, prepared and implemented by the Mineral Resource Authority, make up the framework of environmental regulations that govern the extractive industries' activities in Greenland. The guidelines summarize the requirements, considerations, and limitations that apply to companies preparing project-specific environmental impact assessments and applying for permits for large-scale extractive industries activities. Based on the EIA report and permit application, the authorities draft specific requirements and conditions for the project in question, including a framework for environmental monitoring.

All guidelines are available at this website: www.govmin.gl.

A special set of guidelines has been drawn up for fieldwork, to ensure that preliminary studies and exploration activities are performed in an environmentally responsible manner. The general rules for fieldwork include rules for driving, aviation, and navigation; camps in the field; and the handling of fuel, waste, and clean-up operations (Government of Greenland, 2000). In certain areas, these rules are more restrictive than the standard rules for traffic on Greenland's landscape, as local exploration activities can be quite extensive.

All guidelines include requirements, instructions, and indicative guideline values from a number of countries and international forums. A number of Norwegian standards, for example, are used for Greenland oil activities (i.e., the Norsk Sokkels Konkuranseposisjon (NORSOK) standards), and the environmental provisions of the OSPAR Convention (the Oslo and Paris 1992 Convention for the Protection of the Marine Environment of the North-East Atlantic) are generally used throughout Greenland waters, even though the convention in principle applies only to oceans east of Cape Farewell. The OSPAR Convention has been very effective in reducing pollution from the oil industry in the North Sea. The Arctic Council's guidelines for offshore oil activities in the Arctic also apply (Arctic Council, 2009).

Based on the entire rules set, both mining and oil production are subject to the principle that large-scale activities should be covered by an EIA and should include hearing phases. Exploration activities are handled differently. For large-scale oil exploration activities, EIA requirements apply and guidelines are provided for seismic activities as well as stratigraphic and exploration drillings. For mining projects, major exploration activities are governed by field rules and individual approvals; an EIA procedure is not automatically required. If roads and piers, for example, need to be constructed for a pilot mining plant and the shipment of large quantities of ore for experimental processing, the company must apply for a permit but does not automatically have to adhere to the EIA procedure. Because such operations often leave permanent traces on the landscape, the introduction of an EIA procedure with a hearing process could be considered for these types of activities.

Careful planning and site selection is essential to minimize the harmful impacts of mining and oil industry activities on nature and the environment. In Greenland, the choice of location for industry activities is governed by certain principles, which include activity restrictions for nationally and internationally protected areas and must be complied with. Ideally, an environmental analysis (a strategic environmental impact assessment, SEIA) should be carried out before new areas can be opened for the tendering of exclusive oil licenses.

To manage and meet the environmental challenges and potential consequences associated with offshore oil activities in Greenland waters, the Government of Greenland has commissioned a number of regional strategic environmental impact assessments, in accordance with the recommendations of the Arctic Council, including a number of scientific background surveys and studies. An SEIA summarizes the available knowledge and environmental status of a region without oil activities (a "zero solution") and describes how the region may be affected if oil activities are permitted. Over the last decade, most offshore marine areas around Greenland have been covered by the SEIA program and available knowledge of the area has been summarized. Key environmental risks and gaps in knowledge have also been described in the reports, which are available at the website of the Government of Greenland's Ministry of Mineral Resources (www.govmin.gl/petroleum/environment/environmental-reports). All SEIAs and the corresponding surveys have been carried out at a scientific level, and all data have been organized in a data center.

There, the knowledge associated with the individual regions is stored for use in connection with the development of EIAs for current activities and further administrative regulation and planning. The knowledge about nature and the environment thus generated in connection with mineral resource activities is also available for the planning and regulation of other sectors.

Onshore regional SEIAs, similar to those conducted for offshore areas, have so far taken place only to a very limited extent, in connection with mining operations.

Nunavut

Environmental regulation on the Nunavut side of the BBDS region is governed primarily by Article 12 of the Nunavut Land Claims Agreement (CanNor, 2015). This article establishes the main organization responsible for reviewing resource development projects, the Nunavut Impact Review Board. The Nunavut Planning Commission, in addition to the NIRB, also reviews projects to ensure that they comply with existing land use plans. The process starts with the Nunavut Planning Commission, which evaluates whether a project is exempt from the screening requirement.

The screening process begins when a project proponent submits a proposed project for screening by the NIRB. This initial screening is to determine whether a more in-depth review is necessary in order to better understand project impacts. The NIRB issues a recommendation to the Federal Minister of Indigenous and Northern Affairs regarding whether a more in-depth review is necessary. If the minister decides that a full-scale environmental assessment is necessary, this process will be organized and conducted by either the NIRB (called a Part 5 review process) or a panel composed of members appointed by the Federal Minister of the Environment and Climate Change (a Part 6 review process). After the environmental impact assessment is completed, the organizing body sends its recommendations to the responsible federal minister.

If the project is approved by the minister(s), the process then enters a formal permitting stage that is managed in part by the Nunavut Water Board under Article 13 of the Nunavut Land Claims Agreement.

Approval of a project also depends on the successful negotiation of an Inuit impact and benefit agreement. Within Canada, this requirement is unique to Nunavut – it is the only jurisdiction that formally requires such an agreement. The Nunavut Land Claims Agreement requires that IIBAs be finalized before development projects can begin. These agreements must be negotiated and agreed upon by Inuit and the project proponents, and they must be approved by Canada's Minister of Indigenous and Northern Affairs.

Also, for any project related to oil or gas in Nunavut or Arctic offshore areas, a benefits plan approved by the Minister is required under the Canada Oil and Gas Operations Act. The benefits plan represents a commitment by the project operator to provide employment to Canadians and full and fair opportunity to Canadian businesses, preferably local northern Indigenous residents and businesses in the vicinity of the proposed work.

The Baffin Bay/Davis Strait region also includes Canadian areas outside the Nunavut Settlement Area, where the Nunavut Land Claims Agreement applies. In the Canadian offshore waters of Baffin Bay and Davis Strait, the National Energy Board is the lead federal regulatory agency on safety and environmental effects, and this board is responsible for the administration of all technical and environmental approvals for oil and gas projects. As the regulator, the NEB is responsible for evaluating project applications (e.g., the recently authorized seismic survey program mentioned above) under the Canada Oil and Gas Operations Act. When considering an application for such authorization, the NEB must consider the safety of communities, the public, and workers; protection of the environment; and conservation of oil and gas resources.

In addition to the above regulations, the Government of Canada has also committed to conducting a strategic environmental assessment (SEA) for Baffin Bay and Davis Strait, relying on Inuit and scientific knowledge to better understand the potential effects of future oil and gas activity and to inform whether such activity should proceed.

7.1.4.1 Evironmental impacts of mineral and petroleum exploration and extraction, plus mitigation measures

Mining

The following information is based on Mosbech (2014).

Mines typically have an active extraction phase spanning a few decades, and it is important that the condition in which they are left does not cause environmental problems at a later stage. The initial planning and environmental impact assessments for a mining project therefore cover not only mine operations but also the closure of the mine. Closure plans include both a clean-up plan and a long-term plan to secure deposits of waste material (e.g., tailings) following closure and decommissioning. Governmental authorities can ensure that some of the company's financial means are set aside for the closure and subsequent environmental monitoring, so that funds are available even if the company encounters financial difficulties.

Mining has the potential to affect the environment in many ways. Mining, processing, and transportation of minerals produce waste products, with wastewater, dust, smoke, and noise being discharged into the environment. The local mining (workforce) community, which may comprise hundreds of inhabitants, may also have an impact on the environment and on nearby local communities. Mining normally involves the extraction and crushing of ore and a certain amount of further processing of the extracted ore, as well as disposal of the waste products. Waste products include "waste rock," which is rock that must removed to gain access to the targeted mineral deposit. This rock material may be inert, but it can sometimes contain metals in concentrations too low to make extraction financially viable but still high enough to cause environmental problems. The ore, which contains the valuable minerals, is often crushed into small particles that are further processed and converted to a concentrate that can be shipped out for the next step of processing. In some cases, the concentrate goes through a further chemical process on-site to extract the valuable components. It is important to keep in mind the environmental consequences of this chemical extraction process. The remainder of the ore – the tailings – is deposited onshore, in a lake, or in the ocean.

The environmental pollution caused by mining is often associated with the dust produced when the ore is crushed, the use of chemicals added during the extraction process (e.g., cyanide in the case of gold), and the release of heavy metals from waste products, tailings, and waste rock. It is important that these sources of pollution be carefully considered in the environmental impact assessment to ensure that an environmentally safe solution is at hand to deal with, for example, the removal of tailings.

Petroleum exploration and production

The following information is primarily based on Mosbech (2014) and Wegeberg et al. (2016).

Oil exploration activities are temporary. Development of the field and production activities will be initiated on a more long-term basis only if commercial reserves of oil are discovered. The major impacts from oil exploration and production are disturbance from noisy activities (primarily seismic activities but also the positioning of the drilling rig, drilling, transportation by ship and helicopter) and discharges from drilling activities (including drilling mud and produced water). However, the worst-case scenario for the environment is a large oil spill.

Marine seismic surveys create far-reaching and high levels of noise in the marine environment. This noise can potentially harm marine mammals and fish at close range, but more serious are its disturbance effects, which may displace fish from spawning grounds and marine mammals from feeding grounds and other critical habitats. Physical impacts can be reduced by shutting down the seismic sound source when marine mammals are too close, but disturbance impacts are much more difficult to reduce in any way other than simply avoiding surveying in critical areas during critical time periods or critical seasons. It has been pointed out that limited knowledge is available regarding the migratory patterns of marine mammals (CAFF, 2013). However, as part of the environmental studies program connected to a company's work program and license obligations, studies of marine mammals are included in an effort to accumulate background knowledge (e.g., the environmental studies programs of the Baffin Bay and northeast Greenland licenses).

Cumulative impacts from simultaneous seismic surveys is a risk that remains difficult to assess. In Greenland, seismic operators are required to conduct joint modeling of their combined noise propagation in order to address cumulative impacts.


All Canada Photos/Alamy Stock Photo

An aerial view of Baffinland's Mary River iron ore mine on Baffin Island, Nunavut, Canada

In connection with exploration and production drilling activities, drilling mud is used. This mud, together with drill cuttings, may potentially be discharged to the sea in compliance with current regulations. In Greenland, the OSPAR Convention guidelines are followed (even though OSPAR applies only to eastern Greenland seas), with supplementation by Norwegian regulation on more specific issues (Gustavson et al., 2013). In the oil exploration drilling campaigns of 2010 and 2011, water-based drilling mud was discharged to the sea. Drilling mud may contain a suite of chemicals, which, together with the physical impacts of discharging drill cuttings and mud, may affect seabed fauna. In Greenland, the regulatory requirements state that only relatively environmentally friendly chemicals (low toxicity, non-bioaccumulative, biodegradable) may be discharged (see the Norwegian system of the OSPAR Convention's classification of chemicals). Baseline studies of seabed biology and chemistry must be performed before drilling mud and cuttings can be permitted for discharge. Post-discharge monitoring must also be performed to ensure that discharge requirements are complied with, that no unexpected impacts can be identified, and hence that the regulatory requirements are sufficient to protect the environment.

The discharge of produced water (i.e., water produced in connection with oil or gas extraction) is also of major concern. This water, which is produced in large volumes, contains small amounts of oil and a suite of more or less environmentally harmful substances. In Norway, treatment requirements

Steve Morgan/Alamy Stock Photo

The exploratory drilling rig Leiv Eiriksson off the coast of Greenland in the Davis Strait

and discharge approval are based on a field-specific risk analysis; often, the produced water is not discharged but is instead reinjected into the well (Oljedirektoratet, 2011). In Greenland, however, no oil field development or production has been initiated and no national regulation is yet developed on this issue.

Emissions to the air are also relevant – especially, in the context of this Adaptation Actions for a Changing Arctic (AACA) report, the emission of greenhouse gases. An oil field under production will contribute significantly to Greenland's national greenhouse gas emissions. For comparison, the large Norwegian oil fields emit more than twice as much carbon dioxide as the annual total for Greenland.

The biggest threat to the marine environment from oil exploration and production in the Arctic is a major oil spill (Skjoldal et al., 2007; AMAP 2010). A major oil spill can be the result of a blowout or an accident involving shipping activities, a damaged fuel tanker, or a storage tank. The spreading, breakdown, and effects of an oil spill in the ocean are highly dependent on oil type, weather conditions, and locality.

The high concentrations of oil that result from major spills in the ocean can affect all types of organisms, until the oil has been sufficiently diluted or broken down. Due to the Arctic's low temperatures, darkness, and ice, as well as the limited possibilities for oil recovery and mitigation, it is likely that marine life and resources would be exposed to oil for an extended period of time in the event of an accident in BBDS waters, compared to times experienced at lower latitudes (Fingas, 2011). In connection with the large 2010 oil spill from the *Deepwater Horizon* at the Macondo well in the Gulf of Mexico, oil and gas were broken down even at great depths (>1000 m), where the temperature is as low as in many Greenland waters (4–5°C) (Hazen et al., 2010). However, factors other than temperature are also important for the speed of breakdown, including the presence of microorganisms capable of metabolizing the hydrocarbons. To fill in a knowledge gap for Greenland, studies on the natural potential for oil breakdown in the oceans around Greenland have now been initiated (Kristensen et al., 2015; Vergeynst et al. (2018), Wegeberg et al. (2018).

Offshore, pelagic life or seabirds may be at risk of impacts at the population level. If spilled oil reaches the coast, the required clean-up efforts may be comprehensive and extensive, and long-lasting environmental harm may be a reality. Also, due to the slow growth rates of Arctic biota (also with long life spans), it could take many years for a population to recover after contamination (Chapman and Riddle, 2005). The toxic effects of oil exposure may also result in cascading effects: if organisms at lower trophic levels are particularly affected, less food is available for species at higher trophic levels (Peterson et al., 2003). To assess the scope and consequences of such effects, it is essential to have in-depth knowledge of these often complex ecological relationships.

The major 1989 oil spill from the tanker *Exxon Valdez* in Prince William Sound of southern Alaska (Subarctic bioclimatic zone) had not only major immediate impacts on large wildlife population concentrations but also long-term chronic effects. Oil sank into beach sediments and later slowly seeped out, without having been broken down in the interim. The effects of the spill were local but very long-term – evident, for example, in increased activity of the detoxifying liver enzyme systems of birds, which are affected by oil exposure via their food. Such chronic effects were documented at exposed coastlines in Prince William Sound 25 years after the oil spill; nevertheless, most of the populations affected by the spill are regarded as now having recovered or being well on their way to recovery (Shigenaka, 2014).

Regarding the socio-cultural impacts of oil spills, very few studies particular to the Arctic exist. However, a recent dissertation, based on a year of fieldwork in the Alaskan coastal communities of Chenega and Tatitlek, on the shores of Prince William Sound, has examined the human dimensions of the *Exxon Valdez* disaster (Connon, 2013). Altogether, some 15 native Alutiiq villages along the coastline experienced some degree of oil pollution at their village beaches, lands, and waters, including in their traditional harvesting areas. The long-term impacts of the oil spill continue to affect the lives and subsistence economy of the community residents (Connon, 2013). In addition to the residents' enduring loss of livelihoods and incomes as a direct consequence of the disaster, many residents express grievances about loss of cultural identity and Alutiiq (local) political power on the national stage. Actions taken by the Alaskan authorities and affiliated institutions in the years following the spill did not improve relations between the government and local stakeholders but rather added to an enduring legacy of distrust among the Alutiiq for these authorities.

The mapping of Greenland coastlines vulnerable to oil spills has identified a number of coastlines similar to the Prince William Sound coasts where oil drifted ashore following the *Exxon Valdez* spill. (This mapping was conducted by the Danish Centre for Environment and Energy, DCE.) There is therefore a risk of similar long-term effects in Greenland if a major oil spill were to reach such coastlines. In general, there is insufficient knowledge about the rate at which stranded oil is broken down on different types of coastlines at different latitudes in Greenland, and results from such studies are underway.

7.2 Expected level of medium-term (2030) and long-term (2080) activities

In this section, expected future levels of activity are discussed in relation to the major factors affecting the development of the extractive industries: (1) commercial attractiveness/commodity pricing, (2) political acceptance, (3) environmental sensitivity, and (4) feasibility/availability of resources, including the effects of ice cover retreat.

As quoted from Emmerson and Lahn (2012, p. 19):

> "*Three key factors are sharpening interest in the Arctic's mineral resources:*
>
> - *Feasibility: Technological improvements mean that many more resource projects are technically feasible and commercially viable while geological risks can be better managed.*
> - *Commercial attractiveness: High commodity prices, coupled with uncertainty about access to resources elsewhere in the world, make a far wider range of potential Arctic projects attractive to investors.*
> - *Access: Improving access to large parts of the Arctic reduces costs of operation and eases logistics.*
>
> *These factors are strongly inter-related and tend to be mutually reinforcing. They apply across the full spectrum of mineral resource projects – from oil and gas to mining.*"

This perspective is consistent with the discussions above of BBDS physical (climatic) and socio-economic drivers (Subchapters 3.1 and 3.3, respectively). The trend of ice cover retreat, both at sea and on land, is expected to continue, potentially increasing resource availability. With the retreat of ice cover, more resources may be revealed. Also, previously inaccessible areas will open for increased and easier shipping due to the reduced need for icebreakers. In addition, the seasonal window for exploration and drilling activities (i.e. the ice-free period) will increase in duration. According to Emmerson and Lahn (2012), the most ice-prone areas are likely to experience the greatest changes, whereas areas already more lightly ice infested may experience less radical changes.

On the other hand, climate change may also introduce logistical challenges. For example, ice reduction may make inland areas less accessible due to permafrost reduction – i.e., less stable and less supported terrain (see Chapter 10 for details).

With respect to combating global warming and climate change – and in sharp contrast to the scenario of increasing interest in potential Arctic hydrocarbon reserves – McGlade and Ekins (2015) recommend that the oil and gas within the Arctic Circle be classified as unburnable. They estimate that this area contains100 billion barrels of oil (including natural gas liquids) and 35 trillion cubic meters of gas in fields that are still unexploited (as of 2010). They also put forward that, globally, in order to keep warming below 2°C throughout the 21st century, a third of all oil reserves, half of all gas reserves, and over four-fifths of current coal reserves should remain unused from 2010 to 2050. The authors find "*that development of resources in the Arctic and any increase in unconventional oil production are incommensurate with efforts to limit average global warming to 2°C*" (McGlade and Ekins, 2015, p. 187).

A strong driver of industry development, as mentioned by Emmerson and Lahn (2012) and also described in Subchapter 3.3, is feasibility in terms of commodity prices and extraction expenses. This factor, which is crucial for exploration initiatives, depends on world market prices and economies.

For example, for the Canadian side of the BBDS region, the trends for activities related to mineral resources are assessed as follows:

Medium-term: The level of activity of both mining and oil and gas development in the Qikiqtaaluk region depends heavily on commodity pricing. While climate change could be a factor, there is little strong evidence to indicate what impact it might have. Over the period between now and 2030, it is likely that mineral commodity prices will recover and the Mary River project will proceed at its originally planned level of production. This increase in production is likely to provide substantial financial benefits to the Government of Nunavut, Nunavut Tunngavik Inc., and the Qikiqtani Inuit Association. It is also possible that the diamond exploration currently taking place on the Chidliak site on southern Baffin Island could develop into active production during this time. It is unlikely that oil and gas activity will result in a producing site over this period, but if agreements can be negotiated among local and regional actors and industry, then exploration activity (e.g., seismic surveying) may increase.

Long-term: As current sources of minerals and oil and gas are exhausted and as new sources become more and more difficult to find, it is likely that the Qikiqtaaluk region will experience increased mineral and oil and gas development. While commodity pricing remains the dominant determinant of the extent of this activity, climate change may prove to be a barrier to these activities during this period. Melting of permafrost will result in infrastructure problems (Chapters 3 and 10). Lack of stable sea ice will be a problem for both shipping and offshore oil and gas development as the ice becomes more unpredictable (Chapter 9). In the longer term, however – beyond 2080 – it may be that climate change may provide for easier shipping and offshore development.

7.3 Alternative energy resources

This section treats other non-living resources, especially with regard to energy production: hydropower, wind power, and solar energy.

7.3.1 Hydropower

7.3.1.1 Greenland

Hydropower is the primary source of renewable energy in Greenland and currently covers about 60% of the energy production of Nukissiorfiit (Greenland's energy supply company). However, less than 20% of Greenland's total energy consumption is supplied by hydropower and waste incineration.

Greenland's hydropower is characterized by small natural reservoirs and a few small dams, with little adverse effect on nature, local climate, and people (Government of Greenland, 2016b). As of 2016, Greenland has five hydropower plants; details are summarized in Table 7.1.

The use of hydropower is a priority for the Greenland government, and unused hydropower potential exists in most parts of Greenland. Since 1993, the government has annually spent about 1% of the gross national product on hydropower development (Government of Greenland, 2015). Nukissiorfiit lists 16 sites as being potentially suitable for industrial supply (Nukissiorfiit, 2005): 1 is located in the Narsaq area, 3 are in the Paamiut area, 8 are in the Nuuk area, 3 are in the Maniitsoq area, and 1 is in the Ilulissat area. Micro-hydropower plants are increasingly being installed by sheep farmers in South Greenland (see Subchapter 6.6).

Table 7.1 Greenland hydropower plants (from Government of Greenland, 2016b).

Plant	Supply area	Year established	Capacity (megawatts)
Buksefjorden	Nuuk	1993	45
Tasiilaq	Tasiilaq	2004	1.2
Qorlortorsuaq	Narsaq and Qaqortoq	2008	7.2
Sisimiut	Sisimiut	2010	15
Paakitsoq	Ilulissat	2013	22.5

In 2012, the Government of Greenland licensed rights to hydropower potential to Alcoa, which planned to build an aluminum smelter in Maniitsoq. By 2015, however, these plans were on standby due to falling commodity prices. The Government of Greenland has agreed with Alcoa that the hydropower potential can be made available for other purposes, including potential mining projects such as the Isukasia iron mining project.

The Government of Greenland encourages the use of not only hydropower but also solar energy. Wave energy and tidal energy have not been investigated or mapped for Greenland. As of yet, no mining companies have concluded that ocean energy has usable local potential, but candidate sites might be found where tidal currents are strong and technical problems with ice and icing are tractable (Mai and Lemgart, 2005).

7.3.1.2 Nunavut

Energy is a long-standing challenge on the Nunavut side of the BBDS region. Almost all energy comes from diesel-based generators in each community. These generators are a problem in that many are now extremely old and are experiencing mechanical breakdowns (Senate of Canada, 2015). The dependence on diesel power is problematic in terms of financial costs and environmental issues. As a 2015 report from the Canadian Senate noted, renewable energy initiatives in Nunavut are almost nonexistent (Senate of Canada, 2015).

Hydropower has been examined by the Government of Nunavut and is considered a desirable alternative, despite a certain degree of opposition to hydroelectric developments in the region (McDonald and Pearce, 2013). The government was at one time considering a hydroelectric project outside of Iqaluit. However, the capital costs of the project were prohibitive, and all exploratory work was halted in 2015. According to the territory's Energy Secretariat, the only hope for new hydro projects in Nunavut, as in other parts of the Canadian North, is the possible opening up of new mines with demands for power that would make hydroelectric development possible (Nunavut Energy, 2015).

7.3.2 Wind power

7.3.2.1 Greenland

The policy for wind energy in Greenland, according to Nukissiorfiit, is that this energy resource is not feasible due to the country's wind conditions. The gusts are too strong for standard wind turbines (e.g., as used in Denmark); hence, smaller wind turbines (e.g., as used in the Faroe Islands) would be more suitable.

The potential for energy production by wind power (turbines) in Greenland was investigated in 2000 by PA Energy A/S as part of a project (Mai, 2001) to develop an energy plan for Greenland for 2020 (Mai and Lemgart, 2005). The conclusion from this project, which is reflected in the Nukissiorfiit energy plan and wind energy policy described above, was that wind power is not economically feasible in Greenland for three main reasons (PA Energy, 2000; Mai and Lemgart, 2005):

Peter Jensen / Inuk Media

Solar panels in Greenland

- Wind conditions are extremely variable, being forced by low-pressure systems (strong but relatively few in number), strong autumn winds, and weak coastal breezes; local topography exerts an influence as well.
- Construction costs are high.
- Coordinating new wind energy supply with communities' existing diesel-dependent power grid would be challenging.

Therefore, the recommendation was that if wind power were to be considered for introduction to Greenland, wind measurement programs and feasibility studies should be performed for selected settlements deemed suitable. Small wind turbines were assessed to be potentially relevant to single-building units (e.g., sheep farms, small institutions, tourist facilities, and hunting lodges) (PA Energy, 2000; see also Subchapter 6.6).

In 2010, the Technical University of Denmark initiated wind measurement programs and pilot-scale tests with a wind turbine in the settlement of Sarfannguit (Ingeniøren, 2010; Dragsted et al., 2011). However, even with recent technological improvements, the full potential of wind energy in Sarfannguaq proved to be difficult to assess due to suboptimal performance of the test turbine's electrical installations (Larsen, 2016).

At present, there exist no assessments of wind energy as a long-term future source of energy supply in Greenland. However, in the event of improved technology and increased oil prices, this energy resource may become relevant for Greenland in the future.

7.3.2.2 Nunavut

Three wind power projects have been tried in Nunavut, but none are within the BBDS region (Nunavut Energy, 2015). Wind speeds have, however, been modeled, and the results indicate that Cape Dorset has high wind resources (i.e., wind speed) while Iqaluit has low wind resources. Although the Government of Nunavut does not have the resources to develop potential wind power, it is collecting data on this resource through wind-monitoring towers. The recent installation of a new wind turbine generator combined with hydrogen cells at the Glencore Xstrata Raglan mine in nearby Nunavik suggests that wind power in Nunavut may hold some promise if developed in conjunction with industrial projects (e.g., mining projects) (Canadian Mining Journal, 2014).

7.3.3 Solar energy

7.3.3.1 Greenland

The potential for energy and heat production from solar energy was investigated in 2000 by PA Energy A/S as part of a project (Mai, 2001) for developing an energy plan for Greenland for 2020 (Mai and Lemgart, 2005). Solar irradiation in Greenland was estimated to be at the same level as in Denmark: approximately 1000 kWh/m^2/yr (PA Energy, 2000).

The conclusion from this project was that solar energy may offer some potential as an energy resource in Greenland in the long-term future when the technology is sufficiently developed (but not including the solar heating of water) (PA Energy, 2000; Mai and Lemgart, 2005).

This conclusion has since been supported by studies performed by the Technical University of Denmark (Dragsted et al., 2011), which tested solar panels designed to absorb the sun's rays as a source of energy for generating electricity or heating (i.e., a photovoltaic system built for roofs). The study authors concluded that the energy production was promising provided that suitable connections to the power grid can be obtained.

Technical solutions for the problem of snow-covered panels (i.e., panels shaded from exposure to solar irradiance) are under development (Larsen, 2016). Hence, the increased precipitation described in Chapter 3 is not assessed to prevent the development of solar energy in Greenland, as technical solutions to address this climatic challenge seem likely.

Therefore, solar energy is expected to expand as an energy resource in Greenland in the future. Nukissiorfiit supports solar installations through net metering. Nukissiorfiit purchases excess electricity generation, at a price that is set according to what it saves in diesel fuel at its thermal power generators. Because the net metering tariff is set according to Nukissiorfiit's diesel savings, the tariff is available only in those places that do not receive hydropower.

7.3.3.2 Nunavut

Solar power has been used to a limited extent on the Canadian side of the BBDS region, primarily in experimental pilot projects. The most notable of these is the solar array at Nunavut Arctic College in Iqaluit, which has been in operation since 1995 (Nunavut Energy, 2015). In 2010, four new solar pilot projects were started in Iqaluit to offer supplemental energy to existing diesel energy. While long days in summer mean that solar power can be relatively abundant at that time of year, the short days of winter, when energy demands are highest, mean that solar power is problematic in high latitudes. Although solar power represents a valuable supplemental source of power for Nunavut, the Government of Nunavut also notes that "the start-up costs for installing the systems are potentially high when considering the cost of transporting equipment to Nunavut" (Nunavut Energy, 2015).

7.4 Socio-economic implications

This section lists both the positive and negative potential impacts of developments on communities in the region, as well as factors that influence these impacts. From this list, potential adaptive actions will be identified.

Potentially positive socio-economic impacts:

- Economic development
- Development of infrastructure
- Employment
- Fiscal resources
- Educational enhancement
- Support for traditional activities

Potentially negative socio-economic impacts:

- Boom and bust effects
- Resource curse/staples trap (i.e., continued dependence on primary resource production)
- Environmental impacts (regulation adjustment)
- Loss of culture
- Various social pathologies (e.g., alcohol and drug abuse, family violence, crime)


Melissa Mercier/Alamy Stock Photo

Wind turbine

Elements that influence socio-economic impacts:

- Environmental review processes and regulations
- Negotiating power of communities, communities' ability to say "no"
- Commodity pricing
- Community/industry relations
- Partnerships

Generally speaking, social impact analysis is new as an object of study and adaptive measures are not yet well studied. At the same time, most communities are convinced that extractive resource development will be the best path forward provided they can maximize the benefits of these activities and, if possible, eliminate any negative impacts. Socio-economic adaptions will vary based on the needs of the community.

7.4.1 Impact and benefit agreements

With the expected increase in resource extraction activities, an increase in income and benefits to BBDS societies via impact and benefit agreements is also expected.

In Greenland, for example, IBAs for small-scale mining projects often include agreements on the use of local labor and of supplies from local enterprises; hence, the impact is on local communities (see True North Gems Greenland A/S et al., 2014; Hudson Greenland A/S et al., 2015). However, large-scale mining projects (e.g., the earlier prospected Isua project and the presently prospected Kvanefjeld project), which garner more national political attention, may lead to income and benefits for the entire society as a part of the approval process, especially if the IBAs contain requirements to fund education and research. The IBAs connected to the True North Gems Greenland mining project (now the LNS Greenland Gems project) and the Capricorn 2011 oil project do contain such provisions. The Capricorn IBA also transferred oil spill contingency equipment to Greenland, thus founding the government-owned Greenland Oil Spill Response A/S company, which now houses this equipment. The present differences in IBA terms regarding small-scale versus large-scale mining activites are expected to be maintained.

7.4.2 Local capture of revenues

Generally speaking, the ability of communities to benefit from extractive industry development will be aided by ensuring that the local capture of revenues is maximized. This capture can come in the form of royalties, taxes, and profits, and through other mechanisms such as public/private cooperation. If managed wisely (e.g., through sovereign wealth funds), the monies can be used to ensure the long-term sustainability of the communities. The "resource curse" literature shows that certain negative impacts can arise from the local capture of extractive industry revenues. These potential impacts include corruption, war, and a decrease in the importance given to education. So far these impacts do not seem to be an issue in the BBDS region.

7.4.3 Public/private partnerships

Weak infrastructure is one of the major obstacles for establishing extractive industries in Greenland. The Greenland oil and mineral strategy (Government of Greenland, 2014) aims to clarify whether public/private partnerships could be used to finance some parts of extractive projects (e.g., roads, ports, hydropower facilities). As of the time of this writing (2016), this clarification is being formulated.

In Nunavut, infrastructure for resource development is normally planned in partnership between private and public sectors, but geographical challenges may hamper communities from benefiting from this infrastructure. The fact that mines can be established far from existing communities means that even the closest communities may not receive potentially valuable benefits in association with the infrastructure.

Industry, governments, and communities must work closely together in the planning of infrastructure to ensure that the communities in closest proximity to the projects receive maximum benefits.

7.4.4 Promotion of commercial business collaboration between Greenland and Denmark

A report by the Danish Ministry of Business and Growth and the Greenland government (Business and Growth Ministry and the Government of Greenland, 2015) recommends to continue the dialogue with investors to clarify potential financing models for mine projects in Greenland on commercial terms and conditions. Further, the report recommends a number of initiatives that can contribute to the expansion of current funding opportunities and a strengthening of business collaborations between Greenland and Denmark (e.g., the establishment of an Arctic demand line of credit in the Nordic Investment Bank, as well as access to capital from the European Investment Bank). Infrastructure investments are mentioned as being suitable for this sort of financing.

7.4.5 Employment

Revenues can also be captured locally through employment. Wages earned by community members can be used to stimulate the local economy and to increase personal savings. Employment also supplies the local community with training, which, depending on the type of training, may or may not be useful for the long-term sustainability of the community. For example, training to be a miner may not be useful to the community if it entices the individual to leave the community. Monies earned through employment can also lead to social problems through increased drug and alcohol consumption. This consumption is often the most important negative consequence noted by northern communities when an extractive development is first established. During the initial boom period, increased alcohol and drug use creates other problems such as increased violence and family breakdown. Programs should be established to help deal with these issues (see Chapter 4).

7.4.6 Housing

Housing deficients are another concern expressed in communities involved in extractive industry development. Arctic communities in Canada have pre-existing problems with housing (see Chapters 4 and 10). There is a concern that the development of a mine will exacerbate these problems as more people flow into the community in search of employment and other benefits from the mine. Companies and communities must work together to ensure that the economic benefits of extractive industry development are used to improve housing conditions in communities and not make them worse.

7.4.7 Loss of culture

Communities are concerned that extractive industry development could lead to a loss of Indigenous cultures. Mining and oil and gas development introduce greater influence from outside sources, forcing Indigenous communities to change their cultures – for example, resulting in more English and less Inuktitut being spoken. Sometimes outside influences can lead to an enhancement of local cultures, such as the support given to traditional subsistence activities by employment income and flexible work structures. Other aspects of local culture, such as language, often decline as a result of new extractive development. Programs that try to increase the use of local languages should be promoted. All activities should ensure inclusion of, and respect for, Inuit perspectives and knowledge.

7.5 Adaptation options

The environmental impacts associated with exploring for and extracting raw materials may change with a changing climate. As a result, adaptation actions regarding legal and regulatory requirements and regulatory bodies may be particularly called for:

1. In general, the exposure of previously ice-covered areas may lead to the discovery of new deposits, some of which may be in areas vulnerable to human disturbance (e.g., mineral resource exploration activities). Some sensitive areas may become more accessible. New discoveries and increased accessibility may lead to more infrastructure and its associated impacts.
2. To attract investors, there may be a further need for the development and maturation of mining and hydrocarbon licenses – including investment in geological mapping and exploration, as well as the development of SEIAs to promote mining projects and the knowledge base for project-specific EIAs.
3. Changes in biodiversity, species distributions, or animal behaviors due to climate change (Chapter 6) may call for adjustments and reconsideration of areas or species particularly vulnerable or sensitive to mineral resource exploration and exploitation activities. These considerations can be expressed in authorities' requirements regarding the development of project-specific EIAs, as well as in the approval requirements for industrial activity (as further explained below).
4. Increased precipitation may lead to enhanced construction requirements for containment structures and greater containment volumes. For instance, for the Ironbark Citronen Fjord (zinc–lead) project, the DCE's evaluation comments to the environmental impact assessment emphasized that the EIA should indicate that the design and construction of the depots and the tailings storage facility dam do take into account projected rainfall changes due to climate change (DCE memo dated 7 November 2014). To the extent that climate projections are not adequately incorporated into the government's EIA guidelines and approval requirements, there is a need to adjust these requirements to ensure that mining projects and facilities (including, for example, sedimentation basins) are designed to handle an increase in extreme weather events as well as permafrost changes over the coming decades (Chapter 10).
5. In connection with onshore seismic surveys, it has been recommended to perform these surveys during winter to minimize the physical "footprint" in the vegetation (AMAP, 2010; Hansen et al., 2012). In the future, potentially lighter snow cover and shorter seasons for snow cover may necessitate the development of innovative solutions to reduce survey impacts on vegetation and terrain.
6. The inherent risk of significant impacts from oil spills in the Arctic environment remains high in a changing climate, so there is a need for a continued focus on reducing oil spill risks in the (S)EIA processes, including the development of contingency plans and of capacity to deal with any spills – under new conditions and extreme events.
7. The expected increase of long-range contaminant deposition in the Arctic, especially heavy metals such as mercury (Subchapter 3.2), may call for strict controls on further contributions of heavy metals from local mining and oil exploration activities – e.g., the natural mercury content of the barite used in drilling mud (Wegeberg & Gustavson, 2018). Climate change projections also indicate a risk of increased peak runoff from land (Chapters 3 and 4), which could increase the washout of heavy metals from deposits of waste rock and tailings. Hence, this possibility should be considered when placing, designing, and constructing waste containments (see suggested changes to EIA guidelines mentioned above).
8. The ongoing reduction in sea ice cover may change whale population sizes, as well as the timing of their presence in particular sea areas or regions. Climate change will likely alter the distributions of migratory species due to shifts in the locations of the frontal zones and upwelling areas that concentrate their food (Schiedek, 2011; see also Chapter 6). Therefore, the regulation of some particular seismic activities must incorporate consideration of these potential changes in behavior and sensitivity and of cumulative impacts associated with possibly increased disturbance from shipping (Chapter 9).
9. Regarding terrestrial change, the final integrated activity plan/environmental impact statement of the National Petroleum Reserve in Alaska requires that the "lesee shall submit with the development proposal a 'stop work' plan that considers this and any other mitigation related to caribou early arrival [before 20 May]. The intent of this latter requirement is to provide flexibility to adapt to changing climate conditions that may occur during the life of fields in the region" (United States Department of the Interior, 2012, p. 97).
10. There may be a need for continued development of impact and benefit agreements and other means to ensure the local capture of revenues, including a focus on capacity building for the local workforce and enhancement of local employment opportunities. Similarly, IBAs should promote the strategic use of revenues from the industry for investment in society, including education, social safety nets, and infrastructure. Any new initiatives should promote the use of local languages; all activities should ensure inclusion of, and respect for, Inuit perspectives and knowledge.
11. Providing support for economic development may call for addressing housing limitations in the BBDS region, including the increased housing demand that accompanies mining development – e.g., adapting investments in residences according to job supply.
12. Together with expectations for potentially increased exploration and shipping activities in the future (Chapter 9), regulations must also take into account the cumulative impacts of increased activities in general – e.g., through the development of integrated regulation across multiple sectors to mitigate the cumulative effects of climate change and the expected general increase in activity level (e.g., discharges, emissions, noise). Ecosystem-

based management and planning, for example, includes not only knowledge of the ecosystem and impacts but also a program of ecosystem monitoring, as well as ongoing dialogue among stakeholders, management authorities, and researchers. In an EBM approach, all sectors must negotiate and adapt or minimize their contributions to the overall stress on the ecosystem in order to ensure the sustainability and maintenance of ecosystem services (Halpern et al., 2008; Christensen et al., 2015).

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8. Tourism

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Key messages

- ***The Arctic tourism industry has been growing rapidly over the past decade, in part because of climate change.*** *Reductions in sea ice related to climate change have facilitated increased and reliable access to parts of the Arctic that were difficult to reach in the past. The allure of these newly accessible regions to tourism adventurers has increased tourism demand, including that related to a niche market segment of tourists motivated to see the region before it changes forever.*
- ***The tourism industry in the Baffin Bay/Davis Strait (BBDS) region is generally expected to be a beneficiary of the impacts of climate change, but anticipated risks must also be managed.*** *Increased demand for Arctic tourism experiences will bring economic and employment opportunities to the region, which will be particularly beneficial to smaller hamlets and communities where unemployment and poverty rates are high. However, without proper management and industry support, any climate-induced increases in tourism activity could bring negative impacts to the region, including high economic leakage, social and cultural impacts, and environmental disasters.*
- ***Lack of sufficient infrastructure, such as large airports and harbor facilities, and distances between settlements are major constraints for tourism development.*** *The remoteness of the BBDS region from major urban centers is attractive to tourists who wish to engage in a tourism escape, but it is also limiting, given the distance, time, and costs associated with travel to the region. Areas that invest in physical and communications infrastructure will benefit the most from any increase in tourism demand in the BBDS region.*
- ***The most significant impacts for tourism will happen in areas where government seizes new opportunities for strategic development.*** *Climate change will present increased opportunities for tourism, but melting sea ice and changing temperatures alone will not facilitate a sustainable and prosperous tourism industry. Strategic development that aims to mitigate the negative implications of climate change while enhancing the opportunities will be essential.*
- ***In the BBDS region, the marine areas remain highly hazardous for navigation, and so increased investment is needed in charting, ice-monitoring research, and multi-use infrastructure.*** *Climate change has caused a rapid decrease in sea ice extent across the BBDS region, and these newly accessible areas have not all been charted properly. In addition, tourism vessels, including cruise ships and yachts, are the most likely vessel type to travel off the main shipping routes (i.e., compared to cargo ships, tankers, or resupply barges), in search of marine wildlife, pristine and remote natural environments, and icebergs. Thus, tourism vessels represent the highest safety concern of all vessel types operating in uncharted waters.*
- ***In accord with best practices worldwide, it is important that the tourism industry be developed in close consultation with local communities to ensure strong local involvement.*** *The strongest tourism economies globally are the ones that have been developed by and with local communities and that benefit local residents. Supporting local BBDS-based outfitters and entrepreneurs (and joint ventures) should be prioritized over supporting externally owned and operated businesses that leave limited benefits in communities.*
- ***Increased multilateral collaboration between Canada and Greenland could make it possible to take advantage of transnational business opportunities.*** *The vast majority of cruise expeditions transit the BBDS region and include stops in both Greenland and Canada and thus there are significant economic and socio-cultural opportunities associated with multinational collaboration. Furthermore, current flight patterns between Greenland and Canada often route passengers via Europe or southern Canada. Development of modern air infrastructure in the region could significantly enhance transportation and tourism businesses as more and more transatlantic flights could be routed directly through the BBDS region instead of through mainland Europe and Canada.*

Guiding questions

What is the history of tourism development in the Baffin Bay/Davis Strait region, and what are the major industry trends?

What are the likely impacts of climate change on the tourism industry now and in the future?

What are the opportunities and risks associated with climate and tourism changes in the region?

Which adaptation strategies might be needed to support tourism development, enhance opportunities, and reduce risks?

Introduction

Increased access to the Arctic, stemming from climate change and related sea ice reduction, has resulted in major developments in both land- and marine-based tourism opportunities. Expedition cruise ship traffic in the Baffin

Bay/Davis Strait region increased steadily between 2000 and 2010 and has seen variable growth and decline over the last seven years, while pleasure craft (i.e., sailboats and motor yachts) have shown continuous increases over the same time period. Despite these climate-related increases in tourism activity in the region, the overall numbers of marine and related land-based tourists still remains low compared to other global areas (Johnston et al., 2016; exactEarth, 2016; Statistics Greenland, 2016; Dawson et al., 2017a). In the BBDS region, Greenland may be well positioned to take advantage of near-term changes in accessibility because of a strong tourism foundation and infrastructure investments developed over the past 30 years. Nunavut is at an earlier stage of tourism-strategy implementation but is also poised to take advantage of tourism growth. Regardless of national differences in stage of development, conditions in the region as a whole present tourism opportunities and risks that are likely to arise from the direct and indirect impacts of climate change. This chapter describes these opportunities and risks by providing the historical context of tourism development and outlining the major trends, exploring the impacts of climate change and their relationship to other tourism drivers, outlining possible developments in tourism in response to climate change impacts in the near-term and longer-term futures, and presenting possible adaptation strategies to enhance opportunities and reduce risks. Major findings relate to infrastructural and other capacity issues in the region; the need for investment in marine services, sector regulation, and monitoring; the importance of community-led initiatives and local entrepreneurship; and the importance of multilateral collaboration in the region.

8.1 State and characteristics of tourism activity in the BBDS region

8.1.1 Historical development of tourism in the BBDS region

It was once thought that the Arctic, with its high cost of ice-breaking and elevated risks due to remoteness and harsh weather conditions, would forever remain off the list of popular tourism destinations (Ritter and Schafer, 1998; Jones, 1999; Stewart and Draper, 2006). However, due to a general trend of increasing amounts of disposable income and a desire to travel to remote and exotic locations, coupled with the sudden availability of former Soviet Union icebreakers retrofitted for tourism, the Arctic has shifted from being off the beaten path to being very much on it (Stewart and Draper, 2006; Nuttall, 2013). Climate change has further influenced continued growth in tourism, as changing landscapes and a media focus on climate change impacts attract visitors to the region and as, importantly, sea ice reductions make it increasingly possible to travel there by sea. As a result, tourists now represent the single largest human presence in the Arctic (Arctic Council, 2009; Lamers and Amelung, 2010; Stonehouse and Snyder, 2010). However, the distribution of tourists (demand) and tourism opportunities (supply) vary across the global Arctic, with Alaska (United States of America, USA) and certain regions of the European Arctic (e.g, Svalbard, Norway) attracting the highest numbers of visitors.

A smaller but still growing Arctic tourism industry has developed in the BBDS region and is helping to diversify the historical reliance on resource extraction sectors, which have been more dominant historically. Tourism is often promoted as having an important role in economic development and diversification, and this sector may contribute to curbing the negative impacts of a boom and bust cycle in areas where resource-based economies are in decline or are in flux, such as in the case of the BBDS (see Chapter 7; Milne, 2006; Müller and Jansson, 2007; Hall and Saarinen, 2010; Moksness et al., 2011). Furthermore, tourism is viewed as a valuable economic driver in Indigenous regions, providing an opportunity to share culture with visitors from around the world and enabling local people to be employed on a seasonal basis while also allowing time to engage in traditional cultural activities (SEDSG, 2003). Tourism, nonetheless, can present economic, social, and environmental challenges for Arctic communities and governments, and it must be managed carefully to ensure that it brings the desired benefits without also bringing unacceptable costs.

The BBDS encompasses West and Northwest Greenland, where tourism development occurs largely via regional strategies and national oversight, and a portion of the Canadian territory of Nunavut, where tourism development is largely a territorial responsibility with community-level participation. Despite the existence of two state authorities, the two jurisdictions in the BBDS region have experienced a relatively similar history in terms of tourism development, albeit at different time periods and scales. The most significant differentiating factor between the regions has been the scale of development and infrastructure, which is much more advanced in Greenland (see further details in Chapter 10). The region as a whole is known for its highly attractive landscapes of fjords, mountains, and glaciers, its historically important role as the entrance to the Northwest Passage (NWP), its wildlife-viewing opportunities, and its traditional communities that showcase Inuit culture. As a result, both jurisdictions offer similar tourism attractions, including unique natural and cultural features that are particularly attractive to tourists. Both countries have produced economic development strategies and reports for the region, identifying tourism as an industry with “great potential” and “primed to become a leading sector” in the region (SEDSG, 2003; CGMRBS, 2014). However, tourism is an inherently fickle and adaptive industry that is shaped largely by what might seem to local actors to be uncontrollable external factors, such as changing tourism demand, global financial influences, company resourcing decisions, and opportunities in other markets. As such, tourism is a challenging industry to manage. The historical ups and downs of tourism development in the region are likely to continue in an era of increased uncertainty due to climate change. Yet, with appropriate adaptation strategies in place, many of the negative impacts of change can be mitigated while the opportunities are capitalized upon.

Until the mid-1950s, tourism was barely considered in Greenland and was unheard of in eastern Arctic Canada. For example, until 1953 (the end of the colonial period in Greenland), one needed official sanction to enter Greenland and so the country was essentially closed to visitors except those working in administration, the military, construction, or on polar research. Furthermore, the region was not well known to the outside world (Pelt, 2009). A focus on tourism development increased in 1975 when the Danish Ministry of Greenland published a report titled *Tourism in Greenland*, which described and mapped out the potentials for a tourism industry (Rosing, 1973). After the introduction of Home Rule, Greenland experienced an economic recession, primarily because of declining income in the fishing industry. The economic downturn left Greenland with a growing debt and a need for a new economic driver. Diversification of the economy was now a policy goal, and various development measures were introduced, such as trying to stimulate new sectors (e.g., minerals and tourism). The Home Rule Government of Greenland again believed that tourism could become a leading industry.

An official tourism plan for Greenland was established and adopted in 1991 (Hoff & Overgaard, 1991). In 1992, the agency Greenland Tourism (Grønlands Turistråd) was created and supported by the government (Lyck, 1998). Greenland Tourism was given the responsibility of developing, coordinating, and promoting tourism and marketing Greenland as a destination. The efforts of Greenland Tourism to develop the fast-growing tourism industry were supported by regional and local tourism agencies that played a key local coordination role (Johnston and Viken, 1997). The tourism sector has evolved significantly since it was touted as a key focus in regional economic development plans, but this development has not been without difficulties and subsequent reorganization and new approaches to planning and investments (Tommasini, 2011). In the mid-1960s, Greenland received about 500 visitors a year, which increased to about 6,500 per year by 1972 (Rosing, 1973). There was a drop in tourist overnight stays in Greenland in the mid-1980s, with a rebound in the 1990s (Johnston and Viken, 1997; Tommasini, 2011). By 1994, there were about 8,000 visitors per year, which grew to 15,000 by the mid-1990s (Møller and Nielsen, 2006). However, the actual number of visitors was likely much higher than these official statistics, considering that at this time annual totals did not include excursionists – those who did not stay overnight, such as the more than 6,000 cruise ship tourists and 4,000 Icelandic day visitors in 1995 – and school children on field trips from Denmark (approximately 2,000 in 1995) (Johnston and Viken, 1997). Today, there are approximately 70,000 visitors annually to Greenland (the BBDS population is approximately 53,000), including day, overnight, and cruise visitors (Statistics Greenland, 2015). Importantly, concerted infrastructure development (i.e., accommodation facilities, airstrips, and ports), marketing of tourism opportunities, national policies to reduce taxes on transport, and new direct flights to Iceland have been highly successful and have contributed significantly to the increase in tourism in Greenland, although additional development is still needed to expand further (Government of Greenland, 2016) (also see below).

On the Nunavut side of the BBDS region, tourism also had a slow start but was flagged in the 1980s as a means of creating important local Inuit economic activity through a community-based tourism planning effort (Robbins, 2007). This initiative began with a pilot project in Pangnirtung, a Baffin Island community with a mixed economy that had been hit hard by a decline in fur prices, thus making hunting uneconomical and affecting the livelihoods of many people in the 1970s and 1980s (Robbins, 2007; Snyder and Stonehouse, 2007). Tourism development in the region has also been connected to the establishment of protected areas, with a particular emphasis on providing opportunities for local communities to develop economic activities (Hall and Johnston, 1995). Despite enthusiasm in the 1980s for tourism development, only a few communities maintained this early momentum, and the 1990s have been viewed as a decade of stagnation in terms of investment in the industry (Robbins, 2007). Advances were made on the organizational side with the creation of Nunavut Tourism in the mid-1990s, an industry membership organization that was given responsibility for marketing, product development, and tourism training in eastern Arctic Canada. When the territory of Nunavut officially came into existence in 1999, the territorial government retained planning, licensing, and enforcement (Robbins, 2007). A key limitation for tourism development on the Nunavut side of the BBDS region is a lack of infrastructure and the fact that the region consists of a number of islands accessible only by air or sea. Furthermore, there is a lack of port facilities and only a limited road network, mostly of gravel or dirt. The airstrips are typically gravel and cannot support larger, fuel-efficient airplanes (Chapter 10).

An attempt at strategic tourism planning for Nunavut began with a 2003 report titled *A Strategic Plan for Tourism Development in Nunavut* (Robbins, 2007). Tourism at this time was seen as "*a good fit for Nunavut culture and communities*" (SEDSG, 2003, p. 16) and was viewed as supporting Inuit culture and providing opportunities for more stable, community-based economic activity than the dramatic boom and bust cycle experienced in resource extraction industries (SEDSG, 2003). Indeed, after the 2002 closure of the Nanisivik mine (once Nunavut's major mine project), tourism was thought to be the territory's "*single most important economic activity in the private sector, in terms of its contribution to the Territory's GDP*" (SEDSG, 2003, p. 16). Subsequent reports, including regular "Nunavut Economic Outlook" papers, have been published, recommending diversification of the region's economy through tourism (Nunavut Economic Forum, 2010). Despite these efforts, no official tourism sector strategy was created for Nunavut until 2014, and sector development proceeded on an ad hoc basis, relying on the marketing and training activities of Nunavut Tourism, the product development of the industry itself, and community willingness to participate. Work began on an official tourism sector strategy in 2011, comprising extensive community consultation activities, survey research, and collaborative decision-making among various government and non-government agencies (Viken et al., 2014). The official strategy is now in place, and actions are being implemented (Government of Nunavut, 2013), including the development of the Nunavut Marine Tourism Management Plan (Johnston et al., 2016). Approval of the official tourism strategy by the legislature is important, given recent and rapid increases in tourist demand. Hinch (1995) noted 1,280 summer pleasure visitors in the Qikiqtaaluk region (formerly called Baffin Region) in 1979, growing to 2,740 in 1988, while Johnston (1995) reported 4,100 visitors for the Qikiqtaaluk region in 1992. Historical data on the Canadian side are limited and difficult to compare due to inconsistent collection methods.

However, it is clear that tourism growth began much later than in Greenland and has also been much slower. The Nunavut territory as a whole, which as of July 2015 had a population of almost 37,000 (Nunavut Bureau of Statistics, 2015), hosts just over 30,000 tourists annually, including both pleasure and business visitors (Nunavut Tourism, 2011).

Establishing a reliable and sustainable tourism economy in the BBDS region has been challenging. Various research and consulting reports over the years have identified significant historical challenges to development in the region, including the following: high seasonality and short summer season length; limited human capacity; limited access to markets and sometimes to finance; limited tourist spending in some communities (~50 Canadian dollars, CAD, per day in Nunavut); high economic leakage to external owners; high cost of access for tourists; lack of online information about the destinations; poor Internet communication services in some places; and poor coordination within the tourism sector in Nunavut (see Johnston, 1995; Johnston and Viken, 1997; Lyck, 1998; Robbins, 2007; Nunavut Tourism, 2011; Dawson et al., 2014.) These challenges are accentuated in smaller settlements compared to larger towns, which have larger pools of trained professionals and high-speed Internet (Rambøll Group, 2014). Recent concerns have been raised about the effects of perceived over-regulation in Nunavut and the unintended impacts of federal shipping legislation as factors that might both hinder cruise tourism in Nunavut and contribute to its increase in Greenland (Dawson et al., 2017b). Furthermore, concerns about the potential for negative impacts of tourism on local people and the environment have remained high, despite the potential and evident positive impacts.

8.1.2 Current tourism trends in the BBDS region

Wide ranges of tourist activities are now on offer across the BBDS region, similar to what is typically available across the Arctic – although at a smaller scale than in Alaska or Svalbard, for example. A total of 33 different activity types are advertised as being on offer to tourists in the BBDS region, including hiking, mountaineering, rock climbing, kayaking, snowmobiling, ski touring, scuba diving, dog sledding, wildlife viewing, glacier and landscape tours, overflights, northern lights, Norse and Inuit history tours, historic and archaeological sites, sport hunting, river and sea fishing, expedition cruising, and yachting (see Table 8.1 and Figure 8.1). The peak season for tourism is summer (July and August). The main season for marine tourism runs from mid-July to late August, and sometimes into September in years when navigation is facilitated by higher-than-average ice melts and late freeze-ups. Land-based tourism has three main seasons: summer, autumn, and winter. The main season is shorter when sea ice conditions are difficult or when weather becomes unstable (see INTAARI, 2012). Although not as popular, the shoulder (i.e., autumn and spring) and winter seasons also attract some tourists for activities such as ice floe tours, wildlife viewing, cultural activities, snowmobiling, ice fishing, and hunting. Most of the activities on offer are highly reliant on the natural environment and so are significantly influenced by the impacts of climate change.

Although both land- and marine-based tourism are growing in the BBDS region, increased demand for cruise ship travel has garnered the most attention and is most closely related to climate change because of the reductions in sea ice and resultant

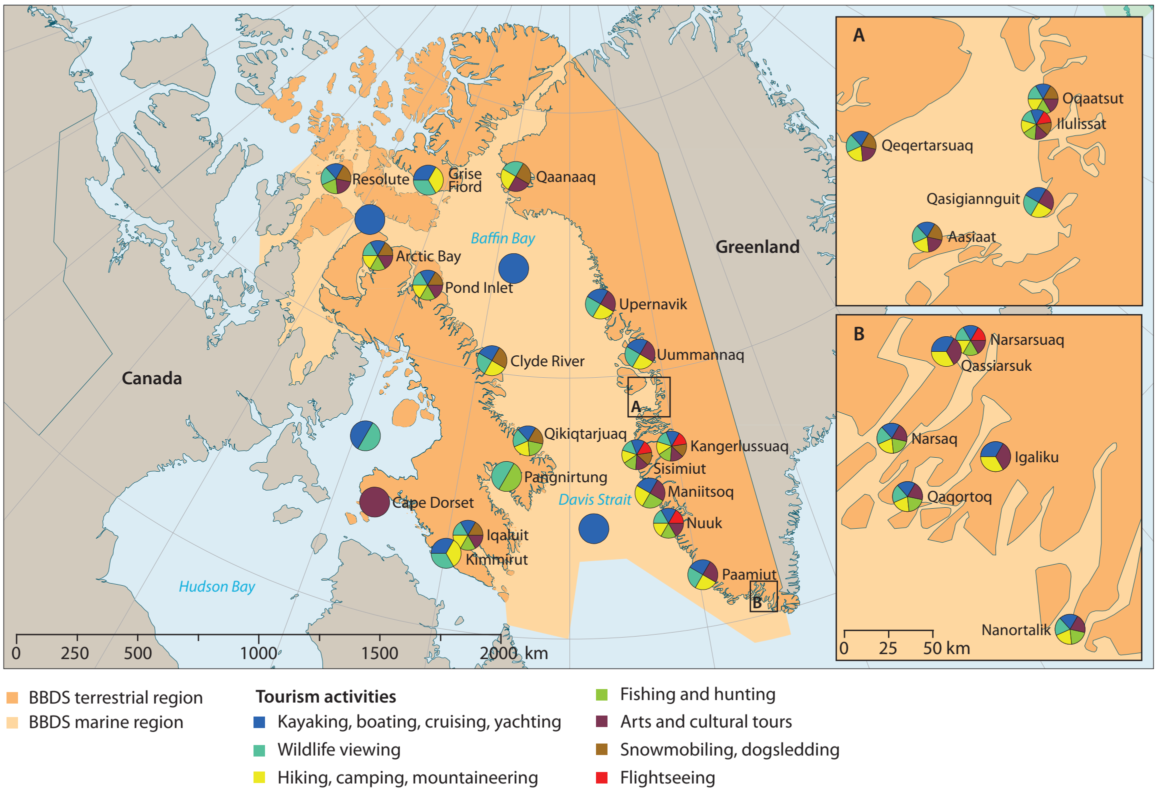

Figure 8.1 Map of tourist activities in the BBDS region (information compiled by J. Dawson).

Table 8.1 Advertised tourism activities in the circumpolar Arctic and the BBDS region (compiled from websites of the national, territorial, provincial, and state tourism authorities).

Country/area	Kayaking or rafting (river and sea)	Wildlife viewing	Cultural heritage tours	Diving and snorkeling	Zodiac and sailing tours	Hunting and fishing	Fjord cruises	Northern lights	Cruise and yacht tours
Russia	×	×	×	×		×			×
Finland	×	×		×	×	×			×
Norway		×	×	×	×	×	×	×	×
Iceland	×	×		×		×	×	×	×
Alaska (USA)	×	×	×	×		×		×	×
Canada North	×	×	×		×	×		×	×
Greenland	×	×	×	×	×	×	×	×	×
BBDS region	×*	×	×		×	×	×	×	×

* Sea kayaking only

increase in marine access (Chapter 9). As seen in Figure 8.2, the number of commercial cruise ship arrivals in the BBDS region more than doubled between 2005 and 2007 and has since increased and decreased over time due to the global economic crisis, regulatory changes, business mergers, and other global socio-economic trends (Arctic Council, 2009; Stewart et al., 2010; Dawson et al., 2014). Pleasure craft (i.e., yacht and private boat) traffic has also grown in recent years, along with access and awareness (Pizzolato et al., 2013; Johnston et al., 2013, 2016). Popular routes for marine tourism include the Northwest Passage and the West Greenland coast, including the world-renowned Ilulissat Icefjord, a UNESCO (United Nations Educational, Scientific and Cultural Organization) World Heritage Site (Marsh and Staple, 1995; Jones, 1999; Stewart and Draper, 2006).

The first transit of the NWP by a cruise ship (the purpose-built expedition cruise ship *MS Explorer*) occurred in 1984 (Marsh and Staple, 1995), and since the early 2000s, expedition cruise vessels have traversed the NWP annually with only occasional summertime ice challenges. Cruise ships carrying tourists from the USA and France were first officially observed in Greenland around the 1930s. However, more organized tourist travel to Greenland began only in 1959, with flights from Copenhagen and one-day tourist flights from Iceland (Thalund, 2000). Today, over 35,000 cruise tourists and several thousand yachters visit the BBDS region annually. Greenland and Canada attract a similar number of cruise vessels each season, yet the number of tourists visiting the Greenland portion of the BBDS (approximately 22,390 tourists by ship and 45,486 tourists by plane in 2015) is significantly higher than tourists to the Canadian side (approximately 6,000 tourists by ship and an estimated 25,000 by plane in 2011) (Statistics Greenland, 2009; Stewart et al., 2010; Nunavut Tourism, 2011; Dawson et al., 2014). The difference in numbers is due both to the size of the vessels that local infrastructure can accommodate and to Greenland's successful destination-marketing and tourism coordination. Importantly, a majority (approximately 70%) of cruise vessels visiting the Canadian side of the BBDS region begin their voyage from Ilulissat in western Greenland, spending 2–3 days there before traveling to Canadian waters, where they spend 7–15 days.

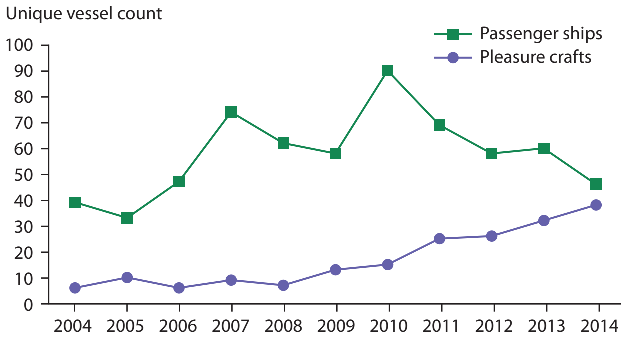

Figure 8.2 Vessel trends in the BBDS region: passenger ships and pleasure crafts, 2004–2014 (from database discussed in Pizzolato et al., 2016, and Dawson et al., 2017a).

In terms of spatial trends, tourism vessels regularly travel within the entire BBDS region, typically moving from east to west. An aggregated analysis of traffic volume from 1990 to 2013 indicates that the greatest numbers of passenger vessels occurs along Southwest Greenland and the northern tip of Baffin Island (Lancaster Sound) at the eastern entrance to the NWP; pleasure craft are similarly concentrated (Figures 8.3 and 8.4). Time series analysis indicates a clear northward shift in cruise and yacht activity. This shift correlates well with changes in sea ice, which has been declining. Historically, multi-year ice has prohibited reliable transit, but in recent years, declines in sea ice extent and thickness have been shown to have directly influenced, at least in part, the increase observed in cruise and yacht traffic (Pizzolato et al., 2013, 2014, 2016; Dawson et al., 2017a).

Some communities are benefiting from tourism more than others. For example, Ilulissat in Greenland and Pond Inlet in Canada tend to benefit because of their geographic location (Pond Inlet, for instance, is at the eastern entrance to the NWP), their majestic landscapes (i.e., fjords, mountains, and glaciers), and, importantly, their development of tourism products, outfitters, and infrastructure (i.e., wharfs, performance centers, hotels) specifically designed to service the tourism industry. Other smaller communities tend to receive less of the local economic benefits. The distribution of tourism activity and development is certainly uneven and will require attention moving forward.

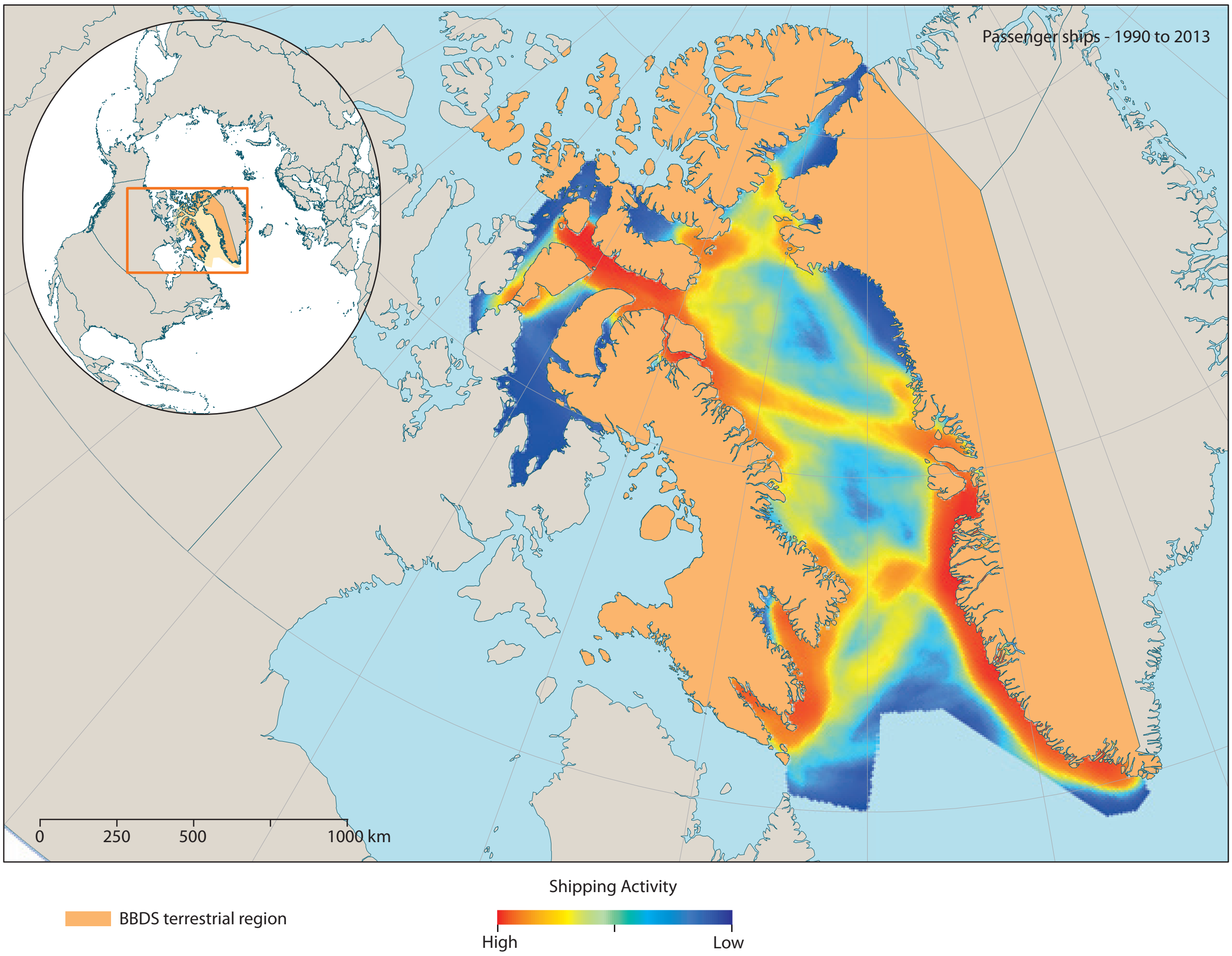

Figure 8.3 Map of the total volume of passenger ships in the BBDS region, 1990–2013 (data from NORDREG and Greenpost).

Tourists visiting the BBDS region tend to be between the ages of 40 and 65, are wealthy compared to national averages, are well educated, and are motivated to visit in order to experience the natural environment, Inuit culture, and amenities on offer. The vast majority of tourists visiting the Canadian side of the BBDS region are Canadian, followed by a smaller proportion of Americans and Europeans (Nunavut Tourism, 2011). The most common nationalities of visitors to the Greenland side of the BBDS region are western European, followed by Scandinavian, and American (Visit Greenland, 2013). Leisure visitors (land and cruise) tend to make up the largest proportion of travel to the region, although there are large numbers of business travelers who also tend to engage in leisure-type activities while visiting (Nunavut Tourism, 2011; Visit Greenland, 2015). In Greenland, approximately two-thirds of the tourism volume is land-based and one-third is cruise-based. However, in terms of spending habits, cruise tourists tend to spend the highest amounts on their visits (approximately CAD 7,500 in Nunavut). Land-based leisure travelers and business travelers tend to spend similar amounts (approximately CAD 4,500), while tourists visiting for personal reasons or to visit friends and relatives tend to spend the least (approximately CAD 1,800) (Nunavut Tourism, 2011). Comparable economic data are not available for Greenland.

8.2 The impacts of climate change on tourism in the BBDS region

Tourism is considered one of the most highly climate-sensitive economic sectors globally (UNWTO-UNEP-WMO, 2008; UNWTO, 2016). Many tourism destinations are directly dependent on climate or on environmental resources as their principal attractions – e.g., wildlife, glaciers, or landscapes. This dependence is particularly the case for the BBDS region, where tourists are highly motivated to travel to the area in order to experience the unique natural landscapes and view Arctic wildlife (see Figure 8.5). Given that Arctic environmental resources are extremely sensitive to climate variability (see Chapters 3 and 6), future environmental changes will lead to both challenges and opportunities for tourism activity in the region and will thereby affect the contribution of tourism to regional economic development. Indeed, climate change is not a remote event for tourism; the impacts of climate change, both positive and negative, are already evident at destinations around the world and are already influencing decision-making and governance decisions (Pagnan, 2003; Becken and Hay, 2007; Dawson et al., 2007; UNWTO-UNEP-WMO, 2008; Scott et al., 2016).

The specific impacts that climate change will have on the tourism sector and on local communities that rely, at least in part, on the tourism industry can be divided into two

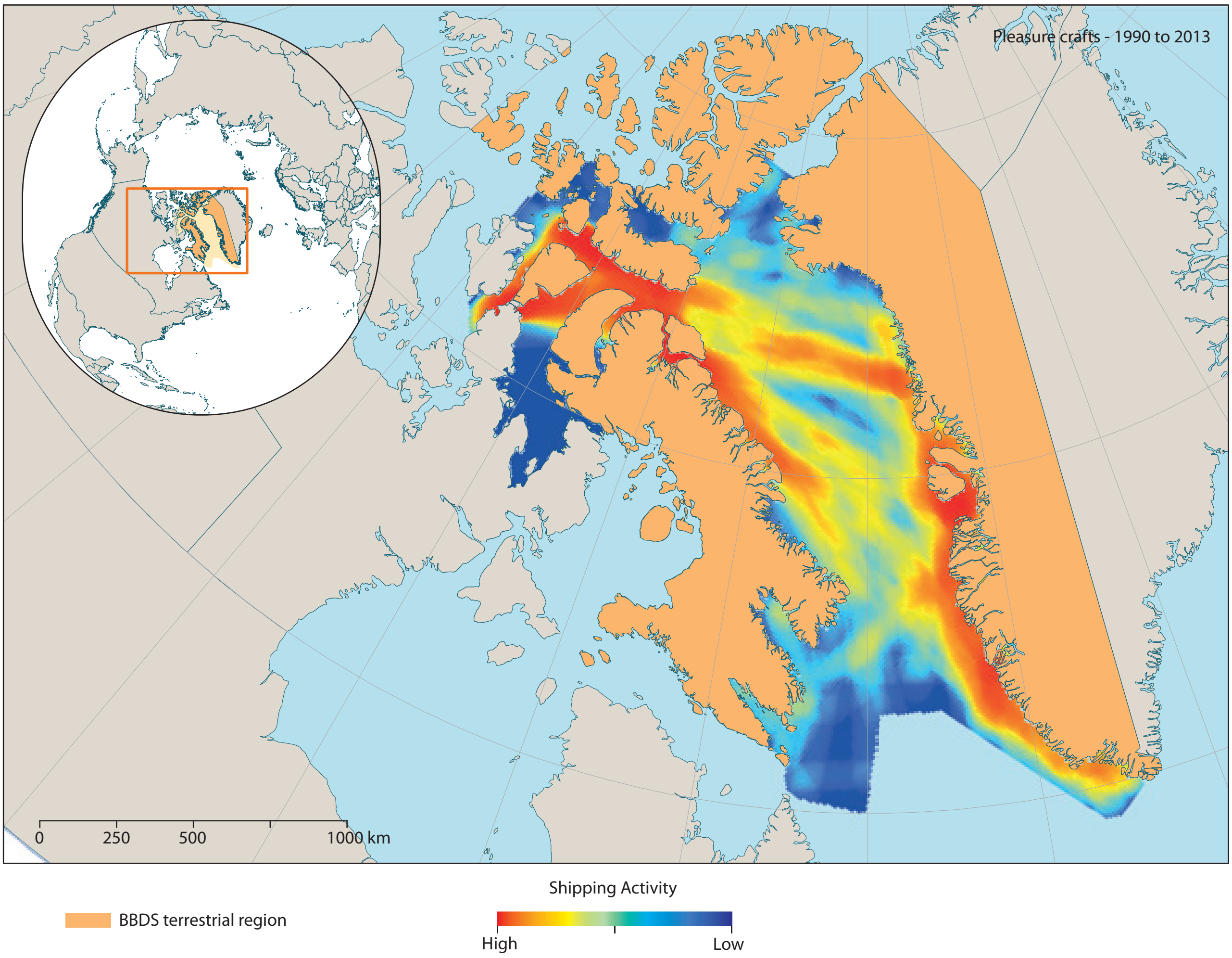

Figure 8.4 Map of the total volume of pleasure craft vessels in the BBDS region, 1990–2013 (data from NORDREG and Greenpost).

categories: direct impacts and indirect impacts (UNEP and the International Ecotourism Society, 2007). Importantly, the impacts of climate change, be they direct or indirect, can be positive or negative and thus can influence both opportunities and risks (see Box 8.1 for further details).

Within the BBDS region, changing climatic conditions offer a number of opportunities for both the tourism industry and the communities involved. For example, it is generally believed that the tourism industry is well positioned to be a beneficiary of climate change over the short term, considering the major role that a changing climate is continuing to play in increasing tourist demand (Dawson et al., 2007; Marquez and Eagles, 2007; Lamers and Amelung, 2010; Dawson et al., 2014). The opportunities associated with climate change for the tourism sector have been recognized in recent politically motivated advertising about Greenland's tourism development, which has been outlined as a strategic tool to achieve a more sustainable future for Greenland (Rambøll Group, 2014). In other words, despite challenges in the management, infrastructure, and legal framework in tourism (Government of Greenland, 2012), investing in the tourism sector has been framed as highly strategic as opposed to focusing all investments in the mining sector (Bjørst and Ren, 2015). Similar sentiments have been expressed concerning Nunavut (Government of Nunavut, 2013).

Demand is increasing, in large part, because of real and expected changes to environmental resources. For example, there has been an increase in the summer season length (Subchapter 3.1), which allows for additional tourism opportunities. The shoulder seasons are also lengthening, as weather during autumn and spring has become less harsh and more amenable to nature-based tourism. Given the climate-induced changes that have opened up shipping routes and created greater access to the marine environment, the Arctic region has experienced increases in cruise traffic and other marine shipping activity (Huebert, 2001; Pagnan, 2003; Brigham and Ellis, 2004; Hassol, 2004; Dawson et al., 2007; Lamers and Amelung, 2010; Pizzolato et al., 2014; Johnston et al., 2016; see also Chapter 9). Furthermore, with reductions in sea ice, new cruising corridors are emerging, creating important tourism opportunities in areas that were not previously accessible.

Demand patterns are also increasing because of increased global attention to the effects of climate change in the Arctic. For example, during the Fifteenth Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP15) in Copenhagen in 2009, changes in the Greenland environment were used as a key message to symbolically illustrate the impact of climate change on the region (Bjørst, 2010). The framing of Greenland and, in particular, the vulnerability of Ilulissat Icefjord, a UNESCO World Heritage Site

Box 8.1 Direct and indirect impacts of climate change on tourism

Direct impacts: Climate is a principal resource for tourism, as it determines the suitability of locations for tourist activities and so is a chief driver of tourism demand. Thus, changes in the season length and the quality of climate-dependent tourism regions could have considerable implications for competition among destinations, the profitability of tourism enterprises, and the long-term sustainability of destinations. Studies indicate that a poleward shift of climatic conditions attractive for tourism is very likely and could yield significant positive effects and opportunities for tourism demand in the BBDS region. However, the expected impacts of climate change – including increases in the frequency or magnitude of certain weather and climate extremes (e.g., wind, waves, storm events; Subchapter 3.1), changes in water availability (Chapter 4), loss of biodiversity (Chapter 6), reduced landscape aesthetics, melting sea ice and glaciers, increased mobility of multi-year ice (Subchapter 3.1), increased natural hazards, and coastal erosion – will directly affect the tourism industry through increased infrastructure damage, business interruptions, increased risk of safety incidents, and an altered landscape aesthetic.

Indirect impacts: Because environmental conditions are so critical for tourism, a wide range of climate-induced environmental changes will have profound indirect effects on tourism enterprises, including environmental, economic, and social effects. Examples of indirect impacts include altered tourism demand patterns, altered local economic and employment opportunities, increased need for emergency preparedness plans and equipment, higher operating expenses (e.g., insurance, backup water and power systems, evacuations), more safety and security issues, more cultural conflicts, and increased criminal activity.

and popular tourism destination, as a place where climate change is particularly evident has created a strong perception of urgency in the minds of potential tourists (Bjørst and Ren, 2015). For some tourists, climate-change fears, such as the disappearance of polar bears and melting glaciers, has facilitated a desire to travel to the region to experience it before it is "too late" (Dawson et al., 2010, 2011; Johnston et al., 2012; Lemelin et al., 2012a). This phenomenon has created a niche market that has been labeled "last chance tourism" (Lemelin et al., 2010; Dawson et al., 2011; Lemelin et al., 2012a). Also referred to as "doomsday tourism" or "climate tourism," last chance tourism involves tourists who explicitly seek out vanishing landscapes, seascapes, natural resources, or cultural heritages before they are changed beyond recognition (Dawson et al., 2010; Lemelin et al., 2010, 2012a; Stewart et al., 2016).

The continued increase in tourism in the BBDS region could significantly benefit local residents via increased seasonal employment and other economic development opportunities related to the provision of services and products for visitors themselves and to tourism companies. Tourism also provides access to and education about Inuit culture and local traditions for visitors, which can help shape positive perceptions of Indigenous people from the region – all of which can lead to increased socio-cultural resilience and well-being (Parlee and Furgal, 2012). Tourism also helps to support a local arts and handicrafts culture that supplies the need for souvenirs, which perhaps reinvigorates local interest. Having a larger market for local art has helped to infuse enthusiasm for traditional activities among youth and elders in the region (Furgal and Prowse, 2008; Stewart et al., 2010). Some also believe that visitors to the region may become advocates for the North, returning home motivated to help fund conservation initiatives or educate others about the region (see Maher et al., 2003; Lemelin et al., 2010; Maher, 2011; Lemieux and Eagles, 2012; and Students on Ice, 2016).

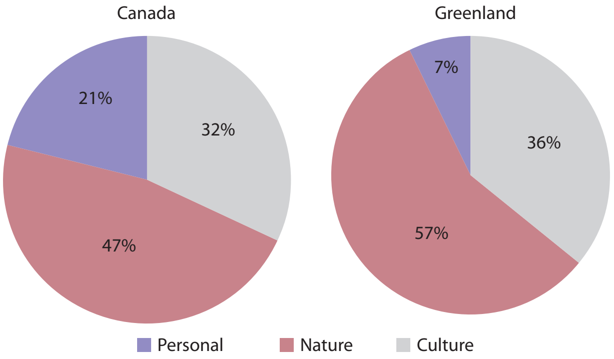

Figure 8.5 Travel motivations to Canada and Greenland.

Despite the opportunities that climate change offers in the BBDS region, the reality of increasing numbers of tourists is also cause for concern. This is a particular issue given that the direct impacts of climate change on the Arctic environment are, in some cases, making the region more hazardous for travel even while increasing the opportunity for it (see Chapter 9). As well, the greater access is increasing the possibility of negative social and cultural impacts from tourism, such as cultural commoditization, disturbance of archaeological sites, and cultural and behavioral conflicts. Furthermore, the opportunities tend to be outnumbered by the propensity for increased risks and negative outcomes that are largely felt at the local level (e.g., conflict, insufficient economic return). Overall, it is challenging to deal with recent growth in tourism demand in the BBDS region, but at present, Greenland has been rather effective in managing the growth through investments in infrastructure, marketing, and other services. The main challenges can be divided into three main categories: (1) safety and security, (2) economic development, and (3) environment and culture.

Given the growing number of tourists visiting the region, there is an increased probability of minor and major human safety and security incidents. In part, due to the fact that tourism has historically played a minor role in the region's economy and, as a result, has been poorly supported, there is a significant lack of tourism-specific services and infrastructure to support the industry. There is limited hydrographic charting across the entire region, search-and-rescue plans have only limited resources to actually perform rescues, and there is inadequate infrastructure for activities, accommodation, food resupply, and medical services to support visitors, particularly on the Canadian side (Stewart et al., 2015; Johnston et al., 2016; see also Chapters 4, 9, 10 and 12). As a result, accidents have become an increasing concern. In 2007 and again in 2010, cruise vessels ran aground in the region and passengers needed rescue. In 2007, two Danish tourists were killed while photographing a glacier in Greenland. In 2013, a group of 20 tourists became trapped on an ice floe near northern Baffin Island, after the ice broke away and floated toward the Arctic Ocean. The majority of safety concerns directly linked to climate change relate to the perceived increase in accessibility to the region due to reductions in sea ice extent. However, the reality is that the region is now more hazardous to navigate than ever before because of the greater mobility of multi-year ice and the increase in calved icebergs from ice islands and glaciers. These hazards are particularly problematic for single-hulled or small vessels, which tend to be more vulnerable to ice penetration. A cruise ship sinking in the region is considered one of the highest-risk incidents across the Arctic, in light of climate change (Dawson et al., 2014). For this reason, a simulated cruise ship rescue was used as the scenario for Operation NANOOK 2014, a major government-organized, multi-nation search-and-rescue training exercise.

In addition to human safety concerns, there are other concerns related to local and national security. It is thought that increased tourism could bring an increase in criminal activity to the region because of the nature of the industry and the regulatory regime governing international movement (Dawson et al., 2014). For example, in 2007, the *Berserk II* sailing vessel made its way from Greenland through the BBDS region and illegally entered into Canada with two inadmissible crew members (Teeple, 2010). However, such incidents are very rare and therefore not of major concern at present. There is increasing concern about drug smuggling, human trafficking, and illegal entry into Canada via tourism vessels now that the region is perceived to be more accessible and there is more tourism activity (Johnston et al., 2013; Dawson et al., 2014).

Large portions of the economic benefits of the tourism industry do not stay in tourism regions. This is particularly the case with cruise tourism, which is the most popular form of travel in the BBDS region. It is well documented that there are limited economic benefits compared to other types of tourism, as most services are provided on board the ship and not in the community (Klein, 2009; Stewart et al., 2015; Dawson et al., 2016). However, in small remote communities, even limited economic options can be of significant benefit. In the Arctic, the contribution of cruise tourism to the local economy depends significantly on the operators, with some operators making greater efforts than others to purchase locally available activities and products (Fay and Karlsdóttir, 2011; Stewart et al. 2015). Foreign or non-local ownership of marine cruise tourism operations is the norm across the BBDS region as in the rest of the world. This is also the case with many land-based, pre-packaged tours and is a challenge in all parts of the world – but is more pronounced within developing regions such as the Nunavut side of the BBDS. However, tourism – as with all trade – is by nature a transaction between local providers, middlemen, and the customer. The idea of total local control and ownership is not realistic given the current financial and human resources in the BBDS region. Outside ownership results in tourism income leaking out of the region despite increased tourist numbers and total industry revenue. There are also challenges with the seasonal nature of the tourism industry. Jobs in tourism tend to be seasonal or part time, which can make them less desirable (Müller and Jansson, 2007). There is also competition from extractive industries for skilled workers, and because these extractive industries typically pay better than tourism, there is a capacity drain from the tourism industry to the resource industry, especially during the summer months when tourism and resource development employees are most in need. Additionally, specific skills and education are necessary for work in the tourism industry, and potential employees with these skills are not always found in small Arctic communities (Dawson et al., 2007; see also Chapter 5). When Johnston and Viken (1997) spoke with tourism operators in Greenland, the industry representatives commented that few community members seemed to have an interest in working in the industry and few had the foreign language skills necessary to communicate with tourists. To deal with human resource challenges related to tourism in the BBDS region, both Greenland and Canada (Parks Canada and the Government of Nunavut) provide ongoing guide and tourism training opportunities for local residents (e.g., Government of Greenland, 2016).

Furthermore, governing the industry in times of rapid environmental change will be challenging. Monitoring for noncompliance with regulations is both difficult and resource- and cost-intensive. It is not uncommon for small outfitters to operate without proper licenses or permits. In some cases, operators are doing so little business that it may not seem worthwhile to pursue a license or permit; in other cases, operators lack the business skills or a sufficient understanding of the permit system to comply (Dawson et al., 2014). When it comes to larger operations such as cruise ships, different challenges exist. For example, ships regularly sail between nations, so multiple national jurisdictions exist, each with differing and sometimes contrasting regulatory regimes. It is therefore difficult to ensure an appropriate, cohesive, and robust regulatory framework that effectively and efficiently supports the tourism industry across the region (Dawson et al., 2014, 2017b; Lassere and Têtu, 2015). Further, at all levels there seems to be limited knowledge of and compliance with the international CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) regulations or of the export regulations for animal products (Kaae and Råhede, 2011; Dawson et al., 2016).

A lack of regulatory enforcement capabilities also has negative impacts for the local environment, compounded by a lack of interpretative and educational information for tourists visiting the BBDS. Other Arctic regions, such as Svalbard and Alaska, have developed tourism-specific and site-specific guidelines that support sustainability. Efforts to develop site guidelines to protect sensitive environmental and cultural sites in Greenland and Canada are underway but not yet complete. The development of such codes or

Table 8.2 Summary of impacts of climate change on tourism in the BBDS region.

Direct Impacts		Indirect Impacts	
Positive	Negative	Positive	Negative
• Increased summer season length and lengthening of shoulder seasons (autumn and spring) • Increased accessibility in the marine environment due to sea ice reductions	• Changes to regional flora and fauna, as well as landscape aesthetics • Decline of key tourism attractions (e.g., glaciers) • Shifting wildlife habitats and migration patterns, including fish, charismatic megafauna, and other animals targeted for wildlife viewing • Increased prevalence of wind, fog, and extreme weather events • Increased instability and unpredictability of ice conditions • Damage to key tourism infrastructure • Uplifting land masses, altered coastlines, lower sea levels, and coastal erosion	• Promotion of local arts and handicrafts culture within communities • Seasonal employment opportunities for youth and entrepreneurs • Potential for development of a strong tourism economy • Opportunities for increasing tourist awareness and understanding of local Inuit culture • Increasing incentive to improve charting in the region	• Higher operating costs • More hazardous ice conditions, causing marine navigation issues • Floe-edge tours less reliable due to unstable ice conditions • Increased safety and security risks related to increased tourism vessel traffic • High proportion of non-local and international operators • Socio-cultural impacts related to cultural conflict, commoditization, and miscommunication • Higher insurance costs for operators related to hazardous ice, fog, wind, probability of extreme events, and weather uncertainty

guidelines will be vital for moving into the future and has been highly recommended by the Arctic Council (Arctic Council, 2015). Studies of tourists in Ilulissat, for example, show tourist interest in environmental guidelines and labeling, as well as a willingness to pay for environmentally conscious services and operations (Kaae and Råhede, 2011). The arrival of large cruise ships unloading high numbers of tourists in smaller communities and at local sites also causes high social and environmental pressures for a short period of time. This practice can result in a trampling of nature and the disturbance of archaeological sites, as well as disruptions of community life as large numbers of visitors walk around the community, visit spaces normally used by residents, and interrupt regular activities. Local people are also highly concerned about the possibility of fuel leaks or spills in the marine or terrestrial environment, as well as the disturbance effects that tourists may have on local and subsistence wildlife and cultural traditions (Stewart et al., 2011; Meltofte, 2014). The potential impacts of climate change on tourism in the BBDS region are summarized in Table 8.2.

8.3 Expected future tourism change – near term and longer term

The tourism industry is expected to continue to experience moderate growth due to climate change. However, caution is warranted in any speculation that changing climatic conditions alone will facilitate an ongoing increase in tourism possibilities as rapid as has been seen over the past ten years in the BBDS. A number of factors influence tourism development in the region, and the relative strength of climate change as a driver of tourism demand in comparison to other factors is difficult to gauge. It is likely that factors such as global economic conditions, resource extraction activities, technological development, and global social trends may play a greater role in driving the tourism industry than does climate change. However, vulnerability is high and even a single disastrous event (e.g., a cruise ship sinking, a plane crashing, or some other accident) could have a very negative, albeit likely temporary, effect on the tourism sector. Climate change will continue to play a key role in facilitating or enabling tourism growth via the direct impacts of change (i.e., increasing season lengths and marine accessibility). It is also possible that the "last chance tourism" phenomenon (i.e., with firsthand observation of climate effects becoming an attraction itself) may continue in the region in the near term (see Lemelin et al., 2012a). The main factors considered to favor or limit tourism development in the BBDS region are described in Table 8.3.

The remoteness of the circumpolar regions and the resulting initial cost to get there act as a key barrier to the expansion of tourism in Arctic regions. Transportation options are limited to air and water, and so the lack of infrastructure in some areas means that larger airplanes and vessels cannot always be supported. Despite the challenges associated with remoteness, the tourism industry (both land and marine) in the BBDS region is likely to increase between now and 2030. This expected increase is linked not only to climate change but also to infrastructure investments – particularly in Greenland, where the Government of Greenland is finalizing plans to construct new runways in key tourism destinations to allow for direct flights to Europe and North America.

Without the efficiencies related to improved airport infrastructure for larger and newer fuel-efficient airplanes and vessels, the cost of travel to Arctic regions is expected to remain high. Airports in both Nuuk, Greenland, and Iqaluit, Nunavut, are being upgraded to deal with increased traffic (see Chapter 10); these upgrades will be useful in supporting a growing tourism industry into the future. However, building and maintaining infrastructure in the Arctic is costly. Given the low population base in the region, it has been historically difficult to justify significant infrastructure development. Nevertheless, there is wide agreement that more transportation and services infrastructure is needed and that any new investments should consider multiple uses, including tourism. The challenge, of course, is that infrastructure development requires upfront capital investments, which will continue to be difficult for the region, particularly when the instability of the tourism and natural resource industries makes the forecasting of returns difficult (Hall, 2007). Furthermore, the thawing of permafrost is making infrastructure development more difficult and more expensive (see Chapter 10). Investment is also risky because tourism is somewhat unstable and demand is highly influenced by global trends and social whims that cannot be counted on in the long term. However, tourism has continued to grow worldwide despite major global events such as economic and health crises (e.g., SARS and H1N1 outbreaks). Thus, the industry in general is thought to be highly resilient to these negative global trends. Finally, infrastructure in Greenland has traditionally been determined by local needs, not dictated by national-level tourism strategies.

There is a lack of accommodation facilities in some parts of the BBDS region. In recent years, accommodation facilities in the town of Ilulissat have expanded based on increasing demand and necessary investments being made. The construction of new facilities will in part depend on increased demand in the future, which may also be facilitated by lengthening of the tourism season. Longer tourism seasons enhance the return on accommodation investments and secure longer periods of employment. The short summer season and harsh winter weather has historically made it difficult to maintain year-round tourism (Kaae, 2002; Gunnarsdóttir, 2006; Grenier, 2007; Robbins, 2007; Snyder and Stonehouse, 2007; Hall and Saarinen, 2010; Fay and Karlsdóttir, 2011), yet a warmer climate by mid-century could potentially support longer tourism seasons and enhanced winter tourism opportunities.

The arrival of visitors often tends to be concentrated at one particular time of year, either due to coincidence with a natural attraction or phenomenon (e.g., wildlife migration or reproduction, the midnight sun, or weather) or the timing of institutional holidays (Grenier, 2007). However, this challenge represents an opportunity for marine-based tourism with on-ship accommodation and increased efforts to extend land-based seasons by attracting tourists outside the high season. There is likely to be an increased reliance on cruise ship and pleasure craft activity, and it is likely that the region will attract bigger and more self-contained vessels than have visited in the past, as well as more luxurious vessels (see also Chapter 9).

Table 8.3 Influencing and limiting factors relevant to tourism development in the BBDS region.

Influencing factors	Main attributes
Climate change	Climate-related changes provide increased tourist access to new geographical areas and an extended tourism season due to reduced sea ice cover for longer periods of time.
Global economic trends	Tourism demand is vulnerable to declines and variability in the global economic situation. Climate change may exacerbate the risk of future economic declines in some nations. Reductions in GDPs (gross domestic products) would shrink the discretionary wealth of consumers, with negative implications for anticipated future growth in tourism.
Resource extraction	Increased resource extraction activity deters tourism and could cause conflicts (i.e., capital, resource, aesthetic, and user conflicts).
Technology	Improved transport, search-and-rescue, communications, and other technologies may enable safe tourism enterprises in even more remote regions. AIS, naval charts, and other satellite technology will improve the search and rescue and safety issues that currently exist and will facilitate monitoring for regulatory compliance.
Growing northern population	A growing population provides a local labor force for the tourism sector, as well as increasing opportunities for entrepreneurship and demand for academic and training programs for local people.
Tourism facilities	Interpretative facilities and greater capacity and quality of tourism overnight facilities and services will attract tourism operators and tourists.
Limiting factors	**Main attributes**
Climate change	Unpredictable seasonal variations, instability, and changes in sea ice pose serious hazards to marine vessels. Undesirable changes in landscape and wildlife deter tourists. Key attractions such as glaciers are melting/receding.
Legislation and regulation	Legislation such as the recent executive orders on pilotage and safe sailing in Greenland, the Polar Code, taxation related to the Coasting Trade Act, and the current tourism permitting system may have a significant impact on tourism development.
Lack of available ice-strengthened vessels	Larger vessels are not readily available, and more small vessels are emerging.
Limited infrastructure	Existing infrastructure will be unable to provide the necessary services for a high level of tourism (e.g., limited overnight bed capacity, limited ability to accommodate increasing numbers of cruise passengers visiting small places for short periods of time). The air link between Greenland and Canada has been sporadic and inconsistent, limiting intra-regional tourism flows. Shorter snow seasons and hazardous ice conditions make dog-sledding tours, ice-floe tours, and other related tourism activities risky and unreliable.
Charts and navigation	Poor charts do not allow vessels to safely navigate through the region. There is also increased safety risk for tourists and locals.
Community resistance	Backlash due to unprofitable local economic returns and disturbance of hunting practices and wildlife may arise.

Table 8.4 Tourism scenarios for various conditions of climate change (lower to dramatic levels) and the development of resource-extractive industries (modest to intensive). For more information about the scenario framework, see Subchapter 3.4.

Scenario 1: Dramatic climate change and modest development of extractive industries

- Ongoing increases in tourism activity, especially among pleasure craft and private yachts
- Northward transition of tourism activity (away from the BBDS region toward the Northwest Passage) because of the northward movement of wildlife and expansion of ice-free waters
- Region loses some tourism activity related to ice, glaciers, etc.
- Continual marine traffic from Greenland to Canada (because of existing Coasting Trade Act regulations, which incentivize international voyages)
- Some negative impacts on demand because of increased resource traffic
- Some negative impacts on demand because of a decline in aesthetic and landscape/seascape qualities from increased resource-extractive activities

Scenario 2: Dramatic climate change and intensive development of extractive industries

- Ongoing increases in tourism activity, especially among pleasure craft and private yachts
- Northward transition of tourism activity (away from BBDS toward the Northwest Passage) because of the northward movement of wildlife and expansion of ice-free waters
- Region loses some tourism activity related to ice, glaciers, etc.
- Continual boating and cruise traffic between Greenland and Canada (because of existing regulations)
- Significant negative impacts on demand because of a decline in aesthetic and landscape/seascape qualities from increased resource-extractive activities
- User conflicts (marine)

Scenario 3: Moderate climate change and modest development of extractive industries

- Slower increase in tourism activity, especially among pleasure craft and private yachts
- Some northward transition of tourism activity (away from BBDS toward the Northwest Passage) because of the northward movement of wildlife and expansion of ice-free waters
- Region maintains existing diverse tourism activity
- Continual boating and cruise traffic between Greenland and Canada (because of existing regulations)
- Some negative impacts on demand because of decline in aesthetic and landscape/seascape qualities from increased resource-extractive activities

Scenario 4: Moderate climate change and intensive development of extractive industries

- Slower increase in tourism activity, especially among pleasure craft and private yachts
- Some northward transition of tourism activity (away from BBDS toward the Northwest Passage) because of the northward movement of wildlife and expansion of ice-free waters
- Region maintains most existing diverse tourism activity
- Continual boating and cruise traffic between Greenland and Canada (because of existing regulations)
- Significant negative impacts on demand because of decline in aesthetic and landscape/seascape qualities from increased resource-extractive activities
- User conflicts (marine users)

The current lack of availability and the high cost of building ice-strengthened or Arctic-ready tourism vessels will limit the growth of commercial cruises in the region (Dawson et al., 2007; Stewart et al., 2007; Pizzolato et al., 2013; Chapter 9). However, with polar tourism companies now building their fleet for other parts of the polar regions (e.g., Hapag-Lloyd and Hurtigruten), new vessels will become available to meet and develop demand. Furthermore, ice-free summers could mean a significant enough reduction in ice hazards that larger cruise vessels currently traveling in more moderate climates would be attracted to the region. Some proponents believe it is unlikely that any new cruise vessels will be built only for Arctic travel, as vessels need to be in operation nearly year-round. However, others believe that new polar-purpose vessels will soon be built for customized sailings during the Arctic and Antarctic summer seasons, especially considering the increasing demand from Asian source markets, which is driving this development.

It is likely that significantly more pleasure craft vessels will visit the BBDS region, including many that have on board individuals without Arctic knowledge and ice navigation experience. It is also expected that there will be increases in entertainment-oriented or adventurous activities, such as yacht races and individual efforts to be the first to accomplish a particular feat (see Viken et al., 2014). It is becoming common now to see snorkeling tours in Baffin Bay, kayaking tours on glacial rivers in the Qaanaaq region (Petermann Glacier), and occasionally even glacier surfing on the waves created by ice breaking off of Greenland glaciers. This type of adventure tourism is expected to increase in the future. It is also expected that, despite a lack of infrastructure, the larger cruise vessels that are already arriving in Greenland will begin to visit the Nunavut side of the BBDS region. The future of the industry will also be highly dependent on how risks and major incidents are managed. For example, there have been a number of close calls in the region, but if there is a major safety issue, such as the sinking of a cruise ship or a similar incident, then the reputation of the industry – or tour operator – could immediately be compromised. The Polar Code has now been implemented and entered into force (1 January 2017) with an aim to reduce such risks.

Knud Falk

Harbour infrastructure challenges - large cruise ship visiting Narsarsuaq, South Greenland

The low population base of the Arctic region results in limited availability of trained service providers. This problem is not likely to be solved in the short- to medium-term future. It is often difficult for Arctic tourism operators to hire enough trained service providers in order to run their businesses (Dawson et al., 2007; Müller and Jansson, 2007; Fugmann, 2012). There will continue to be limited interest among local residents to work in the tourism industry for a number of reasons: personal preferences for other work, seasonal employment only, service employment possibly seen as lacking prestige, better employment opportunities in resource extraction or government services, and temporal conflicts with the timing of traditional and cultural activities such as hunting or fishing, limited education opportunities, and lack of entrepreneurship training (Fugmann, 2012; Müller and Jansson, 2007; Dawson et al., 2009; Lemelin et al., 2012a, 2012b; Ren and Chimirri, 2017). The dual impacts of climate change and the development of resource-extractive industries (see Chapter 7) will also play a significant role in shaping the future of the tourism industry. The likely tourism-related effects of the four scenarios outlined in Subchapter 3.4 are summarized in Table 8.4.

8.4 Climate change adaptation options

The extent to which the impacts of climate change will negatively or positively influence the tourism sector in the BBDS region will depend directly on the effectiveness of adaptation strategies in reducing the sector's vulnerability to climate change. *Vulnerability* is a function of both exposure sensitivity and adaptive capacity. *Exposure sensitivity* is the manner and degree to which the tourism industry is sensitive and exposed to particular forces or stresses, and *adaptive capacity* reflects the industry's ability to cope with, adjust to, or recover from stressors (Smit and Wandell, 2006). The tourism industry's exposure sensitivity reflects both the nature of the climatic conditions and the nature of the industry itself. For example, the extent of a particular impact will depend upon the degree to which the tourism industry is sensitive to that impact or the collective interaction of multiple impacts, and also on the extent (i.e., time, degree, level, scope) to which the industry is exposed. In effect, the same climatic event may affect different aspects of the tourism industry differently, with one sector (e.g., accommodation or food and beverage) not being affected at all by a particular exposure, while another sector (e.g., activities, events, or transportation) could be severely affected. It is vital that the industry as a whole reduce its sensitivity and exposure to climatic change as much as possible. Adaptive capacity relates to industry resilience, resistance to negative impacts, flexibility, and robustness (Smithers and Smit, 1997). Adaptive capacity is influenced by economic wealth, social networks, infrastructure, social institutions, social capital, experience with previous risk, the range of available technological adaptations, and access to resources within the region, as well as by the multiple stresses that contribute to the environment in which decisions are made (Smit and Pilifosova, 2003; Ford and Smit, 2004; Smit et al., 2008).

The tourism industry may be able to decrease its exposure sensitivity and increase its adaptive capacity to climate change through a set of strategic adaptation options. Adaptation options can be divided into five key thematic areas, including (1) policy and regulation; (2) infrastructure and technology; (3) services, economic development, and planning; (4) communication, coordination, and outreach; and (5) environmental and

Table 8.5 Climate change adaptation options for the tourism industry (adapted from Dawson et al., 2014; Arctic Council, 2015; Dawson et al., 2016).

Policy and regulation
Establish a sustainable tourism development and planning strategy for the BBDS region
Improve monitoring and enforcement capabilities
Require all commercial tourism vessels to carry an AIS transponder
Require all commercial tourism vessels over 300 gross tonnes to carry ice pilots and local observers on all voyages
Mandate that all vessels must report their locations to authorities
Improve airport infrastructure and increase market competition in order to reduce travel costs
Infrastructure and technology
Invest in multi-use infrastructure to support tourism development and local use
Improve bathymetric data and invest in better soundings
Invest in additional search and rescue infrastructure, including ships and air support
Invest in docking, museum, and other tourism infrastructure
Services, economic development, and planning
Improve search and rescue coordination and response
Enhance funding and services for the tourism industry
Provide funding and regulatory incentives for locally owned and operated tourism businesses
Capitalize on the growing business traveler market
Capitalize on and manage the rapidly growing pleasure craft tourism sector
Conduct planning directly with local residents and encourage local entrepreneurship
Reduce economic leakage from the region (due to over-reliance on external tourism companies) by encouraging the training of local community members and by reducing the percentage of imported goods needed to cater to visitors; in the Arctic, this leakage is difficult to avoid but could be mitigated
Create tourism opportunities jointly with the resource development sector (e.g., mine tours)
Encourage joint ventures between local and external companies to provide market access, knowledge exchange, and capital infusion
Communication, coordination, and outreach
Enhance search and rescue training
Invest in research to better understand the risks of climate change for the industry and coordinate results with insurance providers
Improve monitoring capabilities, including remote (e.g., satellite imagery) and in situ options
Developed shared marketing strategies between Greenland and Canada/Nunavut
Develop shared tourism experiences/products, for visiting both Greenland and Canada/Nunavut
Enhance interpretation and visitor facilities, focusing on local and Inuit culture and nature
Enhance local guide training
Increase digital infrastructure and the use of social media
Environmental and cultural sustainability
Establish incentives and regulatory mechanisms that favor local tourism operators over non-local or international companies
Provide additional tourism training and education programs
Develop and adopt codes of conduct for tourists and operators (e.g., AECO[1] operator guidelines, Arctic Council best practices)
Establish site guidelines for all environmentally and culturally sensitive sites
Consider a ban on the use of heavy fuel oil in cruise vessels
Enhance and promote cultural opportunities in the region
Enhance protected areas (terrestrial and marine)

[1] AECO = Association of Arctic Expedition Cruise Operators

cultural sustainability. Table 8.5 outlines a number of potential adaptation strategies that address the current impacts of climate change for the tourism sector in the BBDS region.

Focused attention on the development of strategies and policies within these five areas can potentially assist the BBDS tourism industry in taking advantage of opportunities and reducing the mounting risks that climate change brings to the region and to tourism operators. Because the region's tourism industry is relatively young compared to the well-established tourism industries in more southern latitudes, and also because industry growth has been so rapid, the regulatory and governance mechanisms that are in place (or are not at all in place) require development or renewal. This need was acknowledged in part by the Arctic Council in a recent report, *Arctic Marine Tourism Project* (Arctic Council, 2015), which made recommendations for best practices for the tourism industry across the Arctic. Important needs in the BBDS region include improving monitoring capabilities, acquiring bathymetric information in marine regions, and investing in infrastructure that supports safety and security, as well as economic development. The regulatory permitting framework on the Canadian side is particularly problematic and requires immediate reform, as it is onerous for operators. Rather than supporting industry growth, the current framework may be hindering economic development and limiting locally owned and operated businesses in favor of foreign operators (see Dawson et al., 2014, 2016, 2017b). Investment in physical and communications infrastructure is


imageBROKER/Alamy Stock Photo

Cruise ship passengers hiking on a rocky beach at Sunshine Fjord, Baffin Island, Nunavut, Canada

desperately needed in the region. In the short term, automatic identification system (AIS) transponders should be made mandatory for all commercial tourism vessels operating in the region. This requirement, while necessitating improved Internet and satellite technologies, would help to improve safety measures and enable more effective search and rescue planning and preparedness. Furthermore, it is vital that improvements be made in our understanding of ocean depths, including the acquisition of additional soundings and bathymetric data. As sea ice continues to melt, tourism vessels will be traveling off the beaten path into territories unknown, where there is currently limited navigational information (see Chapter 9).

Local community involvement through the provision of tourism services and products also requires consideration and implementation of adaptation options. The residents and local governments of some communities have expressed an interest in certain approaches to adaptation (see Dawson et al., 2014; 2016; Stewart et al., 2015). For example, in Pond Inlet, Nunavut, where increasing numbers of cruise visitors led to local concerns about visitor behavior, a welcoming guide was prepared to help visitors understand local expectations and desires (see Carter et al., 2018). Many of the risks related to increased access and changing tourism patterns are experienced at the local level. While regional adaptation options are needed, alongside those undertaken by a largely external tourism industry, it is vital that the local tourism industry, community residents, and local governments also assess adaptation options.

8.5 Conclusion

Climate change and the resulting environmental changes are now playing a substantial role in catalyzing economic development opportunities across the Arctic as the region becomes more accessible and attractive to private industry investments, including the tourism sector (Avango et al., 2013). Increased climate-related accessibility to the Baffin Bay/Davis Strait region has already resulted in major developments in tourism and related economic opportunities. In particular, cruise ship traffic has expanded and is now joined by even more rapid growth in pleasure craft travel.

Climate-induced changes have direct and indirect impacts, which include positive and negative effects in the BBDS region. It is generally believed that the Arctic cruise tourism industry is well positioned to be a beneficiary of climate change over the short term (Marquez and Eagles, 2007; Dawson et al., 2014). A changing climate brings about new Arctic cruise corridors and a longer cruising season, which – if managed well – could benefit local residents via increased seasonal employment that enables visitors to experience Inuit culture and traditions, promotes historical and contemporary arts, and supports national sovereignty (Furgal and Prowse, 2008; Stewart et al., 2010; Nunavut Tourism, 2011). It is clear that Greenland is considerably advanced in comparison to Nunavut in the development of infrastructure, marketing, coordination, and tourism strategies. West Greenland is currently in a strong competitive position. For tourism in Nunavut to be as successful, the opportunities brought by climate change must be viewed as territorial and community priorities.

The climate-induced changes include a northward expansion of ice-free navigable waters during a longer summer season and a predicted continued increase in both cruise and pleasure crafts in the region. These trends are generally beneficial for the tourism sector in the BBDS region, and a continued increase of tourism demand is expected well into the future. Also, tourism industry expansions are likely to continue on land, along with the expansion of infrastructure and facilities. However, some types of tourism activities, particularly ice- and snow-related activities, may be negatively affected by climate change. For example, popular tourism sights such as glaciers and the Greenland inland ice sheet may recede and eventually become less attractive for tourists (though in the short term, they may be highly attractive to tourists who want to see them before it is "too late").

Climate changes also represent some risks for the tourism sector in the BBDS region. Already, the poor quality (e.g., low precision) of some sea charts is a matter of concern due to the issue of safety. With increased marine access to unmapped regions and an expected uplift of the land and sea floor on the Greenland side due to melting of the inland ice sheet, the risk of accidents at sea is increasing. In addition to these safety and security issues, high economic leakage out of the BBDS reduces the local benefits of tourism and is a structural challenge for the tourism industry. A lack of regulatory enforcement capabilities and of interpretative and educational information for tourists represent additional challenges. Finally, a range of environmental and cultural impacts from tourism – particularly those associated with the practice of making brief visits with high numbers of cruise tourists in small communities – imperil fragile natural and archaeological sites. Some guidelines and codes of conduct are being developed.

The short-term future of tourism change in the BBDS region is expected to be one of moderate growth and expansion. In the longer term, various scenarios of external factors may influence the trajectory of tourism change.

The effectiveness of climate adaptation strategies is important for influencing the positive and negative effects of change on the BBDS tourism industry. A range of climate change adaptation options are provided above in relation to policy and regulation, infrastructure and technology, services, economic development and planning, communication, coordination and outreach, and environmental and cultural sustainability. Many of these options are already urgently needed in the region to help guide transitions, enhance opportunities, and reduce risks. Major findings for the region relate to infrastructural and other capacity issues; a need for investment in marine services, sector regulation, and monitoring; the importance of community-led initiatives and local entrepreneurship; and the importance of multilateral collaboration in the region.

The development of specific adaptation strategies for the explicit purpose of taking advantage of climate-induced economic opportunities – rather than focusing merely on mitigating the suite of readily apparent negative risks – is relatively new thinking (see Ford et al., 2012). This opportunities-based focus has received very limited attention within the scholarly literature on the human dimensions of climate change in general (Ford et al., 2012) and on climate change and tourism more specifically (Weaver, 2011; Kajan and Saarinen, 2013). Some scholars have called for a more focused research agenda on understanding the second-order opportunities that are emerging from climate change, including economic development options (see Ford et al., 2012; Cameron, 2012; Kajan and Saarinen, 2013).

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9. Shipping

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Key messages

- ***The Baffin Bay/Davis Strait (BBDS) region depends heavily on shipping.*** *This sector is an important driver of economic activity.*
- ***Shipping in the region is generally expected to benefit from climate change.*** *This benefit will probably facilitate some growth in the industry.*
- ***However, other drivers of change are probably more important than climate change.*** *Other important drivers include issues of geopolitics (e.g., Suez and Panama canals, political issues outside the region), global and regional economies (e.g., effects on mining, oil exploration/exploitation, and other industries), national priorities (e.g., deep-water port projects along the Canadian coast), and insurance (i.e., winter shipping versus summer shipping).*
- ***Increased shipping may bring some positive economic impacts to the region.*** *However, local residents express concern for the social, cultural, and environmental effects related to expansion.*
- ***Shipping-related environmental impacts on ecosystems and species in the region include oil (and chemical) spills; noise and disturbance, underwater and above; garbage (including organic); invasive species; and light (i.e., artificial illumination) disturbance (especially of seabirds).***
- ***Some shipping regulations related to environmental impacts are currently in place, and new regulations related to the IMO Polar Code and the IMO Ballast Water Management Convention will be important additions.*** *These regulations do not, however, include guidelines for accidental (oil) spills, use of heavy fuel oil, or noise disturbance.*
- ***The BBDS region contains a number of areas of heightened ecological importance and significance.*** *Though these areas are not necessarily ecologically vulnerable to environmental impacts from shipping (i.e., if there are no shipping-related activities or threats in the area), the foreseen changes in shipping may require long-term management and adaptation planning – that is, an adaptive ecosystem-based management (EBM) approach.*
- ***Very limited information is currently available on how increased cruise traffic may affect culturally important sites.*** *Large numbers of tourists wandering on fragile sites may lead to damage.*
- ***Significant areas of the BBDS region are poorly charted or are not charted at all.*** *Increased investment in charting, ice monitoring research, and multi-use infrastructure is needed.*
- ***Safety is a serious concern for some ship types (i.e., passenger vessels and pleasure craft).*** *Should an accident take place involving hundreds of passengers in harsh weather conditions, are safety devices on board and are search and rescue capacities adequate to quickly rescue them?*
- ***In the future, the shipping sector will require increased support, management, and regulation in order to reduce safety issues and to manage cultural and environmental challenges.***

Guiding Questions

What is the status of shipping in the Baffin Bay/Davis Strait region, and what are the major trends?

What are the impacts of climate change on shipping in the region, and what other drivers may influence the shipping industry?

What safety risks and environmental implications are connected with shipping in the region?

How will changes in marine infrastructure, including the amount and type or structure of shipping, interact with the environment and socio-economy in the region?

How may regulations for shipping activities enhance regional opportunities and development?

9.1. Introduction

A warmer Arctic climate is causing a reduction of ice cover. The projected losses of Arctic sea ice will influence future shipping activities and routes, as natural resource development, regional trade, tourism, research activities, and transportation of goods may change. Changes to Arctic shipping activities will have significant socio-economic and political implications. The *Arctic Marine Shipping Assessment 2009 Report* (PAME, 2009), approved at the Arctic Council's 2009 ministerial meeting and often referred to as "the AMSA Report," describes current and potential future Arctic marine activity and also provides a foundation for developing a further understanding of the implications of shipping in the Arctic.

The Baffin Bay/Davis Strait region has also experienced a reduction of sea ice (see Subchapter 3.1), which has increased the navigability of the region's marine waters. How this change may influence the shipping sector is already being discussed among various stakeholders in the region. In 2014, for example, the Greenland government published a "dialogue report" about possible adaptation actions related to shipping in Greenland (Government of Greenland, 2014). In relation to the development of this AACA chapter, many stakeholders were consulted. These consultations contributed to the development of the chapter, and it is hoped that this report will contribute to continued discussions across the entire BBDS region. The chapter includes an overall description of marine use (related to shipping) in the region and also an overview of current factors relevant to future shipping.

Although there are many similarities across the BBDS region, there are also important differences with implications for shipping. The shipping season is longer around Greenland because the open water season is longer than in Canada, which experiences more extensive ice and thicker ice (Figure 2.6). Greenland also has substantial shipping infrastructure (e.g., port facilities, wharfs, docks, refueling centers), whereas Canada has extremely limited infrastructure (see further details in Chapters 2 and 10).

9.1.1 Status and trends in shipping activity

The BBDS region does not at this stage display as great an intensity of vessel traffic as the European seas or the more southern Canadian regions. The reasons are partly because relatively few people live in the region and partly because there are no regular international transit routes through the region. Still, in Greenland waters alone, approximately 50–70 larger ships are navigating in the area at given any time (Stuer-Lauridsen and Overgaard, 2012). The BBDS region is also characterized by extreme weather conditions, numerous icebergs, inaccurate or incomplete sea charts, and limited marine infrastructure overall. Thus, help can be far away. These factors are concerning, as shipping traffic in the region has increased in the past decade and is expected to continue to increase in the future due to climate change effects, including the expected reduction of sea ice (Stuer-Lauridsen and Overgaard, 2012; Government of Greenland, 2014; Pelletier and Guy, 2014; Pizzolato et al., 2014; DNV GL, 2015; Lasserre and Alexeeva, 2015).

The types of ships that typically operate in the region (and that are considered in this chapter) can be divided into seven categories: (1) transport ships (e.g., of passengers, general cargo, bulk cargo, containers), (2) ships related to the mineral industry (e.g., bulk carriers, oil tankers, offshore supply ships), (3) fishing vessels, (4) research vessels, (5) cruise ships, (6) government vessels, and (7) other vessels. Smaller boats such as small fishing boats and yawls are not considered in this chapter. Table 9.1 shows the typical vessel categories that operate in the Greenland part of the region, as well as the number of registered sailings for all of Greenland, 2004–2013 (Arctic Command, 2014). The table shows large year-to-year variation but also a general increase, from 390 registered sailings in 2004 to 507 in 2013. For cruise ships, the number of sailings increased from 84 to 130. The 2010 increase for "other ships" is mainly due to oil exploration during that year. Table 9.2 shows number of voyages by vessel category for the Canadian Arctic, 2005–2014 (no statistics are available for only the Nunavut portion of the BBDS region). In the Canadian Arctic, the total increased from 121 to 301. As shown in both tables, recent years have seen increasing traffic intensity in the region (Government of Greenland, 2014).

Four shipping modes, or types of voyages, undertaken in the BBDS region can be identified:

- **Intra-regional transport within a single country (cabotage).** Examples are fishing vessels that are authorized to do trade or marine transport in coastal waters between ports along the coast of either Canada or Greenland. A prime example is the Arctic Umiaq Line, which carries passengers along the west coast of Greenland (Stuer-Lauridsen and Overgaard, 2012). This type of voyage is specific to Greenland, as sea passenger traffic remains very limited in the Canadian Arctic. In general, ferries play a significant role in domestic travel in the Greenland area because there are no roads between towns and communities and, south of Sisimiut, there is year-round open water (Figure 2.6). In Nunavut, Group Desgagnés, a Canadian shipping company, services northern communities on a cabotage basis. Transportation related to mineral exploration or exploitation may also be included in this type of voyage. In Canada, Fednav is the predominant shipping company that services local mines.
- **Intra-regional transport or marine activity between Nunavut and West Greenland**. Examples include the Nunavut fishing boats that call at Greenland ports to offload their catch, due to the lack of infrastructure (wharves and fish treatment plants) in Nunavut communities (Boyer 2013; see also Chapter 10). It is also very common for cruise ships to begin voyages in western Greenland and then travel to eastern

Table 9.1 Number of recorded sailings (voyages) for the whole of Greenland, by ship category, 2004–2013 (based on Arctic Command, 2014).[a]

Ship Category	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Transport ships (passengers, cargo, container)	142	192	159	240	206	171	162	184	155	143
Tankers	47	51	39	42	42	57	58	60	54	24
Fishing vessels	49	65	58	54	44	54	169	145	101	124
Research vessels	44	44	48	37	77	62	71	44	63	20
Cruise ships	84	83	86	87	124	96	193	113	106	130
Government vessels	8	27	13	21	24	12	16	17	25	12
Other ships	16	36	23	35	74	59	786	134	86	54
Total	**390**	**498**	**426**	**516**	**591**	**511**	**855**	**697**	**590**	**507**

[a] Each sailing (voyage) corresponds to one entry into the Greenland Exclusive Economic Zone.

All Canada Photos/Alamy Stock Photo

The town of Kugluktuk, formerly Coppermine, in Nunavut, Canada

Canada. Over 70% of such voyages currently operate intra-regionally in order to avoid a cabotage duty tax related to the Canadian Coasting Trade Act. The majority of cruise vessels are foreign flagged and would be subject to a duty tax if they operated within Canadian waters only (Dawson et al., 2014).

- **Destinational transport, in which a ship sails into or out of the BBDS region.** This mode includes the cargo and oil transporters and the large cruise ships that sail from southern ports to the west coast of Greenland in summer (Stuer-Lauridsen and Overgaard, 2012). The category also includes the vessels that handle the sealift of cargo from southern Canadian ports to Canadian Arctic communities, as well as the vessels that service mining operations (e.g., Voisey's Bay in Nunatsiavut, for the Voisey's Bay mine; Deception Bay in Nunavik, for the Raglan and Nunavik Nickel mines; and Milne Inlet in Nunavut for the Mary River mine (Têtu et al., 2015). In Greenland, destinational transport also includes the export of fish and shrimp (Government of Greenland, 2014). Goods transport to Greenland is carried out by general cargo ships, container ships, and product tankers.
- **Trans-regional (Arctic) transport or navigation, across the BBDS region.** This type of voyage can be through the Northwest Passage, between the Pacific and Atlantic oceans. Trans-regional voyages also include vessels that use the BBDS region as a marine link to or from other Arctic regions. This category could include pleasure craft vessels and adventure tourists (see Chapter 8).

As described by Pelletier and Guy (2014), port infrastructure is important in relation to intra-regional and destinational transport (see also Chapter 10).

Table 9.2 Number of voyages (sailings) in the Canadian Arctic, by ship category, 2005–2014 (based on data from NORDREG; Lasserre and Alexeeva, 2015; Johnston et al., 2013).[a]

Ship Category	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
General cargo	16	17	28	30	23	34	38	32	35	32
Tanker	17	16	24	29	23	28	30	31	28	25
Bulk	21	17	27	25	27	27	23	24	27	33
Fishing vessels	20	26	39	52	44	78	136	114	137	119
Cruise/passenger vessels	12	15	17	20	11	18	11	10	17	11
Pleasure craft vessels	10	6	9	7	13	15	25	26	32	-
Government vessels (Navy, Coast Guard)	9	9	8	10	10	13	19	15	17	22
Total	**121**	**135**	**181**	**209**	**185**	**257**	**317**	**314**	**349**	**301**

[a] Each voyage (sailing) corresponds to one NORDREG-zone entry and then exit.

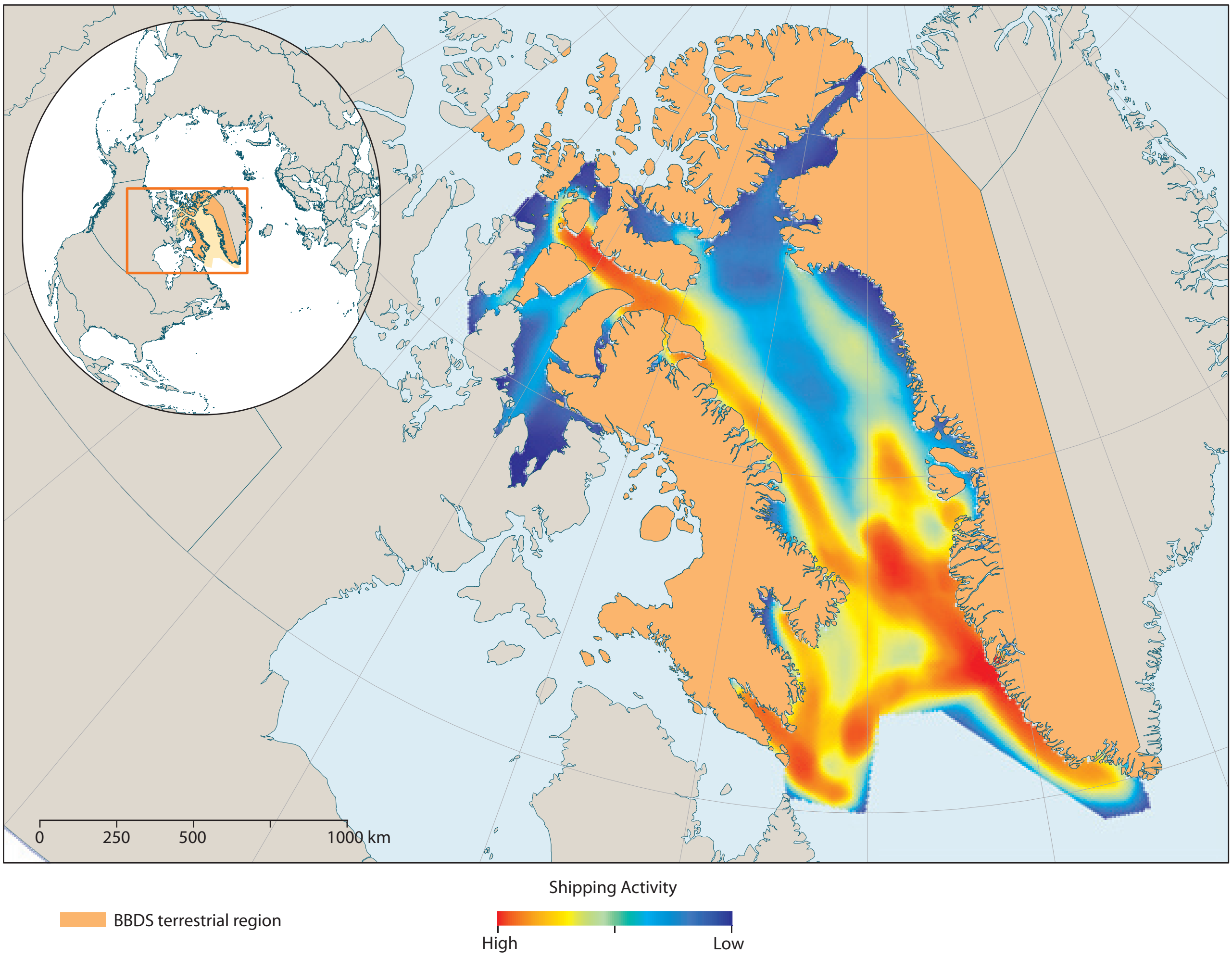


Figure 9.1 Map of traffic patterns (total density of ships) for the BBDS region, 1990–2013 (based on data from the vessel traffic reporting systems NORDREG and GREENPOST).

Historically, it has been challenging to establish a complete understanding of ship volumes and densities across the Arctic due to data and monitoring challenges. Even the AMSA project (PAME, 2009), which produced the preeminent report on Arctic shipping, found it challenging to establish a time series of shipping change and instead had to rely on "snapshot" data for a single year (2004). However, recent years have seen the widespread adoption of *automated identification system* (AIS) technology, which now makes it possible to monitor ship traffic. AIS data have been available in Arctic regions only since 2009 but are now becoming increasingly available and increasingly relied upon by all vessel types in the region. AIS is required for vessels over 300 gross tons (GT) in international traffic, vessels over 500 GT engaged on domestic voyages, and all tankers and passenger ships regardless of size. As of 31 May 2014, there are new rules for AIS on fishing vessels. All fishing vessels bigger than 50 GT must have AIS on board in Greenland. Exempt from the requirement to be equipped with AIS are the special categories of warships, naval auxiliaries, state-owned or state-operated vessels, and small craft yachts. There are, however, far more ships carrying AIS than those that are required (Christensen et al., 2015).

Figure 9.1 shows the traffic pattern (number of ships per unit area) seen in the BBDS study area for the period 1990–2013. For information about fishing (trawl) vessels, see Subchapter 6.4; for information about passenger cruise ships, see Chapter 8.

In Greenland, Royal Arctic Harbour Service handles operations in the 13 largest ports/harbors, and it also has some port authority on behalf of the state in these ports/harbors (Government of Greenland, 2014). There is broad political consensus that Nuuk's port is too small and has too little storage space, which creates bottlenecks for freight traffic throughout western Greenland. Therefore, funds have been allocated to renew the port and facilities in Nuuk, and this expansion has begun. The project was expected to be completed in 2016 (Transportkommissionen, 2011; Rambøll, 2013). Further, there are plans for developing harbors in Aasiat and Sisimiut to better facilitate industry operations (see also Chapter 10).

On the Nunavut side of the region, discussions about the need to build concrete wharves and port infrastructure have been ongoing for several decades, as there are only a few commercial ports in the Canadian Arctic: Churchill in Manitoba (the only port to service a community), closed since August 2016 (the owner, OmniTRAX, is looking for a buyer); Nanisivik on Baffin Island in Nunavut (no commercial operation presently; set to become a naval facility in 2018); Deception Bay in northern Quebec; and Milne Inlet, operational since 2015. The Mary River mine project is now serviced through the new port facility at Milne Inlet, on Baffin Island's north shore (Chapter 7). There is also a small craft harbor in Pangnirtung and one approved for construction in Pond Inlet. All other communities are serviced by ships that anchor offshore and use barges to transfer cargo to the beach or a flat area of the shoreline (Turmel, 2013; see also details in Chapter 10). The lack of port infrastructure is an impediment to the development of the fishing industry and the cruise ship industry in Nunavut. The lack of infrastructure also slows down the delivery of consumer goods to communities, but the current shipping firms are concerned that the construction of wharves could attract competitors. Currently, the area can accommodate only expedition-style cruise ships that carry a maximum of approximately 200 passengers. Cruise tourists must be taken ashore by small inflatable boats, which is a time-consuming process. Improved infrastructure would enable larger vessels to operate on the Nunavut side of the region and could improve economic development opportunities for its communities (Dawson et al., 2014; see also Chapter 8).

9.1.2 Shipping as a part of other socio-economic sectors in the BBDS region

Regarding shipping and its links to socio-economic considerations (see Chapters 2–3, 5–8, and 10), including supply and demand, it is important to note that communities in the BBDS region are located near the coast and that roads between the inhabited areas are absent in most cases (Chapter 10). Therefore, shipping plays a key role in the region, serving as a lifeline and ensuring the delivery of supplies to almost all other socio-economic sectors, in "bigger" towns as well as settlements (Transportkommissionen, 2011). Conversely, the development of other sectors can also have a major influence on shipping.

In Greenland, examples of shipping and logistics companies are Royal Arctic Line, Arctic Base Supply, Martek, and Blue Water Shipping. Royal Arctic Line A/S, which is owned by the Government of Greenland, has the exclusive right (concession) to ship goods to and from Greenland and to ship internally between the towns in Greenland. This exclusivity does not extend to freight between the towns and other possible destinations in Greenland. Several conditions are associated with this arrangement, regarding the frequency, capacity, and security of supply for the towns (NIRAS, 2014). Through Royal Arctic Bygdeservice, a subsidiary of Royal Arctic Line A/S, goods are carried to all the settlements. General cargo ships and container ships supply goods to the population, while product tankers supply gas and oil, which is used as fuel. Goods transport is driven by population size and consumption levels.

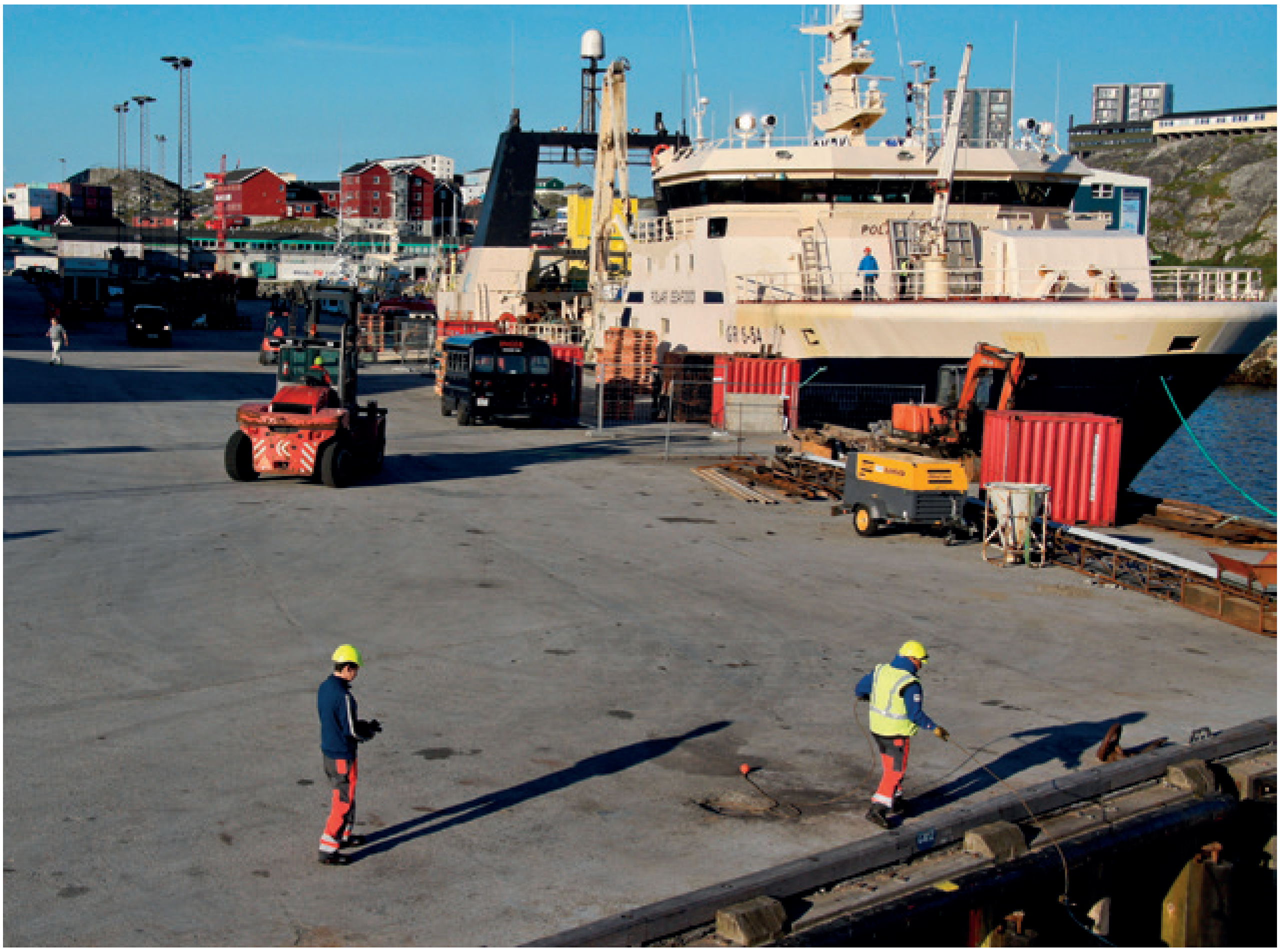
In Canada, the Canadian Coast Guard (CCG) took over responsibility for the resupply of Inuit communities in 1959. Basically, sealift resupply contracts were awarded by the CCG to shipping lines. Resupply services to the Nunavut side of the BBDS region have traditionally been carried out from the Montreal area by general cargo ships and tankers. In 2001, the Government of Nunavut took over the management of sealift contracts from the CCG. These contracts are awarded to shipping lines to deliver general cargo and petroleum/oil/lubricants to specific areas of Nunavut in accord with governmental supply requirements. Individuals and organizations can benefit from the rates negotiated by the government, but they can also contract with other lines.

In general, communities in the BBDS region are supplied all of their durables or consumer goods either by air (a very expensive transportation mode) or by sea when the shipping season is open. Extension of the navigable period thus presents coastal communities and natural resource companies with interesting economic opportunities, as the number of ship callings increase (Pelletier and Guy, 2014).

Natural resources development is linked either directly or indirectly to marine transportation, with ships traveling to and from worksites and across marine survey areas. As mentioned in Chapter 7, interest in the oil and gas potential of the region has experienced many ups and downs over the past fifty years. At times, price spikes have spurred exploration, while at other times, price declines and the lack of significant findings have slowed exploration. Political restrictions have been equally important in shaping activity. In relation to shipping, it should be mentioned that almost all industrial projects in Greenland and many projects in Nunavut can be serviced only through shipping (e.g., the Mary River iron mining project on Baffin Island). Other projected mining sites close to Bathurst Inlet in Nunavut are also considering using sea logistics rather than land roads (Lasserre, 2010; Têtu et al., 2015). There is presently no production of offshore oil or gas in Greenland, but in recent years there has been a significant amount of ship traffic related to exploratory work (Table 9.1; Chapter 7).

Fishing is the primary basis of the Greenland economy (see Chapter 2 and Subchapters 3.3 and 6.4). The fleet in the Greenland part of the BBDS region consists of about 800 vessels of various sizes, plus an estimated 5,000 smaller dinghies (Statistics Greenland, 2016). The ocean-going fleet includes a number of large vessels that fish outside the limit of 3 nautical miles (i.e., the limit of the territorial sea of Greenland). Most large vessels have the capacity to process the catch on board (DNV GL, 2015). In Table 9.1, only large fishing vessels (likely vessels above 20 GT) are included, which explains why only 44–169 fishing vessels per year were recorded.

As shown in Table 9.1, Greenland cruise ship tourism increased over the ten-year period 2004–2013, although a small decline and stagnation was seen after 2010 (likely related to the global economic downturn and business mergers in the region) (Dawson et al., 2014; see also Chapter 8). In the past, high hopes have been placed on the development of a cruise ship industry. So far, growth has been slower in the Canadian Arctic than in Greenland (Stewart et al., 2010; Lasserre and Têtu, 2015; Dawson et al., 2014). For example, tourists account for one-third of the customers on the Arctic Umiaq Line in Greenland (see above) during the three-month high season. Growth in the tourism shipping sector can be highly beneficial to the BBDS region, assuming the industry is well managed and supported. Among the benefits is the potential for economic development and greater employment opportunities in small, remote communities. Cruise ship tourism also facilitates the sharing of Indigenous cultures with international visitors, thus enabling educational experiences and enhancing understanding (Stewart et al., 2012, 2015; Dawson et al., 2016; see also Subchapter 3.3 and Chapters 5 and 8).



Michele Burgess/Alamy Stock Photo

Port of Nuuk, Greenland

As noted in Chapter 5, there is a positive correlation between education and industrial development, and the level of education and skills of the regional work force may influence the development of the shipping industry in the BBDS region. The increased need for skilled mariners in relation to operations, preparation, and planning for voyages in ice-covered waters is recognized not only in the BBDS region but also on a circumpolar scale (PAME, 2009; Ministry of Foreign Affairs, 2011; DFO, 2012; Government of Greenland, 2014). Denmark's 2011–2020 strategy for the Arctic (Ministry of Foreign Affairs, 2011) and a Government of Greenland discussion paper regarding shipping and climate change (Government of Greenland, 2014) both mention that key focus areas for Greenland are education, training, and the improvement of employee proficiencies (see also Chapter 5). In an analysis of commercial opportunities and challenges in the Arctic for the Danish realm's maritime industries (NIRAS, 2014; conducted for the Danish Maritime Authority), it is concluded that an important step can be to integrate training in Arctic maritime conditions, including ice navigation, into the maritime schools. In this regard, it is recommended that attention be paid to new regulations and potential requirements for future shipping in the region, including challenges associated with the International Maritime Organization (IMO) Polar Code. There may also be a need within business schools and technical universities to enhance awareness of the Arctic market. More Arctic-specific training empowers and positions the workforce to engage with the companies that produce or operate in the Arctic. Such training also provides the maritime industry with a larger and more capable recruiting base to meet future demands.

9.2 Current and potential future drivers of shipping change in the BBDS region

In the Arctic Marine Shipping Assessment report (PAME, 2009), Arctic natural resource development (hydrocarbons, hard minerals, and fisheries) and regional trade are described as the key drivers of future marine activity. However, there are many other factors and uncertainties of importance for the BBDS region. These factors include issues of governance, geopolitics (e.g., the Suez and Panama canals, political issues outside the region), oil prices, changes in global trade, changes in regional trade, national priorities for critical infrastructure (e.g., port expansion in Nuuk and deep-water port projects in the Canadian Arctic), new natural resource discoveries, tourism demand, insurance for ships, and Arctic marine technologies. These drivers are considered later in the chapter, to help estimate likely future changes in BBDS activities. Table 9.3 shows different types of shipping activity and their possible main drivers.

Although changing sea ice extent (see Subchapter 3.1) is recognized as an important driver of future shipping, it is a relatively minor driver of change compared to industry and market constraints, as well as geopolitics – e.g., the deepening of the Panama Canal (2016) and the Suez Canal (deepening in 2009 and widening to allow for two-way traffic in 2016). Operational and market factors remain key. For shipping firms deciding whether to invest in a specific market, just-in-time

Table 9.3 Main drivers of shipping change in the BBDS region.

Types of shipping activity	Possible main drivers
Dry bulk shipping – destinational transport	• Ore prices, global demand • Life cycles of Arctic mines
Oil activities	• Oil prices, global demand, technical development, environmental regulation • Mining and oil/gas projects: peak activity during the construction phases • Life cycle of Arctic extraction sites
Regional supply deliveries – general cargo and petroleum products	• Local demographics and economic development
Transit traffic (all types)	• Cost of implementing Polar Code requirements • Insurance markets • Icebreaking/escort policies and fees • Ice cover trends • Panama Canal pricing policy and congestion • Shipping markets and the daily time charter equivalent (when shipping markets are hot, the value of time is higher)
Fishing	• Stock evaluations • Commercialization of new species • Knowledge transfer and fishing rights • Port infrastructure
Cruise (tourism)	• Tourism markets and demand • Availability of ice-strengthened vessels and other vessels

constraints[8] will always prevail in the liner service (container, reefer, general cargo), while freight rates remain a paramount consideration in the bulk segment (Lasserre and Pelletier, 2011; Beveridge et al., 2015, 2016). Cost structures also represent a major deterrent for would-be Arctic shipping companies, including insurance costs and Arctic-specific crew training and equipment adaptations demanded by the insurance industry (Sarrabezoles et al., 2014; Beveridge et al., 2015). Empirical evidence identifying climate change as a relatively minor driver of Arctic ship traffic in Canada was established by Pizzolato et al. (2014), who found only a weak correlation between sea ice and overall ship traffic. The strength of the correlation has been increasing over time, though, and has been strongest in more recent years, suggesting that climate change certainly plays some role in driving ship traffic – albeit to a much lesser extent than geopolitical and economic factors.

It is also important to note that demand within the region can evolve differently for different sectors (e.g., fishing, cruise, bulk exportation, community resupply, transit), as can the associated human and environmental challenges and possibilities. For example, the moderate increase already seen in BBDS shipping activity/traffic to date is provided as an average across all sectors – but at any time, conditions can change very rapidly to affect a particular sector, community, or maritime region quite dramatically. Ship traffic linked to the extraction of resources will see boom and bust trends according to the life cycles of specific projects. If the number of individual projects in the BBDS and adjacent regions remains low, then the opening or closing of a single site can dramatically transform traffic statistics from year to year (see Chapter 7 for details on the development potential for extractive industries in the BBDS region).

Altogether, it must be emphasized that because the drivers of shipping are diverse (see Table 9.3), there can be a sharp increase in one segment simultaneous with a decline in another.

9.3 Environmental issues related to shipping

Increased shipping activity, if not regulated properly, can potentially have serious consequences for the Arctic environment and for the Indigenous peoples who live in the region and rely on the environment for subsistence and livelihoods. The possibility of an oil spill is a major concern for the fishing and hunting sector, including local Inuit who are especially concerned about the disruption of culturally important marine species. Impacts from shipping are potentially more hazardous in the Arctic than at lower latitudes due to the special adaptations of Arctic species and due to the low temperatures and the presence of ice. These physical factors hamper the degradation and removal of pollutants and slow the recovery of impacted habitats. Shipping-related impacts include the accidental or regular discharge of oil, noise in the

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[8] "Just in time" is a logistics management technique by which inventories are kept minimal – thus, finished goods and intermediate parts in a production process must be delivered exactly when the last one is used. This logistical technique reduces inventory costs but forces transportation and manufacturing companies to set up extremely efficient logistical chains lest the production process be disrupted. The container industry works on this basis, selling not only the transportation of manufactured goods but also the pledge to deliver them on precise schedules.

robertharding/Alamy Stock Photo

Container ship unloading at Nanortalik Port, Southern Greenland

underwater environment, emissions to air, discharge of garbage, introduction of invasive species, artificial-light disturbance, and whale strikes. These impacts can potentially act together with impacts from other activities in the area (e.g., fishing, hunting, mineral exploration, and tourism) as cumulative impacts. A large oil spill is probably the most serious hazard to the Arctic environment (Skjoldal et al., 2009).

The consequences of ship emissions to the air – e.g. carbon dioxide (CO_2), methane (CH_4), chlorofluorocarbons (CFCs), aerosols, nitrogen oxides (NO_x), sulfur oxides (SO_x), and carbon monoxide (CO) – are mostly indirect in relation to environmental consequences in the region. However, the emission of black carbon (the primary component of soot) is of particular concern in the Arctic because it accelerates melting when deposited on snow or ice (NIRAS, 2014).

Ship discharges to water include oil, oily water (bilge water, drain water), garbage, gray water, and cargo (liquid or dry). Discharges can have a wide range of impacts on the marine environment, including toxic impacts. Garbage and other debris can cause damage to marine habitats, entanglement of wildlife, and animal ingestion of unsuitable items (Skjoldal et al., 2009). The bioaccumulation of contaminants also has serious health implications for northerners who rely on country food (see Subchapter 3.2 and Chapter 4).

Accidental release of oil is the most serious shipping-related threat to marine ecosystems in the BBDS region (Chapters 6 and 7). Consequences would depend on the amount of oil spilled and on how long the spill endures. Spilled oil has both immediate effects – for example, on birds and marine resources – and long-term effects if the oil persists in the environment (Christensen et al., 2012; see also Subchapters 6.4–6.5).

Ship traffic and associated activities may create numerous disturbances in the marine environment, ranging from direct injury, death, or displacement from key habitats to more subtle behavioral changes (Skjoldal et al., 2009). Shipping-related activities can affect a wide range of marine species, including marine mammals, fish, and seabirds. The underwater acoustic environment is inherently complex and sometimes relatively noisy due to a myriad of natural and anthropogenic sound sources. Impacts from noise will vary by sound source (e.g., vessel operation, icebreaker operations, seismic activities, hydroacoustic devices) and location, as well as by species (i.e., different species hear and use sound differently). Very few of these acoustic effects are expected to include direct physical injuries to hearing or other systems; rather, there is more concern regarding behavioral disturbance and displacement from key habitats, as well as interference masking of acoustic communication (see further in Section 6.5.2).

Compared to other vessels, icebreakers produce louder and more variable sounds, due to the episodic nature of their normal function (i.e., ram forward into the ice and then move in reverse to begin the process again). Still, the act of physically breaking the ice does not produce the majority of icebreaker noise underwater; instead, as with other vessels, propeller cavitation is the main source of noise.

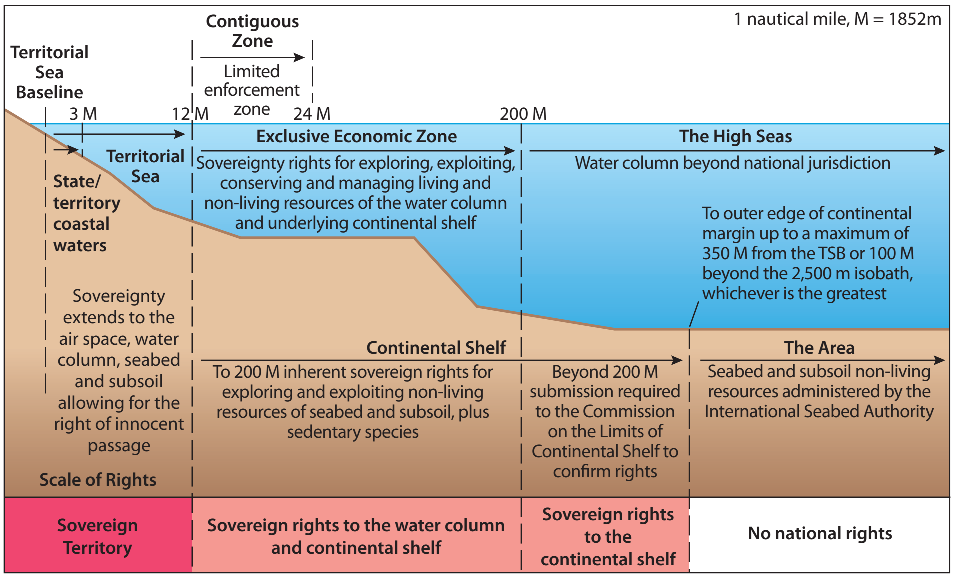

Figure 9.2 Diagram of marine jurisdictional zones (from Symonds et al., 2009; Geoscience Australia). For Canada, the territorial sea limit is 12 nautical miles, as shown on the figure; for Greenland, the limit is 3 nautical miles. M = nautical mile; m = meter; TSB = territorial sea baseline. (Figure from Geoscience Australia, www.ga.gov.au/ausgeonews/ausgeonews200903/limits.jsp; licensed under the Creative Commons Attribution 3.0 Australia License: creativecommons.org/licenses/by/3.0/au/.)

Seabirds are especially vulnerable to certain types of disturbance, mainly because they concentrate in large numbers in colonies or in flocks, so that a single disturbance can affect thousands of birds. The breeding period is a very sensitive period, as is the molting period, when some species are flightless. In this regard, it should be mentioned that most of the important seabird areas are in relatively shallow water or are close to the coast.

Vessel collisions, resulting in death or serious injury, are a threat to marine mammals worldwide. These encounters, also referred to as ship strikes, occur primarily with large whale species. In the BBDS region, slow-moving species such as bowhead whales and right whales are vulnerable to ship strikes.

Many birds are attracted to lights during the dark hours and especially during low-visibility conditions (snow or fog). Birds migrating during the night are therefore at risk of colliding with structures that are within or near illuminated areas. Searchlights on ships have caused bird deaths during migration seasons and in winter (Merkel and Johansen, 2011). There are specific areas in the BBDS region where large numbers of birds winter – including eiders, which are sensitive to light attraction.

Cruise ships constitute a special case of shipping because they actively seek out areas of special interest, including superior wildlife-viewing opportunities – often in areas that are poorly charted, off the main navigational corridors. This situation creates risks to vessels and also creates the potential for cruise ships to have greater impacts on high concentrations of wildlife, not only from the ship transit itself but also other activities related to the tourism package – e.g., close approaches to haul-outs and colonies, small-craft landings of tourists on colony sites, and longer times spent near concentrations of animals (Dawson et al., 2014, 2016; see also Chapter 8). The industry itself tends to be highly aware of its impact and thus reduces impacts when possible. The cruise ship industry has a vested interest in maintaining healthy wildlife populations, in support of their tourism packages (Christensen et al., 2012; see also Chapter 12).

The introduction and spread of alien invasive species is a potentially serious problem with ecological, economic, health, and environmental impacts, including the loss of native biological diversity. The shipping-related threat from invasive species stems from four sources: unmanaged ballast water discharge, hull fouling, invasive species discharge involved with cargo operations and casualties, and shipwrecks. The most important threat appears to be related to ballast water (CAFF, 2013). Only a few studies have examined invasive species in the Arctic, but if no focused preventative management is initiated, then the risk of introduction and establishment of such species in the Arctic is expected to increase (Ware et al., 2013).

9.4 Governance of shipping in the region

The governance of shipping activities in the BBDS region might be described as a complicated mosaic, and this chapter does not provide a full overview of applicable international laws. However, the chapter does outline some of the most relevant issues for the BBDS region and also considers weaknesses in the existing framework, as seen from a regional perspective.

9.4.1 Maritime jurisdictional zones in the BBDS region

The coastal state maritime jurisdictional zone claims for the territorial sea are not the same for Greenland and Canada. In Greenland, the limit is 3 nautical miles (nm); in Canada, 12 nm. For both countries, the extent of the exclusive economic zone (EEZ) is 200 nm (PAME, 2009). Figure 9.2 illustrates marine jurisdictional zones.

In Canada, all ocean areas that are not prescribed to be inland waters are under federal jurisdiction.

In Greenland, the situation is more complex. Greenland is a self-governing unit within the Danish realm, and the Danish Constitution applies to Greenland. Greenland began its state-building process with the introduction of "Home Rule" in 1979, following adoption of the Act on Greenland Self-Government No. 473 of 21 June 2009 (the "Self-Government Act"). As a self-governing unit, Greenland has claimed a territorial sea that extends 3 nm from the territorial sea baseline and, as a part of the Danish realm, an EEZ that extends 200 nm from the baseline. In Greenland territorial waters, specific requirements are in effect regarding ice-strengthening, local knowledge, and certain specific routes, but those rules do not apply across the Greenland EEZ (Stuer-Lauridsen and Overgaard, 2012). In relation to the marine environment, jurisdictional responsibility is also shared between Greenland and Denmark. Greenland Self-Government authorities are responsible for ocean areas within 3 nm of the territorial sea baseline. Beyond the 3 nm limit, responsibility for the marine environment rests with Danish authorities, with the important exception that all activities related to raw materials extraction in Greenland are regulated by Greenland Self-Government, including the export shipping of crude oil but not the shipping of mineral ore. The area beyond 3 nautical miles is in general regulated by the Royal Order for the enforcement of the Environmental Protection Act for Greenland of 2004 (Government of Greenland, 2014).

9.4.2 Polar Code and IMO Ballast Water Management Convention

An important upcoming regulation for the region will be the United Nations' International Maritime Organization Polar Code (IMO, 2015) and the related amendments to make it mandatory under both the International Convention for the Safety of Life at Sea (SOLAS; IMO, 1974) and the International Convention for the Prevention of Pollution from Ships (MARPOL; IMO, 1973). The purpose of the code is to impose stricter requirements on ice classification and safety on board for sailing in Arctic waters. It also includes operational requirements for the maritime education system and the training of crews, as well as navigation in ice-covered waters. In relation to safety aspects, the Polar Code will be mandatory for all commercial carriers and passenger ships of 500 tons or more. In relation to environmental aspects, the Polar Code will in principle apply to all vessels (IMO, 2015). The code, which will contribute to the international maritime safety and environmental conventions that already apply to the Arctic, will come into force in 2017. Though the Polar Code will be a key framework agreement, it is not comprehensive and will not directly address such issues (and impacts) as black carbon from ship emissions, heavy fuel oil use in the Arctic, or ballast water discharge (Christensen et al., 2015). However, in relation to ballast water, the IMO Ballast Water Management Convention (IMO, 2004) will minimize the transfer of alien species. Denmark ratified the convention in 2012, with an exemption for Greenland (Christensen et al., 2015). Canada ratified it in 2010.

9.4.3 Safety and environmental risks

Improved safety (for navigation) and search and rescue is seen as a challenge in relation to shipping in the region (see also Chapter 8). The IMO Polar Code (IMO, 2015) will be a step in the right direction, but some areas of the region remain hazardous for navigation, and increased investment in hydrographic surveys and nautical charting, as well as ice monitoring research, is needed. This need is mentioned as a future priority for the Greenland part of the BBDS region in Denmark's strategy for the Arctic (Ministry of Foreign Affairs, 2011, among others). The focus on this area is also seen through the work of the Danish Ministry of Defence, which has an increased emphasis on improved safety and search and rescue (SAR) through analysis of its future Arctic tasks and capabilities (Danish Ministry of Defence, 2016). The need to invest in Arctic hydrography in Canada was identified in a 2014 report by Transport Canada's Tanker Safety Expert Panel (Transport Canada, 2014).

Another step in the right direction is the increased focus on search and rescue from the Arctic Council and its members. In 2016, the Arctic Council's Emergency Prevention, Preparedness and Response Working Group (EPPR) adopted SAR in its strategic plan (EPPR, 2016). The strategic plan states that "EPPR facilitates implementation of the SAR agreement by focusing on enhancing cooperation, highlighting best practices, exchanging information, analyzing results of exercises, and sharing lessons learned. EPPR will maintain a repository for lessons learned in Arctic SAR exercises and incidents." (EPPR, 2016, p. 4). The EPPR work on search and rescue will be under continuous development (EPPR, 2016).

Safety, especially for cruise shipping, is a serious issue. Existing regulations offer loopholes that allow large cruise vessels with low ice-class notations to enter national waters. In addition, cruise vessels sometimes transit the region without making stopovers – thus, without submitting to port state regulations. There is also a BBDS trend of increasing numbers of larger ships, which would require special search and rescue capabilities in the event of an accident. Commercial ships in the Arctic follow the better-mapped navigation channels (in Arctic Canada, 35% of the marine corridors are well surveyed), but some cruise ships tend to travel off the commonly used transportation corridors in search of wildlife and other viewing opportunities. In general, areas outside the most-used navigation channels are poorly mapped.

Pleasure crafts present some of the highest risks in the region, as these vessels are not ice strengthened, they are exempt from any reporting or other regulatory requirements (e.g., carrying AIS transponders) because of their small size, and their operators typically do not have experience navigating in ice-infested waters. These ships also present security risks because they travel under the radar of most authorities and can more easily enter national waters unnoticed.

Oil tankers may represent a significant risk in the form of a major oil spill. For now, there is no traffic linked to oil exploitation in the Arctic areas of Canada and Greenland because no major discovery has been declared and oil prices have collapsed, thus postponing most exploration plans (Chapter 7). In the past (1985–1996), oil from Cameron Island in Nunavut was shipped by the ice-class oil tanker MV *Arctic* (Fednav). The oil tankers that do ply these waters are servicing local communities, and they represent about 10% of the total traffic (about 25% of commercial cargo ships or barges in the Canadian Arctic and a smaller fraction in Greenland's waters). Because these tankers service local communities, they must comply with port state regulations. On the Nunavut side of the region, Transport Canada regularly inspects cargo ships that fall under its supervision and that ply Canadian Arctic waters (Transport Canada, 2014). Should oil exploitation eventually develop in BBDS waters, specific care from regulatory authorities will be advised (see Chapter 7).

Box 9.1 Areas with a need for heightened awareness in relation to impacts from shipping (based on Christensen et al., 2012, 2015; AMAP/CAFF/SDWG, 2013)

Environmental impacts from shipping include noise in the underwater and above-water environments, disturbances to marine mammals and seabirds, introduction of invasive species, and accidental or illegal discharges of oil, chemicals, and waste. In this context, a large oil spill is regarded as the most serious threat to the Arctic marine environment. Based on IMO guidelines for the designation of particularly sensitive sea areas (PSSAs), the Arctic Council has identified a number of areas of heightened ecological and cultural significance in light of changing climate conditions and increasing multiple marine uses.

The Ministry of Environment and Food of Denmark in collaboration with the Greenland Home Rule government asked Aarhus University and the Greenland Institute of Natural Resources to identify and prioritize marine areas around Greenland that are ecologically valuable and vulnerable, based on 11 criteria for designating PSSAs in line with the IMO guidelines. Seven such areas were identified within the BBDS region (Figure 9.3). (Note that Nunavut was not included in this exercise – for that area of the BBDS region, see the ecologically or biologically significant marine areas, EBSAs, listed in Subchapter 6.2.)

Based on the results of this exercise, the ministry further requested Aarhus University to clarify management initiatives and needs in the Disko Bay and Store Hellefiskebanke area (area V5) with regard to potential environmental consequences from shipping. For this step, 41 map layers of the spatial distributions of important marine species and ecosystem components were combined to show the most biologically important areas, according to a set of criteria incorporating those used by the Convention on Biological Diversity to identify EBSAs and by the IMO to identify PSSAs. Each biological layer was further assessed and ranked according to its specific sensitivity to potential environmental effects caused by shipping. It was thus demonstrated that a number of smaller areas around Disko Bay and Store Hellefiskebanke are sensitive or very sensitive to the environmental impacts that shipping may cause. Five subareas were identified as possibly needing heightened awareness in relation to impacts from shipping (Figure 9.4).

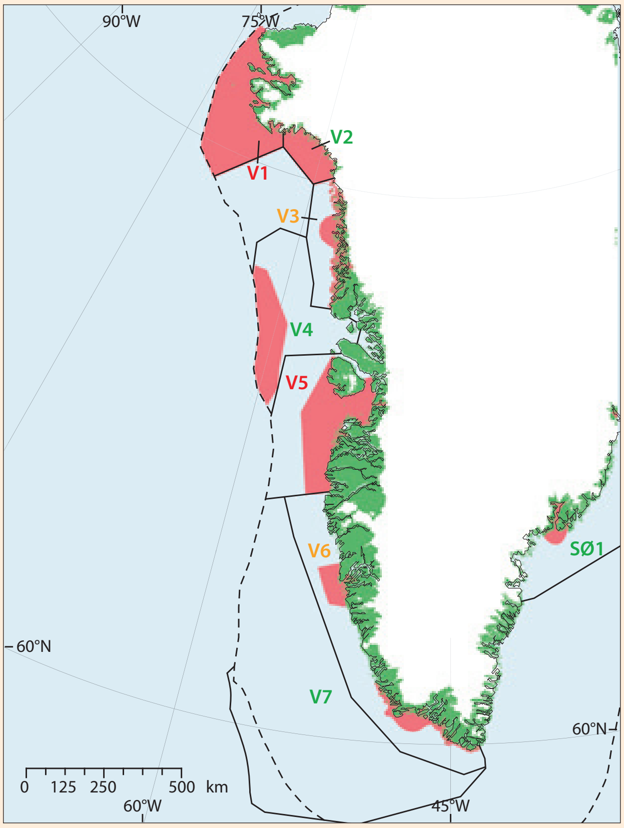

Figure 9.3 Identification of ecologically valuable and sensitive sea areas in the Greenland part of the BBDS region (from Christensen et al., 2012). The color of the area labels indicates priority: Priority 1 in red, Priority 2 in orange, and Priority 3 in green. Especially important "core areas" are marked by red shading. In area V7, the critical resources (whelping seals and foraging seabirds and whales) are associated with the marginal ice zone, which is highly dynamic within a single year and also between years – increasingly so due to climate change impacts. Accordingly, the associated core areas are not mapped here, as they must be equally dynamic.

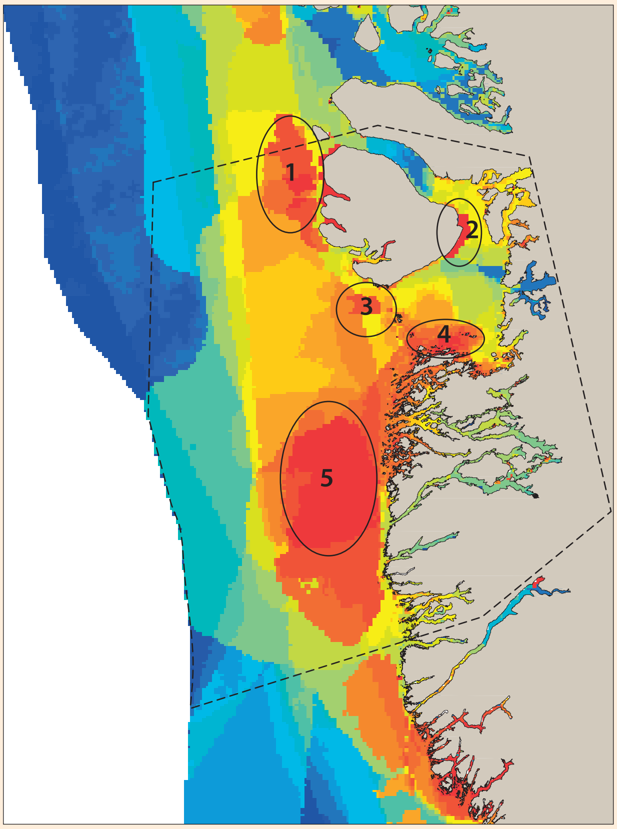

Figure 9.4 Relative environmental sensitivity within the Disko Bay and Store Hellefiskebanke (V5) area, including five subareas (1–5) where heightened awareness in relation to the impacts of shipping may be needed (from Christensen et al., 2015). The colors indicate sensitivity within each grid cell (2.5 × 2.5 km), based on an assessment of the sensitivity of existing species and ecosystem components to environmental impacts from shipping (oil, noise/disturbance, and organic garbage). Relative sensitivity is expressed in 5% bins, with red being the most sensitive and blue being the least sensitive.

Given that destinational traffic is expected to grow more rapidly than transit traffic (see Subchapter 9.5 below), attention to how the safety of shipping has been improved in the south can be relevant. The definition of proper standards can be a first step, but enforcing the standards is equally important and can be challenging. Port state control programs, which verify the application of standards set by IMO conventions, are being implementated worldwide as an essential component of a shipping safety net. This implementation will, however, probably take several years to complete, and in the BBDS, it will potentially also be a very large and expensive task. Thus, implementation of the Polar Code and its requirements will require substantial manpower and logistical management to send inspectors to board vessels as needed.

According to Denmark's Arctic strategy, "*the Arctic and its current potential must be developed to promote sustainable growth and social sustainability. This development must take place firstly to the benefit of the inhabitants of the Arctic and go hand in hand in safeguarding the Arctic's environment*" (Ministry of Foreign Affairs, 2011, p. 7). Based on this principle, the Danish Defence Agreement 2013–2017 stipulated that a risk assessment be prepared for the marine environment in and around Greenland, including the BBDS region (DNV GL, 2015). The scope of work for the analyses was to quantify and assess the effectiveness of oil spill response measures and to recommend potential future solutions for oil spill contingencies, as well as risk-reduction measures (DNV GL, 2015).

In recent years, the Danish Ministry of Environment and the Greenland Self-Government have jointly initiated work on management initiatives regarding the potential environmental consequences of shipping (Christensen et al., 2012, 2015). As noted above (Subchapter 9.3), environmental impacts caused by shipping can potentially act together with impacts from other activities in the region (e.g., fishing, hunting, mineral exploration, and tourism) to contribute to cumulative impacts. Therefore, ecosystem-based management for particularly sensitive sea areas can be applied in the future management of shipping in the region (see also Box 9.1). Fisheries and Oceans Canada has delineated a number of environmentally or biologically significant marine areas (EBSAs) across the Canadian Arctic (see also Chapters 2 and 6).

9.5 Ship traffic, expected future change, and impacts

Shipping will probably continue to be important for the economy of the BBDS region, and in that sense, the demand, supply, and need for marine transportation is a very important driver to consider. However, as previously mentioned, these parameters can evolve very differently by segment (e.g., fishing, cruise tourism, mineral exploration/exploitation and bulk exportation, community resupply, transit). This section provides estimates for future changes by shipping segment and, based on these estimates in combination with the scenarios shown in Table 9.4, also suggests relevant adaptation options (Table 9.5).

The *fishing industry* includes fishing vessels and reefers (refrigerated ships) that carry the catch. The fishing industry is regulated mainly by quotas and license regulations to ensure sustainable use of the natural resources; a number of factors can influence these regulatory mechanisms, including national and international fisheries policies as well as possible changes in ecosystems (see Subchapters 3.3 and 6.4). Fishing vessel activity is also influenced by the size, technology, and efficiency of the vessels themselves. On the Greenland side of

Table 9.4 Future shipping (intensity, patterns, and impacts) in the BBDS region, in relation to scenarios[1] for climate change (moderate to dramatic) and the development of resource-extractive industries (moderate to intensive).

Scenario 1: Dramatic climate change and modest development of extractive industries
Longer cruise tourism season and increasing demand for cruising and yachting
Little growth in cargo vessel movement (which is driven mainly by regional economics and demographics)
Increased safety risks associated with tourism vessels
Increased interest and feasibility in transit shipping through the Northwest Passage; hazards in the passage will remain high
Scenario 2: Dramatic climate change and intensive development of extractive industries
Longer cruise tourism season and increasing demand for cruising and yachting
Significant increases in winter shipping activities, with increased environmental risk
Important growth in cargo vessel movement in the region
Increased user conflicts between resource vessels and tourism vessels
Greater shipping safety, facilitated by extractive industry shipping and associated contingency systems
Increased interest and feasibility in transit shipping through the Northwest Passsage; hazards in the passage will remain high
Climate change is more likely to lengthen the shipping season than to change the routing of traffic
Scenario 3: Moderate climate change and modest development of extractive industries
Important growth in cargo vessel movement in the region
Climate change is more likely to lengthen the shipping season than to change the routing of traffic
Scenario 4: Moderate climate change and intensive development of extractive industries
Increased ice-related hazards and incidents
Little growth in cargo vessel movement (which is driven mainly by regional economics and demographics)

[1] For more information about these framework scenarios, see Subchapter 3.4.

the BBDS, it is very likely (as mentioned in Subchapter 6.4) that some commercially important fish stocks will increase in the future – including cod and mackerel, in particular. For other species (e.g., shrimp), declines are very likely. In Canada, fisheries seem to be on the rise, with trawlers from Nunavut and Newfoundland increasingly plying BBDS waters on the Nunavut side. As described above, however, many factors influence the development of a fishing fleet. Some factors may result in an increase in shipping (as expressed in terms of sailed distances, numbers of ships, or ship sizes), and some may result in a decrease. Fishing fleets are constantly changing, with a general trend toward fewer, larger, and more efficient vessels. The shift toward larger vessels may result in fewer vessels performing the same amount of work as previously performed by a larger fleet of smaller vessels, as well as a decrease in the total distance sailed. On the other hand, an increase in available fish stock could lead to increased shipping activity.

In relation to *cruise ships*, the increasing trends shown in Tables 9.1 and 9.2, coupled with the global growth of cruise activity in remote places, suggests a likely increase in the number of cruise passengers coming to the BBDS region in coming years. Pleasure craft activity, in particular, is expected to increase. It is also expected that the size of cruise ships will increase, which would translate into substantial increases in numbers of visitors, with only moderate increases in the number of voyages (see also Chapter 8). However, a significant shift toward larger ships is not expected before 2030, due to fluctuations in the cruise market (including numbers of passengers) and deficits in major ports and infrastructure in Nunavut (Chapter 10). This anticipated size trend is assumed

Table 9.5 Possible climate change adaptation options related to shipping.

Governance, Policy, and Regulation (see also Environmental Sustainability options and Safety options below)
• Explore the possibility of making AIS mandatory for all vessels regardless of size
• Improve the monitoring of shipping intensity, type, and patterns; enforcement capabilities; and other parameters
• Improve ship reporting capacity
• In the short term, supervise and actively encourage the implementation of Polar Code requirements
• Assess the need for eventual implementation of a pilotage system (as in southern Canadian waters)
• Consider transnational collaboration in the Northern Marine Transportation Corridors initiative
• Incorporate climate change scenarios into policies regarding the annual positioning of icebreakers and other search and rescue assets
Infrastructure (see also the Safety options below)
• Improve port facilities and other marine infrastructure – especially on the Nunavut side of the region
• Enhance the communications infrastructure in the region
• Consider investing in the renewal and development of the Canadian Coast Guard fleet
• Hasten the revision of existing nautical charts and the production of new ones, making the best use of available data acquisition technologies
• Deep-water ports are more challenging to establish in some parts of the BBDS region than in others. When required for extractive activities, these ports will be tailor built by private investors for each specific site. For the resupplying of communities, the current system can be foreseen working until at least 2030 in Greenland. Investments in Nunavut should continue be a priority in order to increase the (re)supply capacity (i.e., operating period and regularity/quality of services) and to improve safety.
• Develop infrastructure in support of emergency response capacity to save lives and combat oil spills
Economic Development and Planning
• Invest in multi-use infrastructure that benefits both the shipping industry and local communities
• Enhance education and skills training for shipping in a changing Arctic
Environmental Sustainability
• Improve the monitoring of sensitive ecosystems in relation to impacts from shipping
• In the short term, supervise and actively encourage the implementation of Polar Code and Ballast Water Management Convention requirements
• Continue work related to the identification of ecologically sensitive areas, and consider implementing ecosystem-based management in such areas (in coordination with other socio-economic sectors)
• In the longer term, consider whether the regulatory framework of PSSA designations, especially in relation to "route and reporting measures," may be a relevant instrument to examine
• In the short term, consider the establishment of codes of conduct for wildlife viewing and of site guidelines for sensitive ecological sites for the cruise tourism industry; create site guidelines for sensitive ecological and cultural sites that are highly visited by tourism vessels (i.e., similar to those of Antarctica and Svalbard)
• Consider environmental impacts and threats from heavy fuel oil in the region, as well as potential regulation related to its use (as seen in Svalbard)
• Establish oil response strategies (e.g., source control, response in open water, in situ burning, dispersion), including ways to shorten response times; consider requirements for on board response equipment on certain ships
Safety
• Improve capabilities for monitoring vessel traffic (AIS, satellite, other assets)
• Prioritize funding to improve bathymetric charting (consider a crowdsourcing approach)
• Engage in focused research to understand sea ice reductions, iceberg transport, and other hazards

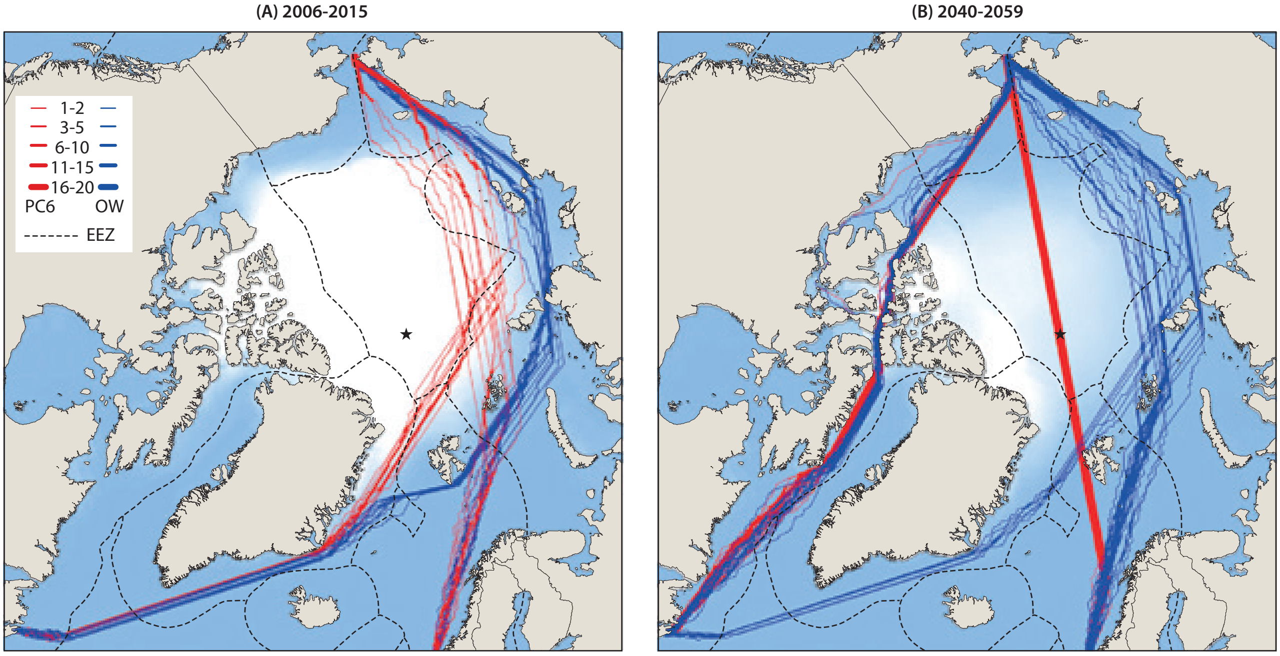

Figure 9.5 Map of optimal Arctic September shipping routes from the Pacific to the Atlantic: (A) 2006–2015, modeled and (B) 2040–2059, projected (reproduced from Smith and Stephenson, 2013, with permission). The red lines indicate the fastest available trans-Arctic routes for Polar Class 6 (PC6) ships (i.e., with medium ice strengthening of the hull), and the blue lines indicate the fastest transits for common open water (OW) ships (no ice strengthening of the hull). Where navigation routes overlap or coincide, the line widths indicate the number of successful transits along that route. The dashed lines represent the limits of the exclusive economic zones (EEZs).

to be a very long-term change (DNV GL, 2015). There is also a trend toward a longer cruise ship season, meaning the season can start earlier and end later (Dawson et al., 2014; Pizzolato et al., 2014). For the next few decades, it can be assumed that cruise ships will be traveling routes similar to today's routes (see also Chapter 8).

Because the local population in Greenland is not expected to increase in the near-term future, population will not drive an increase in Greenland's *passenger ship traffic*. However, because tourists are also using the passenger ships along the Greenland coast, it is reasonable to expect a small increase in passenger ship traffic, especially during the summer, due to the expected increase in tourism.

A lengthening of the navigation season will, in general, entail a regular increase of *container/cargo shipping* for the servicing of northern communities in the region (e.g., delivering fuel, consumer goods, and durables). However, the two biggest factors governing the future activities of container ships and general cargo ships to and within the region are demographic changes and economic growth. For Greenland, potential changes in block grants from Denmark may also be important (DNV GL, 2015). In Canada, ship owners currently serving the community markets have made significant investments in the renewal of their Arctic-dedicated vessels for the future. Their expertise in autonomous loading onto beaches from anchorage points (i.e., using carry-on barges and tugs without the support of port equipment) effectively constitutes a barrier to entry for potential market competitors. Based on ship owners' current demands to policy-makers – i.e., more mapping and better visual aids, but no docking infrastructures – the owners are expected to defend this barrier (Turmel, 2013).

As described in Chapter 7, new projects related *to mineral exploration and exploitation (including oil and gas)* could emerge in the region within the next few years. There is some uncertainty, but the cyclical nature of ore prices is likely to bring mining sites in the region into production, especially those that benefit from a high-quality ore (e.g., Mary River iron ore). The development of mineral projects will generate destinational traffic, first during the site development phase and then during the exploitation phase. This sector can be expected to be the most significant in terms of bringing important and rapid transformations to shipping in the region (Table 9.4). The main drivers of this sector will continue to be linked to the cyclical markets for resources (unrelated to climate or regional factors). The recent evolution of the Mary River mining site perhaps exemplifies potential future trends. After a few years of test shipments, the mine entered into production in 2015. By then, the initial plan to ship up to 18 million tons annually through Steensby Inlet (south Baffin Island) had already been shelved due to dropping demand for iron ore (see also Chapters 7 and 10). The revised plan was to start operations with summer-only shipments from the north coast of Baffin Island, with a yearly target of 3.5 million tons. Because the plugging trend has continued worldwide, though, the first year saw approximately 1 million tons shipped. This lower level of activity still entailed about 20 distinct shipments (Maritime Magazine, 2015), which represents a significant increase in shipping activity through the region.

Future *transit ship traffic* in the region seems only a remote possibility because of navigational constraints. According to the projections of Smith and Stephenson (2013), a trans-Arctic route across the North Pole will be navigable by mid-century for moderately ice-strengthened vessels (Figure 9.5); the Northwest Passage, and thus passage to the BBDS, will be navigable by

2050 for vessels without ice strengthening (53% probability). Other models project that at the end of this century, there will be free passage through the Northwest Passage for 2–4 months of the year (Khon et al., 2010). Projected cost analyses by a number of authors have shown that potential Arctic transit traffic can be highly attractive under various conditions along different Arctic routes (Laulajainen, 2009; Schøyen and Bråthen, 2011). Somanathan et al. (2009), however, emphasize that the profitability of the transit routes may be limited, depending on the locations of the origin and destination ports.

Several other simulations have led to more nuanced conclusions, emphasizing the high costs, difficult operational conditions, and high marketing constraints associated with Arctic transits (Verny and Grigentin, 2009; DNV, 2010; Carmel, 2012; Lasserre, 2014). However, as Xu et al. (2011) and others have noted, there exist numerous operational and environmental issues that prevent a final appraisal of Arctic routes as shortcuts between world markets. Further, as described in Chapter 3, variable ice conditions and icebergs are likely to remain a major hazard for shipping in the Canadian Arctic, including the Canadian Arctic Archipelago and the Northwest Passage, for the foreseeable future (Haas and Howell, 2015).

It is likely that commercial transit traffic will indeed increase from its present nearly negligible level. However, projections for future Arctic shipping activity, as described above, reveal considerable uncertainty in the estimates. In relation to the BBDS region and based on existing literature, it is estimated to be unlikely that transpolar traffic will occur before 2030. Further, the shortcut effect between markets such as China and northern Europe is greater when vessels sail directly through or around the North Pole, as opposed to a routing via Baffin Bay and the Canadian Archipelago. As a result, even if Arctic transit does develop to a significant level (e.g., as in longer-term scenarios of drastic climate change), it would not likely concern the BBDS region directly. However, if traffic should eventually transit through the Northwest Passage, it will most likely be on the Canadian side of the region.

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10. Built infrastructure

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Key messages

- ***Much of the existing infrastructure in permafrost-affected parts of the Baffin Bay/Davis Strait (BBDS) region is poorly adapted to existing conditions and is subject to deterioration or damage.*** *Examples include municipal and residential buildings, roads, and runways.*
- ***Built infrastructure affects permafrost conditions and may itself induce permafrost degradation.*** *Climate change acts as an amplifying factor.*
- ***The limited regulatory framework and lack of appropriate governance structures related to construction in the BBDS region result in the use of southern construction designs and methods that are not well adapted to Arctic ground conditions and climate.*** *A proper regulatory framework is needed to ensure sustainable development of the infrastructure network.*
- ***A housing shortage and the quality of housing construction are major concerns in the BBDS region.*** *Housing conditions need to be addressed in the coming years to allow for the sustainable development of Arctic societies.*
- ***Designs adapted to the changing Arctic climate conditions are needed to improve indoor climate and related health issues.*** *Respiratory problems are one prominent example of such issues.*
- ***Municipal expansion onto permafrost-sensitive areas calls for better permafrost knowledge to inform appropriate design choices.*** *Understanding surficial deposits, stratigraphy, topography, and ground ice content and distribution is crucial in guiding the choice of construction techniques, engineering designs, and solutions.*
- ***Coastal infrastructure should be designed with special concern for the possibility of a lowering of the local (relative) sea level.*** *In the BBDS region, the expected global sea level rise will be counteracted by local isostatic rebound and self-gravitation effects. Predictions are uncertain, but a falling local sea level is plausible and relevant structures should be designed with that in mind.*
- ***A lack of relevant technical skills among the regional workforce, combined with high turnover of qualified employees, is a limiting factor for the development of the construction and infrastructure management sectors.*** *Efforts to strengthen relevant educational activities and provide sufficient legislative and regulatory framework should be continued and prioritized.*

Guiding questions

What are the special characteristics of geology and permafrost conditions in relation to built infrastructure in the Baffin Bay/Davis Strait region?

What are the current states of the transportation network, municipal services, and residential infrastructure? What are their sensitivities to change?

What are the factors and causes that affect infrastructure in relation to construction and maintenance practices, and how can we adapt to limit negative impacts of these factors?

What are the knowledge gaps that need to be filled to support the development of infrastructure in a sustainable fashion?

10.1 Introduction

The circumpolar North is the region of the globe currently experiencing the most severe impacts of the warming of Earth's lower atmosphere. Many consequences anticipated by climate models are already being observed in terrestrial and marine Arctic ecosystems (Chapter 6). The multiple and cumulative pressures on environmental, socio-economic, and geopolitical systems are interacting, contributing to an irreversible transformation of the Arctic (ACIA, 2005; also discussed in Subchapter 3.3). While impacts may pose many challenges in terms of adaptation for Arctic countries, the ongoing changes also create opportunities for development. For example, new sea routes are opening (Chapter 9), facilitating access to new areas and natural resources (Chapter 7) and improving the economic and living conditions of Arctic societies. These new opportunities contribute to increasing international interest from non-Arctic nations, which in turn stimulates activity and development in the Arctic (e.g., tourism; see Chapter 8). This current development trend is occurring while Arctic nations are striving to maintain, adapt, secure, and consolidate existing infrastructure in the face of changing climate conditions and thawing permafrost, in addition to other pressing issues related to poverty, health, and well-being (Subchapter 3.3 and Chapter 4), education (Chapter 5), overcrowding (Subchapter 4.5), and environmental protection and wildlife changes (Chapter 6; Larsen and Fondahl, 2014). Moreover, the intensification of economic activity in Arctic regions calls for new, better-adapted infrastructure. Indeed, with development of the Arctic comes a need for new roads, airports, ports, runways, railways, and many other elements of municipal, service, and residential infrastructure to cope with demographic growth and increasing urbanization (see Subchapter 3.3).

The infrastructure of a society in general comprises fixed, mobile, and other built assets, as well as regulatory, policy, and other governance mechanisms (definition based on Maritime Safety Committee, 2014). This chapter focuses specifically on built infrastructure (facilities with permanent foundations) and its relevance for the safety and well-being of communities and the development of a sustainable Arctic society. Transportation infrastructure, in particular, plays a central role in community services and resupply by ensuring connections within and among isolated Arctic communities and with the global economy. Transportation infrastructure also provides access to fundamental needs such as drinking water and sewage services (see Subchapter 4.4) and represents a crucial pillar required to support any kind of Arctic development. Road networks and airstrips are major components of the Arctic infrastructure, and special emphasis is given here to those elements. Because these structures are linear and broadly distributed, they occur across a wide range of environments and consequently are likely to be affected by permafrost warming (or thawing). At the same time, they are themselves likely to affect areas downstream of the environments they crosscut (Vincent et al., 2013). Ports and harbors, which are also of great importance, are treated briefly here. Their importance in the regional economy and regional functions is fully discussed in Chapters 8 and 9 of this report.

In this chapter, we consider housing to be a critical infrastructure component of Arctic societies. The housing shortage and renovation deficit (Chapter 4) is a universal challenge in the Baffin Bay/Davis Strait region, and it exerts an important limitation on social and economic development. As with transportation infrastructure, municipal services and residential infrastructure also occupy a central role in communities (e.g., sewage, drinking water, energy supply). This type of infrastructure also has deep implications for human health and community well-being (e.g., recreation buildings, hospitals, houses, and other dwellings). In Baffin Island, for instance, it is recognized that poor housing conditions (e.g., overcrowded households, houses that need serious repairs, low indoor air quality) are significantly and directly linked to human health and to social issues such as suicide and violence, including domestic violence (see Chapter 4, Nunavut Health Survey, Iglutaq Survey; Tester, 2006).

The Nunavut side of the BBDS region and the coastal region of West Greenland present important distinctive elements as well as similarities in terms of geology and climate (which determine permafrost conditions) and in terms of governance and socio-economic environments (this discussion is further developed in Chapter 2 and Subchapter 3.3). Natural and societal distinctions within the region lead to a variety of implications related to built infrastructure, which may sometimes require different sets of actions or adaptation options, depending on local conditions. On the other hand, similarities may serve as a basis for sharing experiences and knowledge regarding the infrastructure-related issues that are encountered on both sides of the BBDS region. This chapter emphasizes these regional similarities and differences, as well the identification of gaps in terms of scientific knowledge, engineering solutions, social capacity, and decision- or policy-making processes and structures to address current built-infrastructure issues. The process has been strongly facilitated by local knowledge and community perspectives provided through stakeholder consultations (see Chapter 1). Ultimately, this chapter aims to better inform the formulation of regional adaptation strategies and to assess future needs for adaptation according to projected changes in the region, as generated by both climate changes and socio-economic development. (The projections and framework scenarios are described in Chapter 3.)

In the BBDS region, there are only a few official/legal construction codes in place to ensure quality standards and secure investments. Therefore, construction techniques often rely on unadapted “southern” (i.e., Danish or temperate Canadian) concepts and engineering designs. Furthermore, the ground that supports much of the infrastructure is unstable and is on the brink of massive change due to climatic impacts (Rowland et al., 2010). With such boundary conditions, it is not surprising that the question of infrastructure raises major concerns for stakeholders, communities, and regional governments. To address these regional priority issues, this chapter is structured around the following guiding questions:

1. What are the special characteristics of geology and permafrost conditions in relation to built infrastructure in the BBDS region?
2. What are the current states of the transportation network, municipal services, and residential infrastructure, and what are their sensitivities to change?
3. What are the factors and causes that affect infrastructure in relation to construction and maintenance practices, and how can we adapt?
4. What are the knowledge gaps that need to be filled to support the development of infrastructure in a sustainable fashion?

Based on existing knowledge, this chapter aims to provide a broad perspective on the current status of built infrastructure in the BBDS region and also to assess future needs in terms of both construction/expansion projects and the adaptation of current construction practices to suit future conditions. (For information regarding projections and scenarios, see Chapter 3.) Infrastructure needs under future conditions are then assessed according to a set of framework scenarios in which climate change and extractive industry developments serve as the primary drivers. The details of the framework scenarios and their ranges are presented in Subchapter 3.4. Finally, this chapter identifies knowledge gaps that should be filled in order to properly address the maintenance and development of current and future infrastructure in the region, all while respecting Inuit traditions and cultures and with environmental protections in mind.

10.2 Housing needs and building practices

Access to adequate housing in the BBDS region is a major concern that is directly linked to health and social problems (further detailed in Subchapter 4.5). A housing shortage in West Greenland (BBDS region) of approximately 4,000–5,000 housing units was reported by Statistics Greenland (2004), and the Inuit Health in Transition Greenland Survey (2005–2008) reported that approximately 42% of the respondents in Greenland lived in crowded households, with more than 1 person per room (Riva et al., 2014). Overcrowding is most common in smaller communities with a low rate of vacating or sometimes even population growth – i.e., communities with business potential. The largest communities (e.g., Nuuk) have experienced a strong population increase, which is likely to cause overcrowding, especially in social housing (i.e., housing provided with the assistance of government or nonprofit organizations). Although official housing statistics are not available for recent years, the severity of the problem is indicated by the waiting lists for publicly owned housing – with presently more than 5,000 applicants (INI, 2014; Iserit, 2016).

For the Qikiqtaaluk region of Nunavut (formerly referred to as the Baffin administrative region; see Chapter 2), the total number of housing units was estimated at 5,340, based on a survey conducted in 2009–2010 (Nunavut Bureau of Statistics, 2011). Among these units, 950 required major repairs, 1,390 were considered as overcrowded (i.e., requiring at least one additional bedroom), and 1,970 were below housing standards (i.e., overcrowded or requiring major repairs). Consequently, over 9,900 inhabitants of the Qikiqtaaluk region were living in dwellings below housing standards in 2010. This situation corresponded to a demand of about 3,580 new housing units at the time of the survey.

10.2.1 Age and ownership of the housing stock

Before 1950, most Greenlanders lived in peat houses or poor wooden houses, of which virtually none are still in existence (Madsen, 2001). The few buildings of reasonable quality were inhabited by the leading members of society, primarily Danish officials. Between 1950 and about 1970, the Danish government initiated a comprehensive program to ensure contemporary housing for all Greenlanders, resulting in the construction of small, colorful, wooden gable-roofed houses – often considered the epitome of Greenland housing (Madsen, 2001); see Figure 10.1. Although Greenlanders were not involved in the design or construction of these houses, the buildings were designed specifically for Greenland and they provided a boost in living standards, which contributed to a significant reduction of serious diseases (e.g., tuberculosis) (Bjerregaard, 2004). In the late 1960s and 1970s, large residential apartment blocks were constructed in the cities and towns, after European models, in a general effort to provide good and affordable housing and to bring people together in larger settlements due to the industrialization of the fishing industry. Furthermore, the apartments provided modern conveniences such as water-flushing toilets and central heating. In the small communities, however, there has been no real change in building culture – the single-family wooden houses remain the predominant type.

On the Nunavut side, prior to 1940, Inuit lived a nomadic lifestyle in kin-based camps distributed in over 100 locations in the Qikiqtaaluk region – in skin-tents, in sod/bone houses called *qarmat*, and in snow houses called *igluit*. Between 1940 and 1960, following policy incentives (e.g., access to education,

Figure 10.1 Typical colorful, one-family gable-roofed housing in Sarfannguaq, Greenland (photo by Tove Lading).

Figure 10.2 Example of Euro-Canadian house layouts introduced to the North in the 1950s. This example is from the community of Pond Inlet, Baffin Island (photo by M. Fortier).

health care, and the distribution of food supplies to counter starvation in some Inuit camps), Inuit began to settle into static (fixed-location) communities. These communities were located at traders', missionaries', and explorers' outposts and also around military bases (Kirmayer et al., 2000). Since this period, Inuit in the Qikiqtaaluk region have lived in Euro-Canadian–designed houses (Figure 10.2) that are ill accommodated to the Inuit lifestyle, including key activities such as food preparation, eating, crafts, storage, sewing, socialization, and equipment maintenance (Dawson, 2003, 2006).

Of the approximately 23,000 housing units in Greenland, about 70% are publicly owned (Statistics Greenland, 2016; data from 2010). In the Qikiqtaaluk region, more than 80% of the housing units are publicly owned. Campaigns to encourage tenants to buy their own homes have had little success. In Greenland, approximately 40% of the population moves every year (Hendriksen, 2013), and thus residents often have no long-term interest in their homes. In the region in general, the value of property is difficult to estimate because the market for real estate outside the major communities is very limited; therefore, potential buyers cannot expect to recover their investment by reselling. As a consequence, mortgage-based credit is not available and bank financing may be difficult to obtain. Furthermore, a complex system of governmental subsidies to the housing sector in Greenland (both private and public) disguises the actual cost of housing, increases the housing shortage, and limits mobility (Skatte- og Velfærdskommisionen, 2011).

10.2.2 Indoor climate, maintenance, and refurbishment

Although housing standards have improved over the past decades, some houses, particularly in smaller settlements, have no sanitary facilities. Even in Sisimiut, the second largest community in Greenland, approximately 25% of the households are not connected to a sewer and some do not have year-round running water.

A lack of maintenance in the public housing sector has created a massive refurbishment backlog in older housing. The Survey of Living Conditions in the Arctic (SLiCA, 2015), conducted in 2004–2006, estimated that 40% of Greenland household units and 43% of Nunavut household units were in need of major repair (Poppel et al., 2007). The survey lists coldness, drafts, dampness, and stale air as major housing problems in Greenland. These issues are also reported for the Canadian Arctic in the Arctic Human Development Report (Larsen and Fondahl, 2014). Indoor climates suffer from general deterioration, with building envelopes that are not tight or are poorly insulated (see Figure 10.3) and with outdated installations, including ventilation systems that (when present) are typically limited to simple mechanical vents that are often blocked by occupants due to discomfort from cold drafts (Kotol et al., 2014). As a consequence, mold is a widespread problem among BBDS households, although no statistics are available to document the extent (for health issues see Chapter 4). One recent study, however, describes technology that is now available to provide well-functioning mechanical ventilation

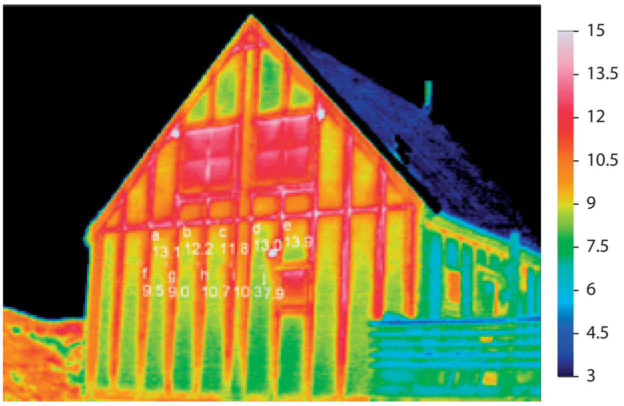

Figure 10.3 Thermographic image of a typical Greenland-style single-family house in Sisimiut, showing poor insulation, especially around windows and structural elements (from Vladyková, 2007). The colors on the image represent surface temperature in °C.

with good comfort and heat recovery under Arctic conditions (Kotol, 2014). The main barriers to the installation of such technologies seem to be an adherence to common practices, a lack of knowledge regarding the technologies, and a lack of professionals qualified to install them.

Newer buildings, although better insulated, typically still suffer from the application of southern construction practices that are not well adapted to the Arctic climate. For example, many buildings have been constructed over the past 20–25 years with impregnated gypsum plasterboards as wind barriers on the facades. Under Arctic conditions, though, this type of cladding deteriorates over a period of about 20 years. As a consequence, many newer buildings are unable to withstand typical wind pressures, leading to a risk of moisture accumulation in the structure, higher energy consumption, and lower occupant comfort.

Whereas refurbishment of older buildings is a big industry in southern regions, it is virtually nonexistent in the BBDS region. Refurbishment is considered too expensive, based on a few examples that were indeed expensive. As a consequence, rundown or obsolete housing is typically abandoned or demolished, or short-term renovation is conducted to extend the service life (e.g., by 10 years). For example, the largest apartment building in Greenland (Block P in Nuuk) was demolished in 2012, while its Danish counterpart (Blokland in Albertslund, built at approximately the same time) is now undergoing a major refurbishment (Figure 10.4). Although Block P and similar buildings were not adapted to a traditional Inuit lifestyle, they were constructed at a time when society was changing rapidly toward a more modern Western lifestyle. Greenlanders today demand housing of the same standard and similar design as that in other Western countries. The choice between refurbishing old housing or building new housing is therefore linked not so much to questions of traditional Inuit lifestyle but rather to arguments of economy, common practices, and new technologies.

There has been no thorough analysis of why refurbishment construction is assumed to be impractical in the BBDS region, nor have there been projects aimed specifically at the development of rational refurbishment methods. Refurbishment in general suffers from a lack of proper incentives. In the public sector, there is no clear link between rent payments and property maintenance, and with the high frequency of migration, residents have only a limited interest in demanding refurbishment of their homes. In the private sector, refurbishment is closely linked to a functioning real estate market in which residents can expect to recoup their improvement investments upon resale. Otherwise, homeowners renovate only if they are relatively wealthy and if they have a long ownership horizon.

In summary, the housing situation (construction, maintenance, and shortage) is a major concern in the entire BBDS region. Consequently, many communities are now dealing with an expansion of their residential capacity and the need to address climate- and lifestyle-adapted construction practices and to improve the service and municipal infrastructure (such as sewers, electricity, and water supply). Any attempts to develop sustainable Arctic societies will be useless if this fundamental human need for proper housing is not adequately addressed in the coming years.

Figure 10.4 Blok P in Nuuk (left, photo by Vincent van Zeijst,[9] CC BY-SA 3.0), once the largest building in Greenland, and Blokland in Albertslund, Denmark (right, photo by Thomas Helsted), built at approximately the same time. Blok P was demolished in 2012, whereas the Blokland is now undergoing a major refurbishment.

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[9] Blok P photo by Vincent van Zeijst (commons.wikimedia.org/wiki/File:Greenland_14,_Nuuk,_Blok_P.JPG), is licensed under CC BY-SA 3.0 (creativecommons.org/licenses/by-sa/3.0/deed.en).

10.3 Natural conditions of special importance for built infrastructure

10.3.1 Current permafrost conditions in the BBDS region

Permafrost is defined as soil or rock with a temperature that remains below 0°C for two or more consecutive years (French, 2007). The existence of permafrost is related to the climate, as the ground temperature regime is driven mainly by the energy balance at the ground surface (as well as the geothermal heat flux). Globally, permafrost affects approximately 24% of Earth's land areas, but in the BBDS region, more than 75% of the area is affected.

In permafrost areas, the ground typically consists of three layers (Figure 10.5). The top layer, which is called the active layer, undergoes seasonal thawing and freezing. Below the active layer, permafrost is encountered, which by definition has a temperature constantly below 0°C. Due to the geothermal heat flux, permafrost has a lower boundary, below which the ground is again unfrozen. Figure 10.5 shows a typical ground thermal profile in a permafrost-affected area. Both the active layer and the permafrost are affected by seasonal temperature variations (note the gray lines), down to a depth referred to as the depth of zero annual amplitude (zaa). In regions with no permafrost, the seasonal freezing that occurs in the active layer is referred to as winter frost.

The geographic distribution of permafrost is related to regional and local climate conditions through parameters such as air temperature, insolation, precipitation, and snow cover thickness and duration. The local distribution of permafrost is also affected by geographical properties such as soil types, organic layers and vegetation cover, surface albedo, topography, and drainage conditions. Permafrost areas are typically classified according to the extent to which the ground is affected by permafrost: continuous (with >90% of the land surface area affected by permafrost), discontinuous (50–90% affected), sporadic (10–50% affected), or isolated patches (<10% affected) (Brown et al., 2002). Because spatially distributed observations of permafrost conditions are not always available over vast areas, mean annual air temperatures are often used as a proxy for delineating permafrost zones (e.g., Washburn, 1973; Christiansen and Humlum, 2000). A map of permafrost distribution in the BBDS region is shown in Figure 3.10.

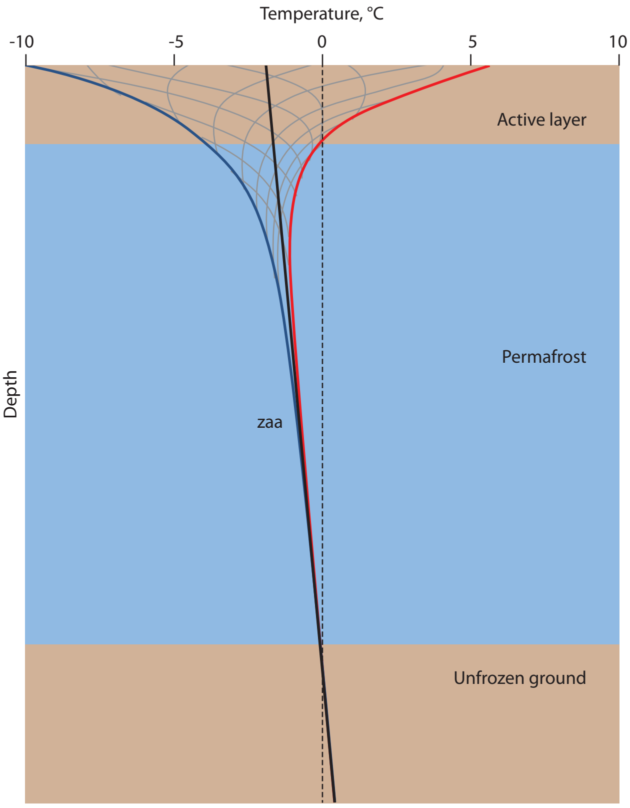


Figure 10.5 Permafrost temperature regime. Blue curve: Minimum ground temperature. Red curve: Maximum ground temperature. Black curve: Average ground temperature. Gray curves: Temperature profiles at specific times of the year. The "zaa" label shows the depth of zero annual amplitude.

The Nunavut side of the BBDS region is classified as having continuous permafrost throughout its entire area (Figure 3.10), from Kimmirut in the south to Alert in the north, with active-layer thicknesses (ALTs) ranging from 2 m (Kimmirut) to less than 1 m (Alert) (Smith et al., 2012). The Greenland side of the BBDS region is considerably warmer (see Section 3.1.3) and as a result spans all permafrost classes (Figure 3.10), from mainly seasonally frozen ground or isolated patches in the southernmost part to continuous permafrost in the coastal regions of Disko Bay and northward (north of about 68.5°N). However, continuous permafrost is also reported inland as far south as Kangerlussuaq (67.0°N), due to the cold continental climate (van Tatenhove and Olesen, 1994). Similarly, discontinuous permafrost is reported as far north as Qeqertarsuaq (69.2°N), which may be related to geothermal activity in this area (Doetsch et al., 2015). In the southernmost part of Greenland (Qaqortoq and surrounding area), permafrost is likely to occur only in mountainous areas, at high altitudes (Christiansen and Humlum, 2000).

10.3.2 Types of ground ice and importance for ground engineering properties

Although permafrost is defined by temperature, it is mainly the presence or absence of ice in the ground (or changes in ice content) that has practical importance in the planning, construction, and maintenance of infrastructure in permafrost areas.

Ground ice may range from massive and large-scale ice bodies (e.g., ice wedges) to microscopic ice inclusions in pore spaces, not visible to the naked eye. Permafrost sediments are typically sampled by drilling techniques that use hollow-stem augers to extract intact sediment cores for the identification of embedded ice content and structure. Such permafrost cores are classified based on standard engineering soil classification schemes, most often the Unified Soil Classification System (ASTM Standard D2487-11, 2011) in Canada or the Danish practice for soil classification (Larsen et al., 1995) in Greenland. Classification of ice content and structure is traditionally performed based on visual inspection (ASTM Standard D4083-89, 2007), distinguishing between sediments with and without visible segregated ice (ice in excess of the natural unfrozen pore space of the sediment) and describing the structure and orientation of observed ice features.

Figure 10.6 Examples of types of massive ground ice (panels A–C) and ground cryostructures (panels D–H) encountered in permafrost over the BBDS region: (A) Massive ground ice mound – a frost blister, (B) Buried massive glacier ice, (C) An ice wedge, (D) Structureless – porous non-visible ice, (E) Lenticular – microlenticular segregated ice lenses, (F) Layered – wavy, segregated ice lenses, (G) Irregular reticulate – segregated ice lenses, and (H) Suspended/reticulate – segregated ice lenses (photos by E. L'Hérault).

Some examples of ground ice are shown in Figure 10.6. The amount of ground ice and its structural disposition in the ground (e.g., ice lenses, massive ice bodies, networks of ice wedges) is closely associated with the type of geological surficial material, landforms, and soil patterns, as shown in Table 10.1. Because permafrost drilling is not always feasible and affordable in isolated Arctic communities, landforms and surficial features are often identified as a first step in mapping the Quaternary geology and assessing potential ice contents.

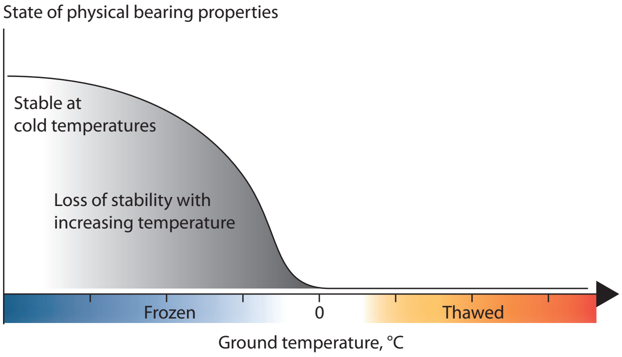


Figure 10.7 Schematic representation of variation in soil strength as a function of temperature (modified from Andersland and Ladanyi, 2004).

For engineering purposes, knowledge of the content and distribution of ice in sediments is extremely important because the presence of ice significantly affects mechanical soil properties. Ground ice content determines the potential for thaw settlement (or subsidence) of a soil, which corresponds to the degree of terrain deformation and readjustment (compaction and consolidation) that occur as the ice melts. Frozen soils may contain significant amounts of unfrozen water at subzero temperatures. The unfrozen water content increases with increasing temperature (below freezing), and fine-grained soils, in particular, may have substantial unfrozen water content even at low temperatures due to grain-surface interactions and small pore spaces.

The bearing capacity of a soil (i.e. the capacity to support a given load without being significantly deformed) is related to the soil type, grain size distribution, and grain shape, as well as the content of ice and unfrozen water. Figure 10.7 shows the decrease in strength (or bearing capacity) of a permafrost soil with warming. This change is mainly due to the increase in unfrozen water content. Frozen ground is considered to have a constant bearing capacity only if it remains at low temperatures, or once it is completely thawed and fully consolidated.

Table 10.1 Morphologic features of permafrost, geological features, and types of ground ice for surficial deposits (from Allard et al., 2012b).

Morphology and cryosols	Surficial geology types	Texture	Permafrost zonation	Ground ice types	Possible presence of excess ice
Frost mounds	Silts and marine clays Sands (low mounds)	Silty clays Fine to medium sands	Discontinuous and widespread Discontinuous and dispersed	Segregation	Yes
Palsas	Peat Peat/silts and clays Peat/sand or till (rare)	Fibric or hemic peat over fine grained deposits	Discontinuous and widespread Discontinuous and dispersed	Segregation	Yes, in mineral sediments under peat
Thermokarst lakes (associated with palsas and frost mounds)	All possible deposits; mostly fine grain and peaty sediments	Peat Silty-clay Sands	All zones	NA[1]	NA[1]
Ice-wedge polygons	Tills Fluvial terrace sands Carex sands	Peat Fine to coarse sands	Continuous	Ice-wedge polygons with pore ice	Yes, in polygon networks
Soil wedge polygons	Tills (on drumlin ridges) Glacifluvial deposits (outwash and deltas), beach sands	Heterometric coarse sands and gravel deposits	Continuous Discontinuous and widespread	Pore ice	No
Low center mudboils	Tills, diamictons (uplifted tidal flat), often associated with soil wedge polygons and solifluction lobes.	Heterometric coarse sands and gravel deposits with very fine sands or silts	Continuous Discontinuous and widespread	Pore ice Small amounts of segregation ice	No
High center mudboils	Marine and lacustrine deposits. Abundant on top of cryogenic mounds	Fine sands and silty clays	Continuous, discontinuous, and widespread Discontinuous and dispersed	Segregation	Yes
Striped soils	Tills Slope deposits	Blocky diamictons in fine matrix	Continuous	Pore ice	No
Solifluction lobes	Tills Marine sands Slope deposits	Heterometric deposits in fine sandy or silty matrix	All zones	Pore ice, Small amounts of segregation ice	No
Hummocks	Tills and diamictons over poorly drained low land	Heterometric deposits in fine sandy or silty matrix	Continuous Discontinuous and widespread	Pore ice	No
Seasonal frost mounds with ice-cores and icing	All deposit types	All grain size deposits and organic soils, near streams and spring run-offs	Continuous Discontinuous and widespread	Intrusive (significant and fast uplift in winter and subsidence in summer)	Yes
Ejection mounds or blocs	Rocks (fractionated)		Continuous Discontinuous and widespread Discontinuous and dispersed	Intrusive ice? Segregation ice?	?

[1] Not applicable

The risk of developing significant thaw settlement or frost heave depends on three main factors: (1) the geological setting, (2) the availability of water or ice, and (3) changes to the thermal regime (see Figure 10.8). The geological setting is typically constant, and the geology-related risk factor will depend mainly on the grain size distribution (and organic content). Silty soils may – if water is available and under certain thermal conditions (e.g., slow top-down freezing) – develop large volumes of segregated ice (e.g., ice lenses), resulting in significant frost heave. Coarser soils seldom develop ice lenses and thus are often considered low risk. However, such soils may, at very low temperatures, be subject to the development of ice wedges (Christiansen, 2005). Ice-rich soils represent a potential risk of thaw settlement but may typically be considered stable under a constant thermal regime. However, with a change in the thermal regime (warming), these soils move from the potential-risk designation to the high-risk designation.

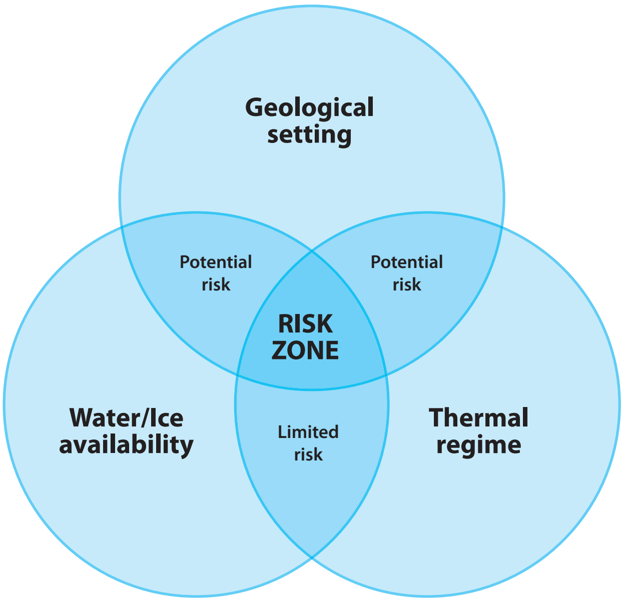


Figure 10.8 The three main risk factors in permafrost engineering are (1) the geological setting, (2) water/ice availability, and (3) changes to the thermal regime. Certain combinations result in a high risk of thaw settlement, frost heave, slope instability, or other problems. If a risk factor is removed or limited (e.g., if water availability is reduced by proper drainage), then the risk of failure is reduced.

Thus, when addressing permafrost-related engineering issues, successful solutions and designs typically aim to keep water away from the construction by ensuring adequate drainage in order to avoid frost heave problems. Proper drainage may also alleviate ponding issues that could otherwise induce permafrost degradation. Another strategy is to target the stability of the thermal regime and keep the permafrost cold by adding insulating layers in the construction or by modifying the heat exchange through increasing the surface albedo or adding passive/active cooling solutions (CSA Group, 2010, 2014). Finally, the chosen solution may target the geological setting, ice availability, and drainage conditions simultaneously by excavating naturally occurring ice-rich sediments and then backfilling with materials (coarse-grained and well-draining) that are non-frost-susceptible (i.e., not susceptible to frost formation). The cost of different adaptation options may vary significantly and must be evaluated on a case-by-case basis. Estimating the construction costs of various adaptation options may often be relatively easy, but not much quantitative information is available on maintenance costs and impacts on service life times. This limitation may be an important barrier to implementation.

10.3.3 Geological setting and distribution of potentially ice-rich formations

At the time of the last glacial maximum, approximately 25,000 years before the present (BP) (i.e., the time of the Weichsel/Wisconsin glaciation), the whole BBDS region was covered by the North American and Greenland Ice Sheets, which are believed to have extended up to 100 km beyond the present coastlines on both sides of the Davis Strait (Weidick, 1976; van Tatenhove et al., 1995; Dyke et al., 2002). Following this last glacial maximum, the retreat of the ice sheets and the resulting marine transgression resulted in the deposition of fine-grained marine sediments in the coastal regions, due to the flocculation and sedimentation of river-transported glacial sediments as they entered the saline marine environment. Isostatic rebound has since elevated some of these sediments above present-day sea level, exposing them to percolating precipitation and thus depletion of the saline pore water. The general climatic cooling in the region, which marked the end of the Holocene optimum around 5,000 to 3,000 BP (Paterson et al., 1977; Bradley, 1990; Dahl-Jensen et al., 1998; Hammer et al., 2001), induced the formation of permafrost in some of these sediments, effectively stopping the depletion process.

Regional differences in isostatic uplift have resulted in differences in the timing and duration of exposure to depletion. Thus, the fine-grained deposits found in some regions may be fully (or nearly) leached, while those in other regions may be only partly leached (Brouchkov, 2003). These differences in residual salinity strongly affect the freezing temperature of the sediments (i.e., higher salinity results in lower soil freezing temperature) and, in combination with the local ground thermal regime, affect the presence and distribution of ice features in permafrost regions.

The geotechnical implication of the presence of these fine-grained glaciomarine silt and clay formations in permafrost regions is extreme thaw sensitivity due to the high ice content – and a resulting high risk of thaw-induced settlement. In some areas where the sediments were completely leached before the formation of permafrost, the sediments have been observed to have high sensitivities (i.e., ratio of intact to remolded shear strength), with some even classifying as quick clays under thawed conditions. These ice-rich sedimentary deposits have bearing capacities that may vary greatly depending on ice content and temperature, and they may represent a high risk of failure during construction as the above-ground load increases.

Where sediments are only partly leached or unleached, the residual salinity causes a freezing-point depression and a general increase in unfrozen water content. Consequently, the soils may behave as unfrozen or partly frozen soils (low shear strength and bearing capacity) even at subzero temperatures. Such situations may lead to overestimation of the bearing capacity and may result in severe settlement and damage to buildings and constructions with improper foundations (Brouchkov, 2003). In some areas, the geological history has resulted in a complex profile consisting of an upper leached and ice-rich part of the permafrost and a lower (partly) unleached zone with high unfrozen water content and low or no ice content and low bearing capacity (Ingeman-Nielsen et al., 2008, 2010). In such a setting, inadequate site investigations may fail to document the change of properties with depth and thereby lead to poor choices of foundation design.

For the coarse-grained sediments of marine, fluvial, or glacial origin, high ice contents are mainly linked to the presence of massive ice features such as ice wedges. In the West Greenland part of the BBDS region, such features are mainly observed in

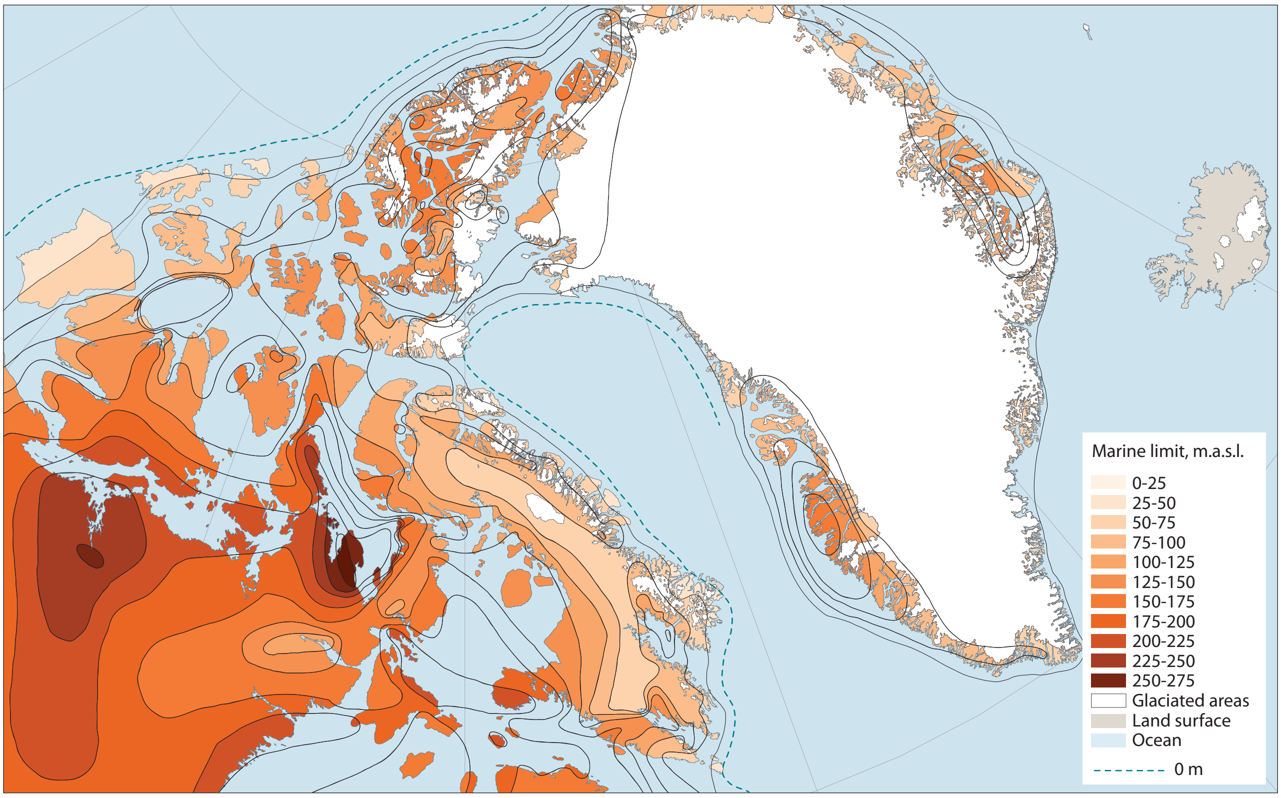


Figure 10.9 Deglacial upper marine limit (maximum relative sea level in meters above present sea level, m.a.s.l.) in the BBDS region (modified from Dyke et al., 2005). In the absence of detailed local observations, the upper marine limit can be used as a first indicator of risk in permafrost regions. At elevations below the upper marine limit, fine-grained ice-rich deposits may be encountered, depending on local depositional history and ground temperature regime. Contour interval is 25 m (the 0 m contour is dashed).

the northernmost parts (e.g., around Thule Air Base; Corte, 1962) and in the central part near the ice cap (Kangerlussuaq region; Ingeman-Nielsen et al., 2012), where the continental climate causes sufficiently cold winters to allow ice wedge formation. In other parts of West Greenland, such massive ice formations have not yet been reported from inhabited areas and thus constitute a minor concern in community and infrastructure planning and construction. However, in the Nunavut part of the BBDS region, these massive ice features are encountered throughout the territory and therefore represent a major concern for construction expansions and for the management of existing infrastructure.

In general, the presence and distribution of fine-grained glaciomarine deposits can be considered as a primary indicator of the risk of thaw-induced settlement for the coastal towns and settlements of the BBDS region. The map in Figure 10.9 shows the upper marine limit (the maximum relative sea level since the last glaciation in meters above present sea level) for the BBDS region. Due to the lack of high-resolution maps of Quaternary deposits and permafrost conditions in the BBDS region, maps depicting the postglacial marine limit can be useful when planning site investigations for infrastructure and construction projects, as they may provide general indications of the risk of encountering ice-rich, fine-grained deposits. At elevations below the upper marine limit, fine-grained ice-rich deposits may be encountered, depending on local depositional history and ground temperature regime.

10.4 General impacts of permafrost changes on infrastructure

Several permafrost–infrastructure issues encountered on the Nunavut side of the BBDS region come partly from the fact that much of the infrastructure was built at a time when climate warming was not yet recognized in the region and permafrost was thought to be stable ground. In addition, permafrost was a poorly known phenomenon and construction projects were often implemented without sufficient knowledge of permafrost conditions (e.g., the type and amount of ground ice). Consequently, the construction design of many buildings and infrastructure is not necessarily appropriate to the underlying permafrost conditions (i.e., the original natural site) and is not adapted to cope with the climate change now occurring in the BBDS region (see Subchapter 3.1). This problem is widespread in the Nunavut part of the region.

Warming of the ground temperature profile and deepening of the active layer are examples of the impacts of climate warming on permafrost already being observed across the Arctic (Smith et al., 2010; Romanovsky et al., 2015). The study of permafrost in northern communities is proving to be an important step in planning adaptation strategies because much residential, municipal, and transportation infrastructure relies on permafrost stability. The sustainability of this infrastructure is closely linked not only to permafrost conditions but also to permafrost degradation processes. In addition to higher air temperatures, a variety of other factors can also contribute to permafrost degradation (Williams and Smith, 1989; Jorgenson

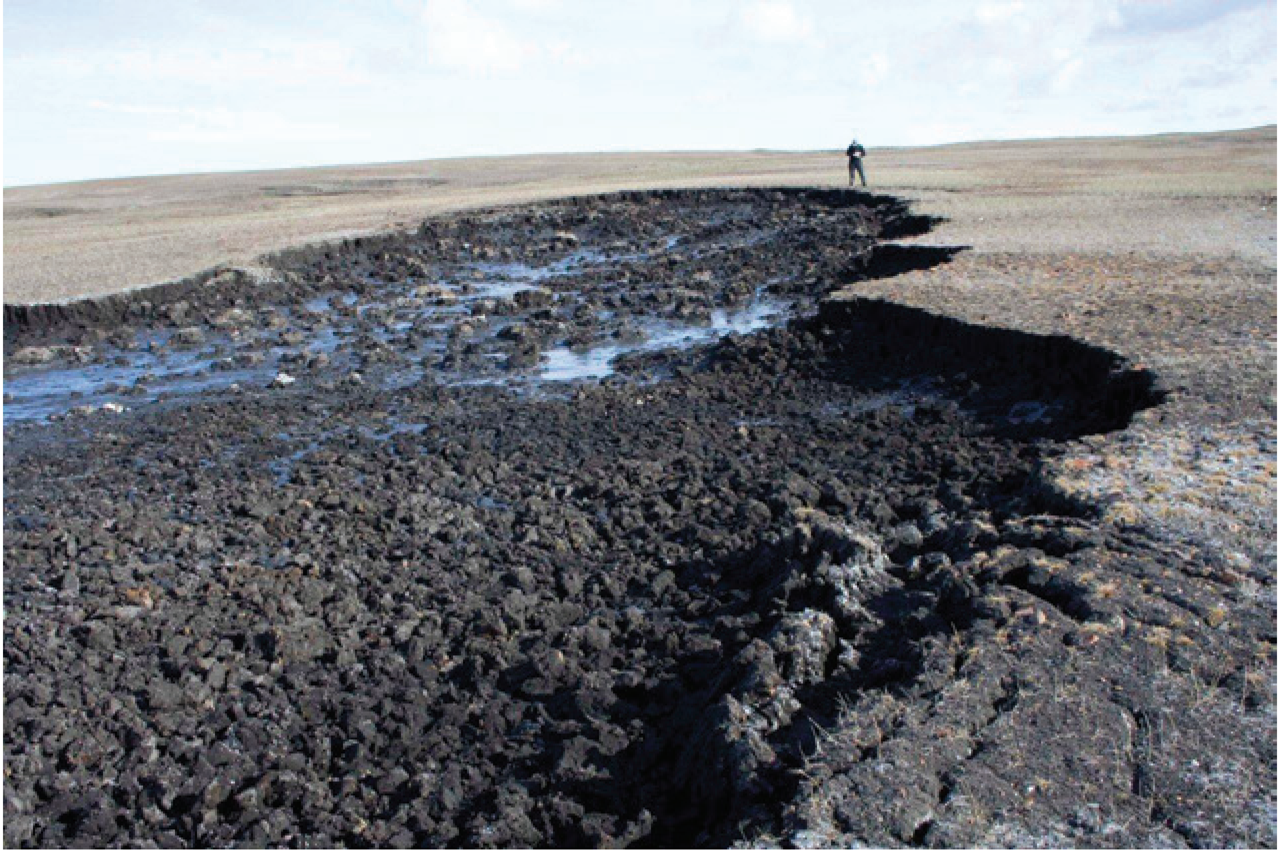


Figure 10.10 An active-layer detachment slide in water-saturated soil at Cape Bounty, Nunavut (photo by Scott Lamoureux). Even though this terrain disturbance is localized, it can have significant downstream impacts – for example, by increasing sediment loads into freshwater ecosystems.

and Osterkamp, 2005). The change of snow cover, changes in rainfall patterns, changing vegetation surface conditions, human activity, and built infrastructure all have, in fact, direct consequences on the thermal regime of permafrost (Jorgenson and Osterkamp, 2005).

All infrastructure built on thaw-sensitive permafrost can be affected by (1) thaw settlement and (2) terrain disturbances triggered by extreme climate events. The amount of ground ice, in particular at the interface of the permafrost and active layer (Figure 10.5), can greatly influence both thaw settlement and other terrain disturbances (e.g., landslide processes). Melting of the ground ice causes the ground surface to settle and leads to a loss of soil bearing capacity (Figure 10.7). Therefore, thaw settlement or subsidence varies spatially according to the distribution of the ice content. When the permafrost below an infrastructure construction thaws, subsequent settlement is enhanced by the infrastructure itself, inducing uneven thaw strain and causing damage to buildings (e.g., cracks in walls and warping of floors). In ice-rich ground, thaw may also affect drainage conditions and result in soils with very high water saturation; such soils are more vulnerable to active-layer detachments (Figure 10.10).

The infrastructure itself often becomes an additional driving factor that can greatly exacerbate the impact of climate change on permafrost stability. Indeed, many observations of infrastructure settlement and degradation are often directly associated with the preparation of the ground that supports the infrastructure foundations or with ill-adapted original construction designs and a poor knowledge of local permafrost conditions (Allard et al., 2012b; Lemay et al., 2018). There are many ways in which infrastructure and construction practices may affect the permafrost thermal balance and create thaw subsidence. A common mistake leading to infrastructure problems is the clearing of the space for the building foundation, which removes the insulating layer (e.g., vegetation) and changes the permafrost thermal conditions. When gravel pads are used for foundations, it is important to let the thermal regime stabilize before continuing construction, in order to avoid trapping heat in the pad. The choice of terrain preparation techniques for a construction project is therefore the first crucial (but often neglected) step that must be taken – considering not only local soil properties but also the nature of the construction project itself.

The infrastructure constitutes an additional upper layer that interacts with and potentially affects the permafrost thermal regime. The heat generated by a building may be transferred to the soil through its foundation, thus contributing to warming of the permafrost. The infrastructure may also provide additional soil insulation, which may significantly reduce heat loss from the soil during winter, thus contributing to keeping the ground locally warmer from year to year. The choice of foundation type is crucial for construction projects and must be adapted to permafrost properties in order to minimize the thermal impacts and any interactions between the infrastructure and the underlying permafrost. However, it is not always easy to significantly limit heat transfer from the construction to the ground (e.g., as when using slab on gravel pad foundations), and

Figure 10.11 Water ponding in a depression created by thaw subsidence at the bottom of an embankment. This subsidence was facilitated by the thermal impact of a snow bank previously at the road's edge (photo by E. L'Hérault).

engineering solutions must sometimes be applied to preserve the permafrost thermal balance.

Infrastructure may also indirectly affect permafrost stability by altering drainage and snow drift patterns. Water ponding and snow banks are two major site factors that may contribute to permafrost thawing (Allard et al., 2012b; Lamoureux et al., 2015). Snow accumulations created against road embankments and along runways insulate the ground surface and consequently reduce heat transfer from the ground to the atmosphere in winter, so that the ground remains warmer. As a result, snow banks often contribute to deepening the active layer, which may ultimately induce ground settlement leading to failure of the infrastructure. The thermal impact of snow banks is further enhanced by water ponding in depressions created by thaw subsidence at the shoulder of embankments (Figure 10.11). Water ponds absorb more energy from solar radiation than do vegetated surfaces, thus increasing the amount of heat transferred into the ground. Soil freeze-back is delayed due to latent heat effects (i.e., the release of energy that accompanies the change of water from liquid to solid phase). There may also be an associated advective heat flow due to water movement in the active layer.

BBDS infrastructure is currently being affected by both climate-induced changes and the cumulative effects of human/infrastructure-induced changes (Vincent et al., 2013; Lemay et al., 2018). In addition to the rise of air temperatures, which contributes to warming of the ground, climate change is also accompanied by (1) an increase of climate variability/instability, which is expressed through an increased likelihood of extreme weather events; (2) general changes in precipitation regimes (i.e., amount of precipitation and liquid:solid ratio), which directly affect drainage and water ponding; and (3) modifications in wind regimes, which are responsible for snow drift patterns that in turn affect water ponding and drainage. The combination of climate- and human/infrastructure-induced changes generates two types of permafrost instability: localized terrain disturbances and thaw settlement. Both have positive feedbacks on water ponding and drainage. Finally, these permafrost changes do not affect only built environments; they may also have impacts on downstream natural permafrost environments and may disrupt ecosystem services, with possible impacts on drinking water quality (detailed in Subchapter 4.4).

10.5 Transportation infrastructure in the BBDS region

A basic condition for communities on both sides of the BBDS region is that they all function as "*islands*" even though they may be situated on the same mainland as other communities. This condition is often referred to as "*island operation.*" There are no connecting roads between any communities in the entire BBDS region. Power supply and other municipal service infrastructure operate completely isolated, with no outside redundancy. Communities are connected only by sea and air transportation, and in that context, ports and airports are crucial to the function and economy of the whole region.

The transportation infrastructure in the region presents many similarities, although it is much more developed in some Greenland communities. In the Greenland part of the BBDS region, many of the larger communities have deep-water ports (i.e., ports capable of accommodating ocean-going vessels; Figure 2.8). On the Nunavut side, there is only one deep-water port (located at Nanisivik on Strathcona Sound near

Table 10.2 Comparison of airstrip lengths and materials in the BBDS region.

Canadian side of the BBDS region[1]			West Greenland[2]		
Airport	Material	Length (m)	Airport	Material	Length (m)
Iqaluit	Asphalt	2,623	Thule	Asphalt	3,000
Resolute	Gravel	1,982	Kangerlussuaq	Asphalt	2,815
Alert *	Gravel	1,676	Narsarsuaq	Concrete	1,830
Mary River **	Gravel	1,463	Nuuk	Asphalt	950
Pond Inlet	Gravel	1,221	Qaanaaq	Gravel	900
Cape Dorset	Gravel	1,216	Qaarsut	Gravel	900
Arctic Bay	Gravel	1,199	Ilulissat	Asphalt	845
Qikiqtarjuaq	Gravel	1,159	Aasiaat	Asphalt	799
Clyde River	Gravel	1,067	Maniitsoq	Asphalt	799
Pangnirtung	Gravel	890	Paamiut	Asphalt	799
Grise Fiord	Gravel	606	Sisimiut	Asphalt	799
Kimmirut	Gravel	579	Upernavik	Asphalt	799

[1] Source: NAV Canada (2008)
[2] Source: Transportkommissionen (2011)
* Canadian Forces Station
** Private airport operated by Baffinland Iron Mines Corporation

Arctic Bay; Figure 2.8); this former ore-shipping port is now a naval facility. Shipping and sea transportation activities on the Nunavut side are therefore paced by sealift services, tides, and seasonal sea ice conditions (further discussed in Section 10.5.3 and Chapter 9). This major difference between the east and west sides of the BBDS region has direct impacts on regional economic activities such as fisheries (see Subchapters 3.3 and 6.4), mineral exploitations (see Chapter 7), supplies management (i.e., the availability, quality, and price of various products in food stores and other markets; see Chapter 4) and the tourism industry (see Chapter 8). Consequently, many socio-economic activities on the Canadian side rely greatly on airports, especially during the sea ice season. Although airports are also crucial in the function and economy of Greenland, most of its small communities are serviced only by ship or, when ice conditions prevent access by sea, by helicopter. In such areas, the sea ice does provide a means of local transport by dog sled, snow scooter, ATV (all-terrain vehicle), and sometimes ordinary cars. Sea ice is therefore often referred to as informal or subsistence infrastructure, and its function is also affected by climate change through changing sea ice conditions, extreme events, and potentially sea-level change (Hatcher and Forbes, 2015; Forbes et al., 2016).

10.5.1 Airports in the BBDS region

All communities on the Nunavut side of the BBDS region have their own airstrips, and air access is their main connection with other communities and with the rest of the world. There are a total of 12 airstrips, 2 of which are not located in a community (the Alert airstrip and the Mary River Aerodrome). Only 1 airstrip is paved (at the Iqaluit airport, Nunavut's hub); the rest are gravel-topped. This ratio of paved to gravel-topped airstrips is a major contrasting distinction between Nunavut and Greenland. Of the 12 airstrips in West Greenland, 9 are paved, 1 is concrete, and 2 are gravel-topped (Table 10.2). The remaining communities in Greenland are serviced mainly by ship and, especially in winter, by helicopter. Airstrip lengths are generally longer on the Nunavut side than on the West Greenland side. Because of the central role of airports in the BBDS region and because they are being affected by permafrost thawing, three major airport case studies are detailed below.

Case study: Kangerlussuaq Airport

Kangerlussuaq Airport (67.01°N, 51.69°W; see Figure 2.1) was established at a remote and uninhabited site by the United States (U.S.) Army Air Forces in October 1941 under the code name Bluie West 8 (BW-8). This site provided an alternative runway to the base at Narsarsuaq (Bluie West 1) and was used as hub and refueling station for transatlantic flights during World War II. During the Cold War, Kangerlussuaq served as a Distant Early Warning Line base as well as a supply station for other such facilities in Greenland (Jensen et al., 2013).

Beginning in 1954, regular civilian flights to Kangerlussuaq were operated as part of the route from Copenhagen to Los Angeles, and Kangerlussuaq thus became also a civilian airport and the main gateway for air traffic to Greenland. The U.S. Air Force operated the base until 1992, except for a short period under Danish authority (1951–1952). In 1992, after the fall of the Soviet Union, the U.S. Air Force abandoned the airport and handed over all facilities to the Greenland government for civilian use, but the United States of America (USA) retains priority military access at short notice (United Nations, 1991). In recent decades, Kangerlussuaq has developed a successful tourism industry, which benefits from easy access to the Greenland Ice Sheet and serves as a hub for cruise ships (tourism in the region is described further in Chapter 8). Furthermore, Kangerlussuaq is an important hub for scientific research and expeditions.

Figure 10.12 The Kangerlussuaq airport and its supporting settlement are located on the river terrace of a glaciomarine delta, in close proximity to the Greenland Ice Sheet (visible in the background) (photo by Thomas Ingeman-Nielsen).

The airport and its supporting settlement (Figure 10.12) are situated in the rather complex geological setting of a glaciomarine delta in the valley system east of the head of the Kangerlussuaq fjord. The delta deposits formed during ice-margin retreat from the area approximately 7,000–8,000 years BP (van Tatenhove et al., 1995; Bennike and Björck, 2002; Roberts et al., 2009), in a period of rapid sea-level fall. The sediments of the delta range from fine-grained marine silt and clay deposits to coarse-grained (sand, gravel, and stone) river deposits (Storms et al., 2012). The major part of the Kangerlussuaq village, airport structures, and runway are located on a river terrace; however, the western part of the runway extends onto a slightly sloping plateau of fine-grained sediments (clays and silts) of marine origin. Younger surficial eolian deposits in the silt and fine sand fraction are widespread in the area.

Due to its inland location and proximity to the ice sheet, the airport experiences a stable dry subarctic climate with a mean annual air temperature of -3.3°C (2004–2014). Extreme winter temperatures range down to approximately -45°C and summer temperatures up to 25°C. The area has continuous permafrost, the thickness of which has been estimated at 130 m at the airport location (van Tatenhove and Olesen, 1994). By the ice sheet margin (25 km inland at 450 m surface elevation), a permafrost thickness of 335 m has been measured (Harper et al., 2011). Temperature measurements show an active-layer thickness, under natural conditions, of about 2 m; below paved surfaces, ground-penetrating radar measurements indicate an active-layer thickness of approximately 4 m (Jørgensen and Andreassen, 2007; Jørgensen and Ingeman-Nielsen, 2008). Perennially frozen fine-grained marine and eolian deposits in the area are typically ice-rich; however, in certain areas the marine sediments contain considerable residual salinity, which depresses the freezing point and leaves the sediments technically unfrozen, although still cryotic (i.e., with a temperature less than 0°C). Coarser deposits typically range from well bonded to friable, with limited excess ice (e.g., USACE, 1957a, 1957b, 1958). Massive ground ice features such as ice-wedge polygons and pingos have been reported in the area (Scholz and Baumann, 1997; Ingeman-Nielsen et al., 2012), although not from the immediate vicinity of the airport and settlement.

Runway construction commenced in autumn 1941, and the airfield became operational in spring 1942. The first simple runway, 1,824 m long and 152 m wide, was constructed with a sand base course and asphaltic macadam pavement placed directly on surface deposits (no replacement). In 1953, a proper runway with an approximately 60 cm subbase and base course of coarse-grained material topped with a bituminous concrete pavement was constructed on top of the first runway. This runway was 1,671 m long and 46 m wide. An operational apron and taxiways were constructed south of the runway. During the period 1957–1960, the runway was extended to 3002 m length and widened to 61 m, and the southern parking area was expanded. Areas adjacent to the existing runway were excavated, and frost-susceptible and ice-rich soils were replaced by non-frost-susceptible materials, typically to a depth of 3.3 m

Figure 10.13 New repairs of pavement cracking and settlement at the west end of the Kangerlussuaq runway, November 2015 (photo by Thomas Ingeman-Nielsen).

below ground surface. The area of the original runway was not reconstructed; the pavement was merely extended northward. The westernmost part of the new runway extended onto a lower plateau of marine fine-grained and very ice-rich sediments. A thick embankment was constructed to protect the thermal regime of the underlying thaw-sensitive permafrost (USACE, 1961a, 1961b).

Load restrictions are in effect for the runway in summertime. The basis of these restrictions has not been publicly reported but may relate to the fact that the oldest part of the runway was constructed without the replacement of surficial deposits. There are no restrictions in wintertime, when the active layer is frozen, ensuring a high bearing capacity. In 2015, the use of the western part of the runway was further restricted due to settlement and cracking of the pavement (Figure 10.13). The cause of this settlement is presently unknown, but it may relate to insufficient compaction of the thick embankment during construction or to thawing of segregated ice formed in the embankment during freeze-up after construction. A similar settlement failure was observed and repaired at the same location by the U.S. Air Force in 1973, indicating a long-term process.

Some runway segments that seem to experience no permafrost-related issues (due to low ice content in the underlying sediments) do still suffer from a deteriorating pavement. Thermal cracking is a severe problem due to the more than 60°C surface temperature variation experienced over the course of a year. Proper crack sealing and repair is extremely important in order to allow continued safe operations and to avoid erosion of the base course and seasonal frost heave problems caused by water entering the construction through the cracks.

Thaw settlement does occur locally on the southern apron and taxiway. A preconstruction ravine filled with fine-grained, ice-rich material has caused differential settlement of up to 45 cm (Jørgensen and Andreassen, 2007), and a few other areas are affected by local settlement as well. The northern apron was originally designed for DC-8 aircraft, and the current use of the much heavier Airbus A330-200 and intensive traffic with domestic Dash 8 flights have caused fatigue cracks and viscous deformation of the asphalt in summer. Some of these issues have been addressed by painting the asphalt in parking areas with a light color to reduce surface temperature.

Early buildings at the military base were typically founded directly on shallow foundations with no special precautions. Many suffered differential settlement and structural damage (Korhonen, 1984; Dzik, 2014) and have since been replaced.

Since the early 1960s, the preferred foundation technique for buildings has been pile foundations in permafrost or shallow footings in gravel fill, often with the building elevated above the ground surface to allow for air circulation or with air ventilation ducts installed below the building. These buildings show little or no evidence of permafrost degradation effects, although the ventilation ducts are no longer actively operated and maintained.

Figure 10.14 Building S385 in Kangerlussuaq suffered differential settlement of approximately 35 cm in its southeast corner after power was cut to an artificial cooling system installed below the building (photo by Thomas Ingeman-Nielsen).

There is one example of a personnel barrack (Building S385) constructed with an active electrical cooling system to keep the ice-rich permafrost beneath the building frozen. Following the transition from military to civilian airport operations in 1992, the power to the cooling system was cut, resulting in differential settlement of up to 35 cm in the southeast corner of the building. Excavations for a new power line close to the building in 2005 exposed a strongly deteriorated and leaking water pipeline, which may have contributed to the permafrost degradation in the area (Figure 10.14).

The practice of using pile foundations in permafrost and elevating buildings has been continued, and most modern Kangerlussuaq buildings, including a new terminal building, have been constructed in this way. However, the effectiveness of elevating the buildings is often reduced by the ill-advised practice of mounting side panels that prevent proper air circulation below the buildings.

Generally, the runway and main aprons are not expected to experience significant damage related to future permafrost degradation, due to the presence of thaw-stable subgrade materials or thick protective embankments. Local thaw settlement may continue to develop in areas with remaining ice-rich eolian deposits. The extent of active settlement will be limited by the relatively small thickness of the ice-rich deposits (typically less than 2 m), and settlement should thus be manageable. However, the surrounding infrastructure, especially the road system, will continue to suffer locally from thaw degradation of ice-rich permafrost, which is expected to accelerate due to future warming and to severe drainage problems that are presently not properly addressed.

Case study: Thule airport

Thule Air Base (76.53°N, 68.50°W; see Figure 2.8) is located in northwest Greenland. The site was originally utilized by nomadic Inuit, but in 1892, Robert Peary established a base of operations at Thule for his North Pole expeditions. In 1910, Knud Rasmussen established a trading post to serve the sparse local Indigenous population. In 1943, the U.S. Army Air Forces established a radio and weather station in the area, with the code name Bluie West 6 (BW-6). In 1951, under the code name Blue Jay, the U.S. Air Force created Thule Air Base to operate as a major strategic forward air operations facility for Arctic defense surveillance and retaliation missions. An asphalt pavement runway was established, and lodging quarters, dining halls, and recreational and medical facilities were constructed to house up to 10,000 personnel. In 1953, a local Inuit community, Uummannaq, was forcibly relocated by the Danish colonial rule at very short notice, as a consequence of the continued expansion of activities at the base. A new settlement, Qaanaaq, was established some 100 km to the north, to house 116 Inuit (Jensen et al., 2013). The relocation is still a controversial issue in Greenland, and claims for compensation and renewed access have been treated by the Danish court system and the European Court of Human Rights (ECHR) over several decades (see *Hingitaq 53 versus Denmark*, Application no. 18584/04, ECHR Admissibility Decision, 12 January 2006).

The climate type at Thule Air Base is tundra, with a mean annual air temperature of -11.0°C and occasional hurricane-force winds. The annual average for air thawing degree-days (ATDD) for the years 1953–2014 is 427, and the annual average of air freezing degree-days (AFDD) for the same period is 4,397. The approximate length of the thawing season is 125 days, from mid-May to mid-September.

The air base is located on an ice-free area of land between Wolstenholme Fjord (Baffin Bay) to the west and the Greenland Ice Sheet to the east. The site lies within the east–west-trending Pituffik Valley, which is drained by the North River; this river flows just to the north of the airfield. The region is devoid of vertical vegetation, and as the valley rises in elevation toward the ice sheet, the landscape becomes very rocky and boulder strewn. The glacially sculpted geology of the region is dominated by an alternating sequence of lithified, undeformed, siliciclastic, and carbonaceous sedimentary rocks (Davies et al., 1963). Glacial sediment overlies the sedimentary bedrock within the valley, varying in thickness from 2 to 20 m.

The airfield sits on approximately 2–10 m of glaciofluvial sediment. The permafrost in the Pituffik Valley is continuous and is estimated to be more than 500 m in depth (Roethlisberger, 1961). The current permafrost temperature is approximately -10°C at the depth of zero annual amplitude (approximately 7 m depth). The thickness of the active layer ranges from about 0.3 m under thick organic mat cover to 1 to 2 m in unvegetated areas. Segregated ice generally delineates the base of the active layer and the top of the permafrost (Bjella, 2013). Wedge ice networks are prominent throughout the area, with wedge dimensions up to 3 m in depth, 1.5 m in width, and many meters in length. The matrix ice content is highly heterogeneous, and Corte (1962) identified the existence of remnant glacial ice, buried in the sediments.

Construction of the airfield began in the summer of 1951. By the end of the 1952 season, a flexible pavement runway (length 3000 m and width 60 m) was in service, with associated taxiways and ramps. Fill material specifications and controls on placement were rigorous, with the fill material being either local borrow or material obtained from quarrying (gravel and hardrock) operations around the area. The runway stretched across five topographic high points generally oriented west to east. The taxiways and ramps were located at slightly lower elevations, and the intervening areas were used for natural drainage and surface water storage. Releveling of the runway was completed in 1977, and removal and new construction of the runway pavement profile was completed in 1993 (Figure 10.15).

The design fill thickness for the airfield embankments was 2 m minimum to prevent thawing of the native subgrade. Nevertheless, thaw settlement began at some locations on

Figure 10.15 Runway, Thule Air Base: 3000 m of flexible asphalt pavement (photo by Kevin Bjella).

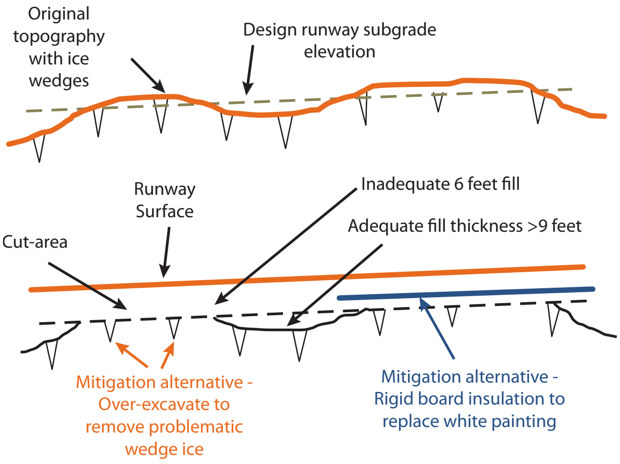


Figure 10.16 Runway condition (top) and two alternatives for addressing thaw-settlement problems (lower) (modified from Bjella, 2013).

the runway in 1952, almost all within a 550 m section. Bjella (2013), taking into account continued climate warming, showed that a minimum of 3 m of fill would have been required to prevent thaw from encountering ice-rich native natural materials at the site. In 1953, studies were conducted to assess the possibility of raising the surface albedo to reduce thaw depth, and it was found that at Thule Air Base, white-painted areas experience approximately 60 cm less thaw depth than unpainted black asphalt (ACFEL, 1955). These results have been confirmed by others (Berg and Aitken, 1973; Jørgensen and Ingeman-Nielsen, 2008). Targeted painting was started in 1955 and, over nearly five decades, was expanded to eventually cover the entire airfield at 371,000 m^2, with refresh painting occurring on a phased schedule of every 3 to 5 years. The pristine white condition required to achieve 60 cm thaw reduction, or an albedo of approximately 0.6, is nearly impossible to maintain due to aircraft traffic, runway maintenance operations, and ultraviolet degradation of the paint color. Painted areas one year or older exhibit albedo values from 0.2 to 0.5, amounting to only 15 to 35 cm of thaw reduction. This condition has been the average best case for the airfield and has not been sufficient to prevent thaw settlement. Compounding the problems, the frequent paint application causes smoothing of the microtexture of the asphalt, thus reducing aircraft braking ability. Rain increases the possibility for hydroplaning in the summer, and hoar frost develops on the white painted surfaces in the winter. Daily brooming is required to remove the frost and rainwater, and this practice also removes the paint. Overall, white painting imposes a substantial safety hazard, cost, and logistical burden.

Due to the runway's low average albedo, some thaw settlement currently exists, with depressions measuring 1.5–2.0 m in length, 1.0–1.5 m in width, and up to 8 cm in depth, all within a centralized area, but these depressions have not hampered aircraft operations. Large thaw depressions exist off the paved surfaces at various locations around the airfield. The South Loop Taxiway and the Southeast Loop Taxiway were, for unknown reasons, constructed with a minimal fill thickness; due to the resulting severe thaw settlement, these sections have been abandoned for almost four decades. In 2012, an experiment was initiated to cease all white painting and determine whether detrimental effects would occur. During the subsequent three summer seasons, the average air temperatures were approximately average and no additional thaw settlement occurred.

An alternative to painting is the installation of extruded polystyrene (EXPS) insulation (rigid board insulation) beneath the pavement asphalt at some optimal depth. This technique has been successful for many cold-regions engineering projects over the past 50+ years (Esch, 1986). One- and two-dimensional thermal solutions are available to calculate low-resolution design guidance; however, the use of insulation in linear embankments is a new concept for the management at Thule. Due to the high risk, a full-scale demonstration of the insulation alternative was conducted. A test embankment was constructed consisting of three test sections: a 10 cm thick EXPS section, a 5 cm thick EXPS section, and a control section with no insulation. A 1.2 m compacted fill section was placed over the EXPS, with 2 m of fill depth in the control section. The results showed that the thermal offset across the insulation is more than 12°C in the vertical distance of 30 cm for the thicker (10 cm) insulation, and 10.5°C for the thinner (5 cm) insulation. Coincidentally, this test occurred during the fourth warmest summer on record at the air base (2011). Finite element thermal modeling was performed, and the results correlate well with the test embankment results (Bjella, 2013). The consequences of continued climate warming were simulated by increasing the imposed mean annual air temperature by 2°C; under these simulated conditions, the 10 cm of EXPS performed satisfactorily in preventing the summer thaw depth from penetrating much below the EXPS layer.

During the summer of 2015, a scheduled runway repaving was begun. The west half of the runway was closed during the reconstruction, thus limiting passenger and cargo flights to aircraft capable of takeoff and landing within the remaining 1500 m length. The eastern half of the runway was repaved during the summer of 2016 in the same manner, and some taxiway repaving is scheduled to occur in 2017. The design includes 10 cm of EXPS insulation board to be installed beneath the entire length of the 550 m thaw-sensitive section, with the insulation placed 1.2 m below the top surface of the runway and extending laterally to the edges of the runway where it transitions to the shoulder (Figure 10.16, lower right). Another alternative for protecting the 550 m thaw-sensitive section is over-excavation of the ice-rich native materials within the 3 m thaw-critical zone (Figure 10.16, lower left). For this alternative, large quantities of appropriate fill material would be required. The cost–benefit analysis comparing the two options demonstrated that EXPS was the most economical alternative. The total projected cost of the 2015–2016 runway reconstruction was 140 million Danish kroner. The cost of the 2017 taxiway repaving is not publicly available at the time of this writing.

The buildings at Thule have been constructed primarily with permafrost foundations of two types, both of which actively maintain the state of the frozen native soils. Lodging, dining,

Figure 10.17 Excavation and placement of pier-and-footer style foundation for new dormitory, Thule Air Base (photo by Kevin Bjella).

and office facilities are constructed primarily with a raised first level, either on a post-and-pad style surface foundation or with a shallow buried pier-and-footer style foundation (Figure 10.17). The nominal 1 m of open air space is adequate to limit summer thaw depths to less than about 1 m. These two types of foundations have performed very satisfactorily. With the surface style foundations, no appreciable movement of the structures has been observed, and with the buried pier-and-footer style, no thaw settlement has been recorded. To offset the effects of continued climate warming, recent construction with the pier-and-footer style incorporates an additional layer of EXPS insulation board buried near the surface under the entire structure. The EXPS cost is weighed against the alternative of a deeper excavation with consequently larger quantities of fill, which provides a deeper footer depth and insurance against an increased summer thaw depth (Bjella, 2012a).

For structures with high loading on the first level (e.g., aircraft hangars, warehouses, vehicle storage and maintenance facilities) under-floor cooling systems have been utilized with generally good success. The concept includes ducting, either placed under the poured concrete floor or incorporated into the concrete structural floor. This ducting is connected to collection manifolds at either end of the structure, with inlet and outlet plenums rising vertically, in some cases 10 m or more into the ambient air (Figure 10.18). The inlet plenums are shorter than the outlet plenums, to naturally create convective flow in the event of still wind conditions (Metcalf and Eddy and Lapierre, 1958). Often, however, katabatic winds blow to the west from the glacier, and therefore all buildings constructed with floor cooling systems are oriented with the piping parallel to the wind flow. The very large hangars of over 100 m length have experienced problems in the past (Tobiasson and Lowry, 1970; Bjella, 2010), where corrugated metal pipe was utilized for the duct material. The problems were twofold: this material greatly increased friction to air flow (Takahashi, 1956), and groundwater inundated many of the ducts. Most other thaw-settlement problems with these types of foundations have resulted from maintenance issues, where central steam condensate piping leaked hot water onto and through the floor system or where mechanical rooms were allowed to overheat to the extent that the under-floor cooling system was overwhelmed.

A new method of construction now being utilized to offset the effects of climate warming is over-excavation of the ice-rich glaciofluvial sediments, down to ice-poor/ice-free competent bedrock (Figure 10.19). This method has an economic threshold based on (a) the costs of excavating and then emplacing large quantities of fill material versus (b) the costs of adding structural components to elevate the highly loaded structure and create a free air space or of utilizing heat pipes (thermosyphons) to

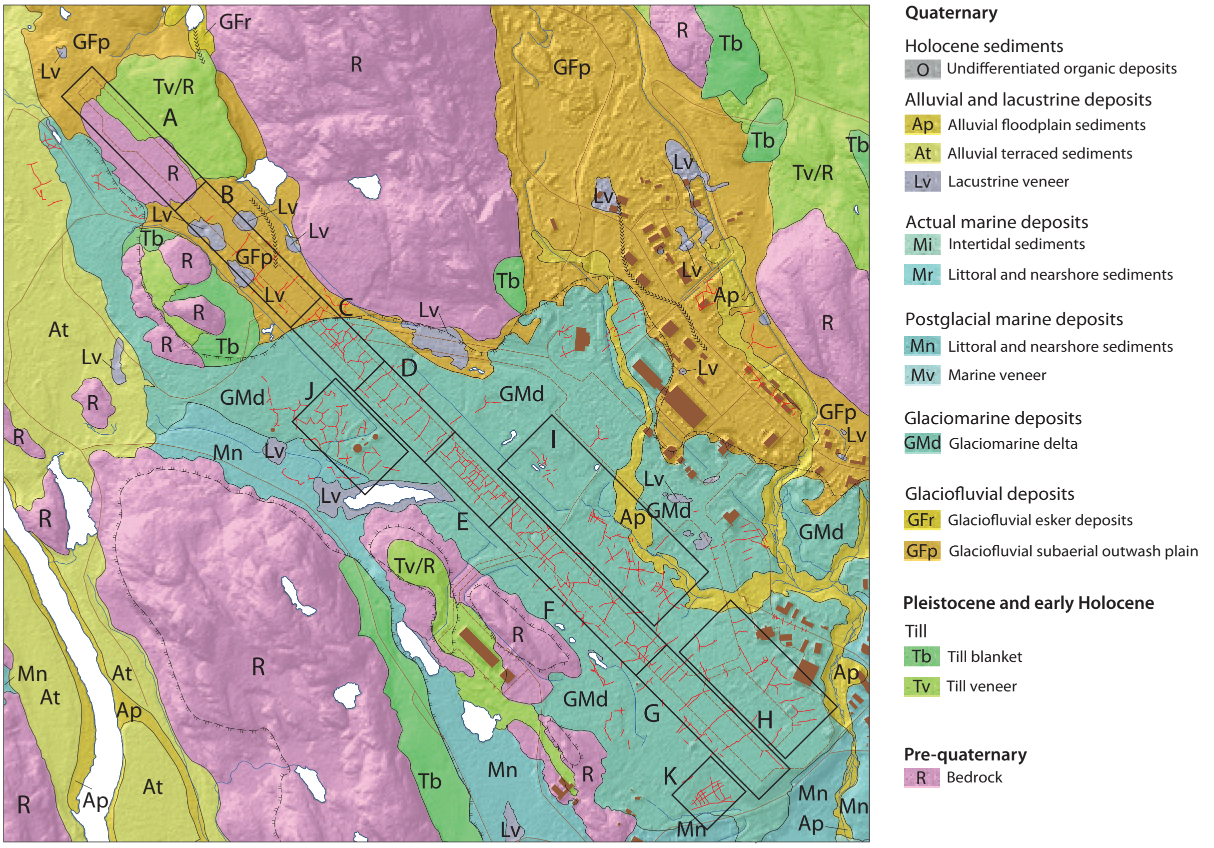
Figure 10.18 Aircraft hangar under-floor cooling plenums, Thule Air Base (photo by Kevin Bjella).

Figure 10.19 Over-excavation for construction of slab-on-grade structure, Thule Air Base (photo by Kevin Bjella).

maintain the sub-floor fill in a frozen state (Bjella, 2012b). Heat pipes have been utilized at Thule Air Base on various limited applications, such as radome antenna foundations and the power plant generator foundations. If over-excavation is cost efficient, one great benefit is that the structure site will thereafter be free of troublesome ground ice and will thus be insensitive to climate change. The site will therefore be conditioned for the future construction of other structures as well.

Case study: Iqaluit airport

The Iqaluit airport (63.76°N, 68.56°W; see Figure 2.8) is a very good example of infrastructure constructed in an area where knowledge of permafrost conditions was minimal and permafrost was assumed to be a permanent and solid substrate. Built by the U.S. Army during World War II, the runway was extended to its current length (2.7 km) at the end of the 1950s (Eno, 2003), becoming the largest airstrip in the Canadian Arctic and a strategic hub in support of the economy, development, and safety of Nunavut. The construction site was chosen mainly because of its relatively flat topography, in a geological setting of glacial and fluvial deposits in a glaciomarine delta (Figure 10.20). Many of these deposits have been identified as very ice-rich permafrost. Consequently, in recent years the entire airport infrastructure has begun to show deterioration patterns associated with permafrost degradation. Given the central role of this transportation infrastructure, and for security and economic reasons, the Canada-Nunavut Geoscience Office (CNGO), along with Natural Resources Canada and Transport Canada, undertook a permafrost survey of the airport area (Mathon-Dufour and Allard, 2015). The intent was to establish a rehabilitation strategy and expansion plan to adapt the infrastructure to recent warming trends and to accommodate projected warmer future climate conditions.



Large crack pattern

Sector	Pattern	Average crack spacing (m)
A	No major frost cracks	0
B	Transverse	100
C	Orthogonal	45
D	Transverse	45
E	Orthogonal	12 to 30
F	Transverse, longitudinal, and oblique	85 (oblique) 25 (transverse)
G	Transverse	85
H	Orthogonal	40
I	Orthogonal non-oriented	2 to 60
J	Hexagonal (isotropic)	45 (larger ones), 25 (smaller ones)
K	Orthogonal oriented	30 (larger ones), 15 (smaller ones)

Figure 10.20 Map of surficial deposits in the vicinity of the Iqaluit airport (from Allard et al., 2012a). The red lines show the locations of the most evident frost cracks and ice wedge furrows. Full legend available at http://geoscan.nrcan.gc.ca/starweb/geoscan/servlet.starweb?path=geoscan/fulle.web&search1=R=289503. (This map is a copy of an official work published by the Government of Canada. This reproduction has not been produced in affiliation with or with the endorsement of the Government of Canada)

Figure 10.21 Linear depression caused by permafrost degradation at the Iqaluit airport (photo by E. L'Hérault).

The permafrost survey evaluated the original permafrost conditions prior to construction and identified the changes that occurred during airport construction and expansion, most notably hydrological changes. Comparison of the original permafrost patterns and natural setting with the listed infrastructure deterioration issues indicates that the Iqaluit airport is affected by ice-rich permafrost degradation. For instance, the study revealed that a large part of the airport infrastructure has been built over an extensive network of ice-wedge polygons. Degradation of ice wedges underneath thin embankments and paved areas creates linear depressions and major frost cracks (Figure 10.21). Drillings with core recovery in affected areas confirmed the presence of ice wedges crossing the runway, taxiway, and aprons. The study also revealed that the original hydrological network of lakes and streams was partly drained and/or filled during construction phases (Figure 10.22), and drillings confirmed the presence of massive ground ice in the fine-grained sediments of these former lacustrine and fluvial zones. Again, these areas are directly associated with sectors of the airport affected by differential settlement and instability. The survey also indicated that many of the former lakes and streams are still affected by groundwater, which contributes to warming and degradation of the surrounding permafrost.

The monitoring of ground temperatures under natural terrain, paved surfaces, and embankment shoulders highlights significant differences in their thermal regimes. Due to the lower albedo coefficient of asphalt pavement, the active layer beneath the pavement thaws during a longer period (about 16 and 27 days longer) and consequently deeper (about 1.0 m and 1.5 m deeper) than in the natural terrain and the embankment shoulders, respectively. This warmer thermal profile likely favors underground water ponding, which in turn contributes to permafrost thawing and, ultimately, to infrastructure deterioration.

The results of this ongoing study are communicated on a regular basis to stakeholders and airport managers through technical reports and face-to-face meetings, and the findings already support decision-making regarding engineering designs/solutions being implemented for rehabilitation and expansion projects. However, further knowledge of the permafrost conditions and monitoring of the permafrost thermal regime at strategic places (e.g., where infrastructure issues are observed) are still needed in order to perform the accurate numerical simulations required to improve risk assessments and better inform adaptation strategies. Based on climate model projections for the BBDS region (see Subchapter 3.1), it is expected that the thawing period will increase and the freezing period will decrease in the future. These changes will likely result in a significant thickening of the active layer beneath paved surfaces, thus exacerbating current infrastructure issues and likely generating new ones.

10.5.2 Roads in the BBDS region

Roads are very important infrastructure in the BBDS region. At the local community scale, roads give access to many fundamental services as well as the territory/countryside. Roads are often necessary to access new areas for infrastructure and community expansion or to ensure the transport of natural

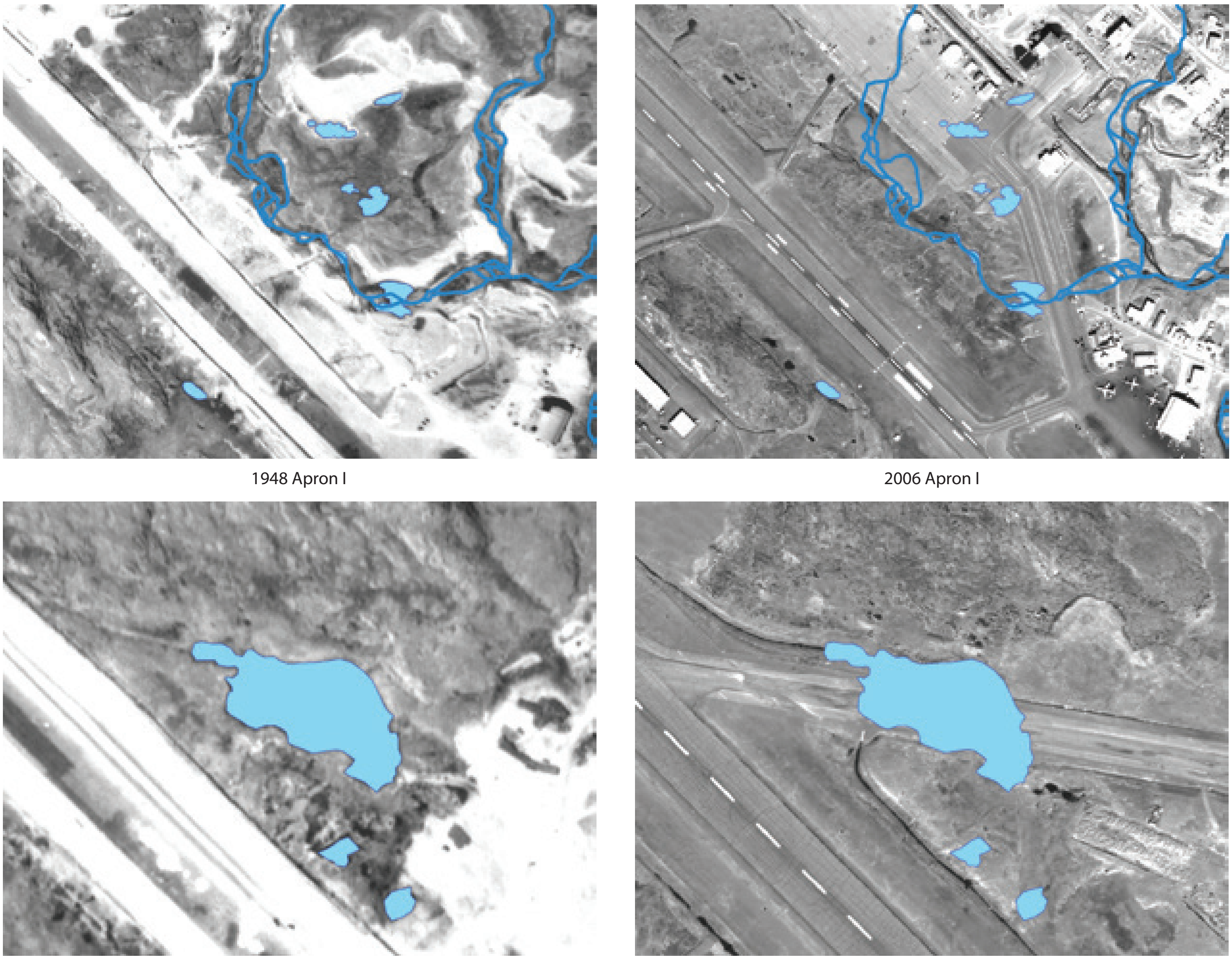


Figure 10.22 Hydrological changes associated with construction and expansion of the Iqaluit airport. The left panels show the natural hydrological settings of two areas (1948). The right panels show post-construction and post-expansion conditions (2006) (reproduced from Mathon-Dufour, 2011).

resources extracted in inland areas. As an example, see the preceding discussion regarding the gravel road network in farming regions of south Greenland (Subchapter 6.6).

Because roads are linear, they cross a multitude of environments with different sensitivities to thaw. A knowledge of permafrost conditions and of spatial variation in ground ice content is of primary importance in managing and assessing the risk of road deterioration. Roads may also cross natural streams and rivers and are therefore vulnerable to extreme weather events, which can generate sudden floods and severely damage infrastructure through mechanical and thermal erosion. Conversely, the impacts of the roads themselves on downstream natural environments can also be significant, with direct implications for ecosystem services.

Linear and extensive infrastructure such as roads (as well as railways and runways) may have significant impacts on drainage. Such structures may function as dams, concentrating water and creating ponds upstream. In this way, the infrastructure contributes to warming of the permafrost and may create associated structural issues (as explained in Subchapter 10.4). In addition to encouraging water ponding, linear infrastructure may also increase water flow in ditches or across roads, via culverts or new seepage pathways in the active layer (McNamara et al., 1999). This surface and subsurface water flow carries heat by advection and thereby contributes to local warming of the ground. This warming may in turn lead to the formation of transversal depressions in the infrastructure due to thaw settlement (Fortier et al., 2011); these features are frequently observed where culverts pass beneath roads and runways.

Permafrost surface and subsurface drainage is a climate-driven variable that changes as precipitation regimes and temperatures change. Changes in climate parameters such as solid:liquid precipitation ratios, wind and snow drifting, and climate conditions during spring thaw or autumn freeze-up all have direct impacts on permafrost hydrology (see Subchapter 4.4). These hydrologic changes may provoke irregular permafrost degradation with significant drainage pattern modifications, thus enhancing thawing and amplifying impacts on downstream infrastructure. In extreme cases, modifications of natural drainage patterns may trigger permafrost degradation processes such as landslides (active-layer failures), gullying in ice wedge complexes (Fortier et al., 2007; Bonnaventure et al., 2018), and rapid riverbank erosion (by thermal erosion). Such processes may in turn severely damage infrastructure and, in a community setting, can have significant implications for community services and safety. These degradation events are often associated with extreme weather anomalies (e.g., a heat wave followed by an intense rain event) (L'Hérault, 2009).

Observations of road deterioration and collape due to permafrost degradation are increasingly frequent in the BBDS region and are a growing source of concern regarding the safety and services of many communities. Damages may develop quickly and require costly repairs. It is currently difficult to assess and quantify the degradation processes and their impact on maintenance costs across the region because the causes of damage and the related costs of maintenance and repair are not systematically registered and reported by communities. Problems are expected to increase as the climate continues to warm and as communities expand their built environments into new areas for the purposes of residential needs or resource exploitation.

Permafrost conditions may to some extent be a limiting factor for socio-economic development in the region, particularly for the mining industry, which needs long roads and railways to access new deposits in remote locations. For instance, the Baffinland Iron Mines Corporation was planning to build a 150 km railway (and a parallel side road) to transport 18–21 million tons of iron ore per year from the Mary River mine site to Steensby Inlet (see Chapter 7). The project was approved by the Nunavut Impact Review Board in December 2012. The challenge of building such a railway over vast thaw-sensitive, ice-rich permafrost areas would require thick protective railway embankments, as well as approximately 24 bridges and more than 300 culvert crossings. The cost of this major infrastructure expansion, including the construction of a deep-water port in Steensby Inlet, was estimated at 5 billion Canadian dollars (CAD). The pronounced November 2013 drop in the price of iron ore on the global market, combined with falling demand from China and other places, led the mining company to postpone the project and revise its production strategy (see Chapter 7). Although the global economy is an important driving factor for mining activity, current and projected permafrost changes represent an additional consideration that remains difficult to quantify for the mining industry and other stakeholders, thus adding to the uncertainty involved in investing in the BBDS region and other Arctic areas.

10.5.3 Coastal infrastructure in the BBDS region

The marine infrastructure on the Nunavut side of the BBDS region is distributed across 10 communities. Most are on Baffin Island, 1 is on Cornwallis Island (Resolute Bay), and 1 is on southern Ellesmere Island (Grise Fiord). This infrastructure is composed mainly of floating docks used by local fishermen and hunters and, to some extent, tourism operators. The socio-economic implications of port infrastructure are discussed in Chapters 8 and 9. Because the nearshore bathymetry of many communities is shallow, dock-face depths are generally about 6 m or less, thus limiting the size and draft of vessels that can berth. Three communities (Cape Dorset, Iqaluit, and Pangnirtung) have public quays, which are bigger than floating jetties and can accommodate larger vessels, cruise ships, and resupply sealifts. Nunavut has only one deep-water port, which is located in Nanisivik (Figure 2.8), with a 12 m depth of face. This infrastructure was built as a mining operation facility and is linked by road to the community of Arctic Bay, but its commercial value is limited by its distance from resources and markets, as well as its recent designation as a naval facility.

Ports and harbors on the Nunavut side of the BBDS region are generally open between July and October. The longest operating period (July through November) occurs in Kimmirut (South Baffin Island), and the shortest operating period (mid-August through mid-September) occurs in Arctic Bay, Pond Inlet, and Resolute Bay. Some Nunavut communities have no access to docking facilities for loading and unloading operations, and boats are therefore landed directly on shore for operations. Some of the marine infrastructure in Nunavut communities includes breakwaters and docking facilities equipped with cranes. The wide variability in tidal range and potential fetch for wave generation across the region is an important factor that affects port facilities and operations. Some communities have minimal tides and limited fetch, while others have large tidal ranges (12.3 m at Iqaluit, for instance) and others are highly exposed (e.g., Qikiqtarjuaq).

Future development projects planned for the Nunavut side include additional breakwater construction and the improvement of existing breakwaters (e.g., Arctic Bay, Grise Fiord). Construction and upgrades of small craft harbors, commercial fishing facilities, and dock maintenance are also needed or planned in Resolute Bay, Pond Inlet, Pangnirtung, Clyde River, Qikiqtarjuaq, and Grise Fiord (Government of Nunavut, 2010). In Iqaluit, there is a long-delayed project to build a deep-water port to provide mooring facilities and improve the small-craft harbor (see Chapter 2). Iqaluit has the largest volume of freight in the territory. At one time (1980s), flat-bottom ships were in use and would be anchored to rest on the bare tidal flats at low tide for unloading. More recently, with an increase in the volume of freight, ships anchor in the approaches and barges then bring the supplies in to the flats, where they can be unloaded at mid to low tide. There are two breakwaters, and the one in town has a wharf at which vessels as large as the Government of Nunavut research vessel *Nuliajuk* (19.4 m length, 6.4 m beam, 3.5 m draft) can berth for an extremely short time window at high tide. This wharf is of no practical value for sealift operations. Mining development projects could also affect future marine infrastructure developments, but impacts at local and regional scales remain uncertain because such facilities are typically built far from communities (Chapter 7).

West Greenland has an extensive network of ports capable of servicing ocean-going vessels (see Table 10.3). Most towns have a low tide draft of 7 m at the main cargo quay, and many have separate quays for the cargo and fishing industries, as well as jetties for local smaller fishing vessels and leisure vessels. The towns of Qeqertarsuaq and Kangaatsiaq have only small quays or jetties with berthing space for smaller coastal passenger ships and resupply ships. Qaanaaq has no port or harbor facilities. Resupply ships anchor up and ferry supplies ashore on barges; local boats are drawn onto the beach for storage.

Table 10.3 Port dimensions in the towns of West Greenland (data from Transportkommisionen, 2011).

Town	Quay draft (m)	Maximum ship length at quay (m)	Ship size (TEU)[1]	Port capacity (TEU)[1]
Upernavik *	7	113	550	300
Uummannaq	3.5	80	100	60
Ilulissat *	7	113	550	300
Qasigiannguit *	7	150	750	290
Aasiaat **	7	150	750	1,500
Sisimiut[3], **	7	150	750	500
Maniitsoq *	7	113	550	350
Nuuk[2], **	10	175	1500	1,800
Paamiut *	7	113	550	150
Narsaq *	7	150	750	200
Qaqortoq *	7	113	550	450
Nanortalik **	7	113	550	50

* Port with dimensions suitable for deep-water service
** Deep-water port that is presently used for transatlantic cargo transport
[1] TEU: Twenty-foot equivalent unit
[2] After completion, the new port of Nuuk will have a quay draft of 13 m and a quay length of 310 m (Sikuki, 2016)
[3] Numbers are for the publicly owned quay; the new municipal quay has a draft of 10 m (Hansen, 2016)

The impact of limited berthing capabilities on the communities is mainly economic. Resupply operations are time-consuming and vulnerable to unfavorable weather conditions and are therefore costly. Furthermore, accessibility of the communities is reduced for both inhabitants and tourists. These effects may result in lower subsistence potential, thus affecting the long-term sustainability of a community.

The port of Sisimiut is the northernmost ice-free port in Greenland. This port and all ports to its south are operational year-round – with the exception of the southernmost ports (Nanortalik, Qaqortoq, and Narsaq), which are occasionally blocked during the spring and summer months due to "storisen" (polar sea ice transported southward along the east coast of Greenland and then around Cape Farewell). The ports north of Sisimiut are operational for only a portion of the year, with the period of operation depending on latitude and local ice conditions.

The port of Nuuk is presently (2014–2016) undergoing extensive expansion, with the construction of a new industrial port for freight handling. The new port will have a draft of 13 m and a quay length of 310 m (Sikuki, 2016), allowing larger container vessels and cruise ships to berth. Furthermore, the port will have new aprons with a total area of 40,000 m^2 (Riger-Kusk, 2013). After the expansion is complete, most international freight to and from Denmark and Iceland (see Chapter 9 on shipping) will be offloaded at the port of Nuuk, then transferred to regional freight ships for distribution among the towns and other communities.

Similarly, the port of Sisimiut was expanded in 2013 with a new quay and apron facilities specifically targeted to larger cruise ships and trawlers. This expansion resulted in a more than 60% increase of cruise ship calls from 2012 to 2015 and about a 40% increase in foreign trawler calls from 2012 to 2014 (Løgstrup, 2015). This increase in activity indicates that the availability and quality of port infrastructure may indeed be a limiting factor for both tourism (Chapter 8) and the fishing industry (Subchapters 3.3 and 6.4) and may also affect resource exploration and extraction projects (Chapters 7 and 9).

Port constructions in West Greenland developed organically over the past century with little central planning, and many ports are now outdated or deteriorating and do not fulfill present-day usage requirements. The Greenland government has therefore formulated an extensive strategy that details priorities for the construction of new facilities and the maintenance or abandonment of older port and harbor constructions in every community in Greenland (Departementet for Bolig, Byggeri og Infrastruktur, 2015). These priorities focus on reducing maintenance costs by decommissioning certain older harbor constructions no longer aligned with community requirements, while expanding other port and harbor constructions to accommodate changes in the fishing industry, increases in tourism, and possible future needs of the resource extractive industry (see Chapters 7, 8, and 9).

The incorporation of current knowledge about sea level change and its likely future evolution should be a major concern in the implementation of the Greenland strategy and in the design or renovation of new or existing port and harbor constructions in the BBDS region in general. Although the future mean global sea level is expected to rise due to the melting of polar ice sheets and local glaciers and the thermal expansion of warming seawater, relative (locally observed) sea level in the BBDS region is expected to fall (see Section 3.1.6). Isostatic adjustments in combination with short-term elastic responses result in significant bedrock displacement, with rates of upward motion as large as approximately 19 mm per year measured

Figure 10.23 Top: Pangnirtung, a community on Baffin Island, located in the continuous permafrost zone (photo by A.-S. Carbonneau). Lower: Sisimiut, second largest town in West Greenland, located in the discontinuous permafrost zone (photo by T. Ingeman-Nielsen).

in West Greenland close to the ice margin (Bevis et al., 2012). Additionally, the projected reduction of ice mass due to the melting of the Greenland Ice Sheet and of local glaciers results in changes to the gravitational field (self-gravitation effects), which redistributes water in the oceans and lends a negative (downward) contribution to the change in relative sea level in the BBDS region. On the Nunavut side of the region, the combination of isostatic and elastic responses and self-gravitation effects is expected to result in relative sea level changes in the range of −1 to −84 cm by 2100 (projected median values of relative sea level change for RCP 8.5 at 2100 relative to 1986–2005) (see Figure 3.23). Although current models are less accurate for sites on the Greenland coast, sea-level projections for western Greenland are also strongly negative (see Section 3.1.6).

As discussed in Section 3.1.6, projections of change in relative sea level vary significantly with the choice of emissions scenarios (i.e., representative concentration pathways) and among different models. Confidence intervals, which provide an indication of the possible range of future relative sea levels, include the possibility of future relative sea level rise in the BBDS region.

The impact of a change in relative sea level may differ significantly from one community to another and for different port and harbor constructions. A future fall in sea level may be of critical importance – for example, when designing port facilities in areas where conditions make it infeasible to deepen the quay draft after construction. At other locations, hazards may relate mainly to a rise in relative sea level (Hatcher and Forbes, 2015).

As a result, future port and harbor constructions should be designed based on a thorough case-by-case analysis, considering risks relating to the full range of available projections for future relative sea levels (see Section 3.1.6). Considering the fact that Greenland's ports are typically designed with reference to a rising sea level, it is very important to stress that projections favor a significant fall in relative sea level in parts of the BBDS region.

10.6 Expanding municipal service infrastructure and housing onto sensitive permafrost

The different geological settings in Nunavut and West Greenland directly affect the current infrastructure of communities in the BBDS region. The Quaternary history of the Nunavut side has generated a landscape where surficial sediments are abundant and diverse in origin (glaciations and interglacials). In West Greenland, the landscape is dominated by undulating bedrock topography with smaller sedimentary infill basins (see Section 10.3.3). The difference in the surficial geology, as well as the generally colder climate on the Nunavut side, has also affected the distribution and types of ground ice in the two parts of the region, with massive ground ice (e.g., ice-wedge networks) being more abundant in Nunavut. Because fine-grained marine deposits may be found throughout the BBDS region, issues relating to segregational ice are common to the entire region.

In Nunavut, most of the communities are established at low altitude in fjords, sheltered from winds, on thick sedimentary terraces, where bedrock outcrops are not always present in the built-up areas (Figure 10.23, top photo). In West Greenland, towns and settlements are often located in coastal locations dictated by the occurrence of natural harbors that allow for sheltered anchoring. Town areas are typically dominated by bedrock outcrops separated by smaller sedimentary infill basins (Figure 10.23, lower photo). Moreover, because infrastructure problems related to thaw-sensitive permafrost were encountered even in the early stages of modern Greenland's community development (see Section 10.6.2), sedimentary areas have been largely avoided by the builders of West Greenland's residential infrastructure.

On the Nunavut side of the BBDS region, permafrost has long been considered stable ground, and for practical and economic reasons, most of the residential and transportation infrastructure in the communities was therefore established on sedimentary deposits – sometimes even on very ice-rich permafrost due to the lack of permafrost knowledge at the time. In fact, bedrock outcrops were often avoided due to limited construction means (or limited funds) and also because they were often at higher altitudes and the locations were considered too windy. Consequently, problems of thaw settlement are currently observed in most of the BBDS communities on the Nunavut side – even threatening the integrity of major infrastructure, such as the Iqaluit airport. Many communities need to expand their residential sectors, but suitable terrain for construction is limited and engineering solutions are increasingly in demand in order to build on thaw-sensitive permafrost.

Regarding residential infrastructure, these differences in geographical setting and related historical urban development have resulted in different priority issues for communities in Nunavut and Greenland. In Nunavut, much attention is focused on permafrost and ground ice conditions, with implications for risk assessments in municipal planning. In Greenland, on the other hand, priority issues seem to be construction quality, indoor climate, and energy consumption. This difference will be reflected in the following treatment of municipal and housing infrastructure.

Regarding linear infrastructure (e.g., roads, pipelines, sewers), the priority issues are similar in permafrost areas throughout the region. The southern area of West Greenland, though, experiences only seasonal freezing and its challenges relate mainly to freeze-up damage rather than permafrost degradation.

10.6.1 Pangnirtung: A case study of a Qikiqtaaluk Region community

Pangnirtung is a representative example of a Baffin Island community that is experiencing rapid population growth and now needs to expand its residential and municipal infrastructure into difficult geomorphological settings and onto thaw-sensitive and unstable permafrost. Major buildings already show severe structural problems associated with thaw settlement (Figure 10.24). In fact, the community is established in a confined area, which is bounded by steep rocky slopes and Pangnirtung

Figure 10.24 Municipal garage showing visible deformation (central depression) due to permafrost thaw settlement, Pangnirtung, Nunavut. Drillings next to this building revealed a very ice-rich surficial deposit (photo by E. L'Hérault).

Fjord (Figure 10.23, top photo; Figure 10.25). In addition, part of the community is built on the alluvial fan of the Duval River, which divides the village into two sectors connected by two bridges (Carbonneau et al., 2012; Carbonneau, 2014). River runoff constitutes a major natural hazard at the site. Indeed, an extreme and sudden flood occurred in June 2008, causing a major episode of thermal and mechanical permafrost degradation of the riverbank (see also Chapter 2). During this high-intensity event, which lasted only a few hours, the riverbed and the underlying permafrost were vertically incised by about 10 m, while the combined action of thermal and mechanical erosion caused 80 m of lateral erosion of the riverbank. This extreme event ultimately destabilized both bridge foundations, cutting off the community from many essential services (e.g., drinking water supply and sewage services) for several days (Figure 10.26). The costs associated with the state of emergency that was declared following this natural catastrophe were assessed to be as high as CAD 8 million. The event raised safety questions regarding community inhabitants and also the sustainability of municipal and residential infrastructure built on the Duval alluvial fan.

Following this catastrophic event, a study of permafrost conditions was undertaken by the Geological Survey of Canada and Université Laval's Centre for Northern Studies, under the Nunavut Landscape Hazard Mapping Initiative launched by the Canada-Nunavut Geoscience Office. Prior to the 2008 extreme event, the land sector near the Duval River was being considered for development and expansion. A recent risk assessment demonstrated that the landscape hazard issue on the alluvial fan is associated with extreme discharge events and that, consequently, the downcutting and related bed and bank erosion is a process that evolves sporadically by catastrophic events. Under the current and expected context of a changing climate and with only short-term and scarce climate-monitoring data, it is difficult to assess what would be the frequency of such extreme events in the future. However, the risk of occurrence is likely rising as climate change is expected to generate greater variability in snow precipitation, faster spring melts, and more abundant rain (see Subchapter 3.1). Therefore, construction in this area was designated as high risk and the Duval alluvial fan was deemed not suitable for community expansion.

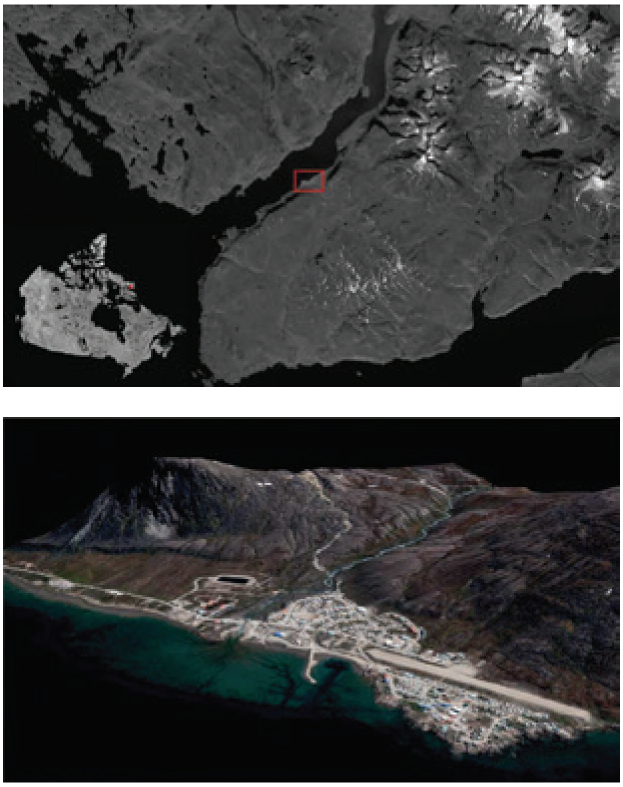


Figure 10.25 Community of Pangnirtung, established on a slightly inclined sedimentary terrace of Pangnirtung Fjord (from Carbonneau, 2014). The red rectangle on the top photo indicates the community location. Original base images are from Landsat 7 (top), all rights reserved, and Worldview-2 (lower), all rights reserved.

Figure 10.26 Extreme peak discharge of the Duval River in June 2008 resulted in downcutting of the riverbed, generating thermo-erosion and causing terrain collapse and the destruction of the Pangnirtung bridges (from Gosselin, 2013, and Carbonneau, 2014).

The urban development of Pangnirtung is concentrated mainly in the sector west of the Duval River, where there is not much additional space for expansion. Another area previously designated for the development of new residential infrastructure is located east of the Duval River, in a sector particularly affected by surface processes associated with ice-rich permafrost. Drillings and surface soil pits have revealed the presence of abundant ground ice in the upper meters of the permafrost, which makes the ground vulnerable to permafrost surface disturbances and slope processes such as active-layer slides. Consequently, the urban management and expansion plans require very precise and reliable knowledge of permafrost conditions, supported by high-resolution maps of surficial deposits along with characterizations of stratigraphy, ground thermal regime, and ice content. This information is crucial to better orient the selection of construction techniques, engineering designs, and solutions for specific sectors that are (or will be) considered for expansion. These adaptation/engineering options and recommended actions can be provided to the community and other stakeholders as maps of surficial deposits and explanations of the main terrain constraints for construction (e.g., Table 10.4). In some cases, permafrost conditions may require specific construction techniques and costly and advanced engineering designs. Such solutions, however, are typically well known and documented, once the site conditions are established.

Table 10.4 Synthesis of recommended engineering options or actions for construction according to permafrost condition (i.e., types of ground ice and soil) in Pangnirtung, Nunavut (Carbonneau et al., 2012).

Soil type	Active-layer depth (m)	Ice type	Characteristics and recommendations
Sand varying in thickness from 0.8 to 1.3 m, underlain by silt	0.8–1.8	Horizontal ice lenses, up to 80% of the total volume in the silt layer	• Avoid affecting the thermal regime of the permafrost • Drive piles into the underlying bedrock • Design surface drainage and culverts to avoid permafrost erosion
Sand, silt, and boulders	2.6	Pore ice practically all contained in the voids between sand grains and between stones	• No thaw-sensitive permafrost
Sand, silt, and boulders	No data	Pore ice	• Bank erosion likely to increase with climate warming; the risk of fast spring melts and rains is also expected to increase • This area is suitable for uses other than housing
Colluvium up to 4 m deep, with an underlying a till of silt, sand and boulders	1.3	Ice lenses in the colluvium, up to 80% of the total volume of the soil; pore ice in the till	• Avoid any heat transfer to the ground from the buildings • Shape side slopes of pads and road embankments to slope only gently (not steeply) • Avoid or minimize drainage concentration as much as possible
Stony material (till) belonging to moraine ridges	No data	No data	• Poor surface and active-layer drainage • Thawing in summer creates saturated conditions • This sector has no buildings and is not likely to be developed
Stony material (till) with a fine matrix	No data	No data	• Steep topography makes access difficult; any cuts will be unstable and will require a large amount of stabilization work • Controlling overland flow and erosion will be very costly

10.6.2 Expansion and infrastructure upgrade on permafrost in Greenland

Following the end of Danish colonial rule and the inclusion of Greenland as an equal part of the Danish Kingdom by constitutional amendment in 1953, a major town expansion and infrastructure upgrade was initiated. The Greenland Technical Organization (GTO, established in 1950) was in charge of the development, construction, and operation of all technical infrastructure and services. Several unfortunate experiences with early foundations on permafrost in Sisimiut (in the zone of discontinuous permafrost) resulted in severe damages to buildings. An example is the first major modern grocery store. Completed in 1953, the building had to be thoroughly renovated just five years later due to severe settlement (GTO, 1958). Following further renovation in 1962, the building was eventually decommissioned, and in 1969, it was torn down (GTO, 1969). As a result of this experience, GTO initiated an intensive site investigation practice and began siting buildings primarily in places where footings could be emplaced directly on bedrock. Where this practice was not possible or feasible (e.g., larger buildings), the buildings were supported by point-bearing piles anchored in bedrock. Actual permafrost foundations were not in common use.

Significant exceptions to this practice were constructions in Kangerlussuaq and Thule, where the geological setting around the airports typically did not allow for bedrock foundations (see Section 10.5.1 case studies). The U.S. military brought North American foundation practices and typically established gravel pad foundations, often with passive air-circulation cooling systems or with buildings elevated on shallow wooden piles (Department of the Army and the Air Force, 1983). In the Greenland/Danish civil part of Kangerlussuaq, buildings and terminals were typically constructed on piles extending into the permafrost.

After the establishment of Greenland Home Rule in 1979, the responsibilities of the GTO were gradually shifted from Denmark to authorities in Greenland, and public service companies were established to handle services and infrastructure. Responsibility for surveying and site investigations passed to Asiaq, Greenland Survey (a company owned by the Greenland government) (Steenfos and Taagholt, 2010). However, the equipment used for geotechnical site investigations (e.g., geotechnical drill rigs) was not transferred. The loss of technical ability in Greenland to conduct geotechnical site investigations has over time resulted in a general loss of expertise and knowledge regarding permafrost. Presently only one geotechnical drill rig capable of drilling and coring permafrost sediments is available in Greenland, at the Greenland School of Minerals & Petroleum in Sisimiut. This rig is, however, mainly reserved for educational purposes, and the lack of local personnel trained in permafrost sampling and classification further limits its use and usefulness. For the occasional use of the rig, drilling personnel are typically brought in from Denmark, but with few exceptions they too lack training in permafrost classification.

For proper site investigations, drill rigs must therefore be brought in from outside of Greenland, typically from Denmark. Long transport times by ship, short ice-free seasons, and the timetables for coastal ship transportation confine the reservation window to only a few shipping opportunities per year. These constraints also result in the risk of rigs being stranded in Greenland over the winter period (i.e., until the first ship of the next spring or summer). With a lack of available helicopters for slinging heavy equipment (and the cost of such operations), these issues result in heavy tie-up of capital and high risk on expenses. Proper site investigations are therefore typically undertaken only for major construction projects.

Hence, a continuation of the practice of building mostly with foundations on bedrock has prevailed, resulting in spread-out towns with large open areas that have often been used for sled-dog pens. Today, many towns are facing expansion problems due to their terrain and coastal location, as well as restrictions on building in water protection zones. Town planners are looking to densify the urban areas, dogs are being moved outside of town, and permafrost-affected sedimentary basins are increasingly in play as construction sites.

In most cases, the chosen option is to excavate to bedrock – even if the bedrock is 15–20 m below the ground surface in permafrost sediments – and then anchor in situ cast piles in the bedrock and backfill the sedimentary material (see Figure 10.27). If site investigations and drilling are performed, available drill rigs designed for rock drilling (as opposed to geotechnical rigs capable of drilling, in situ testing, and sampling sedimentary deposits) are typically used; as a result, proper identification of the bedrock is very difficult at best, especially since the operators often lack permafrost-related training. The only location where pile foundations in permafrost are still established is in Kangerlussuaq, where a local entrepreneur has acquired large-diameter augers for drilling permafrost and installing precast piles (Mortensen, 2015).

In smaller communities (e.g., Qaanaaq), where building on permafrost may be necessary, smaller buildings are being constructed according to early GTO instructions (Rosendahl, 1954; GTO, 1957), with foundations of wooden piles resting on cross members and buried in a gravel pad that serves to anchor the foundation and protect the permafrost below. Within the last decade, developers in Qaanaaq (typically the public housing company, INI) have reduced the foundation depth to 120 cm from the traditional 160–180 cm (Rosendahl, 1954; Sermitsiaq, 2009; Hendriksen and Hoffmann, 2014), and this could be a contributing factor to the severe thaw settlement damage observed on many new houses (Hendriksen and Hoffmann, 2014). However, older housing constructions with deeper foundations are also developing thaw settlement damages (Hendriksen and Hoffmann, 2014). The general practice of mounting skirts (wooden boards that cover the foundation of a house elevated on piles) in order to provide additional storage space and reduce the cooling of the floors by limiting air circulation often results in increased permafrost thaw and additional settlement problems.

Figure 10.27 Excavation and in situ casting of piles for the new district court house in Ilulissat, August 2015. The photo illustrates the current practice of excavating to bedrock for in situ casting of piles anchored in the bedrock, followed by backfilling (photo by Thomas Ingeman-Nielsen).

10.7 Framework scenarios and their implications for infrastructure in the BBDS region

All infrastructure has a limited service life span, which is determined by multiple factors – e.g., the construction design (architecture and engineering) and implemented technologies, the type and quality of materials used, the maintenance program, and the ground engineering properties, as well as environmental and climatic conditions and extreme event occurrences (Hendriks and Janssen, 2004; Yang et al., 2005). In large towns, economic development, urban growth, and land use changes are other important factors that often lead to the demolition of buildings before the end of their service life span (Liu et al., 2014). In the Arctic, the service life span of a building is often shorter than the designed life span. For instance, in isolated Nunavut communities, access to good-quality materials is often limited due to their high cost and limited availability; thus, lower-quality materials inappropriate to harsh Arctic environments are often used, especially for housing construction. In West Greenland, due to the well-functioning port and resupply infrastructure, the quality of building materials is typically not a problem – there, the challenges relate mainly to logistical planning.

This construction reality – combined with designs poorly adapted to local climatic conditions, unstable ground due to permafrost warming, and bad (or limited) maintenance practices – results in lower-quality buildings with a shorter service life span than expected. The short effective service lifetime and rapid degradation of residential infrastructure is partly responsible for the current housing crisis (see Subchapters 4.5, 10.2, and 10.6). Shorter service life spans are observed for municipal and transportation infrastructure as well (mainly airports and roads), resulting in increased maintenance costs and possible impacts on safety. The current infrastructure situation in the BBDS region calls for urgent adaptation actions to help communities cope with the ongoing problems. At the same time, regional and national governments are facing the challenge of formulating adaptation strategies for better and sustainable Arctic infrastructure in support of well-being and socio-economic development under rapidly changing climatic and environmental conditions.

The framework scenarios presented in Subchapter 3.4 were constructed to help investigate the impacts of possible future development trends relating to resource extraction and climatic changes. It is expected that each of these scenarios will, to varying extents, increase the general need for more and better-adapted infrastructure design.

The climate scenarios project a continuation of the ongoing warming trend, which is mainly reflected in future warmer annual mean temperatures, with warmer summers and especially winters, as well as longer thawing seasons. These general climate parameters all play a central role in the permafrost thermal equilibrium.

Independent of the projected range of changes considered, it is expected that ground settlement will increase due to the progressive thaw of surficial ice-rich permafrost. This settlement will result in severe and frequent infrastructure structural failures.

Both the moderate and dramatic climate change scenarios (Figure 3.26) are expected to generate more climate variability and more extreme events (e.g., sudden floods or heat waves) but with different ranges of likelihood and frequencies of occurrence. These changes have direct implications for road embankment design, as well as engineering solutions to decrease thermal erosion impacts (e.g., larger and more frequent culverts).

The main implication of climate change for infrastructure in general will likely be to increase the already established need for better adaptation and engineering solutions to reduce infrastructure vulnerabilities to thawing permafrost and extreme events. The design choices of a given adaptation option, or the choice of the type of adaptation option itself, will depend on the particular scenario considered by policy- and decision-makers and should be based on risk and cost-benefit analyses.

The other main driver of change considered in the BBDS framework scenarios is the development of the extractive resource industry (Figure 3.26). This industry interacts with multiple socio-economic drivers and multiple components of social and environmental systems, which can in turn have multiple implications for BBDS infrastructure (see Subchapters 3.3 and 7.2). The need for new infrastructure is here considered as a principal impact of these interlocked driving forces and system components. However, under a modest resource development scenario, the need for infrastructure is expected to be driven mainly by the already existing need for improved residential infrastructure (in terms of both quantity and quality). Under an intense extractive industry scenario, it is expected that pressure on the residential infrastructure sector will be even greater, driven by the accelerated population growth that would be stimulated by new employment opportunities in the region. The amount of new residential infrastructure needed in communities under such a scenario will greatly depend on employment policies imposed on the industry (which will affect the level of fly-in/fly-out personnel), as well as the capacity of the region to educate and provide highly qualified personnel (with appropriate skills) to fill new general and specialized positions (also discussed in Subchapter 3.3 and Chapters 5 and 7).

It is reasonable to expect that an intensification of resource extraction activities would also generate an increase in the demand for all other types of infrastructure in the BBDS region – e.g., drinking water supply, solid waste and wastewater management facilities, power generation facilities, and other derived infrastructure.

In addition to new industrial infrastructure and related operational facilities (e.g., airstrips, power supply, residential and other service infrastructure), onshore industry developments also mean increased access to remote areas, which implies building new roads or railways to transport the ore to the coast, as well as new deep-water ports to ship the ore or product to processing facilities and to market. In fact, transportation infrastructure is such a central component in developing the industry that it may very well be a significant limiting factor. With the high cost of constructing safe, reliable, and sustainable transportation infrastructure in Arctic regions, resource development projects in these regions are especially sensitive to the global economy and fluctuations in ore price and demand. A lesson learned in recent years from the Mary River mining project (discussed in Chapter 7 and Section 10.5.2) is that the availability of appropriate infrastructure may be an important factor for the feasibility of a given expansion or a new industry project.

Table 10.5 Infrastructure implications of the two driving factors that define the BBDS framework scenarios: climate change and development of extractive industries. (For more information about the scenarios, see Subchapter 3.4.)

Driving factor: Climate change
• Affects the choice of foundation practices, but solutions are already known
• Affects the choice of design and construction practices for buildings (e.g., snow and wind loads, moisture retention)
• Affects the speed of permafrost degradation
• Affects changes in sea ice conditions – may be positive (e.g., less sea ice impact on port constructions) or negative (e.g., increased wave activity)
• Scales the expected relative sea level rise or fall; research is needed to improve projections
Driving factor: Development of extractive industries
• Affects mainly the quantity, size, and accessibility of needed transportation infrastructure
• Does not particularly influence construction practices
• Scales workforce needs and accentuates existing housing issues and shortages
• Available infrastructure and its quality may be a limiting factor in the development of the non-living resources sector due to the cost of establishment

It is expected that resource industry facilities will in most cases develop at isolated locations away from existing communities (with the exception of port and harbor facilities for offshore activities). Consequently, we foresee very little direct benefit to society of the infrastructure constructed for such projects. The main impact would be on the construction sector, which – with the present need for housing, renovation, and planned transport infrastructure expansion – is already stretched thin, with inadequate capacity to meet even existing demands. (See Section 7.1.3 for a discussion of derived impacts.)

However, a scenario of extractive industry development near a BBDS community, including the construction of a new deep-water port or major upgrades to existing port facilities within a community, would generate much greater direct impacts and challenges at a local scale with respect to residential, service, and transportation infrastructure needs. A high-impact scenario would also necessitate an influx of qualified workers at a scale unprecedented in the Arctic. An example of such a project is the rare earth elements mine planned by Australian-owned Greenland Minerals and Energy Ltd. for Kuannersuit/Kvanefjeld in South Greenland (see also Section 7.1.1). This mine, which will be located less than 10 km from the town of Narsaq (1,492 inhabitants, according to Statistics Greenland, 2016), includes plans for the construction of a deep-water port (face depth more than 13 m) near the town. There are also plans for the construction of a hydropower plant, roads, and residential infrastructure (Greenland Minerals and Energy Ltd., 2015). An estimated workforce of 1,000 will be needed during the construction phase, and 735 workers will be needed during the exploitation phase (Mair, 2014).

In summary, most conceivable infrastructure-related problems are already observed to some extent in the BBDS region under present conditions. Therefore, the two axes of the defined framework scenarios (Figure 3.26) mainly scale the impact of well-known issues (Table 10.5). The climate axis mostly scales the extent and severity of current problems, be they settlement and failures due to permafrost degradation or problems with snow and wind loads, moisture trapping, or deterioration of construction materials. The resource development axis mainly scales the need for transportation infrastructure, but housing and other municipal infrastructure requirements are also affected due to impacts on local communities and the need for employees and highly qualified personnel.

Neither factor significantly changes the already established need for better regulation, education, knowledge transfer, and research and development projects relating to construction practices and risk evaluation. Both factors may, however, affect the prioritization of the different issues. Proper engineering solutions are already available for most infrastructure-related problems; research should therefore focus on improving the understanding of relevant processes in order to improve existing solutions and invent new solutions that are more cost effective. Nevertheless, there is still a need to test and compare existing engineering solutions under a wide range of natural conditions.

10.8 Adaptation tools and options

10.8.1 Municipal and residential infrastructure

Several engineering textbooks and abundant other literature (e.g., scientific papers, proceedings, and technical reports) are available to provide construction companies, regional managers, stakeholders, and decision- and policy-makers with not only baseline knowledge and advanced scientific background but also a multitude of adaptation options in terms of engineering solutions to address infrastructure issues in cold regions (see, e.g., Johnston, 1981; Andersland and Ladanyi, 2004; Stephani et al., 2014).

Recent applied research projects conducted in close collaboration with communities and regional authorities in several Arctic communities have revealed that – because of the spatial variability and complex nature of permafrost conditions – an integrated, multi-technique approach is needed for formulating and ultimately proposing an appropriate and flexible set of adaptation options and thus to inform the local decision-making process (Allard and Lemay, 2012). A permafrost-related site investigation and risk assessment methodology of this sort typically consists of four distinct phases.

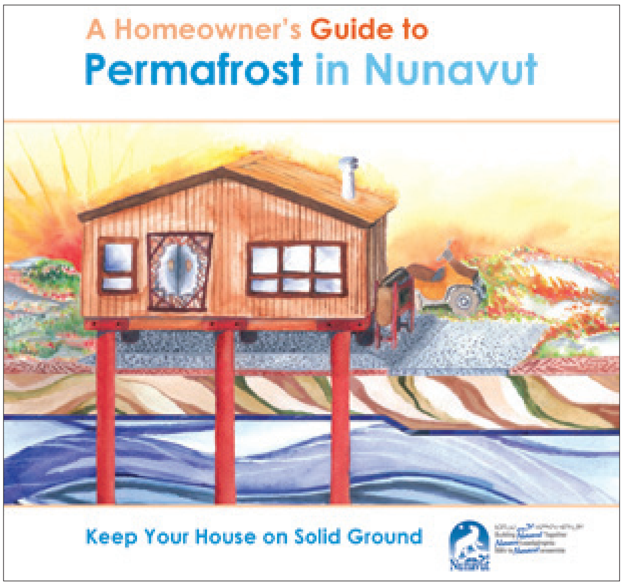
The first step consists of a desk study, with analysis of aerial photographs and satellite imagery to identify the landforms and surface geomorphological features that serve as indicators of permafrost, ground ice content, and general soil properties. Any information available from existing maps and previous site investigations should also be collected and summarized; in some cases, new topographic maps should be created.

The second step typically consists of geophysical surveys conducted at strategic locations determined according to the preliminary mapping produced during the desk study. Due to the contrasting physical properties of ice and water, methods such as electrical resistivity tomography, ground-penetrating radar, and seismic surveys are capable of delineating frozen ground and areas of high ground-ice content (Jorgensen and Andreasen, 2007; Fortier et al., 2008), as well as providing information about site stratigraphy. Such methods therefore provide a good view of the three-dimensional structure of sedimentary basins and the distribution of permafrost and taliks (unfrozen areas surrounded by permafrost) but may be inconclusive with respect to sediment types and properties.

In the third step, geotechnical drilling is performed at select locations based on the desk study and on preliminary interpretation of the geophysical data. The drilled locations should be representative of all sedimentary deposits in the area, and any uncertainties in the geophysical interpretation should be targeted by the design of the borehole survey. In order to obtain representative samples of all deposits, drilling should be performed with recovery of cores where the ground is frozen and with standard sampling where it is not. A visual classification of each deposit and the identification of ice and preserved features is often accompanied by measurements of water content and bulk and dry densities, which allow for estimation of the volumetric ice content. Other laboratory measurements – such as grain size analyses, porewater salinity measurements, and consistency limit determinations (i.e., plastic and liquid limits) – are also regularly performed. In recent years, the use of X-ray computed tomography (CT) scanning has been developed for the imaging of permafrost cores. Such nondestructive imaging techniques leave the core material available for advanced mechanical testing, while also providing very detailed information about ice content and structure in three dimensions (Calmels and Allard, 2004).

In practice, the application of geophysical techniques and geotechnical drilling is often an iterative process, with mutual indications of the need for additional geophysical measurements and boreholes in order to obtain a complete representation of the area. Furthermore, thermistor strings may be installed during drilling operations to monitor the ground thermal regime.

In the fourth step, a final interpretation of all available data is produced and the information is integrated into relevant themes within a geographic information system (GIS), which enables the production of permafrost risk assessment and construction potential maps. These maps are accompanied by detailed legends that list suitable foundation types and existing engineering solution guidelines for each mapped terrain category (e.g., Table 10.4; for a detailed example, see Allard and Lemay, 2012).



A Homeowner's Guide to
Permafrost in Nunavut

Keep Your House on Solid Ground

Figure 10.28 Cover page of the homeowner's guide to permafrost produced by the Government of Nunavut in collaboration with permafrost specialists (reproduced from Government of Nunavut, 2013, with permission; Government of Nunavut, Department of Environment, © Government of Nunavut).

Construction potential maps may be presented and discussed with communitiy members and other stakeholders, thus serving as very useful tools in support of decision-making and the formulation of adaptation strategies.

Adaptation actions to minimize negative impacts on the permafrost thermal regime are often recommended for any construction planned in areas with permafrost. Generally, less disturbance of the natural soil during the construction of new infrastructure results in smaller impacts on its stability. The timing (season) of site preparations is also crucial in minimizing impacts to the permafrost thermal equilibrium. In permafrost areas, it is highly recommended to excavate and install gravel pads in support of foundations during the autumn, in order to allow the disturbed soil and the gravel berm to freeze back during winter (Andersland and Ladanyi, 2004). For very thick embankments, it may be necessary to construct the embankment in multiple stages over several years in order to avoid trapping heat inside the embankment. Conversely, in areas with only seasonal freezing, it is important to complete all excavations and foundations and to re-establish the terrain surface before the onset of freezing in order to avoid frost heave effects.

Thermosyphons, conductive heat drains, and piles are examples of existing engineering solutions that are commonly proposed and used for permafrost foundations, to keep the ground frozen and prevent the thaw subsidence that leads to infrastructure failure (Haynes and Zarling, 1988).

Some problems may be associated with the use of southern construction concepts that are ill suited to permafrost environments – e.g., the use of skirts. In such situations, a simple action like removing the skirts will allow wind circulation below the building to remove excess heat. This practice reduces the thermal impact of the building and helps to prevent structural deformation and damage due to thaw settlement. Constructing new houses with more floor insulation would reduce the temptation to skirt the houses. A desire for additional storage room also motivates the use of skirts. Therefore, increasing the storage capacity of housing units (e.g., by adding a garage or a shed) would facilitate the removal of skirts.

Other options also exist to promote the knowledge of permafrost dynamics and the behaviors that help to prevent infrastructure issues related to permafrost degradation. Public consultations and presentations of research results in communities have proven to be a very efficient way to better inform people and discuss with them the different adaptation options that arise from permafrost surveys. This approach also allows communities to share their experiences and report issues that may not have been considered by the researchers. This exchange can help researchers to adjust their objectives and propose improved adaptation options that are more aligned with the day-to-day life of Arctic communities. Short seminars with infrastructure managers, describing recommended maintenance practices and how to better identify features associated with sensitive permafrost, are also much appreciated and highly valued in Arctic communities; these seminars help to increase awareness and understanding of the processes.

Furthermore, the publication of good-practice guides provides a permanent source of information that may reach a wider audience or act as local informative references after visiting experts leave the community. For instance, the Government of Nunavut has developed a guide (Figure 10.28) to help homeowners and decision-makers to better understand permafrost, climate change effects on permafrost, and how to make simple changes around homes to lessen permafrost thawing (e.g., removing skirts) (Government of Nunavut, 2013). Such initiatives can help prolong the service life span of community infrastructure.

10.8.2 Linear infrastructure

In the case of linear infrastructure (e.g., roads and airstrips that require large embankments), the cascade of thermal consequences associated with snow banks (discussed in Subchapter 10.4) may sometimes be reduced by simple actions such as better management of snow clearing and piling in winter. However, more costly adaptation options may sometimes be required to limit the impact of snow accumulations, such as the modification of embankment slopes according to prevailing winter winds (L'Hérault et al., 2012). The use of coarse embankments and berms that allow the convective flow-through of air is a good example of an engineering adaptation that has proven to be very efficient in countering the local thermal impact of snow accumulations (Allard and Lemay, 2012). However, such embankments should be elevated above the natural terrain to ensure the positive effects, and this elevation may be problematic in terms of town planning and aesthetic appeal.

The impact of flowing water and advective heat flow is not well documented, and an increasing number of research projects is now focused on changes in surface and subsurface permafrost

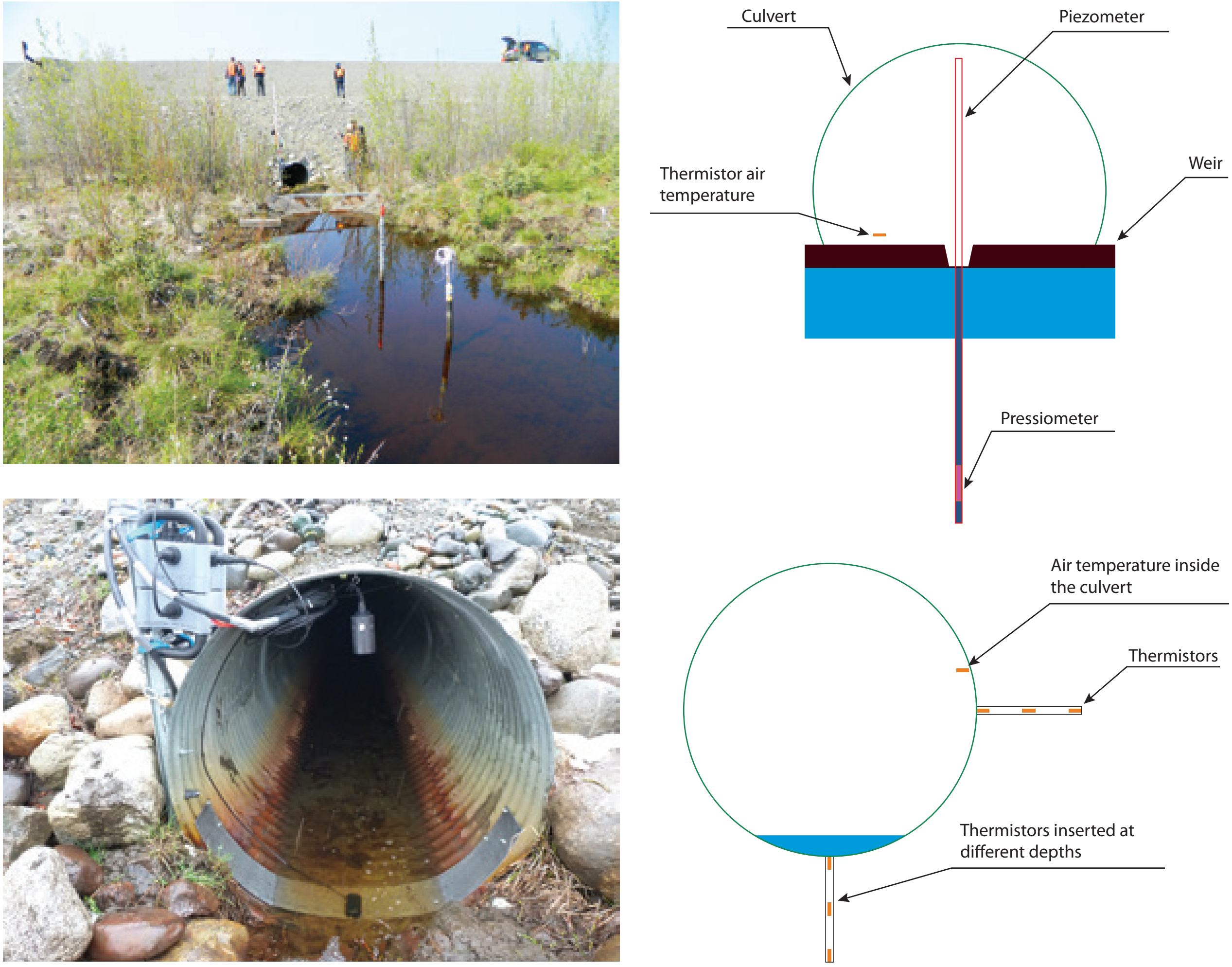


Figure 10.29 Instrumented culvert at the Beaver Creek experimental site, Alaska Highway, Yukon, Canada (sources: Périer et al., 2014, and Périer, 2015).

drainage (de Grandpré et al., 2012; Lamoureux et al., 2015). An experimental site on the Dempster Highway in Yukon (Canada) is a good example of the testing of different adaptive solutions (Figure 10.29). Insulated culverts, culverts of different sizes, and culverts distributed at different distance intervals are being tested for their impacts and abilities to prevent infrastructure damage related to snow drift accumulation, water ponding, and drainage.

10.8.3 Risk assessment for linear infrastructure

Risk analyses for linear infrastructure are more complex to produce than the community risk assessments and construction maps discussed above (Section 10.8.1). Risk analysis that identifies the possible hazards or failure modes associated with linear infrastructure can be used to design and allocate maintenance funding for the structure. In order to evaluate the risk associated with each hazard, one must first determine the probability of failure (P) and the consequence (C) due to failure and then multiply the values to determine the risk (R) (Baecher and Christian, 2003). These analyses can be conducted qualitatively (by evaluating P and C through predetermined rubrics with scalar values) or quantitatively (by individually calculating P and C). The quantitative calculation of P can be completed using reliability analysis methods or frequency analysis from past-occurrence data (USACE, 1999; Vick, 2002).

Comprehensive risk analysis methodologies, qualitative and quantitative, are available from Public Safety Canada (2011), the Public Infrastructure Engineering Vulnerability Committee (PIEVC) (Engineers Canada, 2011), U.S. Army Corps of Engineers (USACE, 1999), and Failure Mode and Effects Analysis (FMEA; discussed in Vick, 2002). However, most of these methods focus on a single location and do not easily take into account the length and varying site conditions that commonly occur along a stretch of linear infrastructure. For example, a PIEVC analysis pairs infrastructure elements (e.g., a bridge, culvert, or roadway section) with a climate factor (e.g., increased frequency of rainfall events), and risk is then assessed for this combination, leading to a large number of combinations to be considered (BGC Engineering Inc., 2011). One study's authors suggest adding site soil conditions as a third dimension to the analysis (Arenson, 2013). One approach to dealing with varying site conditions along a linear structure could be to first conduct risk analyses for individual segments with similar site conditions and then repeat the analysis for additional sections until the infrastructure is assessed in its entirety.

10.9 Knowledge gaps and needs

10.9.1 Production of scientific knowledge relevant to decision-making processes

Although an increasing amount of research and development is focusing on new engineering solutions to propose as adaptation options and actions, there is no warranty on how these newly developed adaptation techniques will perform over time. Adaptation measures are often associated with high costs, and decision-makers need robust information (arguments) and good risk assessments to support their decisions and secure major investments. Such robust knowledge requires more reliable permafrost projections at local and regional scales, and better projections will require more engineering monitoring surveys and in situ experimentation, as well as more spatially distributed and longer-term permafrost monitoring time series. The acquisition of permafrost data with better temporal and spatial resolution would ultimately yield better maps of expected future permafrost distribution and degradation issues (vulnerability/risk maps).

Another way to assist the decision-making process would be to encourage cost–benefit analyses based on risk analyses and high-resolution maps of permafrost conditions. This approach would help people to assess and compare the costs of implementing an adaptation option for a potential infrastructure threat versus continuing operations without adaptation. Such cost–benefit analyses would also help to identify the most effective and affordable adaptation options. Mechanisms or programs that encourage partnerships between scientists and the private sector would greatly facilitate the integration of new technologies, which are often very expensive and unaffordable for publicly funded scientific projects.

10.9.2 Policy and regulation

As highlighted in this chapter, several infrastructure issues related to permafrost thawing result from using designs that are poorly adapted to site-specific ground and environmental conditions in Arctic regions. The use of inappropriate designs clearly reveals limited knowledge at most coordination levels and among various actors involved in construction projects. This current situation results partly from the limited regulatory framework and appropriate governance structures available for construction in the BBDS region.

Greenland authorities have, over the past decades, actively developed a special Greenland building code. However, this code is not always properly adapted to the large variation in climatic conditions observed in the region. The code states, for example, that foundations should be constructed on a material with adequate bearing capacity or should in other ways be protected against damages occurring as a result of movements in the subsurface (Direktoratet for Boliger og Infrastruktur, 2006). The code specifically states that foundations should be protected against movements resulting from variations in ground temperature, but it does not mention permafrost issues specifically. The building code also refers to mandatory instructions about foundation design under Greenland conditions, but these instructions have not yet been published, although they have been anticipated since the time of Greenland's first building codes (Grønlands Hjemmestyre, 1982). Temporary instructions were published in 1983, but they state only that the Danish code of practice for foundation engineering should be followed to the extent possible and with the adaptations necessitated by conditions in Greenland (Grønlands Hjemmestyre, 1983). The Danish code covers only issues relating to winter frost and has since been withdrawn and superseded by Eurocode 7, which covers frost action and frost susceptibility but in the context of European winter frost only (Eurocode 7, 2007). The Greenland authorities are cooperating with the Danish Standards foundation on a National Annexe to Eurocode 7; however, the presently available draft does not mention permafrost (Departement for Boliger, Infrastruktur og Trafik, 2010). When asked about current practices and regulations for foundations on permafrost, most developers and entrepreneurs in Greenland indicate that they are not aware of any or they refer to the early publications (GTO, 1957, 1987).

The Greenland instructions for public development note that proper site investigations (e.g., including drilling to establish depth to bedrock and the presence or absence of permafrost) may often be appropriate and that the results should be incorporated into construction planning (Direktoratet for Boliger og Infrastruktur, 2005). Nevertheless, proper site investigations with geotechnical drilling, sampling, and/or testing are typically performed only for major development projects. Entrepreneurs and consulting engineers are not developing the requisite skills and technical ability (including the necessary investments in machinery) for these types of investigations because they experience no demand. On the other hand, the developers seem not to demand these solutions on the basis that skills and competences are not available, and thus the cost of the demand would be too high for the budget. This example illustrates the vicious circle that can potentially arise in the balancing of needs, capabilities, investments, critical mass, and operational costs.

As a result, ineffective and costly solutions are often applied, typically leading to increased maintenance and renovation costs at later stages. Because very few statistical data are available regarding the construction and maintenance costs of buildings and infrastructure adapted to permafrost areas, it is very difficult to evaluate the cost effectiveness of different options. This lack of information may also be a contributing factor to the lack of demand for specialized engineering solutions.

On the Nunavut side of the BBDS region, no proper construction codes adapted to permafrost zones are available. By default, most engineering and construction companies use the standard North American codes (CGS, 2006; NRCC, 2015), which are often ill suited to the Arctic climate and physical site properties (e.g., permafrost). However, several guides have been published (e.g., Epoo et al., 2005; Government of Nunavut, 2005; Government of the Northwest Territories, 2009; Government of Nunavut, 2013) or are now being developed. The primary objective of these guides is to provide technical reference handbooks that incorporate proven methods and materials to help produce the best quality in northern buildings and also to support improved building performance and the use of new technologies. These

Ambeon/Alamy Stock Photo

Nuuk apartment buildings, Greenland

guidelines are not intended to replace mandatory codes or regulations but rather to supplement the National Building Code of Canada in cases where conditions particular to isolated northern communities require an approach different from typical building practice. Recently, a few Canadian standards that specifically address infrastructure–permafrost issues have been developed through an impartial, responsive, and consensus-based approach (e.g., CANCSA-S500-14, CANCSA-S501-14, CSA S502, CSA S503, CANCSA-PLUS 4011-10). Currently, a geotechnical site investigation standard for building foundations in permafrost zones (CAN/BNQ 2501-500) is under preparation to ensure that geotechnical site investigations will provide sufficient and correct site information, taking into account the particularities of permafrost soils and the Arctic climate.

One particular effect of the lack of proper codes for foundation engineering is that it is difficult to establish responsibility among developers, consultants, and entrepreneurs on a project if a construction failure occurs.

10.9.3 Communication and outreach

Publications such as the Nunavut homeowner guides (e.g., Figure 10.28) show that regional governments already invest in promoting appropriate procedures for maintenance and construction practices. In Canada, a panel of experts has been recently formed to formulate construction and engineering standards for cold and Arctic regions. Arctic regions would greatly benefit from increased exchange with other regions – both nationally and internationally – that are facing similar issues at the regional and community governance levels. Greater efforts to motivate and support education and knowledge transfer (see Chapter 5) specifically targeted to the needs of municipal managers, engineers, entrepreneurs, and technical staff would help to ensure that knowledge is not lost to the rapid turnover of municipal employees and consulting engineers. Such efforts would also ensure the use of proper construction concepts for cold regions and would help to compensate for the lack of regulatory framework.

10.9.4 Housing and designs

The housing crisis in the BBDS region is generally acknowledged, but the driving factors and their interactions are poorly understood (e.g., the complex relations among these several factors: employment situation, migration, and the housing shortage; rapid deterioration of housing due to poor construction and the harsh climate; and designs that are poorly accommodated to the lifestyle and activities of the inhabitants). In addressing the current housing crisis, both public and private housing options seem to be problematic (see discussion in Section 10.2.1). As a result, cooperative housing is an economic model that is currently being implemented in Nunavut (and elsewhere in the Canadian Arctic) to facilitate access to affordable, high-quality dwellings. In the co-op model, individual residents do not own equity in their housing;

therefore, they return the unit to the co-op when they move out. Because the housing federation is a not-for-profit entity, residents pay a co-op membership fee that covers only the costs for repairs and maintenance. Thus, the co-op can offer much more affordable housing. In Nunavut, the cooperative housing model is implemented with partial governmental funding to allow for reduced monthly rents based on household income. Finally, the cooperative housing model gives greater governance control and security to co-op members because they have a vote in decisions regarding their housing – e.g., election of a board of directors and acceptance of budgets (Co-operative Housing Federation of Canada, 2016).

Although it is hard to tell how this model will perform over time, co-ops may represent a very interesting hybrid option (i.e., a cross between privately and publicly funded housing options) to address the housing issue in the BBDS region and to foster housing acquisition and (semi-)ownership through membership. Membership involvement is likely to improve maintenance practices and the management of repairs, to better orient housing needs with regard to the lifestyle and activities of tenants, and ultimately, to improve the quality and life span of housing units.

Improved methods to ensure a comfortable indoor climate, with suitable ventilation and humidity regulation, should be considered in the refurbishment process and for future expansions of housing infrastructure. Community consultations to define housing that is better adapted to the local culture and traditions, to changing and extended familial units, and to communal and daily practices would also help to better inform architectural housing concepts. Another relevant gap is a lack of knowledge about microclimates and the optimization of building shapes in relation to snow drift and runoff patterns in urban environments. Important engineering questions – such as how can housing be self-sufficient in terms of energy, waste, and water, and how can houses be designed to facilitate upgrades and repairs – remain unanswered. Finally, good statistical information on housing quality and refurbishment needs in the BBDS region is not available, thus making it difficult to secure funding to develop cost-effective refurbishment techniques for Arctic conditions. The development of such techniques would likely help to improve the BBDS housing situation.

10.10 Conclusions

In summary, this chapter documents the fact that severe infrastructure problems are already being observed under current conditions in the Baffin Bay/Davis Strait region. The nature of problems varies throughout the region according to geological setting and climatic conditions. Ice-rich sedimentary deposits (e.g., marine clays and other fine-grained materials), mostly abundant in the middle and northern parts of West Greenland and on the Nunavut side of the BBDS region, are very sensitive to thaw settlement and other permafrost degradation processes (e.g., active-layer failures and thermo-erosion) and are associated with many observed infrastructure issues. Permafrost-related infrastructure problems are widespread on the Nunavut side of the region, affecting both municipal/residential and transportation infrastructure. In West Greenland, such problems affect mainly transportation and other linear infrastructure because buildings are usually constructed on bedrock. One of the main driving factors causing permafrost–infrastructure problems is the impact of the infrastructure itself on permafrost thermal conditions. Inappropriate construction designs and practices often induce permafrost degradation. The ongoing and projected climate changes act as an amplifying factor that increases infrastructure vulnerability in the BBDS region.

On the Nunavut side of the BBDS region, most communities are already facing the double challenge of adapting their existing infrastructure to changing permafrost conditions while also planning for urban expansion with limited space suitable for construction. In the growing communities of West Greenland, municipalities are showing an increased interest in developing the sedimentary areas previously avoided due to challenging soil and permafrost conditions. The challenges involved in infrastructure management and expansion onto sensitive permafrost calls for better permafrost knowledge to inform appropriate design choices. Understanding the distributions and properties of surficial deposits, stratigraphy, topography, and ground ice is a crucial requirement in guiding the choice of construction techniques, engineering designs, and solutions.

The urgent need for housing is one of the factors currently driving the push for urban expansion in many BBDS communities. The housing situation is due mainly to demographic growth (on the Nunavut side) and migration (on the Greenland side) combined with the rapid deterioration of houses and dwellings caused by a lack of proper maintenance. Furthermore, designs that are specifically adapted to the changing Arctic climatic conditions are needed in order to improve indoor climate and related health issues.

A major issue affecting the current state and future development of infrastructure in the entire region is the limited regulatory framework and governance structures that are available specifically for construction in the BBDS region. The lack of some relevant technical skills within the regional workforce and the high turnover of qualified employees is a limiting factor for the development of the construction and infrastructure management sectors.

The result is a widespread use of construction designs and practices that are not well adapted to the Arctic climate and ground conditions. A proper regulatory framework would support the development of a sustainable infrastructure network, resilient to future changes.

Communication infrastructure has not been addressed in this chapter, which has focused on built infrastructure. However, development of the communications infrastructure remains a high-priority cross-cutting issue in the region. Such development is needed to improve connections among communities and with the rest of the world, for business and leisure, and also in support of safety and emergency preparedness systems.

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11. Adaptation and resilience

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11.1 Introduction

Over the last decade, adaptation has emerged as a focus of research, policy, and decision-making in the Baffin Bay/Davis Strait (BBDS) region. Arctic residents are also showing that they are not powerless victims of climate change, with their increasing interest in identifying, developing, and implementing adaptations that respond to both climate change and other stresses (Ford et al., 2014a, 2015b). The regional approach to adaptation shows a willingness for people to view change as an opportunity, as well as a threat. In Greenland, with its strong dependency on fisheries and even some farming, the expanding economic opportunities are increasingly appreciated (Nuttall, 2008), although politicians and civil servants also acknowledge that climate change may further marginalize small or remote communities and households with subsistence economies. Difficulties in identifying the most appropriate responses to climate change are compounded by the fact that climate is not the only driver of change in the region. Changes driven by development (e.g., the Mary River mine in Nunavut; see Chapter 7) are also possible, along with changes driven by changing infrastructure, telecommunications, demographics, governance, and other factors. In addition, it is important to realize that adaptation options are not available to meet all adaptation needs, and a continued adaptation deficit will remain and necessitates continued focus on mitigation in global climate policy (IPCC, 2014a). For example, limits to adaptation may be associated with a loss of cultural sites (due to increased tourism pressure or permafrost thaw in some locations) or with impacts to well-being (associated with an inability to partake in certain harvesting activities).

Despite increasing interest in and recognition of the need to adapt, research has identified confusion as to what adaptation is and limited understanding of how adaptation can be integrated or mainstreamed into areas of policy-making, a lack of "usable" knowledge on how to adapt, and only limited research into the prioritization of response options (Ford et al., 2014a; Champalle et al., 2015). These research findings have been further borne out by the feedback from people consulted in Nuuk, Greenland, in two consultations regarding this Adaptation Actions for a Changing Arctic (AACA) report (see Chapter 1). A number of scientific assessments to examine Arctic change have been conducted, along with attempts to package the findings in a manner accessible to end users. Among these assessments are Arctic-wide assessments such as the following: the Arctic Climate Impact Assessment (ACIA, 2005), reports from the International Polar Year (Kulkarni et al., 2012), the "Polar Regions" chapter of the Intergovernmental Panel on Climate Change (IPCC) assessment reports (Anisimov et al., 2007; Larsen et al., 2014), the *Human Health in the Arctic* reports (AMAP, 2009, 2015), the *State of the Arctic Coast 2010* report (Forbes, 2011), the *Arctic Marine Shipping Assessment 2009 Report* (Skjoldal et al., 2009), the *Arctic Human Development Report,* I and II (AHDR, 2004; Larsen and Fondahl, 2015), the *Arctic Resilience Interim Report 2013* (Arctic Council, 2013b), *Taking Stock of Adaptation Programs in The Arctic* (Arctic Council, 2013a), and the *Arctic Biodiversity Assessment* (CAFF, 2013). There have also been assessments targeted at specific Arctic regions, including the following: the northern chapters in *From Impacts to Adaptation: Canada in a Changing Climate 2007* (Lemmen et al., 2008), *Human Health in a Changing Climate: A Canadian Assessment of Vulnerabilities and Adaptive Capacity* (Séguin, 2008), and the ArcticNet Integrated Regional Impact Studies (Allard and Lemay, 2012; Stern and Gaden, 2015).

The Adaptation Actions for a Changing Arctic project complements these earlier assessments, with a specific focus on interactions among the multiple drivers of change and the multiple options for anticipating and responding to change. AACA also targets specific regions of the Arctic: this report focuses on the Baffin Bay/Davis Strait region. The assessment model developed by AACA differs from that used in traditional scientific assessments (e.g., IPCC) in that the AACA model includes a strong focus on engaging the insights and needs of stakeholders alongside reviewing the current state of knowledge. This engagement has been incorporated at multiple stages, including the convening of meetings between chapter authors and stakeholders during the writing process, as well an extensive chapter review process (see details in Chapter 1).

In the final two chapters of this BBDS report (Chapters 11 and 12), we introduce definitions and typologies and we synthesize the findings emerging from the thematic chapters, in order to outline key opportunities and considerations for adaptation and resilience building. We base this outline on a growing understanding of the determinants of vulnerability and adaptive capacity to climate change, on identified adaptation needs, and on adaptation experiences to date. We base the description and summary of adaptation options on the current state of understanding within scientific and traditional knowledge (insofar as traditional knowledge was collected in the source materials), acknowledging that it is not possible to perfectly inform visions of the future. In this spirit, this report offers the potential management responses as options rather than recommendations (see Chapter 12). We have also considered the value of adaptation options as "no-regrets" options – i.e., options that could be deemed to improve on current management regardless of the future trajectory or pace of change. In summarizing the findings from specific chapters, we also draw upon work from the above-mentioned assessments and we integrate additional relevant scientific literature from both the Arctic and more generally in the adaptation field, along with the views of communities and decision-makers as documented in publicly available information. This chapter is thus firmly rooted in the content of AACA but also linked to broader developments in adaptation research and decision-making. This content is synthesized using the typology described in Subchapter 11.2.

11.2 A typology of approaches to adaptation

The Intergovernmental Panel on Climate Change, in its fifth assessment report, defines adaptation as "*the process of adjustment to actual or expected climate and its effects, in order to either lessen or avoid harm or exploit beneficial opportunities*" (IPCC, 2014b, p. 76). As such, adaptation encompasses a variety of strategies, actions, and behaviors that make households, communities, and societies more resilient to climate change. Adaptation may focus on reducing sensitivity to climate change impacts and on strengthening adaptive capacity to manage and take advantage of change (Smit and Wandel, 2006; Fussel, 2007). Adaptation options cross scales, from personal and household decisions to community/local, national, and international decisions, with actions at each level being influenced, constrained, or enabled by developments on other scales. It is also noteworthy that while much of the recent thinking on adaptation has been climate-focused, it is being increasingly argued that for adaptation to be effective, responses need to also target other drivers of change (including social-economic-demographic conditions and development trajectories), which will in many cases determine the impacts of climate change (Hansen and Larsen, 2014; Ford et al., 2015b). A common feature among adaptation options is the need to build flexibility and the ability to adjust to increasing variability and new extremes – from weather or other external drivers (Figure 11.1).

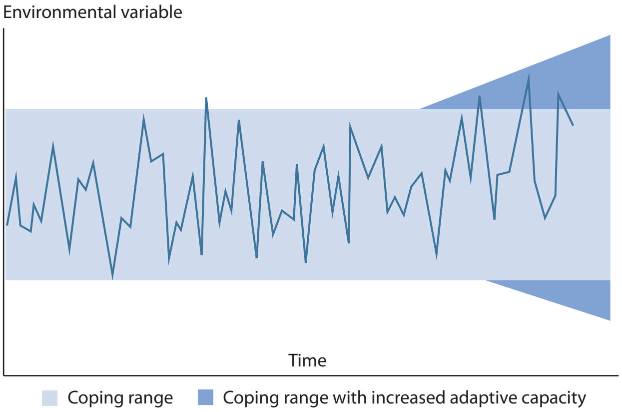

Figure 11.1 Environmental variability and coping ranges (modified from Smit and Wandel, 2006). The coping range of the past (light blue) handles historical variability in the external environment, with rare extremes overwhelming this capacity. Going forward, increased adaptive capacity (darker blue) will be needed to handle increasing environmental variability and new extreme events. Among the different types of variability, climate variability is the one for which science can best provide long-term projections, with estimates of uncertainty. Socio-economic and political variability and extremes are less predictable.

Adaptations may be characterized in a variety of ways, including by purposefulness (autonomous versus planned), timing (anticipatory versus responsive), temporal scope (short- or long-term–focused), spatial scale (localized versus widespread), form (e.g., structural/physical, social, institutional), and stage (groundwork versus action) (Smit et al., 1999, 2000). There are also many different approaches to managing the risks of climate change through adaptation. At one extreme, a climate-centered adaptation (CCA) perspective (Figure 11.2) focuses on developing policies, programs, and actions that have an intentional and substantial focus on responding to climate change impacts, both experienced and projected (Dupuis and Biesbroek, 2013). While such adaptations may have benefits beyond managing climate change, reducing vulnerability to climate change and taking advantage of new opportunities is an intentional and substantial goal. This kind of adaptation is important where climate change poses significant risks, where current and future risks are well known, where climate change has a direct impact, or where current climatic risks are significant. For example, in response to the increasingly obvious effects of permafrost thawing, buildings affected by thaw settlement can be supported by the use of thermosyphons to keep the ground frozen (Chapter 10). Similarly, with expected changes in the distributions and abundances of fish species, governments may adapt regulations or create programs to help fishing fleets and processing plants retool to exploit new stocks.

At the other extreme, a vulnerability-centered adaptation (VCA) perspective focuses on targeting the underlying social-economic-political factors that lead to climate vulnerability by

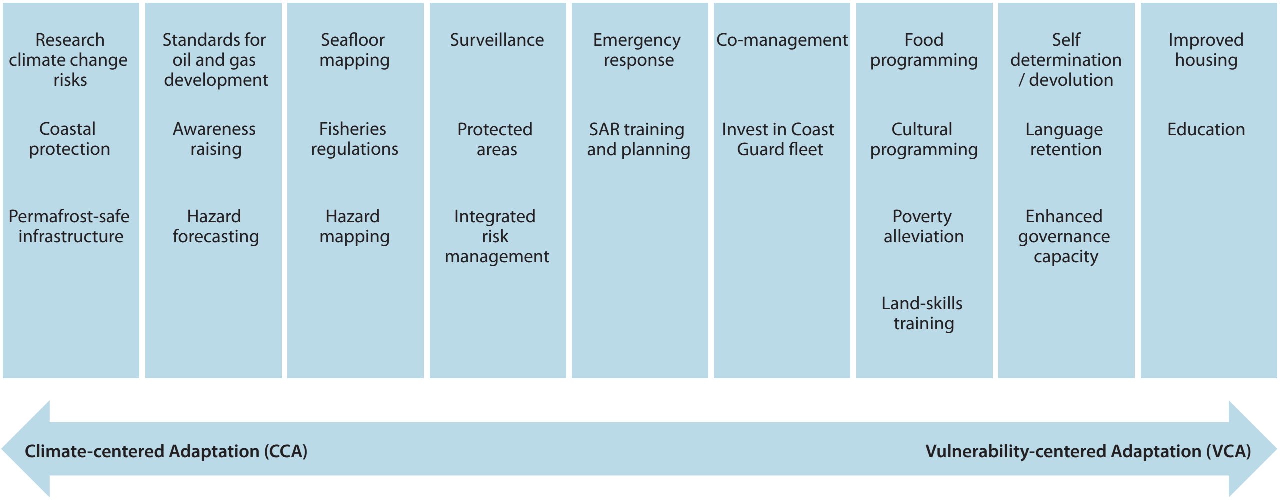

Figure 11.2 An adaptation continuum: climate-centered to vulnerability-centered. The categories of climate-centered adaptations (CCAs) and vulnerability-centered adaptations (VCAs) are not distinct and mutually exclusive. Adaptation options can fall anywhere along the continuum, as illustrated by these examples from the key options reviewed in Chapter 12. "SAR" = search and rescue.

undermining or constraining adaptive capacity or increasing sensitivity to impacts (Dupuis and Biesbroek, 2013; Agrawal and Lemos, 2015). In this perspective, development and ongoing policy processes regarding, for instance, education, sustainable development, cultural programing, health planning, the promotion of equity and justice, and poverty alleviation can be viewed as adaptations in that they address the underlying determinants of vulnerability to climate change (Ford et al. 2010a; Eakin et al. 2014). In relation to sustainable development, the United Nations (UN) recently adopted 17 sustainable development goals, including Global Goal 13: "*Take urgent action to combat climate change and its impacts*." Associated with this goal are three targets: "*Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries* (13.1); "*Integrate climate change measures into national policies, strategies and planning*" (13.2); and "*Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning*" (13.3) (UN, 2015, p. 25). Hence, resilience building is also consistent with vulnerability-centered adaptation, calling for approaches to manage change that promote diversity, self-organization, acceptance of change as the norm, and the preservation and promotion of underlying sources of socio-ecological resilience (Chapin et al., 2006, 2015).

Vulnerability-centered adaptations may not be specifically aimed at addressing climate change impacts, but they can nevertheless be highly contributive toward reducing vulnerability and promoting resilience – so VCAs will tend to make northern communities more resilient to multiple kinds of change, not just climate-driven change. As a result, VCAs have been supported where the nature of future social, economic, and environmental risks is unknown (Klein and Juhola, 2014; Ford et al., 2015b). Vulnerability-centered adaptations are consonant with Inuit beliefs and notions of planning, which historically have focused less on anticipating and responding to expected futures and more on the societal characteristics that underpin the ability to respond to variable and unpredictable conditions (e.g., sharing networks, flexibility) (Ford et al., 2006a, 2006b; Bates, 2007). The more holistic VCA view of adaptation also closely links into how northern governments and Inuit organizations have approached adaptation – as one of a number of interlinked challenges facing the North (e.g., NTI, 2005; Government of Nunavut, 2011; ITK, 2016).

These two approaches to adaptation – climate-centered and vulnerability-centered – have different definitions of what adaptation means, they place different emphases on the origin of the problem for which adaptation is needed, and they present different sets of alternative policy and response options (Dupuis and Biesbroek, 2013). The distinction between CCA and VCA is used here as a typology to examine opportunities for adaptation across scales in the BBDS region. In using this categorization, we note that the CCA and VCA perspectives overlap in many instances, with adaptations occurring on a continuum between the two (see Figure 11.2). Both approaches are needed, and each one complements the other. However, it is often more straightforward to come up with specific projects and "checklists" for the technical solutions associated with climate-centered adaptations than for the less obvious and less tangible options associated with vulnerability-centered adaptations. VCAs are therefore at greater risk of being overlooked or sidetracked in political decision-making and planning processes. As such, the focus on VCA here attempts to illustrate how ongoing policy processes can build in adaptation – an important consideration in the North, where there are multiple competing policy priorities.

Subchapter 11.3 identifies important considerations associated with undertaking climate-centered adaptation. Chapter 12 supplements this information by summarizing specific adaptation options organized according to the sectors covered in this assessment (Chapters 4 to 10). Vulnerability-centered adaptations, which are concerned with human development, poverty alleviation, and enhancement of livelihood security, do not target or recommend specific policies per se. Instead, VCAs more generally illustrate how climate change considerations can be integrated into ongoing policies. As such, the discussion of adaptation in Subchapter 11.4 is cross-sectoral in nature, with items categorized as either addressing the underlying determinants of vulnerability or managing for resilience.

11.3 Climate-centered adaptation

11.3.1 Overarching considerations for climate-centered adaptations

Important considerations for developing and implementing climate-centered adaptations have been identified (see Chapter 12 for specific examples) and are important for activities in the BBDS region:

- **The role of modeling:** Climate modeling and associated assessments of possible impacts are important for informing adaptation options. In the BBDS region, there is a demand for locally downscaled projections. The uncertainties associated with modeling, however, increase dramatically at local scales. The problem of uncertainty is exacerbated, moreover, by the absence of long-term, reliable data on local climatic conditions in some communities and wide variations in the factors that affect local climatology. Adaptation options must therefore rely on general climate projections for the region (Larsen et al., 2014) alongside the available downscaled projections (e.g., DMI, 2015, and six associated reports on local climate projections). The general regional projections indicate increased variability and extreme events, not just gradual change (IPCC, 2012). Communicating projections to decision-makers and communities is important, with specific strategies tailored to specific groups. Including information on known trends and likely future scenarios is also important, to help generate ideas for adaptation. It also needs to be understood that uncertainty will always characterize our understanding of future risks and opportunities, just as it characterizes all forward-looking planning. This uncertainty reflects our incomplete understanding of climate dynamics, as well as the uncertainties associated with the future demographic, technological, economic, and policy changes that will influence greenhouse gas emissions (Klein and Juhola, 2014; Preston et al., 2015). Modeling also needs to be supplemented by studies that document community understanding of how the climate might change and what impacts these changes might have. Communities have widely voiced that they are already experiencing climate impacts. Some communities have led projects to document local knowledge on climate change, but projects that draw upon traditional knowledge (TK) to identify potential future changes and impacts are limited in both Greenland and Nunavut.

- **Planning in the context of uncertainty:** In planning for a future with more uncertain and more variable conditions, it is important not to make radical, non-reversible shifts in expectation of specific new conditions; such shifts may carry the risk of being "high-regret" adaptations[10] (Heltberg et al., 2009; Wise et al., 2014). Rather, it is important to think in terms of ensuring flexibility, agility, and diversification to stand ready for more variable conditions and a variety of potential futures (Barnett et al., 2014; Rosenzweig and Solecki, 2014; Wise et al., 2014); such characteristics of "planning" are central to many Arctic Indigenous cultures (Bates, 2007; Natcher et al., 2007; Ford et al., 2015a). In this context, "low-regret" or "no-regret" adaptations[11] will be helpful and will build resilience almost no matter how the climate changes or how ecosystems and society are affected. As noted in the *Arctic Resilience Interim Report 2013*: "*Rapid Arctic change is likely to produce surprises, so strategies for adaptation and, if necessary, transformation, must be responsive, flexible and appropriate for a broad range of conditions*" (Arctic Council, 2013b, p. xii), building upon – and guided by – cultural values and northern decision-making processes. Adaptations need to be designed in a way that allows for adjustments over time, as impacts materialize and as evidence of the effectiveness of various options emerges – a key component of what has been called the "adaptation pathways" approach (Wise et al., 2014). This approach may involve, for example, designing infrastructure that can be easily retrofitted for new uses or modified to manage new conditions as impacts begin to manifest.
- **Integrating multiple stresses:** Adaptations need to be developed in the context of the multiple stresses that affect the BBDS region and their cumulative effects. This approach necessitates recognition that adaptation is not a one-off "project" but instead a process of ongoing strategic planning across sectors and regions to consider the combined and cumulative effects of adaptations on social, ecological, and economic well-being.
- **Cross-scale governance:** Adaptation research and policy responses in the BBDS region are typically focused on the community/regional level (e.g., community adaptation plan development), which is the appropriate scale for responding to many of the risks posed by climate change. Yet national-level policies and regulations also, in many instances, enable or limit the ability to adapt at lower levels (Keskitalo, 2008; Young, 2012). In Greenland, for example, many small settlements have an uncertain future, with the investment and policy focus of the Greenland Self-Government channeled mainly toward major economic centers. This focus affects the resources generally available for adapting to a changing climate and evolving institutional interests. In Nunavut and Greenland, codes and standards for buildings and infrastructural developments largely reflect southern norms and limit what is possible (detailed further in Chapter 10). Adaptation therefore requires cross-scale interactions and cooperation between communities and regional/national governments (e.g., Government of Nunavut, Greenland Self-Government) to identify and act on cases where high-level policies constrain local-level action.
- **Community and stakeholder engagement and leadership:** The importance of engaging communities and decision-makers in adaptation research, planning, and implementation is widely recognized (Moss et al., 2013), with a need for northerners to take leadership roles in directing such work and planning. Actions that are identified, developed, and led in cooperation with local actors and policy-makers will likely be more successful. Such actions are also more likely to gain local trust and be seen as consistent with local goals, norms, and policy objectives. These points are particularly salient in the BBDS region, where traditional knowledge systems and cultural values are recognized as being essential to adaptation efforts across many sectors and where past policy failures have stemmed from interventions that reflected non-Indigenous worldviews and notions of progress and planning (Bates, 2007; Haalboom and Natcher, 2012). The importance of community and stakeholder involvement and leadership for social learning across sectors and scales is also recognized, with actors exchanging problem frames, making sense of the issues at stake, examining opportunities and barriers to adaptation, and building trust (Fazey et al., 2010; Ford and King, 2015). Communities and decision-makers in both Greenland and Nunavut have repeatedly called for meaningful involvement and leadership roles in research on climate impacts and adaptation in the BBDS region.
- **Monitoring and evaluation:** Developing and implementing adaptation is not an endpoint in itself but rather an ongoing process wherein drivers of vulnerability are identified and monitored and the effectiveness of policies, programs, and actions are continually evaluated over time (Ebi and Semenza, 2008). Monitoring and evaluation ("M&E") is a key part of strategic planning – essential for assessing outcomes of adaptation measures, providing learning opportunities, identifying maladaptations[12] or unforeseen effects (which may develop as a result of incomplete understanding of human–environment interactions or policy interactions), and informing planning and decision-making.

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[10] High-regret options: Adaptation options that involve large-scale planning and investment decisions with a high degree of irreversibility. In view of the considerable consequences at stake, the significant investment costs of some decisions, and the long-lived nature of infrastructure, the uncertainties in future climate projections play a crucial role in the making of decisions about whether to implement potentially high-regret adaptation measures (Fussel, 2007; World Bank, 2010).

[11] No-regret options: Adaptation options that would be justified under all plausible future scenarios, including the absence of human-induced climate change (Fussel, 2007; World Bank, 2010).

[12] Maladaptation: An action or process that increases vulnerability to climate change-related hazards. Maladaptive actions and processes often include planned development policies and measures that deliver short-term gains or economic benefits but lead to exacerbated vulnerability in the medium- to long-term (Fussel, 2007; World Bank, 2010).

11.4 Vulnerability-centered adaptation

Vulnerability-centered adaptation focuses on addressing the underlying non-climatic determinants of climate vulnerability and on building resilience to manage change. In the context of this AACA assessment and consistent with the IPCC, *vulnerability* can be thought of as the susceptibility of households, communities, and regions to harm arising from climate change impacts and other external stressors. Vulnerability is determined by exposure, sensitivity, and adaptive capacity. *Resilience* captures the capacity of a social-ecological system to cope with disturbance, responding or reorganizing in ways that maintain its essential function, identity, and structure, while also maintaining its capacity for adaptation, learning, and transformation (Arctic Council, 2013b). Stated more simply: resilience is the capacity to deal with change and continue to develop (Stockholm Resilience Centre, 2016).

The growing recognition of the importance of VCA perspectives in general – and in the BBDS region in particular – reflects a number of factors:

- First, non-climatic conditions play a major role in determining vulnerability to climate change, through affecting sensitivity and adaptive capacity to impacts.
- Second, climate change in many instances is not the main driver of change but rather one among multiple interacting factors that affect communities and sectors. Other important drivers include global commodity prices, economic development, geopolitics, cultural losses, demographic shifts, and health and educational disparities; climate change acts as a risk multiplier to these factors in many instances (Subchapter 3.3). For example, as noted in Chapter 9, changes in sea ice extent will affect future shipping in the BBDS region (Figure 11.3), but the development of the shipping industry will ultimately depend on industry and market constraints (e.g., just-in-time production), as well as geopolitics (e.g., deepening of the Panama and Suez Canals and changing en route security issues). In many cases, institutional infrastructure (e.g., departments, mandates, policy processes, funding streams) already exists for managing these issues, and a good starting point for adaptation is to integrate climate change considerations into existing processes – what has been termed "mainstreaming." The imperative for such mainstreaming is underscored by the financial, resource, and institutional challenges already facing BBDS communities and regions – a situation that makes it difficult to get standalone adaptation policies, programs, and actions onto the policy agenda (Boyle and Dowlatabadi, 2011; Ford et al., 2014b; Klein and Juhola, 2014). Still, challenges to mainstreaming and difficulties in integrating climate considerations into different sectors have been noted – further underscoring the need to raise awareness on climate impacts and adaptation options across sectors.
- Third, as recognized in the AACA approach, significant uncertainties accompany many of the projected impacts of climate change in the BBDS region, and potential threshold effects in biological and physical systems are poorly understood. These considerations limit the development of climate-centered adaptations. Some uncertainty may be resolved by undertaking further studies, but uncertainty will always characterize our understanding of the future. Therefore, considerations of uncertainty need to be built into decision-making processes – further underscoring the importance of adaptations that respond to multiple risks and the importance of efforts to mainstream adaptation into ongoing policy processes (Dovers, 2009; Prno et al., 2011; Klein and Juhola, 2014; Subchapter 3.3).

These three factors have been widely noted by northern communities and decision-makers, who have stressed the need for adaptation to simultaneously address multiple issues. In Nunavut, for instance, the teaching of land skills and the retention of traditional language have been argued to protect human health and safety and to maintain cultural traditions (NTI, 2005; Nickels et al., 2006; Government of Nunavut, 2011; see also Subchapter 3.3 and Chapters 4 and 5).

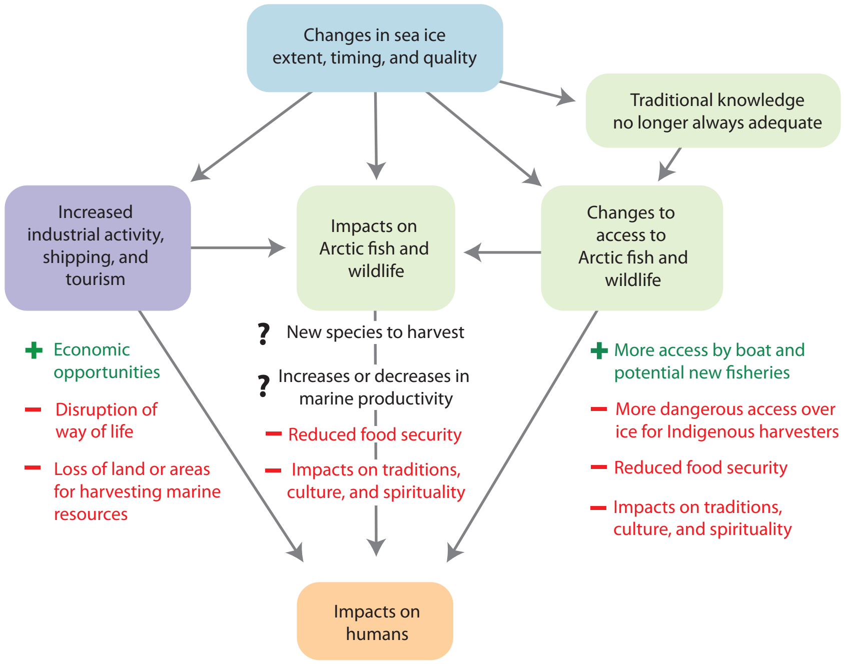

Figure 11.3 Primary pathways of the impacts of sea ice change on Arctic humans (redrawn from Eamer et al., 2013). These pathways can be direct or indirect; some are associated with changes in Arctic biodiversity. Changing sea ice is one of the most well-known and well-characterized effects of Arctic climate change, and this change poses challenges as well as benefits – both of which call for adaptation.

11.4.1 Addressing the underlying determinants of vulnerability

Often, what makes people vulnerable to climate-related risks is reflective of underlying social, cultural, and economic factors (Ford and Smit, 2004; Smit and Wandel, 2006; Papworth et al., 2015). These social determinants in the BBDS region (e.g., housing shortages and poor housing conditions, food insecurity, high burden of ill health, high unemployment, colonial legacies) are likely to increase sensitivity and constrain the adaptive capacity of communities to projected climate change impacts. Accordingly, these determinants have been argued by communities and regional and local decision makers to be important elements of broader sustainable development, within which climate change adaptation must be considered (NTI, 2005; Government of Nunavut, 2011; see also Chapter 4). Efforts to reduce vulnerability and enhance adaptive capacity to climate change can, therefore, be integrated into ongoing policy initiatives that promote social and economic development. The fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC, 2014b) identifies a number of policy areas where this integration can be achieved:

- **Human development:** This policy area covers improving access to Western and traditional education and health services, enhancing nutrition, improving social support mechanisms, and enhancing northern decision-making power – all of which have been identified as underlying factors affecting socio-economic conditions in the BBDS region. Indicators of well-being in the region typically compare unfavorably to indicators in comparable non-Arctic populations (Subchapter 3.3 and Chapter 4). Nunavut, for instance, has the highest documented rate of food insecurity in Canada and one of the highest rates in a developed country. This insecurity in turn creates vulnerability to changes in access, availability, and quality of traditional foods with climate change and increases susceptibility to an increasing incidence of climate-sensitive infectious diseases. The BBDS region has high rates of death, disease, and accidents, and health systems do not have enough capacity to effectively respond to existing and emerging health problems (Young and Bjerregaard, 2008; Young, 2013; NTI, 2014; Larsen and Fondahl, 2015; Subchapter 3.3 and Chapter 4).
- **Poverty alleviation:** Social and economic disadvantage are evident in the persistently high rates of poverty facing BBDS communities, and access to housing is typically well below that of non-Arctic populations in Canada and Denmark (NTI, 2014; Larsen and Fondahl, 2015). The problem of residential overcrowding and poor-quality housing in the BBDS region has been linked to elevated levels of stress. Poor housing also limits social and economic development and favors the transmission of respiratory and gastrointestinal diseases that are sensitive to changing climatic conditions (Chapters 4 and 10). A focus on poverty alleviation needs to address the lack of employment opportunities in communities, promote skills training, invest in social support programs, and develop housing cooperatives to address chronic household overcrowding. Challenges linked to the legacy of colonization (e.g., substance abuse, diminished mental well-being, high rates of school dropout) also need to be addressed (Knotsch and McKinnon, 2011; Council of Canadian Academies, 2014; NTI, 2014; Larsen and Fondahl, 2015; Poppel, 2015; Chapters 5 and 10).
- **Livelihood security:** The challenge of livelihood security for many small Arctic communities has been widely documented. Changes in global markets or policy developments originating from regional governments (e.g., Government of Nunavut or Government of Greenland) or from outside the North (e.g., the sealskin ban of the European Union) can have significant implications for Arctic employment and livelihood opportunities (Section 6.5.2). As Chapin et al. (2006) note, this lack of security to some extent builds resilience, with many people changing jobs frequently or having several part-time jobs rather than specializing in a single profession, yet it also constrains investment in communities and limits the potential for long-term planning. Lack of livelihood security is a particular challenge for livelihoods based on harvesting. These livelihoods are affected by vagaries in environmental conditions, wildlife regulations and population limitations, and access to financial resources. For instance, the loss of a snowmobile in a sea ice–related hunting accident (which could become more common with climate change) can have long-term ramifications if the household cannot afford to replace it (Chapter 6). In this context, a number of harvester support programs exist in Nunavut and Greenland, which seek to maintain a strong traditional resource use sector. These programs include support for new equipment and disaster compensation, although they are believed to be insufficient in light of the demands placed on them (Ford, 2007; Ford and Goldhar, 2012), as summarized in Subchapter 12.2. For businesses operating in the North, the difficulties of slow or unreliable Internet speed and connectivity, an uncertain business environment, and limited training opportunities have been identified as factors challenging business success and constraining the formation of new northern-based companies (Subchapter 3.3 and Chapter 7).

Climate change brings a renewed emphasis to efforts to address these problems, yet an adaptation lens also demands that these policy areas recognize the evolving risks posed by climate variability and change – which could potentially undermine efforts to enhance socio-economic development or could render such efforts maladaptive (Agrawal and Lemos, 2015). For example, food security actions targeted at increasing traditional food consumption need to also consider sustainability issues related to limitations and changes in wildlife availability and accessibility (Chapters 4 and 6). Similarly, policies targeting housing need to consider the effects of permafrost thaw and changing wind and precipitation patterns on built infrastructure (Chapter 10); economic policies based on promoting resource development (Chapters 6 and 7), tourism (Chapter 8), and fisheries (Subchapter 6.4) need to be cognizant of cumulative impacts and projected climate-associated changes; and harvester support programs need to consider the potential for increasing demand with more dangerous ice and weather conditions. Institutional change, meanwhile, needs to promote greater interaction and information flow across scales to support communities as they respond to increasingly unpredictable and variable conditions (Subchapter 3.3).

11.4.2 Managing for resilience

In the BBDS region, there are substantial sources of resilience to multiple perturbations, including climate change. These sources are based on traditional knowledge systems, institutions for collective action, robust governance systems, mixed economies, and a diversity of livelihood choices. These sources also underpin self-organization, learning, and innovation, which are essential components for adapting to the uncertainty and surprise that characterize rapidly changing Arctic systems (Chapin et al., 2006; Berkes, 2007; Forbes et al., 2009; Ford et al., 2015b). Resilience thinking reflects a profound shift – away from a traditional management perspective, which attempts to control changes in systems assumed to be stable, and toward a resilience viewpoint, which aims to sustain and enhance the capacity of social-ecological systems to be resilient in the face of multiple threats (Chapin et al., 2015). Critics of the resilience concept, however, see a risk of focusing on "system"-level resilience while abandoning the interests of vulnerable "individuals" – so it is crucial to maintain a "from-vulnerability-to-resilience" perspective (e.g., Béné et al. 2012; Ribot, 2014).

Many sources of resilience derive from communities and Inuit knowledge systems that have evolved over generations in the context of climatic variability, extremes, and change. Yet some sources of resilience are being challenged by outside stressors, historical legacies, policies, and climate change. Community action and policy action therefore have roles to play in addressing the key drivers that are undermining resilience. Actions that seek to support and promote resilience overlap to some extent with actions aimed at vulnerability reduction (profiled in Section 11.4.1), although resilience-focused actions typically place a greater emphasis on ecosystem management, explicitly focus on enhancing the ability of socio-ecological systems to respond to multiple stresses, and emphasize the importance of diversity, self-organization, and acceptance of change as the norm. BBDS communities, regional and local leaders, decision-makers, and scientists have identified a number of opportunities for supporting resilience and managing for resilience within the BBDS region and the Circumpolar North more generally. These opportunities are outlined below.

11.4.2.1 Traditional knowledge systems

Traditional knowledge systems, grounded in generations of place-based observations and experiences closely linked to land-based livelihoods, underpin multiple aspects of community life (Chapters 4 and 6). This concept is related to *Inuit Qaujimajatuqangit* (IQ), Inuit social values (for information about IQ in other contexts, see Chapters 2, 3, 5, and 6). TK is based on the intergenerational transmission of knowledge and oral histories of human–environment relationships, personal and community well-being, and spiritual considerations. TK guides multiple aspects of Inuit life (Tester and Irniq, 2008; Government of Nunavut, 2011; Inuksuk, 2011; Pearce et al., 2015a). As a cumulative and dynamic body of knowledge and beliefs, traditional knowledge is pertinent to climate change because this knowledge affects the sensitivity and adaptive capacity of communities, households, and individuals; underpins social connectedness and sharing systems; and plays an essential role in avoiding, reducing, and managing climate-related risks (Berkes and Jolly, 2002; NTI, 2005; Nickels et al., 2006; Inuksuk, 2011; Pearce et al., 2015a). While climate change is undermining some aspects of traditional knowledge in the BBDS region (e.g., the ability to forecast weather conditions, predict animal migrations, and understand environmental conditions), other skills are becoming even more important in light of new and exacerbated risks (e.g., survival skills and mentality, knowledge of animal behavior, ability to identify hazard precursors) (Ford et al., 2010b; Government of Nunavut, 2011; Pearce et al., 2015a; Chapter 6).

Competence on the land and in the skills and technology needed for safe and successful harvesting are highly valued aspects of traditional knowledge. These aspects are developed and transmitted through experiences on the land and through learning from elders and experienced individuals. This collective social memory is drawn upon to deal with routine events, and it forms a repository of accumulated experience that helps to manage the dangers of traveling with changing snow, ice, and weather conditions. This collective memory is also drawn upon during search and rescue operations, with experienced individuals often playing an important role in deciding where and how to search (Clark et al., 2016). Such knowledge systems represent an evolving body of knowledge that is continually being updated and refined in light of changing conditions (Berkes and Berkes, 2009; Ford and Goldhar, 2012; Pearce et al., 2015a). Studies have highlighted that the speed of environmental change is in some instances encouraging adaptive learning among subsistence harvesters, who through regular observation of and interaction with the environment are developing and refining adaptive strategies to deal with problematic conditions (Gearheard et al., 2006; Ford et al., 2013c; Statham et al., 2015). TK also underpins food preparation skills, including proper butchering and storage techniques for various wildlife species and the ability to identify bad meat. These skills are important in light of rising temperatures, which encourage the presence and survival of food parasites and pathogens (Furgal and Séguin, 2006; Harper et al., 2015a, 2015b).

The evolution and transmission of traditional knowledge is being threatened, however, as traditional modes through which individuals develop the skills to hunt safely and successfully have been affected by acculturation, socio-demographic changes, and rapid environmental changes. The weakening of traditional knowledge systems has been identified as a concern by communities across the region. Economic development through job creation has also created alternative livelihood options to harvesting, thus reducing the amount of time individuals spend engaged in subsistence activities. On the other hand, access to the monetary economy is also a precondition for being able to buy and maintain the technology now associated with subsistence activities (e.g., boats, snowmobiles, gasoline, outboard motors, bullets) (Wenzel, 2013). Economic development and the formal market economy are therefore not simply a challenge but also a prerequisite for the land-based/subsistence economy of today (Poppel, 2010; Wenzel, 2013).

Still, studies note that while land use and harvesting remain central to northern livelihoods, key skill sets and knowledge systems have been diminished (Takano, 2004; Pearce et al., 2015a). While technological developments have partially compensated for the loss of some skills (e.g., the loss of traditional navigation skills in light of widespread GPS use), technology has also exacerbated other risks by escalating risk-taking behavior (Aporta, 2004, 2009; Aporta and Higgs, 2005; Aporta et al., 2011). Of particular concern is the increasing disconnection between older and younger generations. This documented disconnection has potential long-term implications because the older generations have an important role within the communities – acting as an "institutional memory," maintaining and transmitting TK on how to manage changing conditions, and taking younger generations onto the land (Ford et al., 2013c; Pearce et al., 2015b). Initiatives that focus on maintaining and revitalizing TK (e.g., culture camps, school programming, cultural events that support sense of place) have been identified as important for building resilience to the multiple challenges facing northern communities, including climate change. These initiatives aim to ensure that knowledge is passed on to younger generations and to proactively address the stressors that have compromised knowledge transmission (see Chapter 5 and Subchapter 12.3). A number of training opportunities are currently offered in Greenland and Nunavut.

Such a focus on culture and knowledge systems, for example, underpins Nunavut's strategic planning on adaptation (embodied in the Government of Nunavut's *Upagiaqtavut* document). This plan promotes the encouragement and support of "*continued transfer of knowledge and skills from elders to youth*" (Government of Nunavut, 2011, p. 5). As stated in the plan: "*Learning tools on climate change will be integrated in to Nunavut's education curriculum. This will ensure that students are provided with the opportunities, skills, and knowledge necessary to make informed decisions about climate change and contribute to climate change adaptation*" (Government of Nunavut, 2011, p. 24). Further, *Upagiaqtavut* notes that "*By facilitating intergenerational learning, we ensure the continued knowledge transfer from elders to youth. Land skill knowledge transfer will equip younger generations with the traditional skills needed to adapt to a changing environment*" (Government of Nunavut, 2011, p. 24). Across the North, youth are also taking leadership roles in protecting and advocating for their culture, including in a climate change context. Young Inuit have had a strong voice globally on the risks posed by climate change (e.g., through attendance and advocacy at UN climate change meetings).

Positive developments for the safety and efficiency of the fisheries of Greenland are also occurring, with formal education now being offered across the region to train naval officers, fishers, and hunters (Grønlands Maritime Center, 2016). Formal education becomes increasingly important as the products of the land enter international markets. Even fish caught from small dinghies by hunters in very small settlements are eventually sold to international markets in Asia, Europe, and North America by the fisher-owned fish factories and Greenland's seafood companies. According to stakeholder consultations in Nuuk, new skills are therefore in demand and targeted skills training or formal education has become a critical factor in the success of the sector (Subchapter 3.3).

11.4.2.2 Diversity of resource-use systems

Inuit resource-use systems for hunting, fishing, and trapping have evolved in the context of variable and unpredictable climates, with risk being managed through the sequential utilization of a large number of ecological or climatic niches (Wenzel, 1991; Krupnik and Jolly, 2002; McGhee, 2004; Chapter 6). Harvesting is typically opportunistic: while there are known seasons, locations, and times where certain species are harvested, individuals typically harvest what is available when it is available and where it is available, making changes to take advantage of wildlife availability and specific local conditions. Such diversity and flexibility are widely recognized


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Children learning to use a computer at school in Igloolik, Nunavut, Canada strategies for managing risk (Chapin et al., 2004; Adger et al., 2005; Tyler et al., 2007), and these qualities have helped BBDS individuals, households, and communities to manage changes in the access and availability of harvested species of significant cultural, dietary, and economic significance (Subchapter 4.3).

The success of such strategies is, however, being constrained by a variety of factors. The weakening of traditional knowledge systems (discussed above) has implications for the diversity and flexibility of resource use, which depend on knowing how to harvest in different environments and locations and how to utilize different species (i.e., how to catch, butcher, and prepare different animals) (Pearce et al., 2015b; Ford et al., 2016c). Regulatory systems, resource pressure from increased mobility and technology, and competing land uses compound these stresses, thus limiting the freedom for local-level responses and innovations. For example, formalized wildlife management regimes led by governments (including Greenland Home Rule and, since 2009, Self-Government) have replaced informal mechanisms of local social control and obligation for managing variations in wildlife access and availability, thus limiting local flexibility in managing change (Sejersen, 2009; Wenzel, 2009). While co-management has served to enhance wildlife management and allow for greater flexibility, the translation of information across scales remains challenging. Communities are responding rapidly to alter their behavior in light of observed conditions, but regulatory regimes are slow to change. This regulatory inertia includes agency responses to information showing unfavorable wildlife population changes, which calls for unpopular restrictions on shared resources.

Co-management regimes have struggled to manage conflict where the health of a species is in dispute. These regimes have also been observed to perpetuate the marginalization of communities and to have been undercut by policies at international scales (e.g., the ban in the United States of America on the importation of polar bear hides) (Dowsley and Wenzel, 2008; Dowsley, 2009); such situations may become more common in the future. Future efforts to build resilience in this context need to focus on promoting the sharing of traditional and scientific knowledge in management decisions and the co-production of knowledge on the health and status of wildlife populations (Clark et al., 2008; Dowsley, 2009; Schmidt and Dowsley, 2010; Meek et al., 2011; Chapin et al., 2015).

11.4.2.3 Social and kinship networks

Social networks – the relations of trust and reciprocity that enable people to act collectively – are recognized to be a central component of community resilience (Adger, 2003; Robards and Alessa, 2004). The sharing of traditional foods, in particular, is a key component in Inuit culture and livelihoods, with several types of food-sharing practices identified in the BBDS region. These practices, which are characterized by intent (rule, voluntary, demand) and direction of flow of food (transfer, exchange, redistribution), vary by region and community (Wenzel, 1995; Dahl, 2000; Kishigami, 2004; Wenzel, 2013; Chapter 6). Food sharing is believed to have evolved as an adaptive mechanism to the unpredictable and pervasive environmental change that characterizes Arctic environments, and this practice continues to help individuals and households to access food during times of stress. For example, with climate change affecting the ability of certain people to go harvesting (e.g., those who don't have the equipment, time, or knowledge to alter harvesting behavior), sharing systems can help maintain food access (Ford, 2009; Council of Canadian Academies, 2014). Equally, during periods of scarcity, the success of one person or household can benefit others who participate in the sharing network. Sharing networks also extend beyond communities, with traditional foods being transferred between some communities by plane. The extent and nature of inter-community sharing and links to food security have not yet been formally examined in the BBDS region (Ford and Beaumier, 2011). In Greenland, food sharing has included the commercialization and industrial processing of various types of game, including reindeer, muskoxen, sea mammals, and seabirds.

The sense of collective community responsibility and mutual aid embodied in social networks has also been identified as underpinning resilience in other aspects of community life in the BBDS region. Many communities have informal search and rescue teams that rapidly deploy if a person is missing. The sharing of safety equipment and the provision of financial help within the family unit and occasionally with friends has been documented to help maintain harvesting livelihoods in some instances, and community mobilization and a strong sense of self help have underpinned efforts to anticipate, respond, and rebuild after natural disasters (e.g., power shutdowns in winter, disruption to transportation networks) (Prno et al., 2011; Spinney and Pennesi, 2013; Clark et al., 2016).

The evolving self-governments of the BBDS region have gradually managed to establish generalized safety nets and welfare provisions, which are of utmost importance in supporting families and households throughout their lives – including free health care, education, and elder homes. Still, the growth of the wage economy and the experience of colonial legacies have altered many of the social relationships that historically underpinned Inuit resilience to climate-related stress. Rising inequality and increasing individualism, for example, have considerably strained the networks through which non-food resources are shared (e.g., a number of studies have documented reluctance to share hunting equipment) (Wenzel, 1995; Ford and Beaumier, 2011). Wildlife regulations are a source of conflict in some instances, especially in Greenland, where professional and nonprofessional hunters have differential allocations of quotas and dispensation rights (Sejersen, 2009; Ford and Goldhar, 2012; Subchapter 6.5). In larger communities with significant in-migration from other communities, studies have shown that outsiders often do not have access to the networks through which environmental knowledge is shared (Pennesi et al., 2012; Ford et al., 2013c). Food sharing continues to be important, however, particularly in the smaller communities of Nunavut, in the context of evolving and adapting to contemporary realities (Wenzel, 2013; Organ et al., 2014). How such sharing practices might evolve in the context of future climate impacts has not been investigated.

General thinking on adaptation recognizes the importance of maintaining and strengthening social networks to respond to climate impacts (Ebi and Semenza, 2008; Fazey et al., 2010; Adger et al., 2013; Hess et al., 2014). In the BBDS region, little work by researchers, communities, or decision-makers has explicitly identified or evaluated potential opportunities to maintain or strengthen social networks. However, efforts to maintain and revitalize traditional knowledge, wildlife co-management, and decolonization have the potential to strengthen social networks, as do community-led initiatives that seek to catalyze action to address social problems and organize community events. Climate change creates renewed emphasis on these programs and also creates new needs in light of the potential negative effects of climate change on food systems and natural disasters.

The BBDS region provides some examples of innovative approaches to address these broader drivers of climate vulnerability. The Iqaluit Sustainable Community Plan (2014a, 2014b), for instance, establishes a community goal to share more food and to "*Encourage/support food sharing as a way for hunters to show respect*" (City of Iqaluit, 2014b, p. 11) in light of the multiple stresses affecting the community; the plan also encourages maintaining and enhancing current cultural programs around food preparation and provision. The Iqaluit plan further emphasizes that adapting to climate change will not occur in isolation but rather in the context of interconnected factors such as housing, poverty, food security, language, and modernization – all of which need to be targeted.

In Greenland, the population is declining (in contrast to the trend in Nunavut), especially in the smaller communities. The driving factors are urbanization and emigration (Government of Greenland, 2015a), which may weaken social networks and cohesion. The importance of social networks in underpinning community resilience needs to be broadly recognized by governments in the context of developments that threaten to undermine these networks.

11.4.2.4 Governance and institutions

According to Young (2012, p. 78), "*Governance is a social function involving the establishment and administration of assemblages of rights, rules, and decision making procedures intended to steer socioecological systems toward pathways that are collectively desirable and away from pathways that are undesirable.*" Climate change has brought a multitude of challenges to governance systems across scales in the Arctic: wildlife management regimes have been affected by alterations to the health, availability, and migration timing of fish and wildlife species harvested for subsistence and commercial uses and by uncertainty about the trends and likely future status of populations; a lack of clear jurisdiction or protocols for addressing future climate impacts, along with the cross-jurisdictional nature of impacts, has compromised the ability of institutions to effectively respond; and many northern institutions and regulatory systems are slow or poorly prepared to respond to stochastic change. Further, in many instances, larger-scale pressures external to the Arctic represent main drivers of change (Subchapter 3.3). Demands from outside the Arctic, or from other parts of the Arctic, for regulations on marine mammals and seabirds affected by sea ice and oceanographic changes (e.g., polar bear, murres) will potentially affect community harvesting behaviors and the ability of communities to adapt to change. Similarly, industrial developments and the expansion of marine traffic will be driven primarily by global economic and geopolitical factors (Chapters 7, 8, and 9). Migratory species with complex international movement patterns, population dynamics, and locally varying threats pose special challenges for interregional (BBDS and North Atlantic) management (Chapter 6).

These forces of change demand institutional responses that build upon cross-level interactions and cooperation among communities, regional governments (e.g., Government of Nunavut), national governments (including Greenland Self-Government), and Inuit organizations to respond to change in a manner that promotes the rights and needs of Arctic peoples while also responding to conservation challenges. In particular, polycentric governance has been recognized as important for adaptation (as for other issues) and can be thought of as a "*system of governance in which authorities from overlapping jurisdictions (or centers of authority) interact to determine the conditions under which these authorities, as well as the citizens subject to these jurisdictional units, are authorized to act as well as the constraints put upon their activities for public purposes*" (McGinnis, 2011, p. 171). By integrating organizations operating at multiple and overlapping spatial scales, polycentric governance has the potential to address environmental problems at multiple scales (Folke et al., 2005). These integrative attributes may be seen in co-management or adaptive management, in which decisions are made as dynamic responses to the outcomes of past decisions and changing social and ecological conditions (Folke et al., 2005).

Polycentric governance requires coordination across scales to ensure that decisions are taken at the correct level, based on the best evidence, and also necessitates collaboration and communication across institutions. There is evidence of polycentric governance emerging in the Arctic, with examples being the rise of co-management; the development of bridging organizations to connect stakeholders, scientists, and decision-makers across scales to confront novel challenges (e.g., Nunavut Climate Change Centre, Nunavut Research Institute); and the form of decentralized government in Nunavut. In Greenland, the Home Rule (1979–2009) and Self-Government (since 2009) have been responsible for the formal and centralized management of living resources since Greenland withdrew from the European Union in 1985. The Greenland government manages these resources (based on scientific advice from the Greenland Institute of Natural Resources) in formal consultation with well-established sectoral organizations of fishers, fish industry representatives, fish-processing plant workers, and other stakeholders. In practice, Greenland's politicians and public administration are also highly responsive to different types of informal lobbying, as well as public and parliamentary dissents. Influence and power are thus dynamic and partly decentralized in effect, but little official devolution of power has occurred in the form of co-management institutions (Jacobsen and Raakjær, 2012, 2014). The incorporation of user knowledge into the scientific formulation of total allowable catch (TAC) advice, in particular, continues to pose challenges and fuel conflicts (Jacobsen and Raakjær, 2012), but opportunities for dialogue on a more informal basis are continually being explored. Fishers' observations of environmental change are generally more timely than the scientific surveys; hence, the inclusion of traditional knowledge may be more relevant than ever in the context of rapid climatic changes (Hedeholm et al., 2016). The Arctic Council also plays an important role in these developments by identifying and assessing emerging issues, drawing them to the attention of Arctic and non-Arctic governments, prioritizing the addressing of risks within policy agendas, and bringing together decision-makers from across scales and regions to communicate and assess policy responses (Young, 2012; Chapin et al., 2015). The AACA project is one such example.

11.5 Addressing barriers to adaptation and building readiness to adapt

11.5.1 Research needs

Research plays an important role in informing adaptation efforts, and the last decade has witnessed a significant increase in Arctic-focused studies of impacts, adaptation, vulnerability, and resilience – in Arctic areas in general and in the BBDS region in particular (Ford et al., 2012, 2014a; Larsen et al., 2014). This work has helped to build an understanding of the multiple stresses facing the region and of opportunities for adaptation in a rapidly changing climate. Still, a number of knowledge gaps exist, which limits our ability to inform the development of sustainable and effective policy responses. Some observers have also criticized the extent to which this work has engaged communities, regional and local decision-makers, and Inuit knowledge systems (Ford et al., 2013a; Brunet et al., 2014; Ford et al., 2016a). These gaps have been identified in the scientific literature and also by decision-makers and communities; they were also identified in consultation processes during the creation of this chapter (see Chapter 1).

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A mother carries her child in a sealskin Amaut. Qeqertat, N.W. Greenland

11.5.1.1 Geographic and sectoral understanding

Across the various sectors covered in this AACA assessment, work on the human dimensions of Arctic change was found to be more developed in Nunavut than in Greenland. This finding is consistent with systematic reviews of the state of Arctic climate change literature (Ford et al., 2014a) and, more generally, of work on Arctic well-being (Lehti et al., 2009; MacDonald et al., 2013). In Greenland, challenges from demographic trends (Government of Greenland, 2015a) and education gaps (Chapter 5) have received the most attention, with few studies examining other drivers of vulnerability and resilience to climate change or identifying opportunities for sector-specific adaptation. However, challenges and opportunities in fisheries and hunting, shipping, and agriculture have recently been analyzed (Government of Greenland, 2012; 2015b; Lehmann et al., 2016).

A number of socio-economic sectors are included in a well-established body of research focusing on climate change adaptation – e.g., living resources (Chapter 6) and infrastructure (Chapter 10). In other sectors, studies are evolving – e.g., health (Chapter 4), tourism (Chapter 8), and shipping (Chapter 9). Publicly available information from the education sector (Chapter 5) and the non-living resources sector (Chapter 7) (or the private sector more generally) is limited.

This assessment also reviewed the body of empirical work focusing on specific communities. That research has been conducted primarily in the smaller, more traditional communities. Few research reports are available from the larger towns (e.g., Nuuk, Sisimiut, Iqaluit).

Work that focuses on understanding and capitalizing on the benefits of climate change is generally less well developed than the research into potential negative impacts. At least in Greenland, though, there are high expectations of expanding fisheries opportunities – along with a realization that the benefits may not be distributed equally and that the challenges from changing conditions may affect mainly those who are already marginalized in small settlements or are engaged in small-scale fisheries and subsistence hunting. In Nunavut, the potential benefits from changing fisheries and expanded open-water harvesting opportunities have yet to be fully explored.

11.5.1.2 Futures work

An important component of adaptation is identifying and characterizing potential future drivers of change. Research based on modeling studies has examined the potential impacts of climate change on ecosystems, sea ice environments, landscape processes, and extreme weather (Subchapter 3.1). Yet, despite the availability of projections of climatic drivers (e.g., DMI, 2015) and social drivers (e.g., demographic and economic data; Andrew, 2014; Government of Greenland, 2015a; Poppel, 2015), few studies explicitly incorporate these projections or community knowledge into assessments of how projected climate impacts in combination with socio-economic or demographic trends (e.g., changes in population numbers or structure, employment projections) might affect regional and community vulnerability, resilience, and adaptation. Instead, the majority of studies focus on documenting current and experienced impacts, underlining a need for futures-oriented work in the region across sectors.

In advancing such work, innovative methodologies that respect diverse conceptualizations of time are needed. For instance, many individuals in Inuit communities are often hesitant to speak about the future – a reflection of their beliefs about the sentience of the natural world (Bates, 2007; Natcher et al., 2007). A number of futures-based studies undertaken with communities in the BBDS region offer insights for future work. One example is the Iqaluit Sustainable Community Plan (2014a, 2014b), which created a long-term (50-year) vision of Iqaluit in light of multiple stresses, including climate change. The plan identifies actions the community can take now to eventually reach the desired future scenario. This assessment was based on extensive community engagement in a variety of forms – e.g., storytelling, interactive exhibitions, interviews, focus groups, and meetings with long-term residents (City of Iqaluit, 2014b). In other cases, futures work has been used to consider future community land use – e.g., using participatory three-dimensional visualizations to identify resilient pathways for development in Clyde River, Nunavut (Sheppard et al., 2013) or to identify future drivers of change in Greenland (Hansen and Larsen, 2014). In Greenland's national country planning processes – and in the banking sector's formulation of investment strategies – the effects of changing demographic patterns (including the trends of urbanization and emigration) are applied in projections of infrastructure and social service needs and in investment risk analyses (Government of Greenland, 2015a). Climate change projections are only beginning to be considered in planning.

11.5.1.3 Developing an evidence base on adaptation

This AACA assessment, as well as other work, indicates that adaptation is occurring in the BBDS region, although so far the focus has tended to be on risk assessment and capacity building. These are important first steps, but there is as yet limited evidence of more tangible adaptation actions being taken – for instance, in association with changing laws, regulations, and policies regarding climate impacts, or alterations in land use planning and emergency preparedness. This situation partly reflects the need for more knowledge on adaptation measures, strategies, and policies; the majority of work so far focuses on documenting impacts or assessing vulnerability. Adaptation thinking, as documented by scientists and governments, has tended to produce portfolios or "wish lists" of potential response options – but has provided only limited guidance for decision-makers on how to prioritize such lists (Champalle et al., 2015).

For climate-centered adaptations (Figure 11.2), the various options need to be assessed and prioritized in light of (1) the timescale of adaptation, in terms of how long an option takes to implement and how long before effects are apparent; (2) equity implications, in terms of whether other social groups or regions would be adversely affected by the adaptation action; (3) sustainability, in terms of long-term viability and effectiveness within the context of uncertain future environmental, climatic, and socio-economic conditions (e.g., demographic structure, resource development, livelihood characteristics), including the potential for maladaptation; (4) costs, including the economic value of design, implementation, execution, and monitoring and evaluation; and (5) synergies or contradictions that might occur between and among adaptation options and other policies (Champalle et al., 2015; Ebi and Burton, 2008).

For vulnerability-centered adaptations (Figure 11.2), existing policies and programs in diverse sectors need to be examined in terms of (1) how they may be affected by climate change, (2) how a climate adaptation lens can be incorporated (mainstreamed), and (3) their effectiveness in reducing vulnerability. In addition, there appears to be a need for capacity building among the range of civil servants who will increasingly be required to consider the mainstreaming of climate change effects into sector planning, including the commissioning of specialized studies to aid the process. As an example, at the AACA 2016 Greenland stakeholder consultation (see Chapter 1), orientation and training workshops for ministry staff were requested as a step toward the mainstreaming of adaptations across sectors; the Greenland Self-Rule Government has already commissioned adaptation studies for key business sectors. For all types of adaptation, the importance of monitoring and evaluating initiatives is widely recognized. These activities are helpful for examining the outcomes and effectiveness of adaptation measures, promoting accountability in the allocation of resources, providing learning opportunities, and informing planning and decision-making (Bours et al., 2015). To date, little if any work has monitored and evaluated adaptation initiatives in the BBDS region.

11.5.1.4 Transformational adaptation

Given the magnitude of climate change and projected climate impacts, interest in transformational adaptation (TA) is increasing. Transformational adaptations are those that are adopted at a much larger scale or intensity than other forms of adaptation; are new to a particular region or resource system; or are transformational at a systems level (e.g., shifting a system to other locations) (Kates et al., 2012; Pelling et al., 2015). There is evidence that transformational adaptation has historically occurred in the BBDS region, involving community reorganization and technological innovation in the face of environmental change (McGhee, 2004; Dugmore et al., 2007). An example of this historical TA is the Dorset–Thule transition that occurred around AD 1000, when the Medieval Warm Period caused a shift in bowhead whale migration patterns, which in turn resulted in the movement of Thule hunters from Alaska to the western Arctic. There, the technologically advanced Thule are believed to have coexisted for some time with the Dorset people of the region before eventually displacing them (Raghavan et al., 2014).

Future climate change may bring a need for transformational adaptation in some Baffin Bay/Davis Strait communities, regions, and sectors. So far, however, there has been little consideration of TA in the region – e.g., seeking evidence of transformational adaptations already taking place or developing an understanding of the changes that might eventually require TA. There is a need to identify the potential climatic and other changes that may necessitate transformative responses, as well as the key components of transformative change that are specific to the livelihoods and culture of the BBDS region.

11.5.2 Building readiness to adapt in the BBDS region

While interest in adaptation in the BBDS region and across the Arctic is growing, many barriers have been identified as constraining current action and limiting the potential to move forward on adaptation in the future (e.g., competing priorities, lack of adaptation-specific funding, limited knowledge of projected climate change impacts and vulnerability). Many of these barriers, which parallel those identified outside the Arctic, constrain action on developing climate-centered adaptations and integrating a climate lens into efforts to address the underlying determinants of vulnerability and build resilience (Biesbroek et al., 2013; Eisenack et al., 2014). To prepare for adaptation, action is needed across scales by governments, communities, decision-makers, Inuit organizations, and the research community.

Ford and King (2015), drawing upon research into the factors that motivate adaptation in diverse contexts, identify several overarching factors essential for adaptation to take place through governance systems at various scales. These factors are used here to structure the identification of areas where action is needed in the BBDS region in order to build readiness to adapt and move the adaptation agenda forward. Not all factors are needed in every instance; the importance of each will vary depending on scale and context.

- **Political leadership on adaptation:** Strong political leadership is important for initiating the process of adaptation, providing strategic direction, sustaining momentum over time, and overcoming the bureaucratic resistance and turf battles that often characterize an issue such as climate change. There is evidence of BBDS leadership on adaptation at lower levels of governance: community leaders have lobbied for adaptation action, have led vulnerability and adaptation assessments, and have sought to bring attention to the issue. Similarly, there has been leadership from the Government of Nunavut, with the release of a 2011 strategic adaptation document (Government of Nunavut, 2011); from the Canadian federal government, with targeted funding for vulnerability assessments and adaptation planning; and from Inuit organizations (e.g., the Inuit Circumpolar Council and Inuit Tapiriit Kanatami, Canada's national Inuit organization), in lobbying for action on climate change and for support of Inuit communities on domestic and international stages. Nevertheless, while these actions are important, there has been little evidence of leadership on adaptation at the highest levels (e.g., ministerial, premier). Thus, Nunavut's strategic document on adaptation is more a guide for integrating climate considerations into planning than it is a statutory responsibility. There is no requirement for federally supported adaptation plans to be adopted to guide decision-making (Burton, 2011; Austin et al., 2015; Labbé et al., 2017).

  Greenland has lagged behind Nunavut and Canada in terms of political leadership on adaptation but is now catching up. Public information and sector analyses for fisheries and hunting, shipping, and agriculture are now available (Government of Greenland, 2012, 2015b; Lehmann et al., 2016) – and in 2015, the Self-Government decided to mainstream climate change adaptation into sectoral planning. For example, the 2016–2022 finance plan for infrastructure development explicitly states that "*a modern and effective infrastructure … is important for adapting to climate change in the coming years*," and the Ministry of Finance has requested that sector ministries include climate change aspects in their annual planning documents (AACA Nuuk stakeholder workshop, 2016).

- **Institutional organization for adaptation:** Institutions are the formal and informal rules that structure and constrain human (inter)actions and provide the political and administrative structure that can either enable or restrict adaptation. Research on adaptation in other regions indicates adaptation actions and planning to be particularly effective when a single government agency takes a coordinating lead role or when an interagency group is created to oversee adaptation activities (Biesbroek et al., 2010; Eisenack et al., 2014). National governments, in particular, have been identified as having an important role in coordinating action; in creating coherence, coordination, and long-term planning; and in integrating adaptation into climate-sensitive policies across government scales (Austin et al., 2015). Canada has shown leadership in the North through the creation of the Pan-Territorial Adaptation Partnership, which brings together the governments of Nunavut, the Northwest Territories, and Yukon to collaborate on tangible adaptation efforts by working with a network of academics, practitioners, funders, and community members. Nunavut has also created a Nunavut Climate Change Centre within the Department of Environment, with the aim of assisting with implementation of the territory's *Upagiaqtavut* strategic document on adaptation (Government of Nunavut, 2011). The center acts as the primary hub for climate change and adaptation information for Nunavummiut (residents of Nunavut) and the Government of Nunavut, and it plays a supportive role on adaptation projects in the territory. The center has pioneered an approach to adaptation based on engagement of multiple knowledge systems and has supported initiatives such as community-based committees and other local forums to exchange information on climate change, facilitate training opportunities, and document *Inuit Qaujimajatuqangit* and local knowledge (Government of Nunavut, 2011). These steps are important, but in the absence of a statutory requirement to consider climate change, departments will continue to lack the authority to effectively plan for adaptation (Labbé et al., 2017). In Greenland, progress has been made with the recent decision toward sector mainstreaming (see above). Here, the Climate Unit within the Ministry of Nature, Environment and Justice coordinates climate change adaptation and mitigation. To help inform adaptation and planning, the University of Greenland and the Greenland Climate Research Centre have established the joint Climate and Society program, with research and teaching focused on the intersection of social science, climate science, and public policy.

  Strengthening the cross-boundary networks that link Greenland and Nunavut and sustaining dialogue between the scientific community and stakeholders in government, communities, and the private sector are important for advancing adaptation around shared priority issues in the BBDS region. Future actions will need to build on a number of initiatives currently underway in the region, including AACA and ArcticNet.

- **Regional and local leadership:** As noted in Subchapter 11.3, leadership by communities and decision-makers and the engagement of Indigenous knowledge systems in adaptation research and decision-making are essential for adaptation in the BBDS region (see also Figure 12.1). There is evidence of this leadership in the region, and research in the region is increasingly using participatory approaches. Still, many gaps remain, with participation being often informative (whereby stakeholders are informed of the issues at stake) or consultative (whereby stakeholders contribute their expertise to the policy-making process) but rarely decisional (whereby stakeholders have an actual say in decision-making). There is a need for deeper involvement of regional and local leadership in adaptation decision-making.

  The use of adaptation decision-making approaches can help to overcome barriers to adaptation. For example, vulnerability-centered approaches to adaptation (including the concepts of mainstreaming and no-regrets and low-regrets adaptation) can help bring adaptation into familiar territory for policy-makers by showing that adaptation can be integrated into ongoing policy processes, with present-day benefits (Ford et al., 2014b). Community-based adaptation is an approach that has emerged from work by nongovernmental organizations and development practitioners in low- and middle-income nations, with communities taking a lead role in adaptation projects and directing adaptation actions. The viability of this approach for the North was examined by Ford et al. (2016b). For climate-centered adaptations (Figure 11.2), the concepts of adaptation pathways (which emerged from the City of London's approach) and flexible adaptation (as embodied in New York City's approach) can help to position CCAs as ongoing processes with the potential to change as climate and society change and new needs arise (Rosenzweig and Solecki, 2014; Wise et al., 2014). At present, there is limited evidence that these two approaches to adaptation (developed elsewhere) have been used to guide adaptation policies, programming, or actions in the BBDS region; there is a need to examine with decision-makers and communities whether such ideas are applicable in a northern context and, if so, how they may guide policy processes. When adaptation research in the BBDS region is led by scientists from outside the region, it is essential that communities and decision-makers be fully involved throughout the research process – specifically, in contributing Inuit knowledge and cultural values, which have been identified as central to adaptation to many of the risks posed by climate change (Pearce et al., 2015b). Such values figure strongly into Nunavut's strategic plan on adaptation (Government of Nunavut, 2011) and have been integrated into research on vulnerability and adaptation in Nunavut and Greenland.

- **The need for usable science:** Across sectors, further research is needed on climate change impacts, adaptation, and vulnerability, and this research needs to explicitly integrate scientific and traditional knowledge. (The preceding chapters note sector-specific research needs.) To effectively inform adaptation policy and catalyze adaptation action, simply supplying information to decision-makers is not sufficient (Moss et al., 2013; Klein and Juhola, 2014). As noted above, adaptation research needs to actively involve (and be led by) decision-makers throughout the research process, needs to be informed by user requirements and expectations, and needs to be accompanied by targeted outreach and support on how to use the findings. Recognition of these characteristics of "usable science" is increasing in the research community, but many scientific programs in the North remain focused on top-down approaches that supply decision-makers with information and afford them only limited engagement in the research process (Ford et al., 2013b; Brunet et al., 2014).

  Across multiple levels of government and within the private sector of the BBDS region, the understanding of adaptation is generally low. For example, assessment of the perceptions of climate change impacts and adaptation within the resource industries (primarily mining) has indicated that the decision-makers responsible for designing, building, maintaining, and decommissioning industrial infrastructure have only a limited understanding of the likely impacts of future climate changes (Ford et al., 2011a; Lemmen et al., 2014). Hence, there is a need for capacity building among government staff and, in particular, for more effective dialogue between the producers and users of scientific information (Jones et al., 2015); this need includes contributions from the social sciences, to help shape tools in support of vulnerability-centered adaptation (Figure 11.2).

  Assessments such as the AACA program and the ArcticNet Integrated Regional Impact Studies (IRIS) can play an important role in synthesizing key information on climate impacts and adaptation options (Allard and Lemay, 2012). By linking the assessment process to targeted knowledge mobilization and by engaging knowledge users in generating understanding, these approaches offer useful models. A greater emphasis on targeted knowledge mobilization is needed within the scientific community, to go beyond producing just journal articles. Central to northern adaptation work is the need for targeted policy briefs on research findings, targeted presentations and discussion sessions with decision-makers and communities, ongoing discussions regarding emerging project results, the use of online and social media, and other relevant activities.

- **Funding for adaptation:** Few adaptation policies, programs, or actions can be implemented and maintained solely with existing funding streams; to be effective, adaptation funds need to be integrated into baseline funding (Ford and King, 2015). Funding needs for adaptation include financial support to undertake vulnerability and adaptation assessments; to develop the human resources necessary to successfully identify, implement, monitor, and maintain adaptation efforts; and to cover the capital costs of actions and their maintenance over time. In Nunavut, the federal government has supported a number of initiatives to assess climate change risks and identify adaptation options – e.g., the *Climate Change and Health Adaptation in Northern First Nations and Inuit Communities* program of Health

Canada and the *Assisting Northerners in Assessing Key Vulnerabilities and Opportunities* program administered by Indigenous and Northern Affairs Canada. These programs have been important, yet as noted by Ford et al. (2011b), funding for adaptation research in Canada remains limited and has been volatile, reflecting political influences and an absence of long-term strategic planning for adaptation. No publicly available studies have evaluated spending on actual adaptation activities by different government departments, and none has documented the intramural allocation of funds within departments for adaptation. While public funding is needed for much of the VCA spectrum (Figure 11.2), the fisheries sector, driven by market forces, seems to have efficiently utilized adaptation on an ad hoc basis (Subchapter 6.4) – e.g., Greenland's fisheries consortia have hired specialized foreign vessels for test harvests of "new" resources. However, the political demand (in Greenland) for land-based processing and value chain development may necessitate some public support to make processing plants flexible and receptive to new and fluctuating resources.

- **Public support for adaptation:** Public opinion has an important influence on the initiation and development of adaptation programs – in encouraging decision-making, building institutional capacity, and implementing practical adaptations. Public consciousness is particularly important when adaptations entail unpopular decision choices and a high degree of "social license" is needed (Ford and King, 2015) (see Subchapter 12.9). Public opinion is also essential for the sustainability and success of adaptation actions and for ensuring that the actions are locally and culturally appropriate and relevant, especially at a community level. There is evidence that concern about climate change is growing in the BBDS region, due to direct experience with the rapidly changing Arctic environment, Inuit leadership on climate change globally, and innovative northern programs such as the Nunavut Climate Change Centre, which has a mandate to engage communities on climate change. There are also examples of "adaptation champions" in communities and government positions (Labbé et al., 2017). However, an adaptation consciousness that recognizes the risks posed by climate change and the need to consider climate impacts in planning is still nascent in communities and across levels of government. A key challenge for adaptation in the BBDS region, then, is to raise awareness among the public and decision-makers on the risks posed by climate change, by integrating both scientific and traditional knowledge. Public consultation and presentation of research results are essential to this end; this work also entails having researchers work with decision-makers, along with documenting community perspectives on climate change risks and potential adaptations. Positive developments already underway in the region include the development of a guide by the Government of Nunavut to help homeowners and decision-makers better understand permafrost, how climate change affects permafrost, and how to make simple at-home changes to reduce permafrost thawing (Chapter 10; Figure 10.28). Further efforts aimed at information exchange are needed, including knowledge exchange and the shared promotion of best practices between Greenland and Nunavut – and across the wider circumpolar community, where the Arctic Council can play a prominent role in knowledge management (Arctic Council, 2013a).
- **Climate change mitigation:** "*Climate change poses an increasing threat to equitable and sustainable development*" (IPCC, 2014b, p. 90) – so although the AACA project and this report focus on adaptation to the unavoidable consequences of climate change, the people and governments of the Arctic will also need to contribute to the limiting of further warming through mitigation. Adaptation and mitigation are complementary strategies for reducing and managing the risks of climate change in many instances (IPCC, 2014b): "*Adaptation and mitigation responses are underpinned by common enabling factors. These include effective institutions and governance, innovation and investments in environmentally sound technologies and infrastructure, sustainable livelihoods and behavioural and lifestyle choices*" (IPCC, 2014b, p. 26). Hence, similar to the adaptation-related points enumerated above, efforts to contribute to climate change mitigation will also require funding, political leadership, stakeholder engagement, and public support to promote cross-learning, research and development into climate-compatible development, and, for example, energy-efficient technology for polar conditions. Fortunately, there may often be mitigation co-benefits of adaptation options, including the "no-regrets" or "low-regrets" options summarized in this report.

11.6 Tools to help the adaptation process

A wealth of tools is available to help guide adaptation processes. Some of the most relevant for an AACA perspective on *developed countries* and urban areas include the following:

- The *Adaptation Support Tool of Climate-ADAPT*, the European Climate Adaptation Platform: climate-adapt.eea.europa.eu/adaptation-support-tool
- *Assessing the Climate Change Fitness of Spatial Planning: A Guidance for Planners* (Pütz et al., 2011): www.wsl.ch/fe/wisoz/dienstleistungen/clisp_guidance/index_EN
- The *weADAPT*® collaborative platform on climate adaptation issues, supported by the Stockholm Environment Institute: weADAPT.org
- The *PROVIA Guidance on Assessing Vulnerability, Impacts and Adaptation to Climate Change* (PROVIA, 2013): www.unep.org/provia/RESOURCES/Publications/PROVIAGuidancereport/tabid/130752/Default.aspx
- *Climate Change Adaptation in Developed Nations: From Theory to Practice* (Ford and Berrang-Ford, 2011): www.springer.com/us/book/9789400705661

Under the United Nations Framework Convention on Climate Change, guidance documents are also offered to help countries develop national adaptation plans (NAPs). Although the NAP process is targeted mainly to *developing* countries, many of the general steps are generic – and relevant for any national or local government (LDC Expert Group, 2012):

- *National Adaptation Plans: Technical Guidelines for the National Adaptation Plan Process*: unfccc.int/resource/docs/publications/publication_ldc_nap_techguidelines.pdf

For local (municipal and community) adaptation priorities and planning, a Nunavut guide developed specifically for the Canadian Arctic (Canadian Institute of Planners, 2011) can serve as inspiration for local planners and also as guidance for national-level planning. This guide explains the community-level planning process that leads to community adaptation plans. Two local adaptation plans, each with many practical, low-key examples, are available for the BBDS communities of Clyde River and Iqaluit:

- *Climate Change Adaptation Planning: A Nunavut Toolkit*: www.cip-icu.ca/Files/Resources/NUNAVUT-TOOLKIT-FINAL
- *Climate Change Adaptation Action Plan: Clyde River, Nunavut*: climatechangenunavut.ca/sites/default/files/clyde_river_-_community_adap_plan_eng.pdf
- *Climate Change Adaptation Action Plan for Iqaluit: 2010*: www.cip-icu.ca/Files/Resources/IQALUIT_REPORT_E

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12. Summary of adaptation options for the BBDS region

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> *"Inuit author Rachel A. Qitsualik (2006) cautions that from her cultural perspective, Nalunaqtuq – translated as 'the Arctic environment's inherent unpredictability and indeterminacy' – will continue to confound colonial efforts, as it has in the past. Acceptance of Nalunaqtuq is one key to the resilience of Inuit culture, and this philosophical principle is of immediate and obvious salience for others in or concerned with the Arctic as changes there continue to accelerate"* (Arctic Council, 2013b, pp. 85–86)

12.1 Introduction

The following sections summarize the main adaptation options from this report, consider and consolidate the sectoral responses outlined in previous chapters, and add relevant adaptation options from other sources, including Arctic Council reports. While we summarize potential adaptation options by sector, following the structure of the report, we also note overlaps between sectors and the need to consider how adaptations in one sector or region may affect other sectors or regions – highlighting the need for broad-level adaptation planning at regional to national scales. Consistent with the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2014), the adaptations by sector are categorized as (1) *structural/physical*, capturing discrete adaptation options with clear outputs and outcomes well defined in scope, space, and time, and including technological, engineered, and ecosystem-based options and services; (2) *social*, targeting the specific vulnerabilities of disadvantaged groups, including the targeting of vulnerability reduction and social inequities, and including education, information sharing, and training; and (3) *institutional*, encompassing economic solutions, legal and regulatory actions, and government policy and programs. These sections are followed by a table (Section 12.9) that briefly summarizes key adaptation options distilled from the entire report and other sources as noted above. This table was developed to facilitate easy reference by local, regional, and national decision-makers.

In examining adaptation options for the Baffin Bay/Davis Strait (BBDS) region, we recognize that the worldviews of residents, officials, and politicians will differ and that these worldviews affect the priority and relevance that people will assign to any given option. For instance, a workshop report on Inuit perspectives on climate change adaptation from Nunavut noted that "… *climate change is more of a pressing issue because of its impact on Arctic wildlife and its potential to accelerate the loss of the traditional Inuit hunting culture and the associated socio-economic importance of country foods, than it is an issue through its impacts on areas such as infrastructure*" (NTI, 2005, p. 3). Because this BBDS report will (we hope) be read by a variety of stakeholders with a variety of worldviews, we can therefore not ascribe priority to the adaptation options described in the table in Subchapter 12.9; we leave that prioritization to the stakeholders themselves.

The overall approach that key actors at different levels (e.g., community, region, ecosystem) may take in building resilience to changing risks and uncertainty in the Arctic is outlined in Figure 12.1.

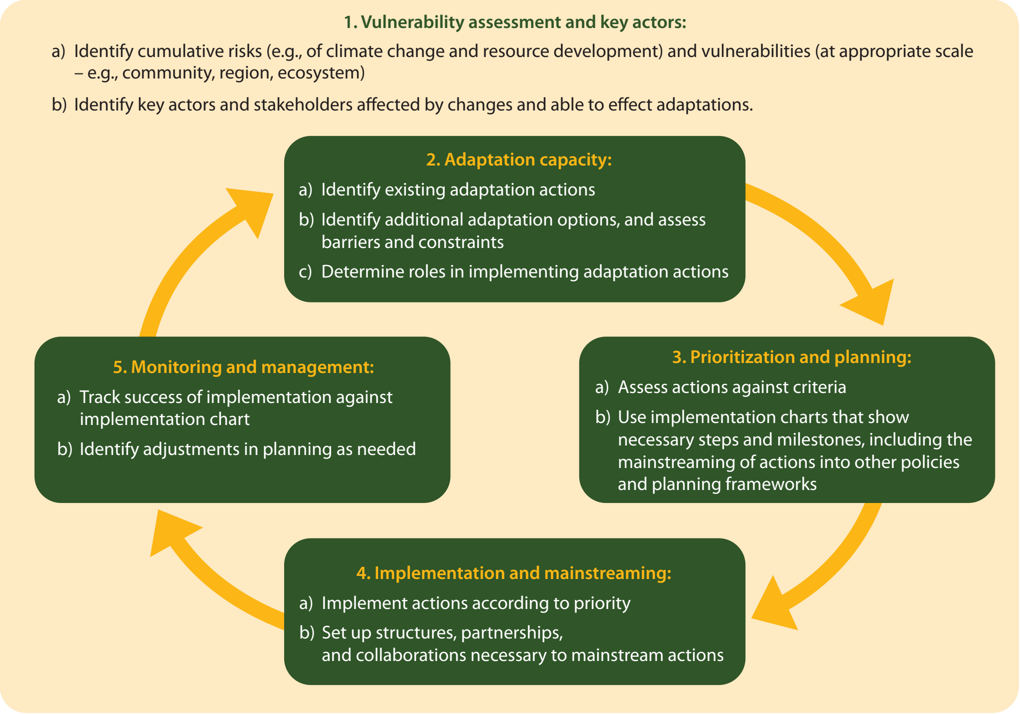

Figure 12.1 Steps in a prioritized climate change adaptation plan for Arctic communities (based on Champalle et al., 2015).

12.2 Health and safety (Chapter 4)

Some health impacts of climate change will be direct, resulting from changes in temperatures or from extreme weather events; other impacts may be indirect, resulting from how climate change affects livelihoods, food systems, infrastructure, wildlife, and infective agents (Furgal and Séguin, 2006). All of these changes will also have an impact on community well-being, and that impact can in turn compromise or enhance resilience. As summarized in Chapter 2, key health challenges directly related to climate change include new vector-borne diseases (e.g., the appearance of diseases such as tetanus, which is not a problem in the Arctic today), drinking water quality problems (resulting from the use of surface water as a source), and greater food insecurity (associated with a compromised ability to harvest local foods, due to changes in sea ice conditions and the health and availability of key wildlife species). Studies have already documented an increased magnitude and frequency of temperature extremes and extreme weather events in the BBDS region, with implications for hunting and traveling accidents, temperature-related deaths, and food insecurity. These risks and associated adaptation options are further discussed below. Because extreme weather and accidents/disasters are not discussed in Chapter 4, those topics are given more emphasis here.

Changing precipitation regimes will have implications for water quality. The important role of spring snowmelt in resupplying reservoirs and lakes, the sporadic and unpredictable delivery of summer rainfall runoff, and the length of the winter period during which supplies cannot be replenished all create unique challenges for water management in the BBDS region. While many water supplies are sufficiently large to avoid water limitation, studies in Nunavut identify some to be at risk, including the Geraldine Lake reservoir system that serves Iqaluit (see Chapter 4). This system is vulnerable to end-of-autumn water limitations, with the critical time for refilling limited to a short interval early in the spring season when snowmelt is abundant. Climate warming may also jeopardize water quality in residential storage tanks and other informal water systems (Chapter 4), and there may be a need to improve water quality monitoring for both primary and secondary sources of drinking water in communities (Allard and Lemay, 2012). There may also be a need for enhanced technical solutions – i.e., "climate-smart" water storage and distribution systems.

Warmer temperatures will likely bring new diseases, including those in water or carried by insects and other vectors. For instance, Lyme disease is expected to expand northward into the eastern Canadian Arctic and become a major public health issue over the next 70 years (Hess et al., 2009). Few studies in the BBDS region have examined how climate-related health outcomes will likely be affected by future climate change (Harper et al., 2015a, 2015b), although it is generally expected that existing risks will increase in magnitude and frequency, with some associated benefits from reduced exposure to extreme cold.

As concluded in Chapter 4, it is important that "*Health-related issues, often framed from a place of health deficit, must be approached from a place of developing sound and vibrant communities to ensure a more holistic understanding of health. Health must be viewed outside the traditional model of solely describing disease and negative health outcomes, and health programs must build on community strengths … Climate change will require individuals and communities to draw upon resilience as a means to cope with changing external conditions …*" And finally, "*… discussions of health and well-being should not be framed strictly as deficits but should instead be focused on … asking ourselves, given the changing environment, what is the state of our communities and what are the opportunities for enhancing health and well-being in our communities*?" Hence – also in line with some of the findings in Chapter 10 (built infrastructure) and the priority issues for regional development summarized in Chapter 2 – efforts to address *current* vulnerabilities, socio-economic risk factors, and main development gaps are "no-regrets" options (see Section 11.3.1) that also build resilience. If we solve the current challenges, at least they will not be exacerbated by a changing climate. Other adaptations in a health context may be targeted more to specific impacts of climate change (i.e., climate-centered adaptation; Figure 11.2) and may involve preventing disease or injury before it occurs (primary interventions), reducing the impact of a disease or injury that has occurred (secondary prevention), or managing the effects of ongoing illness or injury (Ebi and Semenza, 2008; Frumkin et al., 2008; Bell, 2011; Hess et al., 2012). Thus, adaptation in a health context is synonymous with prevention (i.e., seeking to prevent and minimize impacts) and, as such, is sometimes referred to as "mitigation" in a health context. (This usage can create confusion in a climate-change context, where "mitigation" refers to reducing greenhouse gas emissions.)

Social adaptations

- *Monitoring and surveillance*: Surveillance, early warning systems, and improved data collection are critical components of efforts to anticipate and respond to changing risk patterns, including shifting risk patterns in health and safety (Chapter 4; Ebi and Semenza, 2008; Parkinson et al., 2008). Surveillance involves the systematic collection of information about risk factors and outcomes required to identify the occurrence and spread of health risks, identify the emergence of new risks (including those affected by climate change), and disseminate information to relevant actors. Early warning systems provide timely information to populations and front-line health personnel when a threat is expected. Current surveillance and early warning capacity for the BBDS region in general is limited and fragmented, in need of additional investment (Smylie et al., 2006). The current lack of capacity increases sensitivity and constrains adaptation to climate change impacts (Ford et al., 2010a). The increasingly unpredictable and sporadic nature of rainfall/runoff events, for instance, is presenting serious challenges to monitoring water quality (Harper et al., 2011; Harper, 2014), while at the same time, the ability to detect disease outbreaks or the spread of infectious diseases is limited (Ford et al., 2014b). Increasing surveillance and early warning capacity in relation to climate-related health risks is important – including the identification and monitoring of culturally specific and locally relevant health indicators, examination of the potential to use sentinel health events as indicators, identification of indicators to monitor emerging climate change impacts and vulnerabilities, and development of infrastructure to link indicators to early warning (Hueffer et al., 2013; Parkinson et al., 2014; Dudley et al., 2015). Linking monitoring and surveillance systems to decision-making processes at local to regional to national scales is essential if such systems are to inform adaptation planning and risk reduction.

- *Improved hazard forecasting*: Climate change impacts have magnified the risks associated with travel and subsistence ("land-based") activities in the BBDS region. Studies, mostly in Nunavut, have found that individuals lack weather and ice-condition information that is sufficiently reliable and useful for decision-making, while at the same time some traditional forecasting techniques are becoming less reliable (Prno et al., 2011; Pennesi et al., 2012). Communities need access to trusted weather and ice services that integrate both local and scientific knowledge and are transmitted through appropriate media venues accessible to diverse community members (Laidler et al., 2011). As noted by Pennesi et al. (2012), it is important that forecasters have a close understanding of the social and geographical contexts of their operations and have knowledge of the types of weather and ice information used most frequently by the group or sector at which their forecasts are aimed. Such forecasts, particularly as they relate to severe storms, could also assist community planning (Spinney and Pennesi, 2013). Relevant to improved hazard forecasting, a demand for hazard maps that combine both Inuit and scientific knowledge to document how changing climatic conditions are affecting land trails, ice conditions, and harvest areas has been noted in Nunavut communities (Gearheard et al., 2006, 2011; Pennesi et al., 2012; Ford et al., 2013).

Institutional adaptations

- *Housing quality and quantity*: Chapter 4 (see also Chapters 2 and 10) outlines the multiple physical and psychosocial health risks posed by the current housing deficits and poor conditions. Such risks include an increased prevalence of respiratory tract infections (due to exposure to mold, bacteria, and particulate matter, including smoke and other sources), high rates and transmission of tuberculosis, and elevated (physiological) stress. As pointed out in Chapter 4, "*Addressing the housing shortage, overcrowding, and inadequate housing is a prerequisite not only to fostering Inuit health and well-being but also to sustaining community social and economic development across the Arctic*" (see also Knotsch and Kinnon, 2011). Other no-regrets options that will build general resilience in people and society include enhancing health facility access, improving efforts to prevent "modern lifestyle" non-communicable diseases, and, in particular, addressing the general driving forces behind socio-economic vulnerabilities (a "social adaptation").

- *Enhanced search and rescue capability and disaster preparedness*: Climate change is presenting a number of challenges to search and rescue (SAR) efforts – e.g., increasing the frequency and danger of SAR events and creating the potential for new challenges associated with increased shipping (commercial, tourism, fishing) (Clark and Ford, 2017). This problem is acknowledged in the search and rescue exercise (SAREX) agreement approved at the Arctic Council's 7th Ministerial Meeting in Nuuk, 2011. As a result of this agreement, annual live search and rescue exercises among the eight Arctic states have been conducted annually since 2012 (Joint Arctic Command, 2013), supplementing a series of "Operation NANOOK" exercises conducted under Canadian leadership since 2007 (including cruise ship rescue simulations) (Chapter 8). In 2015, the Arctic Council's Emergency Prevention, Preparedness and Response Working Group (EPPR) incorporated SAR into its strategic plan (Chapter 9). Building on these experiences and the emerging capacity, it is important that SAR capabilities and institutional arrangements in the BBDS region be continually reviewed as the frequency, scope, and intensity of climate-related risks and impacts change. These regular assessments could include reviews of the following: multi-jurisdictional integration and alignment of SAR policies and practices; joint contingency planning among the organizations involved in search and rescue at different scales – including at the community level (see next paragraph) – to plan for dealing with changing risks; and worst-case contingency planning (Funston, 2014; Østhagen, 2014; Clark and Ford, 2017).

  Community-based disaster preparedness is successfully employed around the globe and is listed among "priorities for action" in the United Nations Sendai Framework for Disaster Risk Reduction 2015–2030 (UNISDR, 2015), but a systematic development of this approach has not been widely pursued in the BBDS region. With the region's wide expanses – land and sea – where people, boats, and larger vessels can face emergency situations, the formal rescue services (military and police) face enormous challenges in providing effective SAR services, despite the new SAREX collaboration (see above). Across BBDS settlements, communities of skilled hunters and fishermen engage in voluntary SAR within their activity range. For instance, in Nunavut, the hunters and trappers organizations (HTOs) already perform an important function in search and rescue, with the extent and nature varying by community (Ford et al., 2007; Clark et al., 2016) – but often in an ad hoc and partly uncoordinated manner (Funston, 2014). Civil society–based efforts could help harness this potential through "community rescue committees" that offer coordination and basic capacity building and help to raise community awareness. Incorporating volunteer-based capacity as an element within the multi-agency SAR contingency plans at different levels could also help to harness this potential. (In this regard, the Swedish Sea Rescue Society, www.sjoraddning.se/ine-english/, and the 300-team-strong Norwegian Red Cross Search and Rescue Corps may serve as inspiration.) Organized community rescue committees, which would be an asset under current conditions, would become even more important as increasingly unpredictable ice and storm patterns affect people in the BBDS region – as such, these committees would be a "no-regrets" or low-regrets" adaptation option (see Section 11.3.1). Existing organizations – in Greenland, the local Association of Fishermen and Hunters in Greenland (KNAPK), and in Nunavut, the HTOs – may be well placed to pick up parts of this challenge with support from different government levels.

- *Risk preparedness*: Climate change is likely to increase the frequency and intensity of a range of disasters affecting the

BBDS region. Examples include flooding and high winds, which have the potential to knock out key infrastructure (e.g., community power supply, transportation networks; Chapter 10), as well as other adverse events, which can cause land users to lose or damage hunting equipment (e.g., large-scale sea ice break-off events). Contingency planning at regional and community scales, to anticipate and prepare for these changing risks, is especially important for BBDS communities, where remoteness and limited access may delay the transportation of emergency supplies and relief. (For example, if transmission power lines are disrupted during a storm, then a community may need to fly in replacement parts, or if a storm damages transportation routes, then medical evacuations may be threatened.) In terms of developing resilience to such events, greater self-sufficiency for communities or households – for instance, through alternative power generation (e.g., via solar generation) – may be a viable option and a potential co-benefit with climate change mitigation ambitions. Other actions aimed at increasing community resilience – e.g., improved promotion of household preparedness plans, local access to health services, and food-supply security – would also be effective in this context.

- *Emergency funds and risk sharing*: Investing in first-responder training, developing emergency funds to help communities recover after an extreme event, and supporting hunters in replacing lost or damaged equipment have all been noted as being important in light of climate change (Ford et al., 2010b; Giles et al., 2013; Spinney and Pennesi, 2013). In Nunavut, an emergency fund system is already in place; in Greenland, according to the Greenland Ministry of Nature, Environment and Justice (in litt., 2016), the fund was abolished in 2015 and in case of an emergency, money will be found elsewhere. However, the need for such emergency funds can only be expected to increase with a changing climate, so due diligence would call for plans to upscale. In addition, there appears to be a need to more clearly define the criteria and thresholds for the release of emergency funds – for instance, to predefine when "extreme" ice conditions are seriously affecting certain hunting/fishing income opportunities or when extreme drought situations are jeopardizing farming livelihoods, thus warranting various levels of emergency support. Combinations of emergency funds, loans, and various forms of risk-sharing systems (e.g., insurance) may need to be further developed as extreme weather increasingly affects small businesses and vulnerable households.

12.3 Education (Chapter 5)

Climate change will have a variety of impacts on different aspects of education[13] and learning, potentially damaging school infrastructure in areas at risk of permafrost thaw, affecting population demographics where climate impacts may contribute to further outmigration from small communities (Chapter 2), and affecting traditional learning and the promotion of traditional values, which are closely connected to the land-based/subsistence activities that are becoming more challenging with climate change. Industrial development, too, may have negative impacts on the transmission of land-based/subsistence knowledge (Chapter 5), if knowledge holders are increasingly employed in situations that regularly separate them from community and family. Few studies explicitly focus on what climate change means for education and knowledge transmission more broadly, and few examine potential adaptation options – with an exception being research that has highlighted the importance of land skills and cultural programming to help strengthen the transmission of traditional knowledge (TK) and cultural values to younger generations (i.e., vulnerability-centered adaptations) (Pearce et al., 2011a, 2015; MacDonald et al., 2015). For example, while climate change is undermining some aspects of traditional knowledge, including the ability to forecast weather conditions and predict animal migrations, other skills are even more important in light of new and exacerbated risks (e.g., the ability to identify hazard precursors, possession of a survival mentality and skills, and knowledge of animal behavior) (Ford et al., 2007, 2010b; Government of Nunavut, 2011; Pearce et al., 2015). Anticipated regional change bolsters the argument for more culturally relevant schooling in the BBDS region and for alternative approaches to strengthen the transmission of land-based/subsistence knowledge (Government of Nunavut, 2011).

As pointed out in Chapter 5, "*Education has become the key factor for adapting to new changes in the environment and in society at large. Education is always an investment for the future, whatever the content might be.*" In other words, education is a no-regrets vulnerability-centered adaptation option. In terms of building resilience, there is a need to strengthen the northern education system so that people of the region are better prepared to adapt to and take advantage of the new economic opportunities that may accompany change (see Lutz et al., 2014, for a global example of the importance of education for adaptation) – a consideration recognized in Nunavut's *Upagiaqtavut* planning document for adapting to climate change (Government of Nunavut, 2011) (see also Chapter 11). The approach initiated by the Greenland government – working to diversify the range of available educational programs – is also a step in the right direction (Chapter 5). Similarly, there are efforts to meet the demands for more specialized occupational skills. These efforts include new partnerships to offer shorter vocational training that can begin to meet the growing needs of the tourism sector (Chapter 8) – for example, a new initiative to offer a basic (half-year) tourism guide course at "Campus Kujalleq" as a joint venture between two post-secondary educational institutions in South Greenland (Chapter 5).

Language programs in the BBDS region also need to be strengthened (Chapter 5). Education to face a changing world may include an enhanced focus on language skills. In Nunavut, strengthening competency in Inuktitut is a growing need; in Greenland, enhancing English skills (a third language) will help to open more doors to adaptation options: international studies

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[13] It is important to distinguish between *transmission of knowledge* (the higher-level concept of learning), *education* (the Western-dominant form of knowledge transmission), *Indigenous knowledge transmission* (based on learning by experience and observation and the transmission of values), and *training* (a limited transmission of technical knowledge for skills development).

Design Pics Inc/Alamy Stock Photo

Boy working computer, Nunavut

(distance learning and overseas courses), web-based business development, tourism and mining sector employment, and migration. Because of the rapid pace of change (mainly social and economic, but increasingly also climate-related), there is a need for a wide range of knowledge transmission activities, recognizing Indigenous traditions and providing education in all fields. In addition, supplementary private sector (re)training may be needed to adjust to specific emerging opportunities in, for example, the fisheries, mining, tourism, shipping, and construction sectors (Chapters 6, 7, 8, 9, and 10, respectively). Therefore, as opportunities arise in these sectors, development plans should include plans for the training of the local labor force.

Finally, Chapter 5 emphasizes that a significant development in northern higher education is the move toward thinking in terms of "circumpolarity." Despite increased interest, the use of information and communication technology and open learning networks for online courses and distance learning is still somewhat challenged by language barriers and by bottlenecks in the communication infrastructure (e.g., Internet connectivity; see Subchapter 12.8 below).

12.4 Living resources (Chapter 6)

Climate change has wide-ranging implications for terrestrial and marine wildlife resources, given the rapid warming that is taking place and the strong temperature sensitivity of many Arctic species and ecosystem processes. These effects on living resources may be further complicated, especially on a local basis, by industrial activities. There are implications for resource-based livelihoods in the BBDS region, including hunting, fishing, trapping, berry picking, and commercial fisheries and (in Greenland) agriculture. These living resources have significant economic, dietary, and cultural importance. Observed impacts to date have been mostly negative, relating to reduced availability or accessibility of traditionally harvested resources. However, some benefits of climate change have also been noted, including the expansion of open waters and new fisheries opportunities and an increasing abundance and availability of some marine mammals. These benefits may be transient, depending on future unforeseen ecosystem changes. Future climate change is expected to result in further shifts in biodiversity, as well as shifts in the geographic ranges of animal and plant species important to people in the BBDS region (Chapter 6).

The need to improve how wildlife and fish stocks are managed, given the rapidly changing climate and development stressors, is widely documented in major international Arctic-focused assessments and by the scientific community; specific proposals have been made to this end (ACIA, 2005; CAFF, 2013; Eamer et al., 2013). A number of considerations underpin these proposals, including the need to recognize the social and cultural impacts of wildlife management, especially on Indigenous communities, and the need for management regimes to address entire socio-ecological systems rather than focusing only on specific species. Other considerations include the need to identify and conserve key features driving ecosystemic resilience and the importance of taking coordinated action across different levels of government and different kinds of knowledge (Armitage, 2005; Berkes, 2007; Chapin et al., 2010; Christie and Sommerkorn, 2012; Young, 2012; Chapin et al., 2015). These principles are captured in variously termed approaches, including "adaptive ecosystem management," "ecosystem stewardship," and "adaptive management."

Specific opportunities for enhancing the management of living resources in light of climate change are outlined below.

Structural/physical adaptations

- *Ecosystemic and wildlife monitoring*: Responding to climate- or resource-driven change requires monitoring in order to better understand how species and ecosystems are responding and to identify emerging trends and risks. This requirement includes the need to support work at a community level; to combine traditional knowledge and science in documenting how species are changing and in providing continuous, real-time, locally grounded observations coupled with new opportunities to remotely track individual animals; and to fund cross-national efforts to document broad patterns in wildlife behavior and ecology (e.g., polar bear, narwhal, walrus, seabirds) (Gearheard et al., 2006; Huntington, 2011; Chapin et al., 2015). Developing specific ecosystem indicators to be evaluated at regular intervals will help in developing trend and risk information (Subchapter 6.1). Fisheries research is also identified as being helpful for establishing such things as a better understanding of what factors shape fish stocks in the region (see Subchapter 6.4)
- *Proactive conservation management*: The sources of ecosystemic resilience in the BBDS region could be systematically identified, and appropriate conservation management regimes could, to the extent possible, be put into place to safeguard those ecosystem-process drivers. This effort could include the conservation management of significant polynyas (for example, the Pikialasorsuaq/North Water Polynya) and of the projected area of future multi-year ice (the "Last Ice Area") (Christie and Sommerkorn, 2012; CAFF, 2013; Eamer et al., 2013). See Subchapters 6.2–6.3 for additional principles to further inform the selection and management of conservation areas. Conservation management may also be necessary to protect fisheries (Subchapter 6.4). As stocks of some natural resources diminish, divisions among stakeholders who advocate different management approaches – including the forms of knowledge (traditional knowledge and science) that may inform management – may be exacerbated. Co-management boards are a form of management that attempts to integrate the differing perspectives. To the extent that these boards are successful in this regard, they may help to confer resilience and be able to recommend appropriate adaptive management measures. This potential benefit requires that such boards be adequately appointed, resourced, and staffed.

Institutional adaptations

- *Government policies and programs*: A substantial body of research has called for co-management of wildlife resources in light of climate change impacts and observed population changes. Co-management combines Inuit traditional knowledge with scientific understanding of population vulnerability to climate change and harvest patterns and allows Inuit to exercise their traditional rights. (In Nunavut, these rights are legally codified through the Nunavut Land Claims Agreement.) Inuit have also asserted their right to be involved at national and international levels on broader questions of governance (ICC, 2009). In particular, work from the BBDS region and general Arctic scholarship has called for flexible, multi-level governance to help management systems deal with change by promoting the sharing of information among actors at different scales, increasing dialogue and the interactions necessary for conflict management, enhancing the speed at which information flows across scales, and maintaining flexibility in resource systems (Clark et al., 2008; Dowsley, 2009; Keskitalo and Kulyasova, 2009; Armitage et al., 2011). On another governance scale, where the ranges of species cross many national boundaries (e.g., seabirds), sustainable use could benefit from being coordinated or even negotiated at an international level (Chapter 6); the North Atlantic Marine Mammal Commission (NAMMCO) and the North Atlantic Salmon Conservation Organization (NASCO) may serve as examples to build on. Other no-regrets options (see Section 11.3.1) for government and private-sector involvement include providing support to small-scale entrepreneurial activity through research and development related to alternative uses of living resources (e.g., eider down collection, macroalgae/mussel cultivation, or wildlife watching and tourism), taking advantage of future possibilities for agricultural development, and, in general, facilitating ways to combine traditional resource use (hunting, fishing, and agriculture) with alternative services (e.g., with tourism or research and monitoring projects).
- *Laws and regulations*: Regulations that control unsustainable resource use have been identified as being necessary for managing living resources and are a well-established conservation tool. Such regulation is particularly important with regard to commercial operations with a history of unsustainable use (e.g., fisheries and the harvesting of some seabirds and marine mammals) (Chapter 6); changing lifestyles, population growth, and new technologies that increase the likelihood of overharvesting; and those areas where populations are believed to be particularly vulnerable to climate change or other changing external drivers (e.g., disturbances due to mining or oil and gas development). A variety of potential regulatory approaches exist. For fisheries, for instance, regulations can ameliorate the impacts of industrial fishing by specifying such things as gear limitations to avoid despoliation of habitat (e.g., no bottom draggers), bycatch avoidance techniques, and potential seasonal closures in areas where fishing activities are incompatible with significant wildlife use of an area.
- *Regional and international collaborations*: As pointed out at Adaptation Actions for a Changing Arctic (AACA) stakeholder consultations in Greenland (Nuuk, February 2016), a small portion of the eastern BBDS shrimp stock occurs within the Canadian exclusive economic zone (EEZ), and Greenland–Canada management of the shared stock is already a practical challenge under current conditions. As the BBDS becomes increasingly accessible (with diminished ice cover) and as new fisheries possibilities open up (with northward range shifts), there is a need for smoother collaborations and more clear guidelines. Preparations for potential new fisheries need to include multilateral discussions on the management of joint stocks in the BBDS region. Establishing "new-fisheries working groups" may provide one possible forum for advancing considerations and agreements on the sustainable

management of emerging fisheries, as well as for exploring opportunities to increase the value of the fisheries. As an example of long-term management of the emerging open waters of the Arctic Ocean, the five nations bordering the ocean have signed a draft declaration to prevent fishing in the formerly ice-covered area beyond national jurisdictions until better scientific knowledge about the marine resources is available and until there is a regulatory system in place to protect those resources (Danish Ministry of Foreign Affairs, 2015). Other major fishing nations that might use the area are also being invited to sign on to the agreement.

To control the effects of disturbance due to resource development and shipping, ameliorating measures could include the formal designation of particularly sensitive sea areas (PSSAs; areas that need special protection due to their ecological or socio-economic significance) through the International Maritime Organization (IMO) (e.g., the Pikialasorsuaq/North Water Polynya; see Section 6.2.3 for other examples and principles). PSSAs guide ship routing and can limit the kinds of shipping deemed permissible in a specific area, sometimes excluding shipping altogether. Marine protected areas (MPAs) can also be used to protect designated areas of seas, oceans, or large lakes from resource extraction, including fishing – safeguarding the habitat and the populations of organisms that would normally be exploited, as well as their natural predators. MPAs are typically zoned such that some activities are permitted in some locations, while other activities are restricted or prohibited. In designated no-take zones, all fishing and other resource extraction activities are prohibited. MPAs can allow for traditional uses of marine renewable resources and have been proposed for areas highly sensitive to environmental change. An expanded system of protected areas or protective measures for critical habitat has also been proposed for terrestrial species (see Section 6.3.5), to ensure connectivity of seasonal habitats based on current understanding (including coverage of unique Arctic species), allow for physiological diversity, and account for uncertainty in how the landscape will change. Large no-disturbance zones could also be considered to encourage species resilience and the maintenance of a sustainable harvest in surrounding areas.

12.5 Non-living resources (Chapter 7)

Non-living resources refers to those resources that are finite and cannot be reproduced. In the BBDS region, the two main industries based on non-living resources are mining and oil and gas extraction. Climate change presents opportunities to both industries in the form of improved shipping access (Chapters 2 and 9), fewer days of extreme cold, potential reductions in risks to offshore rigs, and glacier retreat (i.e., the uncovering of new prospecting grounds). These potential opportunities are accompanied by potential risks, such as an increase in extreme weather events, the impacts of permafrost thaw on infrastructure, a reduced operations window for ice roads, and changing precipitation regimes, which could affect water management (Nuttall, 2008; Pearce et al., 2010; Lemmen et al., 2014). Industrial activities may also add stress to Arctic species – e.g., through increased underwater noise that can disturb the migration of marine mammals and adversely affect their health due to increased stress levels, or the release of mining contaminants with a potential to accumulate in locally harvested foods (Subchapter 3.2). Industrial developments can also conflict directly with harvesting activities through disturbance, displacement, and pollution effects. At the same time, empirical studies in Canada have shown that industrial developments can assist harvesting activities by providing money that enables local people to undertake subsistence activities (see Kruse, 1982, 1991; Brubacher & Associates, 2002; Bowes-Lyon, 2006; Koke, 2008; Peterson, 2012). Although climate change can facilitate industrial activity in the region, global economic and political factors are recognized to be the main determinants of future developments in the BBDS extractive industries (Subchapter 3.3 and Chapters 2 and 9). Non-living resources are also a significant element that is being considered in this report as a potential driver of change in the BBDS region. In this sense, industrial development can encourage the growth of other industries – for example, road or port infrastructure built to service one mine may encourage the development of another nearby deposit that otherwise would not have been economically viable. Industry development can also have a negative impact on other potential industry growth, by producing cumulative impacts that are unacceptable to regulators or the local population. Hence, an integrated risk management (IRM) approach may be required (see below).

The effect of climate change on water regimes is also a factor to consider in industrial development (particularly mining), including the management of tailings and wastewater, as well as effects on power generation. Identifying supply systems vulnerable to future climate change is important. Water supply management requires forward planning for much of the year to anticipate needs, and future climate risks and potential industrial uses need to be integrated into these management regimes. Some short-term responses are already evident in the BBDS region – e.g., the City of Iqaluit is pursuing plans to supplement its current water supply (from a lake) with water from a nearby river (Chapter 4). In Greenland, the current 5 hydropower plants (see Chapter 7) rely on water from precipitation and glacier melt. With Greenland's strategic energy plan focusing on hydropower (Chapter 2), meltwater is increasingly being planned to supplement the precipitation-based plants, although the receding ice cap is also modifying the watershed. Modeling ice dynamics through the end of this century is therefore already included in the water-prospecting standards.

There is limited publicly available information on adaptation options for moderating the effects of climate change on mining and the oil and gas industry or for managing the off-site effects of such development (Chapter 7; Mosbech, 2014). A number of key considerations for adaptation, however, emerge from the work that has been completed and published.

Structural/physical adaptations

- *Engineering and built options*: Operational industrial facilities and their related transportation networks will be exposed to a variety of climate-related risks over their lifespans; many of these projects will experience conditions that depart from the historical norms used to guide their construction (Chapter 10). Most adaptive strategies typically employed by industry to deal with extreme climatic events and change are reactive and ad hoc. Such strategies, while potentially successful in the short term, may be maladaptive in the long term and may result in costs to companies or to the environment (Kovacs, 2011; Pearce et al., 2011b; Lemmen et al., 2014). Strategic proactive adaptation will be needed to manage climate change impacts – e.g., appropriately constructing or retrofitting industrial buildings and, in particular, linear structures such as roads, pipelines, and runways, in light of permafrost thaw; strengthening and raising tailings ponds and dams, given changing precipitation regimes; monitoring and altering water management protocols to respond to changing water availability; altering machinery used in the construction of ice and snow roads; and constructing drainage facilities based on designs that incorporate projections of future precipitation trends (Lemmen et al., 2014). Chapters 7 and 10 and Subchapter 12.8 provide more detailed information on infrastructure-targeted adaptation.

In terms of moderating industrial impacts combined with climate change, methods may need to be developed to reduce the effects of heavy machinery on sensitive northern terrain, given the shorter periods of snow cover.

To manage industrial impacts not necessarily associated with climate change, Chapter 7 proposes a continued focus on diminishing the risks of oil spills, as well as developing plans and the capacity to deal with such spills.

Institutional adaptations

- *Laws and regulations*: Proactive, long-term planning for adaptation in the non-living resources sector is unlikely to occur in the absence of legislation and regulation, particularly for the post-operational phase of industrial infrastructure (Pearce et al., 2011b). Surveys of the Canadian mining sector, for example, illustrate that operations managers and high-level executives view climate impacts as something that will occur beyond the operational life span of the mine and are therefore of limited immediate importance (Ford et al., 2010c, 2011). Proposed industrial developments in the BBDS region must go through various regulatory processes, and it is important that potential climate change impacts be built into the planning and regulatory approval processes (Ford et al., 2011; Pearce et al., 2011b) and that clearer guidelines be developed and followed. The full life cycles of industrial developments need to be considered, including recognition of the fact that impacts can occur long after operations have ceased (Mosbech, 2014). This process may include a requirement that environmental impact assessments (EIAs) consider the potential impacts of climate change on proposed developments at various life-cycle stages, as well as how such developments may cumulatively affect ecosystems undergoing rapid change over various timescales. For example, changing species distributions and evolving ecosystem processes may call for adjustments and reconsideration of areas or species deemed particularly vulnerable or sensitive to mineral resource exploration and exploitation activities; tailings pond design and siting must consider changing precipitation regimes and permafrost thaw; and operations planning may need to consider production stoppages during animal migration periods while also being flexible in the event of changing migration patterns. Ultimately, climate change impacts may force some resource development projects to be rejected during the planning process, particularly in ecologically sensitive areas where the compounding effects of climate change and resource development would be unsustainable.

  While some EIAs (or strategic environmental assessments, SEAs) already assess potential climate impacts, there are no widespread requirements to consider climate change impacts in industrial planning. The implementation of risk reduction options are often voluntary, and this approach has resulted in limited adaptation in the industrial sector (Pearce et al., 2011b; Ford et al., 2014a; Lemmen et al., 2014). Hence, a more integrated risk management approach may be required, so that assessments do not analyze merely a project's effect on the environment but also the environment's (climate's) effect on the project. In large-scale investments (e.g., hydropower projects), proper climate risk screening ensures better investments. For example, this approach is now mandatory for major World Bank investments (climatescreeningtools.worldbank.org). Regulations and planning in a changing climate must also take into account the cumulative impacts of increased activities in general, in the context of other developments such as increasing shipping activity, commercial fisheries developments, changing harvesting patterns, and infrastructure development. Chapter 7 suggests that integrated approaches to management be adopted – e.g., ecosystem-based management (EBM). Chapter 7 also suggests that strategic environmental impact assessments be conducted to provide a better knowledge base for any subsequent environmental impact assessments.

  Several options developed in Chapter 7 deal with ensuring the best socio-cultural outcomes from any industrial development, including a focus on the generation of local jobs and benefits and on the strategic use of revenues to fund positive social, cultural, and economic outcomes for local communities. These investments will in turn help to build social and cultural resilience.

12.6 Tourism (Chapter 8)

As noted in Chapter 8, "*In the BBDS region, Greenland may be well positioned to take advantage of near-term changes in accessibility because of a strong tourism foundation and infrastructure investments developed over the past 30 years. Nunavut is at an earlier stage of tourism-strategy implementation but is also poised to take advantage of tourism growth,*" pending proper planning and investments. In Chapter 8, the impacts of climate change on tourism in the BBDS region are discussed mainly in terms of cruise boat tourism, where sea ice retreat is increasing the viability of marine transportation and models are projecting a continued steep decline in sea ice cover and thickness this century (Dawson et al., 2014; Pizzolato et al., 2014). A longer ice-free open water season has encouraged rapid growth in the marine tourism sector over the last decade, with associated employment and some income-generating opportunities in communities. So far, the local benefits are still relatively modest and expansion will require new business models. A niche market in "last chance tourism," which explicitly seeks out vanishing landscapes and icescapes before they change beyond recognition, has also been noted to be developing. Some of the future development of tourism will be determined by factors external to the BBDS region (e.g., global economic conditions, technological developments, and global social trends), but climate changes are generally expected to create conditions favorable to continued expansion (Chapter 8). In light of this expectation, a number of concerns have been raised – e.g., the lack of a central authority for governing the northern cruise ship industry and the absence of guidelines (agreed upon or mandatory) for operations and management at a time when the industry is expanding into largely uncharted areas with an increased potential for accidents (Chapter 9). Without targeted policy action, some logistical, regulatory, and financial barriers, along with unique environmental challenges, may result in foregone opportunities (Chapter 8; Stewart and Dawson, 2011; Dawson et al., 2014). Further, tourism has been touted as a relatively low-impact development opportunity, but there are questions as to whether tourism can coexist with other forms of development in the region, given that the draw of Arctic tourism is that tourists are to visit an "unspoiled" place.

A number of the adaptations proposed for tourism (Chapter 8) overlap with response options more generally aimed at shipping (Chapter 9). These options are summarized in Subchapter 12.7 and in the table at the end of this chapter.

Structural/physical adaptations

- *Engineering and built options*: To manage safety concerns around expanding marine tourism, investments in the communications infrastructure are needed. Among these needs is legislation to make automatic identification system (AIS) transponders mandatory for all tourism vessels operating in the region, in order to enhance search and rescue capability and preparedness (Chapters 8 and 9). The capacity of community infrastructure to cope with tourism is already a limiting factor, especially in Nunavut, where a lack of accommodations, medical services, and port and airport facilities presents barriers to capitalizing on the potential benefits of expanded tourism (Chapters 8 and 10). For instance, Nunavut ports can accommodate only the smaller cruise ships, and tourists must typically be taken to shore on inflatable boats. These limitations are not likely to be addressed in the short- to medium-term future, and addressing them will require significant capital outlays. Nevertheless, upgrades are important if the longer-term benefits of the enhanced tourism potential are to be achieved. To provide for more tourism opportunities on land, the accommodation barrier needs to be lowered. Options to be considered include nontraditional and informal options and marketing – such as using temporarily underutilized facilities (e.g., schools, student homes) and expanding informal initiatives (e.g., Airbnb) that may emerge over time.

Institutional adaptations

- *Laws and regulations*: The growth in tourism demand over the last decade has illustrated a number of management challenges that face the industry – e.g., a lack of coordination among operators and communities in planning site visits, the absence of mandatory guidelines for visits to environmentally and culturally sensitive sites, and only limited experiences or products offered in some locations. Search and rescue capabilities are considered insufficient to cope with large emergencies. Studies have noted that future planning will need to develop codes of conduct for tourists and operators – integrating future climate change considerations and based on multilevel governance. While experienced, regular tour operators in the Arctic (and Antarctic) in general "know what they are doing" and pose relatively little threat, the occasional newcomers – often with single-hull vessels and limited Arctic navigation experience – pose serious risks that need regulation and accompanying enforcement. The potential for shared marketing strategies could be developed between Greenland and Canada, along with the promotion of shared tourism experiences or products that allow for visits to both countries. Recent efforts to develop guidelines and good practices include the *Arctic Marine Tourism Project (AMTP) Best Practice Guidelines* (Arctic Council, 2015) and the variety of specific guidelines developed by the Association of Arctic Expedition Cruise Operators (www.aeco.no/guidelines/).


age fotostock/Alamy Stock Photo

Dog sledding in spring time in Greenland

12.7 Shipping (Chapter 9)

With sea ice change in the BBDS region, the length of the navigable season is increasing – extending the operating time for all forms of marine shipping activities in the region, creating opportunities for new shipping routes (e.g., the Northwest Passage and, in the long term, even transpolar routes), and increasing the viability of northern ports (Stephenson et al., 2011; Smith and Stephenson, 2013; Pizzolato et al., 2014). The trend toward increasingly larger fishing vessels and larger cruise ships may continue (Chapter 9). These changes have the potential to further contribute to mine and oil and gas development by reducing shipping costs and improving accessibility, thus providing opportunities for economic development in BBDS communities. These changes could also improve supplies management, especially in Nunavut where the seasonal sealift is the main access route, with only a brief ice-free window of operation. Changes in BBDS transit shipping are also expected to affect mainly the Nunavut side of the region (Chapter 9). However, without targeted climate-centered adaptation action, a number of logistical, regulatory, and financial barriers may result in opportunities not being capitalized on. Increasing marine traffic will also put more – or larger – ships at risk from ice and other marine hazards in a region with limited navigational charting. The noise and pollution associated with increased shipping will contribute to other stresses affecting BBDS ecosystems. Various adaptation opportunities exist, and some of these are described below.

Structural/physical adaptations

- *Engineering and built options*: Research focused on shipping has noted a need for improved safety through enhanced communications infrastructure, improved monitoring capabilities for vessel traffic (e.g., AIS, satellite), greater capacity to respond to oil spills, and more investment in infrastructure, including investments in the coast guard fleets to support emergency response capabilities adequate for increased marine traffic (Chapter 9) – similar to the infrastructural investments required for tourism and fisheries. Correspondingly, improved bathymetric charting – i.e., the revision of existing nautical charts and the production of new ones – has been called for in light of increasing marine traffic and the development of new shipping routes. In Denmark's strategy for the Arctic, this charting is mentioned as a future priority for Greenland, and the coast guard fleet is being upgraded to expand its bathymetric survey coverage. The Canadian Northern Marine Transportation Corridors (NMTC) initiative, aimed at establishing shipping corridors where key navigational information and response services (e.g., hydrography, icebreaking, and aids to navigation) would be relatively predictable, could be considered as a basis for regional (and circumpolar) collaboration and scaling up of capabilities (Chapter 9). The need to invest in new port facilities, particularly deep-water ports in Nunavut, is important if new shipping opportunities are to be realized. Also important is the integration of sea level projections into any development plans (for many locations in the BBDS region, these projections may indicate a future lowering of sea levels due to the land rising up as ice sheets and caps melt; Chapter 10). In Nunavut, the marine infrastructure consists mainly of floating docks used by local fishermen for small ship operations – a situation that will limit the development of the tourism, fishing, and resource extraction industries. In Greenland, harbors are more abundant and generally more favorably placed. Nuuk is now investing heavily in expansion of its deep port facilities, including the construction of a separate section for large cruise ships. However, even here the relative sea level drop needs to be planned for (Chapter 10).

Institutional adaptations

- *Laws and regulations*: With increased marine traffic, the potential for shipping accidents and oil spills is a major BBDS concern – especially given the region's limited rescue and clean-up capabilities and the sensitivity of its marine environments (the nature of which hampers the degradation and removal of pollutants and the recovery of habitats). The IMO Polar Code, which includes mandatory and recommendatory provisions for safety and pollution prevention, will be mandatory as of 2017 for all commercial carriers and passenger ships of 500 tons or more. This code is not designed specifically for climate change impacts, but it will contribute to the international maritime safety and environmental conventions that already apply in the Arctic. The new Polar Code represents an important regulatory development, yet there are still significant gaps that could, if filled, represent adaptive action to better safeguard BBDS coasts. For instance, the use and carriage of heavy fuel oil, a particularly persistent pollutant when spilled, is still permitted in the Arctic (except around Svalbard, where there is a local prohibition). In the Antarctic, this type of fuel oil has been prohibited because of its potential for harm. For maritime schools, it has been proposed that training specifically in Arctic conditions, including ice navigation, be built into the curricula. Another option to reduce the likelihood of accidents is to establish marine transportation corridors that would concentrate maritime traffic. As a longer-term option, Chapter 9 suggests the designation of PSSAs (a designation of the International Maritime Organization) as a tool for improving the environmental sustainability of BBDS shipping (see Subchapter 12.4).

12.8 Infrastructure (Chapter 10)

Built infrastructure (e.g., housing, municipal, and industrial buildings) and transportation infrastructure (e.g., airstrips, port facilities, and roads) are critical determinants of both community well-being and future sustainable growth in the BBDS region. Both of these types of infrastructure also face a variety of risks from climate change and a variety of stresses from industrial development. Most studies have focused on permafrost effects, with rising temperatures, changing precipitation and snow drift patterns, and altered vegetation conditions increasing permafrost thaw in many locations. There is also some anticipated climate impact on relative sea levels (i.e., local levels relative to the land). Thawing permafrost is particularly problematic in communities on Baffin Island, where infrastructure is often sited on sedimentary deposits. Infrastructure itself has always been a thermal factor to take into account when building on permafrost, and recent climate warming has exacerbated the thermal impacts of built infrastructure.

Other long-term infrastructural risks in the BBDS region are associated with falling relative sea levels. (When massive quantities of ice melt, the land that was formerly "pressed down" beneath the weight of the ice rebounds upward; in addition, less ice-cap mass means less upward "gravitational pull" on surrounding ocean waters.) In the long run, falling sea levels may affect port infrastructure and alter the impacts of extreme storm events. Other potential impacts of extreme weather events may be felt through the susceptibility of electrical wires to more frequent or more extreme ice storms, but relatively little research has been conducted on these topics so far. These multiple climate-related changes will exacerbate the infrastructural deficits that already exist in the BBDS region (particularly housing); they will present challenges to community development and expansion and will affect industrial facilities. A number of potential adaptation options have been well studied (Chapter 10; Allard et al., 2012; Champalle et al., 2013; Ford et al., 2015; Hatcher and Forbes, 2015). In terms of infrastructure built to support industrial development, consideration should be given not only to making that infrastructure climate-ready for its projected lifespan but also to the potential for extending the use of such infrastructure beyond its intended industrial life – so that it may potentially contribute to community and regional economic development, which may also help to confer resilience on those communities and regions. Such potential uses should be responsive to community needs as expressed by the communities themselves.

While Chapter 10 does not specifically address issues related to information and communication technology (ICT), this type of infrastructure is a critical cross-cutting enabler for general development. In the BBDS region, ICT development would facilitate local business opportunities, distance learning, telemedicine, early-warning information dissemination, and so on. Hence, continual enhancement of the communications infrastructure, as new technology becomes available, is a no-regrets investment in local development in a changing world and in helping to reduce the "remoteness" of communities dispersed across vast Arctic expanses. Long-term investments in space communication technology may be furthered by the recently adopted European Union policy for the Arctic (European Commission, 2016), which includes a focus on telecommunications and satellites to ensure safe maritime and air transport, search and rescue, and general communication in the Arctic.

Structural/physical adaptations

- *Engineering and built options*: For infrastructure, a variety of structural adaptations have been identified to modify infrastructure construction practices. Design guidelines to minimize disturbance to permafrost are particularly important, given the long life spans of infrastructure. These guidelines have been well studied for a variety of infrastructural types, as summarized in Chapter 10. For building construction, for example, minimizing disturbance of the natural soil has been documented to result in a smaller adverse impact on permafrost stability. The timing of site preparation is also crucial to minimize impacts on the permafrost thermal equilibrium (e.g., excavate and install gravel pads in support of foundations during the fall to allow disturbed soil and the gravel berm to freeze back during winter). Thermosyphons (devices that remove heat) are commonly used for permafrost foundations in order to keep the ground frozen and prevent thaw subsidence. In cases where existing infrastructure may exacerbate permafrost thaw, retrofitting options are possible (e.g., removal of house skirts). Chapter 10 also suggests further research and experimentation to create better solutions for building on permafrost. Beyond structural adaptations, that chapter also notes that the current housing deficit reduces resilience in northern communities and suggests options for reducing the deficit – e.g., encouraging cooperative housing ventures and providing skills training to northern residents to enable them to maintain and upgrade existing housing stock.

  Impacts of climate change on water quality and abundance of supply are also a concern in the region. These aspects are summarized under sections in Chapters 4 and 7.

Institutional adaptations

- *Laws and regulations*: While a number of well-studied engineering options are available to moderate the effects of climate change on infrastructure, implementing them to guide future infrastructural development requires building codes, standards, and related instruments (CSRI) that establish tenets of reasonable practice with respect to the planning, engineering, construction, and management of built infrastructure (Steenhof and Sparling, 2011). Adhering to the guidance and directives contained within CSRI is regarded as due diligence among engineers and those in trades. In the Canadian Arctic, for instance, representatives from territorial governments, the federal government, and northern community government organizations collaborated to develop a National Standard of Canada to moderate the effects of permafrost degradation on existing building foundations, as well as mitigation techniques in relation to changing permafrost conditions (CSA, 2010, 2014). However, CSRI are typically based on norms for southern Canada. In Greenland, attempts have been made to develop national construction codes, but for now the existing codes remain largely based on codes from Denmark; the permafrost guidelines for construction in Greenland date from 1957. If the integration of adaptation options into infrastructure development is to be strategic and proactive, northern-specific CSRI need to be developed. There is evidence that efforts are underway to this end in both regions. In Canada, for example, a panel of experts has been formed to formulate construction and engineering standards for cold and Arctic regions. Climate data also have an important role in CSRI, where climate design values have typically been based on long-term historical values (e.g., snow load, wind direction, average sea level), yet climate change is now changing historical norms, necessitating the integration of climate projections to inform climate design values (Milly et al., 2008). In Greenland, the current permafrost building guidelines could be updated relatively easily, based on standards from northern Scandinavia. For public infrastructure (such as airports), Chapter 10 suggests regular and rigorous monitoring programs to ensure safety and their continued integrity.
- *Technological options*: Infrastructure development requires risk mapping to identify and characterize climate change–related risks, to guide land use planning, and to inform the choice of construction techniques and engineering designs. A number of projects in the BBDS region have generated hazard maps for specific communities or installations – e.g., the "Terrain Analysis in Nunavut" project (Government of Nunavut, 2015) and the Frobisher Bay seabed mapping project (Ham et al., 2016), based on radar satellite images, digital elevation models,

optical images, site visits (including geotechnical drilling in some instances), and local knowledge. These projects have developed and piloted methodologies applicable across the BBDS region. Risk analysis techniques can also be used to design and allocate maintenance monies for infrastructure by determining all the hazards or failure modes associated with the infrastructure; the Public Infrastructure Engineering Vulnerability Committee (PIEVC) protocol developed by Engineers Canada is one approach. Airports pose special challenges in terms of current conditions, as well as issues related to future maintenance and upgrades. These challenges are currently most serious in Nunavut, but they also affect air-based traffic planning in West Greenland. Chapter 10 provides detailed examples of adaptation actions from the BBDS region – e.g., the regular testing of airport structures.

12.9. Summary table

Table 12.1 summarizes and consolidates the key adaptation "options" identified in the technical chapters of this report, supplemented by information from other (mainly Arctic Council) products. For more details on specific issues, interested parties should also review the relevant thematic chapters (Chapters 4–10). The referenced Arctic Council products (listed in the rightmost column of Table 12.1) are broader in scope – not necessarily specific to the Baffin Bay/Davis Strait region but pertinent in the opinion of the chapter authors. Where passages have been imported from other reports, we have kept the original phrasing. As a result, some of the "options" may read more like "recommendations."

Table 12.1 should not be interpreted as a checklist for adaptation in the BBDS region but rather a set of ideas for mainstreaming some specific (short- and medium-term) technical focus areas, as well as some linkages from those adaptation options to longer-term resilience building (see also Figure 11.1). Adaptation will be an ongoing, iterative process.

- *Resilience factors*: To explictly link the adaptation options to the concept of resilience, each option is cross-referenced with key resilience factors wherever possible. These resilience factors are adapted from the regional AACA report for the Barents area; they are fully and appropriately referenced within that document (AMAP, 2017). In Table 12.1, these factors are referenced in the "resilience factors" column by the identifying labels as follows:

  Chng = Acceptance of change as the norm
  Div = Diversity
  Mat = Material well-being
  Cult = Cultural/spiritual well-being
  Know = Knowledge capacity
  Org = Self-organizational capacity and connectedness

- *Levels of difficulty of implementation*: For each adaptation action, a subjective assessment of the implementation level of difficulty within each of the following five categories is also offered:

  Technical (T) – The technology or method requires some degree of advancement, lesser or greater, before the action is feasible

  Financial (F) – The option would require the allocation of some amount of money, lesser or greater

  Governmental (G) – The option would require some amount of regulatory or legislative change, lesser or greater, at one or more levels of government

  Structural (S) – The structures (physical or social) required for the option requires some degree of further development, lesser or greater

  Social License (SL) – The option would likely require some degree of public support, lesser or greater

For each of these five categories, the level of difficulty is ranked from **1** (least difficult) to **5** (most difficult):

1= Should be easy to implement, given current conditions and capacities

2 = Would require investments of additional capacity or resources, likely achievable within a year

3 = Would require mobilization of efforts to raise additional capacity and resources; could require longer than a year, possibly resulting in foregone opportunities for other investments or development

4 = Would require concerted, large-scale mobilization of capacity and resources; would likely result in foregone opportunities for other investments or development

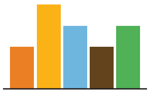
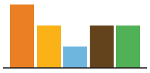
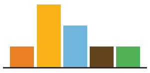
5 = Would require large-scale, concerted, and long-term mobilization of capacity and resources; would almost certainly result in foregone opportunities for other investments or development

For example, an adaptation option with a difficulty level of "T3, F3, G2, S1, SL2" is deemed to be moderately difficult (as defined above, level 3) in terms of technical and financial needs, less difficult in terms of governmental and social license considerations, and relatively easy to do in terms of structural requirements. A graphical representation of the difficulty of implementation is also shown for each category: Technical (orange), Financial (yellow), Governmental (blue), Structural (brown), and Social License (green). The taller the bar on the small charts, the greater the estimated difficulty of implementation.

These assignments of difficulty are as assessed by the authors of this chapter, based on our collective experience. We make no claims for these assessments as rigorous objective standards. They are intended to be indicative, based on our best judgment, to provide some guidance to policy-makers. Regional stakeholders and policy-makers are the people best placed to make final judgments about the degree of difficulty of any option described. The degree of difficulty should not be seen as a proxy for the desirability of implementing an option – some of the most difficult options may result in the most desirable outcomes.

- Numbered (heading) adaptation options in the table may or may not have assigned ratings, depending on whether they are general or specific measures. The dash symbols indicate cases where no rating was assigned.

Table 12.1 Summary table of key adaptation options.

Adaptation options	Scale	Resilience factors[1]	Difficulty of implementation[2]	Main sources[3]
1. There may be a need to further enhance flexible **governance capacities for mainstreaming climate risk management**	--	--	--	--
a. Mainstreaming climate risk management is key to ensuring that climate information guides long-term development and that all major planning decisions are assessed in terms of their climate change adaptation, mitigation, and resilience-building potential. Some ongoing efforts to mainstream climate risk management into sectoral legislation, policies, and financing streams – as well as local (municipal, community) planning – are on the right track and could be accelerated (see, for instance, community-level adaptation planning in some Nunavut municipalities). An additional consideration is whether additional capacity building and education in sector ministries and elsewhere may be needed to gain momentum (see 1b below). The goal of mainstreaming should also be applied to climate change mitigation efforts.	Local to national	Chng, Know, Org	 T3, F3, G3, S1, SL2	Ch 2, Ch 11
b. Assess and address local governance capacity issues – in line with challenges summarized in the *Arctic Human Development Report* (Larsen and Fondahl, 2014, p. 187): "*Devolution and the political empowerment of Indigenous peoples have led to an increase in governance authorities at regional and local levels; this in turn has generated human and fiscal capacity challenges. Having governance authority is one matter, having the people and financial resources to effectively exercise that authority is another issue altogether.*" Building governance capacity is primarily an example of longer-term resilience building. Governance capacity to sustain adaptation planning and resilience building is currently limited – a condition that will only be exacerbated as climate and development stressors add up. Flexible institutions are needed to avoid the imposition of rules, frameworks, and discourses that may limit the ability of local actors to engage proactively with change on their own terms. Devolution (as is being negotiated for Nunavut and as has already largely occurred in Greenland) will help shift resources to a more regional level, but those regions should now examine the extent to which they may further devolve financial and human capacity to local or subregional levels.	Local to national	Chng, Div, Mat, Cult, Know, Org	 T2, F4, G3, S2, SL3	Ch 2 Larsen and Fondahl (2014)
2. It would be highly relevant to further promote **cross-learning and knowledge management** at all levels – circumpolar, national, and local – for sharing adaptation options, as already suggested in the *Taking Stock of Adaptation Programs in the Arctic* report: "*The Arctic Council could … play an important role by further facilitating the exchange of information and expertise about adaptation measures between Arctic Council states and organizations for decision-makers at all levels*" (Arctic Council, 2013a, p. ii) and, reporting on earlier work, "*it was noted that drawing from the knowledge and experience of earlier or similar initiatives helped ensure the success of a project*" (Arctic Council, 2013a, p. 16). Other mechanisms for knowledge sharing on adaptation initiatives ("what works") and for engagement in public hearings and other elements of participatory processes may be important supplements. This set of Adaptation Actions for a Changing Arctic (AACA) assessments is an example of knowledge sharing, but the effort should not stop here.	International, national, local	Know	 T3, F2, G1, S2, SL2	Ch 2, Ch 6, Ch 10–12 Arctic Council (2013a)
3. It may be considered how an **integrated risk management** (IRM) approach – with proper risk screening of all major investment decisions – could be ensured. Environmental impact assessments (EIAs) that specifically include an analysis of changing risks in a changing climate might be one route (see also infrastructure and mineral exploration entries below). Risk screening of all major investment does already take place, but a more holistic IRM approach would be valuable.	National, local	Chng, Know	 T2, F2, G2, S1, SL2	Ch 7, Ch 12
4. Consider how to maintain continuity and stimulate flexibility in policies and **funding streams for research and innovation** – which are central to the identification of new adaptation options – instead of steering public and private research toward politically convenient sectors or sectors expected to be economically profitable in the short-term.	National, international	Chng, Div, Know, Org	 T1, F3, G2, S1, SL1	Ch 11
a. Improved gathering of data on physical, social, and environmental indicators to facilitate adaptive management.	Regional to national	Div, Know	 T2, F3, G3, S2, SL1	Ch 4, Ch 6, Ch 8 Larsen and Fondahl (2014) Arctic Council (2013b)

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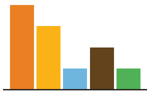
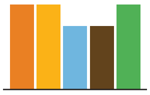
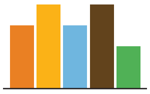
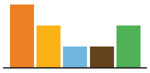
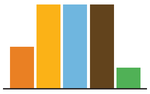
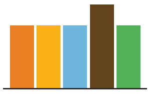
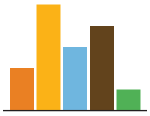
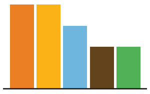
[2] Difficulty of implementation: **T**echnical (orange), **F**inancial (yellow), **G**overnmental (blue), **S**tructural (brown), and **S**ocial **L**icense (green); ranked **1**–**5**, with 1 being the least difficult and 5 being the most difficult. On the small charts, the taller the bar, the greater the estimated level of difficulty of implementation.

[3] Ch = Chapter within this Baffin Bay/Davis Strait (BBDS) report.

Adaptation options	Scale	Resilience factors[1]	Difficulty of implementation[2]	Main sources[3]
b. Developing and scientifically testing innovative technical solutions and promoting partnerships between innovators and the private sector, which would facilitate the integration of new technologies that are often too expensive to be tested under publicly funded projects.	National to international	Chng, Div, Mat, Know, Org	 T4, F3, G1, S2, SL1	Ch 10
5. Investing in training and **education** (formal and informal) is a "no-regrets" option to enhance long-term resilience to a range of external stressors and uncertainty factors. Education also better prepares people for alternative livelihood options – at home or elsewhere, if need be. (See also education-related options elsewhere in this table.)	--	--	--	Ch 5 IPCC (2014)
a. Strengthen education systems in general, to offer more choices and to ensure that people are better prepared to adapt to and take advantage of change alongside new economic opportunities.	National, local	Chng, Div, Mat, Cult, Know, Org	 T4, F4, G3, S3, SL4	Ch 2, Ch 5
b. Promote public and private sector re-education and capacity building to maintain a skilled and flexible work force. This undertaking may include enhancing readiness for expanding tourism opportunities (see below).	Local to national	Chng, Div, Mat, Cult, Know	 T3, F4, G3, S4, SL2	Ch 2, Ch 6, Ch 8, Ch 10
c. Consider how to reduce long-term obstacles to accessing higher education and employment in international organizations/businesses, including strengthening Indigenous languages and (mainly in Greenland) enhancing English and Danish language skills.	Regional to national	Chng, Div, Mat, Cult, Know, Org	 T3, F2, G1, S1, SL2	Ch 2, Ch 5 Larsen and Fondahl (2014)
d. Prepare people with appropriate education that may be applied to either traditional subsistence activities or to the wage economy. The "levels of difficulty" factors for this option will vary according to whether the provision of instruction in subsistence (i.e., "land-based") activities is undertaken as formal or informal education. (Note: Here, the assigned resilience and difficulty factors apply to integration into formal education.)	Regional	Chng, Div, Mat, Cult, Know	 T3, F3, G3, S3, SL3	Ch 2, Ch 5 Larsen and Fondahl (2014)
e. Develop human capital retention strategies. Human capital (in the form of the most highly trained individuals) is currently "in flight" from peripheral areas (i.e., the smaller, less connected communities), thus decreasing local capacity and resilience.	Regional to national	Div, Mat, Cult, Know	 T2, F4, G4, S4, SL1	Ch 2 Larsen and Fondahl (2014) Government of Greenland (2015)
f. The influence of cultural and social values among Inuit should be at the core of educational programs – so more fully incorporate local Indigenous knowledge into educational and economic systems and reinforce cultural sharing norms (thereby reducing impacts such as food insecurity).	Local to national	Mat, Cult, Know, Org	 T3, F3, G3, S4, SL3	Ch 5, Ch 11 Arctic Council (2013b) Larsen and Fondahl (2014)
6. To better prepare for changing **health and safety** risks – which would be no-regrets options – relevant bodies may choose to:	--	--	--	--
a. Address the existing deficit in safe and healthy living standards (see, for instance, the options listed below for infrastructure and planning).	Local to national	Chng, Mat, Cult, Know, Org	 T2, F5, G3, S4, SL1	Ch 2, Ch 4, Ch 10
b. Consider how to enhance social "safety nets" and risk sharing (e.g., privately and publicly supported insurance) – and especially how to provide temporary assistance during extreme events that affect livelihoods and local businesses, as well as during post-event recovery. In particular, the existing mechanisms for administering "emergency funds" may need to be improved (e.g., an increased pool of funds with clear criteria specified for the expeditious release of assistance) to meet the rising intensity and frequency of "surprises" and extreme events (e.g., storms, ice, floods, drought).	National, local	Chng, Mat, Know, Org	 T4, F4, G3, S2, SL2	Ch 12

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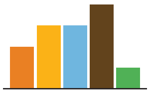
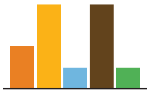
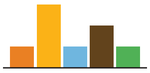
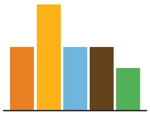
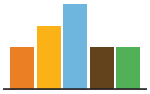
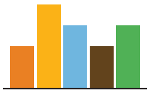
[2] Difficulty of implementation: **T**echnical (orange), **F**inancial (yellow), **G**overnmental (blue), **S**tructural (brown), and **S**ocial **L**icense (green); ranked **1**–**5**, with 1 being the least difficult and 5 being the most difficult. On the small charts, the taller the bar, the greater the estimated level of difficulty of implementation.

[3] Ch = Chapter within this BBDS report.

Adaptation options	Scale	Resilience factors[1]	Difficulty of implementation[2]	Main sources[3]
c. "Climate-proof" water supply systems to the effects of more extreme events (e.g., droughts, floods, extreme snowfall and snowmelt), changing contamination risks, and other threats to water quality (these measures overlap with infrastructure options listed below).	Local to national	Chng, Mat, Cult, Know, Org	 T2, F3, G3, S4, SL1	Ch 4, Ch 10
d. Enhance early warning and information dissemination. Communities need access to trustworthy weather and ice services that integrate both local and scientific knowledge, transmitted through appropriate media venues accessible to diverse community members.	Regional	Chng, Mat, Cult, Know, Org	 T2, F4, G1, S4, SL1	Ch 11–12
e. Consider how the formal emergency response system (e.g., coast guard, police) could be supplemented by a more systematic local (community-based) disaster preparedness capacity to meet the challenge of changing risks (e.g., changing sea ice and water flow). The community-based system may be organized on a public or civil society basis (staff or volunteers) but with some level of standardized skills and including an adequately trained and equipped group of people.	Local to national	Chg, Mat, Know, Org	 T2, F2, G3, S3, SL1	Ch 12
f. Ensure adequate testing for mercury and persistent organic pollutants. Climate change is expected to increasingly mobilize legacy repositories of these substances, potentially jeopardizing food security. This option echoes the suggestions in the *Arctic Human Development Report* (Larsen and Fondahl, 2014, p. 488): "*Indicators of food and water security need to be incorporated into surveillance and monitoring programs across the Arctic.*"	Local to national	Mat	 T1, F3, G1, S2, SL1	Ch 2, Ch 4 Larsen and Fondahl (2014)
7. Development and adaptation of all **marine activities – including fisheries, cruise tourism, shipping, and resource exploration** – to expanding opportunities (e.g., due to diminishing ice cover and changing seasonality) depend on coordinated, national-level investments (pan-Arctic or across the BBDS region) in enhanced information, safety measures, and regulations, including:	National, international	--	--	--
a. Organizing joint BBDS search and rescue training and contingency planning – building on the Arctic Council's search and rescue exercise (SAREX) agreements and experiences.	International	Chng, Mat, Know, Org	 T3, F5, G3, S3, SL2	Ch 9, Ch 12
b. Agreeing on and enforcing clear operational guidelines for vessels (e.g., mandatory AIS transponders, ice pilots, location reporting).	National to international	Mat, Know	 T2, F3, G4, S2, SL2	Ch 8–9
c. Continued improvements in ice and weather monitoring and warning capabilities.	National to international	Mat, Know	 T3, F3, G2, S3, SL1	Ch 8–9, Ch 12
d. Continued and scaled up efforts to improve the spatial coverage and accuracy of bathymetric data, sea charts, and navigation aids – in main navigation lanes (shipping) as well as "off the beaten path" (tourism, exploration).	National to international	Mat, Know	 T3, F3, G2, S3, SL1	Ch 8–9
e. Monitoring and enforcing adherence to the new Polar Code of the International Maritime Organization (IMO) and the Ballast Water Management Convention (even though the latter is not yet formally in force) – including investments in capacity to enforce the conventions.	National to international	Mat	 T2, F4, G3, S2, SL3	Ch 9
f. Upgraded maritime schools and curricula (and relevant legislation) to integrate training in Arctic-specific conditions and in changing Arctic maritime conditions, including ice navigation.	National	Chng, Mat, Know	 T3, F3, G3, S2, SL2	Ch 8–9

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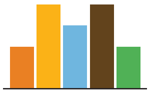
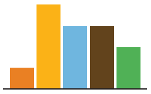
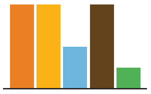
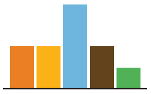
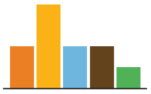
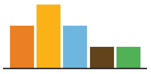
[3] Ch = Chapter within this BBDS report.

Adaptation options	Scale	Resilience factors[1]	Difficulty of implementation[2]	Main sources[3]
g. Political and investment "readiness and flexibility," to plan for and establish improved infrastructure as demands develop for port facilities with adequate wastewater and oil handling facilities, as well as other services and facilities.	Regional to national	Mat	 T2, F4, G3, S4, SL2	Ch 2, Ch 7–8, Ch 10
h. When deep-water docking facilities and associated infrastructure are required for mineral exploration and extraction, these constructions should be planned to also serve other potential (public and private) long-term purposes during and after the expected commercial-operation life span.	Local to regional	Chng, Mat	 T3, F3, G1, S3, SL1	Ch 12
i. Consider investment in further development of the multipurpose coast guard fleets.	National	Mat	 T1, F4, G3, S3, SL2	Ch 9, Ch 12
j. Reduce the threat of pollutants to biodiversity by supporting the development of prevention and clean-up measures and technologies for oil spills, especially in ice-filled waters, such that they are ready for implementation in advance of major oil and gas developments.	National	Div, Mat, Cult, Know	 T4, F4, G2, S4, SL1	Ch 7 CAFF (2013) Eamer et al. (2013)
k. Encourage the development of international standards relevant to Arctic oil and gas operations; move toward circumpolar policy harmonization in sectors such as environmental monitoring and pollution prevention practices; and promote interactions with international treaty bodies that address issues such as spill preparedness and response.	International	Chng, Know, Org	 T2, F2, G4, S2, SL1	Ch 7 Eamer et al. (2013)
8. Support the development of better adapted, sustainable, and culturally relevant (especially with regard to housing/public buildings) **infrastructure and planning** as a no-regrets option with immediate benefits (see also options for special mineral resource infrastructure, listed below). Considerations include the following:	--	--	--	--
a. Access to information and communication technology (ICT) is a critical cross-cutting enabler for general development; hence, continually enhancing the communications infrastructure as new technology becomes available is a high-priority, no-regrets investment.	Local to international	Chng, Mat, Cult, Know, Org	 T2, F4, G2, S2, SL1	Ch 2, Ch 4–5, Ch 8–9, Ch 12
b. Planning for more variability and extreme events – wind, rain, snow – in relation to water supply, sewage systems, building codes, and, for example, variable needs for snow clearing in towns, airports, and other facilities.	Local to regional	Chng, Mat, Know, Org	 T2, F2, G2, S1, SL1	Ch 10, Ch 12
c. Enhancing the regulatory framework to guide sustainable development of the infrastructure network and the building and construction sector, including guidelines on "climate-proof" design, permafrost management, and other climate-related issues.	Regional to national	Chng, Mat, Know	 T3, F2, G3, S2, SL2	Ch 10
d. Supporting education and knowledge transfer targeted to the needs of municipal managers, engineers, entrepreneurs, and technical staff to ensure adherence to proper construction practices for cold regions.	Local to national	Chng, Div, Mat, Know	 T2, F3, G2, S1, SL1	Ch 10
e. Supporting the raising of awareness on permafrost adaptation options, including public consultation and presentation of research results in communities. The publication of good practice guides as a permanent reference for a wider audience – individuals, households, and technicians – may have immediate benefits in reducing risks locally.	Local to national	Chng, Mat, Know, Org	 T1, F2, G2, S1, SL1	Ch 10
f. Providing construction skills training to community members, thus increasing capacity for construction, upgrading, and repair.	Local to national	Chng, Div, Mat, Cult, Know, Org	 T2, F3, G2, S3, SL1	Ch 10

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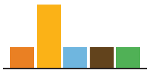
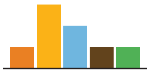
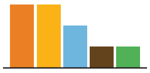
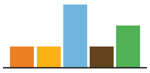
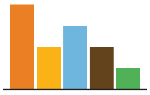
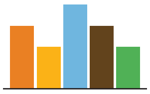
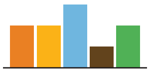
[3] Ch = Chapter within this BBDS report.

Adaptation options	Scale	Resilience factors[1]	Difficulty of implementation[2]	Main sources[3]
g. Maximizing positive community infrastructure outcomes from industrial development.	Local to regional	Div, Mat	 T3, F2, G2, S2, SL1	Ch 11–12
h. Conducting detailed permafrost mapping to support decision-making on community expansion.	Local to regional	Chng, Know	 T1, F3, G1, S1, SL1	Ch 10
i. Conducting regular and robust monitoring of existing infrastructure to ensure continuing safety.	Local to national	Chng, Mat, Know	 T1, F3, G2, S1, SL1	Ch 10
j. Exploiting the potential in sustainable energy, including hydro-energy and emerging solar energy options.	Local to national	Chng, Mat, Know	 T3, F3, G2, S1, SL1	Ch 7
9. For **mineral resource exploration** activities, an IRM approach – to ensure that climate change considerations are built into planning and regulatory approval processes – would be a major step forward. (See also the shipping-related options listed above.)	--	--	--	--
a. EIA procedures should especially consider changes (e.g., extreme events and permafrost changes) at the long timescales relevant for tailings management and storage capacity.	National	Chng, Know	 T3, F2, G2, S2, SL2	Ch 12, Ford et al. (2011) Pearce et al. (2011b)
b. Depending on local context, guidance and permitting procedures for exploration and extraction activities may need to stipulate flexible operations planning to accommodate increasingly variable weather, changing ice conditions, or alterations to animal migration patterns.	Regional to national	Chng, Div, Mat, Cult	 T1, F1, G3, S1, SL2	Ch 12
c. The continued development of impact benefit agreements (IBAs), with a focus on the strategic use of revenues for investment in society – including infrastructure, education, and research – would provide long-term benefits for society and investors.	Regional to national	Chng, Div, Mat, Know	 T2, F2, G3, S2, SL2	Ch 7
10. To promote the expanding **tourism** opportunities, relevant bodies may choose to:	--	--	--	--
a. Establish a sustainable tourism development and planning strategy for the BBDS region, including shared (rather than competitive) marketing between Greenland and Nunavut, to promote the region as a whole.	International (coordination)	Chng, Div, Mat, Know, Org	 T4, F2, G3, S2, SL1	Ch 8
b. Identify incentives and regulatory mechanisms – coordinated across the BBDS region – that could favor locally owned and operated tourism operators over non-local or international companies. This option includes planning directly with local residents to encourage local entrepreneurship.	Regional to international	Chng, Div, Mat, Cult, Know, Org	 T3, F2, G4, S3, SL2	Ch 8
c. Develop and apply "flexible" (BBDS or pan-Arctic) codes of conduct for tourists and operators, including guidelines for sensitive sites. ("Flexible" in this context means that the codes will need to be regularly assessed and perhaps adjusted in response to unforeseen changing conditions and environmental or cultural sensitivities.) There are existing guidelines that could be simply adopted officially or enshrined as regional-level legislation. This approach, if found to be appropriate, would simplify the process of implementation.	Regional to international	Div, Mat, Cult, Know	 T2, F2, G3, S1, SL2	Ch 8, Ch 12 Arctic Council (2015)

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[2] Difficulty of implementation: **T**echnical (orange), **F**inancial (yellow), **G**overnmental (blue), **S**tructural (brown), and **S**ocial **L**icense (green); ranked **1**–**5**, with 1 being the least difficult and 5 being the most difficult. On the small charts, the taller the bar, the greater the estimated level of difficulty of implementation.

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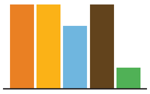
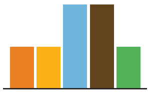
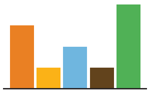
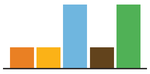
Adaptation options	Scale	Resilience factors[1]	Difficulty of implementation[2]	Main sources[3]
d. Coordinate and enhance the development of education and training programs for tourism guides and other tourism professionals.	National, international	Div, Know, Org	 T1, F3, G2, S2, SL1	Ch 5, Ch 8, Ch 12
e. Invest in local tourism infrastructure and seek ways to utilize and market seasonally vacant or underutilized resources (e.g., school buildings) in planning for peak tourism times.	Local to national	Mat, Org	 T2, F2, G3, S3, SL2	Ch 2, Ch 8
11. Sustainable and flexible **natural resource management, including fisheries,** will be increasingly needed under future changing conditions. In support of no-regrets options, the following could be considered:	--	--	--	--
a. Seeking ways to support a fisheries sector that continues to be flexible, ready to adjust to changes in resource availability and accessibility (e.g., changes in species, distributions) – for example, by adapting the management system to accommodate multi-species fisheries. This option may include investing in research and development of more flexible handling facilities (to support local value chain development) and planning for local fishing fleets that can be retooled or adjusted relatively easily to exploit variable resource opportunities.	Local to national	Chng, Div, Mat, Cult, Know, Org	 T4, F4, G3, S4, SL1	Ch 6, Ch 12 Government of Greenland (2012)
b. Enhancing regional (BBDS) and multilateral collaboration to prepare guidelines for potential new fisheries opportunities, including the management of joint stocks. (Building on existing DFO guidelines could be a starting point.) This option is in line with suggestions from other Arctic assessments, including the suggestion to "*Encourage precautionary, science-based management of fisheries in these waters in accordance with international law*" (Eamer et al., 2013, p. 87).	Regional to international	Chng, Div, Mat, Cult, Know	 T2, F2, G4, S4, SL2	Ch 6 CAFF (2013) Eamer et al. (2013)
c. Establishing new-fisheries working groups to consider and agree on the management of emerging fisheries.	International	Chng, Mat, Know, Org	 T3, F2, G3, S3, SL2	Ch 6
d. Surveying the (changing) distributions and abundances of pelagic forage fishes.	National to international	Know	 T2, F3, G3, S2, SL2	Ch 6 Government of Greenland (2012)
e. Ensuring that fisheries management options promote resource sustainability based on sound scientific advice, thus providing for the potential value addition of eco-certification of the fishery.	Regional to international	Div, Know	 T2, F2, G3, S2, SL2	Ch 6
f. Improving resource/biodiversity monitoring to provide information on patterns of change, including the further collection of traditional knowledge and scientific data and the funding of cross-national efforts to document broad patterns in wildlife behavior.	Regional to international	Chng, Div, Mat, Cult, Know, Org	 T1, F3, G3, S2, SL2	Ch 6, Ch 11
g. Considering the genetic viability of species and adaptation to climate change as guiding principles in determining and managing sustainable harvest levels.	Regional to international	Chng, Div, Mat, Cult, Know, Org	 T3, F1, G2, S1, SL4	CAFF (2013) Eamer et al. (2013)
h. Considering the establishment of no-take zones for some hunted species to improve hunting in surrounding areas.	Regional	Chng, Div, Mat, Cult	 T1, F1, G3, S1, SL3	Ch 6
i. Identifying biological and fishery hotspots that will require protection in the context of future development of the mining and oil and gas sectors.	National to regional	Chng, Div, Mat, Cult, Know, Org	 T3, F3, G3, S2, SL1	Ch 6

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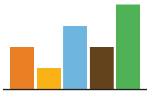
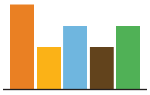
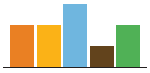
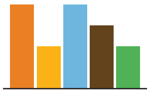
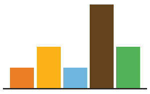
Adaptation options	Scale	Resilience factors[1]	Difficulty of implementation[2]	Main sources[3]
j. Encouraging more international cooperation in the management of shared seabird resources, to ensure sustainable use on a population scale, as currently practiced for some marine mammals and commercial fish species.	International	Chng, Div, Mat, Cult, Know, Org	 T3, F2, G3, S2, SL1	Ch 6
k. Facilitating cooperation among researchers, managers, and local users; supporting local involvement in monitoring (e.g., community-based monitoring programs).	Local to regional	Chng, Div, Mat, Cult, Know, Org	 T2, F2, G2, S2, SL2	Ch 6
l. Considering the expansion of trophy hunting as a means of supplementing hunter incomes (e.g., building on experiences from Nunavut).	Regional to national	Div, Mat	 T2, F1, G3, S2, SL4	Ch 6
m. Promoting alternative harvesting or economic activities related to nature (e.g., mussel cultivation, eiderdown collection, tourism).	Local to national	Chng, Div, Mat, Cult	 T3, F3, G2, S3, SL3	Ch 6
n. Supporting community resilience by developing a broader range of livelihood options, supporting small-scale entrepreneurial activity through "research and development centers," and ensuring that legislation is conducive to marketing options.	Local to national	Chng, Div, Mat, Cult	 T3, F3, G2, S3, SL3	Ch 6
o. Taking advantage of future possibilities for agricultural development, based on realistic assessments of the implications of increased climate variability, the logistic bottlenecks caused by limited infrastructure, and the increasing possibility of introducing alien and invasive plant and pest species.	Local to national	Chng, Mat, Cult, Know	 T3, F2, G2, S2, SL1	Ch 6
12. To safeguard **Arctic biodiversity** under changing environmental conditions (e.g., loss of sea ice, northward shift of the Arctic zones), several options can be considered, including some mentioned in recent Arctic Council reports:	National, international	--	--	--
a. Safeguard areas in the northern parts of the Arctic where High Arctic species have a greater chance of surviving (for climatic or geographical reasons), as a refuge for unique biodiversity; focus on areas of particular richness in unique Arctic biodiversity at present and adjust regulations as changes appear ("adaptive ecosystem management").	Regional to international	Chng, Div, Mat, Cult, Know, Org	 T4, F2, G3, S2, SL3	Ch 6 CAFF (2013)
b. Advance the protection of large areas of ecologically important marine habitats, taking into account ecological resilience in a changing climate. For marine protected areas, build on existing processes to complete the identification of such areas and implement conservation measures.	Regional to international	Chng, Div, Mat, Cult, Know, Org	 T2, F2, G3, S1, SL2	Ch 6 –7 CAFF (2013)
c. Consider how protected-area management could become "adaptive," ensuring connectivity between critical areas and, where needed, being flexible to ensure optimal management of the key biodiversity/resources meant to be protected.	Regional to national	Chng, Div, Mat, Cult, Know, Org	 T4, F2, G4, S3, SL2	Ch 6 Arctic Council (2015)
d. Consider creating a United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage Site in northwest Greenland/northeast Canadian Archipelago as a refuge for ice-associated species (the Last Ice Area).	National to international	Chng, Div, Mat, Cult, Org	 T1, F2, G1, S4, SL2	Eamer et al. (2013)
e. Adapt or develop indicators specific to the BBDS region to periodically assess marine and terrestrial ecosystem status, including the status of ecosystem services.	Regional to international	Chng, Div, Mat, Know, Org	 T2, F3, G3, S2, SL1	Ch 6

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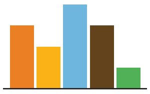
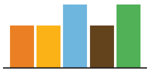
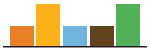
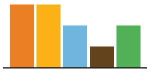
Adaptation options	Scale	Resilience factors[1]	Difficulty of implementation[2]	Main sources[3]
f. Explore the need for internationally designated Arctic marine areas for the purpose of environmental protection (in areas beyond national jurisdictions).	International	Div, Mat, Cult, Know	 T3, F2, G4, S3, SL1	Skjoldal et al. (2009)
g. Safeguard areas critical for sensitive life stages of Arctic species, including polynyas. To accomplish this, develop guidelines and implement spatial and temporal measures to reduce disturbance outside of protected areas.	Regional to international	Div, Mat, Cult	 T2, F2, G3, S2, SL3	CAFF (2013) Eamer et al. (2013)
13. In addition to the more specific **communication** options summarized above, broader communication outreach on science, impacts, and – not least – opportunities in the Arctic could be helpful, including the following:	--	--	--	--
a. Communicate local examples of successful adaptations to change (see also the options for cross-learning and knowledge management, listed above). The Arctic Council's Arctic Adaptation Exchange platform (arcticadaptationexchange.com) is an initiative to build on.	Local to national	Chng, Know, Org	 T1, F2, G1, S1, SL2	Ch 1 Arctic Council (2013b)
b. In official communications from local/regional governments and institutions on climate change, accentuate local capacity and agency to adapt to change so that people do not perceive themselves or others as "powerless spectators" but rather as "adaptive managers" or "future makers."	Local to national	Chng, Know, Org	 T1, F1, G2, S1, SL2	Larsen and Fondahl (2014) Sejersen (2009)
c. Enhance communication about the status of declining or vulnerable species and the impact of climate change on the distribution and behavior of animals; share information on new hunting opportunities or alternative uses of living resources.	Local to national	Chng, Div, Cult, Know, Org	 T1, F1, G2, S1, SL2	Ch 6
d. Enhance funding to climate communicators and give license to explore new methods and media for clear and effective ways to explain climate science and local impacts and opportunities to nonspecialists, especially targeting local-level nonspecialist audiences.	Local to national	Chng, Div, Cult, Know, Org	 T3, F3, G2, S1, SL2	Ch 12

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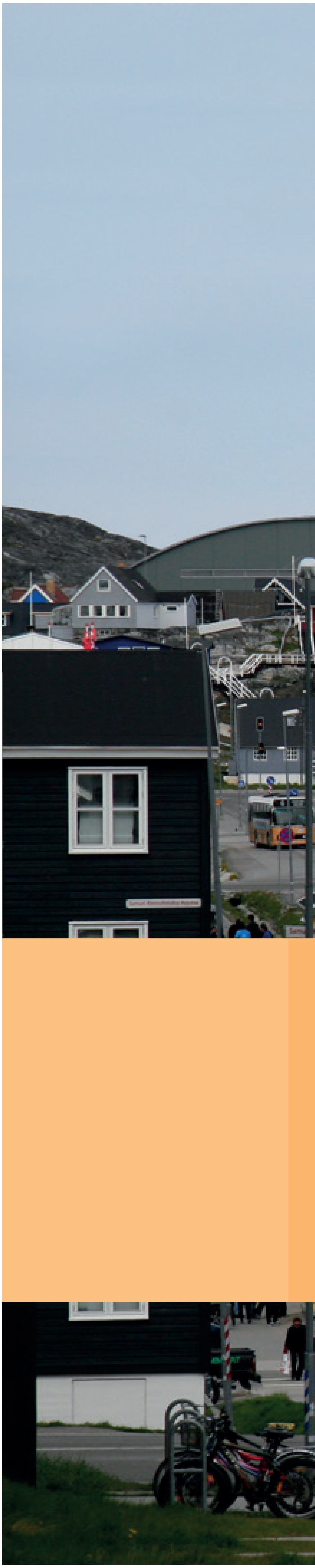
Acronyms and abbreviations

~	Approximately
μM	Micromolar
Ω_{arg}	Saturation state of aragonite
AACA	Adaptation Actions for a Changing Arctic
ABA	Arctic Biodiversity Assessment
ACIA	Arctic Climate Impact Assessment
AIS	Automatic identification system
ALT	Active-layer thickness
AMAP	Arctic Monitoring and Assessment Programme
AR5	Fifth assessment report of the Intergovernmental Panel on Climate Change
BAT	Best available technique
BBDS	Baffin Bay/Davis Strait; the Baffin Bay/Davis Strait region
BCB	Bering-Chukchi-Beaufort; the Bering-Chukchi-Beaufort area
BEP	Best environmental practice
BFR	Brominated flame retardant
BP	Before the present
C	Consequence of failure
CA	Canada
CAA	Canadian Arctic Archipelago
CACAR	Canadian Arctic Contaminants Assessment Report
CAD	Canadian dollar(s)
CAFF	Conservation of Arctic Flora and Fauna
CCA	Climate-centered adaptation
CCG	Canadian Coast Guard
CCSM	Community Climate System Model
Cd	Cadmium
CHL	Chlordane
CHN	Community health nurse
CHR	Community health representative
CI	Confidence interval
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CMIP5 (CMIP3)	Coupled Model Intercomparison Project, Phase 5 (Phase 3)
CO$_2$	Carbon dioxide
CPUE	Catch per unit effort
CRU	Climatic Research Unit (University of East Anglia)
CSRI	Codes, standards, and related instruments
CUP	Currently used pesticide
DCE	Danish Centre for Environment and Energy
DDT	Dichlorodiphenyltrichloroethane
DEW	Distant Early Warning
DFO	Fisheries and Oceans Canada
DJF	December–January–February
DKK	Danish krone(r)
DMI	Danish Meteorological Institute
EAMRA	Environmental Agency for Mineral Resource Activities (Greenland)
EATEP	Eastern Arctic Teacher Education Program
EBM	Ecosystem-based management
EBSA	Ecologically and/or biologically significant area
EEZ	Exclusive economic zone
EIA	Environmental impact assessment
EPPR	Emergency Prevention, Preparedness and Response Working Group
EXPS	Extruded polystyrene
FIFO	Fly-in/fly-out
GCM	Global climate model
GDP	Gross domestic product
GEUS	Geological Survey of Denmark and Greenland
GHG	Greenhouse gas(es)
GIA	Glacial isostatic adjustment
GIPL	Geophysical Institute Permafrost Lab (University of Fairbanks, Alaska)
GIS	Geographic information system
GL	Greenland
GNP	Gross national product
GPS	Global positioning system
GT	Gross tons
GTO	Greenland Technical Organization
HAB	Harmful algal bloom
HBCD	Hexabromocyclododecane
HCH	Hexachlorocyclohexane
Hg	Mercury
HTO	Hunters and trappers organization
IBA	Impact and benefit agreement, impact benefit agreement
ICC	Inuit Circumpolar Council
ICT	Information and communication technology
IIBA	Inuit impact and benefit agreement
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
IQ	*Inuit Qaujimajatuqangit*; Inuit social values
IRA	Inuit Research Advisor
IRIS	Integrated Regional Impact Study
IRIS-RSM	IRIS Regional Science Meeting
IRM	Integrated risk management
ITK	Inuit Tapiriit Kanatami
ITQ	Individual transferable quota
IUCN	International Union for Conservation of Nature
IWC	International Whaling Commission

JJA	June–July–August
KANUKOKA	An association of municipalities in Greenland
KNAPK	Association of Fishermen and Hunters in Greenland
lw	Lipid weight
MAM	March–April–May
m.a.s.l.	Meters above present sea level
Me-Hg	Methylmercury
MLSA	Mineral License and Safety Authority (Greenland)
MPA	Marine protected area
MSC	Marine Stewardship Council
NAFO	Northwest Atlantic Fisheries Organization
NAMMCO	North Atlantic Marine Mammal Commission
NAP	National adaptation plan
NC^3	Government of Nunavut Climate Change Centre
NCP	Northern Contaminants Program
NDF	Non-detriment finding
NEB	National Energy Board (Canada)
NGO	Nongovernmental organization
NHC	Nunavut Housing Corporation
NIRB	Nunavut Impact Review Board
NLCA	Nunavut Land Claim Agreement
nm	Nautical mile
NMCA	National marine conservation area
NOAA	National Oceanic and Atmospheric Administration (USA)
NOS	National Occupancy Standard
NOW	Pikialasorsuaq/North Water Polynya
NP	Nurse practitioner
NRI	Nunavut Research Institute
NTI	Nunavut Tunngavik Incorporated
NWP	Northwest Passage
OGP	Oil and gas province
OHC	Organohalogen compound
P	Probability of failure
PAH	Polycyclic aromatic hydrocarbon
Pb	Lead
PBDE	Polybrominated diphenyl ether
PCB	Polychlorinated biphenyl
PFAS	Perfluorinated alkylated substance
PFOS	Perfluorooctane sulfonate
PIEVC	Public Infrastructure Engineering Vulnerability Committee
POP	Persistent organic pollutant
PP	Primary production
PPR	Persons per room
PSF	Psychosocial factors
PSSA	Particularly sensitive sea area
psu	Practical salinity unit
RCP	Representative concentration pathway (emissions scenario)
RCP2.6	RCP based on a low emissions scenario
RCP4.5	RCP based on a mid-range emissions scenario
RCP8.5	RCP based on a high (business-as-usual) emissions scenario
REE	Rare earth element
RIT	Regional Integration Team (AACA)
RN	Registered nurse
RSM	Regional science meeting
S, *S*	Salinity
SAR	Search and rescue
SAREX	Search and rescue exercise
SCD	Snow cover duration
SDWG	Sustainable Development Working Group
SEA	Strategic environmental assessment
SEIA	Strategic environmental impact assessment
SIA	Social impact assessment
SLiCA	Survey of Living Conditions in the Arctic
SON	September–October–November
Sv	Sverdrup (1 Sv =1 million m^3 per second)
SWE	Snow water equivalent
SWEmax	Maximum snow water equivalent
SWIPA	Snow, Water, Ice and Permafrost in the Arctic
t	Tonne(s) (metric ton)
T, *T*	Temperature
TA	Transformational adaptation
TAC	Total allowable catch
TAH	Total allowable harvest
Tcf	Trillion cubic feet
TEK	Traditional ecological knowledge
TEU	Twenty-foot equivalent unit
TK	Traditional knowledge
TLK	Traditional and local knowledge
T_{mean}	Mean (average) temperature
UNESCO	United Nations Educational, Scientific and Cultural Organization
UPEI	University of Prince Edward Island
VCA	Vulnerability-centered adaptation
WHO	World Health Organization



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