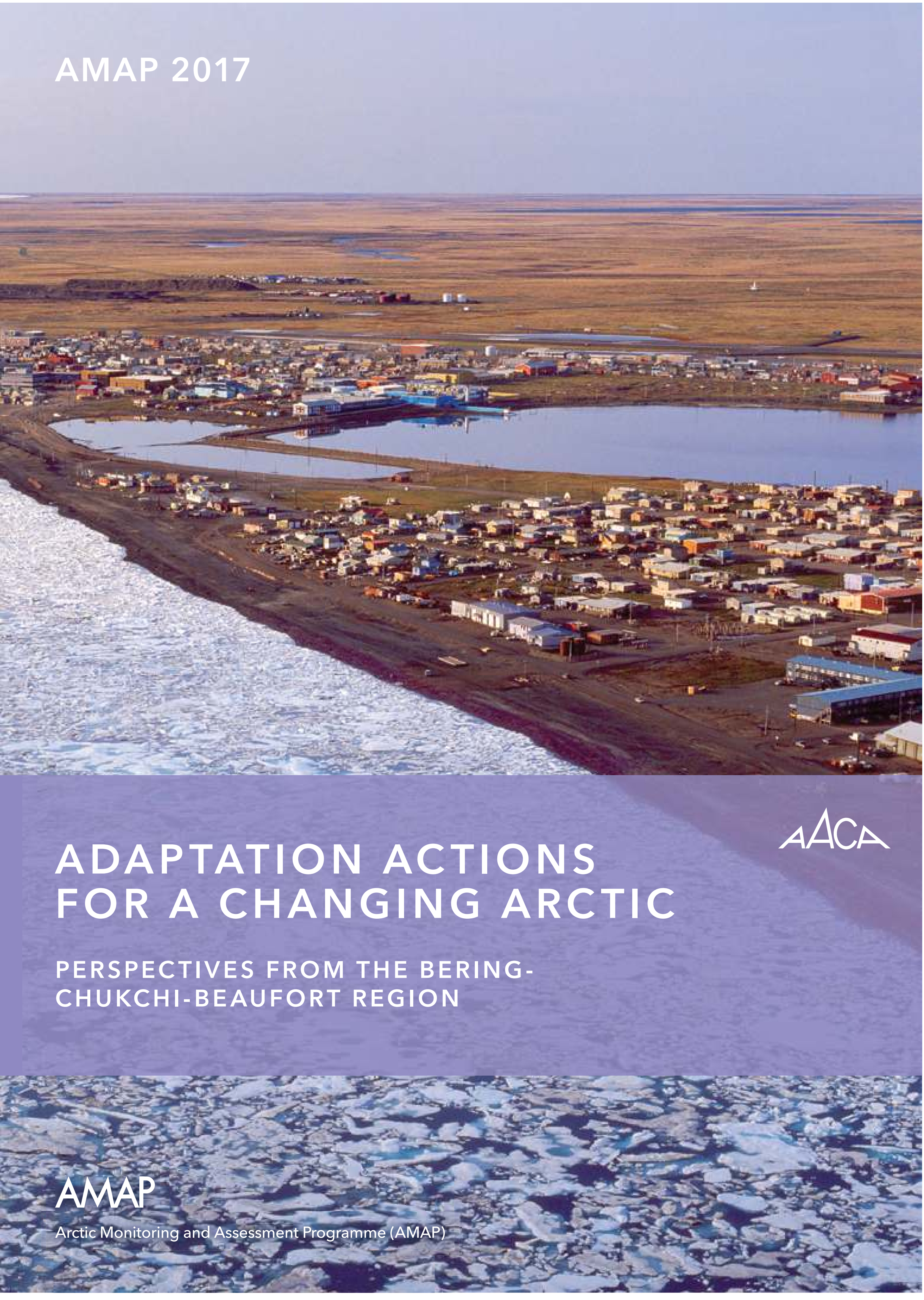

AMAP 2017

# ADAPTATION ACTIONS FOR A CHANGING ARCTIC

## PERSPECTIVES FROM THE BERING-CHUKCHI-BEAUFORT REGION

AMAP
Arctic Monitoring and Assessment Programme (AMAP)

AMAP 2017

# Adaptation Actions for a Changing Arctic: Perspectives from the Bering-Chukchi-Beaufort Region

AMAP

Arctic Monitoring and Assessment Programme (AMAP)
Oslo, 2017

# AMAP 2017 Adaptation Actions for a Changing Arctic: Perspectives from the Bering-Chukchi-Beaufort Region

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*Citing whole report*
AMAP, 2017. Adaptation Actions for a Changing Arctic: Perspectives from the Bering-Chukchi-Beaufort Region. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. xiv + 255pp

*Citing individual chapters*
[Lead author list], 2017. [Chapter title]. In: Adaptation Actions for a Changing Arctic: Perspectives from the Bering-Chukchi-Beaufort Region. pp. [??-??]. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

ISBN 978-82-7971-103-2

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

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

## Production

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*Cover photograph*
Utqiagvik (Barrow) is surrounded by ice, even in mid-summer.
Accent Alaska.com / Alamy Stock Photo

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

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

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# Acknowledgments

Larisa Abryutina, Syeda Mariya Absar, **Maria Ananicheva,** Evgeny Antonov, **Thomas R. Armstrong,** Eugene Asicksik, David Atkinson, Valeria Bashkirova, **John L. Bengtson,** Berill Blair, Ross Brown, Michael Brubaker, Emilie Cameron, Terry Camsell, F. Stuart Chapin III, Valery Chaschin, Doug Cost, Ashlee Cunsolo, Raychelle Daniel, Bathsheba Demuth, David Driscoll, Matthew Druckenmiller, **Laura Eerkes-Medrano,** Kathleen M. Ernst, **Gregory Flato,** Marina Fomenko, James Ford, Nancy Fresco, Ashley Gaden, **James Gamble,** J. Craig George, **S. Craig Gerlach,** Lawrence Hamilton, Mike Harlow, Sherilee Harper, Lawrence Hartig, Lois Harwood, Kevin Hillmer-Pegram, **Larry D. Hinzman,** Layla Hughes, Rich Hum, **Henry P. Huntington,** Gensuo Jia, Mark A. Johnson, Vladimir Kattsov, Nathan Kettle, Ludmila Khudyakova, Takashi Kikuchi, Kirill Kivva, **Alexander Klepikov, Gary Kofinas,** Emily Kudluk, Scott Lamoureux, Aaron Lawton, Olivia Lee, Donald Lemmen, Johnny Lennie, James Lima, Thomas Lohman, **Philip A. Loring, Amy Lauren Lovecraft,** Givi Machavariani, John W. Madden, Elizabeth Marino, Doug Matthews, Magdalena Muir, Phil Mundy, **Elena Nikitina,** George Noongwook, Jon Øyvind Odland, **Peter M. Outridge,** James Overland, Min Pan, Tristan Pearce, **Henry Penn,** Alison Perrin, Irina Pipko, Nina Poussenkova, Natalia Pozhilova, **Benjamin L. Preston,** Lisa Robbins, Robin Rong, Valentina Sergeeva, Vanessa Skean, Alexey Somov, Nadja Steiner, Gary Stern, Kai Sun, Stefan Tangen, **Lyman Thorsteinson, Sarah F. Trainor,** Vilena Valeeva, **John E. Walsh,** Xiaolan Wang, Sonia Wesche, Eduard Zdor

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# Preface

This report presents the results of the 2017 AMAP Assessment of *Adaptation Actions for a Changing Arctic (AACA): Perspectives from the Bering-Chukchi-Beaufort 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 Baffin Bay/Davis Strait region involving western Greenland, the eastern part of Nunavut in Canada and Baffin Bay/Davis Strait between these land masses.

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

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

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

This report provides the accessible scientific basis and validation for the statements made in the *AACA Bering-Chukchi-Beaufort 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 Bering-Chukchi-Beaufort 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 Bering-Chukchi-Beaufort 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, Russia and the USA for taking the lead country role in this assessment and to thank the US National Science Foundation, Canada, 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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Oslo, November 2017

# Executive Summary to the report on *Adaptation Actions for a Changing Arctic: Perspectives from the Bering-Chukchi-Beaufort Region*

## Prelude

> *"It is not the most intellectual of the species that survives; it is not the strongest that survives; but the species that survives is the one that is able best to adapt and adjust to the changing environment in which it finds itself."*
> (Leon C. Megginson, 1963)

This statement provides good context for exploring the rapidly changing Arctic and evolving conditions for the people, plants and animals that claim this region as home. These changes are not limited to those driven by climate, globalization, local, regional or international politics or economics, nor by demographics and changing social and cultural structures. The highly dynamic Arctic is driven by all of these, and communities are affected by the confluence of these interdependent systems and processes. Evaluating the ecological effects of any single driver or projecting trajectories of change is complicated and unrealistic because almost every response has multiple stimuli and variable influence in space and time. In this assessment, rather than attempt to quantify a response to a given impact, the approach has been to characterize the processes driving system dynamics and to examine how the system (people, plants, animals, air, land and sea) is generally responding at various scales to the changes that are already occurring or that are projected to occur. This report synthesizes what is currently known about the region and identifies major knowledge gaps. New learning and understanding will require policies that promote the collection of new data and information, monitoring and evaluation of climate change, and regular synthesis efforts to develop multidisciplinary and system understanding. Existing or planned adaptation planning can benefit greatly by considering process-oriented approaches as advocated herein, to assess current capabilities, ongoing adaptation efforts, and to address information needs to increase understanding and assure the resilience of this region's natural ecosystems and people.

## Introduction

The Bering-Chukchi-Beaufort (BCB) region and its stakeholders are undergoing rapid change in ecological, socio-economic, and political responses to climate and other drivers. Climate effects can result in direct and indirect impacts on the region's physical, chemical, and biological environments. Social and cultural change alters the fabric of indigenous and other communities, including the preservation of native cultures and traditional knowledge. Economic change can bring opportunities but also dislocation, as was evidenced in Chukotka after the collapse of the former Soviet Union. Political change can affect resource use and also the ability of stakeholders to organize themselves and govern Arctic resources.

The BCB region is geographically vast, sparsely populated, and characterized by strong connections among its indigenous people and the land and sea. Understanding the cultural and nutritional ties of indigenous people to geographic place and natural resources (especially coastal resources), especially in light of the limited near-term opportunities for significant community participation in the cash economy, is an important element of realistic adaptation planning for climate change. Adaptation to climate change intersects with other environmental issues and needed policies confronting Arctic residents, including those concerning food security, human health and welfare, environmental security and quality of life, and resilience of BCB ecosystems. Each issue is multi-dimensional with shared ecological components, and this warrants integrative approaches linking air, land, sea, water and ice and effects of changes on natural resource availability, access to these resources, living conditions, human safety, and opportunities for economic development. Coastal resources, especially marine mammals and caribou/reindeer, are important subsistence foods in the BCB region, and the loss of sea ice and changing weather has the potential to limit access to these valued resources through changes in the travel patterns of hunters, and through degraded habitat structure and quality. Increasing numbers of coastal villages are physically threatened by flooding, storm surge, and erosion related to climate changes. Similarly, the low lying terrestrial and freshwater habitats of millions of seasonal migrant species, which use the region for reproduction and summer nurseries, are being impacted by seawater inundation. The underlying physical, chemical, and biological processes being affected by climate warming are important in the assessment of impacts, evaluation of the scientific, management, and technological needs to protect life and infrastructure, and in understanding how best to promote future investment and economic growth in the region. The insights and knowledge of indigenous people and other local residents must be part of an approach to relevant adaptation planning. This process must be guided by science-based management principles, recognize the regional significance of subsistence and have the capacity to evaluate economic opportunities, and includes participation from appropriate scales of community and higher-level government involvement.

The BCB environment is greatly affected by Pacific influences whose impact on climatic conditions extends as far as the Northeast Atlantic. The Bering Strait and vast extent of continental shelf area, notably in the Chukchi and East Siberian seas, are also unique in the Arctic. The Bering Strait region contains many important wildlife areas including the largest seabird colonies in the north American Arctic, located at Capes Lisburne and Thompson. Biological production in Chukchi Sea soft bottom communities (invertebrate infauna) is among the highest in the world and reflects the efficiency of benthic-pelagic coupling in the region. The marine environment is home to many species of seasonal and resident marine mammals, some of international significance, and these species are critical to coastal communities and the persistence of Inuit cultures in the region. The loss of sea ice in the region is not only a threat to ice-dependent species and the hunters who rely on seasonal access to them but also results in changes in climate conditions in other ecosystems locally, regionally, and more distantly.

There are no major marine commercial fisheries in most of the region. Federal legislation has been instituted in the USA to prohibit industrial fishing in US sectors of the BCB until such time as the fisheries resources and their population dynamics are better known. The possible expansion of viable Pacific salmon populations into much of the region is of interest to many. The successful colonization of highly valued species such as chinook, coho, and sockeye salmon (*Oncorhynchus tshawytscha*, *O. kisutch* and *O. nerka*, respectively) in BCB regions to the north of the southern Chukchi Sea (e.g. Kotzebue Sound in Alaska) has not been observed. The lack of fisheries is reflected in the general lack of long-term data from the BCB area compared to southern Bering, Barents and Baffin Bay / Davis Strait regions where commercial fishing is more important. Arctic cod (*Boreogadus saida*) is a keystone marine species and may be more important in regional ecosystems in the BCB area than in other regions. Warming and the potential for geographic range constriction to the north is an ecosystem concern.

The region is sparsely populated and village communities are often remote and poorly connected to urban centers and supply chains. This lack of connection has affected local participation in industrial developments. Lack of training and skill sets in the communities also negatively affects employment opportunities. Regional developments are mostly resource-based (e.g. oil and gas and mining) and much of the earned income leaves the BCB area through outside workers. In Alaska and Canada, state and federal governments are generally located outside the region, whereas local and tribal governments are quite accessible to most residents. Indigenous peoples' participation in adaptation planning will require special attention by planners with respect to efforts to make their voices heard and through collaboration in granting and other fund acquisition processes.

## Drivers of change

Changes in physical climate in the Arctic are largely a manifestation of changes in global climate associated with increasing concentrations of atmospheric greenhouse gases. Warming is substantially amplified in the Arctic relative to lower latitudes due to regional climate processes and feedbacks. There are many related physical changes, such as reduction in the duration and amount of snow and sea-ice cover, warming and thawing of permafrost, and declining glacier area and thickness. Climate model projections indicate that these changes, already being observed, will accelerate; with the magnitude and rate of change dependent on the future trajectory of global greenhouse gas emissions. Surface air temperature in the BCB region has increased by about 1.5°C over the past 50 years and is projected to increase by 3–7°C by the end of the century. Changes in physical climate are driving changes in other aspects of the environment such as terrestrial vegetation, coastal erosion, freshwater balance, and marine productivity.

Climate change matters, but should be considered in the context of other changes, many of which are occurring on a faster timeline. Basic social, economic, and political conditions shape the ways in which climate and other environmental changes affect stakeholders and the ways in which stakeholders are able to respond, and these conditions are still very much in flux owing to the continuing social impacts of westernization. Change is also being driven by global and regional socio-economic factors such as globalization of the economy, technology, changing demand for mineral resources, increasing tourism, and potential increases in marine transportation through the Arctic as the sea ice continues to decline. Regional changes in population, lifestyle and well-being, and political and governance structures are also driving change. It is important to note that there are positive as well as negative aspects to change. Capitalizing on opportunities while reducing negative impacts requires planning and the resources to put that planning into practice.

## Impacts and consequences for northern communities and society

This report represents a significant first-step to synthesize environmental information and to use that information to inform others about future conditions and potential outcomes in the BCB region for people and their communities. As such, many scientific uncertainties were identified and information needs noted as they pertain to climate change adaptation planning. Human needs and considerations tend to be considered holistically throughout. This is somewhat novel, especially given that multiple nations (USA, Canada, and Russia) and governance structures are involved. There is a message throughout that ecosystem-level information is a necessary component for understanding climate effects and their interactions, including changing conditions far-removed from the BCB region. The latter includes environmental effects or changes in the marketplace due to globalization. There is strong agreement throughout the report that continuing subsistence activities will be a critical element of food security despite local participation in the cash economy. Subsistence lifestyles and resources must be protected through effective management across the entire BCB region. Within the planning dimension, scenarios could be more effectively employed to guide these strategies by applying the information assembled in this report.

Documented changes occurring in the environment, including declining sea ice and snow cover, rising sea level, tundra permafrost thaw and degradation, ocean acidification, coastal erosion, and changes in precipitation patterns, are already having consequences for societies, and pose a range of serious challenges to local communities. Some changes in the Arctic environment are clear and their future impacts are predictable, whereas others are more subtle, complex and harder to foresee and so predicting a combination of their consequences for societies and responses to them in the future is extremely difficult.

Ecological, economic, and social changes underway in the Arctic impact human and natural systems. Arctic residents and communities are already experiencing and will continue to experience impacts in their everyday life associated with issues such as anthropogenic contaminants, food and water security, adequate housing, public services and infrastructure, human health, safety, coastal erosion and flooding, permafrost thaw, wildfires, and preserving cultural heritage. Combinations of these impacts result in strong synergy and have important consequences for sustainable development of local communities in the BCB region. Impacts of climate change, in particular, have a variety of direct and indirect consequences not only for ecosystems, but also for its societies. They result in risks and opportunities to individuals, families, communities and economic systems. Both mitigation and adaptation responses to climate change are underway in the region in order to reduce and manage current and future risks. Long-term monitoring and adaptive management approaches are recommended to understand the effectiveness of human interventions (e.g. management or regulatory policies) and to develop an understanding of trajectories of change.

The small number of jobs, high cost of living, and rapid social change make rural (predominantly indigenous) communities highly vulnerable to climate change especially through impacts on traditional hunting and fishing activities and cultural connections to the land and sea. Climate impacts on these communities are magnified by additional social and economic stresses. However, indigenous communities have for centuries dealt with scarcity and high environmental variability and so have deep socio-cultural reservoirs of flexibility and adaptability. The environmental drivers that have been increasingly shaping the lives of people in the BCB coastal communities are expected to continue to grow in magnitude and effect during the 21st century. Impacts on the physiography of the coast will continue to direct, for example, the location of human habitations and the staging and feasibility of subsistence activities. A restructuring of indigenous cultures to accommodate changes in species composition and the availability of subsistence food resources appears inevitable. The loss of multi-year sea ice and changes in the duration and distribution of annual sea ice will also continue to circumscribe the availability of marine and coastal subsistence resources. If multi-year sea ice disappears from the area entirely, variability in the amount of first-year ice is expected to result in profound changes in the availability of marine mammals and birds as sources of subsistence foods.

The thawing of permafrost is having serious implications for the integrity of homes, municipal buildings and essential facilities, including infrastructure of the oil, gas and mining industries. More challenging travel conditions and increasing unpredictability in animal movements and availability can decrease harvest success and require additional hunting effort associated with additional fuel costs, time away from jobs and families, increased wear and tear on equipment, and increased risk of exposure and injury.

In such a highly variable environment, long-term change is likely to be overshadowed by the events of each season. Many adaptation actions are being taken by stakeholders, individually and in collaboration with others. At the same time, there are many challenges to which stakeholders have not yet been able to adapt. Village relocation and disaster prevention are urgently needed in several cases in Alaska, but government agencies have no mandate to provide support or mechanisms for coordinating their actions with each other or with the communities in question. Political pressure on Chukotkan indigenous organizations hampers their ability to serve their members. Regulations and policies governing oil and gas activity are decided at the federal level in the USA and Canada, only partly in response to local conditions and desires. Communication among communities and between communities and outside actors remains inconsistent, with the result that much valuable information is not transmitted effectively in either direction. Economic health and political stability can greatly enhance the ability of all stakeholders to respond effectively and to find ways to collaborate with those who can help. Few major problems can be resolved by just one group or type of expertise. Collaboration will remain necessary to span the scales from local to global. Addressing only the most visible or fashionable problem is likely to miss the fact that communities and ecosystems function together, not as collections of disconnected parts. In addition, integrative planning may address multiple 'connected' problems and not just the high-profile issues.

## Resilience

There is convincing evidence that northern peoples and communities, while vulnerable, are largely resilient to the pressures and multiple dimensions of social, economic, and environmental/climatic change. Yet, while fostering new strategies for enhancing resilience is an important goal in itself, a person or community's ability to recover or adjust to harm does not negate the social impacts or environmental justice implications of any harm, threat or insult that has already been inflicted. In other words, even though a community or a network of communities may be resilient to some aspects of climate change, this is not a reason to ignore emergent and emerging problems, or to fail to develop better strategies for climate change mitigation. Policy must be forward thinking and therefore working to strengthen resilience, but at the same time must work to mitigate the likelihood of future impacts, and to promote collaborative ways to cope effectively with change.

Policymakers must also recognize that at present there are multiple uses of and definitions for resilience, uses and definitions that are often context-specific, inconsistent or incompatible, and that mean different things to different people depending on societal context and problem. Indigenous conceptions of resilience are still rarely explored and/or accounted for in the academic literature and policy discourse on climate change. Likewise, resilience in the academic conceptualization is not necessarily 'helpful', and can be an obstacle to people achieving the kinds of change, adaptation or adjustment that they want and need over short or long periods of time.

It is important to recognize that resilience can be specific to a given threshold or tipping point. In the BCB region and other areas of the Arctic, multiple thresholds of concern exist, toward which climate change, in concert with many other direct and indirect drivers, is pushing rural peoples and communities in positive or negative directions. Examples of some undesirable thresholds, which occur at multiple levels and scales, include individual death; people leaving a community (outmigration); a nutrition transition from local, natural foods to imported store-bought foods; school closure; fishery/hunting closure/collapse; and community demographic collapse.

People in the BCB region have many strengths from which they can draw to avoid these thresholds, including: livelihood diversity; openness to change; reserves of resources for coping during times of stress; tightness of feedback loops between people (social networks) and among people and ecosystems; and social capital across scales, from households to communities to governments and international bodies.

These sources of potential resilience can be important targets for supportive policies.

This report reveals the multifaceted nature of resilience, including overlaps with such concepts as adaptation. Rather than trying to reconcile or privilege one definition over another, the aim here has instead been to focus on thresholds of concern and possible strategies for avoiding them. This is very important for participatory approaches to climate adaptation policy and action.

Resilience is not constant over time; the cumulative effects of the various impacts of climate change interact with the historical legacies of the Soviet collapse in Russia, and the legacies of westernization and mission schools in Alaska and residential schools in Canada, to erode people's ability to respond effectively to the integrated and/or differential aspects of social, cultural, ecological and climatic change. Considering how impacts of climate change interact over space and time is therefore essential for effective policy. One important and positive aspect of resilience is the ability people may possess to 'bounce forward' through purposive transformation (desired thresholds). An important consideration when thinking about resilience and transformation is whether actions that people take to avoid undesirable thresholds actually improve or simply undermine their ability to work toward positive transformation.

## Adaptation

Adaptation is an ongoing process encompassing awareness, understanding, mobilizing resources, building capacity, taking action, evaluating success and adjusting accordingly. This can happen through formal planning processes or spontaneously as real-time responses to changing conditions. In either case, foresight, assessment, flexibility to adjust to continued social and ecological change, and administrative, policy, economic and legal support is needed. In the BCB region, it is change, rather than stability, that has long been the norm, and adaptation is a central part of this. Direct and sustained engagement by communities is an important element for how people and communities will respond to the new challenges discussed above. A range of decision tools is available to assess possible planned adaptation options. These include the precautionary principle, risk management, cost-benefit analysis, multi-criteria decision analysis, and life-cycle assessment. In addition to longer-term environmental and social changes, rural indigenous communities face a range of more immediate stressors such as clean water availability, high fuel costs, alcoholism, domestic violence, and rising health issues such as diabetes and cancer. The combined and cumulative effects of these multiple stressors (both short- and long-term) should be considered. Innovative responses to change that also address these more immediate challenges will be especially impactful. Engaging rural communities in direct and meaningful ways in decision-making is very important.

While the feasibility of trans-Arctic shipping will ultimately be determined by the global market, increased trans-Arctic shipping is already underway. Increased international and intra-national collaboration and coordination, regulatory and governance mechanisms to address environmental and human health risks, increased hydrographic surveys, infrastructure development, environmental clean-up protocols, improved hazard warning systems, climate services, international collaboration, and marine safety staffing and infrastructure development are major necessary elements needed to take advantage of this opportunity. Risk assessment and management can be effective approaches to adaptation. These approaches, coupled with regulatory enforcement have been especially advantageous in the resource extraction and mining sector in Canada. In this realm, the longevity of waste containment sites is of key interest given the likelihood of permafrost degradation and associated hydrologic changes. Monitoring the performance of engineering solutions is also critical. Risk assessment and reduction can be an effective approach in adapting to increasing incidence of wildfires in the Arctic. Examples from Alaska include: increasing the capacity of communities to initiate, complete, and implement Community Wildfire Protection Plans (CWPP); reviewing selected wildland fire management practices; and developing a comprehensive fuels management program to treat high-risk areas. Risks to human, social and environmental components should all be considered. Consideration of short-term disaster risk management should be coupled with longer-term structural policy.

Given the dynamic regional environmental and socio-economic conditions, Arctic governance systems will need to remain flexible and adaptive to meet future challenges. This includes innovations in international, regional, and sub-regional communication, collaboration and partnership. Additional characteristics of governance frameworks that can foster adaptation include responsiveness, flexibility, and diversity. Key features for overcoming known barriers to adaptation include: strong cross-scale coordination in adaptation; strong leadership; communication and collaboration at similar administrative levels; and coordination and partnerships between formal and informal institutions and stakeholders. Capacity building on multiple levels will be needed.

## Responding to change

The future in the BCB region is one of significant socio-economic and climatic changes. The consequences of climate change as well as the capacity of communities to respond effectively will be contingent on the evolution and trajectory of socio-economic development. Over long time-scales, such patterns of social and environmental interaction are inherently uncertain. The evolution of governance systems and the global demands for minerals/energy (a main driver of exploitation of Arctic resources) are two of the key uncertainties affecting future socio-economic pathways in the BCB region and, therefore, the impacts of climate change. Global energy demand will affect future investment in the exploitation of Arctic energy resources and this could have downstream economic, social, environmental, and cultural implications. Meanwhile, the strength and level of cooperation among different government institutions and non-state actors will affect how well the BCB region addresses change and balances the benefits and costs of, for example, different development and conservation opportunities.

Opportunities and challenges associated with climate change in the Arctic will vary significantly over time and place. Different communities face different risks from a changing climate and have different perspectives regarding the implications of those risks as well as the most appropriate response options. This affects how levels of governance (e.g. municipal, regional, national, international), scale of problem definition (e.g. species, ecosystem, governance, community), and socio-cultural approaches (e.g. co-management, traditional knowledge transmission, western science) to adaptation, may or may not align.

Scenario analyses are one mechanism for representing and exploring the uncertainty in future development pathways for the BCB region. They incorporate alternative socio-economic futures into climate change assessment, and identify key opportunities for future investigations. Scenarios as a method can provide significant deliberative opportunities, incorporate local and indigenous knowledge, and facilitate cross-scale understanding of social-environmental systems. Such scenarios have been used extensively in the Arctic, and the BCB region more specifically. They have been used by both public and private sector institutions to evaluate economic opportunities, plan for future development and growth, and analyze potential risks arising from climate change or other hazards.

Scenarios can be useful for navigating the interface between Arctic science and policy and potential futures for Arctic communities and policymakers. Thinking seriously about the future can provide a vehicle for integrating multiple sources of knowledge into assessment and decision-making. Scenario processes can reveal critical uncertainties that are directly relevant to stakeholder needs and livelihoods, which can then become targets for future research to enhance the social impact of science investments. In addition, those uncertainties can help identify aspects of the natural and human systems that should be monitored to receive early warnings of changes that would have important implications.

This report includes a synthesis of how socio-economic scenarios have been used in regional or pan-Arctic research, assessment, and practice. This illustrates the diversity of contexts in which scenarios are being used. A set of local/community scenarios from different subregions within the BCB region illustrate the implications of different socio-economic development pathways in different geographical, socio-economic, and cultural contexts. Guidance is provided on how scenarios can be used in the future to prioritize future research investments, develop early-warning systems for climate change consequences, and help identify critical information and data needs to inform decision-making.

## Recommendations for future efforts

There is a great opportunity to learn by studying what people in communities are already doing to adjust to change, rather than limiting policy development to a theoretical analysis of what conditions foster certain types of adaptation. The often used approach of someone outside the community acting to create a community adaptation initiative is often not the best approach. It is important to pay closer attention to the way the world looks from the community perspective. For communities, the time-scale of climate change impacts may be longer than for more immediate major concerns, each of which could determine the survival of the community. In terms of climate change impacts, the time-scales may be longer and the ecological impacts of great consequence, and ultimately the source of major social changes. Rapid ongoing changes may be reflected in the transitional status of ecosystems. Evidence of ecosystem sensitivity and evolution towards tipping points reflects large-scale movement toward a new normal in the BCB region.

Engagement of stakeholders is not a matter of one-way, one-time communication, but of ongoing dialogue and learning, across scales and sectors. Such a process requires clear commitment supported by adequate financial and time resources. Policies that enhance prevention, response options, and opportunities include education and training, greater stakeholder involvement in decisions, and regulatory flexibility to allow a range of responses. Policies and practices that support prevention, response, and adaptation are likely to provide a range of benefits beyond the realm of environmental change. A commitment to relationship building through information sharing, site visits, and inclusion of locals at the earliest stages of planning, is critically important.

Immediate actions are needed to address existing vulnerabilities. Incremental adaptation actions can be put in place to help communities gradually prepare for an uncertain future. Forward thinking transformative adaptations that involve innovations in social, political, economic and scientific structures will also be required. Examples include new forms of interagency and international collaboration, meaningful empowerment of local people, incorporation of local and traditional knowledge into decision-making, flexible policy and regulation.

An explicit focus on building an effective link between adaptation-related research and decision-making can benefit scientists, decision-makers and ultimately adaptation actions. This can be facilitated by boundary spanning organizations that have subject matter expertise as well as skills in science translation and knowledge exchange. Developing regional capacity in practical adaptation expertise coupled with boundary spanning skills is a potent strategy for advancing adaptation.

This report was intended as a scientific assessment to address adaptation to the combined and cumulative effects of environmental and socio-economic change in the Arctic. However, very little existing research tackles this large, integrative task. There is a need for the development of conceptual models as well as for more research that explicitly integrates environmental change with social and economic change. Additional work is also needed from academic, management and operational perspectives to better understand the processes and explicit links between research and decision-making. New geospatial technologies and models (conceptual and numeric) should be included in future synthesis and assessment efforts. Next steps could provide more (1) community assessments from strategic locations to guide the development of workable adaptation plans that can be transferred within the BCB and to other Arctic areas; (2) process understanding approaches for adaptation planning, regional resource management, and restoration; (3) targeted research to address the need for scientific studies and monitoring for policy and decision makers.

# 1. Introduction and framing issues

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## 1.1 Background

In May 2013, the Arctic Council requested the Arctic Monitoring and Assessment Programme (AMAP) to "*produce information to assist local decision-makers and stakeholders in three pilot regions in developing adaptation tools and strategies to better deal with climate change and other pertinent environmental stressors*" (AMAP, 2017). Adaptation Actions for a Changing Arctic (AACA) is the response to that request: an assessment of climate and integrated social and environmental frameworks or models that can inform adaptation actions in the face of Arctic change. Three Arctic regions were chosen by AMAP for pilot assessments to be conducted simultaneously (Figure 1.1). This report is an assessment for the Bering-Chukchi-Beaufort (BCB) region (see Figure 1.1). It focuses on the challenges that residents have experienced and the adaptations they have implemented in response to the rapid changes of recent decades – in climate, landscape, wildlife, and social, economic, and health systems. It also looks to the future and analyzes the strengths and deficiencies in societies' and individuals' abilities to adapt, so that decision-makers may better understand where assistance is needed or where alternatives must be developed.

The AACA project has three components: AACA-A, AACA-B, and AACA-C. The first component, AACA-A, was led by the Arctic Council's Sustainable Development Working Group (SDWG) and is a compilation of assessments and reports prepared by Arctic Council working groups over the past 10 years, with findings and recommendations that could inform adaptation options and actions (Arctic Council, 2013a). AACA-B was led by Canada and Russia and focuses on taking stock of the adaptation activities that are being implemented by Arctic Council member states on a national, subnational, regional, or local level (Arctic Council, 2013b). The current AACA-C project aims to consider Arctic-focused climate and integrated environmental frameworks/models that can improve predictions of climate change and other drivers of Arctic change relevant to adaptation actions.

## 1.2 Outline of the Bering-Chukchi-Beaufort region

The BCB region is a large (~2,881,640 km$^2$), sparsely populated area (~85,000 people), whose boundaries are shared by Canada, Russia, and the United States (Figure 1.2). This area is best known for its prolonged winters and frozen landscapes, extreme seasonal

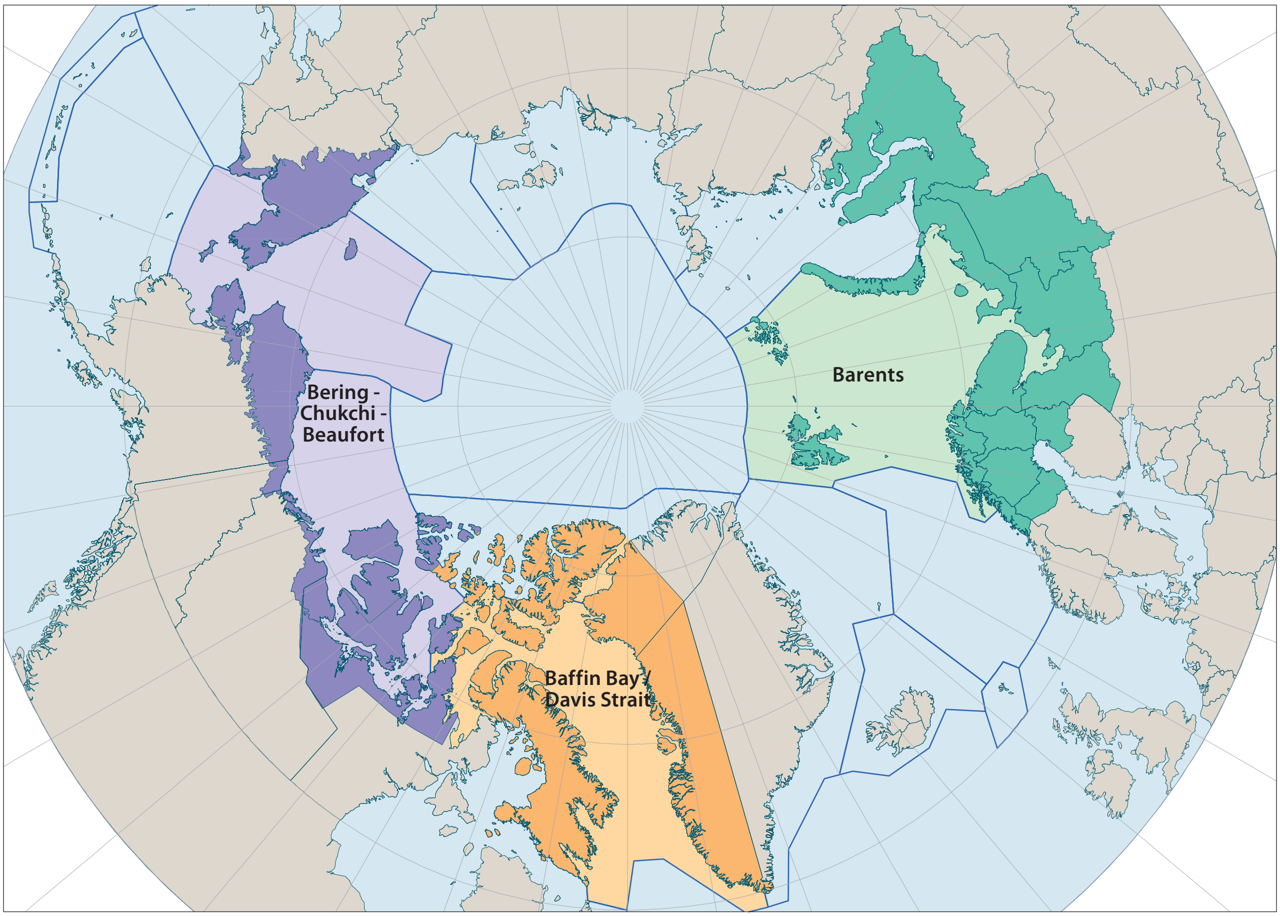

Figure 1.1 The three regions for the project Adaptation Actions for a Changing Arctic. Blue lines delimit Large Marine Ecosystems (LMEs).

Figure 1.2 The Bering-Chukchi-Beaufort region. The southern terrestrial boundary of the BCB region generally follows the treeline–tundra boundary, while the marine boundaries conform to the boundaries of the large marine ecosystem (LME) areas defined by PAME (Skjoldal and Mundy, 2013).

light and temperature conditions, rich Indigenous cultures, and iconic wildlife such as the walrus and polar bear. It is also a region of strategic global significance due to its potential hydrocarbon, mineral, and marine shipping opportunities.

The BCB study area occurs mainly between 61°N and 75°N latitude and 96°W and 163°E longitude. The southern terrestrial boundary is defined largely by the treeline, or tundra–taiga ecotone, which is delineated by a transitional zone 30–150 km wide between the tundra and boreal forest biomes (Callaghan et al., 2005). The altitudinal and latitudinal limits of the treeline generally follow the 10°C isotherm for mean July air temperature. In the eastern part of the BCB region, the terrestrial boundary matches the Kitikmeot (Nunavut) and Inuvialuit Settlement Region borders, including Victoria, Banks and Prince of Wales islands, and Boothia Peninsula. The western boundary of the BCB region in Russia corresponds to the western border of the Chukotka Autonomous Okrug. Thus, the terrestrial boundaries of the BCB region generally conform to the limits of the tundra environment, which also conform to First Nations linguistic/cultural groupings within the Chukotka–Alaska–western Canada region. The eastern, northern, and western marine boundaries of the BCB region are defined by the boundaries of the Protection of the Arctic Marine Environment (PAME) large marine ecosystem (LME) areas of the Beaufort and Northern Bering–Chukchi seas (LME regions 14 and 12, respectively, with the latter including the Chukchi Plateau in the north) (Skjoldal and Mundy, 2013). The BCB eastern marine border divides M'Clure Strait in the Canadian Arctic Archipelago, while the western ocean boundary extends offshore from the Kolyma River estuary in the East Siberian Sea. There are several social and physiographic considerations that often make it difficult to draw conclusions for the Bering-Chukchi-Beaufort region as a whole; as a result findings are frequently presented from the subregions of northwestern Canada, northern Alaska, and Chukotka.

It is emphasized that the regional study boundaries are not hermetic. Essential data and studies conducted outside the BCB region are included in this assessment, although the focus and priority are on information from within the BCB region. When sufficient data on a particular topic were not available from within the BCB region, the report authors used published works from adjacent Arctic areas. For example, many health statistics are not available specifically for Nunavut's Kitikmeot region but are available for Nunavut as a whole (falls outside the BCB region). Economic data, in particular, were typically not compiled and reported specifically for all BCB subregions within the prescribed boundaries of the assessment area.

## 1.3 Summary of ongoing changes

The extraordinary diversity and interrelatedness of the challenges presently being experienced by the Arctic and its human inhabitants can be considered in two broad categories – climatic and other environmental drivers of change, and socio-economic drivers of change. The latter are often associated with modernization and industrialization in the North and with the global economy. There are many linkages between the two groups of drivers. Climate warming has in many cases facilitated or adversely affected socio-economic change – for example, by opening up marine shipping routes or shortening the season available for ice-road transport. This chapter briefly outlines the unprecedented breadth and scale of the changes presently occurring in the Arctic, which are discussed in much greater detail later in this assessment (see Chapters 4 and 5). Many Arctic communities are already adapting to the various social, economic, and environmental changes taking place. Adaptation strategies are discussed throughout the report, to acknowledge the strength of these communities and their ability to adapt and also to provide guidance to community leaders, planners, and decision-makers.

### 1.3.1 Climatic and other environmental changes

The Arctic is warming, and the effects of this warming are apparent in the shrinking of the cryosphere (the part of the Earth system containing frozen water: snow, glaciers, permafrost, and sea, river, and lake ice). Although natural variability is larger in the Arctic than in lower latitudes, the instrumental air temperature record proves that the Arctic is warmer now than at any other time since 1900 (Jeffries and Richter-Menge, 2015). Furthermore, a synthesis of multiple proxy temperature records beginning 2000 years ago has demonstrated that a widespread and long-term summer cooling pattern, probably initiated and maintained by decreasing solar radiation, was abruptly reversed during the 20th century (Kaufman et al., 2009). Four of the five warmest decades of the 2000-year-long record occurred between 1950 and 2000. The BCB region has also had its warmest years in the past decade, although the longer-term warming of this region has been punctuated by occasional decades of cooling in some areas, such as northern Alaska during 2001–2010 (Wendler et al., 2012, 2013). The strongest warming has occurred during autumn in the Chukchi and Beaufort seas and over the adjacent land areas. The winter warming over Alaska is strong, while the warming of Chukotka is much weaker; this pattern is a manifestation of slow variations of major atmospheric circulation features, especially the Aleutian low pressure center. The warmer air temperatures, in turn, have led to a cascade of cause-and-effect impacts in the physical and biological systems of the Arctic.

Precipitation and evapotranspiration trends over the BCB region are much less coherent than those of temperature, although the sparse nature of the monitoring network introduces considerable uncertainty into evaluations of trends. Despite this uncertainty, recent climate assessments indicate that increased precipitation is one of the more robust features of climate model projections for the Arctic, including the BCB region (IPCC, 2013; USGCRP, 2014). Nevertheless, surface drying of the tundra has been observed in conjunction with enhanced drainage due to deeper active layers and degraded permafrost (Hinzman et al., 2013). An increase in fire frequency over Alaska is an indication of summer drying.

Snow cover in the Northern Hemisphere has also undergone a sharp decrease in recent decades, although the decrease is primarily in the spring and early summer (AMAP, 2011b). The decrease since 1967 (when regular satellite coverage began) is statistically significant in each calendar month from March through June – months in which the incoming solar radiation is strong enough that the absence of snow affects the energy available to terrestrial ecosystems in the BCB region. The springtime reduction of snow cover has been larger in Eurasia than in North America, although negative trends of springtime snow coverage are apparent in both Alaska and Chukotka.

The recent loss of Arctic sea ice has been sustained for decades and has indeed been highlighted as one of the key indicators of climate change (AMAP, 2011b, 2012). The decrease of summer sea ice extent exceeds the decrease of winter ice extent, especially as a percentage, and the largest loss of summer sea ice has occurred in the Chukchi, East Siberian, and Beaufort seas, as well as in the Barents Sea in the Atlantic sector. Corresponding to the loss of summer sea ice is an increase in the number of days with open water over large portions of the Arctic marginal ice zone. Consistent with the loss of sea ice, sea surface temperatures have increased in most of the Arctic's marginal seas. The reduced ice cover and increased upper-ocean temperatures have led to increases in primary production in the high-latitude oceans (Frey et al., 2014; Arrigo and van Dijken, 2015). Increased storminess, declining sea ice cover, and rising relative sea level have increased the vulnerability of coastal communities, the frequency of coastal flooding, and shoreline erosion rates along many sections of the BCB coastline (AMAP, 2012; Ravens et al., 2012).

Comparatively little permafrost research has been conducted in the Chukotka region of Russia; however, permafrost is warming and thawing in coastal areas of northeastern Siberia and Kamchatka (Romanovsky et al., 2010), as well as in northern Alaska and northwest Canada (Smith et al., 2010). This has important and mostly negative implications for infrastructure and settlements (U.S. Arctic Research Commission Permafrost Task Force, 2003). Land surface change caused by landslides, thermokarst, coastal erosion, flooding, and wildfire has been observed throughout the study area and will accelerate other ecosystem impacts to flora and fauna species distributions.

Various studies have pointed to increases of photosynthetic activity in the Arctic terrestrial region (Callaghan et al., 2005; Epstein et al., 2015). This increase is most apparent in tundra biomes, where the combination of higher temperatures and sufficient moisture availability results in increased greenness. However, there has been a decrease in the greenness of some parts of the boreal forest (Phoenix and Bjerke, 2016) and a recent (post-2010) cessation of the trend of increasing tundra greenness (NOAA, 2015). Possible contributing factors include drier conditions during the growing season, fires, insect activity, and pollution.

Concurrent with climate change, the Arctic as a whole, including the BCB region, is experiencing additional pressures stemming from human activities in the region and elsewhere, the impacts of which must be considered cumulatively. Contaminants are a prime example. Petroleum hydrocarbon contamination in the BCB region is currently restricted to areas around local anthropogenic sources such as harbors and oil and gas production facilities (AMAP, 2010a). However, this is projected to change significantly if future increases in oil and gas production take place. Despite limited industrial development within the region, relatively large amounts of other chemical contaminants such as mercury and persistent organic pollutants (POPs) are present – brought into the region from southern latitudes by oceanic, riverine, and atmospheric pathways. Certain geographical, physical-chemical, and ecological characteristics of the Arctic biogeosphere either concentrate these chemicals in the Arctic or exacerbate their bioaccumulation in wildlife and people (e.g., mercury; AMAP, 2011a). Concentrations of some POPs, such as DDT and polychlorinated biphenyls (PCBs), are declining because of global curtailment of production, whereas concentrations of other new and poorly understood POPs, including flame retardants, are increasing as their use increases globally (AMAP, 2010b).

Ocean acidification, which has been recognized only relatively recently as a major threat to Arctic marine ecosystems and the people who rely on them, is the result of several interacting factors and processes (AMAP, 2013). A primary driver of ocean

*Barge unloading at Inuvik, Canada*

acidification is seawater uptake of atmospheric carbon dioxide ($CO_2$), and cold waters absorb more atmospheric $CO_2$ than warmer waters. The Bering Sea is experiencing a rapid rate of acidification owing to its oceanographic characteristics and high organic productivity; this in turn means that the Beaufort and Chukchi seas receive relatively 'corrosive' waters from the Bering Sea. The marine environment of the BCB region has large areas of productive continental shelves and high freshwater inflows from the Mackenzie and Yukon rivers which dilute the acid-buffering capacity of seawater – features that make the region especially susceptible to acidification (AMAP, 2013). The attendant possible impacts are wide-ranging and severe, including damage to marine biodiversity, a weakening of the sustainability of traditional and commercial marine harvests, and alterations in many geochemical processes involving energy and carbon balance, nutrient availability, and contaminant dynamics.

## 1.3.2 Socio-economic changes

In areas such as the BCB region, the consequences of socio-economic change can demand human responses as much as, or even more than, changes in climate. Key socio-economic considerations for the BCB region include population, employment opportunities, energy availability and costs, tourism, socio-political change, land use, transportation, and resource extraction and other industrial activity. Health issues, including effects of contaminants on food, water, and air quality, are also important drivers that can be linked to the local economy and climate, as well as influences from outside the Arctic.

Population has been slowly increasing in much of Alaska and northern Canada, although the populations and demographics of individual communities have shown a variety of trends, as discussed later in this report (see Chapter 3). The slow regional increase is consistent with an Arctic-wide growth of Indigenous populations, by about 1.5% annually. On the other hand, the population of Chukotka declined rapidly in the 1990s, by nearly 50%, following the collapse of the Soviet Union. This decline was dominated by outmigration of non-Indigenous residents. The post-2000 population of the BCB region has stabilized, although the trend is still slightly negative. The ongoing trends in all three subregions are projected to continue through 2030, although with ranges of uncertainty that increase with time (Hodson et al., 2012; Overland et al., 2014).

Employment opportunities, migration into and out of the region, and energy availability are all intertwined with the resource extraction industries, especially oil and gas. Oil production in the Beaufort-Chukchi region of Alaska increased rapidly during the 1970s, peaked in the late 1980s, and has declined since then to approximately 50% of the 1980s level (Fried, 2008). Future activity is clearly tied to the market price of oil and gas, which are notoriously difficult to predict. Projections made as recently as 2013 missed the recent price decline by a wide margin, which points to the 'wild card' nature of the oil and gas industry as a driver of socio-economic change in the BCB region. Among other crucial factors shaping oil and gas futures in the BCB region are global energy demand and the development of alternative sources of energy. Nevertheless, there are substantial reserves of oil and gas, especially in the Alaskan and Canadian sectors of the BCB region, as well as prospective reserves in Chukotka.

Although there is a long history of mostly small-scale mining in the Arctic, the number of mining operations is, in a global context, small. High production costs are an obstacle to the expansion of mining in the Arctic. Nevertheless, prices for metals and other extractable materials are projected to increase, and the BCB region contains one relatively large zinc and lead mine (Red Dog mine in Alaska), several operating diamond and precious metal mines, and exploration camps in the Yukon and the Northwest Territories. Due to recent technological innovations in some gold mining operations in Chukotka, production of gold concentrate has become the major source of gross regional product and the dominant product of Chukotka export revenues.

Marine access to the Arctic has increased in the past decade with the reduction of summer sea ice, but the volume of traffic depends upon local ice conditions, service infrastructure, and


Paul Andrew Lawrence

*Red Dog zinc-lead mine at Port Side in Kotzebue, Alaska*

global markets. Ship traffic in the Northern Sea Route, which includes the BCB portion of the East Siberian, Chukchi, and Bering seas, increased substantially between 2009 and 2015; in 2015, the Russian government released Russia's *Integrated Development Plan for the Northern Sea Route 2015–2030*[1]. Canada's Northwest Passage has seen a small cargo traffic increase in recent years (NORDREG, 2015), but slower ice retreat in that region and the scarcity of regional infrastructure has limited the increase in comparison with the Northern Sea Route.

Tourism in the Arctic has increased in recent years and is projected to increase further, with cruise ships bringing the largest numbers of visitors. However, the primary destinations of these ships are Svalbard and Greenland, not the BCB region. Beringia National Park, established in 2013 in the eastern part of Chukotka, and Wrangel Island Reserve, on the UNESCO (United Nations Educational, Scientific and Cultural Organization) World Heritage List, are very important for the development of ecological tourism. In Alaska and the Beaufort region, the absence of deep-water ports will continue to limit cruise ship access to BCB communities.

Food security has been, and will likely continue to be, a key socio-economic concern of Arctic communities (Inuit Circumpolar Council-Alaska, 2015), as it has been identified as one of the major determinants of human health outcomes among Indigenous peoples. Especially in remote areas of Chukotka, northern Alaska, and Canada, imported food is limited in supply and is extremely expensive, creating greater reliance on subsistence hunting and fishing. Food *in*security associated with subsistence activities can be increased by greater costs (off-road vehicles and gasoline), the decline of traditional practices, changes in the availability of wildlife and fish, and the effects of climate change on overland, over-water, or over-ice transportation. The interplay between socio-economic, cultural, and environmental drivers, together with a diversity of food-related issues across the BCB region, makes changes in food security exceedingly challenging to predict.


Accent Alaska.com/Alamy Stock Photo

*Indigenous technician tests an ore sample at the Red Dog mine*

## 1.4 Prior evaluations of rapid Arctic change

In the late 1990s and early 2000s, coordinated evaluations of the changes in regional physical environments were undertaken by the scientific community. The outcomes were the assessment reports of the Bering Sea Impact Study (BESIS; Alaska Regional Assessment Group, 1999) and the Barents Sea Impact Study (BASIS; Lange and The BASIS Consortium, 2003). The first pan-Arctic assessment, the Arctic Climate Impact Assessment (ACIA, 2005), expanded the geographical scope but, like BESIS and BASIS, was focused on changes in the Arctic physical environment, particularly climate. The first SWIPA (Snow, Water, Ice and Permafrost in the Arctic) assessment (AMAP, 2011b, 2012) updated the ACIA findings with foci on several physical components: sea ice, snow, permafrost, the Greenland ice sheet, and glaciers in the Arctic. An extensive analysis of the dynamics of hydrologic processes in response to climate change in the cryosphere documented an increase in the intensity of the hydrologic cycle in recent decades (Prowse, 2009). The recent Assessment Report on Climate Change and its Consequences in Russian Federation (Roshydromet, 2014) is largely devoted

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[1] http://www.maritime-executive.com/editorials/future-development-of-the-northern-sea-route

*Boats frozen into the sea ice beside the harbor cranes in winter, Anadyr, Chukotka*

to the changes in the Russian Arctic and subarctic. The periodic assessments of the Intergovernmental Panel on Climate Change (e.g., Anisimov et al., 2007; Larsen et al., 2014) include 'polar regions' chapters in their Working Group II reports, which emphasize impacts, adaptation, and vulnerabilities. The emphasis of these reports on climate change and its biophysical impacts reflects their mandates.

Although there are fewer prior assessments of drivers of economic, societal, and technological change in an international framework, the Arctic Human Development reports (Einarsson et al., 2004; Larsen and Fondahl, 2015) have addressed many important issues, consequences, and potential solutions. These other drivers, together with climate change, form a complex web of interacting stressors, which are now driving change in the Arctic. In many respects, short-term perturbations in economy, society, or family can have a much greater impact on the individual than will the more subtle consequences of the more gradual impacts on the environment introduced by climate change. But these changes do not occur in isolation, and in many instances they are interrelated or confounded. These systemic changes, driven by multiple stressors, will likely affect the Arctic environment and its ecological and human components far more than climate change alone.

Surprisingly, climate may actually be the easiest topic to address in terms of adaptation. Although it is not yet possible to accurately forecast the rates of change, or even the magnitude of the projected environmental responses, it is at least possible to project the direction of trends. It is clear that air temperatures will continue to increase, that sea ice will continue to decline, and that permafrost will continue to thaw, although the trajectory of climate will also include extreme events and yearly to decadal variations superimposed on the longer-term trends. There is much less confidence in the ability to project economic trends or demographic and social responses, especially in a long-term perspective. There is likely to be a substantial societal response to industrial expansion or withdrawals, but such decisions are usually driven by world markets and the competing investments of corporations located far from the Arctic. Although such economic dynamics are difficult to predict, it is possible to anticipate that a milder climate and greater access to Arctic marine and terrestrial regions will present economic opportunities. Examining these potential shifts in drivers will provide some basis for studying the adaptive capacity and needs of families, communities, and governments.

## 1.5 Assessment needs informed by stakeholder surveys

The understanding that can be gained through Indigenous and local knowledge is highly valued. Local Indigenous peoples and other Northern residents, corporations, governments, and industries were involved in this BCB effort by providing guidance through telephone and online surveys and by participating in community workshops. A survey of stakeholders in the BCB region was undertaken to ascertain perceptions of the climatic, economic, and environmental changes that have occurred, as well as respondents' understanding of these impacts (Sanborn and Hinzman, 2016). A broad range of sectors were engaged, including agriculture/animal husbandry, Arctic research/education, construction, consulting companies, energy suppliers, fisheries, forestry, government (federal, local or municipal, state or provincial, and tribal), guides/outfitters, health, mining, Indigenous organizations, oil and gas, recreation, subsistence, tourism, transportation, and utilities. The information gathered in the BCB survey added to earlier multi-year involvement by

Canadian First Nations and other communities in ArcticNet and its Integrated Regional Impact Study (IRIS) of the Western Canadian Arctic (Stern and Gaden, 2015a,b). Representatives from the many Indigenous groups defined in the Arctic Council as its Permanent Participants were involved initially in project design and then throughout as contributors, authors, and reviewers. Chapter 2 includes narratives contributed by a number of BCB stakeholders.

The present BCB survey (Sanborn and Hinzman, 2016) contained 19 questions, including demographic information, and provided local insight into the challenges presented by rapidly changing environmental, economic, and social structures in the Far North. This process was used to develop categories, which were then conceptualized into broader themes. All participants indicated personal observations of change in the Arctic, and all mentioned noticeable climate changes in their sectors. Although the survey was designed to address a broad spectrum of change, respondents often focused upon the environment. Many participants predicted that a changing climate would have a positive impact upon the economy through increased shipping, resource development, and enhanced fisheries. Everyone indicated a desire to have additional information on the changing Arctic. A large proportion of the respondents indicated uncertainty in the changes that were ongoing and likely to occur in the near future. Most people felt that the changes in climate had already affected their sector. The primary concerns regarding impacts included changes in sea ice, weather patterns, coastal erosion, permafrost degradation, animal migration, fisheries, and cultural resources. Solid suggestions on the tools that individuals need to address these changes included *resources* (informational and financial), *connections* (collaboration and communications), and *education*. Some mentioned a desire to know what the future would bring. Most respondents anticipated major changes, but few had specific ideas of what they would do to respond or how they would adapt to these changes.

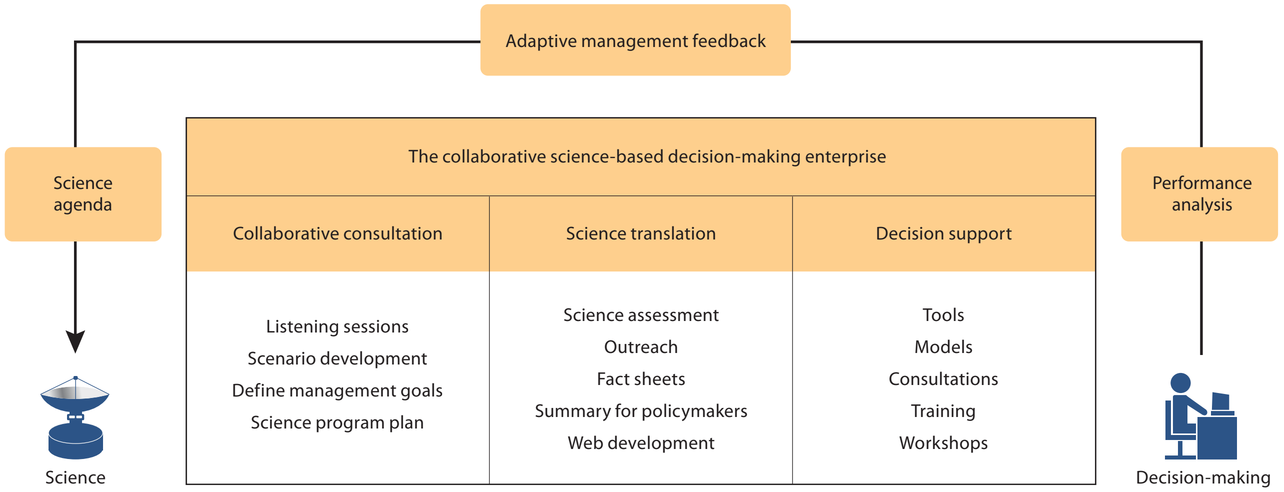
## 1.6 Arctic Council and AMAP initiatives

The Arctic Council – through one of its six working groups, the Arctic Monitoring and Assessment Programme (AMAP) – has a long-standing history and experience in providing scientific assessments on the Arctic in the context of many different issue-based areas (e.g., POPs, radioactive contamination, oil and gas, human health, mercury, and various aspects of climate change, to name a few). Typically, these assessments have been pan-Arctic, but recently AMAP has begun to develop a prototype assessment process that provides more focused and detailed synthesis information about the key regions of the Arctic that are of particular interest for stakeholders and specific economic sectors. This process, called Adaptation Actions for a Changing Arctic, is part of a new paradigm that allows for stronger interaction between the science and decision-making communities – a paradigm that is essential for adaptive governance of environmental change. In Canada, the series of IRIS assessments initiated by ArcticNET on the effects of Arctic climate change and modernization (e.g., Stern and Gaden, 2015a,b) are a part of this new paradigm.

### 1.6.1 The science-based decision-making process

In developing a new paradigm, Northern communities, industries, and governments, together with scientists working in the North, have begun to develop methods for effective and iterative consultation and the development of products that support decision-making. The assessment products themselves have begun to evolve from being focused mainly on informing scientific communities to now informing science-based policy-makers and other types of decision-makers as well.

The evolution of the science assessment process goes farther than just shaping the way that assessments are conducted. It is a metamorphosis of the entire engagement process between scientists and decision-makers. This evolution includes changes in the time frames and methods through which both parties engage and interact in identifying the issues relevant to decision-makers, changes in the structure and content of the scientific assessments, changes in the aspects of science needed to develop the assessments (including the prioritization of areas of continued scientific uncertainty), and changes in the nature and types of decision support and outreach tools and services that are provided (Figure 1.3).



| The collaborative science-based decision-making enterprise | | |
|---|---|---|
| Collaborative consultation | Science translation | Decision support |
| Listening sessions<br>Scenario development<br>Define management goals<br>Science program plan | Science assessment<br>Outreach<br>Fact sheets<br>Summary for policymakers<br>Web development | Tools<br>Models<br>Consultations<br>Training<br>Workshops |

Figure 1.3 Bridging the chasm between science and decision-making: The collaborative science-based decision-making scheme (Madison River Group, LLC).

Table 1.1 'Road map' to the BCB report.

| | Focus | Description | Time Frame |
|---|---|---|---|
| Chapter 2 | Stakeholder Perspectives | What is it like to live and work in the region? | Current |
| Chapter 3 | Current Status | Current environmental, social, and economic features | Current |
| Chapter 4 | Drivers | Forcers of change, including impacts on non-human environments | Past, current, and future |
| Chapter 5 | Consequences | Consequences for humans (families, communities, economic sectors, governments) | Current and future |
| Chapter 6 | Resilience | Capacity to adapt, and barriers to building resilience | Current and future |
| Chapter 7 | Adaptation Actions | Actions already taken to adapt | Past and current |
| Chapter 8 | Socio-economic Scenarios | Implications of alternative development pathways | Future |
| Chapter 9 | Synthesis | Cumulative impacts, interactions, responses; key knowledge gaps | Current and future |

## 1.7 Aims and structure of the report

The overall objective of this assessment report is to develop and synthesize a comprehensive knowledge base on the important drivers of change in the Bering-Chukchi-Beaufort region of the Arctic, how those drivers are interacting, and how human and natural communities are responding or could respond in the future to those changes. The specific goal was to consider Arctic-focused climate and integrated environmental frameworks or models that can improve predictions of climate change and other relevant drivers of Arctic change. This goal was aimed at identifying adaptations that may be implemented, as well as deficiencies where additional understanding is required to promote adaptive capacity. The report includes assessments of environmental, human health, industrial, and socio-economic impacts and also discusses potential adaptation actions to improve community resilience and adaptive capacity to the anticipated effects of the changes identified.

This report builds on an analysis of existing assessments and other work conducted under the auspices of the Arctic Council and its various agencies, as well as other relevant information, including peer-reviewed publications, Indigenous and local knowledge, statistics, and other documented information and data. This holistic approach covers a broad range of human, ecological, and biophysical characteristics; results of socio-economic and institutional analysis; and responses and trends – highlighting in particular the synergistic and antagonistic interactions among drivers. These interactions create new and unexpected challenges and opportunities for Northern communities. The report provides decision-makers with the pertinent information they need to respond prudently and expeditiously to challenges, while taking judicious advantage of opportunities, now and in the future.

This report includes nine chapters, the aims and content of which are outlined as a 'road map' in Table 1.1. Readers are encouraged to use this table to find the information they need. Following this introductory chapter, Chapter 2 presents the perspectives of various stakeholders (individuals, communities, industries, governments) involved in the BCB region on recent and expected changes, challenges, and adaptations. Chapter 3 summarizes the climatic, environmental, and socio-economic characteristics and important processes of the BCB region. Chapter 4 opens with a brief summary of the global drivers of change that affect the BCB region and goes on to describe regional climate trends and projections, consequent trends and impacts in the bio-physical environment (cryosphere, landscapes, waters, and terrestrial and aquatic ecosystems), and regional socio-economic drivers (demography, governance, economic development, the subsistence economy). Chapter 5 discusses the impacts and consequences of recent Arctic change for human systems, as well as projections of impacts into the future. This chapter also looks at how and to what extent the multiple changes are affecting communities, residents, and economic sectors. The resilience of Northern communities to the negative effects and consequences of unwanted change is considered in Chapter 6, followed by discussion in Chapter 7 of the adaptive actions that have been and are being taken by Northern communities, together with the major barriers to adaptation. A methodological approach and rationale for developing scenarios for future decision-making and policy options, as well as an outline of socio-economic 'scenarios thinking' about the future of the BCB and its subregions, form Chapter 8. The report concludes in Chapter 9 with a synthesis of the key findings of the assessment.

Readers will note some duplication of information among the chapters, which is inevitable when dealing with such a multifaceted and interconnected set of conditions in a region that is susceptible to such a wide range of stresses and drivers. Each chapter was designed to build upon prior chapters, contributing to the complete report, but each chapter was also written to be understandable if read on its own.

### Disclaimer

The word 'Eskimo' is often still used in Russia to describe Inuit people, and is not regarded there as a derogatory name. Thus, translated Russian contributions in Chapters 3 and 5 of this Report sometimes use 'Eskimo' rather than 'Yupik'; 'Eskimo' is sometimes also used by Yupik and Inupiat in Alaska in the names of their own organizations, for example the Alaskan Eskimo Whaling Commission. Therefore, readers should be aware that use of the word Eskimo, while regarded as a negative term in some parts of the BCB region, it is culturally appropriate in other parts. Here, the usage has been retained if the original authoritative source in Russia or Alaska used that term.

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# 2. Stakeholder perspectives

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## Key messages

- ***The BCB region and its stakeholders are undergoing rapid social, economic, and political change, which can often outweigh concerns about climate and environmental change****. Studies and assessments could start with the ideas of the region's stakeholders about what matters to their lives and their work, to better understand the interplay of many concurrent forms of change. Addressing climatic conditions without awareness of social and economic conditions is unlikely to produce effective adaptations.*
- ***Stakeholders are taking many adaptation actions, on their own and in collaboration with others****. Communities, agencies, companies, and others making decisions and taking action in the region could think about the broader perspective of changes affecting those who live and work in the region, with the goal of identifying policies and practices that reflect what is already occurring and thus have a greater likelihood of successful outcomes.*
- ***Stakeholders are not yet able to fully adapt to the many challenges due to a lack of adequate policies, mandates, and regulations****. Village relocation and disaster prevention are urgently needed in several cases in Alaska, but government agencies have no mandate to provide support nor are there mechanisms for coordinating their actions with each other or with the communities in question. Political pressure on Chukotkan Indigenous organizations hampers their ability to serve their members. Regulations and policies governing oil and gas activity are decided at the federal level in the United States and Canada and are only partly responsive to local conditions and desires.*
- ***Communication and collaboration among communities and between communities and outside scholars and agencies remains inconsistent, with the result that much valuable information is not transmitted effectively in either direction****. Few major problems can be resolved by only one group or one type of expertise. A model that promotes communication and collaboration is necessary to span the scales from local to global. Addressing only the most visible or fashionable problem is likely to miss the fact that communities and ecosystems function together, not as collections of disconnected parts.*

## 2.1 Introduction

The Bering-Chukchi-Beaufort (BCB) region spans three countries; is home to Chukchi, Iñupiat, Inuvialuit, St. Lawrence Island and Siberian Yupik, and Yup'ik and other Arctic Indigenous peoples and their traditional and modern activities, as well as more recent arrivals (see Section 3.2.2); encompasses subsistence activities, as well as commercial fishing, mining, and oil and gas activities; is the gateway for shipping from the Arctic to the Pacific; has experienced some of the most rapid warming in the world; is a vibrant ecosystem with iconic Arctic species; has been the subject of extensive scientific research; and is of interest to individuals, organizations, and nations outside the region. A qualitative stakeholder survey (the AACA-BCB survey; Sanborn and Hinzman, 2016) on climate change and adaptation actions undertaken in the BCB region was conducted as a part of this *Adaptation Actions for a Changing Arctic* (AACA) project and can be read as a complement to this chapter. This survey report focuses on identifying actions already taken in the BCB region to adapt to rapid changes, on how scientific information is informing decisions, and on additional information required to respond to changes. Section 2.2 also points to sections of the AACA survey that are relevant to the contents of this chapter.

Section 2.3 presents 19 stakeholder views, organized into five major thematic sections: community, regional, legal and policy, and commercial perspectives on adaptation to changing conditions in the BCB region, and, as an example of a perspective from beyond the region, a description of Chinese interest in the BCB region. The order of presentation – first a framing discussion in Section 2.2 and then the stakeholder perspectives in Section 2.3 – is intended to provide readers with the overall rationale for the selection of perspectives, as well as a view of the wider context within which the perspectives provide insight into change and adaptation in the BCB region. The discussion identifies common themes, their connections to other chapters of this report, their implications for a study such as AACA, and further needs for research and policy. The stakeholder perspectives respond to this chapter's guiding question:

*What is the current status of the region and its stakeholders?*

To do so, the perspectives address what is changing, how people are adapting, and what this means for a diverse range of stakeholders throughout the region and beyond. The individual essays are not intended to be comprehensive or authoritative but rather to express the views of knowledgeable individuals who describe their own experiences and their

Henry P. Huntington

*Mural outside the community store in Old Crow, Yukon Territory*

efforts to adapt to changing conditions in the BCB region. For this purpose, 'stakeholders' include those who live, work, or have an active interest in the BCB region.

The purpose of this chapter is to provide vivid, specific examples of what it means to live or work in a setting of rapid change across many dimensions. Part A of *Adaptation Actions for a Changing Arcti*c (Arctic Council, 2013) found that the effects of climate change are vast, and a truly holistic vision of those changes is required in order to fully implement adaptation options. Climate change is happening, and Arctic communities and inhabitants are already adapting (Arctic Council, 2013). That said, many of the perspectives presented in this chapter offer a complementary, more detailed view. The effects of climate change occur within a context of social, cultural, economic, political, and environmental change; short-term concerns tend to be dominated by social, economic, and political issues.

Many studies, programs, and assessments have looked at different aspects of change, in different locations, and with different responses and impacts (e.g., Cohen, 1997; ACIA, 2005; Furgal, 2008; Furgal and Prowse, 2008; Diatchkova, 2010; Wiese et al., 2012; Stern and Gaden, 2015). Often, these efforts attempt to disentangle one particular thread of the fabric that forms the life of an individual, a community, or a region. While this approach can be valuable, it can also obscure the ways in which different types of change interact or the ways in which the relative importance of different changes may shift through time. In Section 2.3, individual stakeholders describe how the various types of change affect them and what matters to them. Some focus on particular drivers of change, specific sectors or communities, or particular topics. Others describe the ways in which multiple types of change combine to affect livelihoods, well-being, and other aspects of life in the region. In doing so, these perspectives complement the presentation of specific themes in subsequent chapters of this report.

The idea of multiple types of change is reinforced when the history of this region is considered. The BCB region has been inhabited for more than 10,000 years (Fitzhugh and Crowell, 1988). Commercial exploitation of the region's resources began in 1848 with the hunt of bowhead whales (*Balaena mysticetus*) by Yankee whalers (Bockstoce, 1986). Subsequent activities included walrus (*Odobenus rosmarus*) hunting, fur trapping, the development of the Northern Sea Route, oil and gas exploration, construction of national defense systems such as the Distant Early Warning (DEW) Line across northern North America, mining, tourism, and commercial fishing, (e.g., Huntington, 1992). These developments have been accompanied by far-reaching social and political change – from the influence of the dominant cultures in the national territories of Canada, Russia, and the United States to the settlement of Indigenous land claims in Alaska and Canada and the creation of local governments in northern Alaska, and from the advent of modern technology and communications to the ongoing loss of Indigenous languages (e.g., Slezkine, 1994; Hensley, 2010). It is in this context that more recent environmental change must be understood.

## 2.2 Discussion

The perspectives collated in Section 2.3 largely confirm the findings of the Arctic Council (2013), namely, that the effects of climate change are vast and that Arctic communities and inhabitants are already adapting. This section explores some of the common themes that emerge from the various stakeholder perspectives, with reference to the individual contributions that follow.

The effects of climate change take many forms, from loss of sea ice (see Chapters 4 and 5) to greater erosion in the village of Shishmaref (see Perspective M), from shifting distributions of animals to more hazardous travel in Ulukhaktok (Perspective C) – the same findings are reflected in the AACA-BCB survey report (Sanborn and Hinzman, 2016; see their analysis of responses to Question 3). The recognition of climate change as an urgent issue, however, is not universal. Especially in places where economic conditions

*Iñupiaq whalers bringing in a massive (almost 15-metre) bowhead whale in the Chukchi Sea, Alaska*

are poor, such as the port town of Pevek, other problems take precedence for locals (Perspective T). And even where climate change is recognized as a threat, other factors may appear more important – at least in the short term. Imposed regulations may affect polar bear (*Ursus maritimus*) hunting in Chukotka (Perspective H) or bowhead whaling in Alaska (Perspective J), irrespective of climate change. The prospects for oil and gas development in the Chukchi and Beaufort seas depend more on global markets (see Chapter 4) and national policy than on sea ice trends (Perspective R). Cruise ship tourism will be affected by permit requirements as much as or more than by ice (Perspective Q).

These contrasts show the need to consider the drivers of change in an interrelated and interlinked way, over global-to-local and local-to-global scales (see Chapter 8). Global policies and agencies such as the International Whaling Commission (IWC) can potentially influence community harvest quotas that affect subsistence hunting, and oil and gas extraction in a given location can have regional and transboundary consequences (Perspective S). Scale is relevant for many aspects of adaptation – from infrastructure needs and impacts to generating and sharing knowledge within and across communities, and from resource development to social services. These ideas permeate the perspectives and are developed further in later chapters.

Climate impacts act alongside impacts from other causes. Climate change may directly threaten health (see Chapter 7), but for remote communities like Ulukhaktok, access to health care is a greater concern (Perspective D). Industrial development affects animal abundance and distribution, produces pollution, and also offers jobs and resources that can be used to support community well-being (see Chapters 5 and 7). Tuktoyaktuk faces rising sea level but also seeks to be a base for offshore oil and gas operations (Perspective L). Pevek explores the potential for a nuclear power plant, and even those who oppose the plant concede that it is likely to benefit the community (Perspective T). Regulatory change can affect Shaktoolik's fishers as much or more than environmental change (Perspective P).

Political relations also loom large in the region. The Yupik whalers of St. Lawrence Island are affected by local conditions, by regional oil and gas activities, by marine shipping, and by a bloc of Latin American nations acting through the IWC (Perspective J). The hunters of Chukotka see their organization sidetracked and imperiled, as it must answer to the demands of government agencies (Perspective H). Economic conditions also have far-reaching effects. Prior to the 1991 collapse of the former Soviet Union, Chukotka experienced a degree of stability and support – the loss of which has radically reduced Chukotka's population and greatly changed the ways of life of its peoples (Perspectives E and G). China's interest in the region, as an example of a perspective from a non-Arctic state, brings the potential for investment in research and resources from a large nation eager for recognition of its interests and priorities (Perspective U). These and other aspects of governance, in its various forms, are important considerations – both for understanding how change affects stakeholders and for developing appropriate adaptation actions.

Although there are abundant examples of responses and adaptations to change, it is also evident that change can surpass the ability to respond effectively or rapidly. Sea ice loss has extended the shipping season in the Beaufort Sea, but government regulations and support have not kept pace (Perspective N); this is true throughout the Arctic. More ships are enticed northward, but expertise, charts, and weather data may not be adequate for the potential hazards that await. Experience with travel routes and Arctic conditions may be inadequate if those conditions change quickly, and this problem is exacerbated by the lack of opportunity for communicating travel knowledge and survival skills in the first place (Perspective C). Plus, the magnitude of many impacts depends greatly on local conditions.

The significance of sector-specific and location-specific details underscores the need for collaborative ways of generating, using, and communicating information. A good example of this need going unmet is the publication of major climate change and environmental assessments that are sometimes available

Table 2.1 Summary of perspectives by community or sector, with key challenges and key adaptation actions underway or recommended. The letters 'PC' indicate a primary challenge and 'SC' a secondary challenge, from the stakeholder perspective.

| Perspectives, by community or sector | Domain of key challenges | | | | Key adaptation actions underway (or recommended) |
|---|---|---|---|---|---|
| | Political | Economic | Social | Environmental | |
| Community | | | | | |
| A: Sea ice use, Wainwright, Alaska | | SC | | PC | Collaborations with academia, industry, regulators |
| B: Conservation, Kuskokwim River, SW Alaska | | | SC | PC | Conserving environment<br>Sustaining traditional practices |
| C: Climate change, Ulukhaktok, NWT | | | SC | PC | Collaborative research<br>(Training and education)<br>(Sustaining traditional knowledge) |
| D: Community health, Ulukhaktok, NWT | | PC | SC | SC | (Better support for patients who need to travel)<br>(Improvements to standards of living) |
| Region | | | | | |
| E: RAIPON, Chukotka | PC | SC | SC | SC | (Collaborative research)<br>(Better information and communication) |
| F: Regional impact assessment, NWT | | SC | SC | PC | Collaborative research<br>(Training and education) |
| Legal and Policy | | | | | |
| G: Natural resource use in 20th century Chukotka | PC | SC | SC | | (Better support for Chukotka residents)<br>(Greater local involvement in decision-making) |
| H: Marine mammal hunting, Chukotka | PC | SC | | SC | (Education)<br>(Local involvement)<br>(Better communication)<br>(Economic support) |
| J: Bowhead whaling, Savoonga, Alaska | PC | | | SC | Self-organization by communities<br>Political activism nationally and internationally |
| K: Emergency response, Alaska | SC | PC | | SC | Preparation<br>Planning<br>(Sustaining budgets) |
| L: Inuvialuit Regional Corporation, NWT | | PC | | PC | Planning for sea level rise<br>Planning for economic opportunity |
| M: Erosion, Shishmaref, Alaska | PC | PC | | SC | Community organization<br>Lobbying state and federal governments |
| Commercial | | | | | |
| N: Shipping, Beaufort Sea | PC | SC | | SC | Lobbying for improved navigation aids, support |
| P: Fishing, Shaktoolik, Alaska | PC | PC | | PC | Organizing of fishers<br>(Effective regulations) |
| Q: Cruise tourism, Beaufort Sea | PC | SC | | | (Streamlining permitting process)<br>(Improving support infrastructure) |
| R: Oil and gas, Beaufort Sea | PC | PC | | SC | Lobbying for appropriate regulations |
| S: Arctic oil and gas, Inuvialuit | | PC | | SC | Community organization<br>Benefits to communities |
| T: Mining, Pevek, Chukotka | | PC | SC | | (Creating economic opportunity)<br>(Local involvement) |
| Non-Arctic | | | | | |
| U: Non-traditional security, China | PC | PC | SC | SC | Substantive engagement within the region<br>Collaboration<br>(Recognition of Chinese interests) |

Table 2.2 Summary of stakeholder perspectives by BCB subregion. The letters 'PC' indicate a primary challenge and 'SC' a secondary challenge, from the stakeholder perspective.

| Perspectives, by BCB subregion | Domain of key challenges | | | |
|---|---|---|---|---|
| | Political | Economic | Social | Environmental |
| Alaska | | | | |
| A: Sea ice use, Wainwright, Alaska | | SC | | PC |
| B: Conservation, Kuskokwim River, SW Alaska | | | SC | PC |
| J: Bowhead whaling, Savoonga, Alaska | PC | | | SC |
| M: Erosion, Shishmaref, Alaska | PC | PC | | SC |
| P: Fishing, Shaktoolik, Alaska | PC | PC | | PC |
| K: Emergency response, Alaska | SC | PC | | SC |
| Chukotka | | | | |
| E: RAIPON, Chukotka | PC | SC | SC | SC |
| G: Natural resource use in 20th century Chukotka | PC | SC | SC | |
| H: Marine mammal hunting, Chukotka | PC | PC | | SC |
| T: Mining, Pevek, Chukotka | | PC | SC | |
| Canada | | | | |
| C: Climate change, Ulukhaktok, NWT | | PC | SC | SC |
| D: Community health, Ulukhaktok, NWT | | | SC | SC |
| F: Regional impact assessment, NWT | | SC | SC | PC |
| L: Inuvialuit Regional Corporation, NWT | | PC | | PC |
| Q: Cruise tourism, Beaufort Sea | PC | SC | | |
| N: Shipping, Beaufort Sea | PC | SC | | SC |
| R: Oil and gas, Beaufort Sea | PC | PC | | SC |
| S: Arctic oil and gas, Inuvialuit | | PC | | SC |
| Non-Arctic | | | | |
| U: Non-traditional security, China | PC | PC | SC | SC |

only in English or are difficult to find in the region's remote communities – and are therefore inaccessible, especially in Chukotka (Perspective H). The AACA-BCB survey identified the need for plain-language versions and summaries of assessments and reports (Sanborn and Hinzman, 2016: Question 10). In Alaska, Native villages must shift focus from one problem to the next without having the information and resources they need to take stock of challenges and develop effective strategies (Perspective B). Even when strategies are developed, as in the case of moving the village of Shishmaref, a lack of government coordination makes it difficult or impossible to act on that strategy (Perspective M). Community-based monitoring and programs such as ArcticNet's regional impact assessments (RIAs) can help connect local residents with outside expertise (Perspective F), and local and regional organizations such as the Inuvialuit Regional Corporation, in the Northwest Territories can put that information to use (Perspective L). Local communities, industry, and academia all benefit when they pool their knowledge (e.g., Wainwright currents and sea ice, Perspective A), but such efforts must be broad enough to address the suite of issues facing stakeholders, rather than emphasizing a single issue that is popular at the time.

Amid the discussions of change, it must also be acknowledged that many things do not change. The need for emergency services, for example, still requires preparation and prevention (Perspective K). Climate and other changes may affect what is needed and when, but the providers of such services must still be ready for whatever occurs. In a highly variable environment, long-term change is likely to be overshadowed by the events of each season. Economic health and political stability can greatly enhance the ability of all stakeholders to respond effectively and to collaborate with others who can help (see Chapter 6). Few major problems can be resolved by only one group or a single type of expertise. Collaboration will remain necessary to span the scales from local to global. Addressing only the most visible or fashionable problem is likely to miss the fact that communities and ecosystems function together, not as collections of disconnected parts. Connections among communities offer great potential for sharing successes, avoiding repetition of failures, and encouraging innovation and action rather than isolation and despair. In the AACA-BCB survey (Sanborn and Hinzman, 2016: Question 4), connections and collaboration were the tools commonly identified as being needed to respond to climate change impacts.

Table 2.1 presents a summary of the contributed stakeholder perspectives (Section 2.3), noting the domain in which the largest challenges fall, as well as key adaptation actions that are underway or recommended. It should be noted that environmental issues are important in 16 of the 19 cases but are a major challenge in only six. Political issues matter in 11 cases and are of major importance in ten. Economic issues are important in 16 cases and are a major challenge in nine. Social concerns are an issue in eight cases, but are not a major challenge in any.

For the community perspectives, an integrated view of the primary and secondary challenges shows environmental challenges as the first or second priority (four out of four community responses) and social challenges as a lower priority (three out of four responses), reflecting that subsistence activities play a large role in livelihoods. The survey also showed that at the community level, changes in the environment are very relevant and are usually seen as negative (Sanborn and Hinzman, 2016: Question 5).

At the regional level, Chukotka shows political issues as being the primary challenge, while the Inuvialuit region in the Northwest Territories shows environmental issues as primary. Economic and social issues are secondary in both regions (two out of the two regional responses). The legal and policy perspectives show either political or economic matters as the main challenges and environmental matters as generally secondary in importance.

From a commercial perspective, the economic and political challenges are primary (four out of six responses in each case) followed by environmental challenges (one out of six responses). Finally, in terms of the non-Arctic (China) perspective, political and economic concerns weigh more heavily than social and environmental concerns, but all four categories rank highly.

Considering the stakeholder perspectives by region (see Table 2.2) shows that in Alaska, political, economic, and environmental challenges are equally represented in the primary challenge category, each for three of the five Alaska cases – although not the same three across the board, while social challenges are not prominent. For Chukotka, political and economic challenges are a priority, followed by social and environmental challenges. For the Canadian sector of the BCB region, economic challenges are prominent (four out of eight responses), followed by political (three out of eight responses), and environmental (two out of eight responses).

This analysis is inevitably subjective to some degree; the boundaries of political, economic, social, and environmental issues are not always clear. Nonetheless, it is clear that environmental issues, although important, are not the dominant concern for the region as a whole and that the relative roles of social, economic, and political challenges vary by location and by sector.

The key adaptation actions, however, show some consistent themes, also reflecting the survey findings (Sanborn and Hinzman, 2016). Education, collaboration, organization, and planning come up repeatedly. Local and stakeholder involvement beyond the community, sector, or region is also needed in many cases – for example, to seek economic support or to oppose the imposition of restrictions that limit local flexibility and capacity. Regulations may be necessary to cope with changing environmental conditions, but the regulations should reflect actual conditions and should recognize the capacities of those being regulated to respond appropriately. Some of the key adaptation actions shown in Table 2.1 have been taken in the past or are currently underway. In other cases, they remain a goal. It is significant that in all cases the stakeholders seek to be involved in the responses and adaptations (Sanborn and Hinzman, 2016).


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*Aerial view of electric transmission lines over tundra leading to an oil development structure in Prudhoe Bay, Alaska*

### 2.2.1 Next steps

The diversity of perspectives presented in this chapter indicates that the BCB region faces a wide range of challenges. This idea is reinforced by the recognition that social, economic, and political change may be as important as climatic and environmental change. The AACA joins some regional and local efforts to consider the multiple drivers of change simultaneously, but even so the emphasis has often been largely on climate and environmental change as the main factors. Further studies and assessments could start with the ideas of the region's stakeholders about what matters to their lives and their work, to better understand the interplay of the many concurrent forms of change.

The same idea applies in practice. Communities, agencies, companies, and others making decisions and taking actions in the region could think about the broader perspective of the changes affecting those who live and work there, with the goal of finding policies and practices that reflect what is already occurring and would thus have a greater likelihood of successful outcomes. An approach that addresses climatic conditions without awareness of social conditions is not likely to work. This is not to say that every action needs to address every challenge, but simply that actions should not be undertaken in isolation.

Change will not stop in the BCB region. The need to document, assess, and act on change will not go away. Efforts such as the AACA are equally useful in summarizing what is known now and in revealing what still needs to be learned. Such learning will largely take place by acting on the information currently available and evaluating what to do next.

These observations point to several guiding messages:

- Climate change matters, but should be considered in the context of other changes, many of which are occurring on a faster timeline.
- Basic social, economic, and political conditions shape the ways in which climate and other changes affect stakeholders and the ways in which stakeholders are able to respond.
- Change has both positive and negative aspects. Capitalizing on opportunities while reducing negative impacts requires planning, as well as the resources to put that planning into practice.
- Engagement with stakeholders is not a matter of one-way, one-time communication but rather ongoing dialogue and learning, across scales and sectors. This stakeholder engagement requires a clear commitment supported by adequate budget and time resources.
- Policies that enhance the prevention of impacts, facilitate response options, and provide opportunities for adaptation include education and training, greater stakeholder involvement in decision-making, and regulatory flexibility to allow a range of responses to changing conditions.
- Policies and practices that support prevention, response, and adaptation are likely to provide a range of benefits beyond the realm of environmental change.

These ideas can be summarized succinctly in the words of tribal government leader Eddie Ungott from Gambell, Alaska: "*Why don't we work together? We can help each other.*"

## 2.3 Perspectives

The following stakeholder perspectives are organized into five categories. *Community perspectives* describe local views from within or near the BCB region. *Regional perspectives* take a broader look at shared concerns across a large area. *Legal and policy perspectives* consider institutional dimensions of change. *Commercial perspectives* reflect upon the economic and business implications of change. A *non-Arctic perspective* offers insights from a stakeholder (China) outside the region but with a great interest in what occurs within the region, as an example of the ways that non-Arctic states see the Arctic and their role in Arctic affairs. While these descriptions are not comprehensive in the sense of trying to cover all aspects of all communities and sectors, they collectively offer a compelling picture of why an effort such as the AACA is important and what the AACA needs to address. Figure 2.1 shows the locations of the various perspectives.

Figure 2.1 Areas of study. The letters that accompany the pinned locations refer to the different stakeholder perspectives in Section 2.3.

### 2.3.1 Community perspectives

#### Perspective A: Coastal North Slope communities

Wainwright, Alaska (*Ulġuniq* in Iñupiaq), a village of about 600 people, is situated on a narrow coastal peninsula separating the Chukchi Sea and Wainwright Inlet. It is the closest of the North Slope communities to the outer continental shelf oil and gas lease area in the Chukchi Sea (Figure 2.2). This proximity to offshore oil and gas activity and the associated risks to traditional livelihoods, coastlines, and marine resources creates opportunities for local Iñupiat hunters to communicate and apply their knowledge of the ocean, its ice, and the interplay with wind and land.

It is through the Iñupiat's whaling identity and subsistence way of life that they shape and share their views on the potential impacts from oil and gas development. Industry representatives, government officials, and scientists increasingly recognize the practical implications of the Iñupiat's highly experience-based knowledge.

In spring 2013, two workshops – one in Utqiagvik (Barrow) and one in Wainwright – brought local Iñupiat ocean and sea ice experts together with a range of scientists and national-level emergency response planners to co-assess the state of coastal ocean knowledge of the eastern Chukchi and western Beaufort seas (Johnson et al., 2014). The goal was to share different types of knowledge and experience within a framework relevant to improving emergency preparedness.

Wainwright residents continuously observe the waters along their coast and describe what they see in terms of the relative strength of ocean currents and how the currents converge, move ice, and indicate and respond to changing winds. The prevailing currents are alongshore, either northward or southward (Figure 2.2), depending upon regional weather conditions. Unlike the *Piruġaġnaq* current from the north, the *Qaisaġniq* current from the southwest – which is said to often be so strong that it can be heard – can carry a boat dangerously far from home. Local experts can identify places where coastal rip currents are common or where opposing regional currents meet and increase the choppiness of the water's surface. Additionally, those familiar with the local ocean and shorelines possess detailed knowledge of locations where debris regularly washes ashore. Such places are often identified in the context of retold stories from past hunting travels.

Specific and place-based, expert knowledge from Wainwright's hunters could prove critical to emergency operations, particularly when such operations are conducted from small boats or are focused on tracking or collecting drifting material. For example, knowing where flotsam washes ashore may help to identify where to prioritize coastline protection in the event of an oil spill. Stagnant locations along the coast are where skimmers may be most effective at collecting oil from the ocean surface. Hunters note that a change in wind direction is almost always preceded by a change in current. Such indicators are important, as shifts in wind along a coast can quickly bring obtrusive ice shoreward or send floating contaminants into inlets or up rivers.

Local experts acknowledge the difficulties of boating during autumn freeze-up when launching and navigation are controlled by slush ice formation, lagoon freeze-up, and shoreline freezing. This is especially of concern to emergency planners because the non-discrete nature of autumn freeze-up makes it difficult to monitor from satellite or other means. In addition, slush ice, which moves entirely with the current as opposed to with the wind, can clog water-cooled engines, thus eliminating the use of outboard engines – the mode of boating that would typically be used during a local response to any environmental or shipping disaster.

The workshops resulted in specific recommendations for new or more focused future studies, such as studies to compare community-identified convergence locations with spill trajectory models. Participants collectively recognized the need to map emergency shoreline staging locations and barrier island access points, especially where coastlines have migrated such that nautical charts are outdated. Importantly, the workshops also revealed the dimensions necessary to include in planning scenarios in order to reveal the full complexity of executing an emergency response in potentially ice-filled coastal waters.

At least one workshop recommendation noted the need for continued efforts to reconcile disparities between the knowledge, observational scales, and vocabularies that local experts and scientists rely on when discussing ice and ocean monitoring. The degree to which local communities in the BCB region can contribute to improving information for sustainable development depends on their adapting to a world where their local and traditional knowledge can be practically communicated to scientific, operational, and other technical audiences. At the same time, all other Arctic stakeholders with an interest in partnering with the communities must reciprocate through exploring and committing to new ways of listening and co-producing knowledge.

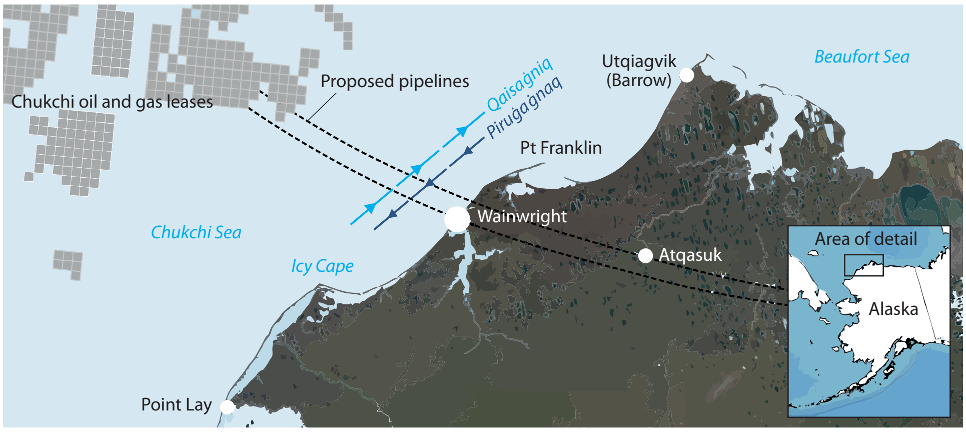

Figure 2.2 Wainwright and Alaska's North Slope, showing the dominant offshore currents (Matthew L. Druckenmiller, NSIDC). *Piruġaġnaq*, the dominant current off Utqiagvik and Wainwright, flows from the northeast and is more frequent during winter. This current typically creates conditions that make it safe to be out on the ice. *Qaisaġniq*, the more seaward current flowing from the southwest, is more common after late May and is known to bring warm water that can accelerate the melt and break-up of shorefast ice. *Qaisaġniq* is also known as the current that brings the animals.

## Perspective B: Conservation and tradition

*First person account by Raychelle Daniel, Yup'ik, Kuskokwim River, Alaska*

The perception of climate change across my relatively short professional life span working in the natural resource field has gone from a prodigious threat looming in the distant future to an inescapable reality that we have to be prepared for and need to 'adapt' to before it's too late. Nonetheless, I've had some difficulty in connecting with the messaging of climate change, in part because we're constantly responding to SOMETHING – someone else's objectives, someone else's timeline, and always in triage mode.

I grew up at the southern extent of the seasonal sea ice in the Bering Sea, an area close to the BCB region and sharing many of its characteristics. Over time, we've come to adapt to both environmental and social changes. For example, seals and walrus have been an important cultural resource – for food, for clothing and footwear, for storage, and for expressions of art. We've had to learn to recognize and adapt to some of the patterns of change that come along with access to these species. Socially, we've had to adapt to the presence of permanent Western-based education institutions whose schedules often conflict with important subsistence practices like egg gathering, seal and walrus hunting, and salmon fishing. One of the steps that our school undertook that many people in Western society can relate to is the identification of a school mascot – the blue jay in our case, a decision I never quite understood.

Changes have been happening that seem out of the ordinary and can't be explained as 'year-to-year variation', from changes in snow and ice to observations of new species and altered migratory patterns. I remember the first time I saw a robin, when I visited Washington, DC, in the late 1980s. But they have since become a regular part of the landscape across Alaska and were even observed in my village this past December. New observations aren't necessarily a bad thing and can present new opportunities for subsistence – for example, collecting dandelion greens. But, other changes may present obstacles. This February saw the arrival of pairs of nesting tundra swans – which typically arrive in April and May to nest in bogs around my village. How this type of a change could play out in the future remains to be seen, but we can be thinking about some of the implications in our decision-making today.

We are experiencing a number of changes that are amplified in both occurrence and extremity, and in order to be appropriately prepared and climate-ready, we need to be actively engaged in developing our own adaptation strategies rather than relying solely on agencies based outside of the Arctic. Being appropriately prepared also means accounting for the health and social well-being that originates from our environment. For example, to be able to understand how these changes may cascade into social contexts, we need to understand the impact of nesting tundra swans that may arrive months early, or sea ice conditions that prevent spring sea mammal hunting. The success of harvest, too, results in other social steps needed for defining success, such as sharing and throwing celebrations.


Design Pics Inc / Alamy Stock

*Yup'ik father and daughter subsistence drift netting for salmon, Kuskokwim River, Alaska*

While we may live in permanent villages today, we still have practices that have been carried over from our nomadic lifestyle that followed the seasons; there are places that we fish, places that we pick berries, and places that we hunt for marine mammals. And most importantly, there are cues that we look out for that help tell us direction of change. In the case of an extreme shift in range, it is possible that there will be both lost and new opportunities, but the culturally relevant sharing of information could maintain cultural connections.

Environmental health and my cultural identity are inseparable. Having grown up in this environment, I tended towards an occupation within natural resource management and am currently working with an environmental conservation organization. I can see the value of safeguarding the environment and how conservation efforts can provide for the perpetuation of my values. At the same time, I don't see people as separate from the environment; in the Arctic, people are a central part of the land and seascape. This is why conservation efforts need to account for and directly link with values important to people.

This means, for example, recognizing the value of my grandmother sharing and imparting her knowledge to me when I was learning to hunt for eggs, and not just managing the numbers of nesting swans that return from year to year. Not only will decision-makers need to include these social aspects, but we as communities and cultures will also have to play some role in mapping out our future and determining how we preserve the intangibles like transmission of knowledge.

Given that we now see robins regularly, it is only a matter of time before blue jays really do arrive in my village. I can see that we will have to live with decisions made by previous generations, and our decisions made today will affect our children tomorrow. Naming the blue jay as our school mascot may actually have been foreboding. Across the Bering Sea region, we have seen change. Ironically, this is how we've adapted through time and persevered. This is our shared characteristic, and it holds the key to how we should anticipate further changes.


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*Inuit man fishing on the Beaufort Sea coast, Victoria Island, Northwest Territories*

### Perspective C: Inuit subsistence hunting and climate change: Ulukhaktok, NWT, Canada

Ulukhaktok, formerly Holman, is a coastal Inuit community of about 400 people (99% Inuit), located on the west coast of Victoria Island in the Inuvialuit Settlement Region, NWT, Canada, established in 1939. Despite undergoing sweeping social, political, and economic changes in the past half century, Inuit in Ulukhaktok continue to value the activities of subsistence hunting, fishing, and trapping. 'Country foods', locally harvested fish and wildlife, are often nutritionally superior and preferred to the imported food items, which are also often expensive to purchase. Participation in subsistence activities is also about gaining respect in the community by providing vital, tangible benefits (Pearce et al., 2011).

In the context of subsistence hunting, changes in temperature, seasonal patterns, sea ice and wind dynamics, and weather variability and extremes have already exacerbated risks associated with hunting and traveling, compromised travel routes to hunting and fishing areas, and affected the health and availability of some species of wildlife important for subsistence (Pearce et al., 2010).

Traveling and hunting on the land, water, and ice are inherently dangerous, and Inuit have long known about and coped with these risks. However, in recent years changes in the climate have altered and in some cases increased the magnitude and frequency of hazards that people face. This has resulted in an increase in climate-related accidents while traveling on the land, water, and ice, often associated with thinning and earlier break-up of sea ice and more unpredictable weather. For example, hunters report that they are increasingly faced with changing sea ice conditions in the autumn, winter, and spring. Some areas of sea ice, over which hunters are accustomed to travel, are no longer stable, and in some instances the ice has not formed. These risks are compounded by less predictable weather and an increase in the frequency, duration, and intensity of strong winds and severe storms, which make traveling difficult, if not impossible. In the past, Inuit hunters relied on knowledge of the local environment to forecast and navigate weather events. Under changing climate conditions, however, hunters explain that they are unable to read signs in the weather like they used to because the weather and seasonal changes no longer follow regular patterns.

Climate change has also affected travel routes. For example, the spring is a popular time for community members to travel on the land to ice fish at lakes and hunt muskoxen and on the sea ice to hunt seals, ducks, and polar bear. However, in recent years the spring melt has happened earlier and more rapidly, and this is making travel by snow machine more difficult and sometimes impossible. A respected Elder and active hunter explained that in the years that he has been traveling on the land, the spring melt usually started in May and June and the snow would melt gradually from the top down. In the last few years the melting has started from underneath the surface of the snow, and although snow conditions appear to be good for traveling, they are not because there is so much moisture and water under the snow that snow machines can become easily stuck (2005 interview with A. Akoakhion, cited by Pearce et al., 2010).

Climate change has implications for the migration timing, population health, quality of meat and fur, and availability of some species of wildlife important for subsistence. While most of these changes are considered to have negative effects on hunting success and food security, some changes may be positive, at least in the short-term. Between July and September 2014, Inuit in Ulukhaktok harvested 32 beluga (*Delphinapterus leucas*), its largest recorded catch of beluga. Prior to 2014, there were a few occasions on which more than three whales were caught, but in most years, one was considered a success. The likelihood that climate change is a factor in beluga moving north is strong but has yet to be substantiated with empirical evidence. In the short term, Inuit hunters have been successful with bountiful hunts, which means plenty of healthy food for the community.

Policies that promote and facilitate the generation and transmission of traditional knowledge are central to reducing risks in a changing climate and also have the potential to increase safe hunting practices among vulnerable groups, targeting three important aspects of reducing climate vulnerability: prevention, preparedness, and response (Pearce et al., 2015). Cultural programs that provide land skills training are currently offered in an ad hoc fashion in Ulukhaktok and elsewhere in the North. Addressing the erosion of traditional skills through the integration of traditional knowledge and land skills into education curricula, as well as the creation of cultural schools/land skills programs, should be part of a broader program in Northern regions to emphasize skills training and development. This is particularly important given the demographics of Canadian Inuit communities, where young populations will be entering the workforce and beginning to engage in harvesting activities as the effects of climate change become pronounced.

## Perspective D: Community health: Ulukhaktok, NWT, Canada

*First person account by Emily Kudluk, Language Program Officer, Ulukhaktok, NWT, Canada*

A noticeable rise in health issues in Ulukhaktok has our community working together to try a positive approach to ensure all individuals receive the care they need. Some of the issues include climate change, loss of language and culture, food prices, medical travel, education, employment, and the costs of clothing, gas, and ammunition – and like all other communities, alcohol and drugs is a factor when addressing health issues.

All the changes in weather have made it dangerous to travel for hunting; have affected the health of our fish, birds, and animals; and have made some of our main food sources scarce. Hunting and fishing for traditional foods also require money. The cost of gas and supplies to go out hunting for country food to stock up for winter months has become very high, which is a problem even for those who have full-time employment. Also the upkeep of hunting equipment such as boat and motor, snow machine, and four-wheeler (all-terrain vehicle, or ATV, known locally as a 'Honda') has become very expensive, making it difficult for hunters to have proper hunting equipment. This causes a huge amount of stress for everyone because the alternative, food and meat at the store, is very expensive, the quality is not always good, and the change of diet can affect health and well-being. The high cost of food, for example, has people purchasing food items that are put on sale because they are near or past their expiration date, which has to be unhealthy but that is the only way one can purchase food due to the high cost of living.

Health is affected by many things besides the environment and climate. The lack of local services is one example. Medical travel is another issue, as medical check-ups at the local health center usually lead to appointments out of town, which means traveling to the hospital in Inuvik, Yellowknife, or Edmonton. The taxi fare from home to the airport costs fifteen dollars one way and if the plane does not land due to poor weather conditions, this means paying another fifteen dollars for the taxi to go back into town. This comes out of the patient's pocket, and most people cannot afford the taxi so they are driven out by four-wheeler or snowmachine, even when they are sick, which adds another worry to patients heading out on medical travel. Once you get into Inuvik, Yellowknife, or Edmonton, rides are provided to the hospital unless you are a government employee, in which case you have to pay for the costs and get reimbursed. Having to travel alone or with an escort is another big issue in small Northern communities. Elders and adults over nineteen who can speak and understand English travel without an escort, but most do not know how to read in English or how to find gates to board flights at larger airports and how to locate their luggage once they have reached their destination. Meeting with doctors and taking on medical information even if one can speak English can be very challenging. As a result, many preventive measures are not available or not used, and instead treatment is most often for people who are already very ill.

Health includes overall well-being, too, which in turn is affected by many things. Loss of the Indigenous language among the adults and children has caused communication barriers between elders and children and some adults; therefore, interaction between these age groups can sometimes be difficult, resulting in a loss of cultural continuity.

Housing shortage is an issue in the community – also house rent for the working families and individuals, as one works and pays maximum rent, leaving almost next to nothing for food and clothing as one also pays for power usage. This can undermine well-being and also physical health, due to stress and poor living conditions.

Many healthy initiatives have been put in place to bring the community together towards a healthier tomorrow, such as sewing programs for youth and adults, traditional tool making, summer cultural camps, and recreational activities for community members during the evenings. The community works together to provide healthy activities for all ages to help face the challenges the individuals face on a daily, weekly, and monthly basis in our fast-changing world in hopes of providing a safe and healthy environment for the people in our community and the next generation. In this context, climate change is an additional challenge to our health, affecting many of the things that matter to us and our well-being. Addressing all of the causes of our health issues will go a long way to helping us deal better with climate change.


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*Children in the Inuit community of Ulukhaktok, Victoria Island, Northwest Territories*

## 2.3.2 Regional perspectives

### Perspective E: Russian Association of Indigenous Peoples of the North (RAIPON)

During the Soviet period, positive change was seen among the peoples of the North in the sharp decline in morbidity, mortality, and infant mortality, and decreased rates of infectious disease. These achievements were made possible by unprecedented levels of support from the government. Market reforms, which began in the 1990s, destroyed the achievements of the Soviet period and aggravated hidden problems. Yesterday's herders, hunters, and fishers were forced to migrate to towns and villages, where they met with unemployment. These zigzags undermined the ability of the peoples of the North to set goals and eventually led to the return of maladjustment and demographic and health problems. Life expectancy in Russia's northern population as a whole is three to four years less than the national average, but among the Indigenous population it is 10 to 11 years shorter. The increase in such problems was exacerbated by the development of mining in the North, which destroyed and polluted regions important to traditional life and methods of managing the North.

Prospects for overcoming the current socio-economic crisis are made more complex by new adverse factors, including climate change. Among the issues discussed by peoples of the North are: sudden changes in temperature frequently leading to icy conditions, which cause great harm to reindeer herders; frequent changes in the winds, and blizzards at the 'wrong' time; irregularities, changes, and loss of precipitation, especially changes in snow that affect the depth of snow cover; new kinds of animals, birds, and insects; changes in ice thickness on ponds, making them more dangerous; a reduction in walrus rookeries, and in the fatness of marine mammals; and frequent forest and tundra fires.


Danita Delimont / Alamy Stock Photo

*Health clinic, Yanrakynnot village, Chukotka*


ARCTIC IMAGES / Alamy Stock Photo

*Health center, Amguema, Chukotka*

For the Indigenous peoples of the Russian North, climate change and associated phenomena are additional factors in a larger crisis, which for some reason is not usually taken into account. Although climatic and environmental changes have long been part of the history of Indigenous peoples in the North, and were largely addressed through adaptation, for various reasons the same adaptation approaches do not work under present-day conditions. The most realistic, and state-supported, response to current changes for peoples of the North is their movement from traditional territories to settlements and their integration in larger towns. But this is a difficult path. The fact is that the destruction of traditional forms of husbandry and economy for people in the North leads to painful transformation and new losses to which climate change and other factors contribute.

Critical issues include:

- The Soviet weather service was seriously compromised through reorganization, adversely affecting the system for tracking ongoing changes in weather and climate, and timely notification.
- A similar loss was suffered by the aviation protection service. It is clear that the loss of weather and aviation services will lead to disaster.
- The work of researchers and scientists remains without practical consequence. Generally, there is no planned response to natural disasters or climate change, to the threats of new diseases, and so on.
- Researchers, in turn, do not get full, consistent, or timely information from communities in the North.
- In programs aimed at sustainable development in the North, climate change and the possible extinction of some traditional occupations are not given due attention.
- In the Soviet era, healthcare in Russia was a single network under federal and republic-level ministries. In the post-Soviet transformation, this health network collapsed.
- At the level of practical public health interventions, the increased risk of new infectious diseases and other infections is of great concern but is ignored by the health services.

What can mitigate this climate threat? Clearly, pollution and destruction of nature should be reduced in all regions of the Arctic. Serious study is required to find preemptive and preventive measures to the revolutionary aspects of climate change. Revival of the network of weather and air control stations would help. It is also necessary to insist that programs for sustainable development among Indigenous peoples in the North be created, and include the crisis of climate change. Adequate measures are needed in the health sector, including rebuilding mobile medical teams and assessments of the epidemiological situation in areas inhabited by Indigenous minorities in the North. A health center combining researchers and peoples of the North could gather information about Indigenous health and climate change and provide appropriate advice to Northern residents and state agencies. All of these impacts are a forgotten cost of destroying nature in these regions.

LOETSCHER CHLAUS / Alamy Stock Photo

*The Inuvaluit community of Tuktoyaktuk, Northwest Territories, on the Beaufort Sea coast*

## Perspective F: Integrated Regional Impact Studies

The accelerated pace and extent of climate change and modernization over the last several decades have diminished Inuit abilities to cope with new environmental, socio-economic, and health conditions in Arctic communities. Thus, Inuit have expressed the need to develop adaptation capacity in the Arctic (Nickels et al., 2005; SCEWG, 2008). To answer this call, ArcticNet coordinated four Integrated Regional Impact Studies (IRISs) across four regions of the Canadian Arctic. Regional impact assessments (RIAs) were tailored to address region-specific priorities and issues related to climate change and modernization.

Key findings of the western and central Canadian Arctic RIA (Stern and Gaden, 2015) were divided into seven themes addressing the main interests and priorities of the Inuvialuit Settlement Region and Kitikmeot Region of Nunavut:

*Human health* –The risk of dehydration, sunburn, and insect bites to people are likely to increase with higher summer temperatures. The context of health in the two regions is also important: 70% of adults in the Inuvialuit Settlement Region and the Kitikmeot region smoke, and 85% of homes have secondhand smoke. Vitamin D and iron deficiency are present in 30% of adults in the two regions.

*Food security* – Community freezers and having an active hunter in the home improve food security. Traditional foods are eaten more by older people. Among Inuit Health Survey participants, 60% say they experience food insecurity.

*Human safety* – Sea ice thickness has decreased, making traveling dangerous. More extreme, variable, and unpredictable weather has compromised the safety of travelers. These conditions also reduce the ability of traditional knowledge holders to forecast weather. As a result, extra safety supplies are often needed but are not always accessible to all hunters.

*Preservation of culture* – One in four households maintains the use of an Inuit language. Among adults, 60% have not completed secondary school. Due to the accelerated changes in climate, environmental conditions, wildlife, and modernization, Inuit have experienced limited opportunities to pass on traditional knowledge and land-based skills to youth.

*Resource exploitation and socio-economic development* – Oil and gas and mineral exploration and associated activities (e.g., shipping) are likely to increase in the BCB region. Furthermore, cruise tourism appears to be growing in the Arctic. Yet, Inuit are limited in their participation in wage-related jobs due to inadequate education and skill levels.

*Infrastructure* – Increasing permafrost thaw in the western Arctic since the 1970s and high rates of shoreline retreat at the Coppermine delta at Kugluktuk, Nunavut, since the 1950s have reduced the integrity of infrastructure in the region. Furthermore, projected sea level rise at Tuktoyaktuk, NWT, has implications for coastal infrastructure via erosion and flooding.

*Wildlife and environment* – Abundance, distributions, and types of wildlife populations have changed due to habitat change. Polar bears range farther out to sea, following ringed seals (*Pusa hispida*). Increased shrub coverage attracts shrub-nesting birds and moose (*Alces alces*). Pacific salmon and capelin (*Mallotus villosus*) are expanding into areas frequented by Arctic cod.

The RIA's recommendations were co-developed by representatives of land-claim, territorial, and Canadian Inuit organizations:

1. Promote and increase access to community-based services that enable skills development and enhance quality of life, including but not limited to healthcare, harvester-support programs, hands-on safety training, food-sharing networks, nutrition and food preparation classes, weather forecasting and communications, and skills training for employment in the industrial sector.
2. Enable Inuit participation in decision-making, including the incorporation of traditional knowledge, towards policies, services, codes of conduct, and programs (including school curricula) that have a direct or indirect impact on their way of life.
3. Account for climate change impacts in community planning, such as proactive measures that include large-scale surveys of surface and subsurface features, which will determine areas susceptible to permafrost disturbance. Conduct regular inspections and maintenance of community infrastructure.
4. Encourage research into housing, food security, education, health, employment, and water quality, as well as the impacts of climate change and resource development on these factors in the Arctic. Supporting the development and continuance of community-based monitoring projects and other long-term studies (e.g. contaminants, wildlife populations) will help establish baseline conditions from which impacts of climate change and resource development can be detected.

## 2.3.3 Legal and policy perspectives

### Perspective G: Wildlife resource use in 20th-century Chukotka

The relationships between Indigenous coastal peoples on the Chukchi Peninsula (both Yupik and coastal Chukchi), the natural resources upon which they depend, and the governments of Russia have gone through several major transitions in the 20th century. Some context regarding these political changes, their ecological impact, and their social effects can support our contemporary understanding of relationships between Indigenous natural resource users and their political and physical environments.

Coastal Chukchi and Yupik societies were historically dependent to a large extent on marine mammal resources. In the late 19th and early 20th centuries, these resources – especially bowhead whales and walrus – were put under considerable pressure from commercial whalers, who killed an estimated 20,000 bowheads and over 200,000 walrus. Periods of starvation due to harvest failures were common into the early 20th century. Indigenous hunters also began using whale boats, harpoons, and firearms traded from whalers. During this period, the presence of the Imperial Russian government was minimal. When the Soviet Union took control of the region in 1923, the state focused on providing better hunting technology, both as a way to forestall famine and as an incentive for Indigenous hunters to join collective hunting operations.

Collective production was ideologically critical to the Soviets and focused both on pooling the equipment and results of walrus and seal hunting and on maximizing the size of harvests. To this end, the Soviet government began providing outboard motors in 1929, along with other hunting equipment. Only members of collectives were allowed access, but these collectives generally functioned along lines acceptable to Yupik tradition, especially regarding the distribution of the catch. As a result, collectivization among the coastal Indigenous peoples, with some exceptions, was much less violent than among the reindeer herders of inland Chukotka. Over the next 25 years, Yupik and coastal Chukchi were increasingly absorbed into Soviet political and social norms. Marine mammal hunting was mechanized and expanded, taking advantage of walrus populations that had recovered somewhat from 19th-century overharvesting. Marine mammal products were processed industrially at several sites along the coast, where oil was refined and ivory-carving industries were established. Although ideologically part of a push to make all landscapes and environments maximally productive, these industries were largely subsidized by the state. And while people generally lived in their ancestral village locations and faced no open prohibitions on speaking Indigenous languages or participating in traditional social organizations, their importance decreased and was replaced by state institutions.

After the Second World War, new Soviet reforms changed coastal life more dramatically. Most critical was the policy of consolidating and closing villages. In Chukotka, 20 communities were closed by 1965. Hundreds of people were forced to leave their homes and move into new communities, where cultural ties were lacking, along with access to traditional hunting sites (e.g., Krupnik and Chlenov, 2007; Holzlehner, 2010). Although this process was conducted without open violence, the results were traumatic for the people involved. Dependence on the state increased, as people were moved away from traditional economic activities. These relocations coincided with new walrus conservation programs, which limited the size of the walrus harvest due to the over-harvesting in previous decades. Later in the Soviet period, shore-based whaling was also prohibited. Given these economic changes, the massive relocation programs, and the policy of residential schooling that began in the late 1950s, many coastal hunting families became increasingly dependent on state-provided jobs and subsidies.

The fall of the Soviet Union brought an end to most of the subsidies that had helped to support marine mammal hunting brigades and coastal communities. Coastal residents have since regained rights to whale from the International Whaling Commission and are now able to hunt marine mammals other than polar bears. However, the Soviet pattern of oversight without community input remains largely intact, but without many of the financial benefits provided during the Soviet period.


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*Hunters from the Yupik village of New Chaplino, launch a boat at the start of a grey whale hunt in the Checheykiyum Strait. Beringia National Park, Chukotka*

## Perspective H: Marine mammal hunting communities in Chukotka

*First person account by Eduard Zdor, Executive Secretary of the Chukotka Association of Traditional Marine Mammal Hunters*

There are few Indigenous people in Chukotka, and they inherently depend on how our natural resources are protected. Almost any change in the animal and plant world is difficult, and in the worst case scenario could lead to the extinction of the Indigenous peoples of Chukotka as ethnic groups. Here are a few examples describing our situation.

The Pacific walrus is a critical species for the Indigenous peoples of Chukotka. Our supply of protein and fat during the long polar winter depends on the success of the autumn walrus hunt. The products of walrus harvesting sustain people exceedingly well even in the absence of modern technology for processing and storage. As a result, almost every man is able to provide his family with food, guaranteeing enough to eat for a long period. Keep in mind that unemployment in Chukotka's villages ranges from 50 to 70% of the working-age population. This means that the coastal inhabitants of Chukotka are highly vulnerable to any temporal or spatial changes in the migration of marine mammals.

Another issue of concern for our organization is the plan to increase industrial development in the Bering Strait region as a result of the increased ice-free period in the spring–summer–fall period. We believe that an increase in global shipping traffic, as well as plans for oil production in the Chukchi Sea, would in the long term cause irreparable damage to the traditional natural resource management of Chukotka's Indigenous peoples.

The recent economic crisis in Russia has led to cuts in programs for socio-economic development in the region – which even prior to the crisis did not match the level of need. The expected increase in the price of boats, fuel, hunting weapons and other equipment for hunting, personal items, and other goods and services has added to local anxiety and insecurity.

All polar bear hunting was banned in the Soviet Union in the 1950s. The 60-year moratorium on the traditional use of polar bears is a serious problem. Public authorities made this decision without consulting the Indigenous peoples of Chukotka. It was not the Indigenous people of the Arctic who reduced the size of the polar bear population, and the Indigenous people of the Arctic are not now a contributing factor to reducing the number of polar bears. For many years, we have explained to public authorities that the products of hunting polar bear are important to Indigenous peoples because it is a traditional food source, a means of preserving material and spiritual culture, and a factor in ethnic identity.

A lack of feedback between the state and society has been characteristic of the Russian government in recent years. State power refuses to accept information that does not fit in its understanding of the status quo. Moreover, any information perceived as 'wrong' in terms of the interests of those in power is taken as an unfair accusation or attack. Organizations that have different opinions from the state about the existing order of things and ways of solving problems are under considerable pressure. The Association of Traditional Marine Mammal Hunters of Chukotka has repeatedly been subject to attempts to close it – mostly through accusations of various sorts of violations that, after careful inspection and the depletion of the organization's resources, proved not to be true. In such circumstances, people and the organizations they create prefer to remain silent or speak only about comfortable things. Distorted information about the real state of affairs leads to management decisions that do not improve the situation.


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*Yupik woman from the village of New Chaplino, skinning a young ringed seal at a summer camp. Beringia National Park, Chukotka*

Studying the problems that face us and their causes and possible solutions is a fundamental purpose of our organization. To this end, we collaborate with researchers from different locations and share information with public authorities, and organize meetings of scientists and marine mammal hunters. The results, ideally, of this cooperation are recommendations for hunters, villagers, and government bodies. However, in our opinion, there is not enough work in this area, primarily due to a lack of financial and human resources.

We can offer five recommendations to help people in the region solve their problems: (1) educate people in Chukotkan villages on how to conserve key habitats for flora and fauna; (2) involve local people in decision-making processes about the use of natural resources; (3) organize civilian control over industrial development projects in Chukotka and the surrounding seas; (4) involve independent experts in environmental impact assessments and ethnology; and (5) create a federal program of state support for marine mammal hunting.

Additional information would help. The international scientific community produces a significant amount of research related to global climate change, but the base language for publication is English. The Chukotka population is in need of Russian-language results.

Dialogue at all levels is also needed, especially for joint problems. The hunters represented by our organization have relatives on the other side of the Bering Strait. But even without a familial relationship, the Indigenous inhabitants of Alaska and Chukotka have similar lifestyles and similar cultures, and the same factors influence the preservation of their cultures.

## Perspective J: Hunting and co-management

*First person account by George Noongwook, Savoonga Whaling Captains Association, Savoonga, St. Lawrence Island, Alaska*

The Iñupiat and Yupiget of western and northern Alaska have hunted whales since time immemorial. In 1977, the International Whaling Commission established a quota for our bowhead whale harvest, set at zero. This was done without any notice or consultation, and was soon replaced with a small quota to allow the traditional hunt to continue. Since then, Alaska's whalers have proven through science, traditional knowledge, and sound management that our bowhead whale hunt is sustainable and humane, resulting in a more appropriate quota based on cultural need. However, after 30 years of proving this to our people, our government, and the IWC, the threat to IWC's renewal of our harvest quota and the continuation of our whaling is based purely on politics – not on facts. The international community in the debate is using Aboriginal subsistence hunts as a pawn in the debate over commercial whaling. As one example of how far this debate takes us, we whalers want to travel to Latin American countries that have consistently been unsupportive of our quota renewal and produced negative press coverage of our subsistence hunt.

We also work to coordinate our meetings with the US Government, seeking support for our quota renewal. Our quota is now set for six years at a time, most recently in 2012. Prior to the IWC meeting that year, I and another leader among the Alaska whalers traveled to Washington, DC, to discuss the prospects for IWC action and what we would do if no quota were passed. Whaling is not just important nutritionally. Our subsistence activities and traditions define our identity. The social structure and health of our communities and all are centered on the great bowhead whale. With this in mind, we also discussed the potential impacts of offshore oil and gas activity in our region. These discussions give an idea of the range of issues facing our communities and our whalers, and the lengths we have to go to in order to preserve our culture, tradition, the whales, and our environment.

We met with various government agencies and also with the members of the Alaska congressional delegation. The intent of these meetings was to discuss the Plan B strategy, to amend the Whaling Convention Act so that it expressly applies to Aboriginal subsistence whaling and requires the commerce secretary to set catch limits in the event the IWC fails to adopt a block quota. The timing of the introduction is critical so as to provide us some leverage at the IWC meetings. There are factions in the IWC and also the US State Department that would be against the quota legislation if it were to be introduced.


Steven J. Kazlowski / Alamy Stock Photo

*Iñupiaq whaling camp at the edge of an open lead in the pack ice, Chukchi Sea*

We also met at the Department of Commerce. We talked about some of the strategies on handling the block quota renewal. There was a problem at the IWC's 63rd (2011) meeting in Jersey, UK, where an impasse on a proposed South Atlantic sanctuary caused a lack of quorum when Japan and its supporters walked out of the convention. The convention ceased without completing the agenda. The IWC was without a chairman to run the meeting, and we had not heard who would be the chair for the IWC. Since 2012 was the quota year for the Aboriginal subsistence whaling countries, it was critical to know beforehand when our quota would be up for the vote.

We had a meeting with the Environmental Protection Agency (EPA). We wanted to educate them about the Alaska Eskimo Whaling Commission (AEWC) and its two decades of experience negotiating an annual Conflict Avoidance Agreement (CAA) with the oil and gas operators seeking to develop resources in the Chukchi and Beaufort Seas. The CAA process is designed to ensure that development occurs without causing adverse impacts to the subsistence hunt for the bowhead whales. The AEWC is also concerned about the potential impacts to our food sources from discharges under the permits that EPA issues.

Next we met with the Department of the Interior to explore a means of better facilitating federal–local communications regarding Arctic offshore development. The Arctic communities are organized as hunter-based societies with special emphasis on our marine mammal hunter organizations, operating under delegated Tribal authority and through contractual co-management agreements with the National Oceanic and Atmospheric Administration (NOAA) and the US Fish and Wildlife Service. Federal engagement related to marine mammals should be directed through these organizations and the borough (local) governments.

The Bureau of Safety and Environmental Enforcement (BSEE) and NOAA are trying to enhance the federal Environmental Response Management Application (ERMA) process for the Arctic region. It is a mapping tool used during the *Deepwater Horizon* spill in the Gulf of Mexico. It is also a communication plan to address oil spills and use real-time applications as the activities unfold.

We are subsistence users; this defines us and gives us a sense of purpose. Our resources are healthy in spite of changing environmental conditions in the Arctic. We will continue to rely on subsistence resources to maintain the physical, mental, and social health of our communities. We are going to continue to combine scientific research with traditional knowledge. This is the world we live in now – where to go whaling we first need to go to Washington, then to the IWC, and perhaps even to Latin America. Our ability to do so is a key adaptation to changing conditions, but one that requires a lot of travel, effort, and time away from our families.

## Perspective K: Emergency management and climate adaptation

*First person account by John W. Madden, Director, Alaska Division of Homeland Security and Emergency Management*
*Past President, National Emergency Management Association*

There is an old saying with countless variations that when you are up to your neck in alligators, it is easy to forget your objective was to drain the swamp. We in the profession of emergency management face a similar challenge with weather and climate. We confront weather each day to protect the people from harm. We seek to understand the current and forecast conditions at a particular place and time so we can prepare a swift, coordinated response. We eagerly study the seasonal outlooks for precipitation, temperature, and other measures so we can set our priorities for building our communities and their capabilities. We seek to learn from past disasters how best to reduce the consequences of future disasters.

We understand the relationship between weather and climate. We know that climate is weather over time and that weather can change every day. But we are greatly challenged with how to translate this understanding into actions of investing in equipment and skills through plans, training, exercises, threat and vulnerability assessments, risk analyses, and other traditional tools. Our budget cycle and our performance period are far shorter than the years and decades offered in climate assessments. The capabilities we need for preparedness, response, and recovery are unlikely to change as the climate also changes. But we anticipate that we may need more innovative means to work with communities on dealing with uncertainty.

If the climatic prediction of warmer annual temperatures for Alaska comes about, we do not yet know how this will change the threat profiles for our communities. The notion of higher annual average temperature contributing to river break-up remains rather abstract. Our experience is that the dominant factor in the severity of spring river break-up in Alaska is the daily temperature fluctuation between day and night and above and below freezing for a critical ten-day period that varies season to season, community to community, and river to river. We have experienced extremely damaging floods during periods of low water and below-average snowpack. By contrast, we have seen very benign break-ups with well-above-average snowpack.

With this experience and acceptance of the variability, we must prepare every riverine community for potential flooding every year. There is nothing offered from the climate assessments that will change that decision and priority.

We continue to study the past for insight into the near future, but the thirty-year averages – temperature, precipitation, snowpack, acreage lost to fire, river ice thickness, and similar measures – contain rather extreme variation. In the years from 2004 through 2014, the annual acreage in Alaska lost to wildland fires has varied from 6.5 million acres in 2004 to 103,000 acres in 2008, with five of the past eleven years with acreage less than 300,000 acres. Of the 233,000 acres burned in 2014, 222,000 were human caused. We must avoid simple statements or predictions on climate and its consequences when based on highly complex, interrelated, interdependent threats and hazards. We must embrace the complexity and the variability by considering the other relevant variables. In understanding or predicting trends in firefighting, these should include resources available and deployed to fires, decisions on priorities on which fires to fight, daily and hourly temperature, precipitation, wind variations within an area, changing vegetation, and proximity to communities and critical infrastructure.


Accent Alaska.com / Alamy Stock Photo

*Erosion of coastal permafrost during a winter storm*

We know from years of experience and scientific counsel that the range of consequences from a sea storm varies extremely with the presence or absence of sea ice. But we also know that the risk to the community is also affected greatly by the direction and fetch of the wind and the stage of the tide. In the assessments of a changing climate – in Alaska and the Arctic or elsewhere – we see indicators that we may encounter more serious consequences from storms. But if we have more storms, we will continue to prepare all the coastal communities as we do today. If we have more damaging storms, we will continue our efforts for fail-safe alert and warning systems and safe havens for all the communities as we do today.

We have threats from nature, technology, and humans. Each has unique features but all have some things in common. Within emergency management, we cannot wait for perfect information nor can we leap to the obvious solution. The needs of the people rest somewhere in between. As we challenge our assumptions on weather, climate, and the consequences these bring, we must also challenge our methods, our priorities, and our policies. We must seek ways to ensure that a single investment can draw down the risk of several hazards. We must build a problem-solving enterprise that combines the practical knowledge of confronting the immediate danger with the academic rigor underpinning the assessment and implications of a changing climate over the decades.

## Perspective L: An Inuvialuit story concerning impacts of climate change

Tuktoyaktuk ("Tuk"), situated on the shores of the Beaufort Sea with an Inuvialuit population of 950 people, faces two opposing realities with regard to impacts from climate change. On one hand, the community is literally sinking into the sea. On the other, climate factors make adjacent natural resources more accessible for potential large-scale development. While most people and organizations recognize that the impacts of climate change need to be addressed, the promotion of an economically self-sufficient community and region is also very important.

Tuk's shorelines are eroding as a result of increased wave action due to loss of sea ice and increased sea levels. To slow the pace of erosion, the municipal government repeatedly has had to install riprap material at vulnerable locations, at significant cost. Relocation of the school and police station happened as a direct result of a shrinking land base. In addition, local people's ability to travel via boat or snowmobile to access hunting and fishing areas has been affected by climate changes. Tuktoyaktuk residents' knowledge of travel routes and animal migration patterns are being tested as their environment changes, forcing adaptation through new thinking and use of new technologies like GPS and SPOT devices. And of course this story is not Tuk's alone; other Inuvialuit communities are experiencing the same reality.


Aurora Photos / Alamy Stock Photo

*Caribou hides stretched outside a home in Tuktoyaktuk, Northwest Territories*

At the same time, however, the potential for economic activity – exploration and production of Beaufort Sea oil and onshore Mackenzie Delta natural gas – increases as reduced sea ice cover results in a longer operating season and a Northwest Passage that is a viable transportation option. Developing these large hydrocarbon resources could create employment opportunities and other benefits for Inuvialuit, if conscientiously carried out on Inuvialuit terms. Tuktoyaktuk specifically could benefit directly through use of its natural harbor as a staging area.

And as infrastructure is developed to make oil and gas development more accessible, doors could be opened for other economic activity. The USD 300 million Inuvik to Tuktoyaktuk highway, currently being constructed, could not only provide access to the region's hydrocarbon resources but also help facilitate other opportunities in mining, transportation, or tourism. As more infrastructure is developed, the chances of economic potential increase.

The Inuvialuit Regional Corporation (IRC) was established by the Inuvialuit Final Agreement (IFA), an agreement between the Inuvialuit and the federal government of Canada, signed in 1984. IRC is responsible for the social, economic, political, cultural, and environmental aspects of Inuvialuit life. Consequently, IRC must examine how Inuvialuit communities are being impacted by climate change and, if necessary, develop strategies to mitigate or adapt to these impacts. This also includes an examination of how to potentially benefit from these changes. IRC is receptive to developing or enhancing partnerships with responsible hydrocarbon developers to explore the possibility of carrying out their work in the Inuvialuit Settlement Region.

Hand in hand with these efforts, IRC is learning more about the conditions in a typical Inuvialuit household to develop strategies to increase education levels, diversify the economic base, maintain food security, and promote healthy living. These efforts will hopefully help future generations of Inuvialuit from Tuk and other communities take advantage of opportunities that come with industrial developments and also adapt to the impacts of climate change.

Specific to Beaufort Sea offshore development, IRC must also consider that, although the Inuvialuit have successfully participated in resource development activities on shore and near shore in shallow waters, there could be limited economic benefit to Inuvialuit from deep-water exploration for oil and gas. This lack of economic and employment benefits, coupled with the concern of a major oil spill in the Beaufort Sea that would impact the Beaufort Sea ecosystem, makes the requirement for measured progress paramount. The desire for jobs and revenues must be measured against the impact of an oil spill, which would be devastating to Inuvialuit subsistence harvesting and culture.

IRC's current efforts are therefore not solely designed to address climate change nor to single-mindedly promote industrial activity. Due to the wide range of IRC responsibilities, the organization is focused on better preparing Inuvialuit to take advantage of opportunities the future may bring, be they a result of climate change or perhaps now unknown factors.

### Perspective M: Relocation and climate change in Shishmaref: Dealing with flooding as a new ecological norm

In Shishmaref, Alaska, an Iñupiaq island community on the Chukchi Sea, it often floods. Six state-declared disasters have occurred since 1988, and a US General Accounting Office report has listed Shishmaref as one of three villages in Alaska that is in 'imminent danger' due to the extent of erosion and flooding (USGAO, 2003, 2009). In 2013, not during one of the state-declared disasters, 12–15 m of land washed away in a single night, on an island that is only 800 meters wide. These habitual floods are linked, in part, to increased erosion, diminished sea ice, increased windiness and storminess, and permafrost thaw – all characteristics of an Arctic and subarctic region in profound flux due to anthropogenic climate change.

The most threatening storms and the floods that follow occur in the autumn. During these events, passage on and off the island is compromised. This creates the distinct possibility that a large flooding event could cause numerous fatalities, as well as extensive damage to homes and other infrastructure. Because of these risks, Shishmaref residents voted in 2002 to relocate the community to the mainland. Without an organized relocation plan, residents fear that evacuation during or following a major flooding event could result in diaspora if the island becomes permanently uninhabitable. The community has landholdings on the mainland, and residents express the desire to see any relocation carried out to a site within traditional subsistence territory. Residents see removal from traditional subsistence territory as a loss of cultural integrity (Marino, 2012; Marino and Lazrus, 2015).

Rebuilding essential infrastructure such as a barge landing, a clinic, a school, or an airport on the mainland is beyond the capabilities of this 500–600 person village. Without these basic pieces of infrastructure, the daily lives and occupations of people could not continue. Therefore, in the years following the vote, residents have worked at length with state and federal agencies to establish a way forward. Despite these extensive efforts, there has been very little progress.

The lack of progress in these cases is linked to the lack of a policy mechanism or state or federal mandate to preemptively relocate populations that face recurring risk. There is no clear policy mechanism for dealing with habitual disasters that render tribal communities subject to repetitive risks, in which relocation is the best option. Generally, disaster policy in the United States is ill equipped to handle changing ecological norms that result in habitual disasters. And even the few policy mechanisms that exist are targeted at individuals and require local cost-sharing that is not suited to extremely rural, tribal communities (Marino, 2012; Bronen and Chapin, 2013). Alaska Native communities need the political and financial support to carry out community-driven relocations in ways that protect cultural lifeways, tribal sovereignty, and local decision-making power (Marino, 2012, 2015).

The Shishmaref case points to a number of challenges that residents and policy-makers face when considering climate change risks. First, research has shown that while climate change outcomes (erosion, storminess, windiness, less ice) contribute to flooding challenges, vulnerability in Shishmaref is also linked to historical processes and political marginalization that ignored local ecological knowledge and contributed to the dilapidation and inefficiencies of sea walls and other protection measures (Marino, 2012, 2015). Shishmaref residents simultaneously have not contributed significantly to historical greenhouse gas emissions. The least culpable, in this case, are suffering the greatest adverse outcomes.

This case study shows that any serious climate change policy debate must include consideration of what to do about previously inhabited villages, cities, or regions that become increasingly uninhabitable due to changing ecological norms. If it is a challenge to move the village of Shishmaref, what of larger towns and cities that face similarly significant changing conditions? Lastly, this case demonstrates that adaptive capacity often requires coordination at multiple scales of intervention. Without coordination, the scales of intervention can work against one another. Efficient adaptive capacity building for a region, nation, or the world requires a significant coordination of efforts. This might be the most daunting obstacle of all.


Lawrence Hislop

*Aerial view of the old runway now used for housing*

## 2.3.4 Commercial perspectives

### Perspective N: Marine shipping and changing weather patterns in the Beaufort Sea

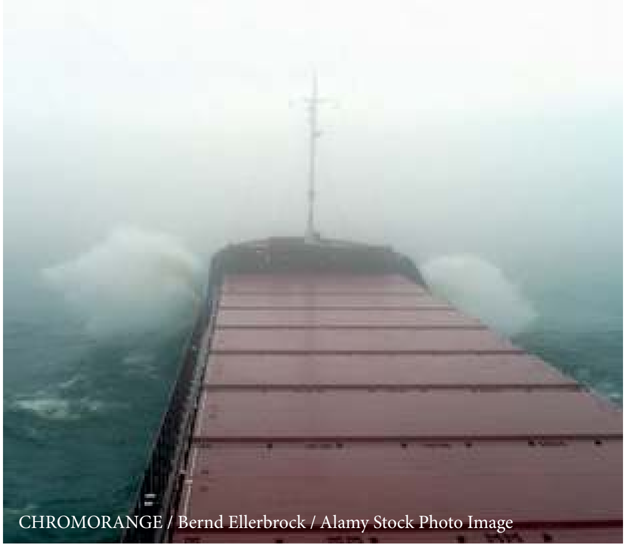
In the past decade, the Beaufort Sea has experienced relatively ice-free conditions and an increase in marine shipping activities. Despite the perception that an ice-free Arctic will mean easy transit in Arctic waters, the decrease in sea ice presents new challenges to navigation in the Beaufort Sea.

While sea ice cover and thickness have diminished over the entire Arctic, ice can shift on an hourly and daily basis (Snider, 2012). In some years, ice melt is not as fast or extensive in certain areas, and navigational plans can be delayed. When this happens, barges encounter two types of problems: the start of the freeze-up period and the fact that icebreakers finish operations in September. In summer 2014, one barge broke loose from its tug in unexpectedly bad wave conditions and began drifting west towards the Chukchi Sea. Poor weather and ice conditions precluded the recovery of the barge just after its cable parted.

Multi-year ice, although much less common now than in the 1980s (Lackenbauer and Lajeunesse, 2014), was during the 2014 open water season pushed by winds and currents to M'Clintock Channel, posing risks for navigation in the area. At the beginning of the 2012 season, pack ice against the Alaskan Beaufort Sea coast made navigation difficult even for ice-strengthened ships. Other challenges include unmarked/uncharted shallow areas, frequent low visibility and fog, shifting sand and gravel bars, and the lack of infrastructure to support shipping or respond to oil spills and other marine accidents.

The increased exploitation of hydrocarbon resources in the Arctic in the near future is expected to increase shipping activity. This will result in the arrival of diverse stakeholders who may not be familiar with Arctic conditions. Most vessels rely on open-source ice information, which is not real-time, and nautical charts are typically maintained for main routes but are often out of date for less-traveled areas. They are also not properly georeferenced (Camsell, 2014).

These challenges and increased shipping activity open the door to potentially negative impacts on the Arctic marine environment. Although Canada has a zero discharge requirement, there are no enforcement mechanisms in place to guarantee that increased shipping traffic will not result in operational discharges and emissions, the introduction of alien organisms, or anchoring impacts (Camsell, 2014). The lack of reliable ice information and nautical charts, combined with the use of ships not designed for the region and operated by ill-equipped crews, further increases the chances of problems. In addition, Canada has limited ability to respond to oil spills or marine incidents such as groundings and disabled ships in the Arctic.


CHROMORANGE / Bernd Ellerbrock / Alamy Stock Photo Image

*Bulk carrier in heavy seas*

As more vessels navigate the Arctic, there will be an increased demand for ice-breaking and navigational support. There is only one icebreaker operating in the United States and only one Canadian icebreaker, CCGS *Sir Wilfrid Laurier*, routinely operating from the Beaufort Sea to Queen Maud Gulf. A recent review (Office of the Auditor General of Canada, 2014) revealed that, while vessel traffic in the Arctic is increasing, the Canadian Coast Guard ice-breaking presence is decreasing.

A common concern of many captains in the marine shipping industry is the lack of a government vision and commitment to a long-term strategy for safe marine transportation in the Arctic. Canada would benefit from developing shipping infrastructure and enforcing shipping regulations to protect Arctic waters. For example, vessels could be required to have an ice navigator on board. Under current Canadian regulations, only tankers, passenger ships, or certain other specified vessels are required to have ice navigators.

The use of ice observers – Canadian Ice Service personnel who disseminate ice information to support navigation decisions onboard Canadian Coast Guard ships – was discontinued after the 2013 shipping season (Office of the Auditor General of Canada, 2014). To compensate for this loss, shipboard deck officers should be sufficiently trained to identify ice and understand ice physics, as is required in other countries when conducting ice-breaking operations.

The remoteness of the Arctic waters, the limited availability of maritime safety information, the challenges of navigating in these areas, and the lack of new operational search and rescue bases (Snider, 2013) may mean that, if and when an incident occurs, the response will be slow and likely inadequate to address immediate rescue needs and other, longer-term impacts on the marine environment. There is a need for communication facilities that allow for effective distress communication, warnings, and response. Satellite communications are a problem, and radio coverage is highly seasonal. The establishment of new guidelines and the identification of specific needs, such as locations for new wave buoys, are critically dependent on gathering input from those who are operating in the region.

Such challenges mean that an increase in marine shipping is unlikely to occur soon. They point to an approach requiring participation from different levels of government within Canada and internationally, and participation from the local communities that will be affected by marine shipping.

### Perspective P: Commercial fishing in Shaktoolik: A fisherman's perspective

*First person account by Eugene Asicksik, Vice Mayor, Shaktoolik, Alaska*

Shaktoolik is a community of 250 people, situated near the north end of a sandspit in Alaska's Norton Sound. The local economy is mixed, based on commercial fishing, traditional subsistence activities, and local jobs. Although climate-related impacts such as loss of productive spawning or rearing habitat have been seen, they have not done substantial damage to commercial fishing so far. In general, the fishermen's income has been reduced because there are just too many permits in the region, spreading the available catch and money across too many people.

A combination of lower precipitation and increased erosion along the riverbanks since the late 1980s and early 1990s results in the chum salmon not having enough places to spawn and a lower salmon return. With rivers eroding, the silt is deposited in eddies or river channels, smothering the salmon eggs. Two years ago, there was barely any snow, and the little snow we had melted and flowed downriver on top of the river ice. It took a while for the river ice to melt, so the fish just stayed out in the ocean until we got some warmer weather. But once the salmon started going upriver, they didn't have enough water.

We are also observing that the ice is freezing to the bottom of the river. When the river freezes to the bottom, water builds up at the back of the river. Eventually this water explodes and pushes ice on top. I do not know what happens to the spawning or the eggs in the river. I've heard that the salmon eggs also freeze. In the Tagoomenik River, there are so many beavers building dams that the flow of the river has gotten very slow – so slow that algae is growing and you do not see as many fish going up to spawn, due to lack of spawning areas.

Using beach seines for subsistence fishing is causing a form of selective fishing where bigger fish, mostly male fish, are caught, and small or female fish go through. The targeted subsistence fish here is king salmon. They are getting smaller, and I think we are genetically changing them. With the king salmon decline, everyone points their finger to the bycatch and pollock fisheries, but some of this is happening within our community. It's hard to hear that people are eating 300 king salmon for one family. When you take that many fish back to the village, you take the nutrition out of the river.

When I was growing up, the state went limited-entry and Shaktoolik had 19 permits. Now we have 31 permits; we are pretty crowded and everybody is catching fish, but it's more even. Now it is so easy for young people to buy a permit from other communities or from one of the surrounding villages, or from anyone who wants to sell a permit. There are a total of 301 Norton Sound salmon permits.

The Norton Sound Economic Development Corporation (NSEDC), our community development quota (CDQ) organization, represents 15 villages. Shaktoolik is one of them. We are the second producer in commercial salmon fishing, and sometimes the second in crab. The NSEDC loan programs provide for advanced gear and advanced fuel. You can also get boats, motors, nets, buoys, and anchors. If you live in one of these villages for one year, you could get a loan of up to USD 100,000 for crabbing; for salmon you can get up to USD 25,000. You can also get an advance, or fishermen's receivable. If you are flat broke at 12 noon on July 1 and you have your permit, your boat, your net, and motor purchased through the loan program, they'll advance you 300 gallons of fuel. You pay all that back through your delivery of fish to them.

NSEDC has benefited the community not only from a commercial fishing perspective but also to support the building of a gravel berm to protect the town from erosion caused by storms, impacts that are exacerbated by the lack of ice. A total of USD 120,000 from community development funds and USD 500,000 from an outside entity grant were used to build the berm in the summer of 2014 (MacArthur, 2014).

I started fishing when I was 16. I would fish at Cape Denbigh and then head south, towards Unalakleet. That was our livelihood – approximately USD 60,000 to USD 70,000 per season. But today you cannot even do that. Sometimes you are at the wrong place or there are too many permit holders, too many boats, or the fish are running further south. I think in general commercial fishing will become more problematic, not only with environment change but also more economically problematic. This year I didn't even make USD 17,000 from crabbing and fishing.

We have the option to increase this income by improving operational efficiencies such as handling, storage, and preservation of the fish, as well as by having a fish processing plant in Shaktoolik. Regarding the potential long-term impacts of climate change, one could say that more research is needed to understand the potential impacts on fish habitat and on the productivity, distribution, and behavior of fish and shellfish stocks. It is hard to anticipate what might be impacted. There will be benefits and there will be adverse impacts.


JJ / Alamy Stock Photo

*Fishing boats wait on the Koyuk River, Alaska*

## Perspective Q: Arctic expedition: cruise tourism

Expedition cruise tourism involves 100- to 250-passenger ships traveling into the Canadian Arctic, Greenland, Svalbard, and to a lesser extent the Russian Arctic. Expedition cruises involve visits into Arctic communities interspersed with 'expedition' stops on the land to view wildlife, experience historic sites, and adventure over new terrain. Expedition cruising takes vessels away from the designated navigation routes and into seldom-visited bays or fjords in search of new experiences. The limited number of passengers on these vessels makes for less intrusive interaction with Arctic communities, which tend to be small and have limited infrastructure to support day visitors.

There are nonetheless several big issues of concern: (1) lack of infrastructure: from port facilities, bunkering facilities, and limited access points for passenger transfers from southern Canada to the ships themselves; (2) complex bureaucracy in permitting: it is very challenging to carry permits over a multi-year period despite limited change in the shipboard operation; (3) limited search, rescue, and ice escort capability: the Canadian Coast Guard is stretched to its limits and is therefore unable to meet the demands placed upon it by the Canadian Arctic marine industry.

Other factors of importance include: (1) limited charting, leading to restricted waterways for navigation; (2) lack of designated port of entry into Canada in the Canadian High Arctic, leading to high costs and limited ports for clearance; and (3) growth in non-renewable resource industry in the region, placing high demand on the limited infrastructure in the region; this industry tends to have higher economic gain in the short term and therefore is perceived to be of greater value to the communities in the region.

Expedition cruise tourism is a growth industry in the region because: access to certain parts of the Arctic has improved due to the longer ice-free season; demand for expedition cruise programs is increasing; wildlife behavior is shifting due to changing ice and climate patterns; and interest in the Northwest Passage is increasing due to the Franklin Expedition search and recent discoveries.

With effective management, this industry can be shaped and molded into a valuable low-impact contributor to the economy. Economic benefit to the region from cruise tourism will grow as the industry grows, but the regulatory and permitting process will need to be streamlined in order to allow for growth.

The greatest barrier to growth in the Canadian Arctic is the lack of a single gateway for permitting. A single vessel can require up to 50 permits from various levels of government and various departments. Compare this with the expedition cruise industry in Svalbard, where a single comprehensive application is submitted and a letter of authorization with conditions is issued. Expedition cruise operators can plan with certainty in Svalbard, while Canadian Arctic operators must constantly wonder what new permit requirements are needed each season.

If we could solve the challenge of permitting, more operators would move into the region. As an industry, we have learned that we can create market demand for a new region, which in turn leads to greater cruise passenger numbers. With an increase in passenger numbers comes new business opportunities for Arctic communities in providing services, which in turn leads to spin-off economic benefit in the region.

Growth in the industry would lead to an increase in marine traffic in the region, increasing the need for greater Coast Guard presence. This would lead to better search and rescue coverage across the Canadian Arctic, directly benefiting the hunters and fishers of Arctic communities who spend a lot of time on the water in small boats in this region.

At the moment, the expedition cruise industry in the Canadian Arctic is relatively small and is perceived as generating limited economic benefit to the communities. An ability to expand the industry will lead to an increase in economic benefit in these communities, which will help to diversify the economy of the North.

Yvette Cardozo / Alamy Stock Photo

*Zodiac boat getting ready to take tourists ashore from an expeditionary cruise ship in the Canadian Arctic*

## Perspective R: Oil and gas in the Beaufort Sea

The Beaufort Sea region is undergoing significant and not yet fully understood changes. This situation presents both great opportunities and significant challenges to the industries most associated with the modern Arctic: petroleum exploration (see Chapter 4, Figure 4.23) and shipping. These two industries will make the Beaufort Sea a major petroleum province in the years to come. Ships filled with Beaufort oil can freely transit anywhere in the world with their cargoes, in stark contrast to land-based pipelines that face continued and sophisticated opposition in both Canada and the United States.

This promise of major development in the newly opening waters faces a number of challenges, not the least of which arises from that very opening water itself. First, the increase in both the areal and temporal extent of the open water season will result in increasing fog states, a clear danger to shipping in a region already lacking complete hydrographic charts and sophisticated weather forecasting ability. Next, these open waters will result in stronger and more severe wave action as the area available to create fetch increases and the resulting swells increase. This will affect both vessels at sea and the coastal support bases upon which they depend.

Beyond environmental challenges, the energy industry must deal with a variety of legal, regulatory, and operating challenges. The long-standing border dispute between Canada and the United States in the Beaufort Sea must be resolved in order to ensure the two countries can cooperate in the event of an offshore incident. This shared maritime area also requires Canada to closely align its offshore petroleum regulations with those of the United States. Given that any oil spill in Canada's Beaufort waters will ultimately end up in offshore Alaska, it is highly unlikely that the United States will be content to let Canadian drillers operate under regulations less stringent than those in American Arctic waters. Thus, the coordination of regulations concerning the requirement for a same-season relief well capability and the use of chemical dispersants, among many others, will need to be negotiated and agreed upon.

Exploration activity in the Canadian Beaufort is currently on hold, awaiting a determination by Canada's National Energy Board of the acceptability of an alternative to its long-standing same-season relief well policy. Alaska's Beaufort waters will likely also remain quiet pending the success, or otherwise, of Shell Oil's planned Chukchi Sea exploration program.

This delay provides an opportunity for governments at all levels to prepare for the challenges ahead. Both the Canadian and the United States federal governments have moved ahead with increasing the liability limits faced by Arctic shippers and petroleum operators, and this is to be welcomed. Ongoing research is being conducted into oil spill response techniques, and Arctic standards for petroleum exploration structures and operations are being reviewed. At a municipal level, the Hamlet of Tuktoyaktuk has been engaged for the past four years in planning an offshore supply base to support deep-water drilling while providing employment and business opportunities to local Inuvialuit. The opportunities, then, are potentially great, and the challenges, while also great, can with time and effort be overcome.


Design Pics Inc / Alamy Stock Photo

*Aerial view of an oil well drilling platform on the tundra at the edge of the Beaufort Sea in summer*

But that only addresses the *how* of Arctic offshore development. It does not address the *whether*, and that is the debate to be held. In an ironic twist, the greenhouse gas emissions that are generally considered to be the cause of the warming climate and by extension the opening of the Arctic waters can only increase if countries choose to continue to search for and use the carbon fuels that lie under those newly opened waters.

This *whether*, then, becomes a much more challenging issue to deal with than the *how* of Arctic operations. The way countries choose to respond to the challenges of global warming will have a significant impact on Arctic development. Governments have traditionally focused on regulating the *how* of petroleum operations and seldom engaged in debates as to the *whether*, with the exception of specific tracts of land such as the Arctic National Wildlife Refuge in Alaska.

A strong and enforceable commitment by world leaders to limit greenhouse gas emissions will require governments to address all forms of petroleum development and their impacts on the environment, to the detriment of oil company operations. Companies will be caught between government action to mitigate climate change, the actions of many of their own shareholders as the disinvestment movement proceeds, and the continued demands of insurers and financiers for a clear statement of individual companies' exposure to climate change.

How the industry responds will determine the future of petroleum exploration and development. Some companies have clearly stated their support for climate action, while others continue to obfuscate. It could be that industry's best chance to survive may be to adopt an 'honesty is the best policy' approach and engage legislators, environmentalists, and citizens in a very realistic discussion of both the benefits and impacts of fossil fuels.

## Perspective S: Arctic oil and gas – issues and concerns: A personal perspective

*First person account by Johnny Lennie, Inuvialuit beneficiary*

During the Inuit Circumpolar Council general assembly in Inuvik in July 2014, it was stated that if development is allowed to go ahead, Inuit regions should support a project only if Inuit are going to get a part of the royalty. The statement was well received, but oil and gas development is planned at least 20 years after any discoveries are made in remote areas and the whole Arctic is remote. The stranded petroleum resources in the Mackenzie Delta were all discovered over 30 years ago. If we relied only on royalties, we would have not received any benefits yet. We need a combination of guaranteed employment and royalties during the full lifetime of activities.

Inuvialuit communities are already preparing for oil and gas impacts. There has been some community preparation for oil spill response and some community planning for the proposed development in the Canadian Beaufort. For example, the community of Tuktoyaktuk has a B4B (Base for the Beaufort) initiative in the planning stage. Under this plan, Tuktoyaktuk is to be proactive to get ready for the planned Beaufort drilling. At the same time, Imperial Oil is promoting business opportunities, planning job opportunities, seeking support, and explaining their project. The Environmental Impact Review Board, a co-management body established under the 1984 Inuvialuit Final Agreement, is reviewing Imperial's drilling proposal. This process gives the Inuvialuit a strong say in what will happen and under what conditions. For example, one question is whether a single-season relief well is necessary in case of a blowout or whether other measures offer equivalent protection.

In the Canadian Beaufort, an issue has been raised that there are significant discovery licenses for oil and gas that are not being developed. The concern is why should we risk a blowout by approving any more exploratory drilling (all of the new exploration that has been proposed is in deeper water with a shorter ice-free season) when there is not yet a plan to begin producing oil or gas in these areas. A blowout is a definite concern, due to remoteness for response and the effect on a fragile ecosystem.

Another concern is that offshore seismic programs have been done, which cost USD 50–80 million each. Although local suppliers/contractors benefited, there were only a few seasonal jobs created for local residents. The companies argue that the ships are international ships with foreign crews and that Canada has to honor international laws, but this gives little benefit to the Inuvialuit and the residents of the North for activities that are in the Canadian Beaufort.

A policy similar to the Petroleum Incentives Program that the Canadian federal government had from the 1970s until 1986 would encourage development and increase local employment. The policy can be applied to other Arctic regions so that the maximum benefit for local residents will be achieved. Another policy should be developed to designate a part of the royalty to benefit Arctic communities once production starts. So long as the overall royalty does not increase, this will have no impact on the economic viability of a project.

Peter Llewellyn RF / Alamy Stock Photo Image

*Oil drilling rig, Tuktoyaktuk, Northwest Territories*

John T. Fowler / Alamy Stock Photo

*Supply ship servicing offshore oil drilling from an artificial island in the Beaufort Sea, Northwest Territories*

National Geographic Creative / Alamy Stock Photo

*Gas flaring in the Canadian Arctic*

## Perspective T: Pevek and Chaun-Chukotka

Pevek is the administrative center of the Chaunsky District or Chaun-Chukotka, one of the municipal divisions of the Chukotka Autonomous Okrug. More than 80% of the district's total population lives in Pevek (Administration of the Chaunsky District, 2013). Besides Pevek, there are also three rural communities in the district: Rytkuchi, Ayon, and Billings. The Indigenous population of the district, primarily Chukchi, resides mainly in these localities. In January 2013, the population of Chaun-Chukotka was 6170 – less than one-fifth of the district's population in the times of perestroika (Census of the USSR, 1989; Administration of the Chaunsky District, 2013).

Geology and mining are an important part of both the history and the present of Chaun-Chukotka. Mining here began with the discovery of huge tin deposits in the 1930s (Zelyak, 2004). In 2013, gold mining accounted for 41% of the district's industrial production (Administration of the Chaunsky District, 2013). The recent revival of mining in Chaun-Chukotka is due to the start of mining at three large gold ore deposits: *Kupol* in 2008 (Haley et al., 2011), *Dvoinoye* in 2013 (Kommersant, 2013), and *Maiskoye* in 2013 (Arctic-info, 2013). Indigenous people emphasize the corporate social responsibility (CSR) programs of mining companies in the district and their contribution to improvement of the living conditions of Chukchi people, as well as their financial support of cultural events. People believe that mining will increase in the district in the future and that it will be good for Chaun-Chukotka.

Pevek is one of the main ports of the eastern part of the Northern Sea Route (NSR) and is the deepest port of the NSR. The cargo turnover of the port of Pevek dropped in the 1990s and has increased in the past few years due to the increase in mining (Sever Nash, 2012). To assure the safety of future shipping, there are plans to base one of the Russian Arctic search and rescue centers in Pevek (Barents Observer, 2013). However, most Pevek residents expect only a slight increase in the number of ships to call at the port of Pevek.

Changes in the power supply of the district is another important issue. At the moment, the main power supplier of the region is a rundown central heating and power plant built in 1944 (Administration of the Chaunsky District, 2013). There are plans to install a floating nuclear power plant (Barents Observer, 2009), but as of 2014 the completion date had been postponed to 2019 (Slivyak, 2014). Half of Pevek's residents are worried about the health consequences of the plant, while the other half thinks it will be safe. Only half believe that the new plant will be installed.

Chukchi live mostly in the district's smaller communities and are primarily reindeer herders. A smaller number are fishers and marine mammal hunters. Reindeer herding in Chaun District has been improving during the last 10 years (Administration of the Chaunsky District, 2013) and is better than it was in the 1990s, in terms of numbers of reindeer and proficiency of herders (Pilyasov, 2009). The main challenge for Chukchi and their traditions is the very low salary paid to herders, termed 'offensive' by some. Such low incomes do not motivate young Chukchi to stay on the tundra. Many are leaving their villages for a better life. The existing education system is another reason why young people do not want to stay. Children who are educated in boarding schools far away from their parents often lose their connection with family and traditions and have no desire and skills to live their ancestors' lifestyle.

District residents have noticed changes in the climate over the last 10 years in one form or another. Summer has become significantly warmer. Snow cover has become thinner in the winter, and spring has started a month earlier in recent years. Most have only a very vague picture of the nature of climatic changes and their consequences. The Indigenous people of Pevek point out negative consequences of ongoing changes for reindeer herding ("thin snow cover thaws now every month in winter and turns to ice crust; reindeer can't break this crust and get food") and for marine mammal hunting ("sea ice near the shore of Billings disappears a month earlier, and hunting has to stop earlier in summer").

Environmental issues are not perceived as issues of primary importance. People are aware of environmental pollution as a result of resource extraction and want mining activities to be performed in compliance with ecological standards. However, environmental concerns are not perceived as a reason to stop any project. For example, even those who think that the floating nuclear power plant will affect the health of the population of Pevek stress that the net effect of this project will be positive for the district.

The socio-economic dynamic in Pevek and the Chaunsky District is typical for Chukotka: collapse in the 1990s, improvement in the 2000s, and resource extraction seen as the main economic driver and hope. People are primarily worried about economic problems – low salaries, high prices – and many of them would like to leave Chukotka. Climate and environmental issues are not the number one concern.


Yuri Kravchenko / Alamy Stock Photo

*Port of Pevek, Chukotka*

### 2.3.5 Non-Arctic perspective

#### Perspective U: Addressing China's non-traditional security in the Arctic

With global warming and especially the loss of Arctic ice, the once remote northern area is being drawn closer to the forefront of the world stage (Li et al., 2010). China has defined itself as a 'near-Arctic state' because it is greatly impacted by Arctic change, particularly in four areas: environmental impacts, Arctic shipping, resource development, and strategic interests. This section looks briefly at these aspects of China's non-traditional security and the resulting Chinese policy of 'substantive presence'.

Arctic climate change can contribute to drought and floods in China. The past ten years have seen abnormally low winter temperatures, a continuous drought in the north, and more frequent sandstorms in winter and spring. These conditions have affected hundreds of millions of people and cost the country more than 100 billion ren min bi (approximately USD 15 billion) since the 1990s (Fu, 2007). Melting of Arctic ice sheets will lead to sea level rise, resulting in greater coastal erosion, more frequent storm surges, more lowland inundation, more salinity intrusions into drinking water supplies, and reduced functionality of coastal defense installations (Liu, 2004).

The opening and commercial use of the Arctic passages have great potential impacts on China's economic development, overall economic arrangement, and import/export business. But not all aspects of Arctic shipping are positive for China. China is not a maritime power and is likely to face fierce competition for realizing any benefits from Arctic shipping. While the opportunity exists for China to benefit, too, there is no guarantee that things will go as China may hope. Russia, North America, and Europe may be in a better position to capitalize on the opening of Arctic shipping routes.

The summer retreat of Arctic sea ice opens the way to develop resources once covered by ice and unavailable for human use. China is looking to join the development of Arctic resources to fuel China's economic engine. Here, too, China will face stiff competition from not only the Arctic countries but also other countries such as Japan, Korea, and India. Business risks and environmental risks are high in the region, and Chinese businesses and individuals have already experienced some opposition to an expanded presence in the Arctic. China's demand for natural resources is also seen by some as a geopolitical threat, resulting in greater scrutiny of China's Arctic activities.

China is playing a larger role in global affairs and is taking steps to address its national security in traditional as well as non-traditional ways. For Arctic engagement, in light of global warming, one risk is that international expectations may change. Addressing the causes of global warming requires global action, but China and other developing countries will not accept restrictions on economic growth that keep them from achieving equal standing with developed countries. In China's view, its presence and interests in the Arctic cannot be separated from its presence and interests globally.

At the same time, engagement in Arctic affairs offers China a chance to forge cooperative relationships with Arctic countries, based on substantive contributions to Arctic science, greater business involvement, and high-level diplomatic interactions. China has conducted six scientific expeditions with its icebreaker *Xuelong* (Snow Dragon) in the Arctic since 1999. In 2004, China's research station Huang He was built in Ny-Ålesund, Svalbard, and is an icon of China's 'substantial presence' in the Arctic. China also started building a second icebreaker in 2016. Several research institutions dedicated to Arctic and polar research have been established in recent years, such as the Polar Law and Politics Institute at the Ocean University of China, the Center for Polar and Oceanic Studies at Tong Ji University, the Polar Research Institute of China at the Shanghai Institute of International Studies, and the Center for Polar and Deep Ocean Development at Jiao Tong University. Arctic issues have also been listed as key research fields in the past two years for the China Social Science Fund, the most respected funding agency in social science in China.

Business opportunities are one of the most important aspects of China's Arctic engagement, and Chinese companies are spearheading the movement. Chinese businessman Huang Nubo's aborted deal with Iceland to buy (later reported to rent) a piece of land for the development of tourism is a highly publicized example of a Chinese businessman's interest in the region and of the potential opposition China's businesses face. In the energy field, Chinese national companies are also tapping opportunities with counterparts in Arctic countries for oil and gas development and mining. A Chinese tanker went through the Northern Sea Route in 2013, but it is not yet clear if this will become a routine shipping route for Chinese vessels.

China has realized from the beginning that cooperation with Arctic countries is the only way for China to be able to engage effectively in Arctic affairs. Friendly, high-level political relations with Arctic countries are a must for further opportunities for Chinese businesses. In 2012, then-Premier Wen Jiabao visited Iceland and signed deals for China–Nordic Arctic cooperation, marine and polar scientific cooperation, free trade, and joint business ventures. The same year, then-President Hu Jintao visited Denmark – the first Chinese president to set foot in Denmark in 62 years. These events all paved the way for China's smooth acceptance as an observer country in the Arctic Council, which symbolically recognizes China as a stakeholder in the Arctic.

China should be clear that China's interests can only be better served through cooperation with Arctic states. Maintaining a peaceful, stable, and prosperous Arctic is also in China's best interests. With China joining the Arctic Council as an observer, and also joining some Arctic-related international organizations, the Arctic states now reasonably expect China to contribute to Arctic matters at a level commensurate with its ability to do so. Thus, for China, future engagement in the Arctic should be focused on contributing to the public good and good governance in the Arctic.

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# 3. Status of natural and human environments

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## Key messages

- ***The BCB environment is characterized by geographically isolated and small rural communities. Population densities are low, and in the North American subregions, population numbers are relatively stable.*** *Among Indigenous residents, socio-economic and cultural ties to the living sea are especially strong. Urban centers, especially in Chukotka, are located near natural resource industrial developments. Key socio-economic characteristics include mixed cash/subsistence economies, a predominance of natural resource industries, minimal economic diversification, lack of training opportunities for skilled labor, and deficient healthcare systems.*
- ***Except for Chukotka and the Inuvialuit Settlement Region in northern Canada, the main seats of government are far removed from the BCB region.*** *Engagement of local and Indigenous peoples in climate policy-making thus varies by country, with opportunities for direct interactions by local residents being greatest in Canada, followed by Alaska and Chukotka.*
- ***The BCB environment is underlain by permafrost and characterized by tundra conditions and low-lying coasts that are vulnerable to erosion and storm surges.*** *This vulnerability threatens public safety, sanitation, human and wildlife health, and infrastructure. BCB landscapes are transitioning to new states in response to changes in sea ice, permafrost, temperature, and precipitation and other environmental stressors.*
- ***Pacific, Atlantic, and Arctic water masses are present over BCB continental shelves and contribute to temporal and spatial variability in oceanographic processes and wildlife patterns.*** *The productivity of BCB benthic ecosystems, especially in the northern Bering and Chukchi seas, is among the highest for soft-bottom communities in the world. Benthic–pelagic coupling processes (e.g., advection, upwelling, freshwater influxes, primary production, grazing by zooplankton) are responsible for high shelf productivities and are major sources of natural variability.*
- ***Marine mammals, caribou, and reindeer are highly valued subsistence resources in the BCB region.*** *Ice dependency and migration strategies require adaptations to changing Arctic conditions and also represent potential vulnerabilities for many species to climate change. For keystone species, such as Arctic cod, sea ice provides critical substrate for reproduction, nursery, and forage.*

## 3.1 Introduction

The Bering-Chukchi-Beaufort (BCB) region is one of the least populated regions in the Arctic. It is a rural environment with no major population centers (i.e., none greater than population 10,000) and is serviced by industrial hubs and, in some cases, government centers located outside the region. Its natural wealth, especially its mineral reserves, is of national and international economic interest, whereas its living resources are significant in the currency of subsistence economies (CAFF, 2014). Natural resource development is integral to the region's economy and outlook (Glomsrød and Aslaksen, 2006, 2009). On-the-ground changes in temperature, precipitation, erosion, sea ice, and permafrost are important considerations in vulnerability and risk assessments.

This chapter describes the ecological and human attributes of the BCB region, including its major landscapes; later chapters describe the impacts of human developments. Subsistence ties to regional landscapes, which are the natural focus of traditional economies, are emphasized (e.g., Poppel, 2006; see also Chapter 2). An additional focus on marine, terrestrial, and freshwater ecosystems in this description sets the stage for integration into adaptation planning and resource management to reduce climate vulnerabilities, as described in Chapters 6, 7, and 8. A primary goal is to provide the environmental and socio-economic background information needed to support more detailed assessments of climate trends and drivers (see Chapter 4) and to describe the potential consequences for people of recent climatic and other kinds of change (see Chapter 5) in the region. Four guiding questions were developed to help structure this information:

> *What are the key features of human settlement, the physical environment, and the distribution of valued natural resources in the region?*
>
> *What is the status of the social, cultural, economic, and political systems that sustain the region's mixed cash/subsistence economy?*
>
> *What is the status of the ecosystems that sustain the region's mixed cash/subsistence economy?*
>
> *Are government and organizational structures in place for local participation in climate adaptation planning?*

## 3.2 Geography of the BCB region

### 3.2.1 Regional setting

The BCB region is geographically expansive, encompassing parts of two continents, three countries (Russia, United States, and Canada), and diverse marine, terrestrial, and freshwater environments; environmental features; human settlements; and administrative units (Figure 3.1). The geography of the

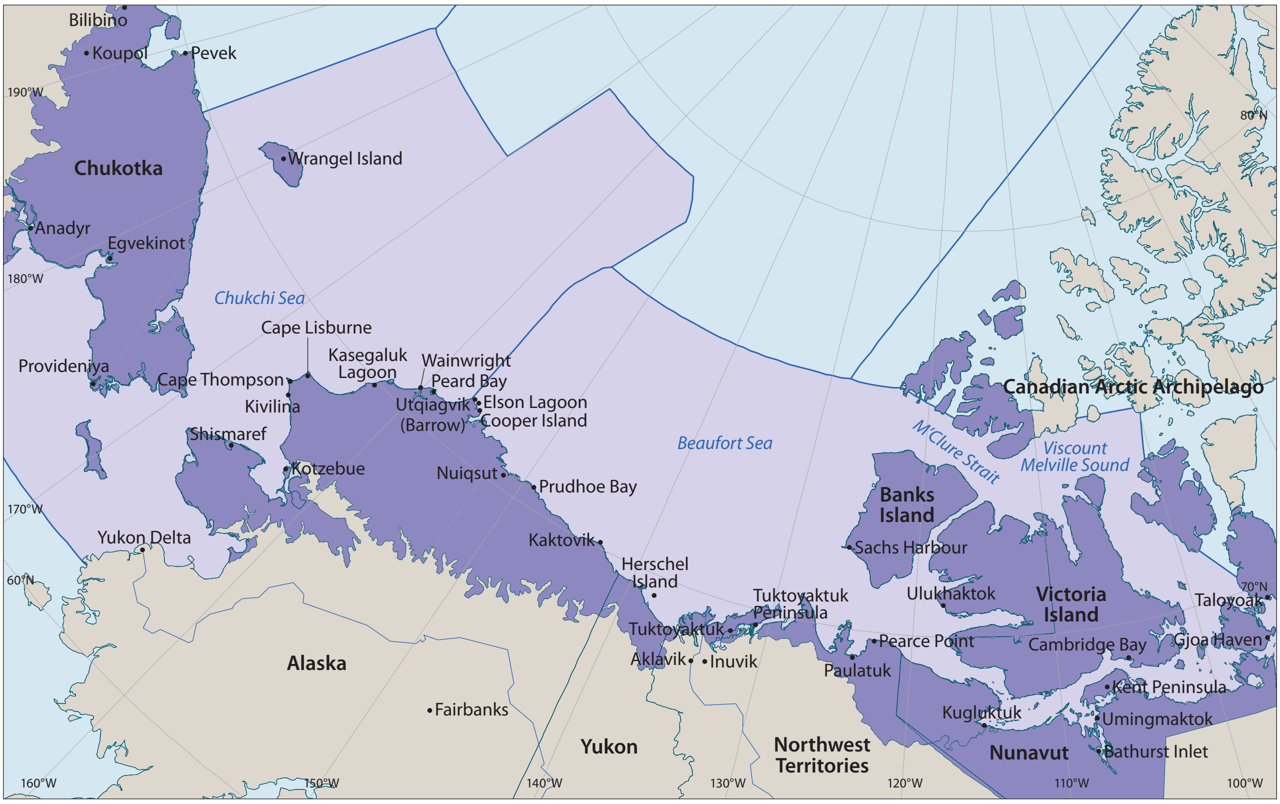


Figure. 3.1 Geographic place names in the BCB region.

BCB region is different from other Arctic regions because of the BCB connection to the Pacific Ocean. The oceanic influence affects the region's climate, oceanography, terrestrial landscapes, and human–environmental relationships. Like other Arctic regions, subsistence activities are important in the BCB region, and petroleum and mineral resource development are crucial for the economic growth of the region. While there are broad similarities in the industrial and traditional economies of Chukotka, northern Alaska, and western Arctic Canada, there are significant differences in each nation's social, economic, and political systems and their effects on livelihoods and lifestyle choices.

The continental landmasses of the BCB region occupy an elevational gradient characterized by increasing surface roughness from coastal plains to foothills to mountains. The topography of Chukotka and Alaska is much more rugged and mountainous than that of northern Canada, giving rise, primarily through snowmelt, to many rivers (with catchment areas of up to 100,000 km$^2$). In general, the largest mountain ranges are separated by lower mountains, plateaus, and highlands, as well as lake-dotted lowlands located primarily along the courses of these watersheds and smaller rivers and streams. Wetlands and ponds are common along the coasts. Small glaciers are present in mountainous areas of Chukotka and Alaska.

Mountains cover much of Chukotka, ranging in elevation from 1200 to 1800 m. The east–west-trending Chukotsky Mountains extend over much of the northern interior and include headwaters for northward-flowing rivers, such as the Rauchua, Chaun, Palyavaam, and Pegtymel, and eastward-flowing rivers, such as the Chegitun and Amguema. The Anadyr Range is more centrally located within Chukotka, and the primary river of its largest watershed, the Anadyr River, flows to the southeast and into the Gulf of Anadyr. In northern Alaska, the Brooks Range (peak elevation 2758 m) extends eastward from Point Hope, Alaska, into Yukon, Canada. Major rivers springing from the westernmost Brooks Range include the westward-flowing Noatak, Selawik, and Kobuk rivers and the northward-flowing Colville, Sagavanirktok, Canning, and Kuparuk rivers. The smaller Seward Peninsula mountains (peak elevation 1437 m) and Nulato Hills (peak elevation 1040 m), to the south of the Brooks Range, separate northwest Alaska and the Yukon River basin. Major rivers of the Seward Peninsula include the Koyuk, Kuzitrin, Niukluk, Fish, Tubuktilik, Kiwalik, Buckland, and Agiupuk rivers. From the Nulato Hills, located on the west bank of the lower Yukon River, the major rivers – Inglutalik, Ungalik, Shaktoolik, and Unalakleet – flow to Norton Sound. In Canada, the large Mackenzie River, as well as interior lake-fed rivers such as the Anderson, Horton, and Coppermine rivers, are part of the Arctic Ocean drainage basin. Several smaller rivers flow into Amundsen Gulf.

The BCB region has several large tracts of public land that conserve natural and cultural places, serve as a refuge to wild species, and provide areas for recreation. In Alaska, these lands include the Bering Land Bridge National Preserve, Noatak National Preserve, Kobuk Valley National Park, Gates of the Arctic National Park and Preserve, Selawik National Wildlife Refuge, Arctic National Wildlife Refuge, and the National Petroleum Reserve in Alaska. Canadian public lands in the BCB region include the Ivvavik National Park, Vuntut National Park, Tuktut Nogait National Park, Herschel Island - Qikiqtaruk Territorial Park, Kendall Island Migratory Bird Sanctuary, and Anderson River Delta Migratory Bird Sanctuary. In Chukotka, public lands include the Beringia National Park and the Natural System of Wrangel Island Reserve.

The BCB region is remote and sparsely populated. Its economic similarities to other Arctic areas include strong dependencies on natural resource wealth and extractive industries, especially in the energy and mining sectors. Because of the region's geography and lack of economic diversity, local challenges to economic growth and development persist; local employment and training opportunities are limited and subsistence remains integral to traditional lifestyles. Socio-economic and cultural issues – including affordable energy and housing, healthcare, and education and skills training – are high-cost problems that, in combination with low population growth and lack of economic diversification, are major impediments to sustainable development. Infrastructural and communication deficiencies, which are common, contribute to other issues. While improvements in community services and welfare are being made, the financial capacity to sustain future progress appears to be largely dependent and potentially overdependent on oil and gas development and mining. Other interdependent factors affecting economic prosperity and environmentally sustainable development in remote areas include political will, local governance, self-determination, cultural integrity, adaptive capacity, and social license (Chance and Andreeva, 1995; Larsen and Fondahl, 2014).

Among the raw materials of global interest (Andrew, 2014), petroleum and other mineral resources hold the greatest prospects for economic development in the BCB region (Lindholt, 2006; Glomsrød and Aslaksen, 2009). However, the combination of currently low oil prices and considerable advances in the development of unconventional hydrocarbon resources (shale oil and gas in particular) and alternative sources of energy threatens new petroleum exploration and development in the geologically, technically, financially and environmentally challenging Arctic environment. Details on current and planned activity in the extraction of hydrocarbons, minerals, and metals are presented in Section 3.3.3.3.

### 3.2.2 Human settlements

The BCB region is one of the least populated areas of the Arctic. Indigenous populations constitute nearly half the 85,000 people living in the BCB region. The majority of Indigenous residents live in small rural villages located along rivers or near the coast. Non-Indigenous residents typically live in regional hubs near centers of industry or government activity. Rural communities (hundreds of people or less) are scattered across large, sparsely settled areas, and even the regional hubs have relatively small populations (thousands of people). Rural settlements are typically situated near large tracts of wilderness and subsistence foods and cultural resources (Aslaksen et al., 2009). (Unless otherwise indicated, the community profiles described here for Chukotka, Alaska, and Canada were taken from Antonov, 2015; State of Alaska, 2015a; and Stern and Gaden, 2015; respectively).

The major Indigenous groups of the BCB region are the Inuvialuit, Iñupiat, Central Alaskan Yup'ik, Siberian Yupik, Gwich'in, and Chukchi peoples. The proportion of Indigenous people relative to the total population size is greatest in Canada, followed by Alaska and Russia. In Russia, the resettlement of people from small villages to larger villages (i.e., 'collective farms' or kolkhoz) or towns during the former Soviet period greatly affected the distribution of people, especially in villages and smaller settlements in Chukotka. Cultural attachments to natural resources and subsistence practices are strong in each country and constitute the major determinant of where people live.

Nearly 60% of the BCB region's total population lives in Chukotka (50,526 people; Rosstat, 2016). About 70% of Chukotka residents are non-Indigenous and live in small cities and urban-type settlements where they are employed in management and service sectors (Abryutina, 2007; Oparin, 2013). The Indigenous population of Chukotka is diverse, including different cultures and language families such as Chukchi, Eskimo, Evens, Chuvans, Yukagirs, and Korvaks (Leontiev, 1977). Evens, Korvaks, and Yukagirs live along Russia's northern coast. The Chukchi are distributed throughout Chukotka, and Eskimos are found almost exclusively along the eastern coast. The Eskimos are closely related to Alaska Natives living on St. Lawrence and Little Diomede islands and in villages along Alaska's northwest coast. Evens also live in western Chukotka, and Chuvans live in the south. Some Korvaks also live in the south near Chukotka's border within the Korvak Autonomous Okrug (AMAP, 1998). Roughly 30% of the Indigenous population resides in coastal villages, and the rest live inland on farms and countryside associated with reindeer herding.

In Russia, Chukotka is part of the Far East District. Its official name is the Chukotka Autonomous Okrug (CAO), and it is a federal subject of the Russian Federation, among 85 others. The CAO includes 46 permanent settlements, including seven municipalities (the city of Anadyr and six municipal districts). The majority of residents live in the urban (administrative) centers (populations as of 1 January 2015, as reported by the Russian Federation Federal State Statistics Service, 2015). The administrative center of the CAO is Anadyr, a Bering Sea port town with a population of 14,000 people (see Figure 3.1). Anadyrsky District is the largest district of Chukotka with a population of 7000 people. Bilibinsky District is the westernmost district of Chukotka and includes a small coastline along the Eastern Siberian Sea. It too has a population of about 7000 people, with 5600 living in Bilibino. Chaunsky District lies to the east of Bilibinsky and also has a small stretch of coastline along Chukotka's northern coast. It has a population of 5000 people, with more than 4700 inhabitants residing in Pevek. Iultinsky District, to the east of Chaunsky, has a long Chukchi Sea coastline and a shorter segment along the northern Bering Sea. Its population of just more than 4000 people includes almost 3000 living in Egvekinot. Chukotsky District, in the most northeast part of Chukotka, borders the Chukchi Sea, is closest to North America, and has a population of about 5000 people, with approximately 1500 living in Lavrentiya. Finally, Providensky District, in the northeast part of Chukotka lies to the south of Chukotsky District. It includes some Chukchi Sea coastline and has a population of around 4000 people, about half of whom live in Provideniya.

In the United States, the BCB region encompasses part of the state of Alaska and includes (1) the incorporated boroughs of North Slope and Northwest Arctic and (2) the Nome Census Area, with unincorporated boroughs covering the Seward Peninsula and the Yukon-Kuskokwim Delta. The North Slope Borough, along the northern Beaufort Sea coast, has a population of around 9000 people. Approximately 50% of the residents live in the administrative center of Utqiagvik (Barrow). About two-thirds of the population is Alaska Native. The Northwest Arctic Borough is on the southeast coast of the Chukchi Sea and has a population of 7000 people, about 80% of whom are Alaska Native. The largest community in the Northwest Arctic Borough is Kotzebue, where nearly 50% of the borough's residents reside. The Seward Peninsula, with a population of roughly 9000, is the closest part of the North American continent to Russia. This area consists of unincorporated towns and villages. The largest is Nome, which is home to nearly 50% of the population. Finally, to the south of Norton Sound is the Yukon-Kuskokwim Delta, an area of roughly 25,000 residents, with 85% being Alaska Native. About 25% of the delta population lives in the city of Bethel, an unincorporated borough located outside the BCB region. This city serves as an industrial hub to the approximately 50 small native villages of the Yukon-Kuskokwim Delta. Recent trends of population in the BCB communities of Alaska are provided in Chapter 4.

In Canada, the BCB region largely corresponds to the Inuvialuit Settlement Region of the Northwest Territories and the Kitikmeot area of Nunavut, with a total population of about 13,000 in 2011 (Stern et al., 2015). The Inuvialuit Settlement Region has a total population of around 6200 people, of which more than 50% are Indigenous. The region's boundaries encompass the Yukon North Slope, the Mackenzie River Delta, the Beaufort Sea, and six communities in the Northwest Territories. These communities are Aklavik, Inuvik, Tuktoyaktuk, and Paulatuk on the mainland; Sachs Harbour (Ikaahuk) on Banks Island; and Ulukhaktok (formerly Holman) on Victoria Island (Stern et al., 2015). The largest town is Inuvik, in the Northwest Territories, with a population of about 3400 people. The next largest town, Tuktoyaktuk, is an important harbor and base for oil and gas operations and has a population of about 850 people. The Kitikmeot region of western Nunavut includes the communities of Kugluktuk, Cambridge Bay, Gjoa Haven, Taloyoak, and Kugaaruk, with a combined population of 6600 people, together with the mainly seasonal villages of Bathurst Inlet and Umingmaktok (Stern et al., 2015).

### 3.2.3 Physical environment

Arctic landscapes are dynamic and responsive to climate change (Hinzman et al., 2005). In the BCB region, climate factors are strongly variable through time, they vary with latitude, and they are nonlinear and cumulative in effect (e.g., Vörösmarty et al., 2001; Prowse et al., 2006). Climate effects on ecological processes and human interests are especially important because of the high values placed on the living resources that support traditional economies (Fischlin et al., 2007; Larsen and Fondahl, 2014; CAFF, 2015a). The effects will be direct (climate-related) or indirect (climate-mediated; e.g., Stern et al., 2012, describe climate effects on mercury cycling), acting on key landscape processes and ecological states at physical and biodiversity scales most responsive to climate forcing (e.g., Carmack and Wassmann, 2006; Fischlin et al., 2007; Wrona and Reist, 2014; Moore and Stabeno, 2015).

#### 3.2.3.1 Climate

Regional weather and climate conditions vary widely in time and space as a result of the complex interactions between solar radiation, ocean circulation and sea ice, teleconnections between Arctic and subarctic atmospheric pressure systems, topography, and land cover. The region's high latitude (between 60°N and 75°N) assures a climate characterized by extremes in light and heat, resulting in sub-freezing mean annual temperatures, wide ranges in seasonal average temperatures, variable sea ice conditions, and moderately low rainfall and snowfall. The tundra biome predominates (Callaghan et al., 2005) across the region's large longitudinal and latitudinal extent and climate divisions (e.g., Bieniek et al., 2012; Candlish et al., 2015; Roshydromet, 2015). Winters are long and cold, especially north of the Arctic Circle, where, for at least one day in the year, there is almost no sunlight. Winter precipitation typically consists of dry snow, with seasonal snowfall equivalents being less than rainfall amounts in summer. Snow cover is typically present for more than eight months of the year, beginning in early October, reaching a maximum depth by late March to early April, and disappearing in late May to early June. Annual precipitation totals tend to be less than 350 mm but can be higher in upland areas. In contrast, summers are comparatively mild, with maximum air temperatures over much of the region between 15 and 18°C; higher temperatures have been observed (e.g., 30°C at Nome, Alaska, in June 2013). The summer growing season (i.e., period of plant growth) is typically less than 100 days in the BCB region (Table 3.1).

The timing and duration of summer and winter varies according to latitudinal differences in solar radiation and other factors, including temperature, precipitation, topography, vegetation, variability in snow and sea ice cover, and distance from the coast. At lower latitudes, the summer period (May to October) is longer than at latitudes farther north (July to September). The converse is true for the duration of winter periods. Sea ice is present for much of the year, and temperatures average about -27°C during winter periods but occasionally drop to -48°C or less. Although the sun is above the horizon 24 hours a day during summer, low-level clouds and fog are common once the sea ice begins to melt. Ocean circulation and the transport of heat and freshwater moderate coastal temperatures, creating cooler and cloudier conditions, often with localized and persistent fog, with higher precipitation than in interior areas removed from the coast.

The climate of Chukotka is determined by the subregion's location in an area influenced by the Arctic and Pacific oceans. Key atmospheric circulation features include Arctic anticyclones (high-pressure systems) and midlatitude cyclones (storms) during winter and cyclones that form along the polar front during summer (Dudarev et al., 2013; Serreze and Barry, 2014). Cold northerly and wet southerly winds are outstanding characteristics of the region's highly variable weather and climate. The intensity of storms and high-speed winds can be great, and wind systems near the headlands at Cape Navarin in the northwestern Bering Sea contribute to this area's being the windiest location in the Northeast Pacific Ocean (Moore and Pickart, 2012). Coastal areas are typically windy and cloudy, with light precipitation; they range widely with respect to average winter and summer temperatures. During winter, cold continental air from mainland Yakutia moves across much of Chukotka and lessens the warming influence of the Pacific Ocean on coastal areas. Cyclonic activity is especially strong in winter, in response to atmospheric temperature differences between the Bering Sea and the Chukchi Peninsula.

Table 3.1 Climate conditions in the three BCB subregions. Sources listed below table.

| Climate metric | Chukotka (Russia) | Alaska (United States) | Canada |
|---|---|---|---|
| Winter | October–May | October–May | September–June |
| Summer | June–September | June–September | July–August |
| Mean annual temperatures | -4 to -14°C | -2 to -12°C | -4°C |
| Mean winter (January) air temperatures | -15 to -42°C | -15 to -35°C | -40 to 0°C |
| Mean summer (July) air temperatures | 4 to 14°C | 5–8°C | 7 to 18°C |
| Winter minimum air temperature | -61°C | -48°C | -50°C |
| Summer maximum air temperature | 42°C | 30°C | 30°C |
| Mean annual precipitation totals | 300–500 mm | 100–600 mm | 200–500 mm |
| Precipitation as rainfall | ~100–230 mm | 250–300 mm | 150–400 mm |
| Precipitation as snowfall | 700–900 mm | 737–2000 mm | <57 mm |
| Length of growing season | ~100 days | 1–110 days | 62–125 days |

Data sources: BCB region (Callaghan et al., 2005; AMAP, 2012); Russian Far East, annual climate conditions (IGCE, 2005 to 2015) and climate and weather (http://чукотка.рф/en/region/info/climate/ and nsidc.org/cryosphere/arctic-meteorology/factors_affecting_climate_weather.html, accessed 15 January, 2016); Alaska (Stafford et al., 2000; Kautz and Taber, 2004; Huryn and Hobbie, 2012; Alaska Climate Research Center, 2015; USFS, 2015); and Canada, climate and weather (Pomeroy and Gray, 1995; Liston and Sturm, 1998; Barber et al., 2008; Candlish et al., 2015; Historica Canada, 2015; Stern et al., 2015).

On Alaska's North Slope, the average annual temperature is about -12°C (Huryn and Hobbie, 2012). July is the warmest month, and February is the coldest. Seasonal differences in coastal and interior areas relate to distance from the Arctic Ocean and heat transfers from its waters (Huryn and Hobbie, 2012). Compared to interior areas, coastal areas are warmer in winter and cooler in summer. The freeze-free period is short throughout but especially abbreviated along the coast (~10 days at Utqiagvik) and slightly longer (~30 days) at interior locations (Huryn and Hobbie, 2012). Precipitation on Alaska's North Slope is highly influenced by seasonal patterns in sea ice formation in the Bering, Chukchi, and Beaufort seas. As the continuous ice cover of winter develops, atmospheric moisture is reduced, resulting in low precipitation between November and April (Huryn and Hobbie, 2012). Precipitation is highest in July and August, during ice-free periods in the nearshore zone. The heaviest snowfalls occur in October, and the lightest occur in April. The average annual precipitation is about 100 mm (rainfall) and 76 cm (snowfall).

In western Alaska between the Yukon-Kuskokwim Delta and the Seward Peninsula, the climate is more moderate, being transitional between the continental and coastal zones. This region is influenced by cold interior air, fluctuations in seasonal sea ice coverage, and low-pressure systems in the Bering Sea – conditions that result in severe winds and low temperatures in winter and cool temperatures in summer. The coldest month is January, and the warmest month is July. Summer temperatures are typically ≤10°C. The growing season begins in early June and extends through mid-September. The area receives greater amounts of precipitation than the North Slope, averaging 600 mm/y (Stafford et al., 2000). Average annual precipitation on the Yukon-Kuskokwim Delta is 180–300 mm (rainfall) and ~110 cm (snowfall). The Seward Peninsula, in comparison, averages 460 mm (rainfall) and 100–200 cm (snowfall) (USFS, 2015).

Much of western Arctic Canada is snow- and ice-covered for half the year, with some limited moderation by the relatively warm waters in coastal areas (Stern and Gaden, 2015). Air temperatures generally remain below freezing between October and May. Seasonal transitions are extremely short, with mean daily temperatures rising or falling as much as 0.5°C/day. Winters are long and extremely cold; January is the coldest month of the year. Strong winds are common during winter. Dry, cold air is prevalent throughout most of the region during winter, and snowfall is often light. Snow on the ground usually persists after October, to achieve maximum depth in April (e.g., 54.2 cm average annual maximum snow depth in Inuvik, Northwest Territories; Candlish et al., 2015) and remaining until the spring thaw in mid-May. During the short summers, much of the region is snow free, and July temperatures have historically ranged from about -10 to +10°C. More recently, some areas have reported temperatures regularly exceeding 30°C. Annual precipitation totals in the Canadian Arctic Archipelago increase dramatically from north to south. Most of the precipitation occurs in summer as rainfall, with minimum amounts in the north.

### 3.2.3.2 Marine environment

The BCB marine environment encompasses the Pacific Arctic region, extending from the northern Bering Sea across the Chukchi Sea to the East Siberian and Beaufort seas and, to the north, bordering with the Arctic Basin (Grebmeier and Maslowski, 2014; Moore and Stabeno, 2015). Pacific influences distinguish the BCB marine region from other Arctic seascapes. The BCB marine environment is characterized by seasonal coverage of sea ice; polynyas and open water leads; water masses of Pacific, Atlantic, and Arctic ocean origins; extensive shallow shelves in the Chukchi and East Siberian seas; large peninsulas (e.g., the Seward and Chukchi peninsulas and Victoria Island); numerous coastal deltas and lagoons; and several large islands (e.g., Wrangel and Herschel islands). In the east, the inter-island waters of the Canadian Arctic Archipelago are largely situated outside the Pacific Arctic region, and they differ significantly in configuration and oceanography from the waters of other BCB coastal areas. The bathymetric gradient between the shelf and deep basin of the Arctic Ocean is sharp and regionally significant with respect to the roles of fronts and eddies, regional transport processes, and marine ecosystem dynamics. The Beaufort Gyre and Mackenzie River discharge plume are prominent oceanographic features; however, the narrow (90 km) Bering Strait that connects the northern Bering and Chukchi seas may be the singularly unique feature with respect to Pacific gateway effects on BCB marine conditions. Coastal lagoons along the Alaskan shoreline, in the Mackenzie Delta, and along the Northwest Territories and Kitikmeot coastlines are recognized for their special habitat value for migratory wildlife.

#### 3.2.3.3 Physical oceanography

Interactions between currents, winds, ice, stratification, upwelling, frontal dynamics, plume spreading, coastal constraints, and bathymetry define the physical structure of the BCB maritime domain (e.g., Moore and Stabeno, 2015; Wood et al., 2015a,b). BCB shelf area (Figure 3.2) is most extensive in the East Siberian Sea (16% of total Arctic Ocean shelf area) followed by the Chukchi Sea (10%), Beaufort Sea (3%), and Canadian Arctic Archipelago (~2%) (Carmack and Wassmann, 2006). The total volume of seawater over all Arctic shelves is 829,000 km$^3$, of which 7% is associated with the East Siberian Sea, 6% with the Chukchi Sea, ~4% to 5% with the Canadian Arctic Archipelago, and 3% with the Beaufort Sea (Carmack and Wassmann, 2006).

The geographic relationships between advection, sea ice, and stratification were described by Carmack and Wassmann (2006) to classify the BCB shelf types as inflow shelves (northern Bering and Chukchi seas), interior shelves (East Siberian and Beaufort seas), and outflow shelves (Canadian Arctic Archipelago). Inflow shelves are typically a source of distinctive waters for the deeper Arctic Basin. Seasonally, the circulation shows marked differences between inflow and interior shelves. For example, the strongest northward current speeds are typically observed in the Chukchi Sea in winter, while upwelling events are a signature phenomenon of the Beaufort Sea during open water periods (Wiese et al., 2013; Moore and Stabeno, 2015). The extent of sea ice cover over both shelf types, inflow and interior, has the capacity to alter local circulation patterns by diminishing the direct effects of wind forcing. Circulation on both inflow and interior shelves is linked to pan-Arctic teleconnection mechanisms (e.g., the Arctic Oscillation), as well as regional atmospheric circulation, which is driven mainly by the Beaufort High and Aleutian Low. Interior shelves are also strongly influenced by the seasonal outflow of relatively warm freshwater from Arctic rivers (Carmack et al., 2015).

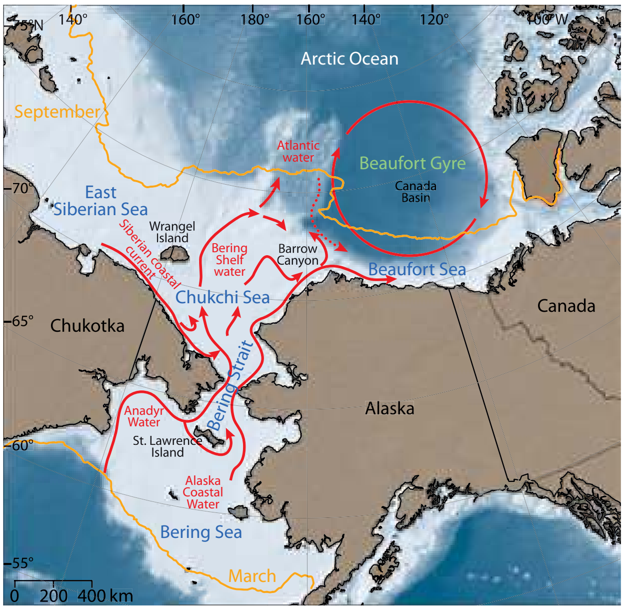


Figure 3.2 Ocean circulation in the BCB region. The major currents and water masses of the region are depicted, as are the approximate southern ice-edge locations of March and September (orange lines) (adapted from Wiese et al., 2013; Moore and Stabeno, 2015).

Sea surface temperatures (SSTs) in the BCB region vary between freezing in winter to more than 10°C in summer, in response to ocean mixing, solar radiation, and the influence of sea ice cover. In winter, SSTs over most of the northern Bering shelf are near freezing due to the presence of sea ice. In contrast, SSTs over slope and basin areas are higher (~1–4°C) due to the warming influence of the northeast Pacific Ocean. In spring and summer, as sea ice retreats to the north, SSTs increase due to solar heating. Ocean moorings in the Bering Strait have revealed that temperatures begin to increase in May and reach maximum values in September (5–9°C). Autumn temperatures rapidly decrease to freezing temperatures by late December (Woodgate et al., 2012). Summer temperatures and salinities throughout the BCB region are warmer and fresher near the coast due to freshwater inputs from river runoff and melting sea ice (Carmack et al., 2015).

#### Circulation

The northern Bering, Chukchi, and East Siberian seas are characterized by broad, shallow continental shelves; the Beaufort Sea has a narrow shelf and a steep slope that descends to the deep Canada Basin. Sea ice covers the BCB region for 5–7 months of the year, typically reaching maximum and minimum areal extents in March and September, respectively (Moore and Stabeno, 2015). The narrow (90 km) and shallow (<55 m) Bering Strait is the sole gateway for Pacific water to enter the Arctic (Figure 3.2; the annual mean volume transported is about 0.8 Sv, where $1\ \mathrm{Sv} = 1 \times 10^6\ \mathrm{m^3/sec}$; Woodgate et al., 2013). Bering Strait inflow peaks in summer, providing a strong pulse of heat, nutrients, plankton, and relatively low-salinity water to the Chukchi–Beaufort marine environment (Moore and Stabeno, 2015; Woodgate et al., 2015).

The Chukchi Sea has a wide and shallow shelf (average depth 80 m) and remains ice-covered throughout the winter. This sea is well mixed from autumn through spring and is stratified in summer due to the input of relatively warm, low-salinity Alaska Coastal Water (2–13°C, to 32.2 psu). Ice retreat in the Chukchi Sea begins in May or early June, with melting driven by solar radiation and the advective influx of relatively warm waters from the Bering Sea. The system is fed by currents flowing northward through the Bering Strait, driven by sea level differences between the Atlantic and Pacific oceans (Weingartner, 1997).

The East Siberian Sea has the widest shelf of all the Arctic Ocean seas (~800 km). This sea is a shallow (average depth 52 m) and, after the Chukchi Sea, has the smallest volume of the Arctic seas (Jakobsson, 2002). The East Siberian Sea is a transit area for seawater of Pacific origin entering from the east, water of Atlantic origin entering from the west, and freshwaters entering from Siberian rivers (Carmack and Wassmann, 2006; Anderson et al., 2011). Water column temperatures are uniformly close to freezing during winter, then rise several degrees higher in ice-free areas during summer.

The Beaufort Sea has a shallow (<100 m) narrow (50–100 km) shelf with a steep continental slope and an extensive barrier island–lagoon system. There are extensive spits and barrier islands with lagoons on the Yukon coast and the coast east of the Mackenzie Delta. In the latter area, many of the back-barrier water bodies are breached thaw lakes, with gaps in the coastal barriers allowing for water exchange and estuarine circulation. The Beaufort Sea remains ice-covered throughout winter; it is well mixed from autumn through spring and becomes stratified in summer due to warm freshwater inputs from the Colville River (~4°C), Mackenzie River (up to 15°C), and the Chukchi shelf (Pacific waters up to 6°C); marine intrusions from the Beaufort Gyre; and wind- and gyre-induced upwelling of deep Atlantic Water. Important features of winter ice in the southeastern Beaufort Sea are the extensive landfast ice, the flaw lead that develops along the west coast of Banks Island, and the polynya in the mouth of Amundsen Gulf. Ice retreat occurs between June and August and is driven by solar radiation, heat advection from the Chukchi Sea (Barrow Canyon) and Mackenzie River discharge, and winds.

The accumulation and melting of sea ice in the clockwise circulation of the Beaufort Gyre (Figure 3.2) has an enormous impact on local and global climates (Krishfield et al., 2014). The Beaufort Gyre is a major reservoir of freshwater in the Beaufort Sea. (By oceanographic convention, 'freshwater' refers to the excess of freshwater relative to a benchmark salinity of 35 psu.) The accumulation of freshwater in the gyre has important regional implications for biological production because its presence inhibits nutrient flux into surface waters, reduces primary production, and suppresses biogenic fluxes (Li et al., 2009; Nishino et al., 2011; Watanabe et al., 2014).

Freshwater discharge from the Mackenzie River exerts a strong geophysical influence over the Beaufort Sea shelf (Figure 3.3) (Wood et al., 2013; Tremblay et al., 2014). In summer and autumn, the river plume can easily extend across most of the Alaskan Beaufort shelf; its winter extent and physical interactions are unknown. Spring ice retreat in the Beaufort Sea is triggered when the river delivers fresh but turbid waters to the coast above and below the landfast ice, thus lowering the surface albedo (Dean et al., 1994).

Figure 3.3 Mackenzie River discharge plume, 15 June 1998. Image provided by the SeaWiFS Project, NASA Goddard Space Flight Center, and ORBIMAGE.

### Thermohaline structure

The seasonal timing and magnitude of regional stratification are highly variable in the Beaufort and Chukchi seas in response to varying atmospheric conditions (e.g., heating and cooling), wind stress, and ice formation and melting (Chu et al., 1999). This variability in thermohaline structure has profound climatic and ecological influence on the BCB marine environment (Chu et al., 1999; Peralta-Ferriz and Woodgate, 2015). In winter (November–April), the stratification of shelf waters is weakened as the surface mixed layer deepens and eventually extends from the sea surface to the seabed (water depth 150 m; Chu et al., 1999), in response to strong atmospheric cooling and brine rejection associated with sea ice formation (Figure 3.4). In spring and early summer, sea ice melts, rainfall increases, rivers discharge, and solar radiation warms the surface ocean waters; as seawater temperatures increase and salinities decrease, stratification strengthens throughout the region. The strong spring stratification creates a density barrier to the mixing of nutrients from deep waters into surface layers and euphotic zones. In the Chukchi and Beaufort seas, halocline influences on nutrient transport and primary production are more important than temperature effects; this contrasts with the Bering Sea, where the thermal and salinity components of stratification are of similar importance (Peralta-

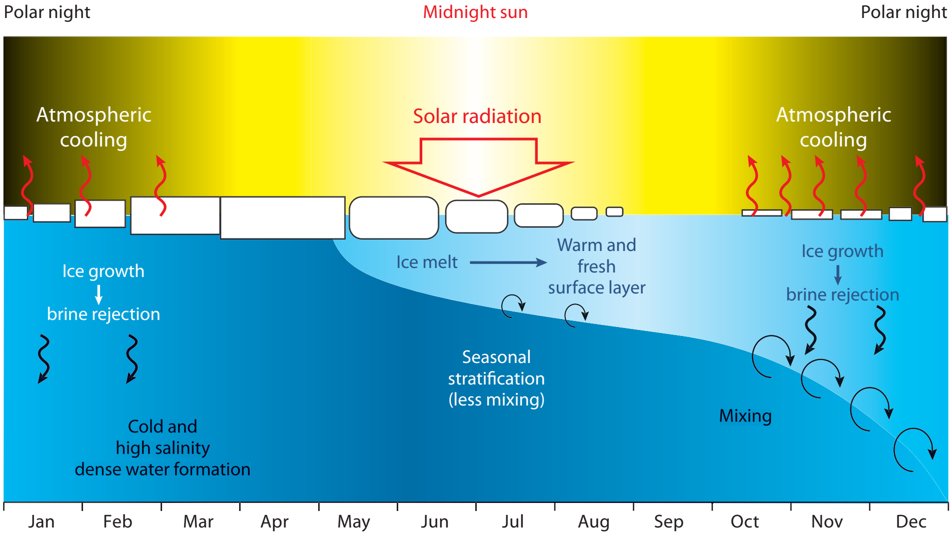


Figure 3.4 Seasonal evolution of stratification and dynamics of the mixed surface layer in the BCB region (Peralta-Ferriz and Woodgate, 2015).

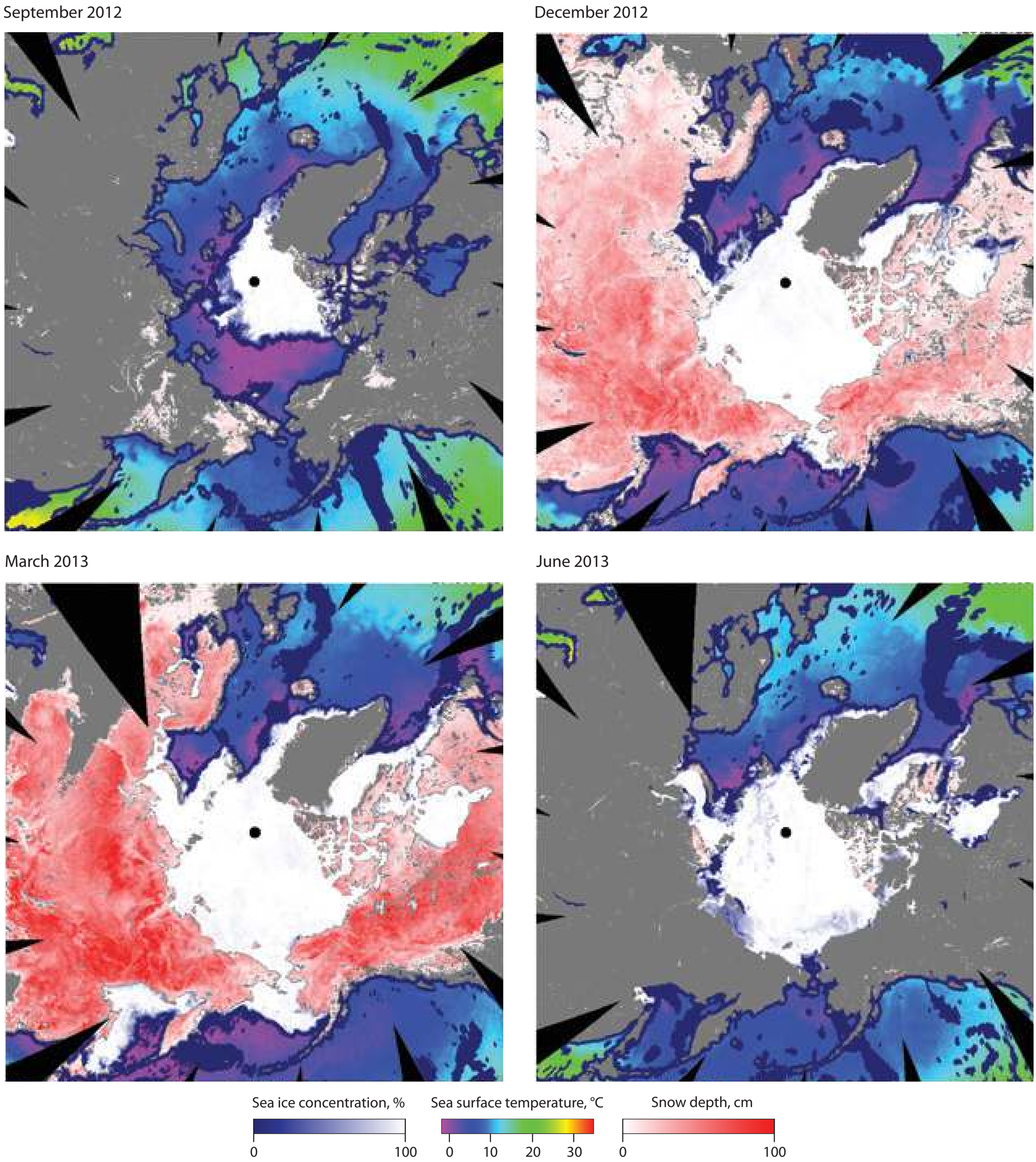


Figure 3.5 Distribution of sea ice concentration, sea surface temperature, and snow depth from September 2012 to June 2013 (images provided by Arctic Data Archive System, https://ads.nipr.ac.jp/vishop/#/monitor).

Ferriz and Woodgate, 2015). Regional variability in stratification relates to annual and seasonal differences in ice–atmosphere–ocean dynamics and hydrologic conditions (e.g., Krishfield et al., 2014; Peralta-Ferriz and Woodgate, 2015).

## Sea ice

In general, minimum sea ice extent in the Arctic Ocean occurs in mid-September. The BCB region is recognized as a 'seasonal sea ice area.' The Chukchi Sea is typically covered by sea ice from November to May, and ice retreat during spring is driven by increased solar radiation and advective influx of relatively warm water from the Bering Sea.

Seasonal changes in sea conditions (i.e., ice concentration, sea surface temperature, and snow depth on sea ice), as sensed by the AMSR-2 satellite, are shown in Figure 3.5. The images show the region to be mostly ice free in September. Sea ice forms during winter and advances southward, usually covering the Chukchi Sea by December and reaching a maximum extent over the Bering Sea by late March. In spring, sea ice cover begins to decrease, and the Bering and Chukchi seas become ice free in late May–early June and late July–early August, respectively.

Atmospheric patterns influence ocean circulation, freshwater pathways, and the movement and melting of sea ice (Moore and Stabeno, 2015). The eastern Beaufort Sea appears to be particularly susceptible to anomalous winds and their effects on the advection of warm freshwater from the Mackenzie River plume. Observed anomalies of ocean water transport in the Bering Strait have been linked to the Beaufort High and Aleutian Low atmospheric pressure systems (Danielson et al., 2014).

#### Polynyas and shoreline leads

Polynyas – persistent and recurrent areas of open water or thin ice within sea ice zones – are of oceanographic significance in the BCB region. These features differ from persistent shoreline leads, which are fractures of sea ice area formed by dynamically divergent motion of sea ice. Polynyas are responsible for the formation of sea ice and cold saline water during ice-covered periods, and they contribute to stratification and the supply of nutrients, minerals, and other chemical constituents through the interactions of cold, saline waters and sediments and shelf seafloors that are critical to ecosystem functioning (e.g., Codispoti et al., 2005; Hioki et al., 2014). There are several active and large polynyas in the Bering and Chukchi seas. In the northern Bering Sea, these distinctive features are located to the south of St. Lawrence Island, in Norton Sound, and in the Gulf of Anadyr. In the Chukchi Sea, polynyas are located in Kotzebue Sound, along the northwest Alaska coast between Wainwright and Utqiagvik, along the Chukotka Peninsula, off Kolyuchin Bay, and adjacent to Wrangel Island. They are also found in Chaun Bay in the East Siberian Sea and off Cape Bathurst at the mouth of Amundsen Gulf in the Beaufort Sea. The Anadyr Gulf polynya, one of the most active polynya areas in the Arctic, is the source of Anadyr Water, whose transport contributes to the high primary production and benthic (near-bottom) production in the region (e.g., Stirling, 1997; Grebmeier et al., 2015).

Open water areas between pack ice and landfast ice and between pack ice and the shore are often important wildlife habitats and sites of subsistence hunting. These areas may be connected to polynyas. The shear zone along the outer edge of the landfast ice or 'floe edge' is especially important in some areas – in western Arctic Canada in Mackenzie Bay, along the Tuktoyaktuk Peninsula, in Franklin and Darnley Bays, along the west coast of Victoria Island, and around Banks Island (Barber et al., 2010). The flaw leads that develop across the mouth of Amundsen Gulf and up the west coast of Banks Island are of similar ecological significance (Barber et al., 2010).

#### Lagoon processes

Lagoons may be formed by rising sea level and coastal overflows, especially during storm events. The barrier beaches that separate the lagoons from the sea are low and frequently overtopped. More common is the breaching of freshwater lakes by coastal erosion, resulting in the conversion of freshwater lakes to estuaries or lagoons (Forbes et al., 2014). In some cases of breached deep (kettle or thermokarst) lake basins with shallow sills, stable lake stratification can develop, with anoxic brines forming at depth and salt precipitating on the lake bed (Grasby et al., 2013). The lagoons may be quite open to marine exchange, or may have a single entrance with more limited, or pulsed, tidal exchange.

### 3.2.3.4 Terrestrial and freshwater environments

The terrestrial environment of the BCB region encompasses 900,640 km$^2$ of the Arctic tundra biome. Tundra landscapes include areas of coastal plain (23.5% of the total area), foothills (47.8%), and mountains (26.6%) (CAVM Team, 2003; Walker et al., 2005), where life has evolved in response to low temperatures, little precipitation, nutrient limitations, short growing and reproductive seasons, and the widespread distribution of permafrost conditions (Figure 3.6). The permafrost can be deep (>200 m) and either continuous

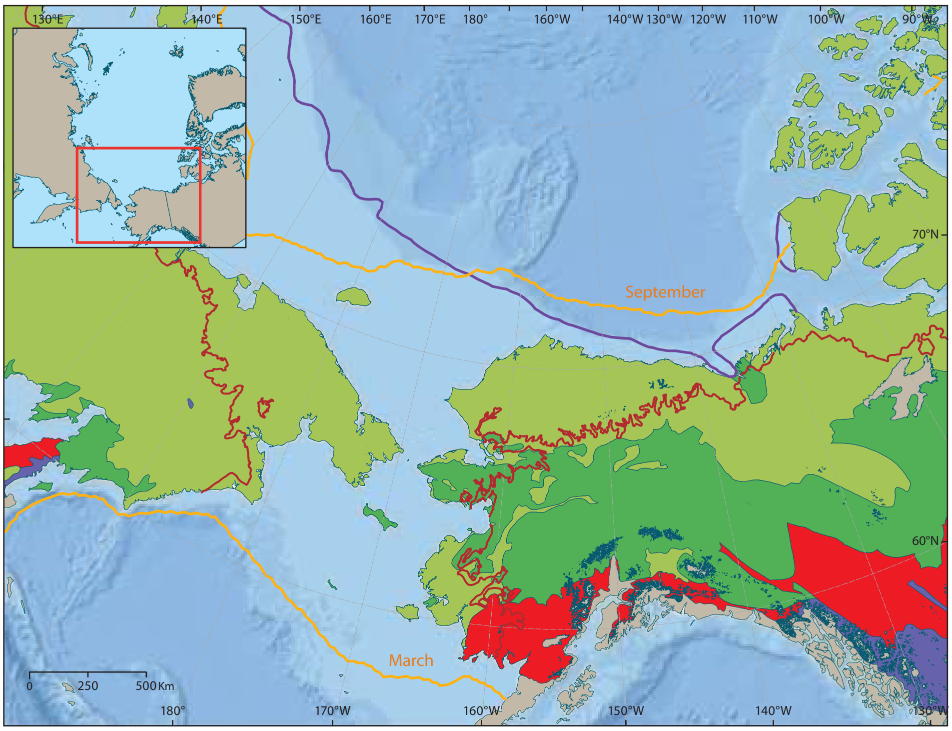


Figure 3.6 Spatial distribution of permafrost in the BCB region, adjacent lands, and subsea areas (Brown et al., 2001). Permafrost is defined as the ground that remains at or below 1°C for more than two years. It is differentiated by its spatial extent into continuous (90–100% areal coverage), discontinuous (50–90%), sporadic (10–50%), and isolated (0–10%) permafrost.

(-2°C to -5°C) or discontinuous (-1°C to -2°C) in geographic distribution (Maybeck et al., 2001; Romanovsky et al., 2010; Grosse et al., 2013). A large proportion of the continuous permafrost zone comprises lowlands that contain ground ice-rich deposits consisting of massive ice bodies (e.g., large ice wedges, pingo ice cores, massive segregated ice lenses) and pore ice in small ice lenses and ice bands. Polar desert tundra is found on Wrangel and Herald islands and in a narrow corridor along Chukotka's north coast. The discontinuous pattern of permafrost distribution is most prominent in the north-central part of interior Alaska, south of the Brooks Range and west to the Seward Peninsula. Farther to the south, the Yukon-Kuskokwim Delta is underlain by continuous permafrost and tundra vegetation of the floristic province characteristic of the Beaufort coast (CAVM Team, 2003). Permafrost extends to depths >700 m in some areas (Dallimore et al., 1988). The distribution of subsea permafrost is extensive on BCB shelves from north of the Bering Strait, beneath the East Siberian and Chukchi Seas, and across the Beaufort Sea to the east coast of Banks Island (NSIDC, 2016). Shelf features associated with subsea permafrost involve fluid escape, including pockmarks and mud volcanoes (Blasco et al., 2013).

Pools of standing water, extensive wetlands, ponds, lakes, rivers, and streams are common features of the tundra landscape (e.g., Huryn and Hobbie, 2012). A major feature of the lowland landscapes, especially near the coast, is their large number of lakes and ponds, which in some regions, such as the Mackenzie and Yukon river deltas, can cover up to 90% of the total surface area (Rautio et al., 2011; Grosse et al., 2013). Emmerton et al. (2007) documented over 49,000 lakes in the Mackenzie Delta, covering 25% of the delta area; lakes, channels, and wetlands combined represent 51% of the 13,135 km$^2$ delta plain, which has an even higher proportion under water (typically 85%) during break-up flooding in spring. The lake-area proportion of thermokarst-affected lowlands in northeastern Chukotka, the Alaska North Slope, the Yukon-Kuskokwim Delta, and the Mackenzie Delta exceeds 40% (Grosse et al., 2013).

Summer temperatures in rivers and streams in the BCB region are variable but typically range between 12 and 15°C, with highest temperatures in August. Peaks in temperature greater than 20–22°C are becoming more common in summer in the Yukon, Mackenzie, and other large rivers. High-gradient mountain streams, many of which are spring-fed, characterize the coldest watersheds, with temperatures rarely exceeding 11°C. Lower-gradient watersheds draining the coastal plain and tundra are characterized by slower-moving, meandering streams that are warmer than mountain streams. Coastal plain streams are of intermediate length (100–300 km), and tundra streams are smaller (<100 km), serving as tributaries to other stream types. River and stream flows are highest between late May and November, with maximum flows associated with snowmelt and ice break-up in late May and early June (Figure 3.7), coinciding with the formation of the coastal band (a narrow band of relatively warm and brackish water that hugs the shoreline in summer; Craig, 1984). Winter temperatures in rivers and streams are 0–1°C. The minimum-flow period occurs in winter, between January and April. In winter, the coastal band is absent, and nearshore lagoons freeze to depths of about 2 m. Mountain streams, such as those found in the eastern Brooks Range of Alaska, have perennial springs that do not freeze in winter. Extensive icings (naleds or aufeis) formed by the freezing of winter baseflow discharge when it emerges at the surface can cover large areas of the lower reaches of some rivers flowing to the Beaufort Sea and can persist well into the summer (Church et al., 2012).

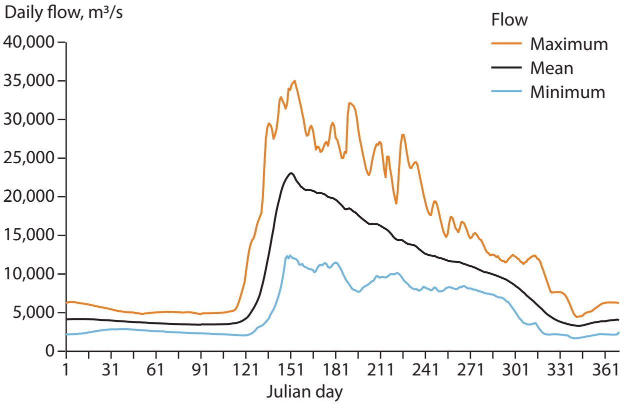


Figure 3.7 Hydrograph for the Mackenzie River at Arctic Red River (Yang et al., 2015).

The proximity of the BCB region to several of the Arctic's largest rivers (catchment areas ≥0.5 million km$^2$, Table 3.2) is important with respect to regional ecosystem dynamics and changes in the hydrologic cycle, as their inflows affect the Arctic Ocean's freshwater budget and regional and global climate (Carmack, 1998; Hinzman et al., 2005; Walsh et al., 2005, 2014; CliC/AMAP/IASC, 2016). It is notable that the Mackenzie, Kolyma, and Yukon rivers collectively represent three of the six largest Arctic watersheds, each has Asian or North American headwaters, and each flows through multiple climatic zones (Walsh et al., 2005). Other relatively large rivers in the BCB region include the Indigirka and Anadyr rivers in Russia. With the exception of the Anadyr River, these drainages are major contributors to the annual freshwater budget of the Arctic Ocean (Walsh et al., 2005) and the maintenance of the pan-Arctic Riverine Coastal Domain (Carmack et al., 2015). When river discharge through the Bering

Table 3.2 Mean annual river discharge of freshwater into the BCB region (Shiklomanov et al., 2000; Bailey, 2005; Walsh et al., 2005; van Dongen et al., 2008; Anderson et al., 2011).

| River | Mouth location | Length, km | Catchment area, km$^2$ | Average discharge, m$^3$/s | Total annual discharge, km$^3$ |
|---|---|---|---|---|---|
| Kolyma | East Siberian Sea | 2600 | 644,000 | 3800 | 103–132 |
| Indigirka | East Siberian Sea | 1726 | 360,400 | 1810 | 57 |
| Anadyr | Western Bering Sea | 1150 | 191,800 | 1000 | 64 |
| Yukon | Eastern Bering Sea | 3185 | 832,700 | 6430 | 283 |
| Mackenzie | Beaufort Sea | 4224 | 1758,602 | 7500 | 325 |

Strait is included (~301 km$^3$/y), the total freshwater contribution from BCB drainage basins is ~786 km$^3$/y or about 17% of the total riverine budget for the Arctic Ocean. Due to the presence of permafrost, the freshwater contribution of groundwater to surface flows is thought to be low (~1.3%; Walsh et al., 2005).

There are hundreds of thousands of lakes and ponds throughout the BCB region, including in northwestern Canada, but with few exceeding 10 ha in size and 50–60 m in depth; most are <2 m deep (Wrona and Reist, 2014). The majority of these waterbodies occur in wetlands on the coastal fringe and are inaccessible by road. The lakes are situated in topographic depressions or dammed river channels, and many are of glacial origin. Many lakes become ice free in June, but ice may persist in some locations until mid-August. Small lakes can become relatively warm (>10°C), with highest temperatures near the treeline (>15°C) and lower temperatures farther north. The importance of ponds and wetlands occurring in deltas and lowlands is often cited with respect to their spatial extent (e.g., Mackenzie River Delta; Emmerton et al., 2007; Wrona and Reist, 2014) and increasingly with respect to their physical and biological contributions to local and larger ecosystem processes – such as biogeochemical effects (Emmerton et al., 2008), generalized food webs (Prowse et al., 2006), and wetlands carbon cycling and sequestration (Wrona and Reist, 2014).

Large lakes and lakes over 10 m deep are rare in the BCB region. The largest lakes in Chukotka are Lake Krasnoye and Lake El'gygytgyn. Located in central Chukotka, Lake El'gygytgyn is an ancient (3.6 million yrs) meteorite crater (maximum depth 175 m) located in the upper Anadyr River basin. The less remote Devil Mountain Lakes on the northern tip of the Seward Peninsula, Alaska, are the largest maar lakes on Earth, offering a unique ecological setting. These maar lakes are different from others in that they were created by explosions generated by volcanic activity and magma rising beneath thick permafrost during the Pleistocene. Farther north, on the North Slope, is Teshekpuk Lake, Alaska's largest Arctic lake. Toolik Lake, near the foothills of the coastal plain, is the main site of long-term ecological research in the BCB region.

Glaciers are important in the headwaters of some watersheds, but in the BCB region they account for only 1079 km$^2$ or 0.12% of the landscape. In Chukotka, glaciers are rare, found mostly in the higher elevations of the highlands along the northwestern coast (Sedov, 2001; Ananicheva et al., 2012). Glaciers are most common in the highest mountains nearest the Bering Sea coast. The highest elevations in Chukotka are found west of the Amguema River, in the Shelagskii (elevation 1105 m), Ekiatap (elevation 1522 m), and Pegtymel' (elevation 1810 m) ranges. East of the river, these mountains give way to uplands and ridges with elevations of 500 to 1000 m. This region, known as the Chukchi Highlands (also Chukchi Range, Anadyr Range), forms the natural divide between rivers that flow to the Arctic Ocean (Pegtymel', Palyavaam, Amguema) and those that flow to the Bering Sea (Belaia, Kanchalan). There are 64 glaciers in Chukotka, covering 17.07 km$^2$ (Sedov, 1997).


All Canada Photos / Alamy Stock Photo

*Mackenzie River Delta, Inuvik, Northwest Territories*

In North America, a handful of small glaciers are found in the mountainous belt that extends from near the Chukchi Sea, across northern Alaska, and into northern Yukon and extreme northwestern Northwest Territories. This region consists of three large interconnected areas along a continuum: the western Brooks Range, with relatively low, less rugged mountains and less permanent ice; the eastern Brooks Range/British Range, with higher, more rugged terrain and more permanent ice; and a lower area near Anaktuvuk Pass, which divides the two mountainous areas. Elevations range from 800 m to 2400 m, with peaks above 1800 m retaining the last of the once-extensive Pleistocene glaciation (Pielou, 1994; Gallant et al., 1995). There is no glaciation in the easternmost Brooks Range (e.g., Richardson, Barn, or British mountain ranges) in the Yukon and Northwest territories.

In Alaska, the Brooks Range contains approximately 600 km$^2$ of ice-covered area (Berthier et al., 2010). Glaciers are found in the Romanzof, Franklin, Endicott, Philip Smith, and Schwatka mountain ranges (Molnia, 2008). The McCall Glacier, located in the northeastern Brooks Range, has the longest history of scientific research of any US Arctic glacier (Klok et al., 2005; Weller et al., 2007). Research on this glacier began with the International Geophysical Year in 1957–1958 and continues to this day (Weller et al., 2007). The Kigluaik Mountains are a 68-km mountain chain running east to west on the western Seward Peninsula. Unlike the Brooks Range of interior Alaska, the Kigluaik Mountains are close to the coast. Their highest point is the summit of Mount Osborn (1437 m). These mountains host three small glaciers, including the Grand Union Glacier (~25 km$^2$). This glacier is climatically significant because it is the only remaining active glacier in the transitional maritime-continental climatic regime of western Alaska (Przybyl, 1988).

## 3.3 Human dimensions

Sustainable economic growth and development is a goal of the Arctic nations, including those of the BCB region. The climate, remoteness, small population size, and lack of infrastructure pose special challenges for initiating natural resource projects. These challenges are compounded by the high costs of living, lack of skilled workforces, regulation and permitting requirements, volatility in resource markets, and needs for government funding. In Chukotka, the distance from industrial centers, lack of roads and other transportation infrastructure, deficiencies in public services, and needed investments in fixed capital (Gadzhiev et al., 2015) are major financial impediments for new starts.

In Chukotka, the initiation of new projects, especially in the mining industry, requires hard-to-get financial commitments from government, private, and foreign sectors and requires both strong legal and political support. In some instances, such as in the gold mining and energy industries, preconditions for government funding include improvements to roads, airports, and coastal seaports funded by nongovernmental entities. The public–private funding relationship is common in Alaska and Canada, as well. The State of Alaska is currently arranging partnerships within the oil and gas industry to construct a trans-Alaska gas pipeline to deliver product from North Slope production sites. The Mackenzie Gas Project and mining operations in Nunavut portions of the BCB region (e.g., Doris North gold mine in the Hope Bay area) are examples from Canada.

### 3.3.1 Subsistence values

The mixed cash/subsistence economy is the predominant way of life for many local residents and especially for Indigenous people in the BCB region (e.g., Usher et al., 2003; ADFG, 2014). In many communities, it is not uncommon for subsistence lifestyles to be supported by wage employment. Wages and other remittances are used to purchase snow machines, ammunition, fuel, boats and motors, and other equipment. Active hunters may receive financial assistance from wage earners, who in turn share in the foods harvested (Pedersen et al., 2009).

Subsistence living is an essential component of food security and the social interactions and bonds involving family ties and kinship, cooperation and the sharing of food, traditional knowledge, teaching of skills, and ceremonial practices (Aslaksen et al., 2009; Larsen and Fondahl, 2014). European settlement of the BCB region introduced new socio-economic dimensions and cultural norms and brought environmental change, enculturation, and government dependencies. In Chukotka, for example, Soviet authorities forced relocations to centralized villages, required people to embrace collectivization and the industrialization of their traditional livelihoods, made school obligatory, and brought other changes to daily life (Nielsen, 2007a,b). More broadly, social expectations and cultural networks were altered and in some cases weakened (e.g., erosion of native languages) or entirely lost (e.g., the Kerek people of Chukotka). However, subsistence-based cultures have, for the most, proven to be resilient and adaptive – for example, Eskimos in Chukotka (see Poppel et al., 2007; Oparin 2013), Yup'ik and Iñupiaq in Alaska (see BLM, 2005; USEPA, 2012), and Inuit in Canada (see Harder and Wenzel, 2012; Stern and Gaden, 2015) (see also Chapters 2 and 6).


© B&C Alexander / ArcticPhoto

*Gold mine near the town of Bilibino, Chukotka*

Recent surveys of residents from Chukotka, Alaska, and Canada demonstrate the continuing importance of subsistence in the BCB region (*Chukotka*: Poppel, 2006; Kozlov, 2008; Kochnev and Zdor, 2014; *Alaska*: DeGange and Thorsteinson, 2011; *Canada*: Douglas and Chan, 2015; also see Chapter 2). Many villages annually harvest hundreds of kilograms of food per person that, and while important as a source of energy, are also believed to be healthier than store-bought foods. The locations of many communities are strategic with respect to seasonal access to traditional foods, and many communities are situated on or near the coast. Historically, the natural wildlife abundance on the coasts has been the basis of life and local economy for villagers who have relied on these resources for food, shelter, and clothing for thousands of years (Forbes, 2011). Marine mammals, including cetaceans (e.g., bowhead whale *Balaena mysticetus*, gray whale *Eschrichtius robustus*, and beluga *Delphinapterus leucas*) and pinnipeds (e.g., Pacific walrus *Odobenus rosmarus divergens*, bearded seal *Erignathus barbatus* and ringed seal *Pusa hispida*), are highly valued. These protein sources are supplemented by a wide variety of fish, shellfish, and birds and their eggs. Land mammals (notably reindeer and caribou *Rangifer tarandus*), freshwater fishes, and plants and berries are also important components of the subsistence diet in some communities in the region. In general, coastal communities typically harvest marine and terrestrial species, while inland communities rely more heavily on terrestrial species and freshwater fish (Magdanz et al., 2010). In Chukotka, reindeer herders and coastal residents actively engage in trade and barter for subsistence foods and products (Abryutina, 2007; Oparin, 2013); in Alaska, a small barter fishery is present in the Colville River Delta (Thorsteinson and Love, 2016).

A 'seasonal round' describes the cycle of subsistence, including hunting, fishing, and gathering, that a community follows each year. This annual seasonal sequence of activities varies from community to community and represents evolved local responses to weather (e.g., effects on travel) and predictable patterns of abundance and access to valued resources. Changes in the seasonal round result from expanding or diminishing fish and wildlife populations, changes in technology, geographical shifts in human settlement and land use, and regulatory changes (Georgette and Loon, 1993; LaVine et al., 2007; Carouthers, 2013). The establishment of subsistence quotas for polar bears (*Ursus maritimus*), instituted in response to international concerns about the animals' status and conservation, is an example of regulatory change in the BCB region: North Beaufort Sea subpopulation (quota of 76 animals), Southern Beaufort Sea (70), and Alaska-Chukotka (58) (Thiemann et al., 2008; Peacock et al., 2011; IUCN, 2015; Schliebe et al., 2016).

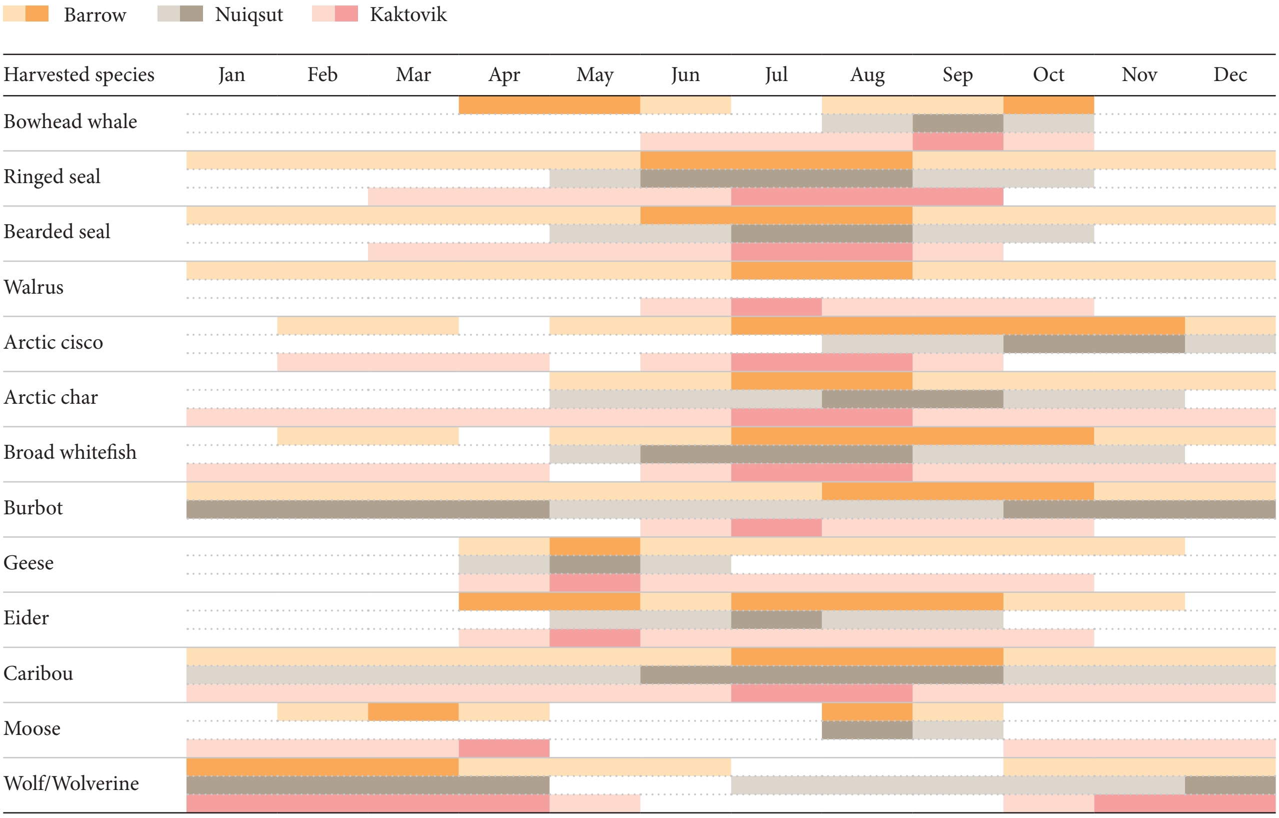
The seasonal availability of many species directs the timing and location of subsistence harvests (e.g., Braund, 2010, 2012, 2013). The distributions, migrations, and seasonal and cyclical variations of animal populations make it difficult to generalize about the precise timing and location of these activities (Renner and Huntington, 2014). While the nature and timing of the seasonal round varies from community to community, some generalizations can be drawn from the extensive documentation of subsistence activities in three adjacent North Slope communities in Alaska: Utqiagvik, Nuiqsut, and Kaktovik. While each community has somewhat different seasonal harvest patterns, certain activities are common to these three communities, and, by similarity in species harvested, also more broadly to other locations across the BCB region. Winter hunting is mostly limited to harvest of caribou and furbearers because the snow cover on the tundra facilitates travel by snow machine. Some harvests of fish, especially burbot (*Lota lota*), occur during the winter. The spring is dedicated to the harvest of bowhead whales in Utqiagvik and geese throughout many BCB communities. Fishing, caribou hunting, and seal hunting are common activities during the summer and autumn, with autumn whaling occurring in all three communities when the bowhead whales migrate out of the Beaufort Sea (Table 3.3). Although not included in the Table 3.3 community analysis, polar bears are an important resource to Indigenous peoples in Canada, Alaska, and Chukotka, and about 200 animals are harvested annually (IUCN, 2015).

The North Slope example (Table 3.3) highlights some general similarities about subsistence practices in the BCB region:

- Subsistence is a year-round activity, with highest use of harvest areas occurring May through September
- Harvest activities are concentrated near established communities and along productive rivers and coastlines
- Harvest activities can occur over wide areas, with overlap between communities
- Subsistence resources are often harvested from seasonal camps that have been used for generations
- Favorite hunting areas are not always dependent upon hunting success alone but are also based on family camp or cabin locations, personal knowledge of the areas, quality of the harvested resources, and personal or family connections to the area.

Subsistence patterns in Alaska and Canada are remarkably similar with respect to marine species dependencies (e.g., whales, seals, and fishes) and different with respect to the primary importance of caribou in northern Canada (Douglas and Chan, 2015). A comparison of BCB household surveys regarding family consumption of traditional meats and fishes suggests a slightly

Table 3.3 'Seasonal rounds' for key subsistence species harvested by residents of three adjacent Beaufort Sea communities in Alaska: Barrow, Nuiqsut, and Kaktovik. The colored cells indicate the months in which subsistence harvest areas are used as reported by hunters for each community. The dark-shaded cells indicate months of peak use; the pale-shaded cells indicate non-peak use, when the resource may still be harvested; and the empty cells indicate months when use of harvest areas was not reported. Peak use of areas for all resources (collectively) occurs in May and from July through September. Sources: Braund (2010, 2012, 2013) and Lima (2015).



□ ■ Barrow  □ ■ Nuiqsut  □ ■ Kaktovik

| Harvested species | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bowhead whale | Barrow | | | | ■ | ■ | □ | | □ | □ | ■ | | |
| | Nuiqsut | | | | | | | | □ | ■ | □ | | |
| | Kaktovik | | | | | | □ | □ | □ | ■ | □ | | |
| Ringed seal | Barrow | □ | □ | □ | □ | □ | ■ | ■ | ■ | □ | □ | □ | □ |
| | Nuiqsut | | | | | □ | ■ | ■ | ■ | □ | □ | | |
| | Kaktovik | | | □ | □ | □ | □ | ■ | ■ | ■ | | | |
| Bearded seal | Barrow | □ | □ | □ | □ | □ | ■ | ■ | ■ | □ | □ | □ | □ |
| | Nuiqsut | | | | | □ | □ | ■ | ■ | □ | □ | | |
| | Kaktovik | | | □ | □ | □ | □ | ■ | ■ | □ | | | |
| Walrus | Barrow | □ | □ | □ | □ | □ | □ | ■ | ■ | □ | □ | □ | □ |
| | Nuiqsut | | | | | | | | | | | | |
| | Kaktovik | | | | | | □ | ■ | □ | □ | □ | | |
| Arctic cisco | Barrow | | □ | □ | | □ | □ | ■ | ■ | ■ | ■ | ■ | □ |
| | Nuiqsut | | | | | | | | □ | □ | ■ | ■ | □ |
| | Kaktovik | | □ | □ | □ | | □ | ■ | ■ | □ | | | |
| Arctic char | Barrow | | | | | □ | □ | ■ | ■ | □ | □ | □ | □ |
| | Nuiqsut | | | | | □ | □ | □ | ■ | ■ | □ | □ | |
| | Kaktovik | □ | □ | □ | □ | □ | □ | ■ | ■ | □ | □ | □ | □ |
| Broad whitefish | Barrow | | □ | □ | | □ | □ | ■ | ■ | ■ | ■ | □ | □ |
| | Nuiqsut | | | | | □ | ■ | ■ | ■ | □ | □ | □ | |
| | Kaktovik | □ | □ | □ | □ | | □ | ■ | ■ | □ | □ | □ | □ |
| Burbot | Barrow | □ | □ | □ | □ | □ | □ | □ | ■ | ■ | ■ | □ | □ |
| | Nuiqsut | ■ | ■ | ■ | ■ | □ | □ | □ | □ | □ | ■ | ■ | ■ |
| | Kaktovik | | | | | | □ | ■ | □ | □ | □ | | |
| Geese | Barrow | | | | □ | ■ | □ | □ | □ | □ | □ | □ | |
| | Nuiqsut | | | | □ | ■ | □ | | | | | | |
| | Kaktovik | | | | □ | ■ | □ | □ | □ | □ | □ | | |
| Eider | Barrow | | | | ■ | ■ | □ | ■ | ■ | ■ | □ | □ | |
| | Nuiqsut | | | | | □ | □ | ■ | □ | □ | | | |
| | Kaktovik | | | | □ | ■ | □ | □ | □ | □ | □ | | |
| Caribou | Barrow | □ | □ | □ | □ | □ | □ | ■ | ■ | ■ | □ | □ | □ |
| | Nuiqsut | □ | □ | □ | □ | □ | ■ | ■ | ■ | ■ | □ | □ | □ |
| | Kaktovik | □ | □ | □ | □ | □ | □ | ■ | ■ | □ | □ | □ | □ |
| Moose | Barrow | | □ | ■ | □ | | | | ■ | □ | | | |
| | Nuiqsut | | | | | | | | ■ | □ | | | |
| | Kaktovik | □ | □ | □ | ■ | | | | | | □ | □ | □ |
| Wolf/Wolverine | Barrow | ■ | ■ | ■ | □ | □ | □ | | | | □ | □ | □ |
| | Nuiqsut | ■ | ■ | ■ | ■ | | | □ | □ | □ | □ | □ | ■ |
| | Kaktovik | ■ | ■ | ■ | ■ | □ | | | | | □ | ■ | ■ |

Table 3.4 Household consumption of meat and fish from subsistence harvests within the BCB region, rounded number of survey respondents shown in brackets after country name (Poppel et al., 2007).

| Proportion of meat and fish harvested, % | Proportion of household meat and fish consumption originating from subsistence harvests, % | | |
|---|---|---|---|
| | Canada (4700) | Chukotka (600) | Alaska (700) |
| >50 | 39 | 30 | 61 |
| ~50 | 35 | 38 | 23 |
| <50 | 24 | 30 | 15 |
| None | 1 | 2 | 1 |

higher dependence on subsistence foods by Alaskan families, which may reflect a greater access to resources (Poppel et al., 2007; Table 3.4). The coastal connection is reflected in the relative importance (highest to lowest) of marine mammals, large land animals, fish, and migratory birds in BCB harvests (e.g., DeGange and Thorsteinson, 2011; Douglas and Chan, 2015).

Reindeer are a mainstay of the subsistence lifestyle in Chukotka for Indigenous people living away from the coast. Inland herders often use reindeer meat and hides to trade/barter with coastal residents for fish and marine mammal foods and products, and thus this practice is considered a primary traditional activity (Oparin, 2013). Chukotka's reindeer herd is one of the world's largest but the population crashed in the early 2000s to about 117,000 animals, about a quarter of its peak size. The sharp decline was related to weather anomalies and ice encrustation and related limitation of the carrying capacity of pasture lands, together with increased hunting related to economic pressures arising through the collapse of the former Soviet Union (Klepikov et al., 2015). The government in Chukotka is currently fostering recovery of the reindeer industry through increased processing of reindeer products and diversification of markets.

Reindeer herding also exists in the Seward Peninsula (~12,000 animals) and is seen as a potential growth industry in western Alaska. A smaller herd of 3000 animals is located on grazing reserves in the Mackenzie Delta region (Dory, 2015).

Herding, hunting, fishing, and gathering of plants are important in the seasonal round and mixed cash/subsistence economy in Chukotka (Poppel at al., 2007). Subsistence varies between coastal residents and reindeer herders (Oparin, 2013). The Eskimo and coastal Chukchi primarily pursue marine hunting and fishing. They spend summers on the water and winters on the ice. Key subsistence species include cetaceans (bowhead whale, gray whale and beluga) and pinnipeds (walruses, sea lions, and four species of seal) (Bogoslavskaya and Krupnik, 2008, 2014). Whales are hunted seasonally, as available, and other resident species are hunted year-round (Abryutina, 2007). Among fish, Arctic char (*Salvelinus alpinus*) and pink salmon (*Oncorhynchus gorbuscha*) are dominant in local catches. Other important fish species include Arctic cod (*Boreogadus saida*), other cods, flounders, and gobies (Bogoslavskaya and Krupnik, 2014). Sea squirts and other marine invertebrates (e.g., crab, shrimp, sea urchins and starfish, small octopus, mussels, and whelks) and seaweed are important in the daily diets of the Eskimo and coastal Chukchi people (Bogoslavskaya and Krupnik, 2014). Geese and ducks, as well as large sandpipers, are also important foods (Bogoslavskaya and Krupnik, 2014).

### 3.3.2 Social and cultural well-being

Subsistence areas are delineated by the habitats of the living resources that are hunted or gathered, and there can be considerable seasonal and annual variation in wildlife abundance. In addition, cultural preferences and differences, as well as other factors (e.g., poor weather or ice conditions), may explain why harvest success can vary from year to year. The species harvested and the success of the harvest can vary greatly over short periods of time. The Inuit Circumpolar Council-Alaska (2015) identified fuel economy, sea ice variability, ground stability, temperature changes, wildlife health, and contaminants as major sources of variation in subsistence harvests. If a community is unable to harvest an important species, other components of subsistence (i.e., kinship, sharing, and barter) compensate for the lack of the resources. In this way, the cultural value of sharing and reciprocity ensures food security in communities affected by the lack of a certain resource (USEPA, 2012). As an example, Indigenous communities in Chukotka maintain close family and trade ties with neighboring and distant settlements (Bogoslavskaya and Krupnik, 2014). In times of need, marine hunters help reindeer herders and vice versa. The two have had a history of regular trade, exchanging reindeer for marine mammals and fish (Bogoslavskaya and Krupnik, 2014). Today, the size of the reindeer herd is smaller, and trade ties between coastal and non-coastal people are much weaker (Oparin, 2013).

In Inuit populations of the BCB region, sharing of food and material wealth is an intrinsic cultural value that ensures that families or individuals are provided for in times of need (Poppel, 2006; Poppel et al., 2007; AMAP, 2009; Stern and Gaden, 2015). Sharing is an important element of the social health and cultural norms of communities – directly tied to environmental health and stresses that may be associated with ecosystem conditions or societal discrepancies between Indigenous and non-Indigenous values (Bjerregaard et al., 2004). In the mixed cash/subsistence economy, these norms are major determinants of individual and community reliance on traditional foods, of broader perceptions of societal conditions that can affect drug and alcohol use, and of trust and participation in regional and local networks for healthcare and education (including traditional knowledge) – and ultimately of human health (AMAP, 2009).

Human health is potentially affected by many factors, such as income, education, social status, dependency, heredity, access to social safety networks, personal lifestyle choices, and individual coping capacities (AMAP, 2009; ANTHC, 2010; BREA, 2015). The availability and quality of primary healthcare systems at the community level is also important. Healthcare and social services are lacking in much of the BCB region, and many communities do not have sufficient water and sewage systems. There is a high dependence on government subsidies, and communities face problems related to rapid social change, including an increasing transition to Western diets (e.g., ACIA, 2005; AMAP, 2009; Brubaker et al., 2015). Knowledge about the relationships between climate, environmental conditions, and human health, while incomplete, is especially relevant to Indigenous people of the BCB region as it relates to their perceptions about environmental quality and use of traditional foods. Examples include contaminant cycling and human exposures, and pathogen reservoirs and infectious wildlife diseases and potential transmissions to subsistence users (Kunkel et al., 1999; AMAP, 2009; Bright et al., 2012).

In many parts of the BCB region, the living conditions of Indigenous people are also a cause of concern. Many settlements experience high rates of poverty and economic distress, unemployment, alcoholism, suicide, and a variety of infectious diseases, such as tuberculosis and sexually transmitted infections (Poppel et al., 2007; Kruse et al., 2008; Canadian Institute for Health Information, 2012; Dudarev et al., 2013). Kruse et al. (2008) reported that 50% of surveyed Canadian and Alaska Inuit self-rated their health as at least 'very good' compared to one in five Chukotka Indigenous people. As an example, 22% of Chukotka Indigenous people reported having three or more diagnosed health problems such as arthritis, chronic bronchitis, high blood pressure, heart problems, hepatitis, and tuberculosis (Poppel et al., 2007).

The Survey of Living Conditions in the Arctic (SLiCA) examined many facets of Inuit lifestyles, including peoples' health and well-being (Poppel et al., 2007). The SLiCA concept for well-being was inclusive, as it covered all aspects of living experienced by individuals; included a person's subjective evaluations as well as perceptions of objective conditions; covered the material satisfaction of vital needs as well as aspects of life such as personal development, a balanced ecosystem, and being in control of one's own life and destiny; and related individual and collective well-being of social groups, communities, and nations. SLiCA was designed to relate the concept of well-being to individual resources (i.e., money, goods, and services; mental and physical health; social relations and physical security; self-determination; and arenas of interaction such as wage employment, hunting and fishing, and civic participation) in order to determine what is important to well-being and what constrains people from achieving the well-being they seek.

Although data collection occurred over multiple years and nation responses were uneven with respect to all questions, a general summary of well-being was suggested by the respondents' feelings about the quality and satisfaction of their lives within the communities in which they reside (Table 3.5).

The SLiCA surveys reported similar and relatively high satisfaction with life in residents of Canada and Alaska but much higher levels of dissatisfaction in Chukotka. Poppel et al. (2007) found that an individual's attitudes about satisfaction were most shaped by job opportunities, abundance of fish and game, economic diversity, influence over natural resources and environment, and job satisfaction (in order of relative importance).

## 3.3.3 Economy

### 3.3.3.1 Mixed cash/subsistence economy

Subsistence activities are essential in the region's economy. Because the cash economy is so dependent on extractive industries for raw materials, global drivers affecting commodity markets impact local opportunities for employment and revenue streams within the BCB region (Andrew, 2014).

#### Subsistence

Conventional measures of workforce participation do not adequately reflect the complex work reality or contribution of traditional activities in BCB communities. Traditional activities include making clothing and footwear; creating arts and crafts; hunting, fishing, and trapping; and gathering wild plants. In the mixed cash/subsistence economy, these activities supplement, or substitute for, participation in the labor market. As an example, subsistence surveys in northern Canada conducted in 2012 revealed that a majority (84%) of Inuit adults had participated in traditional activities in the past year, 20% of this participation was for monetary gain, men were more likely to participate for money than women (28% versus 18%), and education was not a factor (Statistics Canada, 2013). The estimated annual value of traditional foods in Nunavut, Canada, is CAD 30 million which is equivalent to the value of imported foods (Simpson, 1999). With respect to the Inuvialuit Settlement Region, employment opportunities are limited and subsistence is a mainstay of the employment experience.

The structure of the mixed cash/subsistence economy differs by country. In Alaska, most subsistence hunting, fishing, and gathering does not enter the market economy. Arts and crafts are a notable exception. Subsistence products are consumed

Table 3.5 Satisfaction with life within the BCB region, rounded number of survey respondents shown in brackets after country name (Poppel et al., 2007).

| Indicator of well-being | Level of satisfaction | Proportion by subregion, % | | |
|---|---|---|---|---|
| | | Canada (4700) | Chukotka (600) | Alaska (700) |
| Quality of life in this community | Very satisfied | - | 1 | 31 |
| | Somewhat satisfied | - | 13 | 50 |
| | Not satisfied or neither | - | 86 | 19 |
| Life as a whole | Very satisfied | - | - | 56 |
| | Somewhat satisfied | - | - | 35 |
| | Not satisfied or neither | - | - | 10 |
| Life as a whole in this community | Very satisfied | 50 | - | 54 |
| | Somewhat satisfied | 42 | - | 39 |
| | Not satisfied or neither | 8 | - | 7 |

- no data available

by the harvesting household, given away, or exchanged. Cash is important for snow machines, fuel, and ammunition, and waged work may conflict with or enhance subsistence practices. In Chukotka, there has been a widespread return to the subsistence economy and reindeer herding is a key segment of the agricultural sector (Oparin, 2013). In some Far East districts, traditional life has changed very little. For instance, in the Chukotsky District, there has been no industrial activity and the residents have long relied on reindeer herding, fishing, and marine mammal hunting.

#### Global influences

Within the BCB region, the extractive industries (e.g., those related to oil/gas and hard rock mining) are the major sources of employment outside of public sectors and are also leading sources for gross regional product (GRP). Oil prices, which have responded to new trends in global demand and recent worldwide development of non-conventional and alternative sources of energy, are currently stifling oil/gas exploration and development activities and are negatively affecting tax revenues and publicly funded programs in the BCB region. These forces in global oil markets may heighten the relative importance of traditional components of the region's economy and may affect quality of life through lost revenue streams. Oil and gas development has played a dominant role in the economic development of many Arctic communities and, in the BCB region, this is especially true for northern Alaska. The tax base in the North Slope Borough, for example, consists mainly of high-value property owned or leased by the oil industry in Prudhoe Bay. Tax revenues from oil and gas infrastructure have provided opportunities for improving or creating schools, economic opportunities, and infrastructure (e.g., housing, transportation, waste storage, access to clean water, and affordable/reliable electricity), as well as other benefits. Similarly, revenues from the mining of precious metals and nonferrous ores play a leading role in Chukotka's socio-economic development – again highlighting the dependence of the BCB region on global drivers.

### 3.3.3.2 Employment

In Chukotka, employment rates are relatively stable, with a labor force of 33,000 people (Russian Federation Federal State Statistics Service, 2015) and an officially registered unemployment rate of 2.7% (CAO, 2016a; see Box 3.1). The real unemployment rate is likely to be much higher; for example, in Chapter 2 (Perspective H) it is stated that "unemployment in Chukotka's villages ranges from 50 to 70 percent of the working-age population".The mining industry is the single largest employer, accounting for 18.9% of the region's jobs. The second largest employer is the energy and water sector (14.7% of jobs). Other major sectors include transportation, communications, education, automotive repair, and health and social services. Construction activities have slowed since 2013. The Indigenous population's participation in the workforce is greatest in reindeer herding/hunting and commercial fishing, with these sectors representing about 5.3% of the entire workforce. Low employment rates among Indigenous populations have been partially offset by increasing part-time job opportunities in the public administration, education, and housing and utilities sectors of rural communities. In certain areas, small-scale industries, such as those producing souvenirs in association with tourism, are emerging (Oparin, 2013).

In northern Canada and Alaska, the cash economies are largely fueled by jobs in the oil/gas, mining, Native corporation, and public sectors (e.g., Arctic Slope Regional Corporation, 2015; Lockhart et al., 2015; AOGA, 2016). Under provisions of the recently completed settlements between Canada and the Indigenous governments of the territory of Nunavut and the Inuvialuit Settlement Region, funding is annually transferred to the Inuit governments to support public administration, health and social services, and other public services. Similar transfers are made to provincial governments in the Northwest and Yukon territories (Muir, 1994). In northern Canada, the governments are the major employer (Gaden et al., 2015). In Alaska, the North Slope Borough, Arctic Regional Native Corporation, other Alaska Native–owned corporations, and oil companies are the primary employers (Knapp, 2012; Goldsmith, 2012; MacDowell Group, 2014; Arctic Slope Regional Corporation, 2015; AOGA, 2016). The North Slope Borough's operating budget derives primarily from taxation of the oil and gas industry. Importantly, while the oil/gas industry has resulted in limited direct employment for local residents, tax revenues have provided substantial employment opportunities (BOEM, 2015a). Most jobs in the oil patch are filled by non-locals who possess specialized technical skills and work experience. The borough is the primary employer in North Slope villages, accounting for over a half of all jobs. Corporate dividends are a major source of disposable income for Arctic stakeholders.

### 3.3.3.3 Economic sectors

Energy, mining, shipping and transportation, and tourism are the major economic sectors in the BCB region. The conventional energy sector (oil/gas and coal) is notably significant; however, the relative importance of the industrial sectors varies across the region and is reflective of (and to some extent a driver of) settlement locations and employment patterns, especially with respect to knowledge and experience requirements in non-Indigenous populations. The status of these sectors is further dependent on the amount and location of resource exploration, development, and production activities; ownership of land and mineral resources; regulatory environments; and availability of skilled workforces. Indigenous participation and leadership is commonly, but not uniformly, limited by a lack of training and experience in operational and management functions. As a result, a large non-residential workforce represents a major source of money earned but leaving local labor markets – such as in energy and fisheries (e.g., MacDowell Group, 2014).

#### Energy

*Oil and gas.* The Arctic is recognized for its petroleum potential. According to the US Geological Survey (USGS, 2008), areas north of the Arctic Circle are estimated to have 90 billion barrels of undiscovered, technically recoverable oil and 44 billion barrels of natural gas liquids in 25 geological basins. Theoretically, this unproven resource represents 13% of the world's undiscovered oil and 30% of the undiscovered gas (Bird et al., 2008; Gautier et al., 2009a).

### Box 3.1 Chukotka economy

Large segments of Chukotka's population are concentrated in urban centers where energy, mining, and government are major employers (Figure 3.8). Anadyr, Bilibino, Egvekinot, and Pevek are examples of urban areas with larger populations and, when compared to other settlements, can be shown to support greater economic diversity (e.g., presence of military, transportation and communication, and construction). Reindeer husbandry is widespread, and subsistence hunting and fishing are aggregated in communities along the Bering and Chukchi Sea coasts.

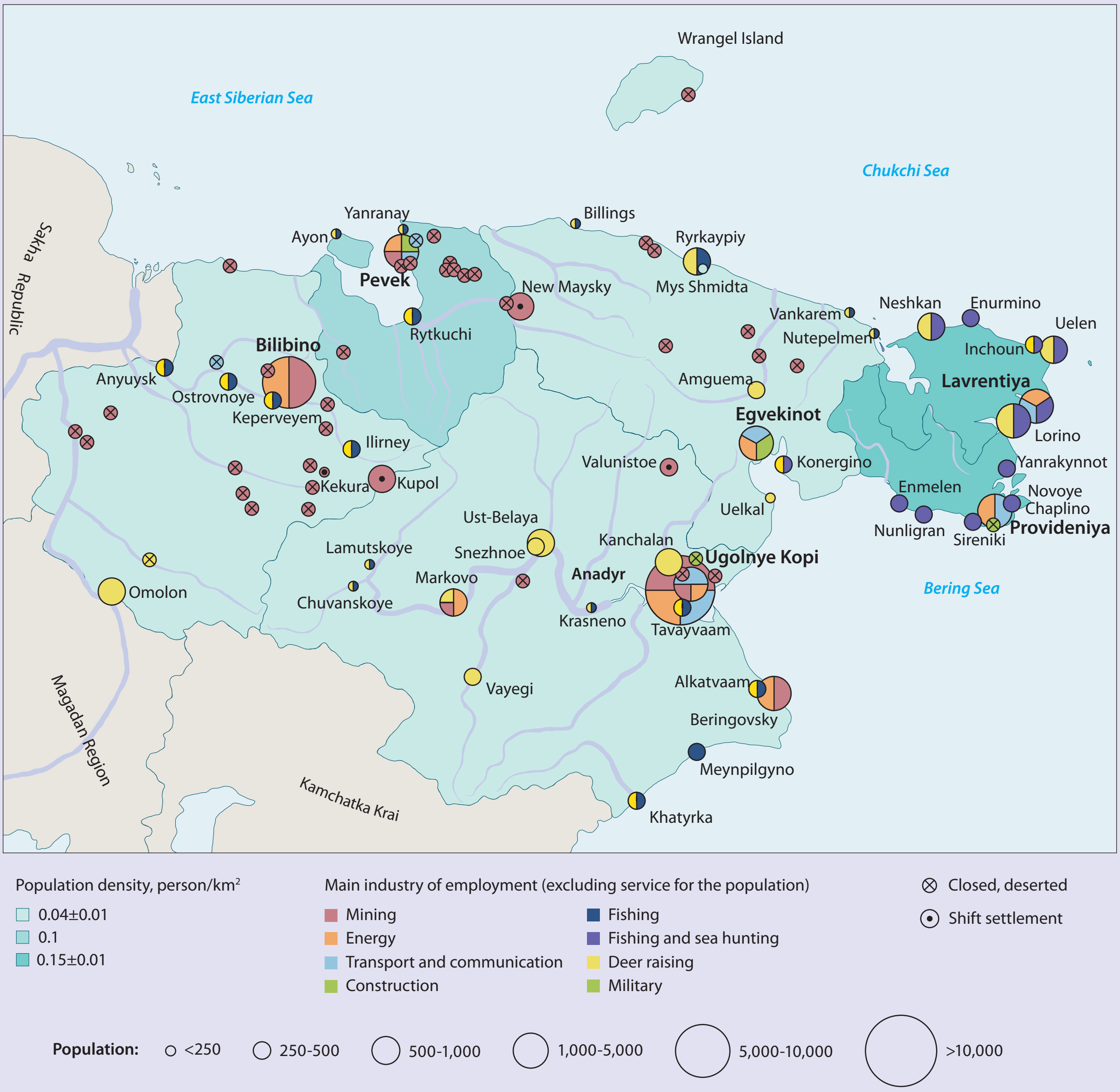


Figure 3.8 Distribution of urban centers and areas of economic development in Chukotka (deserted settlements: Litvinenko, 2013; actual population 2014 and employment 2015: Russian Federation Federal State Statistics Service; populations of shift settlements: official CAO website and websites of mining companies).

However, limited knowledge of the location, character, age, and geological setting of sedimentary successions has hindered a greater understanding of this potential (Kolak, 2011; BREA, 2013). Some BCB areas, such as northern Alaska, have received more oil and gas exploration than others, but geophysical data from the BCB offshore area are generally sparse. A new map delineating 143 prospective sedimentary successions was recently compiled, and oil and gas resources were estimated for the Arctic (Bird et al., 2008; Gautier et al., 2009a,b, 2011; Grantz et al., 2010; Bird and Houseknecht, 2011). The estimated sizes of reserves of potentially recoverable oil and gas from the BCB region were limited by the numbers and locations of completed seismic surveys, discovery wells, and production fields (Table 3.6). Estimates are most reliable for northern Alaska, including the nearshore waters of the Alaska Beaufort Sea, and for northern Yukon, including the lower Mackenzie River Delta basin.

Development of the oil and gas industry was a cornerstone of planned economic recovery in Chukotka during the early

Table 3.6 Estimated oil and gas reserves in the BCB region. Sources: Bird et al., 2008; Gautier et al., 2009a,b, 2011; Grantz et al., 2010; Bird and Houseknecht, 2011; Swenson, 2012; Ministry of Natural Resources and Environment, 2015.

| Country | Oil reserves | | Gas reserves | |
|---|---|---|---|---|
| | billion barrels | billion tonnes | trillion ft$^3$ | trillion m$^3$ |
| Russia | | | | |
| Offshore | <0.1 | <0.01 | <0.1 | <0.002 |
| Onshore | 0.3 | 0.04 | 2.9 | 0.08 |
| United States | | | | |
| Offshore | 28 | 3.8 | 122 | 3.45 |
| Onshore | 15.3 | 2.1 | 99 | 2.8 |
| Canada | | | | |
| Offshore | 1–10 | 0.1–1 | 6–100 | 0.2–3 |
| Onshore | 0.1–1 | 0.1–1 | 1–6 | 0.03–0.2 |

2000s (Antonov, 2015; Klepikov et al., 2015). Today, the prospects for this industry are more uncertain. Exploration for oil and gas reserves continues, but there is currently almost no production. Exploration in offshore areas has been limited, and although substantial resources may exist in the Chukchi Sea, Chukotka needs investors for an industry challenged by a lack of infrastructure and the high costs of exploration and development. An additional barrier is associated with Western financial sanctions, imposed in 2014, and technological embargos on drilling equipment and technologies for Arctic projects, deep-water reserves, and hard-to-recover reserves. Exploration activities are currently primarily land-based and are focused on petroleum reserves at Lagunnoye (estimated 38 million tonnes of oil, or 270 million barrels), Telekaisk (2.8 million tonnes of proven oil reserves and 2 billion m$^3$ of natural gas, or 20 million barrels of proven oil reserves and 71 billion ft$^3$ of natural gas), and Zapadno-Ozernoye (estimated 5 billion m$^3$ of natural gas, or 200 billion ft$^3$) (Ministry of Natural Resources and Environment, 2015). The most recent version of Russia's Energy Strategy through 2035 envisages exploration of both onshore and offshore energy resources in the East Siberia and Far East regions and also regards Arctic oil and gas development projects as basic focal points for economic growth in the remote northern regions (Russian Federation Department of Energy, 2016).

For the State of Alaska, oil accounts for more than 90% of all natural resource revenues collected (Knapp, 2012; Goldsmith, 2012). A third of all jobs in Alaska are directly or indirectly related to the oil and gas industry, and this sector accounts for about 2000 jobs (roughly half the total employment in BCB parts of Alaska) (MacDowell Group, 2014; AOGA, 2016). In 2014, petroleum revenue accounted for 88% of the State of Alaska's unrestricted revenue (Alaska Department of Revenue, 2014). Oil production has steadily declined since 1988, however, raising concerns about the economic sustainability of the Trans-Alaska Pipeline System.

Recent assessments of recoverable oil and gas resources in northern Alaska indicate that significant accumulations of oil and gas exist on state-owned and federally owned lands (MMS, 2008, 2011). Oil production is presently most significant on state lands and in state waters of the central North Slope around Prudhoe Bay. Although there has been a decline in volumes of produced oil, volumes are being maintained by increased pumping of existing fields rather than production from new fields. New but relatively small production wells have recently begun to produce oil from wells on federal lands in the Colville Delta in the National Petroleum Reserve, about 50 miles west of Purdah Bay, and at the Hilcorp/Liberty gravel island oil project in Prudhoe Bay. A major oil discovery (estimated production 200,000 barrels per day) was announced from Smith Bay, near Point Barrow, in September 2016. The federal waters of the US Beaufort and Chukchi seas are highly prospective areas for oil and gas; MMS (2011) estimated 26 billion barrels of oil (3.5 billion tonnes) and 131 trillion ft$^3$ of gas (3.71 trillion m$^3$). However, Royal Dutch Shell's exploration of the Burger Prospect, located about 70 miles offshore from Wainwright in the northeastern Chukchi Sea, was terminated in August 2015, and the company has relinquished all but one of its federal offshore leases in the Chukchi Sea. In late September 2015, Shell terminated its entire offshore Alaska program for the foreseeable future, in light of uncertainties associated with oil prices and high costs associated with government regulations and operational logistics. A month later, the United States canceled all offshore lease sales that were scheduled for the Chukchi and Beaufort seas (BOEM, 2015b). The most recent national offshore oil and gas leasing schedule (2017–2022) proposed one sale each in the Chukchi and Beaufort seas (BOEM, 2016), and these were canceled. Despite the economic impacts of current oil and gas prices, the State of Alaska is vigorously pursuing the construction of a trans-Alaska natural gas pipeline and the development of markets for North Slope product within Alaska and abroad (Wood Mackenzie, 2016).

In western Arctic Canada, oil and gas exploration began in earnest after oil was discovered in Prudhoe Bay, Alaska, in 1968 (CAPP, 2009; Callow, 2012). Between 1970 and 1989, 53 discoveries were made in the Mackenzie River Delta and coastal Beaufort Sea (SCEWG, 2008). In 1982, it was estimated that between 6 and 32 billion barrels of recoverable oil (between 0.8 and 4.4 billion tonnes) were present in the Beaufort Sea and that production could begin as early as 1986 (EIS, 1982). However, environmental concerns and global markets made oil and gas exploration infeasible during the 1990s. The estimates of technically recoverable Canadian oil and gas changed in the most recent assessments (Gautier et al., 2009a; Callow, 2012) and are now more conservative with respect to estimated oil, and are greatly expanded with respect to natural gas. Exploration rights to land parcels on the Mackenzie River Delta and in the Beaufort Sea were issued by the federal government in the 2000s; by 2007/2008, licenses for the deeper continental shelf were received by the oil and gas industry (INAC, 2010). Between 2010 and 2013, the area licensed had grown from 2 million ha to more than 3 million ha (INAC, 2010; AANDC, 2013, 2014).

*Non-conventional energy*. Non-conventional oil/gas resources, such as coalbed methane, gas hydrates, oil shales, and heavy oil and tar sands, also hold great potential (Kolak, 2011). For example, Collett et al. (2008, 2011) assessed the undiscovered, technically recoverable gas hydrate resources of Alaska's North Slope and state-owned waters and estimated that 85.4 trillion $ft^3$ (2.42 trillion $m^3$) of gas, approximately 11% of the total estimated volume of recoverable North Slope gas resources, was present. However, questions about the long-term productivity and economic feasibility of gas hydrates remain (MMS, 2009), and long-term production testing is needed (Collett et al., 2008).

The Beaufort-Mackenzie Delta and other basins in northern Canada have gas hydrate potential as well. Majorowicz and Osadetz (2001) analyzed the potential for development in the Beaufort-Mackenzie basin and the Canadian Arctic Archipelago and estimated their volumes of methane in hydrates to be 2.4–87 trillion $m^3$ (85–3100 trillion $ft^3$) and 19–620 trillion $m^3$ (670–22,000 trillion $ft^3$), respectively. Osadetz and Chen (2010) refined the evaluation for the Beaufort-Mackenzie Basin, estimating gas in place as ranging from 4.4 trillion $m^3$ (160 trillion $ft^3$) to 6.7 trillion $m^3$ (237 trillion $ft^3$).

Chukotka currently produces electrical energy at the Bilibinsk nuclear station. This unique station, constructed on permafrost in 1974, is part of the Rosenergoatom electrical grid; because of its age and inefficiency, its decommissioning is anticipated in 2019. In order to meet anticipated regional energy needs, a new nuclear power plant is being planned as its replacement – a first-ever offshore floating nuclear station, based on innovative coastal and hydrotechnical facilities, in Pevek. Chukotka's northern energy sector is also supported by other electrical power stations in Pevek, Egvekinot, and Anadyr, which are a part of the Chukotenergo system. Electrical demand associated with expanded mining operations in Baimskaya (ore zone), Peschanka (copper), and Pyrkakaisk (tin) is expected to exceed existing network capabilities. Other regional enhancements in energy transfer and availability will be achieved by incorporating the Chukotka grid into the Magadan network.

Renewable energy development is very limited in the BCB region (Offerdal, 2009). Alaskan communities rely heavily on diesel or natural gas for heat, electricity, and transportation, even though heating fuel costs are high – averaging USD 0.50–1.68 per liter. Despite a recent drop in the price of fuel oil for the rest of the United States, northern Alaska saw little change in average commodity price during the same period (State of Alaska, 2015b). High energy prices have prompted local governments to subsidize residential heating fuel costs and incentivize small-scale renewable energy integration (e.g., NANA Regional Corporation, 2016).

Wind energy is currently the most feasible renewable energy source for the BCB region, due to strong winds in coastal and mountainous areas. Vasil'ev et al. (2005) described prospective areas for wind power generation with capacities of 95 MW or more in Chukotka, noting the costs and benefits of wind–diesel plants for this region. They estimated that wind energy would reduce the delivery of expensive diesel fuel by 106,000 tonnes of coal equivalent per year (about 117,000 short tons). Alaska's goal is to generate 50% of the state's electricity from renewable resources by 2025; the Northwest Arctic Borough has a strategic goal of 50% reliance on local fuel sources, both renewable and nonrenewable, by 2050 (AEA, 2011; NANA Regional Corporation, 2016). Kotzebue and Nome have wind turbines with capacities of 2.28 MW and can fully power up to 360 homes in each community. Several federal, state, and local entities are encouraging rural energy generation via wind turbines and solar panels. In addition, the NANA Regional Corporation, an Alaska Native association of 11 villages, is planning to expand the Kotzebue wind farm and also study the potential for wind energy generation in other Northwest Arctic Borough communities (Kotzebue Electric Association, 2013). The US Department of the Interior has initiated a project with the National Renewable Energy Laboratory and several leading energy companies to explore the potential development of a standardized and reliable small-scale wind–diesel renewable energy system for siting in small, off-grid Arctic villages.

Most Canadian communities are dependent on diesel-generated energy, and energy costs are high. Community-based wind generation is being explored as an alternative source of sustainable energy. Small micro-grid energy production from waste heat removal is occurring at Fort McPherson; other possibilities for the region include solid biomass, solar, and small hydro (Muir, 2015). A bank of solar panels was recently installed along the entire southern wall of the hamlet office in Sachs Harbour on Banks Islands.

*Coal*. Russia holds the world's second-largest recoverable coal reserves, behind only the United States (BP, 2016). According to official CAO government statistics, forecast coal resources account for about 57 billion tonnes (63 billion short tons; 86% black coal and 14% brown coal); the bulk of the coal is concentrated in Bering coastal areas (CAO, 2015a). In 2014, Russia produced 357 million tonnes (394 million short tons), of which about 33 million tonnes (36 million short tons) were from the Far East (USEIA, 2016). Coal mining serves local needs (in 2009–2014, the two largest mines produced about 300–435 thousand tonnes annually, or 331–480 thousand short tons). The CAO government plans to export coal to Asia, especially from the deposits of the Beringovsky coal basin. Construction of a mining complex with annual production capacity of 10 million tonnes (11 million short tons) of coal is currently envisaged (CAO, 2016b). As part of its regional economic planning, the Far East District is seeking funds and investors for new roads and other infrastructure required for this development.

Although largely unexplored, northern Alaska's known coal resource within North Slope and Northwest basins may be greater than the rest of the United States (Flores et al., 2003, 2004; USEIA, 2012). It is estimated that a ninth of the world's known coal resource and a third of the United States total resource lies within the Northern Alaska-Slope coal province (Arctic Slope

Regional Corporation, 2015). As much as 300 billion tonnes (331 billion short tons) of coal may lie within the Colville River basin (USBM, 1995). However, mining in Alaska is challenging and expensive due to the remote and harsh environment, lack of roads, and potentially frozen shipping lanes. Nevertheless, exploration and development investment has increased in the last few years, driven in part by high commodity prices (Haley et al., 2011). The Arctic Slope Regional Corporation (2015) has concentrated its development on a single coal deposit located six miles from the Chukchi Sea. This deposit has more than 100 million tonnes (110 million short tons), and an additional 50–100 million tonnes (55–110 million short tons) may be proven.

## Mining

*Base Metals and Precious Minerals.* The BCB region is rich in hard rock ores and precious metals, and the mining industry is especially significant in Chukotka and Alaska. Although exploration is ongoing, the mining industry is less active in Canada. Gold mining is the largest industry in Chukotka. In 2015, its booked reserves of gold amounted to 732 tonnes (CAO, 2015a). Today the number of known gold deposits in Chukotka is 390; forecast resources are larger by several orders of magnitude than proven reserves. About 10% of Russia's gold reserves are located in Chukotka. The region also holds vast reserves of silver, coal, platinum, tin, and tungsten and is home

Figure 3.9 Minerals of the Chukotka district (Federal Agency of Geodesy and Cartography, 2005, 2008; Mineral Information and Analysis Center, 2015).

to one of the world's largest copper mines (Federal Agency of Geodesy and Cartography, 2005, 2008; Volkov et al., 2006; Mineral Information and Analysis Center, 2015; Figure 3.9). As the core industry in Chukotka, mining is also a major source of non-Indigenous employment. Among Chukotka's economic activities, the mining sector generates the leading share of the gross regional product (42% in 2011; CAO, 2015b). Current development is hindered by transportation needs, lack of energy infrastructure, and high capital expenditures (see Section 4.5.4). Tin and gold prompted the early exploration and settlement of Chukotka by European settlers. Since then, the development of gold, copper, tin and tungsten has been quite extensive. For example, Chukotka (Iultin deposit) was the main area of tin production in Russia. A current focus is on the development of minerals in the Anadyrsky, Chaunsky, and Bilibinsky districts. Today, precious and nonferrous industrial production accounts for almost 96% of all non-living resource revenues collected by the CAO. In 2014, nonferrous mineral production in Chukotka was about 183,000 tonnes (CAO, 2015b). Gold mining is especially important in the Chaunsky and Anadyrsky districts. During the 1990s, gold extraction was in decline. However, in the 2000s, it stabilized and then began to increase. For example, a major breakthrough in extraction technology at the Kupol deposit has led to a recent annual production of more than 20 tonnes of gold from this mine annually. Further, Chukotka ranked second highest among Russia's gold-mining regions in 2014, with a total production of 32 tonnes of gold (website accessed 11 March 2016 at www.чукотка.рф); gold concentrate is now the dominant export commodity of Chukotka. The Peschanka copper deposit is the site of one of the world's largest copper mines. Identified reserves of copper in Peschanka are 3.73 million tonnes (Peschanka also contains 233 tonnes of gold). There are plans to produce about 180–200 thousand tonnes of copper annually after a renovation of facilities during the next decade within the Baimskaya deposit, which includes the Peschanka field.

The combined northern and western mineral regions of Alaska (which approximate the area of Alaska within the BCB region) host a variety of important mineral deposits – including one of the world's largest zinc deposits, near Kotzebue Sound. Mining for gold, lead, and silver is also important in Alaska. Copper and zinc deposits in the southern Brooks Range and graphite near Nome are of current industrial interest. In 2014, the value of mineral production in Alaska was estimated to be USD 1.713 billion, with employment of more than 600 full-time positions (Freeman et al., 2015). These production values and employment numbers were dominated by the Red Dog Mine, near Kotzebue. The Red Dog Mine is the largest in Alaska, in terms of production and reserves, and is processing zinc, lead, and silver ore from one of the largest zinc deposits in the world. Red Dog resources represent 95% of US zinc reserves and accounted for 41% of Alaska's total non-fuel mineral production in 2013. High gold prices have brought increased exploration activity for placer gold in Alaska's Northern region in recent years, and gold production in 2013 totaled a reported 82,591 grams (Athey et al., 2013).

In Canada, major mining developments in the Yukon and Northwest territories are located south of the Arctic Circle. Little to no mining takes places in the northern regions of these territories, including the BCB region. The mineral resources of the Kitikmeot region of Nunavut are of industrial interest (Cameron, 2012) and are being explored. While there are currently no operating mines in the Kitikmeot region or the Inuvialuit Settlement Region, residents of both of these BCB areas are employed in exploration and development activities in mining operations in the Northwest Territories. The mining exploration sector is emerging as an important component of labor, investment, and economic development in the Inuvialuit Settlement Region. Gold, base metals (iron, nickel, copper, and zinc), and diamonds are the dominant metals and mineral deposits in the region, but there are also significant showings of lead and various rare earth elements (Nunavut Geoscience, 2012). Nickel deposits at Darnley Bay in the Mackenzie River Delta are being considered for development (SNL Metals and Mining, 2014).

### Commercial fisheries

Commercial fisheries are located in the northern Bering and southern Chukchi seas. In Alaska, the creation of the Northern Bering Sea Research Area, St. Lawrence Island Habitat Conservation Area, and Arctic Management Area prohibits bottom trawling in all US federal waters of the BCB (Hermann and Martin, 2015). There are no industrial fisheries in the BCB area north of the Arctic Circle (Christiansen et al., 2014b).

Russian fisheries in the northwestern Bering Sea and Gulf of Anadyr are significant (annual catch ~100,000 tonnes); they are dominated by Pacific cod (*Gadus macrocephalus*) and saffron cod (*Eleginus gracilis*), flounders (e.g., Bering flounder *Hippoglossoides robustus*, Pacific halibut *H. stenolepis*, Greenland halibut *Reinhardtius hippoglossoides*, northern rock sole *Lepidopsetta polyxystra* and Alaska plaice *Pleuronectes quadrituberculatus*), Alaska pollock (*Gadus chalcogrammus*), and Pacific salmon (*Oncorhynchus* spp.) (Gavrilov and Khrapova, 2004). Pacific cod and flounders are the most abundant species in the catch (Stepanenko, 2001; Parin, 2004). In Russian waters, pelagic fisheries target Pacific herring (*Clupea pallasii*), Pacific capelin (*Mallotus catervarius*), and smelt (e.g., pond smelt, *Hypomesus olidus*).

Large salmon runs occur in the Anadyr River in Chukotka. Commercial fisheries for salmon and char are located in the main stem and tributaries to the Anadyr River. The principal species harvested are chum salmon (*Oncorhynchus keta*; with an average annual catch of 2386 tonnes), pink salmon (*O. gorbuscha*; 56 tonnes), and Dolly Varden (*Salvelinus malma*; 44 tonnes) (Chereshnev and Shestakov, 2003). Currently, annual catches are below historic highs, as many processing facilities were forced to close following the collapse of the former Soviet Union and are only now beginning to recover. More than 75% of the total Pacific salmon catch from Chukotka is taken in chum salmon fisheries in the Anadyr River basin. In 2012, about 700,000 chum salmon were harvested, compared to the long-term annual average of 2.8 million fish (Baranov, 2013).

In Alaska, salmon are commercially harvested in state-managed waters and watersheds as far north as Kotzebue Sound. Chinook (*Oncorhynchus tshawytscha*) and chum salmon are harvested by villagers of the lower Yukon River (ADFG, 2016). Other salmon species, while present, are of minor importance. Chinook populations have been in decline, and fishing closures have resulted in financial hardship for many residents of the Yukon River area. The total ex-vessel value of the Yukon-Kuskokwim Delta fishery is relatively small, amounting to about USD 1 million per year.

Small but locally important salmon fisheries are located in Kotzebue and Norton sounds. Only chum salmon are found in sufficient abundance to support a set-net fishery in Kotzebue Sound. The 2014 harvest of more than 636,000 salmon was the second highest on record, with an ex-vessel value of USD 2.9 million; this compares to 300,000 chum salmon captured in 2015 with an ex-vessel worth of USD 825,000 (ADFG, 2016). Local buyers for commercial salmon cannot be found in some years, and this relates to fluctuations in resource availability and the market value of salmon (ADFG, 2016).

An important king crab fishery takes place in Norton Sound, Alaska. In 2013, the fishery harvested more than 130,000 red king crabs (*Paralithodes camtschaticus*) with a total ex-vessel value of USD 2.165 million (ADFG, 2013).

There are no commercial fisheries in the Canadian Beaufort Sea. Arctic char, Arctic cisco (*Coregonus autumnalis*), and broad whitefish (*C. nasus*) are valued species in subsistence and recreational fisheries (Christiansen et al., 2014a). The species are locally important, and declining abundance for Arctic cisco and broad whitefish has been reported in fishery catches from the Mackenzie River (Christiansen et al., 2014a). A small through-the-ice trade-and-barter fishery for whitefishes for local villagers in Nuiqsut and Utqiagvik is located in the Colville River Delta, Alaska. Subsistence fisheries for chum, chinook, and coho salmon are important in the Yukon River, and several thousand fish are harvested annually. In Chukotka, Indigenous harvests are mostly for local consumption and limited trade and barter (Oparin, 2013).

### Transportation and shipping

Current shipping activity in the BCB region is regionally based or destination shipping that supports the export of natural resources and the resupply of villages and remote facilities. There are many similarities across the BCB region with respect to reliance on land- and sea-based forms of transportation. Villages and smaller settlements are distant and remote, located in areas where population densities are low. Costs for permanent roads are prohibitive, and many settled areas have their own airstrips, relying on aircraft for personal transport and provisioning of consumer goods. In winter, there is a greater dependency on ice roads. There are very few ports, and many are only seasonally navigable.

There are five main ports in Chukotka. Anadyrsky is the largest cargo port (navigable June–November), while Pevek (July–October) is the major port of the Northern Sea Route system. There are no deep-water ports in the Alaskan part of the BCB region, and many remote villages are serviced by air from transportation hubs located at Bethel, Nome, Kotzebue, Utqiagvik, and Deadhorse (Prudhoe Bay). A gravel causeway extends several miles offshore in Prudhoe Bay and provides access for barges and service vessels supporting oil and gas activities during open water periods. The Dalton Highway, between Fairbanks and Deadhorse, Alaska, is maintained year round. In the western Canadian Arctic, Tuktoyaktuk, near the Mackenzie River Delta, serves as a barge trans-shipment port for local communities and an offshore supply port for some oil and gas operations (Lamoureux et al., 2015). A barge terminal in Inuvik supports regional services. Nome has been considered as the potential site of a future deep-water port.

There are more road systems in Chukotka than in other parts of the BCB region. In 2014, paved roads (664 km) accounted for about a third of the total length of the road system: their density within the territory (0.9 km/1000 km$^2$) is the lowest among the federal regions of Russia (SPIEF'17, 2016; Rosstat, 2016). The construction of a federally funded Kolyma–Omsukchan–Omolon–Anadyr road was initiated in Chukotka in 2012 (Russian News Agency TASS, 2012); this new road will establish year-round connections with other roads in the Far Eastern federal district. There are no railways in Chukotka or elsewhere within the BCB region.

Other shipping activity consists of trans-Arctic shipping, mainly through the Northwest Passage and the Northern Sea Route (Figure 3.10). Additionally, adventure tourism, consisting of cruise ship and yacht traffic in these routes, supports a limited but growing industry. Most shipping involves tug and barge operations due to the absence of deep-water ports. Oil and gas exploration and development continue to be the primary drivers for commercial maritime traffic in the BCB region. Successful offshore oil and gas exploration and extraction ventures will depend heavily on safe marine transportation (Northern Economics, 2014).

### Tourism

Chukotka has very little tourism. Ecotourism is a fledgling industry, and a few wilderness cruises are available each summer, popular primarily among foreign visitors (UNEP, 2007).

Alaska's Arctic has a long history of tourism, but the total activity remains low compared to tourist visits elsewhere in the state. In 2013–2014, the Arctic accounted for less than 1%, or about USD 30 million, of total visitor spending in Alaska, accounting for 300 jobs (State of Alaska, 2014). Tourism and recreation are promising but are challenged by a lack of infrastructure and the potential for conflicts with subsistence activities (North Slope Borough, 2005). Visitation to national parks, preserves, and monuments (Gates of the Arctic National Park and Preserve,

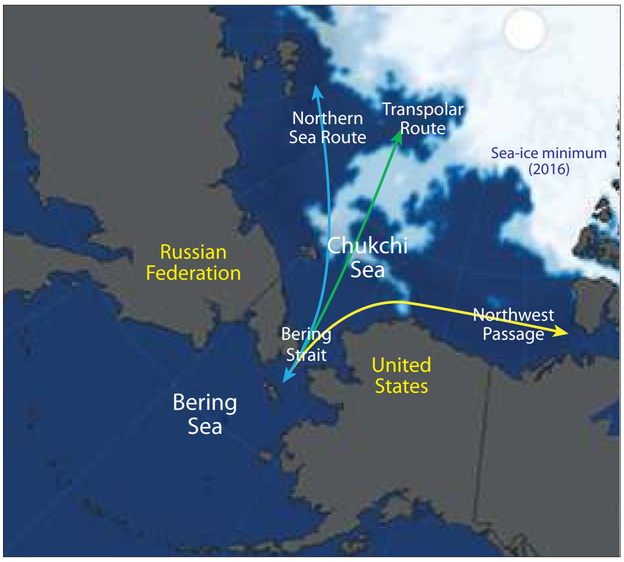


Figure 3.10 Arctic shipping routes. Graphic shows the convergence of Arctic shipping (Bering, Chukchi, Beaufort seas) through the Bering Strait, the Northern Sea Route (along the coast of the Russian Federation), the Northwest Passage (along the coasts of the United States and Canada), and potential transpolar routes across the North Pole. (Base map courtesy of the US National Aeronautics and Space Administration, showing the sea ice minimum from 10 September 2016.)

*Photographers observing polar bears in the Arctic National Wildlife Refuge, Alaska*

Noatak National Preserve, Kobuk Valley National Park, Bering Land Bridge National Preserve, Cape Krusenstern National Monument) as well as the Arctic National Wildlife Refuge has remained stable or has increased in recent years, contributing to the overall visitor experience and economy of the region (Conley, 2013; Cullinane Thomas et al., 2014; USFWS, 2015). Marine tourism is almost nonexistent in Alaska's Arctic waters (Arctic Council, 2009).

In western and central Arctic Canada, tourism represents a small industry. Ship operators interested in expanding their services face significant financial and policy challenges (Lasserre and Têtu, 2013). The current economy and high cost of oil (in the region) are major barriers to growth. The region's lack of maritime infrastructure is also a major impediment to business (e.g., Stewart et al., 2013). Other constraints relate to Canadian regulations that limit port visits, thus further limiting economic opportunities for vessel operators. The most popular cruise ship destinations are Cambridge Bay and Gjoa Haven. Sea ice hazards restrict some vessel visits in the Inuvialuit Settlement Region due to hull specifications.

There is increasing interest in traveling the Northwest Passage. In summer 2016, more than a thousand passengers paid between USD 22,000 and 133,000 to experience the Arctic passage, traveling from Seward, Alaska, to New York City aboard the 13-story cruise ship *Crystal Serenity*. The relatively large vessel size and visitor numbers taxed local Arctic community capacity; at some stops, villagers were brought on board to share their cultures, artwork, and handicrafts (e.g., see Thiessen, 2016).

### 3.3.4 Political systems

> *"Governance is fundamental to the future of the Arctic region, both for the people who make the Arctic their home and for the lands and resources that are of increasing global importance. For the purposes of this chapter, governance comprises* political systems *– the structures, processes, and actors involved in public decision-making for a political community, and* geopolitics *– the international relations among political communities."* (Poelzer et al., 2014, p.185).

With the exception of Chukotka and the Inuvialuit Settlement Region, the major seats of government are centered far outside the BCB region. The political systems representing the BCB region constitute a complex web of differing governmental controls and influences ranging from local to international structures and responsibilities, including federal and state-based governments, regional and municipal administrations, and self-governing Indigenous organizations. Each nation, through varied forms of government and citizen involvement, has broad responsibilities for the safety and security, public health and education, regulation/compliance, natural resources and development, and environmental protection of its citizenry. In many instances, these functions are sector-, resource-, community-, and ownership-based, and government missions and presence vary with respect to agency mandates, priorities, and capabilities. Agency missions and priorities can overlap with respect to all-encompassing issues, such as climate change, and understanding the nature of common needs and addressing them should be among the strategic goals of interagency planning and coordination. While the nature and degree of functional overlap differs by nation, the political systems in the BCB, especially in Alaska and Canada, are currently evolving structures and processes to expand and streamline coordination networks. As an example, the Denali Commission in Alaska was identified by the US federal government to lead the coordination of intergovernmental and private sector planning and funding of the most urgent adaptation needs of rural communities (Denali Commission, 2016). While serving an important purpose, this approach is not strategic with respect to long-term perspectives and regional needs and the expected consequences of climate change.

The political systems of the BCB region are complex and are not easily known or navigable by local residents (Thompson, 2003; Holzlehner, 2015). However, local knowledge and participation are critical in the planning process, and as a first step in gaining perspective it is important to establish what government and organizational structures are in place for effective local participation in climate adaptation planning.

Table 3.7 Political systems in the BCB region. State and territorial legislatures are included as the State of Alaska and Yukon and the Northwest Territories.

| | Organizational responsibility | Chukotka | United States | Canada | Parallel governance structures |
|---|---|---|---|---|---|
| Higher | Local | Settlement and town | Village* | Hamlet* | |
| | Regional | CAO authorities (governor, Duma, government) | Boroughs*<br>State of Alaska* | ISR and Kitikmeot Region (Nunavut), Yukon and Northwest Territories * | Indigenous organizations and governments<br>Cooperatives, councils, and commissions*<br>Co-management bodies<br>Nongovernmental organizations, professional societies |
| Citizen/Community participation | Regional and national | Federal agencies | Federal agencies | Federal agencies | |
| | National | Federal assembly (including state Duma and Federation Council) | Congress* | Parliament | |
| Lower | International | President | President | Prime minister | |
| | | | High 'Centralized control' Low | | |

* Denotes governance structures where local participation in climate adaptation planning may have greatest impact.

The core governance structures of the BCB nations (i.e., local through national levels) provide a high-level but practical model for international comparisons, including comparison of the government levels where citizen or community engagement may affect planning most effectively. The central roles of the national governments are different with respect to the functional and administrative controls of the state, ranging from a federal model of joint competences and responsibilities in Russia, to a mixed control model in the United States, and a shared control model in Canada (Table 3.7). In each model, the nation's leader represents where final decision-making rests regarding international affairs (e.g., Arctic Council, United Nations Framework Convention on Climate Change, United Nations Convention on the Law of the Sea).

After the collapse of the former Soviet Union, with its highly centralized governance system, a new federal model, formalized by the 1993 Constitution of the Russian Federation, was established in Russia. A wide package of responsibilities was transferred to the regions, including the CAO, as a federal subject. Joint responsibilities of the federation and CAO were enacted by law in 1997, including, for example, protection of the rights of minorities, land use, development of natural resources, environmental protection, housing, families, healthcare, and education (Wilson and Kormos, 2015). Federal authorities remain responsible for the elaboration and implementation of federal policies; budget, defense and security issues; and international relations of the Russian Federation. In the CAO's seven municipalities, non-state authorities possessing self-governance functions are engaged in decision-making at the local level (i.e., land, roads and infrastructure, agriculture, disaster protection, and small- and medium-sized enterprises).

In Alaska, the federal government is the major landowner (e.g., national parks, refuges, and forests), and its legislated maritime responsibilities extend across the Exclusive Economic Zone (e.g., Fortenbery, 2015; Alaska Humanities Forum, 2016). The mixed model of governance recognizes the constitutional rights and authorities of the State of Alaska and tribal sovereignty. Subsistence harvests are managed by federal and state authorities, and co-management agreements exist with Alaska Natives for federally managed species (USDOI, 2016). The federal government has regional offices or representatives in the major urban centers of Alaska; its national headquarters are located in Washington, DC. The Department of the Interior maintains a Special Assistant to the Office of the Secretary in Anchorage.

In Canada, Inuit Nunangat (or Inuit homeland) includes the four Inuit regions: Inuvialuit, Nunavut, Nunavik, and Nunatsiavut. The federal government has established the Inuit Relations Directorate within Indigenous and Northern Affairs Canada as the Government of Canada's primary point of contact for collaboration with Inuit organizations; the directorate also serves as an internal government source for information, advice, and expertise on Inuit matters. Inuit Tapiriit Kanatami (ITK) is the national organization representing approximately 60,000 Inuit living in Inuit Nunangat and other parts of Canada. Inuit land claims organizations – the Inuvialuit Regional Corporation in the Inuvialuit Settlement Region, Nunavut Tunngavik Inc. in Nunavut, Makivik Corporation in Nunavik (northern Quebec), and Nunatsiavut Government in Nunatsiavut (northern Labrador) – protect Inuit rights and oversee the recognition and implementation of these rights.

The shared control in Canada is a relatively new governance model resulting from the settlement of land claims and the consequent relationships between the Inuit, territorial, and national governing structures. Inuit Tapiriit Kanatami is the national organization representing Indigenous residents in Inuit Nunangat land claims areas and other parts of Canada. As a result of these land claims, the Inuit are the largest nongovernment owners of land in Canada. The Inuvialuit Settlement Region was established under the Inuvialuit Final Agreement in 1984, and Nunavut was established in 1999. The federal government, headquartered in Canada's capital in Ottawa, has established that the Inuit land claims in Canada have precedence over conflicting federal, provincial, and territorial laws (Muir, 1994). ITK, its member Inuit organizations, and the Inuit Circumpolar Council Canada consistently promote legal and political recognition of Inuit in Canada at national and international levels. The territorial governments are aligned with the national government and, as necessary, assist in the co-management of shared species nationally and internationally (e.g., transboundary salmon).

The BCB political systems have developed in response to legislative mandates and authorities and the associated regulatory and policy frameworks for the core levels depicted in Table 3.7. Acknowledging this texture is important because it relates to the origins and missions of the parallel governance structures whose goals establish their requirements of information for resource management, conservation, and sustainability. The parallel structures include organizations that work in concert with governments, or more independently, for the public good.

In Table 3.7, the highlighted (*) structures suggest the levels of governance structures and established partnerships (e.g., US and Canada in the Landscape Conservation Cooperatives, LCC, Network), where local participation is occurring or could be improved in climate planning and decision-making. They designate governmental entry points where citizens can influence local climate change adaptation planning and outcomes. The LCC partnerships stand out as an example where US and Canadian residents have played an active role in identifying and prioritizing adaptation issues in northern Alaska and western Arctic Canada. In general, lower levels of governance (i.e., village/town/hamlet, district, or territory/state) or tribal or Inuit governments are initially appropriate organizations for citizen-based participation, where residents can effectively engage and affect climate policy. In Alaska, Congressional contact by Alaska Native leaders is often effective in addressing local emergencies, supporting research and management priorities, and helping to resolve state–tribal conflicts. Similarly in Canada, leaders in the Inuvialuit Settlement Region and Nunavut now have access to territorial and federal decision-makers and greater influence than previously.

## 3.4 Regional ecosystems

### 3.4.1 Marine ecosystems

The BCB region is distinctive with respect to its large shelf area, diverse shelf types, presence of large rivers, and Pacific influences (Carmack and Wassmann, 2006). Horizontal advection (transport in ocean currents) is a key forcing function for the region (Grebmeier et al., 2015). The advection of water, ice, and biological constituents through the Bering Strait and the inflow of freshwater from rivers and melting sea ice are principal influences on the region's biology. Sea ice is a primary forcing factor in the region and is inherently connected to advection and stratification (Grebmeier et al., 2015; Wiese et al., 2015). Because primary production depends fundamentally on light and nutrients and therefore on stratification, upper ocean stratification may be the single most important link between climate and biology – responsive to climate and strongly influential over ocean biology (Carmack and Wassmann, 2006).

The position of the southern marine boundary of the BCB region is ecologically significant because it approximates the northern edge of the Bering Sea 'cold pool' (bottom temperatures <2°C) near St. Lawrence Island and a zoogeographic boundary between boreal and Arctic marine fishes (Mecklenburg et al., 2011). The diversity of marine fishes to the south of this transitional zone in the Bering Sea (~400 species) is about four times greater than in the BCB region, with the southern Bering Sea representing one of the world's most important fishing areas.

#### 3.4.1.1 Lower trophic levels: plankton, benthos

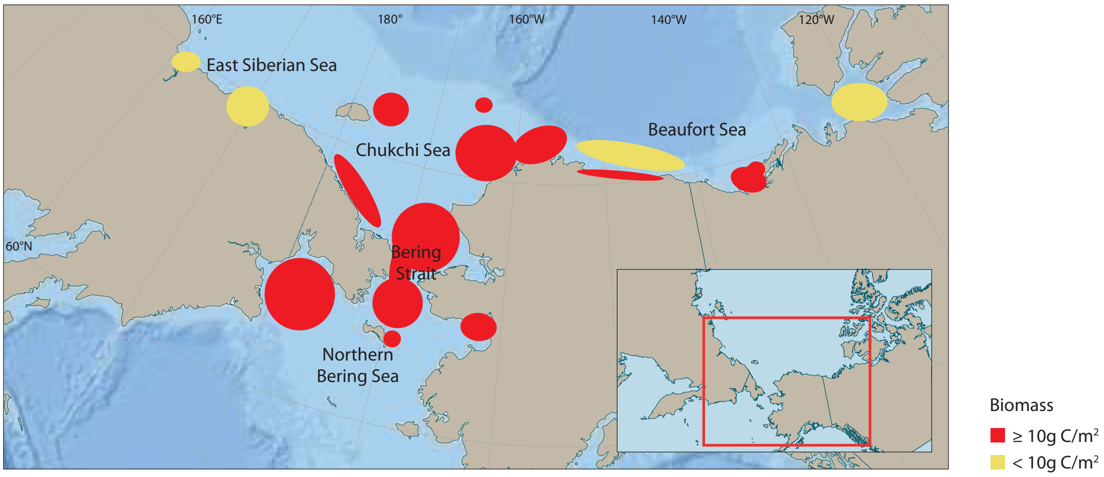
A large number of planktonic algae thrive in Arctic waters, but there are relatively few endemic species. Estimates of phytoplankton biomass vary widely in the BCB region, with highest values in the Chukchi Sea. Algal production and biomass are controlled primarily by light, stratification, and nutrient fields. The seasonal productivity associated with phytoplankton and ice algae communities is an important source of carbon in benthic and pelagic food webs (Alexander, 1974, 1992). The loss of multi-year ice, increasing production in ice melt ponds, and earlier occurrence of phytoplankton blooms may be shifting the relative importance of ice edge dynamics toward food webs associated with open water species assemblages in areas of reduced sea ice coverage and increased upwelling (e.g., Li et al., 2009; Mundy et al., 2009; Ardyna et al., 2011; Arrigo et al., 2012, 2014; Pickart et al., 2013). Secondary producers include the microbes and protists, microzooplankton, and zooplankton, as consumers of algae and phytoplankton. Although it is likely that phytoplankton and sea ice algae represent major food sources for larger zooplankton, microzooplankton may also be important during periods when phytoplankton standing stocks are low or of poor quality (Cota et al., 1996).

The Canadian Arctic Archipelago, in the easternmost part of the BCB region, is a complicated network of channels, straits, and sounds, where water mass transit times are long enough for thermohaline and biogeochemical changes to occur en route (Smith et al., 1988). There are no large rivers, and stratification derives primarily from ice melt. Primary production in the region is spatially variable and can be significant in southern areas, such as Amundsen Bay, where rich benthic communities may be found (Smith et al., 1988).

Benthic productivity, especially in the northern Bering and Chukchi seas, is potentially vulnerable to physical changes that favor pelagic ecosystems (Grebmeier and Dunton, 2000; Grebmeier et al., 2006b) or alter benthic–pelagic coupling processes responsible for the vertical flux of organic carbon to the seafloor. For example, coincident decreases in vertical organic carbon flux rates and benthic bivalve biomass in the northwestern Bering Sea (Chirikov Basin) are thought to be related to earlier seasonal sea ice retreat and warming sea surface temperatures (Lovvorn et al., 2003; Grebmeier et al., 2006b). In contrast, a 1.5-fold increase in the biomass of bivalves was reported from the Gulf of Anadyr for the period 1985–2005 (Nadtochiy et al., 2008).

Differences in stratification partially explain bivalve abundance patterns across the northern Bering/Chukchi shelf, with biomasses tending to be highest in the west (Grebmeier et al., 2006a, 2015; Grebmeier and Maslowski, 2014). Water masses are colder, more marine, and richer in upwelled nutrients in the west. Primary production is higher over the western parts of the northern shelves, but the marine algae are inefficiently grazed by the small-sized herbivores dominating the region's zooplankton community in the spring and early summer months. As a consequence, the vertical flux of organic matter from pelagic to benthic ecosystems is strong over northern shelves, especially in the southern Chukchi Sea and other areas where biological hotspots in the benthos have been identified (Table 3.8). Other processes such as the vertical flux of ice algae, benthic remineralization, and predation of benthos contribute to regional patterns in the abundance of benthos on BCB shelves.

Table 3.8 Location of benthic hotspots in the BCB region (Dunton et al., 2005, 2006, 2012; Darnis et al., 2012; Grebmeier and Maslowki, 2014; Grebmeier et al., 2015; Moore and Stabeno, 2015).



| Shelf area | Benthic biomass | | |
|---|---|---|---|
| Shelf region | Nearshore (≤30 m depth), g C/m² | Offshore (30–200 m depth), g C/m² | Comments |
| Northern Bering Sea | | | |
| Eastern | 0.1–10 | | Island nearshore on central shelf |
| Central | 0.1–10 | 10.1–20 | |
| Western | 10.1–20 | | |
| Hotspots[a] | | | ~ 20.1–30 g C/m² |
| Bering Strait | | | |
| Eastern | 0.1–10 | | |
| Central | | 10.1–20 | |
| Western | 20.1–30 | | |
| Hotspots[b] | | | ~ 20.1–30 g C/m² |
| Chukchi Sea | | | |
| Southeastern | 0.1–10 | | |
| Northeastern | 0.1–10 (S), 10.1–20 (N) | 0.1–10 | Increase at Cape Lisburne, AK |
| South-central | 0.1–10 | 10.1–400 | Increasing biomass east to west |
| North-central | | 0.1–10 (E), 10.1–20 (W) | Effects of cross-shelf exchange |
| Southwestern | 30–400 (S), 20–30 (N) | 20.1–400 | Anadyr Water in the west |
| Northwestern | 20–30 | 20.1–30 | |
| Hotspots[c] | | | ~ 40–100 g C/m² |
| Beaufort Sea | | | |
| Western | 10.1–40 | 0.1–10 | Increasing westward |
| Central | 0.1–10 | 0.1–10 | Excluding lagoons |
| Eastern | 0.1–10 | 0.1–10 | |
| Hotspots[d] | | | Inshore–offshore differences |
| East Siberian Sea | | | |
| Eastern | 0.1–10 | 0.1–10 | |
| Central | 10.1–20 | 10.1–20 | |
| Western | 10.1–20 | 10.1–20 | |
| Hotspots[e] | | | Data lacking |
| Western Arctic Archipelago | | | |
| Southeastern | | | Data lacking |
| Hotspots[f] | | | Overwintering |

[a] Gulf of Anadyr, Chirikov Basin, northwest St. Lawrence Island, and northeastern Norton Sound; [b] western Bering Strait; [c] West-central sector of southern Chukchi Sea, Hanna Shoal, Barrow Canyon, Herald Valley; [d] northeast of Barrow, Alaska coastal lagoons, Mackenzie River Delta; [e] potentially west of Kolyma Bay and east of Chaun Bay; [f] Amundsen Gulf, Tuktoyaktuk Harbor.

### 3.4.1.2 Upper trophic levels: fish, birds, mammals

Invertebrate-dominated benthic communities form the base of marine food webs (e.g., Stoker, 1981; Grebmeier and Maslowski, 2014; Divine et al., 2015; Moore and Stabeno, 2015). Invertebrate species are important prey of many marine fish, diving birds, and marine mammals. Freshwater and terrigenous influences on food webs are more pronounced in inshore waters, especially protected lagoons, where different processes govern the seasonal composition and abundance of the invertebrate community as well as food web dynamics (Dunton et al., 2005, 2006, 2012).

Marine fishes – important predators of zooplankton, benthic invertebrates, and other fishes – are important in food webs. There are 124 species of marine fish known from the BCB region (Mecklenburg and Steinke, 2015; Mecklenburg et al., 2016); their trophic position, mostly as secondary consumers, occurs at intermediate levels of the marine ecosystem (Thorsteinson and Love, 2016).

The ecological processes (e.g., Smetacek and Nicol, 2005; Grebmeier et al., 2006a,b; Reist et al., 2006; Murphy et al., 2007; Jay et al., 2011; Christiansen et al., 2014a; Logerwell, 2014; Outridge et al., 2015) associated with the BCB region's water masses (e.g., Crawford et al., 2012) provide stable habitat conditions for shelf-affiliated assemblages, especially adults, in the Chukchi Sea. The primary marine fish assemblage is composed of relatively few species of small size and biomass (Irvine and Meyer, 1989). Small schooling species such as the Arctic cod can be abundant over shelf waters and near shelf-break and slope waters (Crawford et al., 2012). Many of the common species are benthic or demersal in their habitat orientation, and snailfish, poachers, and pricklebacks are relatively abundant in shelf waters. The small sizes and low densities of many species suggest that they may be living at the abiotic and biotic extremes of their ranges (Thorsteinson and Love, 2016).

Benthic and demersal fish are more abundant than pelagic species (Whitehouse et al., 2014; Mecklenburg and Steinke, 2015), with important differences in relative abundances found in nearshore, shelf, and deeper habitats (Datsky and Andronov, 2007; Lauth, 2014; Logerwell et al., 2015). The most common families in the northern Bering and Chukchi seas include cods (Gadidae), sculpins (Cottidae), eelpouts (Zoarcidae), and righteye flounders (Pleuronectidae). The most abundant species include Arctic cod, saffron cod, Arctic staghorn sculpin (*Gymnocanthus tricuspis*), shorthorn sculpin (*Myoxocephalus scorpius*), eelpouts (*Lycodes* spp.), and Bering flounder (Norcross et al., 2013). Arctic cod, Pacific capelin, Pacific sand lance (*Ammodytes hexapterus*), and least cisco (*Coregonus sardinella*) can be abundant in nearshore waters. Salmonid species, especially Pacific salmon (*Oncorhynchus* spp.), broad whitefish, and inconnu (*Stenodus leucichthys*) are typically most abundant south of 67°N.

The marine fish assemblages of the Beaufort Sea are similar to those in the East Siberian Sea (Popov, 2009; Datsky, 2015; Mecklenburg et al., 2016). The shelf assemblage tends to be widely dispersed, represented by small populations characterized by patchy distributions, occurrence of rare species, and variable species composition with numerous local absences. Arctic cod may be the exception, occurring in large schools at depths of 300–400 m (Crawford et al., 2012). Fish biomass over offshore shelves is dominated by small benthic species such as eelpouts, sculpins, and Pacific sand lance, as well as the more pelagic Arctic cod. The inshore species assemblage is dominated by Arctic char, Dolly Varden, least and Arctic ciscos, and broad and humpback whitefish (*Coregonus pidschian*) (Mecklenburg et al., 2016). Chum salmon are native to the Mackenzie River. Chum and pink salmon are the most abundant salmon species north of the Arctic Circle, although other species have been recently detected (Thorsteinson and Love, 2016).

The Arctic cod is the most widespread and abundant marine fish in the BCB region. Its keystone role is supported by its mid–trophic level status, dominance in regional fish assemblages, and importance in marine food webs (e.g., Andriashev, 1970; Bradstreet, 1982; Bradstreet et al., 1986; Mueter et al., 2016). Arctic cod are abundant in deeper waters, over the shelf break and upper slope (300–500 m), throughout the year (Crawford et al., 2012; Norcross, 2015) and in coastal waters during summer.

Marine birds have evolved life strategies, including nesting and feeding behaviors, that are in synchrony with biological productivity and food webs in the physical regimes defined by hydrographic features that best meet their feeding ecologies (Springer et al., 1987, 1989; Divoky and Springer, 1988; Haney, 1991; Elphick and Hunt, 1993; Springer and McRoy, 1993; Russell et al., 1999; Hunt et al., 2002; Piatt and Springer, 2003; Gall et al., 2013; Divoky et al., 2015). These regimes are defined by sea ice dynamics (ice edge, open leads, and polynyas), advection and thermohaline structure, wind and upwelling patterns (benthic and pelagic processes on the shelves), and estuarine processes (nearshore and lagoon dynamics). Most of the marine birds that occupy marine and coastal habitats are seasonal migrants and are important seasonal foods for local residents (Rothe et al., 2015). In the northeast Chukchi Sea, a variety of birds may be observed seasonally, including loons, phalaropes, kittiwakes, gulls, terns, murres, auklets, murrelets, and shearwaters (Day et al., 2013b). Arctic coastal lagoon systems, such as the barrier islands of the Chukchi Sea and Beaufort Sea, are an important breeding habitat for waterfowl, gulls, and some seabirds (Morse, 2007). In the Bering Strait and Chukchi Sea, planktivorous seabirds (small auklets, *Aethia* spp., and murres, *Uria* spp.) are the most abundant breeding seabirds (USFWS, 2003) due, in part, to the availability of suitable cliff-nesting habitat at Cape Lisburne and Cape Thompson (North America) and the Diomede Islands and surrounding coast (Chukotka). These cliff-nesting colonies occupy most of the habitat for thick-billed murres (*U. lomvia*) and black-legged kittiwakes (*Rissa tridactyla*) in the eastern and western Chukchi Sea, and they are the region's largest colonies, with more than 200,000 birds present at each location. During winter, the open water area around St. Lawrence Island supports the world population of the benthic-feeding spectacled eider (*Somateria fischeri;* Lovvorn et al., 2009; Larned et al., 2012).

The black guillemot (*Cepphus grille*) is a year-round BCB resident. This species nests on Cooper Island, approximately 40 km east of Utqiagvik in the Beaufort Sea, and overwinters in open water leads within the pack ice of the Chukchi and Beaufort seas. The nesting colony on Cooper Island was first described by Divoky et al. (1974) and has been monitored intensively each year for the past 40 years. This monitoring has demonstrated the importance of sea ice and Arctic cod to the breeding ecology and successful reproduction of the species (Divoky et al., 2015).

More than 70 species of marine birds visit the BCB region each year, and their numbers are in the millions. There are few resident species, and most migratory birds are present between May and November. Some species (e.g., eiders) winter in polynyas and at the ice edge. Spring migration for most species takes place between late March and late May. Arrival times coincide with the formation of shoreline leads off northwest Alaska, eastern Chukotka, and Amundsen Gulf. Since 2006, three seabird species have been reported in the eastern Chukchi Sea for the first time: short-tailed albatross (*Phoebastria albatrus*), northern gannet (*Morus bassanus*), and rhinoceros auklet (*Cerorhinca monocerata*) (Day et al., 2013a). Sometime prior to 2006, ancient murrelet (*Synthliboramphus antiquus*) expanded its usual maritime range northward into the eastern Chukchi and now has reached the Beaufort Sea (Day et al., 2013a).

Sea ducks migrate in large flocks to and from nesting grounds in Alaska, Russia, and the Canadian Arctic, and are important subsistence species (Dickson and Gilchrist, 2002; ACIA, 2005). Derksen et al. (2015) described the phenology, habitats, and status of sea ducks in the BCB region. Coastal lagoons, especially in the Beaufort Sea, are important shoreline staging areas for post-breeding and juvenile birds (late July and early August) prior to freeze-up (mid-September). Fifteen species are known to nest in coastal habitats and to winter nearby in southern open water marine habitats.

Spectacled eider and Steller's eider (*Polysticta stelleri*) are of international conservation concern and are listed as threatened under the US Endangered Species Act (Bowman et al., 2015). Spectacled eiders are uniquely adapted to extreme Arctic conditions and environments, including sea ice and tundra ecosystems (Derksen et al., 2015). Most of the world's population breeds along the Arctic coast of Russia, with important delta habitats at the Indigirka and Kolyma rivers. In Alaska, populations are currently stable on the Arctic coastal plain (~6400 birds) and increasing in the Yukon-Kuskokwim Delta (~6000 nests; Bowman et al., 2015). Estimates of the wintering population size range from 305,000 to 375,000 birds (Bowman et al., 2015).

A number of bird habitat areas in the BCB region are of national, continental, and global importance (Figure 3.11). These Important Bird Areas (IBAs) are sites that provide essential habitat for one or more species, as determined by management authorities. International significance is reflected in their distribution in the Chukchi and Beaufort Large Marine Ecosystem areas (Skjoldal and Mundy, 2013). IBAs include sites for breeding, wintering, or migrating birds, and range in size from very tiny patches of habitat (<5 km$^2$) to large tracts of land or water (>10,000s km$^2$). Usually they are discrete sites that stand out from the surrounding landscape. The concentration of IBAs in the Bering Strait region is indicative of the land–sea components and relationships in seabird ecology and the oceanography in this part of the northern Bering and Chukchi seas.

Marine mammals are apex consumers in BCB marine ecosystems and are valued subsistence resources. The status of resident populations has been reviewed relative to regional trends in sea ice conditions, functional habitat relationships, and animal diversity patterns (Laidre et al., 2015). Two cetaceans (beluga and bowhead whale), five pinnipeds (ringed seal, bearded seal, spotted seal *Phoca largha*, ribbon seal *Histriophoca fasciata*, and Pacific walrus) and the polar bear were reviewed. Walruses and some seals are sea-ice obligates – distinct from the ice-associated mammals that use sea ice habitats but are not completely reliant on them (e.g., bowheads and polar bears). Collectively, these obligate and ice-associated species will be most directly affected by changes in sea ice as it relates to foraging, reproduction, resting, and other behaviors (Table 3.9).

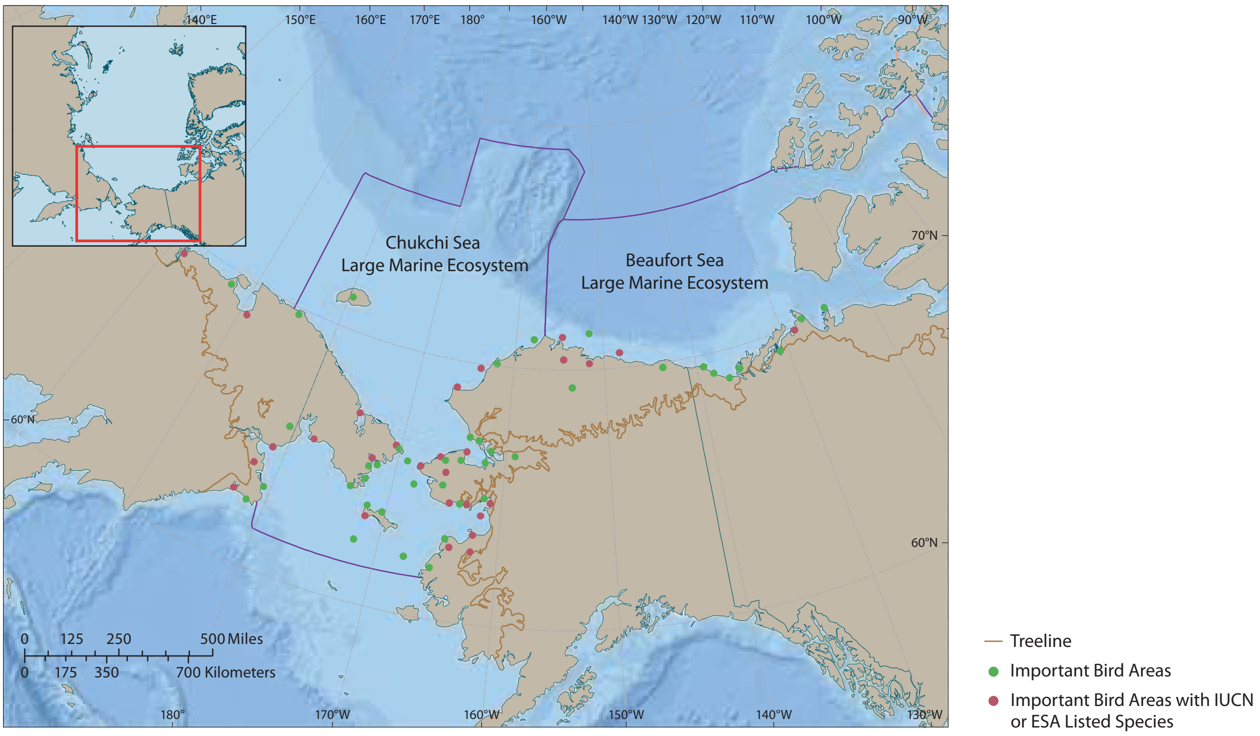


Figure 3.11 Locations of Important Bird Areas (IBAs) in the BCB region (Audubon Alaska, 2014; Bird Studies Canada, 2015; BirdLife International, 2015).

Table 3.9. Status of selected marine mammals and their vulnerability to climate change in the BCB region (DeGange and Thorsteinson, 2011; Laidre et al., 2015). Climate vulnerability estimates are based on conservation status and potential changes in species ranges, foraging habitats, and sea ice dependencies (Laidre et al., 2015).

| Species | Subpopulation or stock | Minimum population size | Population status | Climate vulnerability |
|---|---|---|---|---|
| Beluga | Eastern Siberian and Western Chukchi | Unknown | Unknown | Low |
| | Eastern Chukchi | 3,700 | Unknown | |
| | Eastern Beaufort | 39,258 | Unknown | |
| | Eastern Bering | 18,000 | Unknown | |
| | Gulf of Anadyr | 15,127 | Unknown | |
| Bowhead whale | Bering-Chukchi-Beaufort | 15,704–18,928 | Unknown | High |
| Ringed seal | Beaufort and Chukchi Seas | 1,000,000 | Unknown | High |
| | Bering Sea | 34,0000 | Unknown | |
| | White, Barents, Kara, and East Siberian seas | 220,000 | Unknown | |
| Bearded seal | Bering Sea | >299,000 | Unknown | High |
| | Chukchi Sea | 27,000 | Unknown | |
| | Beaufort Sea | Unknown | Unknown | |
| | East Siberian Sea | Unknown | Unknown | |
| | Canada waters | 190,000 | Unknown | |
| Spotted seal | Bering Sea | >460,000 | Unknown | Low |
| Ribbon seal | Bering Sea | 143,000 | Unknown | High |
| Pacific walrus | Bering-Chukchi seas | ~129,000 (55,000–507,000) | Unknown | High |
| Polar bear | Chukchi | Unknown | Unknown | High |
| | Southern Beaufort | 900 (606–1,212) | Declining | |
| | Northern Beaufort | 980 (825–1,135) | Stable | |
| | Viscount Melville | 161 | Unknown | |
| | M'Clintock Channel | 284 | Increasing | |

Large-scale changes in seasonal sea ice and other habitat conditions will directly or indirectly affect BCB marine mammal populations. Seasonal and resident species may be affected differently (Jay et al., 2012; Allen and Angliss, 2013; Moore and Stabeno, 2015). The seasonal residents include orcas (*Orcinus orca*; throughout the BCB region) and harbor porpoise (*Phocoena phocoena*; throughout the Chukchi Sea), gray whales (throughout the region), and sea lions (Bering Strait and southward). Rarer occurrences include reporting of fin whales (*Balaenoptera physalus*), humpback whales (*Megaptera novaeangliae*; northern Bering Sea), minke whales (*B. acutorostrata*; northern Bering and Chukchi seas), and narwhal (*Monodon monoceros*; circum-Arctic distribution). Seasonal migrations and more localized movements are common in marine mammals inhabiting the BCB region. Species patterns generally relate to predation and the bioenergetic benefits conferred by foraging near the ice edge. For some species (e.g., the bowhead whale), seasonal habitats for overwintering and breeding are in the Bering Sea and summer and autumn foraging areas are in the Chukchi and Beaufort seas (Moore and Reeves, 1993; Wynne, 1997; Figure 3.12). Some North Pacific species (e.g., fin, minke, humpback, and orcas) have been observed in the Chukchi Sea following the retreat of the sea ice during late summer and autumn, presumably to take advantage of seasonally abundant prey (Clarke et al., 2013, 2014). Pelagic foragers include beluga and bowhead whales; ringed, spotted, and ribbon seals; and polar bears. Common benthic foragers include walruses, bearded seals, and gray whales (Highsmith et al., 2006; Dehn et al., 2007). Bowhead whales feed on epibenthic as well as pelagic prey (Moore et al., 2010).

Beluga and bowhead whales and bearded and ringed seals have special importance to the nutrition and cultures of BCB communities (e.g., Quakenbush and Huntington, 2010; Allen and Angliss, 2013). The Bering-Chukchi-Beaufort stock of bowhead whales inhabits the Beaufort Sea from late spring to early autumn (e.g., Moore and Laidre, 2006; Quakenbush et al., 2010; Citta et al., 2014), where they feed on dense aggregations of zooplankton (Lowry, 1993). Some bearded seals are probably year-round residents of the Beaufort Sea, using leads, polynyas, or areas of broken ice in winter (Stirling, 1997). Two distinct populations of beluga exist in the eastern Chukchi and eastern Beaufort seas (e.g., Hauser et al., 2014; unpublished data,

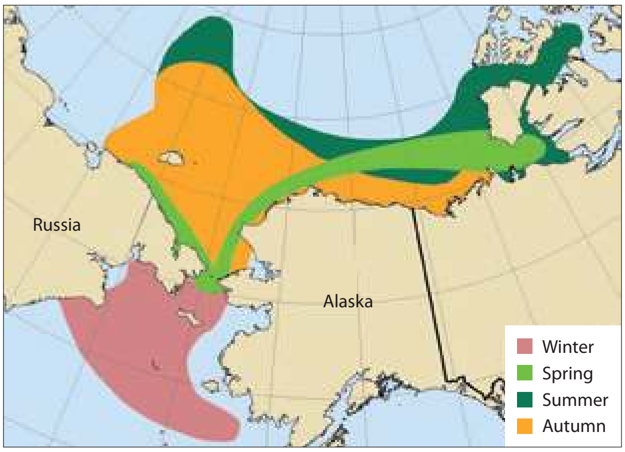


Figure 3.12 Generalized range and seasonal migration of bowhead whales (Quakenbush, L., Alaska Department of Fish and Game).

North Slope Borough). They are piscivorous and frequently encountered at the shelf break.

The shallow continental shelves in the northern Bering and Chukchi seas represent the largest continuous expanse of preferred habitat for bearded seals in the world (Burns and Frost, 1979; Lowry et al., 1980). Only bearded and ringed seals are believed to overwinter in the Beaufort Sea, although changes in sea ice extent and thickness may induce changes in the phenology of these species (Moore and Huntington, 2008). Bearded and ringed seals rely on sea ice during the breeding season, and limited tagging studies have provided evidence that both species exhibit breeding site fidelity (Kelly et al., 2010; Boveng and Cameron, 2013). Ringed seals are particularly dependent upon sea ice for breeding because they give birth in lairs (snow caves) that they dig in sea ice (Furgal et al., 1996).

## 3.4.2 Terrestrial ecosystems

### 3.4.2.1 Lower trophic levels: vegetation

Most of the BCB tundra vegetation is characteristic of the Arctic tundra biome and varies from shrub tundra in the south (bioclimate subzone E), where plant communities have all the plant life forms known in the Arctic and have continuous canopies in several layers dominated by erect shrubs, to polar desert in northern Chukotka (bioclimate subzone A), where vegetation colonizes 5% or less of the ground surface, is less than 10 cm high, and is dominated by herbs, lichens, and mosses (CAVM Team, 2003). Species richness in the Arctic tundra is low and decreases toward the north: there are about 1800 species of vascular plants; 4000 species of cryptogams (Chernov, 2002); and thousands of prokaryotic species (bacteria and Archaea) whose diversity in the tundra is unknown (ACIA, 2005). Alaskan tundra vegetation has greater species diversity than other tundra in the High Arctic regions (Walker, 2010). The physiographic regions of the BCB (Figure 3.13) are indicative of similarities in the vegetation found in Chukotka and northwestern Alaska. Figure 3.13 is a generalized version of the Circumpolar Arctic Vegetation Map (CAVM Team, 2003). The original map has more detail in the mountainous areas and contains an expanded legend (Walker et al., 2005). Changes in the treeline zone are occurring throughout the region (e.g., MacDonald et al., 2008; Olthof and Pouliot, 2010). Although not shown in Figure 3.13, the tundra vegetation of the Yukon-Kuskowim Delta is similar to that associated with the continuous permafrost of Wrangel Island and northern Alaska (CAVM Team, 2003).

The vegetation of the BCB region is a nearly continuous carpet of plants less than about 50 cm in height – mainly sedges, low shrubs, and mosses. Lichens, forbs, grasses, and horsetails are also common in some areas. Shrubs are taller along drainages and in western Alaska. Trees are mostly absent, except for groves of small balsam poplar (*Populus balsamifera*) at warmer inland locations (e.g., Yukon) and small larch, pine, birch, poplar, and willow trees at coastal/river valley sites (e.g., Gulf of Anadyr). The western and central Canadian Arctic region extends from the northern extent of the boreal forest to the High Arctic tundra (Outridge et al., 2015). Tundra vegetation in this region spans sparse woodland at treeline, shrub tundra, wetlands, and High Arctic tundra. In the shrub tundra, tall shrub species such as willows (*Salix* spp.), alder (*Alnus* spp.), and dwarf birches (*Betula* spp.) dominate, with canopy heights of 40–400 cm. At higher latitudes, dwarf shrubs less than 40 cm high (*Arctostaphylos* spp., *Ledum decumbens*, *Empetrum nigrum*, and *Vaccinium* spp.) and sedges (*Carex* spp. and *Eriophorum* spp.) predominate. Further north, erect dwarf

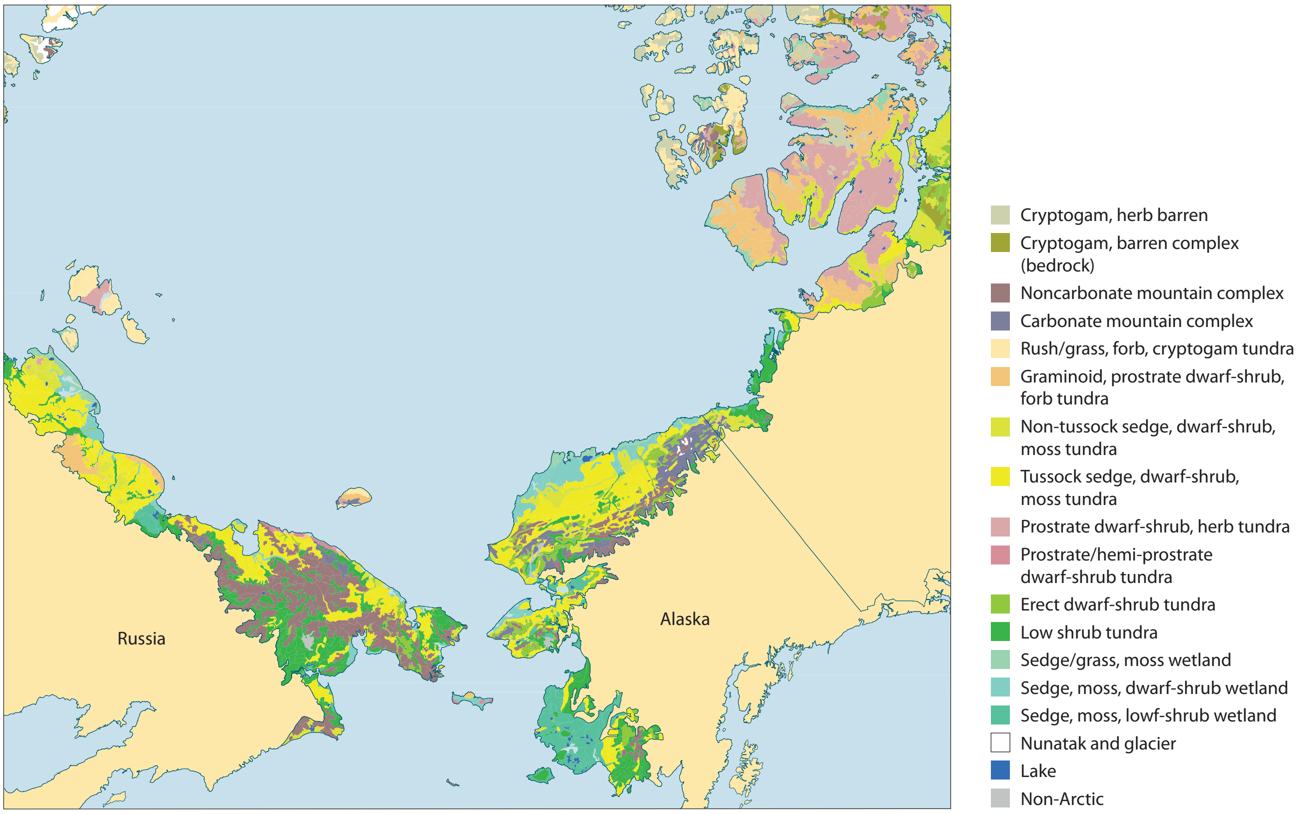


Figure 3.13 Physiography of the BCB region (CAVM Team, 2003).

*River flowing through open tundra near Provideniya, Beringia National Park, Chukotka*

shrubs are replaced by prostrate dwarf shrubs and forbs less than 10 cm high (*Cassiope tetragona*, *Dryas integrifolia*, *Draba* spp., and *Saxifraga* spp.).

Recent satellite-based studies indicate widespread and matching patterns of increased temperature and normalized difference vegetation index (NDVI) values and a corresponding lengthening of the vegetation growing season throughout northern lands (Jia et al., 2006, 2009; Xu et al., 2013; Guay et al., 2014), although this so-called 'greening' of tundra biomes appears to have ceased or even reversed since 2011 (Bhatt et al., 2013).

#### 3.4.2.2 Key vegetation processes

Many factors influence the diversity, composition, and abundance of tundra vegetation, including temperature and light, age since deglaciation, nutrient availability, and other soil properties (i.e., temperature, moisture, and chemistry; Chapin et al., 1995; Walker et al., 1998; Sturm et al., 2001; Callaghan et al., 2005; Christie et al., 2015).

The portion of the soil above permafrost – the active soil layer, which thaws and freezes seasonally – has critical roles in tundra ecology and northern hydrology. Depending on the location and year, maximum thaw depths range from 0.3 m to more than 1.0 m (Sturm et al., 2005). Because the permafrost is nearly impermeable to water infiltration, the active layer is often saturated, far more so than would be expected in the BCB climate. Zonal vegetation is strongly linked to active-layer regimes across the summer climate gradient in northern Alaska. Active layers are affected by two opposing trends along the climate gradient: higher air temperatures promote deeper thaw, but this is countered by the insulation provided by denser plant canopies and thicker soil organic horizons. Thus, the increased warming associated with climate change will not necessarily lead to uniform thickening of the active layer (Walker et al., 2003).

Evapotranspiration in the Arctic is controlled mainly by climate, soil water availability, and vegetation structure and function. In the BCB region, evapotranspiration is generally low, related to the region's cold soil and low air temperatures and the lower productivity of tundra vegetation relative to southern biomes.

#### 3.4.2.3 Upper trophic levels: birds and mammals

The BCB region supports many species of seasonally resident land birds. Population estimates are available for very few land birds, mainly for those with very small populations. The species are distributed in small numbers across many families. Most families are represented by small passerine species. For example, in Chukotka, 114 species have been reported from 28 families, and within 19 of these 28 families, 90 passerines have been classified (Bird Studies Canada, 2016). In the Arctic, there are several species of raptors, which play an important role as top predators in the tundra food web (Legagneux et al., 2012; Outridge et al., 2015).

The ptarmigans (*Lagopus* spp.) and snow buntings (*Plectrophenax* spp.) are the only two landbird genera endemic to the Arctic, subarctic and contiguous mountains (Ganter and Gaston, 2013). Several landbird species breed only in the Low and High Arctic, including the snowy owl (*Bubo scandiacus*), gyrfalcon (*Falco rusticolus*), rough-legged buzzard (*Buteo lagopus*), and Arctic redpoll (*Acanthis hornemanni*) (Ganter and Gaston, 2013). Only six species remain in the Arctic over the winter: the two ptarmigans, raven (*Corvus corax*), snowy owl, gyrfalcon, and Arctic redpoll (Granter and Gaston, 2013). The Naumann's thrush (*Turdus naumanni*) and dusky thrush (*T. eunomus*) are breeding endemics in Chukotka; the Siberian accentor (*Prunella montanella*) and Taiga nuthatch (*Sitta arctica*) are endemic to Chukotka (Bird Studies Canada, 2015).

The tundra ecosystem is relatively simple with respect to vegetation structure and energetic pathways leading to small- and large-sized herbivores and carnivorous predators. The mammal portion of the tundra food web has two main branches, which are defined by the body size of the herbivores. Herbivore body size is a major determinant of predator success, with large herbivores mostly escaping predation (Legagneux et al., 2014).

The large herbivore branch includes Dall's sheep (*Ovis dalli*), muskoxen (*Ovibos moschatus*), and moose (*Alces alces*). The smaller Arctic hare (*Lepus arcticus*) is grouped with the large herbivores and, like them, is an important traditional food. The populations of large herbivores, especially caribou and muskoxen, appear to be primarily food-limited; these animals consume a relatively large proportion of the annual production of their key foods and experience relatively little predation mortality from only a few large carnivores that themselves appear food-limited (Krebs et al., 2003; Legagneux et al., 2012). Herbivores at high densities can severely deplete the abundance of key food plants such as lichens, and unusual snow conditions (very deep or hard snow) can limit access to food (Miller, 2003).

Small mammal herbivores occur at intermediate trophic levels in tundra food webs. Species in this group include voles, lemmings, Arctic ground squirrels, and pika (*Ochotona* spp.). Small herbivore populations, notably the brown lemming (*Lemmus trimucronatus*), collared lemming (*Dicrostonyx groenlandicus*), and tundra vole (*Microtus economus*), are limited most strongly by predation by a large suite of competing mammalian and avian predators.

Lemmings are the preferred prey of many predators, so predation pressure on other species is reduced when lemming densities are high (Summers et al., 1998). Lemmings and voles go through periodic population fluctuations in many North American Arctic regions.

Large predators occur in low densities and include brown bears (*Ursus arctos*), polar bears and wolves (*Canis lupus* and subspecies). Four of the 19 Arctic polar bear populations (Laptev Sea, Chukchi Sea, Southern Beaufort Sea, and Northern Beaufort Sea) are present in the BCB region. Here, sea ice melts and drifts away from the coast during the late summer and autumn; historically, polar bears have remained with the sea ice during this period (Oakley et al., 2012; Pagano et al., 2012). As sea ice melt now occurs earlier and more extensively, more polar bears are choosing to move onshore when the ice recedes (Oakley et al., 2012). Other common smaller predators include weasels (*Mustela nivalis*), wolverines (*Gulo gulo*), Arctic and red foxes (*Vulpes lagopus* and *V. vulpes*, respectively), and American mink (*Neovison vison*).

### Caribou and reindeer

Caribou and reindeer are an important subsistence resource for rural and Indigenous peoples throughout the North. Indeed, Arctic communities are culturally and nutritionally reliant on caribou, as this ungulate serves as a primary source of terrestrial protein (Hummel and Ray, 2008). Caribou are medium-sized herbivores that dwell in forests and tundra from coasts to mountain ranges over a large latitudinal gradient (50°N to 80°N; Blix, 2005). Diverse behavioral and physiological adaptations, such as migration, gregariousness, and timing of reproduction (Bergerud, 1996; Barboza and Parker, 2008), are used to respond to changes in environmental conditions, forage availability, and risk of predation.

Arctic-dwelling migratory caribou are highly gregarious, occur at high localized densities, aggregate on calving grounds to bear young, undergo long seasonal migrations, and have very large annual ranges (Figure 3.14). These caribou typically migrate to the Arctic tundra for the growing season and winter in the boreal forest and the forest–tundra interface (Russell and Martell, 1984; Festa-Bianchet et al., 2011). In the Alaskan and northwestern Canadian Arctic, there are approximately 542,000 caribou in six migratory populations: Western and Central Arctic, Teshekpuk, Porcupine, Cape Bathurst, and Bluenose-West. Although population changes differ by herd, the total number of caribou in this area doubled from the

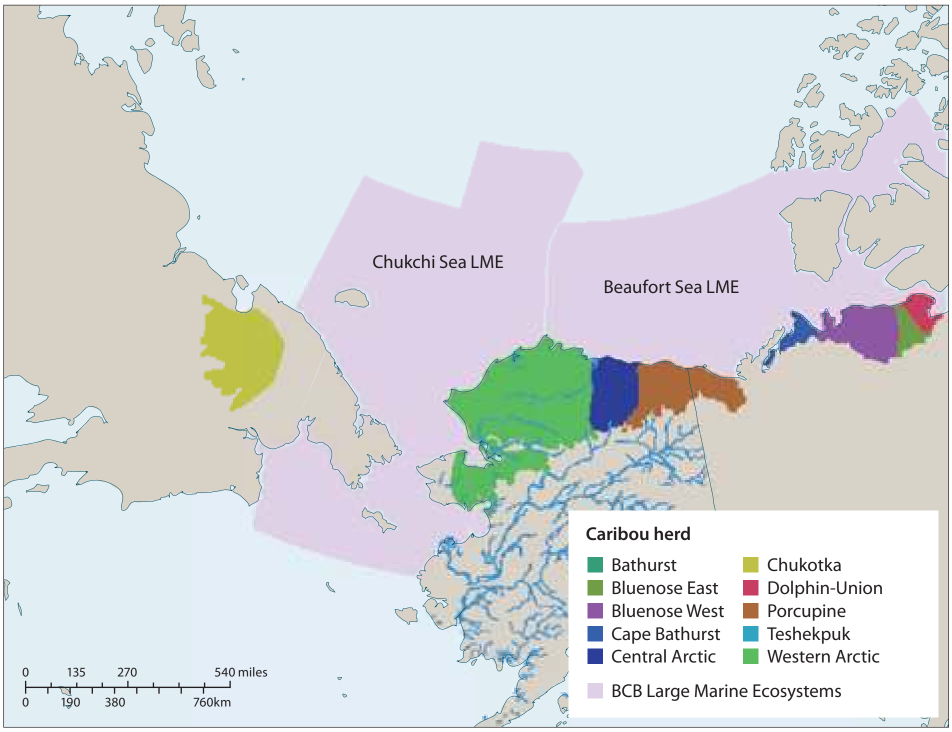


Figure 3.14 Distribution of caribou herds in the BCB region (CAFF, 2015b).

Table 3.10 Status of caribou herds in the BCB region (CAFF, 2015b; Parrett, 2015.)

| Herd name | Herd size | Census year | BCB nation | Herd status |
|---|---|---|---|---|
| Bathurst | 35,000 | 2012 | Canada | Stable |
| Bluenose-East | 98,600 | 2010 | Canada | Increasing |
| Bluenose-West | 20,000 | 2012 | Canada | Stable |
| Cape Bathurst | 2,400 | 2012 | Canada | Stable |
| Central Arctic | 70,034 | 2010 | United States | Increasing |
| Chokotka | 125,000 | 2002 | Russia | Increasing |
| Porcupine | 169,000 | 2010 | Canada/United States | Increasing |
| Teshekpuk Lake | 66,000 | 2011 | United States | Declining |
| Western Arctic | 200,000 | 2015 | United States | Declining |

1970s/1980s to the early 2000s (from approximately 468,000 to 915,000); by 2013, however, caribou abundance had declined in five of the six herds, to the current estimate of 786,000 (CAFF, 2015b).

In the four Alaskan herds, approximately 24,300 caribou are harvested each year. At ~45 kg of consumable protein per harvested caribou, that level of harvest provides almost 1.1 million kg of terrestrial protein for northern communities, with a beef replacement value of approximately USD 21.9 million (CAFF, 2015b). Douglas and Chan (2015) found caribou to be the most preferred traditional food in the Inuvialuit Settlement Region. It is an especially important species in Chukotka's mixed cash/subsistence economy. The status of the BCB herds is now generally stable or increasing, after declines over much of the past 50 years (Table 3.10).

Winter starvation is thought to have been responsible for some of the declines in caribou herds in the BCB region during the last 50 years (e.g., Miller and Gunn, 2003). More recently, the Western Arctic herd has declined from a high of 490,000 animals in 2003 to 200,000 in 2015. These starvation-induced die-offs are strongly correlated with severe winters – in particular, with ice-crusting events that restrict access to forage (e.g., Miller and Barry, 2009). The adverse effects of reduced access to food in winter are more pronounced when caribou are at relatively high densities; herds at low densities may be able to cope with difficult winters when per capita food abundance is still high (Ferguson, 1996; Tyler, 2010).

## 3.4.3 Freshwater ecosystems

Freshwaters sustain life and ecosystem functions and are sensitive to changes in the hydrological cycle (White et al., 2007; Francis et al., 2009). The freshwater landscapes of the BCB region are geologically young, having been disturbed by Pleistocene glaciations and deglaciation (Pielou, 1994; Payer et al., 2014). Glacier processes largely shaped the patterns of freshwater distribution, locations of habitats, and, in concert with other ecological factors, distributions of species on the landscape today (Chereshnev, 1998; Christiansen et al., 2014a).

Freshwater ecosystems in the BCB region exhibit large variations in size, characteristics, and location (Wrona et al., 2005; Prowse et al., 2006; Wrona and Reist, 2014; Outridge et al., 2015). The lotic (running water) systems include aquatic habitats in rivers, streams, deltas, and estuaries, where flow regimes are a dominant hydrological feature shaping their ecology. Brackish waters (<5 psu in estuaries and <25 psu in the coastal band; 5–10°C) overlap with the nearshore marine zone but are ecologically significant with respect to species adaptations (e.g., amphidromy in fishes) within the freshwater–estuarine continuum. Lentic (standing water) ecosystems include habitats in lakes, ponds, wetlands, and mudflats where standing water regimes are important.

Thermokarst lakes and drained basins cover much of the ice-rich, low-lying tundra of the BCB region (Hinkel et al., 2007), and mechanistic features of their hydrology and geomorphology have been described (Grosse et al., 2013). The lakes occur over underlying permafrost, are supplied by spring melt and rainfall, and are altered by seasonal warming and permafrost degradation. Warmer or cooler lake surface temperature gradients along wind direction are found for both coastal and inland lakes (Huang et al., 2015). Small, deep lakes and lakes in inland and southern latitudes are likely to have higher mean temperatures than other lake types during the summer (Huang et al., 2015). A recent paleoecological analysis of Arctic lakes revealed relatively high taxonomic diversity and productivity of plankton in shallow lakes compared to assemblages in deeper lakes (Smol et al., 2005).

### 3.4.3.1 Lower trophic levels: aquatic invertebrates

Invertebrate functions in freshwater ecosystems include herbivory, decomposition, nutrient cycling, pollination, parasitism, and predation (Hodkinson et al., 2013). The key environmental factors determining species success are thought to include mean summer and winter temperatures, soil moisture availability, length of growing season, and the frequency of freeze–thaw events that may disrupt preparation for and emergence from the overwintering state (Hodkinson et al., 2013).

### 3.4.3.2 Higher trophic levels: fishes and birds

The diversity of species and abundance of freshwater fishes is relatively low and highly variable in the BBC region. One family, the Salmonidae (i.e., char, salmon and trout, and whitefishes) comprises many species and is of particular human importance. Other families, such as Esocidae (pike), Gadidae (burbot), and Osmeridae (smelts), are also harvested but are of less prominence in subsistence fisheries. The salmonids are of large size, are easily exploited, and are a favored traditional food. In the BCB region, the most dominant species are Pacific salmon; Arctic char, Dolly Varden, and lake trout (*Salvelinus namaycush*); inconnu;

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*Chukchi boy fishing for grayling in the Matachingay River, Iultinsky District, Chukotka*

robin chittenden / Alamy Stock Photo

*Canada goose (Branta canadensis)*

Arctic, least, and Bering ciscos (*Coregonus laurette*); and broad, humpback, and round whitefish (*Prosopium cylindraceum*).

The large rivers of the BCB region are centers of high fish diversity and are probable sources of dispersal in the region. The Mackenzie River is the second largest river in North America and is home to 41 fish species. With exceptions, most of the salmonids reported from the Mackenzie River are reported elsewhere in the region. In the eastern part of the BCB region, salmon are abundant as far north as Kotzebue Sound; in Chukotka, they appear to be dispersed across the northeast region in higher abundance than in northern Alaska and Canada. Char, broad whitefish (in the Kotzebue area of Alaska), least cisco, humpback and round whitefish, and inconnu are abundant salmonids of northwest Alaska and northeast Chukotka. Regional differences in salmonid composition and productivity between the northeastern Chukchi Sea and southeastern Beaufort Sea are related to differences in stream size and freshwater runoff. Low salmonid abundance along the Chukchi coast has been related to the small size of the streams draining tundra habitat (<100 km long) and persistent marine conditions (Craig, 1989). In Chukotka, the pygmy whitefish (*Prosopium coulterii*) is found in the Amguema River basin; the Kolyma region includes the northernmost localities of the round whitefish and Eurasian minnow (*Phoxinus phoxinus*).

Mountain streams, especially those having perennial springs that do not freeze during winter, are important to Dolly Varden, Arctic grayling (*Thymallus arcticus*), and round whitefish in the eastern Brooks Range. To the west, coastal plain streams meander through a network of lakes and provide important habitat for whitefishes, ciscos, grayling, and other freshwater forms. Tundra streams are important for grayling. Similar habitat relationships are found in the eastern Brooks Range in western Canada. The large rivers draining the Canadian tundra to the east are important for char, whitefishes, and grayling. Arctic ciscos are less abundant to the east of the Mackenzie River than in northern Alaska.

In Chukotka, rapidly flowing rivers draining mountains and foothills are important for salmon and char. Slow-flowing rivers within a network of lakes on the coastal plain are characterized by freshwater fishes reflecting the Siberian assemblage. This assemblage is common to the large rivers of northern Siberia and includes Arctic char, humpback whitefish, least (sardine) cisco, grayling, and burbot (Chereshnev, 2008).

Although the diversity of resident birds is low compared to temperate regions, the numbers and abundances of migratory species using inland freshwater and delta habitats during summer is especially significant considering their long-distance migrations (Ganter and Gaston, 2013). In some instances, large segments of North American and world populations of migratory geese and waterfowl are found in BCB habitats (Ganter and Gaston, 2013). The physical extent and productivity of freshwater ecosystems and the quality of these habitats for nesting and foraging birds, in concert with relatively low predation pressure, factor heavily into migratory strategies and reproductive success.

Geese and swans are the largest of the waterfowl that use lowland and delta areas of the BCB region. The tundra swan (*Cygnus columbianus*) and four species of geese – the greater white-fronted goose (*Anser albifrons*), lesser snow goose (*Chen caerulescens*), Pacific brant (*Branta bernicla nigricans*), and Canada goose (*B. canadensis*) – exploit these habitats during the summer months. Tundra swans are a common breeding bird on tundra habitats of the Yukon-Kuskokwim Delta and the coasts of the Beaufort and Chukchi seas. Tundra swans that nest on the coast of the Beaufort Sea winter in the Atlantic Flyway (Figure 3.15), and marked swans that nest along coast of the Chukchi Sea winter in the Pacific Americas West Flyway. The

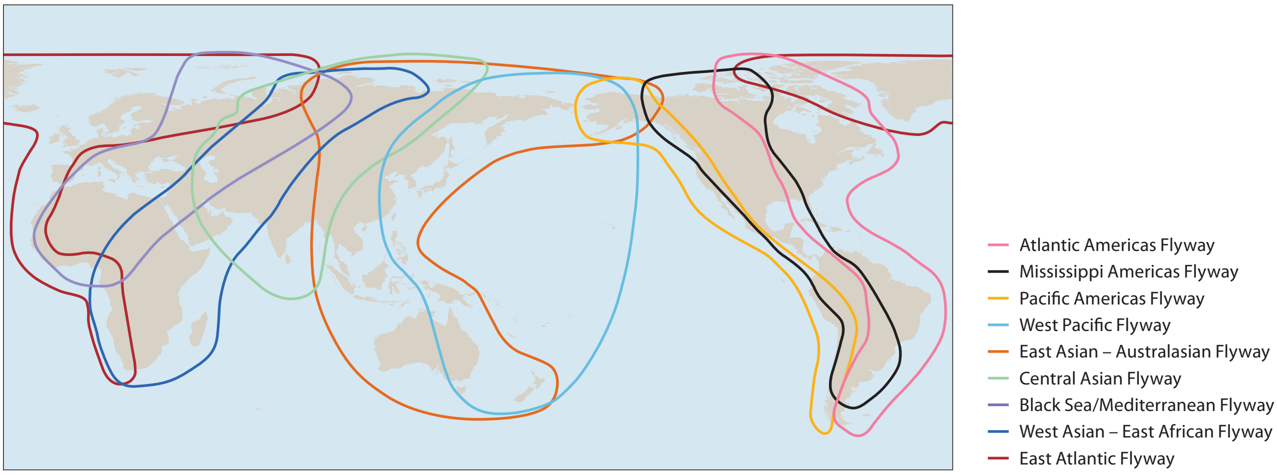

Figure 3.15 Global flyways for migratory waterbirds (Ganter and Gaston, 2013).

East Asian–Australasian, West Pacific, Pacific Americas, and Mississippi Americas flyways are the main migration routes for BCB waterfowl. Figure 3.15 depicts the geographic ranges and overlaps of birds with summer habitats in Chukotka, Alaska, and western Arctic Canada.

All four species of geese breed in the BCB region. The most critical habitats for waterfowl species in the Beaufort and Chukchi Seas include areas for coastal nesting colonies, pre- and post-breeding staging habitats in estuaries (e.g., Kasegaluk Lagoon, Peard Bay, Smith Bay, Harrison Bay), and molting sites in the large-lake and coastal areas northeast of Teshekpuk Lake. Breeding Canada geese have increased in numbers on the Arctic Coastal Plain over the last two decades, although the density of molting birds in the Teshekpuk Lake area has remained relatively stable over the past three decades (Wilson, 2015).

The Teshekpuk Lake area in the National Petroleum Reserve in Alaska (NPR-A) is an internationally important habitat for molting Arctic-nesting geese, especially white-fronted, brant, and Canada geese. Many failed-nesting and non-nesting brant from the Yukon-Kuskokwim Delta migrate northward to molt in this area. Recent research suggests that brant are shifting molting sites within the NPR-A, from freshwater lakes to coastal areas, perhaps in response to ecosystem changes related to saltwater intrusion into freshwater marshes, which enhances growth of the saltwater-tolerant vegetation that brant favor (Flint et al., 2008; Lewis et al., 2009; Wilson, 2015).

Coastal areas of the BCB region support large numbers of breeding, staging, and migrating shorebirds. At least 29 species of shorebirds nest in Alaska, and the Arctic Coastal Plain of Alaska is considered one of the premier shorebird breeding areas in the world. Distributions of shorebird species vary within the area; in general, the largest numbers and the greatest diversity occur west of the Colville River, although certain sites east of the Colville River (for example, Prudhoe Bay and the Canning River delta) also have high species richness. The Alaska Shorebird Group (2008) identified a number of areas on the coasts of the Chukchi and Beaufort seas that are important to shorebirds. These include the Colville River Delta, the Canning River delta, Kasegaluk Lagoon, Peard Bay, Elson Lagoon, and shorelines and barrier islands along the coastal plain of the Arctic National Wildlife Refuge.

All shorebirds leave the Arctic Coastal Plain during the non-breeding season. Many undertake spectacular migrations to southern hemisphere wintering areas after gorging on invertebrates on western Alaska tidal flats (e.g., Gill et al., 2009, 2013). As a result, Alaskan-breeding shorebirds are vulnerable to a variety of threats outside of Alaska (Alaska Shorebird Group, 2008).

All Alaska breeding species of shorebirds are considered at risk. Alaska currently has 20 shorebird populations considered to be of high concern or imperiled and 21 populations of low to moderate concern. The Alaska Shorebird Group (2008) recognized American golden plover (*Pluvialis dominica*), upland sandpiper (*Bartramia longicauda*), whimbrel (*Numenius phaeopus*), bar-tailed godwit (*Limosa lapponica*), red knot (*Calidris canutus*), sanderling (*C. alba*), dunlin (*C. alpina*), and buff-breasted sandpiper (*Tryngites subruficollis*) as priority conservation species for the Arctic Coastal Plain. Many of these species, such as pectoral sandpiper (*C. melanotos*), western sandpiper (*C. mauri*), and semipalmated sandpiper (*C. pusilla*), as well as red phalarope (*Phalaropus fulicarius*) and red-necked phalarope (*P. lobatus*), use coastal areas for post-breeding and pre-migration feeding and could be vulnerable to development and oil spills.

## 3.5 Summary

The preceding sections have summarized the present status of the BCB region in terms of its physical environment; its human dimensions, including economies and political systems; and its ecosystems. These components are intertwined in a region where dependencies on the natural world are great and the sustainability of the mixed cash/subsistence economy, food security, and quality of life can be closely tied to ecosystem condition and health. For example, changes in ecosystems and their key processes can also affect human activities that are tied to the physical and biological environment. The wide range of impacts of regional change on humans is discussed in Chapter 5, following discussion of ongoing and projected future changes in the BCB region.

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# 4. Regional drivers and projections of regional change

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## Key messages

- ***Changes in the Bering-Chukchi-Beaufort (BCB) region are being driven by global as well as regional factors.***
- ***Changes in the physical climate of the Arctic are largely a manifestation of changes in global climate, associated with increasing concentrations of greenhouse gases.*** *Regional processes and feedbacks lead to Arctic warming that is substantially greater than the warming observed at lower latitudes.*
- ***Many physical changes are related to Arctic warming.*** *Examples include a reduction in the duration and amount of snow and sea ice coverage, warming and thawing of permafrost, and declining glacier area.*
- ***Climate model projections indicate that these physical changes, already being observed, will continue into the future even more rapidly.*** *The magnitude depends on the future pathway of global greenhouse gas emissions.*
- ***Surface air temperature in the BCB region has increased by approximately 1.5°C over the last 50 years.*** *Surface air temperature is projected to increase by 3–7°C by the end of this century.*
- ***Changes in physical climate are driving changes in other aspects of the BCB environment.*** *Examples include changes in terrestrial vegetation, coastal erosion, and marine productivity.*
- ***Change in the BCB region is also driven by global and regional socio-economic factors such as globalization of the economy, changing demand for mineral resources, increasing tourism, and potential increases in marine transportation through the Arctic.*** *Regional changes in population, lifestyle, and political and governance structures are also driving change.*
- ***Observed and projected reductions in sea ice cover and duration are particularly noteworthy in the BCB region.*** *These changes have potentially important ramifications for marine activities (e.g., offshore oil and gas exploration and development, shipping, tourism).*
- ***The BCB region is perhaps more heterogeneous than some other Arctic regions, with political and socio-economic situations differing significantly between Russia (Chukotka), the United States (Alaska), and northern Canada.*** *This heterogeneity is reflected in profound differences in historical and projected population growth and regional socio-economic drivers.*

## 4.1 Introduction

Change in the Arctic has many drivers. Global climate is changing as a result of human activities – primarily the emission of greenhouse gases – and that climate change is amplified in the Arctic. Physical quantities such as temperature, snow cover, sea ice, and permafrost are all experiencing changes, and these changes are projected to continue into the future. Other global factors also drive change in the Bering-Chukchi-Beaufort (BCB) region specifically. For example, changes in the global economy, demand for resources, international shipping, and the transport of pollutants in the atmosphere and ocean are all felt in the region.

Local drivers of change are also apparent, from shifting ecosystem boundaries, to population and demographic change, to pressures on local economies; all are driving changes that will affect residents, their health, and their livelihoods. This chapter provides an overview of some of these global and regional drivers of change, building upon the regional description provided in Chapter 3 and setting the stage for Chapter 5, which discusses the impacts these drivers of change for the BCB region.

This chapter is organized around a set of four questions, addressed in the following sections and then summarized at the end of the chapter.

*How are global factors driving change in the region?*

*How has climate changed in the past, and how much change is expected in the future?*

*What changes are occurring, and are projected to occur, in the regional marine and terrestrial ecosystems?*

*What changes are occurring, and are projected to occur, in regional socio-economic conditions and forms of governance?*

## 4.2 Global drivers of change

The Arctic is intimately and inextricably linked to changes – physical, social, economic, biogeochemical – that occur elsewhere on the planet. In some cases, these changes are amplified in the Arctic. For example, warming in the Arctic over the past century has occurred at a rate that is roughly double that of the global mean, particularly in winter, and this is illustrated in Figure 4.1. Global warming has been clearly linked to a human cause (primarily the emission of greenhouse gases) (IPCC, 2013a), and the amplification in the Arctic is, at least in part, a result of positive feedbacks involving sea ice and snow.

As the climate warms, the autumn onset of snow and ice accumulation is delayed, and its springtime melt occurs earlier. As a result, the extent of sea ice, particularly at the time of its annual minimum in September, has been declining over the

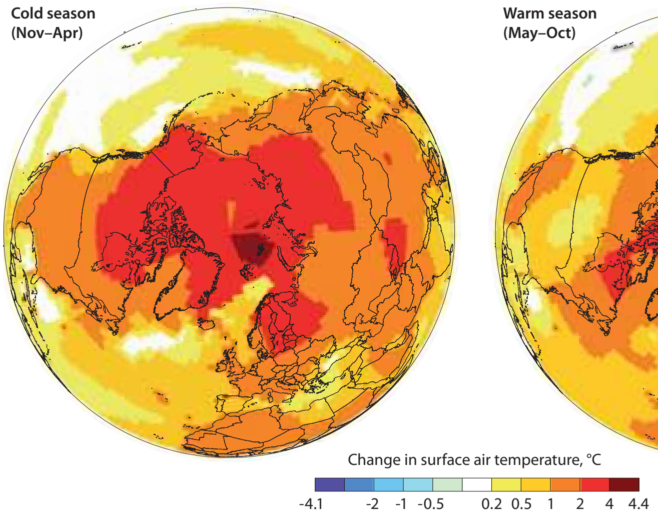


Figure 4.1 Historical trends in surface air temperature. Graphic shows the spatial pattern of Arctic warming for the period 1961–2014 in the cold season and warm season. Warm colors indicate warming trends and cool colors indicate cooling trends (NASA GISTEMP http://data.giss.nasa.gov/gistemp/maps/).

past few decades (as illustrated in Figure 4.2), and the number of days with sea ice on the ocean and snow on the ground has also seen a large-scale decline (Figures 4.3 and 4.4). These changes are having a profound effect on the ecology and socio-economy of the Arctic.

Socio-economic changes in the Arctic are also driven by other factors, such as global population growth and economic development (Andrew, 2014). These factors affect the demand for various mineral resources (e.g., oil, gas, metals), which are available, in some cases in large quantities, in the Arctic. Exploitation of these resources is strongly dependent on fluctuating commodity prices, and as evidenced by the recent downturn in global oil prices, this dependency can have rapid and profound implications for development activities and the economy at national, regional, and local levels.


Design Pics Inc / Alamy Stock Photo

*Whaling crew pushes their Umiaq off the Chuchki Sea ice at the end of the spring whaling season in Utqiagvik, Alaska*

Finally, the Arctic is susceptible to contaminants and pollutants that are emitted in other parts of the world and then transported to the Arctic. Examples include persistent organic pollutants and heavy metals, which can have impacts on ecosystem and human health. Black carbon and other short-lived climate pollutants also act to drive climate change in the Arctic, and these are the subject of other AMAP assessments (AMAP, 2015).

In summary, changes in the Arctic are driven, to a large extent, by influences on a much larger scale. Climate change is a global phenomenon driven primarily by human emissions of greenhouse gases, but the rate and magnitude of change is amplified in the Arctic. Of course, changes in the Arctic can also influence the global climate system through feedbacks involving, for example, sea ice and snow cover and midlatitude weather (e.g., Cohen et al., 2014). The economy of the Arctic is driven primarily by demand for resources and commodity prices, which are determined by various global factors. Pollutants from industrial activities at lower latitudes are transported into the Arctic via the atmosphere and ocean. Changes in the Arctic therefore cannot be viewed in isolation – and within the Arctic, all of these drivers interact to affect vulnerability to, and impacts of, a changing climate. Adaptation actions must therefore be planned and undertaken in the context of global environmental and socio-economic change.

The remainder of this chapter focuses on changes that have occurred and are projected to occur, specifically in the BCB region.

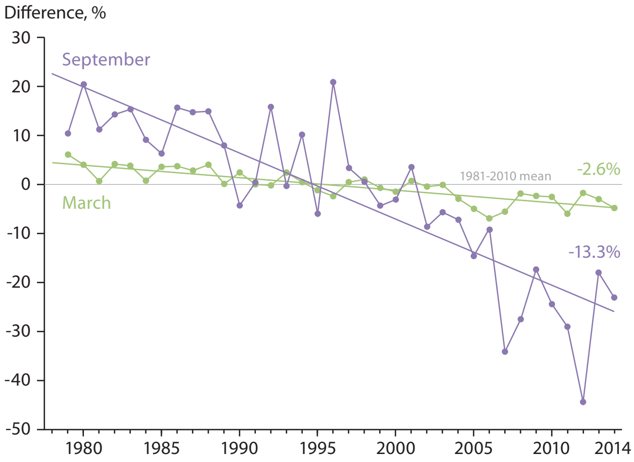


Figure 4.2 Historical trends in Arctic sea ice extent. Graphic shows anomalies in sea ice extent for March (month of maximum extent) and September (month of minimum extent). The anomaly value for each year is the difference in ice extent relative to the mean values for 1981–2010. The straight lines show least squares linear regressions and indicate ice losses of 2.6% (March) and 13.3% (September) per decade (Perovich et al., 2015).

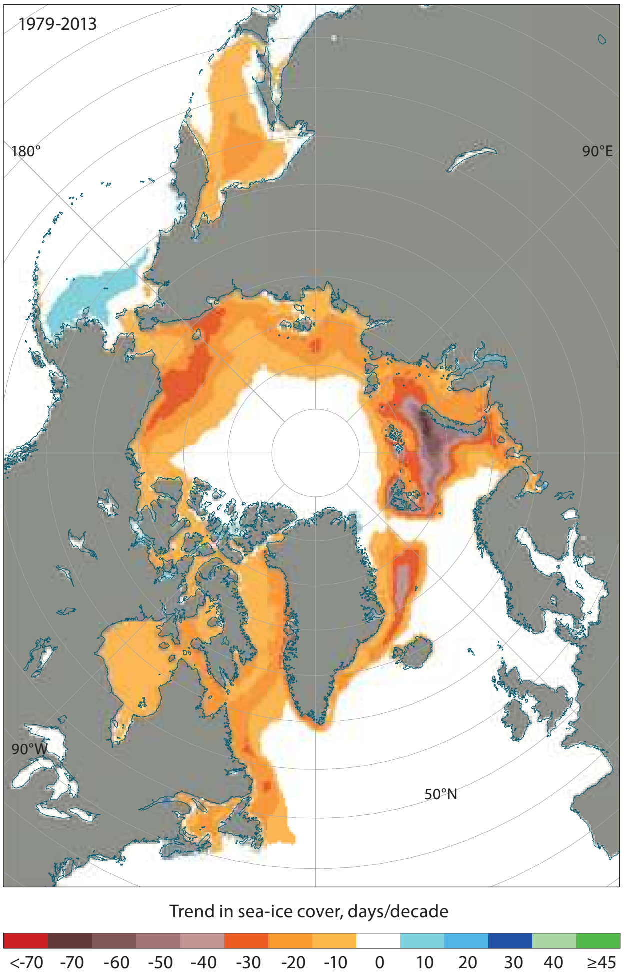


Figure 4.3 Historical trends in sea ice cover. Graphic shows spatial patterns in the number of ice-covered days per sea ice season over the period 1979-2013. Warm colors indicate shorter ice cover duration and cool colors indicate longer ice cover duration (Parkinson, 2014).

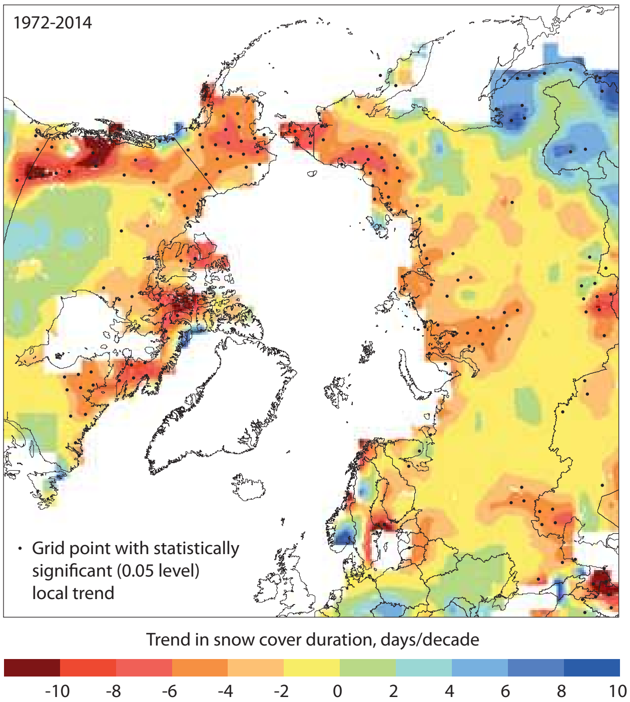


Figure 4.4 Historical trends in snow cover on land. Graphic shows spatial patterns in annual snow cover duration (the number of days with snow on the ground) from the NOAA Climate Data Record data set (Robinson et al., 2012) for the period 1972–2014. Warm colors indicate shorter snow seasons and cool colors indicate longer snow seasons.

## 4.3 Climate change in the BCB region

### 4.3.1 Historical climate change

Surface air temperature in the Arctic is increasing more quickly than the global average, and this warming is driving a host of changes in other components of the climate system. Local historical changes are evident from near-surface air temperature measured at various meteorological stations in the region. Figure 4.5 shows two examples of historical temperature trends: one observed in the Chukotka region (Russia) and the other at the Inuvik station in Canada (near the Mackenzie River Delta). The individual station time series exhibit interannual variability, which is a feature of climate everywhere, superimposed on a background trend driven primarily by increasing concentrations of greenhouse gases. This variability is important in that, regardless of future changes in mean climate, there will continue to be individual years that are anomalously warm or cold, and these variations must be accounted for in adaptation planning.

Temperatures have increased across northern Canada (Figure 4.5), consistent with the larger-scale trends described in the previous paragraphs. Temperature extremes, such as the extreme high daily maximum temperature, are also increasing (Figure 4.5). The cold extremes show greater warming than the warm extremes. Average regional temperature trends across Chukotka over the last ~45 years (1966–2012) are also positive (Ananicheva and Karpachevsky, 2015, 2016). Strong warming in the Russian Far East region as a whole has been observed in spring and autumn (RosHydromet, 2014).

Precipitation trends over the Canadian Arctic have been large, with increases of roughly 40% since 1948 (Zhang et al., 2000; as updated in Bush et al., 2014). Over the Chukotka region, by contrast, the trend has been a small decline – a less than 5% per decade decrease (Ananicheva and Karpachevsky, 2016).

Increasing temperature and changes in precipitation lead directly to changes in snow and sea ice amounts. For example, the amount of snow on the ground has been declining, as illustrated in Figure 4.6. The trends in snow water equivalent (the snow mass, given in terms of the equivalent depth of liquid water) are not uniform, however, with some parts of the region experiencing increasing trends and others experiencing decreasing trends. This pattern is a consequence of spatial variability in precipitation and, in some areas, changes in vegetation. It should also be noted that observations of snow depth or snow water equivalent are sparse, so there is considerable uncertainty in the detailed spatial pattern of this quantity. Figure 4.6 also illustrates trends in annual snow cover duration – that is, the number of days each year for which there is snow on the ground. Estimates based on two different data sets are shown, and they are generally consistent, with both indicating a decline in snow cover duration over much of the area.

Changes in both temperature and snowfall affect the mass balance of glaciers, and on a global basis, the decline in glacier extent is well documented (e.g., Jacob et al., 2012). The BCB region does not include the heavily glaciated mountains of southern Alaska, but it is worth noting that Alaskan glaciers in general are experiencing a substantial decline (Jacob et al., 2012). The small glaciers in the Chukotka region have lost substantial area since they were originally surveyed in the 1980s, and the equilibrium line altitude (i.e. the altitude of a glacier's isoline of zero mass balance) has shifted upward from approximately 500 to 1100 m (Ananicheva and Karpachevsky, 2015, 2016).

Warming of the air also has a direct effect on permafrost, as it leads to warming of the ground, permafrost thaw, and deepening of the seasonal active layer (the upper soil layer that thaws and refreezes each year). Figure 4.7 shows observed ground temperature measured at several points along a north–south transect in Alaska; in all cases, ground temperatures have been increasing over the period of record.

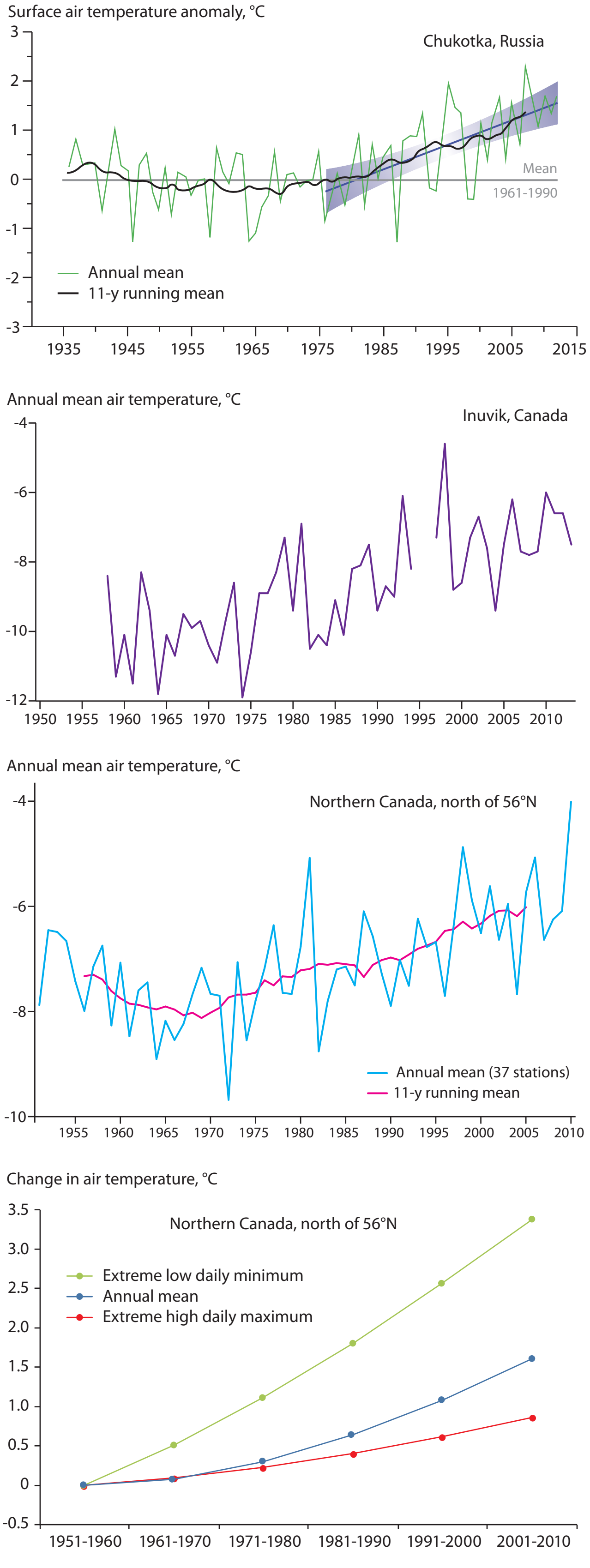


Figure 4.5 Historical trends in air temperature in the BCB region. Plots show spatially-averaged annual mean surface air temperature anomalies for the Chukotka region (based on RosHydromet, 2014); annual mean air temperature at Inuvik (from Environment Canada's Adjusted and Homogenized Climate Data and based on Vincent et al., 2012); annual mean air temperature averaged across northern Canada (based on Wang et al., 2013); and change in regional average (relative to 1951-1960) of the 20-year return values of extreme high daily maximum temperature and extreme low daily minimum temperature and the annual mean temperature (Wang et al., 2013). Return values represent the level that is attained, on average only once in 20 years.

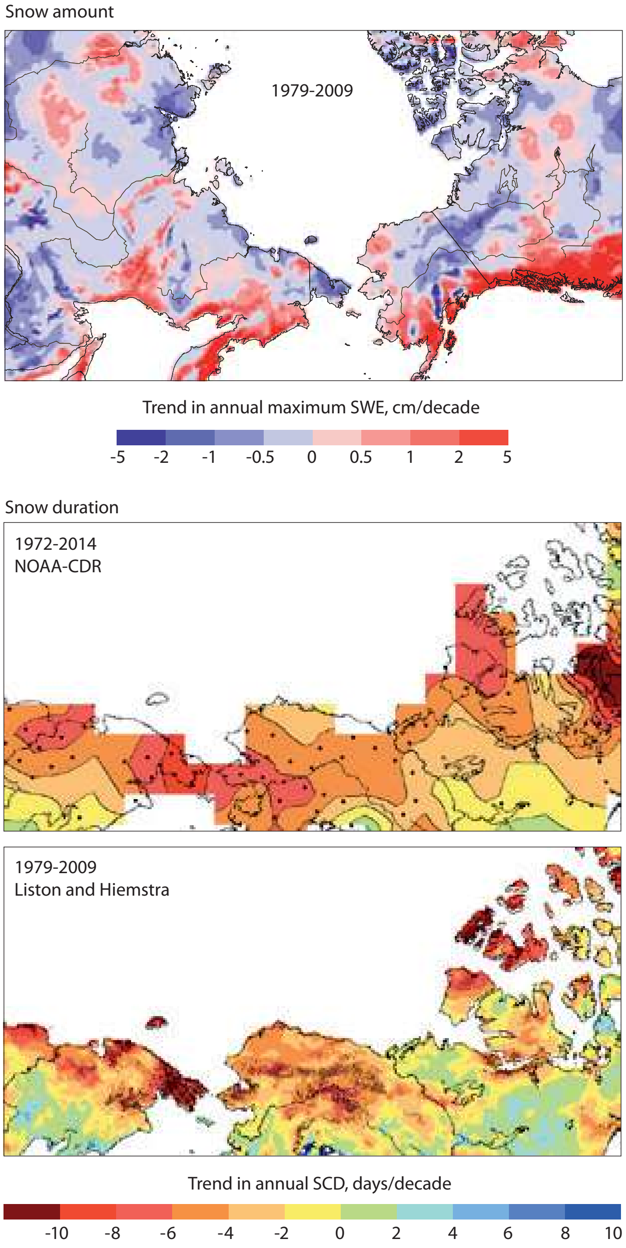


Figure 4.6 Historical trends in snow amount and duration in the BCB region. Plots show trends in annual maximum snow water equivalent (SWE) for the period 1979–2009, as estimated from the snow cover reconstruction of Liston and Hiemstra (2011), and trends in annual snow cover duration, as estimated from the NOAA CDR satellite record (Robinson et al., 2012) and the Liston and Hiemstra (2011) reconstruction.

The 2017 update to the Snow, Water, Ice and Permafrost in the Arctic (SWIPA) report (AMAP, 2017) provides much more detail on the current state of Arctic climate and recent trends and variations. The original SWIPA report (AMAP, 2011a) contains an extensive discussion of Arctic climate, and the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (IPCC, 2013a) summarizes observations in the atmosphere, ocean, and cryosphere domains. Although these reports are considerably broader in geographic scope than the current BCB report, they do provide a backdrop against which the projected changes discussed in the following text should be viewed.

Changes and variability are also apparent in the ocean. As noted in Section 4.2, sea ice extent has been declining, particularly in summer, over most of the Arctic as a whole. The BCB region is primarily in the so-called marginal ice zone, which is free of ice in the summer. Figure 4.8 shows a time series of daily sea ice extent in the Bering Sea from 1979 to present. Because there is no summer sea ice in this area, there is no summertime trend. The winter maximum ice extent is determined largely by ice growth, wind-driven transport, and proximity to warmer ocean water to the south. Although there is no discernible trend in winter maximum ice extent, there is an indication of enhanced variability since the early 2000s and a notable recent decline over the last five years. Both the largest and the smallest winter extents of the post-1979 period have been observed in the last five years (2012 and 2015, respectively).

The decline in Arctic-basin summertime sea ice extent has direct implications for ocean waves and hence coastal erosion. Using the

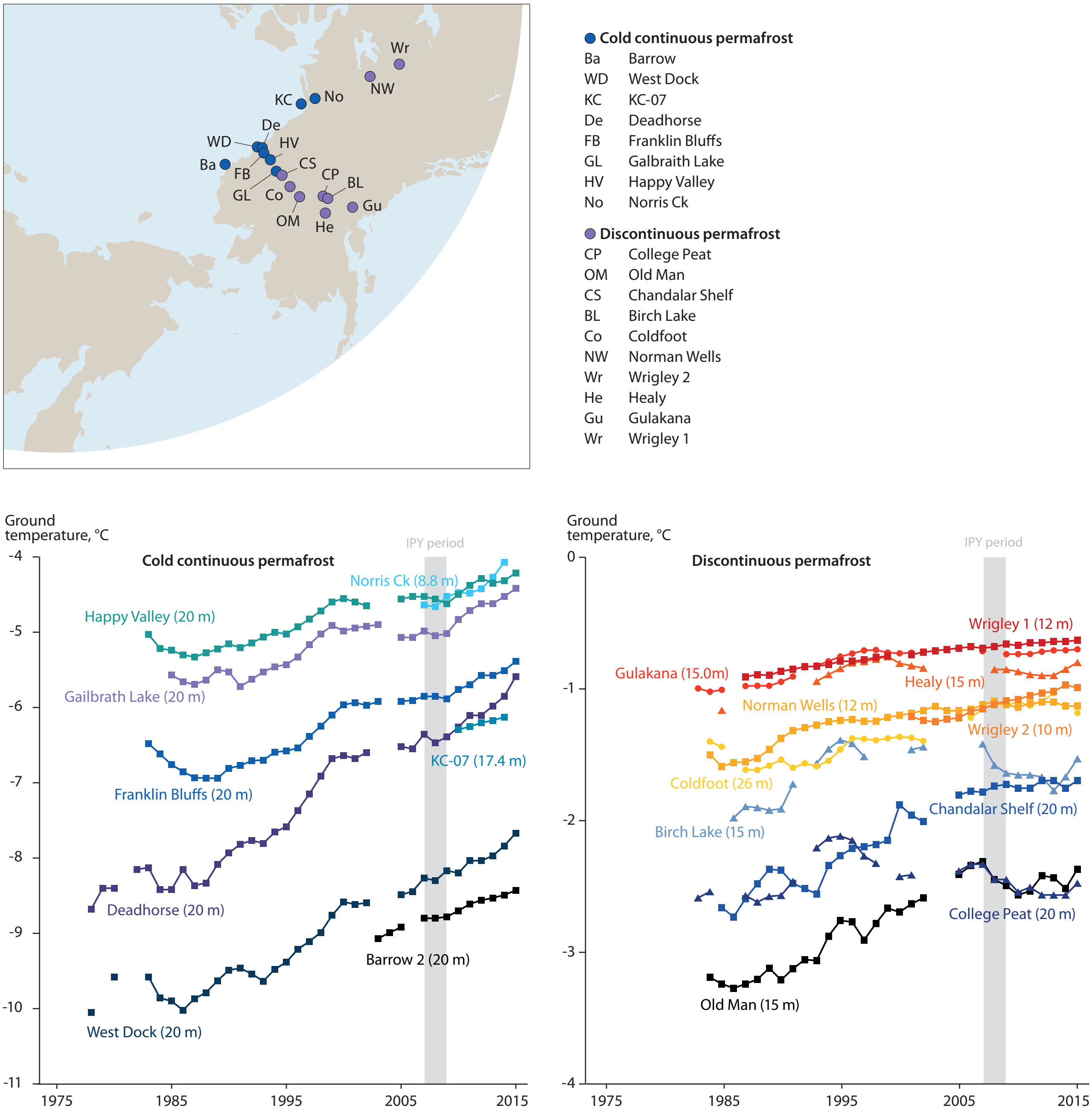


Figure 4.7 Historical trends in ground temperature in Alaska. Graphic shows time series of annual mean ground temperature at depths of 9 to 26 m below the surface at selected measurements sites in Alaska in both the zone of cold continuous permafrost and in the more southerly zone of discontinuous permafrost. Temperatures are measured at or near zero annual amplitude. Based on Romanovsky et al. (2012, 2014, 2015).

*Crests of breaking waves showing airborne spray and spindrift due to high winds*

only existing wave reanalysis for the Arctic Ocean (Environment Canada's Beaufort Wind and Wave Reanalysis for the period 1970–2013), Wang et al. (2015) assessed historical changes in surface wind speed and ocean surface waves in the Beaufort-Chukchi-Bering seas. Their results – an example of which is shown in Figure 4.9 – indicate that significant wave height (the mean height of the highest third of all waves), mean wave period (the elapsed time between wave crests), and mean wave age have increased significantly over the Bering Sea in July and August and over the Canadian Beaufort westward to the northern Bering Sea in September. Furthermore, the 1992–2013 trend in September mean significant wave height agrees well with satellite-based trend estimates for 1993–2010, which increases confidence in the analysis. In particular, Wang et al. (2015) reported that the regional mean wave period has increased at a rate of 3% to 4% per year – more than tripling since 1970. Also, the regional mean significant wave height has increased at a rate of 0.3% to 0.8% per year. Wang et al. (2015) pointed out that the trends of lengthening wave period and increasing wave height imply an increasing wave energy flux, providing a mechanism to break up sea ice and accelerate ice retreat. Changes in the local wind speeds alone cannot explain the significant changes in waves. These trends are, however, consistent with the observed declines in sea ice coverage, leading to longer wave fetch and hence larger, older, and longer-period waves.

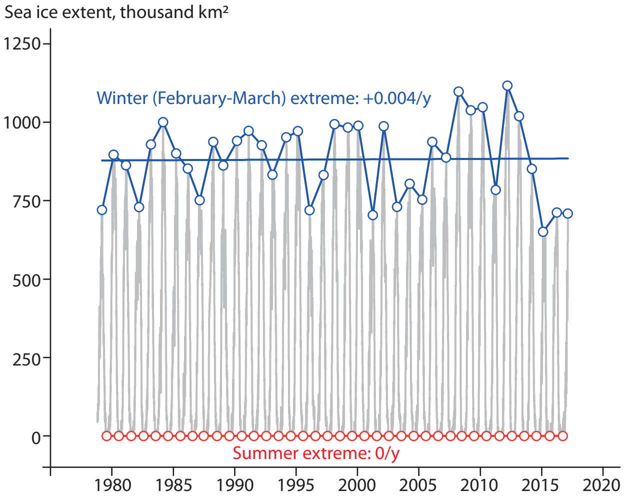


Figure 4.8 Time series of daily sea-ice extent in the Bering Sea for 1979-2017, highlighting winter (Feb-Mar) extremes. There are no summer extremes because the sea ice completely melts in summer in this area. Based on data from the Arctic and Antarctic Research Institute, St. Petersburg, Russia (wdc.aari.ru/datasets/d0042/).

The input of freshwater from the land to the ocean constitutes a direct connection between the terrestrial and marine systems. Some studies have argued that observed increases in Arctic river discharge in the late 20th century follow the global rise in surface air temperatures (e.g., McClelland et al., 2006), allowing more moisture loading in the atmosphere, which in turn leads to higher net precipitation fluxes in the Arctic (IPCC, 2013a). Annual fluctuations in river discharge could also be related to changing precipitation patterns driven by the Arctic Oscillation (Déry and Wood, 2005). A warming climate also leads to changes in the timing and intensity of freshwater discharge. For example, Burn (2008) found that the spring freshet in the Mackenzie River has tended toward an earlier date over the past 40–45 years (although with substantial interannual variability). This is consistent with the findings of de Rham et al. (2008), who noted a trend toward earlier river ice break-up in northern rivers, including the Mackenzie, and Prowse et al. (2010), who analyzed the connection between ice break-up and changing temperature.

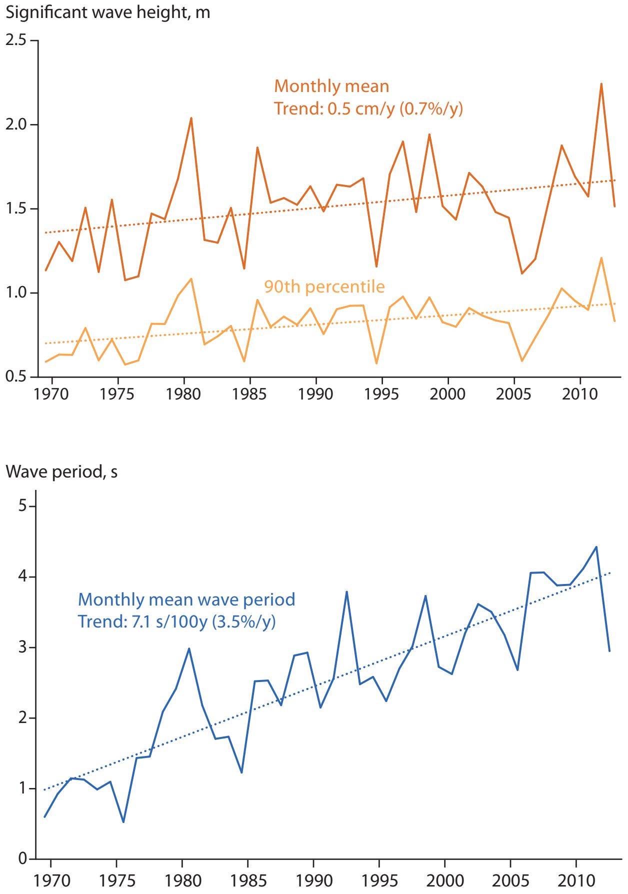


Figure 4.9 Historical trends in ocean surface waves in the Beaufort-Chukchi seas. The plots show the regional mean time series of significant wave height and mean wave period (Wang et al., 2015). The trend estimates are expressed as a percentage of the 1970–1999 climatological mean (the numbers in parentheses). Trends shown are significant at the 5% level or above.

### 4.3.1.1 Coastal issues

Many of the changes described above have direct implications for the coastal environment. Environmental factors influencing the BCB coastal region arise from the action of weather either directly or, more often, via interaction with coastal seas. The North Pacific Ocean has one of the most active storm tracks in the northern hemisphere. While most storms stay south of the Bering Sea, some cross the Aleutian Islands and make their way into the Bering Sea, either directly or along the Kamchatka Peninsula (Mesquita et al., 2010). Once in the Bering Sea, many storms stall in the southeastern part, in the vicinity of Bristol Bay. If wind patterns in the upper atmosphere are favorable, some of the Bering Sea storms can re-energize into powerful systems that affect the northern Bering Sea and can then move into the southern Chukchi Sea. Storms along the Beaufort and north Chukchi sea coasts tend to be less common but can still be powerful (Lynch et al., 2003; Pisaric et al., 2011).

Storm winds transfer energy into the surface water layers, causing waves and temporary (several hours duration) changes in water level, termed 'water set-up surges'. Note that while a surge often results in water level increases, decreases can also occur. Higher water levels can inundate low-lying coastal regions, especially barrier islands, deltas, and estuaries; lower water levels can result in problems for nearshore marine operators such as hunters and tug or barge traffic. Along coastal margins consisting of unconsolidated bluffs, positive surges can allow wave action to attack higher up the beach against the toe of the bluff, resulting in greater erosion. As mentioned, some storms stall in the Bering Sea, where they can remain for several days. This situation is problematic because even though these storms do not exhibit the strongest winds and are in fact in a decaying phase, they still result in sustained wave and storm surge action against a particular stretch of coast. Storms on the north coast, while less frequent than in the Bering Sea, have resulted in severe inundation events in the past (Reimnitz and Maurer, 1979; Marsh and Schmidt, 1993; Pisaric et al., 2011).

Inundation and erosion represent a serious stressor for coastal regions, both for the natural ecology (Pisaric et al., 2011; Terenzi et al., 2014) and for human/built environments (Harper et al., 1988; Mason et al., 1996; Radosavljevic et al., 2016; Wicks and Atkinson, 2016).

An important modifying factor in the BCB region is the presence of sea ice, which typically covers an area extending south to the mid–Bering Sea region in late winter. Sea ice serves to limit wave action and surge activity via several mechanisms. One is that sea ice reduces the initial transfer of energy into the water. Floating ice also dampens wave heights, and landfast ice armors the coast and prevents erosive activity. Recent reductions in sea ice cover and duration have been matched by greater erosion problems along the BCB coasts. In some areas, mostly along the Bering and Chukchi sea coastlines, when sea ice is forming or when ice has been temporarily blown away from the coast, slush ice (sea ice that is just beginning to form) can be driven ashore where it can freeze into solid berms (Eerkes-Medrano et al., 2017). These berms have been able to protect communities from storm surge, but often they represent an impediment to gaining access to the sea ice.

Another weather problem along the coast is the occurrence of fog and other forms of low visibility. All types of transportation and outdoor activity – aviation, moving on the water, and moving over the land – are curtailed in the presence of low-visibility conditions. Low visibility occurs during storm events when rates of precipitation, snow or rain, are great enough. Poor-visibility conditions also occur when fog moves in. Less commonly, smoke from forest fire can reduce visibility (Jobard and Atkinson, 2012).

### 4.3.1.2 Sea level

Past and present-day glacial changes affect relative sea level and, for much of Canada, reduce the impact of rising absolute sea level. Isostatic adjustment of Earth's surface in response to the loss of continental ice sheets at the end of the last ice age causes land uplift across much of Canada. Observations of present-day vertical crustal motion and past relative sea-level changes indicate that while the rate of land uplift due to post-glacial rebound is 10 mm/y or more for part of the eastern Canadian Arctic Archipelago, land subsidence is occurring along the Beaufort Sea coast (e.g., James et al., 2014). In the Mackenzie Delta, there are two other causes of vertical motion of the land surface. One is isostatic adjustment (subsidence) to the weight of sediment deposited on the shelf by the Mackenzie River over thousands of years, and the other is the compaction of that sediment as water is forced out of it. The thawing of permafrost, the decomposition of gas hydrates and, in the future, possibly the extraction of oil and gas from Beaufort sediments may also contribute to local subsidence.

A second consequence of the reduction in volume of terrestrial ice caps is a decrease in their gravitational pull. Although the ice lost from an ice cap is delivered as water to the ocean, thereby contributing to rising sea level, this meltwater is redistributed across the globe, but the consequent change in gravitational attraction is concentrated locally. This disparity in effect causes relative sea level to be reduced within about 1500 km of Greenland, in contrast to rising sea level at distant locations (Kopp et al., 2010). The observational records of present-day sea-level change are sparse, and the net effect of the competing influences varies across the region. An analysis of 35 years of water-level measurements at Tuktoyaktuk by Manson and Solomon (2007) suggests a relatively rapid (3.5±1 mm/y) rise in relative sea level at the edge of the Mackenzie Delta. Relative sea level has been dropping over much of the eastern Canadian Arctic Archipelago while rising in the Mackenzie Delta, with generally small changes in between. Farther west, on the north coasts of Alaska and Chukotka, records are sparser, but predictions of vertical crustal motion from postglacial rebound models (e.g., Peltier et al., 2015) suggest that relative sea levels have been rising and will continue to rise.

## 4.3.2 Projections of future climate change

Climate change projections, made with global climate models, indicate ongoing warming with a magnitude that depends on future greenhouse gas concentrations and other anthropogenic forcing. The most recent suite of climate projections were summarized in the recent IPCC Fifth Assessment Report (IPCC, 2013a), which made use of several forcing scenarios – the so-called representative concentration pathways or RCPs (van Vuuren et al., 2011). Uncertainty in projecting future climate arises not only from assumptions regarding future forcing but also from natural internal variability (interannual, decadal, etc.) and from differences in the detailed manner in which climate models represent the many climate processes that determine the response to that forcing. As a result, in order to best inform adaptation planning, it is important to consider a range of future projections, spanning the range of plausible future forcing scenarios and the range of models used to simulate future climate.

A systematic approach to climate projections is made possible by the coordinated set of historical and future climate simulations undertaken as part of the World Climate Research Programme's ongoing Coupled Model Intercomparison Project. The most recent (fifth) installment of this effort, termed CMIP5, provided a large multi-model ensemble of climate projections that was used extensively in the IPCC Fifth Assessment; details are provided by Taylor et al. (2012). Future climate forcing (e.g., concentrations of greenhouse gases, aerosols, land use) is specified in terms of four RCPs, each identified by a numerical suffix that indicates the approximate radiative forcing at the end of the 20th century: RCP2.6, a low forcing scenario that implicitly assumes aggressive emission mitigation policies; RCP4.5 and RCP6.0, intermediate scenarios; and RCP8.5, a high-emissions scenario. More details

Table 4.1 Models used to construct the ensemble climate projections in Figures 4.10–4.14.

| Model name | Place of origin | Institution |
|---|---|---|
| BCC-CSM1-1 | China | Beijing Climate Center, China Meteorological Administration |
| BCC-CSM1-1-m | | |
| BNU-ESM | China | Beijing Normal University |
| CanESM2 | Canada | Canadian Centre for Climate Modelling and Analysis, Climate Research Division, Environment and Climate Change Canada |
| CCSM4 | United States | National Center for Atmospheric Research |
| CESM1-CAM5 | | |
| CESM1-WACCM | | |
| CNRM-CM5 | France | Centre National de Recherches Météorologiques and Centre Européen de Recherche et Formation Avancée en Calcul Scientifique |
| CSIRO-Mk3.6.0 | Australia | Queensland Climate Change Centre of Excellence and Commonwealth Scientific and Industrial Research Organisation |
| EC-EARTH | Europe | A consortium of European institutions |
| FGOALS-g2 | China | State Key Laboratory of Numerical Modelling for Atmospheric Sciences and Geophysical Fluid Dynamics, Institute of Atmospheric Physics |
| FIO-ESM | China | First Institute of Oceanography, State Oceanographic Administration |
| GFDL-CM3 | United States | NOAA Geophysical Fluid Dynamics Laboratory |
| GFDL-ESM2G | | |
| GFDL-ESM2M | | |
| GISS-E2-H | United States | NASA Goddard Institute for Space Studies |
| GISS-E2-R | | |
| HadGEM2-AO | United Kingdom | UK Met Office Hadley Centre |
| HadGEM2-ES | | |
| IPSL-CM5A-LR | France | Institut Pierre Simon Laplace |
| IPSL-CM5A-MR | | |
| MIROC-ESM | Japan | University of Tokyo, National Institute for Environmental Studies and Japan Agency for Marine-Earth Science and Technology |
| MIROC-ESM-CHEM | | |
| MIROC5 | | |
| MPI-ESM-LR | Germany | Max Planck Institute for Meteorology |
| MPI-ESM-MR | | |
| MRI-CGCM3 | Japan | Meteorological Research Institute, Japan Meteorological Agency |
| NorESM1-M | Norway | Norwegian Climate Centre |
| NorESM1-ME | | |

regarding the forcings and underlying assumptions can be found in van Vuuren et al. (2011).

The subsequent graphics follow the example provided by the *Atlas of Global and Regional Climate Projections* (IPCC, 2013b) and show results of the 29-member ensemble of models (identified in Table 4.1), for which historical, RCP2.6, RCP4.5, and RCP8.5 results are available. (Several modeling centers did not run RCP6.0.) Results are only shown for the intermediate scenario, RCP4.5, as was done in the printed version of the IPCC *Atlas of Global and Regional Climate Projections*, but readers should be aware that if future emissions follow a pathway more like RCP2.6, the changes will be smaller than shown here, and if future emissions follow a pathway more like RCP8.5, the changes will be greater.

As a way of illustrating uncertainty (which includes both model uncertainty and internal variability), this study adopts the IPCC approach of estimating percentiles of the multi-model results – namely, the 25th, 50th, and 75th percentiles for different time periods in the future and for different forcing scenarios. The 50th percentile is an estimate of the 'median' model result for a particular forcing scenario; 25% of the model results are less than that shown by the 25th percentile, and 25% of the model results are larger than that shown by the 75th percentile. (In other words, half of the model results fall between the 25th and 75th percentiles.) In all cases, results are shown as differences relative to the reference period of 1986–2005. The first example of this form of presentation is shown in Figure 4.10.

Projections of temperature change are perhaps the most fundamental indicators of climate change, and these are shown in Figure 4.10, based on the CMIP5 multi-model ensemble for RCP4.5, an intermediate radiative forcing scenario. As noted in Section 4.2, warming is enhanced at high latitudes, particularly over marine areas where sea ice retreat leads to a positive warming feedback. Although there is a spread amongst model projections, as indicated by the difference between the 25th and 75th percentile results, the pattern is very similar across the multi-model ensemble. The same pattern is apparent in the projections for different time periods in the future. By the end of the century, even the models projecting smaller change (i.e., the 25th percentile results) indicate warming of 3°C or more in winter in the BCB region; the models projecting greater changes indicate warming of 5°C or more. If the rate of increase of greenhouse gas forcing is curtailed, as in RCP2.6, then the rate of warming is likewise reduced; with high-emissions scenarios, such as RCP8.5, projected warming is substantially greater. There is no basis at this point for an assessment of which of these scenarios is more likely, and it should be emphasized that using RCP4.5 in the illustrations here is not meant to imply that it is the most likely scenario – rather it is used to illustrate the pattern of change and inter-model uncertainty. Showing all scenarios would lead to an unwieldy number of graphics.

As previously described, climate warming is accompanied by many other fundamental changes in the climate system. For example, precipitation is projected to increase across the entire Arctic under future climate warming (Collins et al., 2013). In high-latitude regions, warming has a direct consequence (and indeed is enhanced by) changes in snow, ice, and permafrost. Some projected changes in these quantities are illustrated here, starting with projected changes in snow depth (see Figure 4.11). Changes in projected snow depth are characterized by substantial spatial variability, with summertime changes being relatively large (100% reduction indicates complete disappearance of summertime snow). Note that when projected changes are negative (as for snow and sea ice), the largest negative values are in the lowest percentile (i.e., 25% of the model results are more negative than the 25th percentile). Changes in wintertime snow depth are projected to be more modest, with decreases projected over ice-covered areas and in the more southerly parts of the domain.

Sea ice has been declining over recent decades, and model projections indicate an ongoing decline in both thickness and concentration but with a large spread in the rate of change between models (Stroeve et al., 2012). Projected changes in sea ice thickness tend to be similar between winter and summer (Figure 4.12). Projected changes in sea ice concentration, on the other hand, have a marked seasonality, with changes being largest in the marginal ice zones (Figure 4.13) (largest changes are therefore projected to occur farther south in winter and farther north in summer). In the central Arctic, changes in wintertime sea ice concentration are projected to be small even toward the end of the century, but in the BCB region, substantial changes are projected in the vicinity of Bering Strait.

As temperature patterns and surface characteristics (e.g., ice and snow cover) change, so too does atmospheric circulation. An illustration of atmospheric change is provided in Figure 4.14, which shows projected changes in near-surface wind speed.

Projected changes in surface wind, along with reduced ice cover (hence longer fetch), are projected to lead to increased wave height and ongoing coastal erosion (e.g., Church et al., 2013). Model projections suggest increases of about 3–4 m/s in the strongest winds and increases of about 2 m in significant wave height, particularly in the southern areas of the Beaufort Sea (areas that are largely occupied by sea ice in the present climate and are expected to become ice free in September in the future). Elsewhere (e.g., near the Bering Strait), increases in wave height are expected to be on the order of 1 m. Increases in wave height in waters off the Mackenzie Delta are estimated to not exceed 0.5 m. Although storm frequency or intensity may not change significantly, large open water areas in the Arctic summer will allow for the development of larger waves. The available data do not allow for conclusions regarding historical trends of storm surge frequency or magnitude (Wang et al., 2015).

Measurements of water temperature and salinity at 50 m depth on the Beaufort Sea mid-shelf indicate a substantial (and occasionally strong) interannual variability, with a weak cooling trend over the past 25+ years that is not statistically significant. Trends in salinity from the same site, available since 1999, seem largely spurious (Steiner et al., 2015, their figure 20). The density stratification of seawater at low Arctic temperatures is almost completely dominated by the effect of salinity, but there are insufficient data to assess how upper-ocean stratification in the region may have changed in the past 10 to 50 years. However, a review by Haine et al. (2015) indicates that a shift has occurred in the balance of sources and sinks of freshwater in the outflow region of the Canadian Arctic Archipelago, leading to an average freshening.

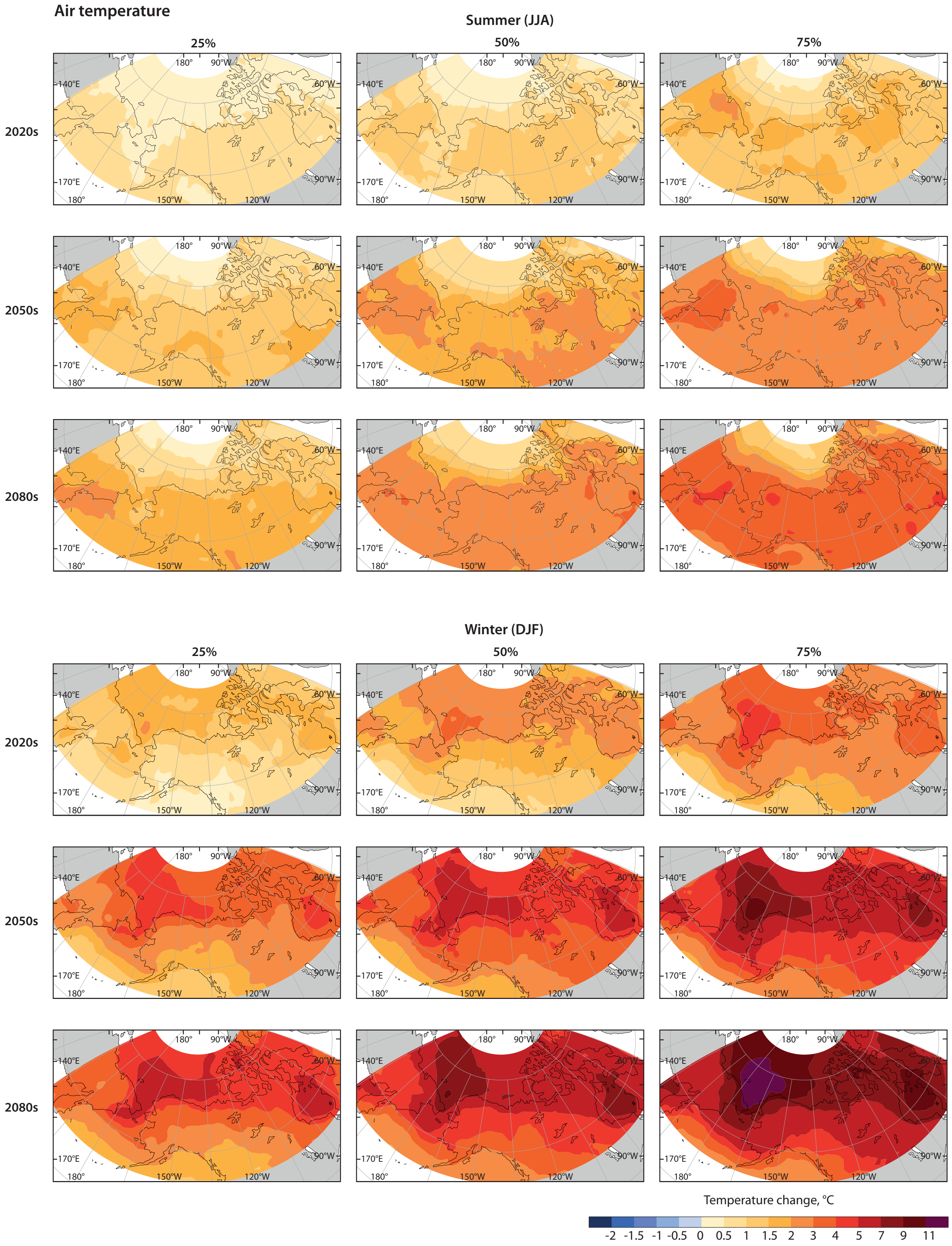


Figure 4.10 CMIP5 multi-model ensemble projections of future change in surface air temperature (relative to the 1986–2005 average) for summer and winter, based on the RCP4.5 scenario. Results are shown for three future periods: 2016–2035 ('2020s'), 2046–2065 ('2050s') and 2081–2100 ('2080s'). Panels illustrate the 25th, 50th, and 75th percentiles of change as projected by the 29 CMIP5 models listed in Table 4.1. Graphic based on re-gridded CMIP5 data available at ccds-dscc.ec.gc.ca

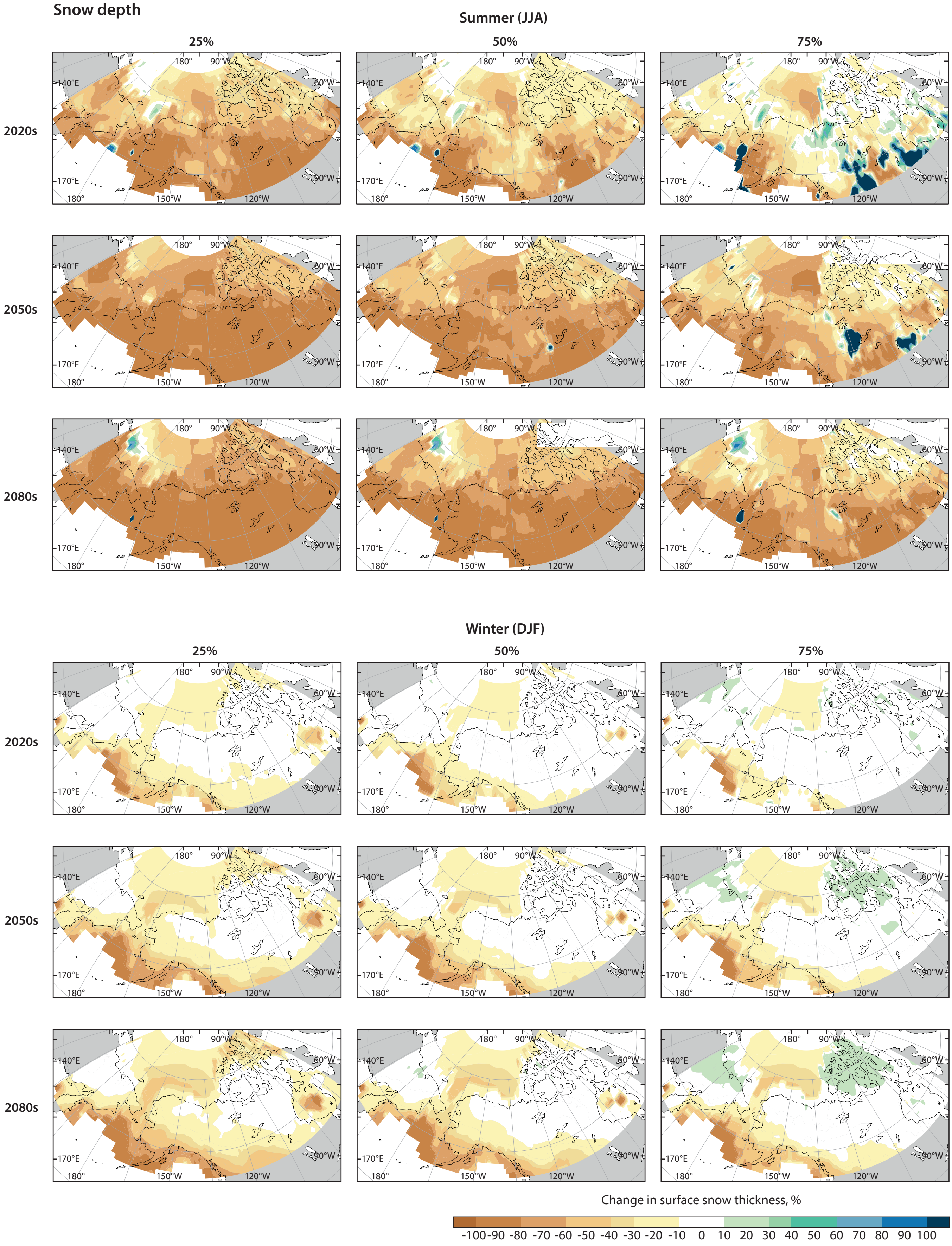


Figure 4.11 CMIP5 multi-model ensemble projections of future change in snow depth (relative to the 1986–2005 average) for summer and winter, based on the RCP4.5 scenario. Results are shown for three future periods: 2016–2035 ('2020s'), 2046–2065 ('2050s') and 2081–2100 ('2080s'). Panels illustrate the 25th, 50th, and 75th percentiles of change as projected by the 29 CMIP5 models listed in Table 4.1. Graphic based on re-gridded CMIP5 data available at ccds-dscc.ec.gc.ca

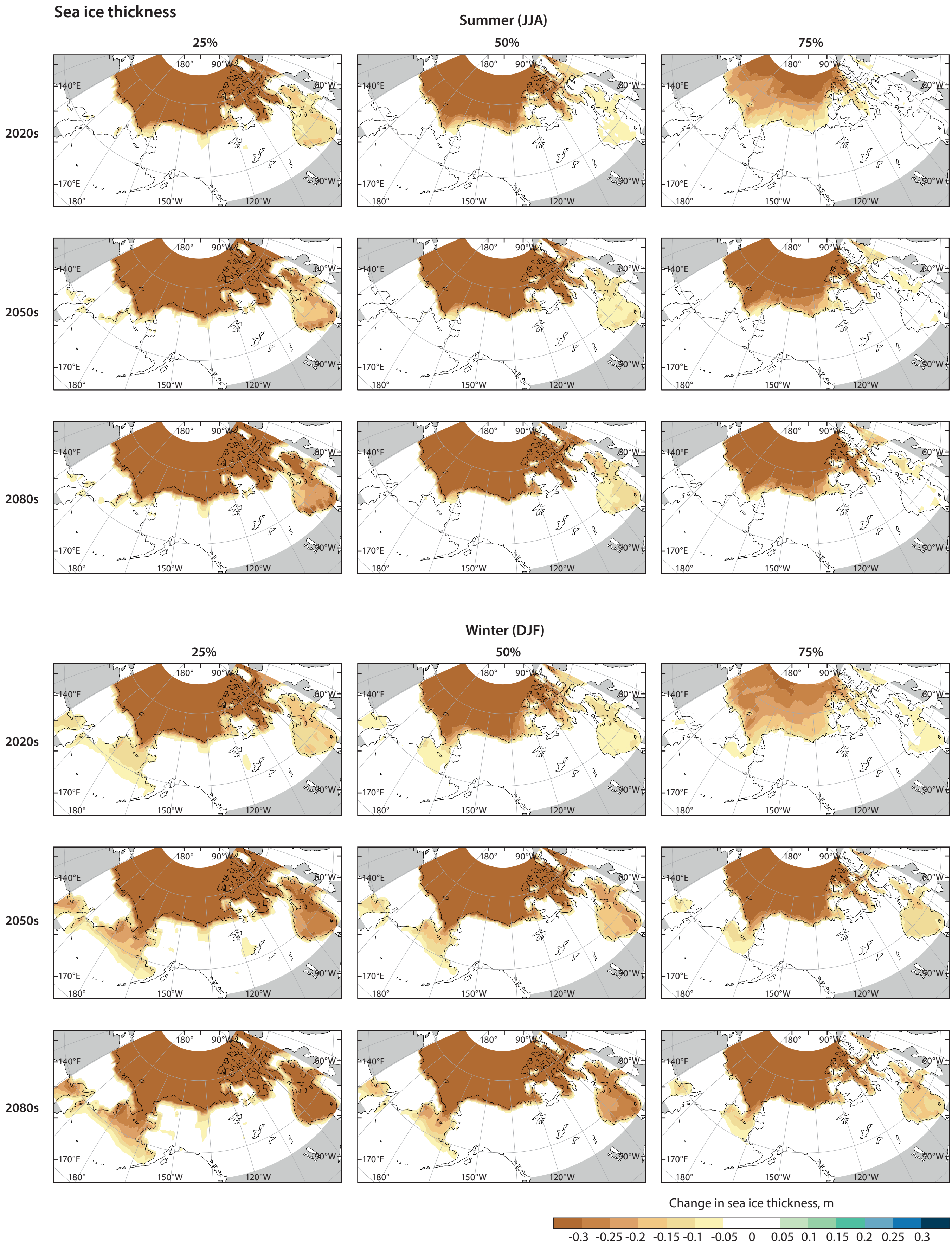


Figure 4.12 CMIP5 multi-model ensemble projections of change in sea ice thickness (relative to the 1986–2005 average) for summer and winter, based on the RCP4.5 scenario. Results are shown for three future periods: 2016–2035 (‘2020s’), 2046–2065 (‘2050s’) and 2081–2100 (‘2080s’). Panels illustrate the 25th, 50th, and 75th percentiles of change as projected by the 29 CMIP5 models listed in Table 4.1. Graphic based on re-gridded CMIP5 data available at ccds-dscc.ec.gc.ca

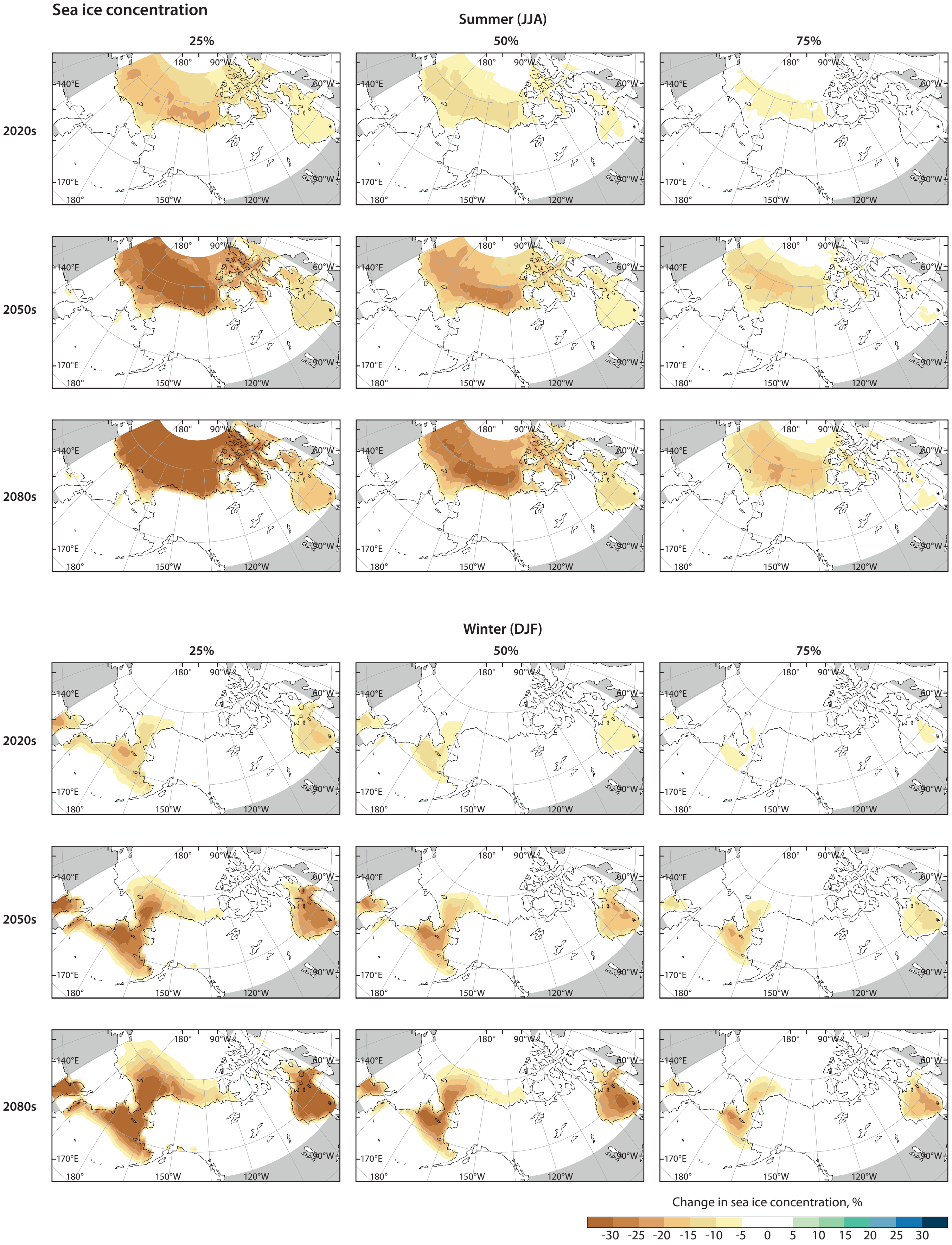


Figure 4.13 CMIP5 multi-model ensemble projections of future change in sea ice concentration (relative to the 1986–2005 average) for summer and winter, based on the RCP4.5 scenario. Results are shown for three future periods: 2016–2035 ('2020s'), 2046–2065 ('2050s') and 2081–2100 ('2080s'). Panels illustrate the 25th, 50th, and 75th percentiles of change as projected by the 29 CMIP5 models listed in Table 4.1. Graphic based on re-gridded CMIP5 data available at ccds-dscc.ec.gc.ca

## Near-surface wind speed

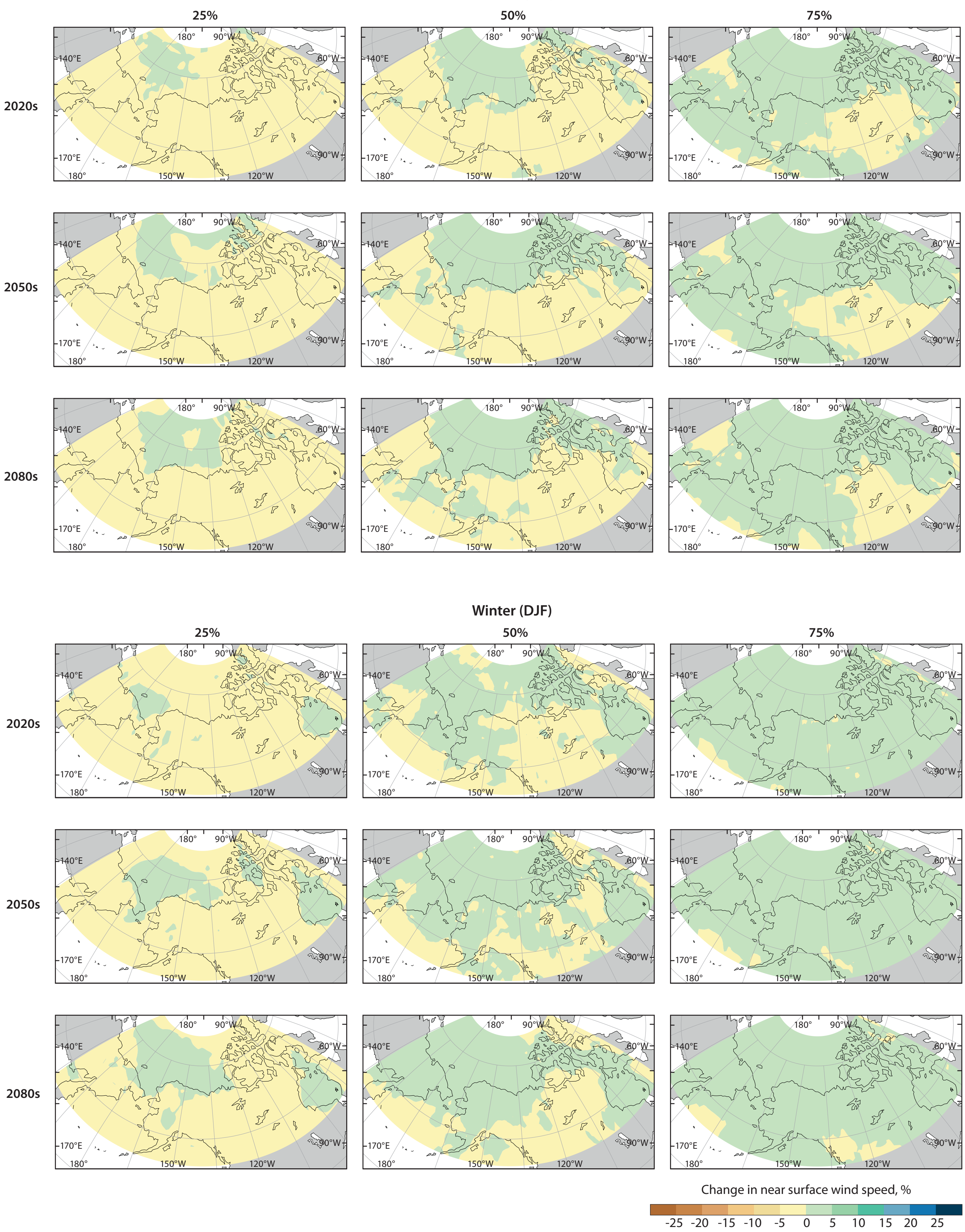


Figure 4.14 CMIP5 multi-model ensemble projections of future changes in near-surface wind speed (relative to the 1986-2005 average) for summer and winter, based on the RCP4.5 scenario. Results are shown for three future periods: 2016-2035 ('2020s'), 2046-2065 ('2050s') and 2081-2100 ('2080s'). Panels illustrate the 25th, 50th, and 75th percentiles of change as projected by the 29 CMIP5 models listed in Table 4.1. Graphic based on re-gridded CMIP5 data available at ccds-dscc.ec.gc.ca

Paul Andrew Lawrence / Alamy Stock Photo

*Sea ice in Norton Sound and fog over open water*

## 4.4 Regional environmental pressures

### 4.4.1 Sea level

Projections of relative sea level rise in the IPCC's Fifth Assessment Report (AR5; IPCC, 2013a) are larger than those in the Fourth Assessment (AR4; IPCC, 2007): the rise by 2100 is now projected to be 0.52–0.98 m (relative to 1986–2005), with a rate during 2081–2100 of 8–16 mm/y. Changes in the Arctic are projected to be as much as 50% lower than the global mean sea level change. James et al. (2014) gave relative sea-level projections for 59 locations across coastal Canada, based on the IPCC AR5 and utilizing GPS (global positioning system) measurements of vertical crustal motion. As pointed out in Section 4.3.1, there are already large BCB regional differences in sea level rise, and future projections also show substantial variations, mainly due to differences in vertical crustal motion arising primarily from glacial isostatic adjustment. The largest spatial variation in projected relative sea level rise occurs in northern Canada because of the influence of ice loss from the Greenland ice sheet (James et al., 2014).

### 4.4.2 Ocean temperature and salinity

Seawater surveys during expeditions since the 1950s have been brief initiatives that illustrate ranges of variation but are not adequate for projecting long-term changes in the rapidly fluctuating waters of the continental shelf. Conditions are more stable within the deep basins, such as the anticyclonic gyre of the Canada Basin, where prevailing winds establish and maintain a vast and only slowly varying reservoir of lower-salinity water.

Loss of sea ice, combined with increased precipitation, affects the freshwater input into the Arctic Ocean, as well as radiative energy, wind mixing, and material transfers that affect upper ocean water properties and circulation patterns. The IPCC AR5 Earth System models (ESMs) project a warmer and fresher surface ocean for the Beaufort, Chukchi, and Bering seas under the RCP8.5 scenario (illustrated for the Beaufort and Bering seas in Figure 4.15) and also under the RCP4.5 scenario (not shown).

A projected 60-year change in mean surface water temperature and surface salinity was calculated as the difference between the bi-decadal means of 1986–2005 and 2046–2065. For the RCP8.5 (high greenhouse gas emissions) scenario in the Beaufort Sea, the change in surface water temperature is +1.1°C (equivalent to +0.18°C/decade), and the change in surface salinity is -1.3 ppt (-0.22 ppt/decade) (Steiner et al., 2015; see also Hu and Myers, 2014). For the deeper Canada Basin, the multi-model mean shows continued warming that is most pronounced at the surface and in the Atlantic-influenced intermediate waters, with less warming in the Pacific-influenced subsurface waters. Freshening is more pronounced in the near-surface and Pacific waters, due to the influence of ice melt and enhanced stratification. Changes in stratification vary spatially,

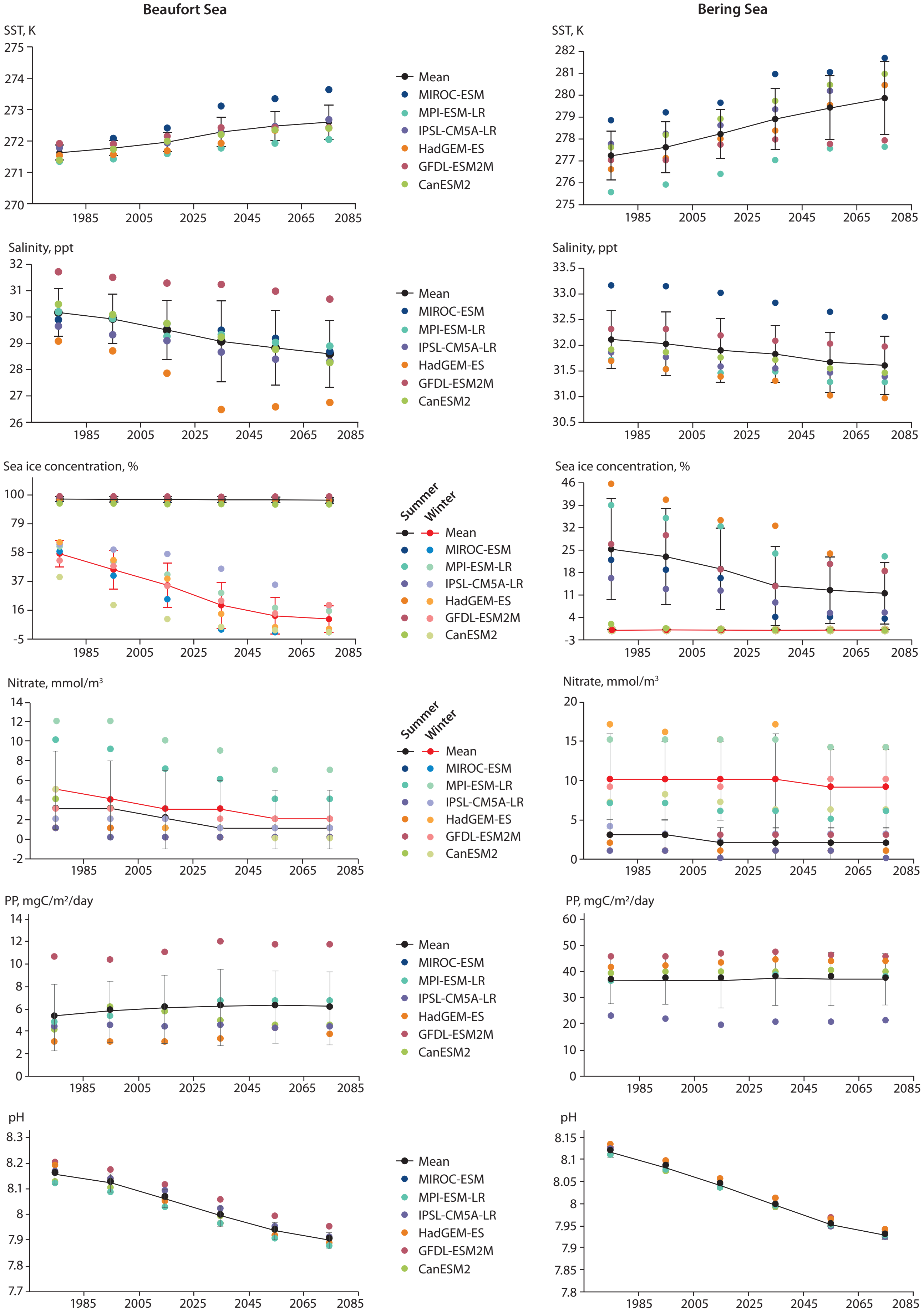


Figure 4.15 Multi-model comparison based on output from six Earth System models under the RCP8.5 scenario for the Beaufort Sea and Bering Sea. Plots show annual mean sea surface temperature, sea surface salinity, sea ice concentration (March and September), surface nitrate (summer JJA and winter DJF), annual mean primary production, and pH. Error bars indicate multi-model standard deviation. Data points are 20-year averages and are centered in the midpoint of the 20-year range. Modified from Steiner et al. (2013, 2014).

with enhanced mixing above shelves and enhanced stabilization over deep ocean regions (central Beaufort) (Steiner et al., 2014).

For the Chukchi and Bering seas under the RCP8.5 scenario, the projected 60-year surface water temperature changes are +2.0 and +2.5°C (+0.33 and +0.42°C/decade), respectively. The projected 60-year changes for surface salinity are -0.62 (Chukchi) and -0.40 ppt (Bering) (-0.10 and -0.07 ppt/decade, respectively). Similar to the case of surface water temperature, the model agreement in surface salinity decreases over time (see Steiner et al., 2015, for details). Multi-model simulations of the vertical distribution of temperature and salinity for the central Canada Basin (75°N, 140°W) indicate about 1°C warming over 60 years at the surface, minimal cooling at 50 m depth, and increasingly warmer temperatures down to 350 m, indicative of warmer Atlantic waters entering the Arctic. Freshening is strongest at the surface in response to ice melt (Steiner et al., 2014). Global ESMs and higher-resolution models for the Arctic both indicate enhanced stratification in much of the Arctic Ocean, especially in the central Beaufort Sea, likely driven by changes in upper-ocean currents and freshwater input (Steiner et al., 2016). However, ocean stratification changes are not uniform across the Arctic. Decreased stratification is projected in several coastal areas (e.g., Beaufort Sea) and shelf seas (e.g., Chukchi Sea) due to enhanced mixing (Steiner et al., 2014), which affects not only temperature and salinity distributions but also ocean acidification and nutrient supply for primary producers.

### 4.4.3 Arctic Ocean acidification

About a quarter of the global anthropogenic carbon dioxide ($CO_2$) released to date has been absorbed by the ocean. This uptake has increased the acidity of seawater and reduced its carbonate ion concentration. Increasing atmospheric $CO_2$ emissions and consequent ocean uptake will further enhance ocean acidification, which can significantly affect growth, metabolism, and life cycles of marine organisms (Gattuso and Hanson, 2011, and references therein). Hence, ocean acidification has received increased attention both within the scientific community and from stakeholders (AMAP, 2013). Ocean acidification in the Arctic is intensified due to low temperatures, as well as increased freshwater supply from river runoff, ice melt, and Pacific water. Colder water temperatures increase $CO_2$ solubility, while regional oceanographic features (high freshwater inputs and large ocean area relative to volume over the continental shelf) limit the Arctic Ocean's capacity to compensate for increased acidity.

The Beaufort and Chukchi continental shelves are especially vulnerable compared to the central Arctic Ocean Basin. These shelves experience naturally corrosive Pacific seawater inflows with pH as low as 7.6, created upstream by high primary productivity in the Bering Sea combined with the generally high $CO_2$ content and low calcium carbonate ($CaCO_3$) saturation state of old, deep Pacific upwelling water. Aragonite and calcite are the two forms of calcium carbonate commonly produced by marine organisms. The saturation state of seawater with respect to calcium carbonate (Ω) is a measure of its potential to corrode the $CaCO_3$ shells and skeletons of marine organisms. These start to dissolve when the waters become undersaturated with respect to $CaCO_3$, i.e., when $\Omega < 1$. Miller et al. (2014) evaluated changes in the marine carbonate system of the western Arctic and found substantial changes since the 1970s. Averaging observations from the Beaufort Sea and Canada Basin, they found that the mean saturation state at the sea surface was still supersaturated (i.e., $\Omega > 1$) but that upper halocline waters and deep waters had recently begun to regularly experience undersaturation of aragonite (the less stable form of shell $CaCO_3$).


Cultura Creative (RF) / Alamy Stock Photo

*Scientist preparing plankton net onboard a research ship*

Similar conclusions have emerged from annual systematic surveys of the Beaufort gyre, conducted since 2003; these observations indicate that as of 2008, waters at 100–200 m depth had become undersaturated with respect to aragonite (Yamamoto-Kawai et al., 2009, 2011). The water at this depth in the Canada Basin forms on Arctic shelves in winter, predominately in the Chukchi Sea, where cold water allows high uptake of $CO_2$ from the atmosphere; in situ remineralization of organic material produces additional $CO_2$ (Bates et al., 2011). Aragonite saturation state values as low as 0.8 have been recorded in surface and bottom waters of the Chukchi and Beaufort Seas, with values as low as 0.1 in bottom waters of the Bering Sea (AMAP, 2013).

So far, model simulations of biogeochemical changes such as future Arctic Ocean acidification are largely limited to global ESMs (e.g., Schneider et al., 2008; Steinacher et al., 2010; Steiner et al., 2014). ESM simulations all show enhanced ocean acidification in polar regions (e.g., Orr et al., 2005; Steinacher et al., 2009; Denman et al., 2011; Joos et al., 2011; AMAP, 2013; Deal et al., 2013; Steiner et al., 2014) and suggest that Arctic Ocean acidification will continue over the next century with accelerated reductions in Ω, at least until the sea ice cover reaches a new steady state with largely ice-free summers (Steiner et al., 2014). Projections under RCP8.5

for the Canada Basin consistently show reductions in the bi-decadal mean surface pH, from about 8.1 in 1986–2005 to 7.7 by 2066–2085 (see Figure 4.15 for the Beaufort and Bering seas). These pH declines are closely linked to reductions in Ω, from about 1.4 to 0.7 for aragonite and from 2.0 to 1.0 for calcite – in accord with earlier results based on IPCC Special Report on Emissions Scenarios (SRES) scenarios (e.g., Steinacher et al., 2009). The seasonal amplitude of Ω shows little change because the main drivers (dilution of total alkalinity, and dilution and biological drawdown of dissolved inorganic carbon) have opposite effects and cancel each other out. An emissions scenario with mitigation (RCP4.5) reduces the rate of acidification (with a pH of 7.9 being reached about 25 years later in RCP4.5 than in RCP8.5). However, the emergence of undersaturated surface waters, which is projected to occur within the next decade, differs little between the scenarios (Steiner et al., 2014). The Canada Basin shows a characteristic layering with respect to saturation states. Under the influence of ice melt and inflowing Pacific water, two shallow undersaturated layers form at surface and subsurface depths, creating a shallow saturation horizon that expands from the surface downward. This shallow horizon is in addition to the globally observed deep saturation horizon, which is continuously expanding upward with increasing $CO_2$ uptake (AMAP, 2013; Steiner et al., 2014).

### 4.4.4 Nutrients and primary production

Marine ecosystems in the Canadian Arctic are characterized by a short productive period in spring–summer, driven by the high seasonality in solar radiation and often limited nutrient supply. Nelson (2013) assessed the biodiversity and biogeography of the lower trophic taxa in the region with regard to sensitivities to climate change and found that range shifts and changes in the relative abundance of particular taxa have occurred within the last decade. As described earlier in this chapter, a warming, freshening upper ocean and increasing density stratification have been observed recently and are predicted for the future of the Beaufort Sea. Deep-water nutrient concentrations have not changed, while upper ocean nutrients have decreased. Picoplankton, having a large surface-area-to-volume ratio and a slow sinking rate, should do better under these conditions than the larger nanoplankton (Li et al., 2009; Lee et al., 2013; Yun et al., 2014).

Although few modeling studies of future primary producer and nutrient trends have been conducted, recent trends may be indicative of near-term future changes. Ardyna et al. (2014) identified the recent development of a secondary algal bloom in the autumn, coinciding with delayed freeze-up and increased exposure of the sea surface to wind stress, over large areas of the Arctic Ocean's continental shelves (Figure 4.16). Over the last decade, the area affected by secondary blooms has increased by about 30% in most areas and about 15% over the Beaufort Shelf. Similarly, Martin et al. (2010) found a widespread occurrence of long-lived subsurface chlorophyll-a maxima in seasonally ice-free waters of the Canadian Arctic during late summer and early autumn. Fujiwara et al. (2014) found that shifts in algal community composition were related to the timing of sea ice retreat, and a combined model–satellite observation analysis by Ji et al. (2013) indicated a strong correlation between the timing and variability of sea ice retreat and pelagic production at any specific location.

Arrigo et al. (2012) reported that the occurrence of large areas of sea ice with under-ice algal blooms was attributed to a thinning sea ice cover with more numerous melt ponds, with enhanced light penetration through the ice into the upper water column (Frey et al., 2011). Changes in irradiance transmitted through snow and sea ice also directly influence the production of sea ice algae (Arrigo, 2014; Leu et al., 2015). Tremblay et al. (2012) summarized the current state and recent trends in Arctic Ocean

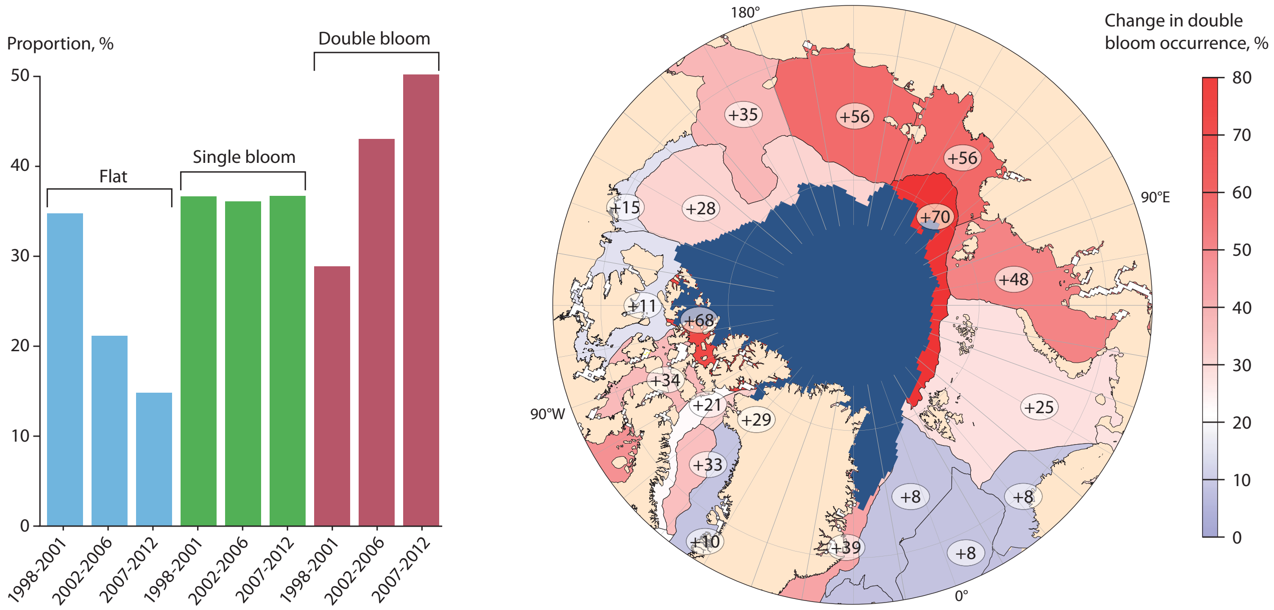
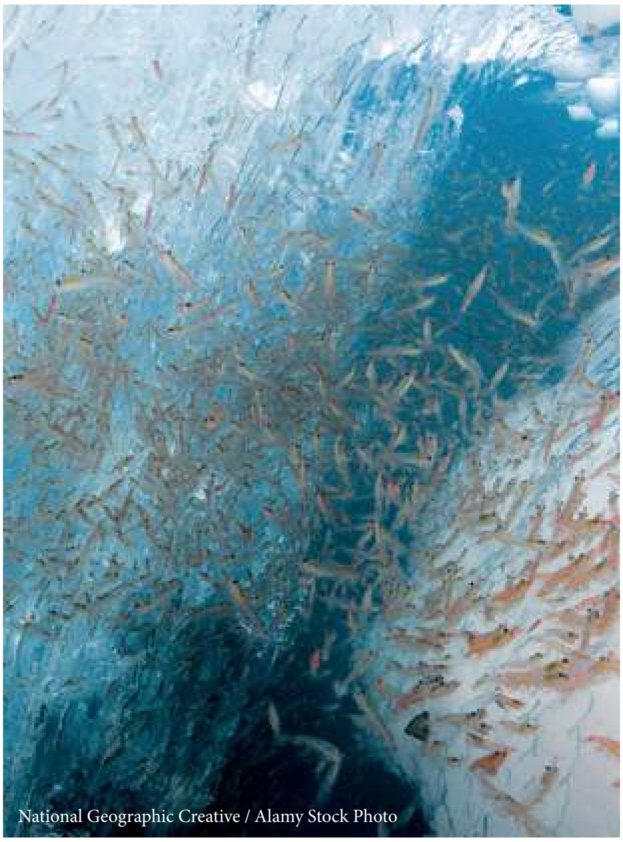


Figure 4.16 Shifts in Arctic phytoplankton phenology within the Arctic Circle (>66.58°N). The histogram shows three types of annual phytoplankton bloom cycle (flat, single bloom, double bloom) for three consecutive periods since the late 1990s. The circumpolar map shows percentage change in autumn/secondary bloom occurrence between the earlier and later periods for 19 Arctic areas. The minimum September sea-ice extent in 2012 is shown in dark blue (Ardyna et al., 2014).

primary productivity in six points: (1) Offshore, the warming and freshening of the surface layer is leading to a displacement of large nanophytoplankton species by small picophytoplankton, with potentially profound bottom-up effects within the marine food web. (2) In coastal areas, primary productivity is increasing as favorable winds and the seaward retreat of ice promote upwelling. (3) Multiple upwelling events repeatedly provide food to herbivores throughout the growth season. (4) A substantial amount of pelagic primary productivity occurs under thinning sea ice (e.g., Arrigo et al., 2012) due to enhanced light penetration through the ice (Frey et al., 2011), and this primary productivity cannot be detected by satellite sensors. (5) Early primary productivity in spring does not imply a trophic mismatch with key herbivores. (6) The epipelagic ecosystem is very efficient at retaining carbon in surface waters and preventing its sedimentation to the benthos. Trembley et al. (2012) further concluded that while enhanced primary productivity could result in increased fish and marine mammal harvests for northerners in the future, the changes will most likely be insufficient to sustain large-scale commercial fisheries in the Canadian Arctic.

Flint et al. (2014) disputed the previously reported positive relationship between the length of the ice-free season and the amount of annual new primary production in the Chukchi Sea, emphasizing the importance of nutrient limitation. Nutrient flux through the Bering Strait plays a crucial role in shaping the features of primary production within the Chukchi Sea (Walsh et al., 1989; Springer and McRoy, 1993; Cota et al., 1996) and is responsible for the sea's 'hotspot' productivity areas (where daily rates of primary production are about 5–10 gC/m$^2$; Springer and McRoy, 1993). Recent observations suggest an increase in the annual mean volume transport through the Bering Strait (Woodgate et al., 2012), caused by local wind changes and the influence of remote pressure changes in the Aleutian Basin (Danielson et al., 2014), although it is not clear if this trend is stable as it shows significant interannual variability. Existing evidence suggests higher Chukchi Sea productivity rates during years of higher Bering Strait transport; however, projected sea ice loss in the northern Bering Sea might stimulate locally higher primary production rates, thus reducing the amount of nutrients flowing downstream to the Chukchi Sea (Brown and Arrigo, 2012).

Arrigo et al. (2008) suggested that in the Arctic, the loss of ice during spring could boost overall productivity more than three-fold above 1998–2002 levels, potentially altering marine ecosystem structure and the degree of pelagic–benthic coupling. Vancoppenolle et al. (2013), in an assessment of projected primary productivity, nutrients, and sea ice concentrations in 11 CMIP5 ESMs, found that the ensemble mean represents Arctic-integrated primary productivity for 1998–2005 quite well but that the models do not agree on what limits current primary production or on the sign of future change. A net decrease in available nutrients due to increased stratification and an increase in light availability due to reduced sea ice cover operate in all models. However, there is disagreement among models as to whether the benefits of the light increase would overcome the decrease in available nitrate. This uncertain future can also be seen in the regional ocean parameter averages shown in Figure 4.15, based on six ESMs. Steinacher et al. (2010) and Vancoppenolle et al. (2013) suggested that the main cause for the large inter-model spread is a poorly constrained observational data set of Arctic seawater nitrate concentrations.

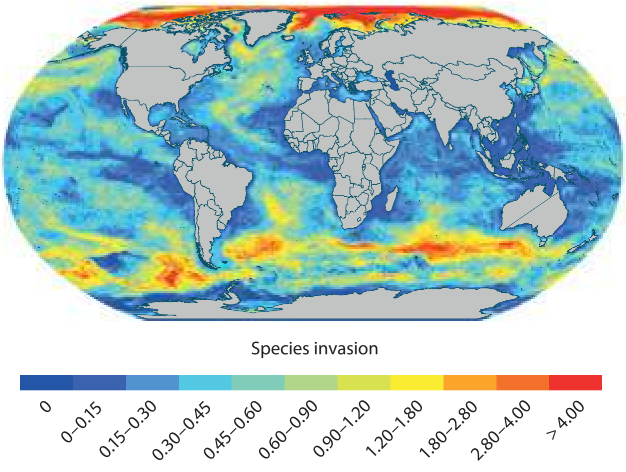

National Geographic Creative / Alamy Stock Photo

*Krill feeding on phytoplankton growing on the underside of sea ice*

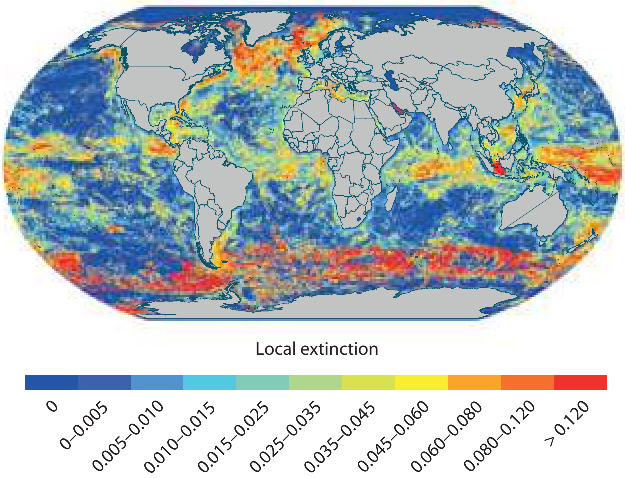
### 4.4.5 Zooplankton and higher trophic levels

There is evidence of a northward spread of Pacific marine species during the past few decades, which is believed to be linked to changes in water temperature. An example is the presence of Pacific zooplankton now as far north as the Beaufort Sea (Nelson et al., 2009). While the observations of zooplankton and higher trophic level animals are insufficient to allow a trend analysis, the studies clearly show that zooplankton distributions as well as hatching success and growth of Arctic fish species respond to changes in environmental properties.

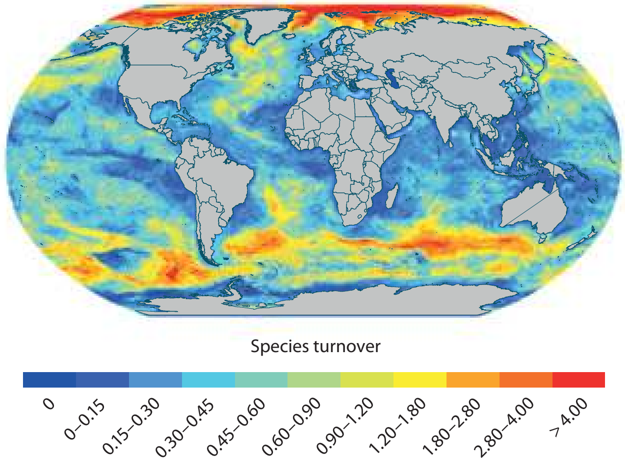
Future projections of changes in higher trophic levels within an ESM framework are not yet possible. Combined species redistribution and ecological models are an intermediate step to allow projections of global marine biodiversity impacts (e.g., Cheung et al., 2009) and fisheries catch potential (e.g., Cheung et al., 2010, 2011) under a changing climate (Figure 4.17). In these models, shifts in species distribution can be projected by evaluating changes in physical and biological conditions relative to those suitable for a given species and by correlating current environmental conditions with maps of current species abundances. Projections of future environmental conditions are provided using ESMs (e.g., Cheung et al., 2009), but there are large uncertainties in projected timing and spatial structure because of the combination of the complexities of environment–ecosystem interactions and the limitations and deficiencies of presently available models. Cheung et al. (2009) predicted numerous local species extinctions in the subpolar regions and intense species invasion in the Arctic. Cheung et al. (2010) projected a 30–70% increase in maximum fisheries catch potential in high-latitude regions. A more extensive discussion of the impacts of changing climate on the BCB ecosystem is provided by Steiner et al. (2015).



Species invasion



Local extinction



Species turnover

Figure 4.17 Biodiversity-related changes projected to result from projected high-range warming as of 2050 (relative to 2001–2005 means). Plots show species invasion intensity, local extinction intensity, and species turnover. Species redistribution models using ESM output and current species distributions based on selected environmental variables (temperature, salinity, oxygen) to project future change indicate the Arctic could become a hotspot for species invasions and species turnover (i.e., extinction of local species and replacement by invading species) (Cheung et al., 2009).

### 4.4.6 Contaminants

Aside from petroleum hydrocarbon (AMAP, 2010a) emissions from oil and gas development on the Alaskan North Slope and near Norman Wells, NWT, none of the contaminants considered here – including mercury (Hg; AMAP, 2011b) and persistent organic pollutants (POPs; AMAP, 2010b) – has significant urban or industrial sources within the BCB region. Thus, global emissions transported to the region by atmospheric, riverine, and oceanic pathways dominate over regional emissions of all contaminants except petroleum hydrocarbons. However, the region possesses a number of physiographic and climatic features that make it particularly susceptible to contaminants, either by influencing transport/deposition rates or by altering natural biogeochemical processes acting on those chemicals.

Mercury concentrations in BCB marine and freshwater ecosystems are significantly affected by local climate-related processes that appear to be driving increased Hg concentrations and associated risks in some sediments and species, despite stable rates of global airborne Hg emissions and deposition in the BCB region over recent decades (AMAP, 2011b). Atmospheric Hg deposition rates across the Arctic Ocean are elevated by springtime mercury depletion events (MDEs), in which gaseous elemental Hg in the lower troposphere is photolytically converted into particulate Hg with a high vertical flux. MDEs are driven by marine bromine emitted from freezing flaw leads in sea ice and shore leads, which occur, for example, off Utqiagvik (Barrow), Alaska (Douglas et al., 2005). MDE frequency is projected to increase as leads become more common and larger under a warming climate (Stern et al., 2012). Coastal erosion and rivers supply considerable additional inorganic Hg, organic matter, and methylmercury (MeHg) to the Bering and Beaufort seas, with riverine fluxes strongly correlated to flow, which is in turn driven by precipitation (Graydon et al., 2009; Schuster et al., 2011). In the eastern Beaufort Sea, Hg inputs from the Mackenzie River and from atmospheric deposition produce a surface Hg enrichment that is reduced or absent in areas of sea ice cover, suggesting a key role for ice as a barrier to atmospheric deposition (Wang et al., 2012). Photoreduction of dissolved inorganic Hg and evasion of gaseous Hg, again limited by sea ice, and vertical export of Hg on settling particles are major loss processes (AMAP, 2011b). Conversion of the inorganic Hg, which dominates atmospheric deposition and terrestrial inputs, into more toxic and bioavailable MeHg occurs in subsurface waters of the Beaufort Sea (Lehnherr et al., 2011), as in other oceans. However, MeHg production is likely to be a seasonal and spatially variable event, probably responding to microbial remineralization of local marine primary production and terrestrial organic matter inputs from rivers and coastal erosion (Wang et al., 2013). Thus, future climate-driven increases in Arctic Ocean marine productivity, as well as riverine and coastal erosion inputs of organic matter and Hg, could increase the risk from MeHg to marine wildlife and their human consumers even if global emissions increase no further (AMAP, 2011b).

Petroleum hydrocarbons (which include n-alkanes and polyaromatic hydrocarbons) in the Arctic Ocean are currently dominated by natural regional sources. Anthropogenic sources (mainly localized oil spills from non-oil and non-gas industrial activity, shipping, and Arctic oil and gas facilities) are equivalent to only about 6% of the 10,000 tonnes annual input from natural sources (equivalent to about 73,000 barrels); atmospheric petroleum hydrocarbon deposition is negligible (AMAP, 2010a). However, these estimates are poorly constrained. Within the BCB region, natural oil seeps from the intertidal zone along the Alaskan coastline, from coastal erosion on the Beaufort Sea coast, and from peat, coal, and petroleum outcrops along the Mackenzie River are believed to be the main natural sources to BCB offshore areas. petroleum hydrocarbon concentrations in the Mackenzie River are ten times higher than in other northern rivers, and its outflow has raised petroleum hydrocarbon levels in nearshore marine sediments to relatively high levels (AMAP, 2010a).

Current exploration and production activities in the BCB region, centered on the Alaskan North Slope and Norman Wells areas, have resulted in measurable petroleum hydrocarbon contamination of ponds and small lakes within at least 200 m of wells; small spills (<80 $m^3$) in marine settings occur at a rate of 3.9 spills per million $m^3$ of oil produced or handled (AMAP, 2010a). Based on the prevailing spill rate, and with many simplifying assumptions, it is projected that future planned production increases around the Arctic Ocean, including from fields in Prudhoe Bay, Alaska, may increase Arctic anthropogenic emissions by approximately ten-fold to levels approaching those of natural sources (AMAP, 2010a). Within the BCB region, therefore, future oil and gas production, and transportation of that production, is likely to be one of the key drivers of petroleum hydrocarbon levels in terrestrial and marine environments.

Pathways of halogenated organic contaminants (also referred to as persistent organic pollutants, POPs) are susceptible to a myriad of potential climate-driven ecosystem changes. Examples include, but are not limited to, changes in precipitation patterns; sea ice extent and type (air–water exchange); food web structure, either from the top down or from the bottom up; change in the organic carbon cycle; and change in animal diets and biotransportation. The consequences of these changes are difficult to predict because halogenated organic contaminants have been so widely released, in many cases including very complex mixtures (e.g., polychlorinated biphenyls, technical toxaphene, short- and medium-chain chlorinated n-alkanes, polybrominated diphenyl ethers, and so on), and exhibit a broad range of chemical properties (volatility, phase partitioning, and degradation kinetics), all of which are sensitive to temperature and hydrological change (AMAP, 2010b). Ma et al. (2011) reported new evidence showing that the more volatile group of halogenated organic contaminants are revolatilizing back into the atmosphere from repositories such as water, snow, and ice as the climate continues to warm and the sea ice retreats. This process subsequently alters biological exposure pathways in as-of-yet unknown ways.

Specific examples of how the rapidly changing icescape in the Arctic Ocean may affect contaminant exposure are given in a series of papers by Pućko et al. (2010a,b, 2011, 2012). Melt ponds, a harbinger of climate change in the Arctic, are common features of the summertime sea ice cover in the Arctic Ocean, resulting from snowmelt on the ice due to a positive net surface energy balance (Light et al., 2008). Concentrations of α-hexachlorocyclohexane (α-HCH) measured in Beaufort Sea melt-pond water were three to nine times higher than concentrations in the underlying old ice. Two routes of α-HCH enrichment in the ice over the summer were identified. First, atmospheric gas deposition results in an increase of α-HCH concentration from 0.07±0.02 ng/L (old ice) to 0.34±0.08 ng/L, or ~20% less than the atmosphere–water equilibrium partitioning concentration (0.43 ng/L). Second, late-season ice permeability and/or complete ice thawing at the bottom of ponds permits α-HCH–rich seawater (~0.88 ng/L) to replenish pond water, bringing concentrations up to 0.75±0.06 ng/L. Enrichment of α-HCH in ponds may lead to substantial concentration patchiness in old ice floes and altered exposures for biota as the surface meltwater eventually reaches the ocean through various drainage mechanisms.

NG Images / Alamy Stock Photo

*Scientists sampling melt ponds on sea ice*

## 4.4.7 Changing coastal environments

There is broad agreement that under continued warming, Arctic river discharge will increase due to permafrost degradation and an increase in precipitation minus evaporation (Holland et al., 2007; Rawlins et al., 2010). However, the range of increase is uncertain (Holland et al., 2007). Organic carbon stored in the permafrost may be released, although the resulting changes in organic carbon flux to the Arctic Ocean remain unclear as there is a lack of data on how carbon cycling is changing (Holmes et al., 2013, and references therein). Decreases in permafrost are likely to result in higher soil weathering rates and, together with increases in runoff, may induce greater bicarbonate and major-ion fluxes (Holmes et al., 2013). Inorganic nutrient fluxes may also increase. Contemporary riverine fluxes of inorganic nutrients are substantial in terms of nutrient supply to inshore ecosystems, especially in the nutrient-poor areas of the northeastern Bering Sea and eastern Beaufort Sea. Silica transport to the Bering Sea shelf via shelf–basin interactions is negligible compared to the flux from the Yukon River alone (Clement Kinney et al., 2009).

Martin Shields / Alamy Stock Photo

*Carbon dioxide release from thawing permafrost is measured along with tundra growth at a research site, Alaska*

Eolian deposition of macro- and micronutrients (e.g., labile iron) may also increase in the future due to higher rates of weathering and stronger winds. This possible change is potentially important for iron-limited systems such as the Bering Sea (Banse and English, 1999; Agular-Islas et al., 2007).

Physical changes of the coastline itself are also ongoing. Jones et al. (2008) reported that long-term rates of erosion along the Alaska Beaufort Sea coast averaged 2.5 m/y, with higher rates along the western stretches (3.0–5.4 m/y) and lower rates along the eastern stretches (1.0–1.4 m/y). In a more recent detailed analysis of coastal retreat in an area of high erosion near Utqiagvik, Alaska, the mean erosion rates were found to have increased from 5.0 m/y (1955–1979) to 6.2 m/y (1979–2002), averaging 5.6 m/y for the entire period. By comparison, recent long-term rates of erosion have averaged 1.0–2.0 m/y (weighted mean by coastline length, 1.12 m/y) along the Canadian Beaufort Sea coast and 0–1.0 m/y in Chukotka (ranging from 0.27 m/y along the Chukchi Sea coast to 0.87 m/y along the East Siberian Sea coast) (Lantuit et al., 2012). Similar weighted averages are reported for the US coastlines of the Chukchi Sea and Beaufort coast (0.49 and 1.15 m/y, respectively). Much lower erosion rates are reported for the Canadian Arctic Archipelago (average of 0.1 m/y). The high spatial variability in erosion rate is related to regional differences in geomorphology and organic carbon and ice content in permafrost soils. The high erosion rates in some areas of BCB coastline, which are likely to continue into the future, have significant implications for human settlements and industrial infrastructure in coastal areas (see Chapter 5).

### 4.4.8 Changing terrestrial environment

Arctic tundra ecosystems are very sensitive to temperature shifts and play an important role in ecosystem feedbacks (Levis et al., 1999). Vegetation productivity in Arctic ecosystems has increased over the past few decades, resulting in a trend of greening that is coincident with increases in Arctic surface air temperatures. There has been a reversal of the greening changes in some areas over the past few years, for reasons that are unclear but may be a result of increased evapotranspiration and soil dryness (Bhatt et al., 2013). However, the expected continuation of greening over the next century is likely to produce multiple climate feedbacks. For instance, expansion of woody shrubs and trees into the tundra biome may enhance climate warming through albedo reductions associated with taller and darker canopies and through additional insulation of the ground from increased snow trapping. Locally, shading associated with increasing shrub canopy cover may reduce soil temperatures, potentially slowing carbon release due to permafrost degradation and thus acting as a negative feedback to climate warming (Pearson et al., 2013).

Some of the key changes in the Arctic tundra biome are related to the onset of vegetation, senescence, length of growing season, and dates of peak greenness. These represent key phenological indices of vegetation–climate interactions (Olthof and Pouliot, 2010). The timing of snow cover is likely to be a particularly important driver of vegetation phenology over the Arctic tundra (Zeng and Jia, 2013).

An observable measure of terrestrial vegetation 'greenness' is the Normalized Difference Vegetation Index (NDVI). Figure 4.18 shows the seasonal evolution of NDVI from May to September for the BCB region. Regional differences in photosynthetic activity over the BCB parts of Chukotka and Canada early in the growing season (May–June), mid-season (July) in Alaska, and late (September) in northern Canada are most striking. Longer-term changes in vegetation directly affect surface albedo and heat budget, soil microbial activity, and even hydrological patterns in the Arctic (Chapin et al., 2005; Swann et al., 2010; Pearson et al., 2013).

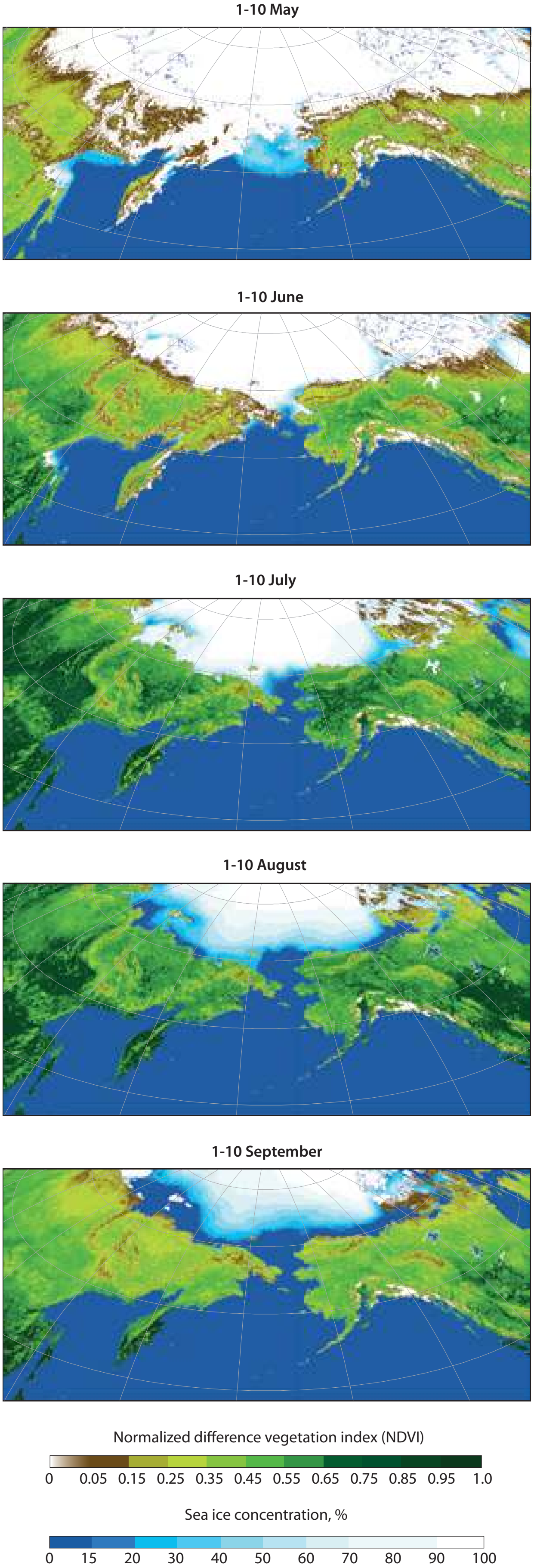


Figure 4.18 Mean seasonal changes in vegetation phenology as indicated by NDVI-derived indices, 1982–2010, for May through September (David Douglas, US Geological Survey, Alaska Science Center).

## 4.5 Regional socio-economic drivers

### 4.5.1 Population

Three administrative divisions in northern Alaska – the North Slope Borough, Northwest Arctic Borough, and Nome Census Area – together correspond approximately to the Alaska subregion of the BCB region (see Section 3.2.2). Figure 4.19 charts the combined population of these three areas, together called 'northern Alaska', from 1970 to 2014 with projections to 2042. From 1970 to 2014, the population of northern Alaska approximately doubled, from about 13,000 to 27,000 people. The apparent jump in population in 2010 is a statistical artifact caused by the census decision to begin counting people at remote work sites – primarily connected with Prudhoe Bay oil development – within the population of the North Slope Borough. This jump, an increase of almost 40% above the official 2009 population, emphasizes the importance of the industrial workforce in this region. This workforce is for the most part not attached to traditional communities. New energy or mining development could bring further in-migration and population jumps in the future; conversely, a contraction of development, if resources or prices decline, could bring equally rapid out-migration. Neither change is predictable on decadal or longer scales.

The population projections to 2042 were calculated by the Alaska Department of Labor and Workforce Development. These projections involve separate models for each of the three northern Alaska administrative areas (and others within the state of Alaska). Birth, death, and migration rates are based on recent historical data from each area. Projections are then made using the cohort component method (ADL, 2014). Variations in birth, death, and migration rates that might be caused by future social or environmental change are not predictable and are therefore not recognized in these projections, which provide only rough guidance about future population – provided that things continue, on average, as they have been. According to these projections, northern Alaska will continue to grow at close to the present rate, reaching 33,000 people (20% above the 2014 population) by 2042.

Populations within the North Slope Borough, Northwest Arctic Borough, and Nome Census Area are distributed among hub towns (Utqiagvik, Kotzebue, and Nome, respectively) and many smaller villages. Figure 4.20 charts the components of population change for the Northwest Arctic hub town of Kotzebue, 1990–2014 (methods as described by Hamilton and Mitiguy, 2009). Bars along the bottom indicate births and deaths; births are much more numerous. Vertical lines in the plot indicate net in- or out-migration. The net migration is mostly negative, with out-migration (i.e., vertical lines above the trend line) outweighing in-migration in most years. This outflux keeps the town's population from rising much faster than is suggested by the high birth rate. Net migration can respond quickly to changing economic and social conditions, emphasizing the uncertainty of long-range projections such as those in Figure 4.19.

Additional projections of Arctic region populations are given as background material by Andrew (2014). In that earlier report, all of Alaska is considered together, instead of separating northern Alaska (less than 10% of the state's population) as in

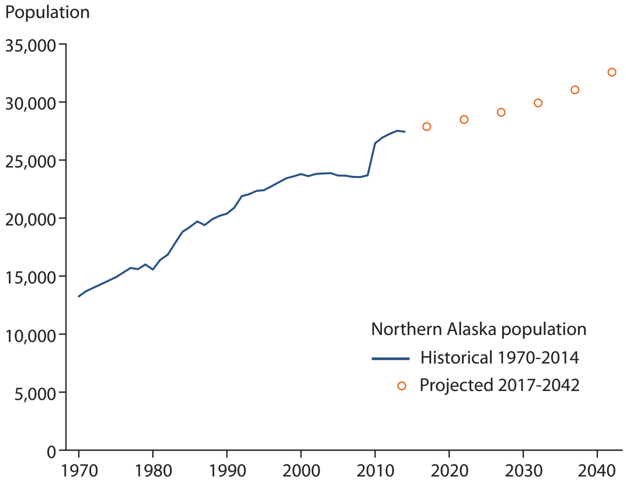


Figure 4.19 Change in population over recent decades in northern Alaska, plus projections to 2042 (based on ADL 2014 and Hamilton et al., 2016).

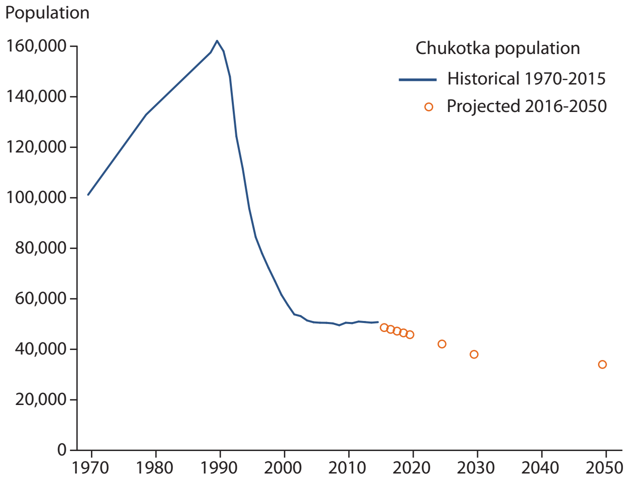


Figure 4.21 Change in population over recent decades in Chukotka, plus projections to 2050 (Russian Federation Federal Statistical Service. Official population forecast, www.fedstat.ru/indicator/36727).

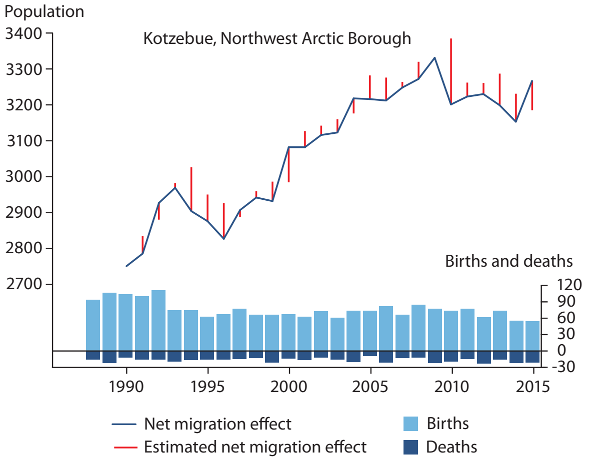


Figure 4.20 Population dynamics of Kotzebue, a community in Alaska's Northwest Arctic Borough, where food insecurity and the impacts of climate change are being actively experienced (population and birth/death numbers are graphed from different baselines, but with comparable y-axis scales) (Hamilton et al., 2014).

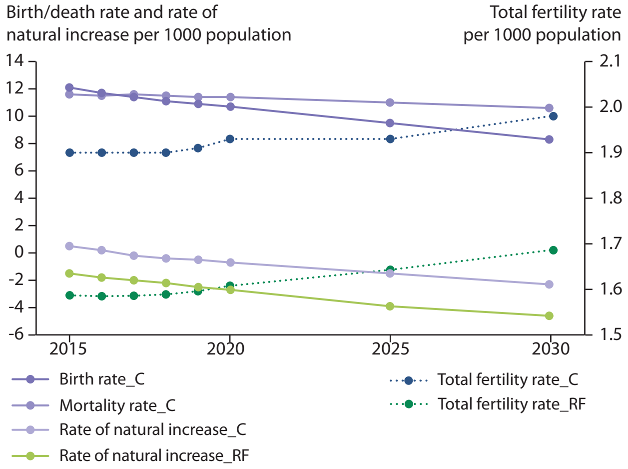


Figure 4.22 Forecast of demographic indices in medium variant scenario for Chukotka (C) and the Russian Federation (RF) (Russian Federation Federal Statistical Service. Official demographic forecast, www.fedstat.ru/indicator/36727).

Figure 4.19. The analysis for northern Alaska and Chukotka (Figures 4.19 and 4.21) follows the timeline from 1970 to 2042 or 2050, covering a longer historical and projection period than in the Andrew (2014) report.

Population in Chukotka rose steeply with in-migration during the late Soviet period and then fell even more rapidly after 1990, with the fall of the Soviet Union and the withdrawal of central government financial support for regional economic activities (see Chapter 5). Figure 4.21 charts these historical changes through 2015, followed by demographic projections to 2050. From 1990 to 2015, the Chukotka population dropped by almost 70%, and is projected to decline further. This very large, rapid, and unforeseen change emphasizes the potential scale for impacts from socio-economic events on relatively small Arctic populations.

Accessible demographic predictions for the Chukotka region are available only to 2030. The main demographic indices for the period up to 2030 are shown in Figure 4.22, which indicates that total fertility rate is expected to rise slightly, from 1.9‰ to 2‰, and life expectancy is expected to be 67.5 years, up from the current level of 61 years. These tendencies will limit the rate of population decline to 0.5–1% per year after 2030. Consequently, total population (disregarding possible migration flows) is projected to be 32,000 to 36,000 by 2050.

The population of the Canadian sector of the BCB region is smaller than the Alaskan and Chukotkan sectors, totalling nearly 13,000 people across 11 villages and towns in 2011. Historical trend data and future projections of population are not available, but the high proportion of youth under 15 years of age in the Inuvialuit Settlement Region in 2011 (21%) suggests the potential for relatively rapid population growth in coming decades (Stern et al., 2015).

### 4.5.2 Governance

While overall governance in Alaska has been fairly stable, both the Canadian and Russian parts of the BCB region are experiencing decentralization as powers are transferred from national to regional governments. Within Canada, the federal government has been transferring powers to the Northwest Territories, Nunavut, and Yukon under an ongoing process known as 'devolution'. Devolution enables the territories to become more self-sufficient and prosperous and to play a stronger role in the Canadian federation. Devolution is considered to be a key component to the development of northern Canada and is presently the most advanced in Yukon. Recent devolution in Yukon and the Northwest Territories focuses on managing public lands, shaping resource development, and controlling royalty revenues (Coates and Poelzer, 2014).

At a subregional level, northern Canada is subject to comprehensive land claims agreements, which transfer private lands; establish land, water, and wildlife management boards, and environmental assessment processes within claims areas; and provide compensation for negative impacts on subsistence harvesting and other Indigenous rights. The Inuvialuit Settlement Region was established under the Inuvialuit Final Agreement in 1984, and Nunavut was established in 1999 with ratification of the Nunavut Final Agreement. Both agreements incorporate traditional Inuvialuit and Inuit knowledge, describe local participation in shared management and the institutions of public government, and will play an important role in future development of the region (Muir, 1994).

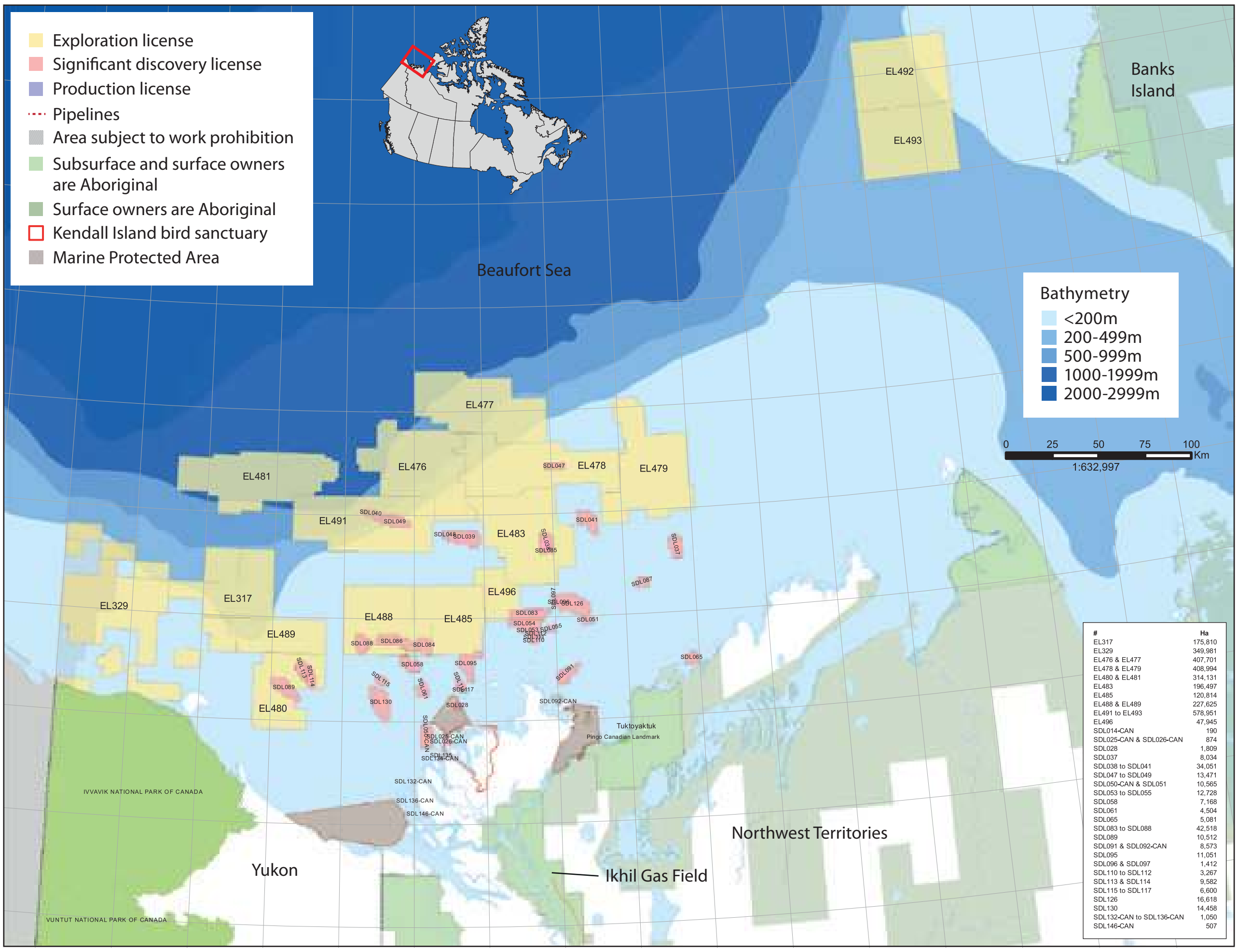
Within Russia, decentralization within the new federal system after 1991 has evolved with profound consequences for the Russian Arctic territories. New environmental, climate change, and natural resource policies have been established, and functions and competences have been transferred from the federal level to the Chukotka Autonomous Okrug and local governments (see Chapter 3). As a result, options and initiatives for the implementation of environmental or climate change policies at the regional and local levels have been considerably enlarged.

### 4.5.3 Oil and gas developments

Oil and gas development has the potential to be one of the most important drivers of change in the BCB region. This section discusses recent changes in these developments and their impacts as regional drivers. As noted by Andrew (2014), there is already significant oil and gas production in the Arctic, representing roughly 10% of global oil production and 25% of global natural gas production.

The Beaufort Sea has extensive oil and gas potential, and there is current production in the Mackenzie River Delta. However, despite interest by several petroleum companies in offshore areas (as reflected by ongoing exploration licenses, shown in Figure 4.23), production is not expected to commence before 2025 (BREA, 2013); in the longer term, activity may well be expected. Oil prices, technological developments (related to both accessibility and the transport of oil/gas to market), sovereignty, and energy security all play a role in setting the pace and magnitude of future development. Many of these issues are discussed in more detail by Andrew (2014, and references therein).

Most recently, dramatically fluctuating oil prices, stranded assets, and analysis of the fossil fuel divestment campaign suggest that not all global hydrocarbon resources can be developed (Ansar et al., 2013); the more remote and expensive-to-develop hydrocarbon resources in the Arctic may be among those left unexploited. There is also a movement away from the use of diesel and fuel oil for power and transport in the Arctic, toward the use of cleaner energy such as liquefied natural gas and renewable energy.



| # | Ha |
|---|---|
| EL317 | 175,810 |
| EL329 | 349,981 |
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| EL478 & EL479 | 408,994 |
| EL480 & EL481 | 314,131 |
| EL483 | 196,497 |
| EL485 | 120,814 |
| EL488 & EL489 | 227,625 |
| EL491 to EL493 | 578,951 |
| EL496 | 47,945 |
| SDL014-CAN | 190 |
| SDL025-CAN & SDL026-CAN | 874 |
| SDL028 | 1,809 |
| SDL037 | 8,034 |
| SDL038 to SDL041 | 34,051 |
| SDL047 to SDL049 | 13,471 |
| SDL050-CAN & SDL051 | 10,565 |
| SDL053 to SDL055 | 12,728 |
| SDL058 | 7,168 |
| SDL061 | 4,504 |
| SDL065 | 5,081 |
| SDL083 to SDL088 | 42,518 |
| SDL089 | 10,512 |
| SDL091 & SDL092-CAN | 8,573 |
| SDL095 | 11,051 |
| SDL096 & SDL097 | 1,412 |
| SDL110 to SDL112 | 3,267 |
| SDL113 & SDL114 | 9,582 |
| SDL115 to SDL117 | 6,600 |
| SDL126 | 16,618 |
| SDL130 | 14,458 |
| SDL132-CAN to SDL136-CAN | 1,050 |
| SDL146-CAN | 507 |

Figure 4.23 Exploration licenses and significant discovery areas in the Canadian Beaufort Sea as of November 2012 (based on BREA, 2013).

### 4.5.4 Mining

As is the case for oil and gas development, mining is an activity that is heavily influenced by global demand and commodity prices. Aside from the Red Dog zinc–lead mine in Alaska, most of the mining activity in Canada and Alaska takes place outside the BCB region, although there are significant potential deposits within the region, for example the Yukon North Slope, Bathurst Inlet area, and Mackenzie Delta. By contrast, the Chukotka region has significant deposits of gold (and often, associated silver), coal, tin, copper, tungsten, mercury, and uranium, which have been exploited for some time (see Chapter 3, Figure 3.9). Nonferrous and precious metal mining is now a major driver of the regional economy and is the major source of gross regional product; Chukotka ranks third among the regions of Russia (after Tyumen and Sakha) in terms of mining's economic contribution on a per capita basis. Technological innovations introduced at some mines have contributed to a reduction of production costs and growing profitability. However, the remoteness of the region, with its severe climate and underdeveloped infrastructure, limits the extent to which mineral extraction is economically viable.

Under the former Soviet system, mining in the Chukotka region was undertaken on the basis of the strategic interests of the country rather than economic viability, with regulations and tariffs serving to support industrial development. This complicated system of financial support, with its multiple mechanisms of state assistance, was nonviable after the fall of the former Soviet Union and the mining industry suffered a severe collapse after 1991. Subsequent technological modernization and the transfer of the mining industry to a market economy resulted in rapid increases in nonferrous metals production, leading to a 34-fold growth in total production between 2002 and 2014 (CAO State Statistical Service, 2015).

Gold production in Chukotka declined by about 80% between 1989 and 2007 (from 21 to 4.4 tonnes per year), but recent price increases have begun to reverse this decline. In 2008 the Kupol deposit went into operation, and in 2013 two big deposits – Mayskoe and Dvoynoe – began operations; further expansion is anticipated. Foreign investments and innovations account for the recent rapid leap in the production of gold concentrate: as of 2015, gold was the dominant commodity in Chukotka's exports and a major source of hard currency revenues. Today, Chukotka ranks among the highest of all regions of Russia in terms of its gold production (see Chapter 3).

Active mining for tin and tungsten ceased following the economic shock of the mid-1990s, but increasing commodity prices may lead to renewed activity in the future. One of the world's largest copper deposits – Baimskaya – is located in Chukotka and may contain more than 50% of total Russian reserves. Active geological survey of this deposit is underway.

Extraction of coal in the Chukotka district is concentrated at two deposits in the Anadyr municipal district (Berengovskoe and Anadyrskoe). Extracted coal is currently used only for local energy production; none is exported.

### 4.5.5 Fisheries

Most of the commercial fishery of Alaska and Chukotka is located south of the BCB region, so it is not clear whether commercial fisheries are or will be a significant driver of change within the BCB region. Currently there is a moratorium on commercial fishing in the US section of the Beaufort Sea under the Arctic Fishery Management Plan of 2010, and there are no commercial fisheries in the Canadian Beaufort Sea (Muir, 2010). This situation may change over time, depending on the fish species that may migrate into or through the BCB region.

The total annual catch in Canada's Arctic was approximately 900 tonnes in the early 2000s (Booth and Watts, 2007), with a total annual revenue or landed value estimated at $\text{USD}_{2005}$ 1.47 million (database of Sumaila et al., 2007). Historical catches from the Canadian Arctic region increased rapidly in the first half of the 1950s from around 2000 tonnes to 3300 tonnes per year. However, there followed a rapid decrease to around 1000 tonnes per year in the early 1970s, largely as a result of reduced catch for sled-dog consumption; the annual catch has subsequently remained at approximately 800–900 tonnes (Figure 4.24).

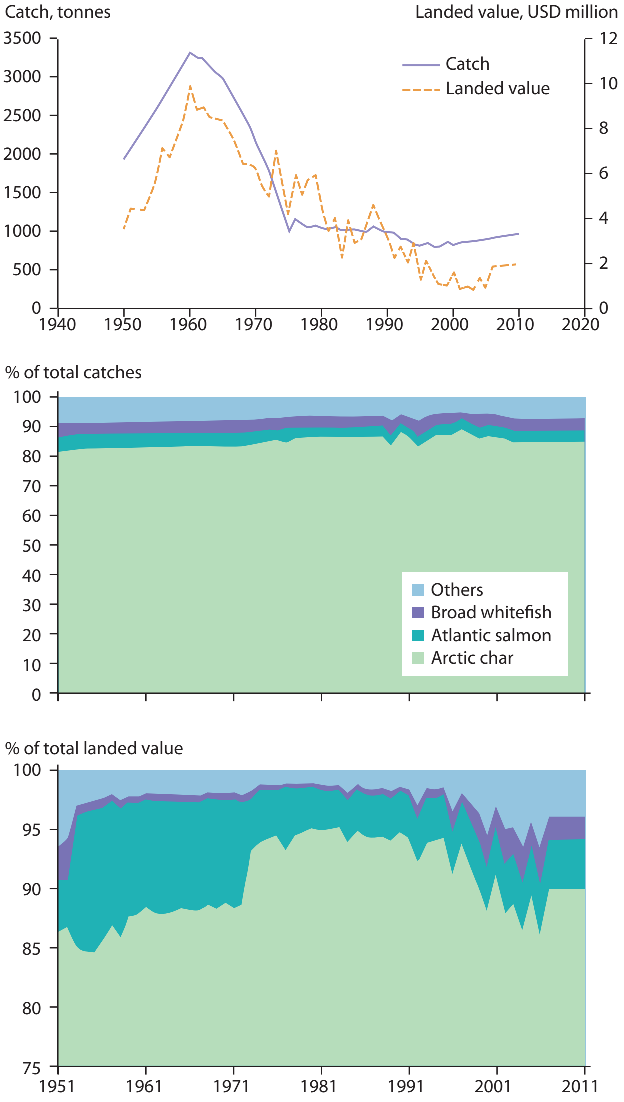

Figure 4.24 Catches and landed value of marine fisheries from the Canadian Arctic region (data from Sea Around Us, www.seaaroundus.org), and the relative contribution of individual species (Cheung et al., 2016).

Species with the highest annual catch and landed value were Arctic char (*Salvelinus alpinus alpinus*), Atlantic salmon (*Salmo salar*) and broad whitefish (*Coregonus nasus*), which have been the dominant exploited species since the 1950s (Figure 4.24).

Under scenarios of climate change, maximum potential catch and economic benefits from fisheries in the Canadian Arctic region are projected to increase, while ocean acidification may reduce expected catches and values (AMAP, 2013; Cheung et al., 2013; Lam et al., 2014). Under the SRES A2 scenario, maximum catch potential in the Canadian Arctic region is projected to increase by 27% by 2050. The projected increase in catches is driven by poleward shifts in the distribution of subarctic and temperate fish species, a decrease in sea ice extent, and an increase in net primary production. Ocean acidification is projected to reduce the expected catch by 5%. Potential wages (income) earned through fishing is projected to increase from USD 7.0 million per year in the 2000s to USD 7.6–10.6 million per year in the 2050s due to climate change, whereas ocean acidification is projected to reduce the expected wages by an average of USD 900,000 per year. Overall, the total economic contributions from fisheries are projected to increase by USD 2.1–14.7 million, while ocean acidification is projected to reduce the positive effects of climate change by an average of USD 1.8 million (Lam et al., 2014).

### 4.5.6 Transportation

Many communities in the BCB region are small, remote, and coastal. Some communities and industrial installations are served by year-round roads, but many are dependent on seasonal ice roads, marine shipping, or air transport for supplies and equipment. In addition, resource extraction in the Arctic is often facilitated by ship transport of equipment and fuel to a mine or drill site and by the subsequent shipment of resources to southern markets or processing facilities. As sea ice conditions change, there is also the potential for enhanced marine shipping through the Arctic between Europe and Asia, as well as increased cruise ship tourism. These topics are discussed in more detail in the following sections.

#### 4.5.6.1 Marine shipping

A topic that generates significant media attention is the potential for enhanced ship traffic between Europe and Asia through the Arctic. In the context of the BCB region, the potential for shipping through the Northwest Passage is particularly relevant. As noted by Andrew (2014), there is significant economic incentive for trans-Arctic shipping in that Arctic routes are roughly 40% shorter than routes through the Suez or Panama canals. Although trans-shipping via the Northwest Passage would not necessarily yield economic benefits for the BCB region, there are potential negative impacts associated with air and water pollution, particularly in the event of an accident. As Andrew (2014) noted, the infrastructure along Arctic shipping routes (limited repair and port facilities, poor quality maps and charts, limited satellite navigation coverage) is currently not conducive to significant ship traffic, and limitations on the use and carriage of heavy fuel oil in Arctic waters will also be an important factor.

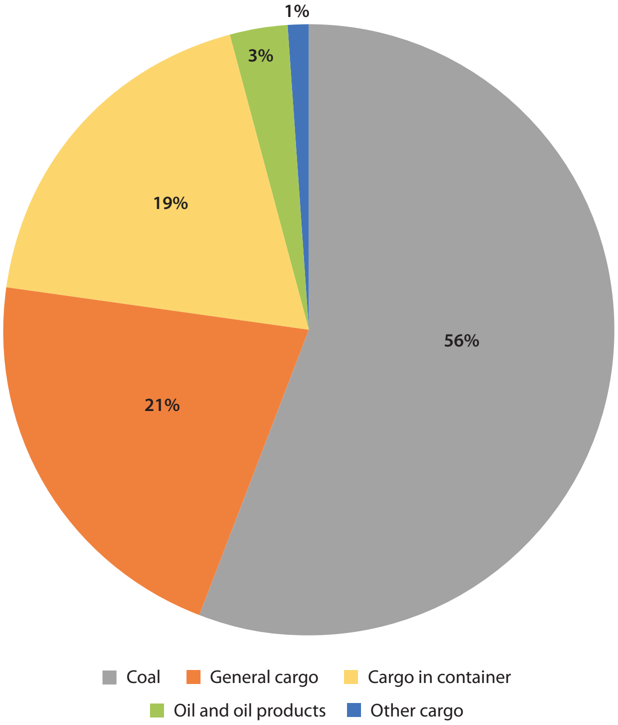

Figure 4.25 Types of freight cargo in the main ports of the Chukotka district in 2014 (All Freight of Russia, 2015).

It is also the case that, even with the observed and projected decline in overall sea ice extent and lengthening of the open water season, the Northwest Passage will continue to be a summertime-only route throughout the 21st century. For ships that are not ice-strengthened, the season will be limited to one or two months, largely because of the short open water season in the Parry Channel (Stephenson et al., 2013). As a result, extensive through-shipping via the Northwest Passage is unlikely. However, the Northern Sea Route, which passes through the Chukchi Sea along the Russian coast, has more potential to be used. By mid-century, open-water class vessels may be able to navigate this route for three months of the year (Stephenson et al., 2013). Destination shipping – that is, the delivery of goods to local communities – is likely to increase during the 21st century and may offset some of the pressures on road and air transport (Andrew, 2014). There is already extensive cargo shipping in the Chukotka region, as illustrated in Figure 4.25.

In November 2014, the International Maritime Organization adopted the International Code for Ships Operating in Polar Waters (the 'Polar Code'), and related amendments to the International Convention for the Safety of Life at Sea (SOLAS) made the code mandatory. This adoption will in turn drive marine insurance requirements. Based on the Polar Code and plans for mining projects in the Canadian Arctic, there seems to be an evolving best practice of having Arctic ships that support industrial development use liquefied natural gas for a transport fuel, thus reducing the risk of ship-based spills.

### 4.5.6.2 Road transport

Permanent roads are limited in the Arctic and are generally founded on permafrost soils (hence susceptible to seasonal thaw and longer-term degradation). As the climate warms, the seasonal thaw depth increases, reducing the bearing capacity of these roadways in summer. As a consequence, the cost of maintaining roadways in the North is expected to increase substantially (e.g., Government of the NWT, 2007; Hong et al., 2014).

Ice roads, which are accessible only in winter and are constructed by clearing snow from frozen lakes and rivers and the intervening ground, serve as a vital link to many communities and industrial installations. Climate warming is expected to ultimately reduce the operating season for such roads; however, there is so far only limited evidence for significant change in Canada and Alaska. Figure 4.26 shows the length of the winter travel season in Alaska since 1970. Although the tundra travel season has shortened, the climate-driven changes are offset to some extent by ongoing adaptations in the form of improved monitoring of road conditions, revised routing, and new vehicle technology (Alaska Department of Environmental Conservation, 2014). Ultimately, alternative means of transporting supplies and raw materials may need to be developed. Air transport is very expensive, but as noted in the previous section, marine shipping may be expanded in some cases.

Because the ice road from Inuvik to Tuktoyaktuk was deemed particularly vulnerable to climate change, an all-season road is being constructed between the town of Inuvik and the hamlet of Tuktoyaktuk, extending the Dempster Highway from Whitehorse in the Yukon Territory all the way to the Arctic coast. The Inuvik to Tuktoyaktuk highway opened in autumn 2017. The highway establishes a permanent transportation link to the Arctic coast, facilitating and reducing the costs associated with commercial-, mining-, and security-related operations in the Arctic (Barton, 2016).

### 4.5.7 Tourism

Sustainable tourism, implemented in collaboration with Arctic communities, may allow for local benefits and facilitate adaptive responses. Tourism activities, including those that originate with or are supported by northern communities and governments (and which fully engage local communities and respect traditional knowledge and land uses), could provide sustainable economic development throughout the region, encourage biodiversity and conservation, and support adaptation and resilience to global and climate changes.

Tourism in the Arctic is expected to continue growing, owing to increased accessibility and increased demand. Much of Arctic tourism may be aboard cruise ships, which are largely self-sufficient and, unless sensitively implemented, may have limited economic benefit to Arctic communities (Andrew, 2014).

Arctic countries are aware of tourism opportunities, and the Arctic Council supported the Sustainable Model for Arctic Regional Tourism project, which issued a report in 2006 (SMART, 2006). The Protection of the Arctic Marine Environment's Arctic Shipborne Tourism Initiative, 2013–2015, is part of a renewed effort by the Arctic Council to analyze and promote sustainable tourism across the circumpolar Arctic (PAME, 2017).

Regional governments are also interested in sustainable Arctic tourism. The Sustainable Arctic Tourism Association includes the participation and support of the State of Alaska, the Northwest Territories, and Nunavut, which also collaborated in the design of tourism principles, guidelines, and best practices under the SMART project (Sustainable Arctic Tourism, 2016).

### 4.5.8 Education

Increased access to education is seen by many in the BCB region as an important driver of desirable regional change. At present, access to education and skills training is a challenge in many remote areas, and this limits the ability of local residents to take

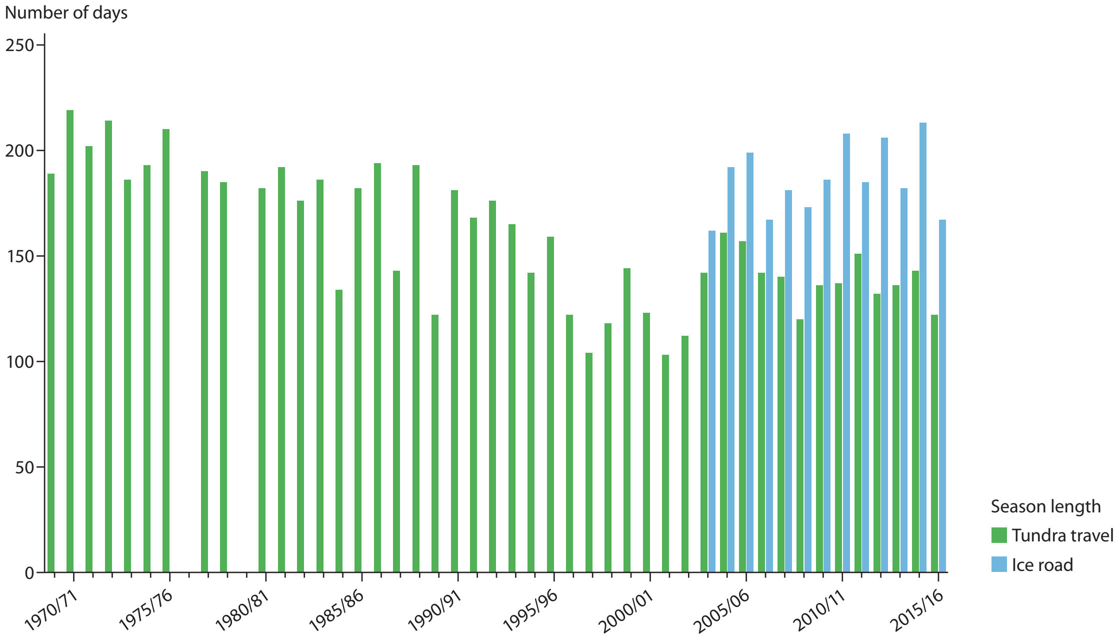

Figure 4.26 Ice road and tundra travel season lengths on the North Slope of Alaska, 1970–2016 (updated from Alaska Department of Environmental Conservation, 2014).


Hemis / Alamy Stock Photo

*Observing polar bears from pack ice, Alaska*


Cindy Hopkins / Alamy Stock Photo

*Schoolchildren playing, Komsomolskaya Bay, Chukotka*

full advantage of economic development opportunities that may arise. Many of the higher-paying jobs (e.g., in the oil and gas industry) require specialized training or trade certifications. In Chukotka, this need has been addressed and education is becoming a significant driver of socio-economic change. The Chukotkan regional government has increased its support for specialized professional secondary education and it envisions more for the future; during the last three decades, the number of students in this category increased almost three-fold, to 303 such students per 1000 people of the general population in 2014 (CAO State Statistical Service, 2015).

### 4.5.9 Subsistence economy

Arctic Indigenous communities and households tend to be characterized by mixed subsistence/cash-based economies (Usher et al., 2003). The Aboriginal Peoples Survey of Statistics Canada and the Survey of Living Conditions in the Arctic (Andersen et al., 2002) contain extensive information about the engagement of communities and households in both traditional subsistence and nontraditional cash economic activities, as well as data on other social indicators. The subsistence or informal economy plays a large role in the Canadian North, with an estimated annual value of CAD 30 million for country food in Nunavut, which is equivalent to the value of imported food (Andersen et al., 2002). The importance of the subsistence economy extends far beyond economic considerations, as wildlife resource sharing, especially for country food, follows traditional kinship patterns and remains an important contributor to family income, cultural and familial cohesion, and identity (see Chapters 2, 3, 6 and 7).

This fundamental importance suggests that the subsistence economy will undoubtedly remain one of the pillars of future community and family economic activity in the BCB region. However, as described in Chapter 2 and particularly in Chapters 6 and 7, there are many environmental, economic, cultural, and social challenges emerging as a result of change in the Arctic. It is impossible to predict how the role of the subsistence economy in Arctic communities will change in response to these challenges over the longer term (to the middle of the 21st century) – but it seems clear that in the short-term at least (on the scale of one to two decades), the subsistence economy will continue to be an important determinant of social and regional cohesion, culture, and economy.

## 4.6 Summary

*How are global factors driving change in the region?*

Global climate is changing, driven by enhanced radiative forcing associated with increasing greenhouse gas concentrations in the atmosphere. For many climate indicators, change is greater and more rapid in the Arctic than at lower latitudes owing to processes and feedbacks in the climate system that act to amplify change in the Arctic. In addition, pollutants produced at lower latitudes are transported by the ocean and atmosphere into the North. These large-scale changes in global climate are therefore reflected in local environmental change.

Global socio-economic conditions – such as globalization of the economy, changing demand (and price) of resources, and changing national and international governance structures and regulatory regimes – all act in various ways to affect conditions regionally. Other global influences, such as the potential for enhanced shipping between Europe and Asia via the Arctic and growing demand for access by tourists, will also have regional implications for both the economy and the environment.

*How has climate changed in the past, and how much change is expected in the future?*

Observations reveal a consistent and compelling picture of environmental change in the region. Mean surface air temperature has increased roughly 1.5°C over the last 50 years or so, snow cover duration has declined, permafrost temperatures have risen, and the summertime extent of sea ice has shrunk. All of these trends are projected to continue in the future, with the magnitude of change depending directly on future greenhouse gas emissions. There is, of course, uncertainty in future climate projections (due to natural variability and unknown future greenhouse gas emissions pathways), and this must be kept in mind as impacts and risks are evaluated. However, it is clear that warming will be greater in winter than in summer. Wintertime warming for a mid-range greenhouse gas emissions scenario is projected to be in the range of 3–7°C over the land portion of the BCB region by the end of the century and more over the Beaufort and Chukchi seas.

*What changes are occurring, and are projected to occur, in the regional marine and terrestrial ecosystems?*

As the climate has warmed and the summer open water season has lengthened, ocean temperatures have warmed – and will continue to warm. More extensive open water results in larger waves and enhanced coastal erosion. Increased precipitation, projected for the high latitudes in general, will lead to increasing river runoff (providing freshwater to the ocean).

Carbon dioxide, emitted due to fossil fuel combustion and land use change, is absorbed by the ocean, and this $CO_2$ uptake leads to increasing ocean acidity with implications for the ocean ecosystem. Changing temperature, sea ice conditions, and upper ocean nutrient supply are altering the timing of phytoplankton blooms and the composition of algal communities. Projections of future primary productivity remain uncertain, however.

Contaminants from lower latitudes are transported into the BCB region, and changing climate can affect transportation pathways, deposition rates, and biogeochemical processing. Future oil and gas development in the region is projected to increase local sources of petroleum hydrocarbon pollutants to levels approaching current natural sources. Increasing melt-pond abundance on sea ice may increase biological exposure to halogenated organic contaminants.

On land, coastal erosion rates have generally been increasing in the BCB region. As in the ocean, the terrestrial ecosystem is responding to warmer and longer summers, with observed changes in vegetation productivity and 'greening'. Feedbacks between vegetation and climate – such as changes in surface albedo and the trapping of snow by shrubs – will affect water availability, permafrost degradation, and carbon release, although comprehensive model-based projections are lacking.

*What changes are occurring, and are projected to occur, in regional socio-economic conditions and forms of governance?*

Population in northern Alaska has been increasing steadily, and this trend is projected to continue. In the Chukotka region, by contrast, population peaked in about 1990 and has since declined sharply as a result of major socio-economic and political changes in the Russian Federation. Population in Chukotka is projected to continue a slow decline into the future.

Regional socio-economic changes will continue to be driven to a large extent by external influences, such as commodity prices and demand for oil and gas and minerals. The pace and magnitude of such changes will vary considerably within the BCB region owing to differences in resource availability and governance systems.

Until recently, oil and gas development was anticipated to grow in the coming decades, particularly in the Beaufort Sea, but low oil prices mean all exploration and development activities are currently on hold. In Chukotka, mining has been an important economic activity and some growth, particularly in gold and coal, is expected in the coming decades.

Marine shipping is expected to increase within the BCB region as sea ice decline leads to a longer open water season. Road transportation, by contrast, may become more difficult under changing climate as the ice-road season becomes shorter and permafrost degradation affects trafficability. However, these impacts have so far been largely offset by adaptive measures such as alternate routing and new vehicle technology. There is also ongoing expansion of the highway network, at least in the North American part of the BCB region.

Tourism is expected to continue its current growth, bringing economic opportunities to the region. The prevailing lifestyle in Arctic Indigenous communities is a combination of traditional activities and cash employment. In Nunavut, the annual economic value of traditional foods is comparable to that of imported foods, indicating that the subsistence harvest continues to be an important part of the regional economy. The impact of climate and socio-economic drivers on the subsistence lifestyle will be explored further in later chapters.

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# 5. Impacts and consequences for northern communities and society

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## Key messages

- ***The small number of jobs, high cost of living, and rapid social change make rural, predominantly local communities highly vulnerable to climate change through impacts on traditional hunting and fishing and cultural connections to the land and sea.*** *Climate impacts on these communities are magnified by social and economic stresses. However, Indigenous communities have for centuries dealt with scarcity and high environmental variability and thus have deep cultural reservoirs of flexibility and adaptability.*

- ***The combination of ongoing environmental, climatic, economic, social, and cultural changes in the Arctic and globally affects processes and transformations in natural and socio-economic systems, with consequences for society, including the everyday lives, well-being, and economic development of individuals, families, and communities.*** *Arctic residents are already adapting to climate warming impacts and will be increasingly challenged to adapt as the pace of warming increases.*

- ***The environmental drivers that have been increasingly shaping the lives of people in the coastal communities of the BCB region are expected to continue to grow in magnitude and effect during the 21st century.*** *Impacts on the physiography of the coast will continue to direct the location of human habitations and the staging and feasibility of subsistence activities and local economic development.*

- ***The restructuring of Indigenous cultures in response to changes in the species composition and availability of subsistence food resources appears to be inevitable.*** *The loss of multi-year sea ice and changes in the duration and distribution of annual sea ice will also continue to circumscribe the availability of marine and coastal subsistence resources. When multi-year sea ice becomes absent from the area completely, this is expected to result in profound changes in the availability of mammals and birds as sources of subsistence foods.*

- ***Arctic residents and communities will all experience impacts in their everyday lives, associated with issues such as anthropogenic contaminants, food and water security, housing, public services and infrastructure, transportation, human health, safety, coastal erosion and flooding, permafrost thaw, wildfires, and cultural heritage.*** *There are intimate and inseparable linkages between the subsistence way of life and the physical, economic, and sociocultural well-being of Arctic residents, their families, and communities. The connections and dependencies among these conditions extend in all directions, and each element is seeing – and will continue to see – changes, challenges, and opportunities in the coming years.*

- ***The thawing of permafrost is affecting the integrity of homes, municipal buildings, and essential facilities, including roads, infrastructure of the oil, gas, and mining industries.*** *More challenging travel conditions and increasing unpredictability in animal movements and availability can decrease harvest success and require additional hunting effort. Additional hunting effort entails additional fuel costs, time away from jobs and families, increased wear and tear on equipment, and increased risk of exposure and injury.*

- ***Scientific observations and traditional knowledge suggest that the BCB region is moving toward conditions unlike those recorded in the past.*** *Scientists and observers have documented significant changes in sea ice and snow, sea levels, permafrost, ocean acidification, coastal erosion, precipitation, hydrology, and ecology. Additional challenges for coastal communities include flooding, changing weather patterns, and ecological and cultural impacts of increased maritime access, resource development activities, and new infrastructure, as well as diminishing habitats for some ice-dependent species important for subsistence harvests, such as polar bears, seals, and walruses.*

- ***Climate change influences short- and long-term ecosystem structure and function, but because these environmental variables are so deeply interconnected, it is difficult to predict the status of future ecosystems.*** *Some ongoing changes in the Arctic environment are clear and their impacts are predictable, but many others are more subtle and complex and will play out in unforeseen ways for generations.*

- ***Vulnerability and adaptive capacity of northern communities to climate change has been extensively studied in recent years, but the importance of resource extraction and shipping as climate-related sources of vulnerability has not yet been thoroughly assessed.*** *This gap remains an important focus for future research. There is a growing understanding that climate change has diverse impacts on different economic sectors and that sectoral adaptations to major consequences are essential in the future; so far, concrete directions and trends remain uncertain.*

- ***The BCB region remains a frontier economy highly dependent on natural resources development.*** *Economic activities here are technically challenging and costly, mainly due to the harsh environment and limited transport routes and service infrastructure. Development can have major impacts on communities through the creation of new jobs, personal income, and revenues for municipalities and other government entities. The global economy challenges future economic development and sustainability in the BCB region and its communities.*

## 5.1 Introduction

Climatic, environmental, economic, and social changes underway in the Arctic and globally are affecting the Bering-Chukchi-Beaufort (BCB) communities and society. The combination of these changes results in synergy and has important consequences for the sustainable development of local communities and economies of the BCB region. Impacts of climate change, in particular, have a broad variety of direct and indirect consequences. These effects result in challenges and opportunities to individuals, families, communities, and economic systems in the region. Both mitigation and adaptation responses to climate change are underway in the BCB in order to reduce and manage current and future risks.

With the warming Arctic climate, coastal communities face many impacts to which they have already been adapting and to which they will increasingly be challenged to adapt, as the pace of warming increases. As noted in Chapter 4, the primary drivers of these impacts are environmental, economic, and social. The consequences of these changes will, in turn, become evident, both directly and indirectly, on the environment itself as well as on coastal communities bordering the Bering, Chukchi, and Beaufort seas and also on inland communities.

Scientific observations and traditional knowledge suggest that the BCB region is moving toward conditions never before witnessed. Scientists and observers have documented significant changes in sea ice and snow, rising sea levels, rapid permafrost thawing, ocean chemistry, coastal erosion, precipitation, hydrology, and ecology (IPCC, 2007; Overland et al., 2011; Markon et al., 2012). Additional challenges for coastal communities include flooding, changes in weather patterns, ecological and cultural impacts of increased maritime, resource development activities, new infrastructures and diminishing habitats for some of the ice-dependent species important for subsistence harvests, such as polar bears, seals, and walruses. Climate change influences ecosystem structure and function in the short and long term, but because these environmental variables are so deeply interconnected, it is difficult to predict the status of future ecosystems.

Shifting environmental conditions such as the combination of thawing permafrost and loss of coastal ice cover for increasingly long periods each year have led to substantial changes in the physiography of the coastline. The loss of ice cover results in longer distances (fetch) over which winds can propagate waves, resulting in more energy being transferred from the wind to the ocean, with both driving coastal erosion processes. Such processes are also enabled by the lack of coastal armor ice to absorb the wind-driven energy. Large areas of coastal land are being removed by wind- and wave-driven processes, and some areas are being inundated by brackish water. Communities located along the coast in these areas (e.g., Shishmaref, Alaska) have experienced the consequences of having their dwellings and other buildings compromised or of being forced to move structures to prevent them from being destroyed.

The loss of seasonal sea ice has led to changes in the distribution of ice-dependent or ice-associated marine mammals and birds. Coastal communities have been affected as subsistence species have declined in number or have moved beyond the geographic reach of harvesters. Ice seals, walruses, and polar bears have shown changes in distribution, which affects their availability to coastal communities. Changes in migratory pathways and the phenologies of mammals and fishes, related to changes in sea ice and water temperature, have changed the areas in which subsistence mammal and fish species are harvested and even the species composition and seasons of harvest.

Recently, there has been a growing worldwide discussion about climate change and possible associated increases in the scale and intensity of natural disasters and their negative impacts. Observations from the BCB region indicate growing evidence of a variety of adverse consequences for the northern human population, their livelihoods, and economic activities – from both extreme events (e.g., severe storms, floods, wildfires) and slow-onset events (e.g., coastal inundation and erosion, permafrost destruction). Although regularly collected and directly comparable or compatible data on damage and loss from natural disasters in the region are still scarce, it is expected that the negative impacts of such events will increase in the future (Larsen et al., 2014) if consistent response measures to avert and reduce risks are not taken.

The scales of adverse effects vary significantly across the region. An extreme event or a slow, creeping event can be a disaster when communities, livelihoods, and economic infrastructure are affected or destroyed. When such events occur in the region's vastly unpopulated wilderness, their impacts can be regarded as a component of the natural cycle. Poor northern communities appear to be most vulnerable to negative consequences. Actions taken for hazard prevention, preparedness, rescue, rehabilitation, and mitigation – coupled with broader sustainable development measures – contribute to averting or reducing the scales of risk and damage (to life and property) associated with natural disasters (Lebel et al., 2010). The scale of negative impacts might be lower when communities are well informed and prepared in advance; prepared communities may live with risk and cope better with disasters than communities that are unprepared or that lack the capacity, skills, knowledge, and resources to respond to unexpected events. In recent years, the development of climate services (i.e., the production, transfer, and use of climate knowledge and information), better delivery of tailored predictions and advice about possible climate change impacts, and assistance to stakeholder planners (helping to make more informed decisions) have been acquiring broader attention (Blue-Action, 2017).

This chapter explores some of the observed and projected consequences of changes for the social, economic, and cultural aspects of northern communities, as well as important supporting ecosystem services, over time frames varying from several years to several decades. Longer-term scenarios of the possible consequences of warming in the Arctic are considered in Chapter 8.

## 5.2 Impacts on Arctic residents and communities

Climate change is affecting all parts of the environment, with direct and indirect effects on the types and frequencies of disease and injury, challenges to mental health, and issues of food and water security throughout the Arctic. In the Arctic, climate change has emerged as arguably the most important public health topic of the decade, presenting a wide range of effects – largely negative but also sometimes positive.

*Inuvialuit woman cutting beluga meat with a traditional knife (Ulu) near Inuvik, Canada*

### 5.2.1 Human health and well-being

The health status of residents in the Far North of Canada provides insight into patterns found in many communities across the Arctic. In the western Arctic of Canada, the latest and largest survey of the state of the health of northerners is the Inuit Health Survey (IHS) (Young et al., 2015), conducted in 2007–2008 under the auspices of ArcticNet. Data were collected from interviews, clinical measurements, and sample analyses from 802 individuals in 595 households selected from all of the communities of the Inuvialuit Settlement Region (ISR), Northwest Territories, and the Kitikmeot Region of Nunavut. Many key findings from that survey are summarized below.

#### 5.2.1.1 Epidemiology and zoonotic diseases

Obesity among Inuit in Canada is a real and rising health issue in the ISR and Kitikmeot Region (Sheikh et al., 2011). The average body mass index (BMI) of Inuit increased between 1999 and 2008 by 1.0 among people below 40 years of age and by 0.8 among those over 40 years old. These increases were entirely due to changes among females; male BMI exhibited little or no change during the same period. This change is believed to be due mostly to dietary shifts, with a significantly smaller proportion of calories now coming from traditional food animals, especially among young people, and a corresponding rise in calories from 'market' foods such as potato chips, pasta, and sugared beverages (Young et al., 2015). Among IHS respondents, 82% of all respondents (and 91% of those under 40) reported consuming soft drinks daily, and people under 40 ate 27% less traditional food than those 40 and older – suggesting that a generational change in traditional food consumption patterns may be underway. Country foods, especially caribou (*Rangifer tarandus*), beluga (*Delphinapterus leucas*), and Arctic char (*Salvelinus alpinus*), are the primary dietary sources of key nutrients such as selenium and omega-3 fatty acids for those who eat them (Young et al., 2015).

Changed eating habits appear to be reflected in adverse blood chemistry results. The IHS found that 30% of adults (57% among the under 40 age group and 10% among the over 40 age group) were vitamin D-deficient (Young et al., 2015). Hemoglobin in blood was so low in 14% of men and 23% of women as to be defined as anemic (i.e., <130 g/L). Blood serum ferritin, a measure of body iron stores, showed that 4% of men and 29% of women had chronic iron deficiency. The Inuit Health Survey (Young et al., 2015) further found that about 20% of adults reported that they had been diagnosed with hypertension, while just under 5% had diabetes.

In Alaska, the health of residents is being affected by environmental change, whether in a city or a rural village (Driscoll et al., 2013). Arctic air that is largely free of industrial pollutants can become hazardous with high levels of pollen, dust, or wildfire smoke or when confined by wintertime inversions. Community water from lakes and streams is vulnerable to the effects of low snowpack, drought, rainstorms, and erosion, which affect water quality and availability. Food resources are dependent upon delivery from distant suppliers and upon seasonal conditions for raising, growing, and harvesting local foods.

In Chukotka, a number of infectious diseases such as varicella (chickenpox), respiratory tuberculosis, acute respiratory infections, HIV, and viral hepatitis are perhaps reflecting a potential climate change impact on public health. This suite of diseases is consistent with those suggested to be climate sensitive (Wilson, 2001).

#### 5.2.1.2 Anthropogenic contaminants

Although anthropogenic contaminants are found across the various Arctic environments, concerns with specific types of pollutants vary from region to region. For example, among Inuit in the ISR and Nunavut, blood concentrations of metals and persistent organic pollutants (POPs; such as polychlorinated biphenyls, DDTs/DDEs, toxaphene, chlordane) are higher than Canadian average values (Young et al., 2015). However, the average Inuit concentrations are still below Health Canada guidelines, suggesting that most people are unlikely to experience contaminant-related adverse health effects. A high percentage of consumers of country foods are exposed to elevated levels of mercury (Hg; AMAP, 2011a) and POPs (AMAP, 2010a), which are present in high concentrations in some traditional food animals, especially beluga and seals. In recent years, blood levels of some contaminants (e.g., mercury, legacy POPs) have declined; this is believed to be in part due to a shift away from country foods to market foods (Young et al., 2015).

In Chukotka, economic activities conducted under the former Soviet regime resulted in heavy contamination of inhabited sites, with large amounts of abandoned hazardous wastes. In the villages, years without infrastructure for bulk fuel storage resulted in the accumulation of thousands of metal drums containing spent oils and other waste products, including persistent toxic substances and, in particular, polychlorinated biphenyls (PCBs). Major health impacts associated with human exposure to PCBs include toxic, mutagenic, carcinogenic,

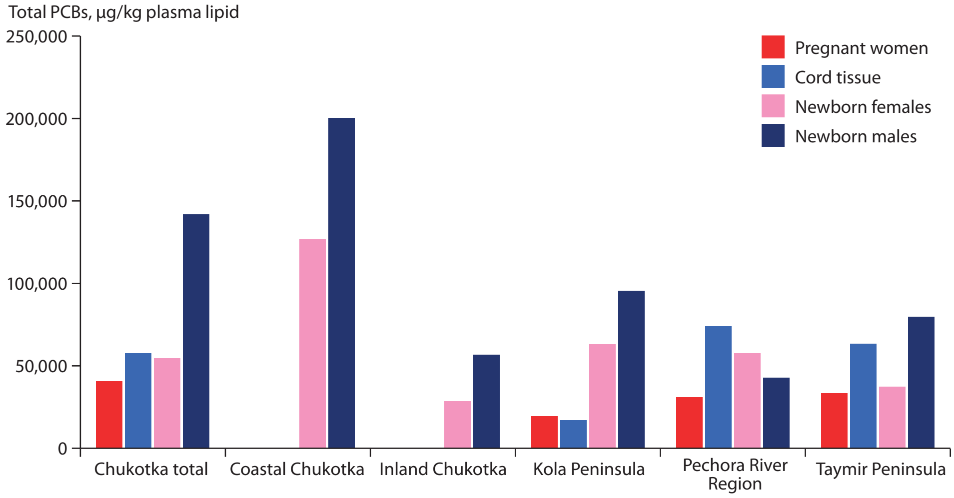

Figure 5.1 Mean serum concentrations of total PCBs measured in Indigenous populations of the Russian Arctic, as sampled from pregnant women, fetal umbilical cord tissue, and newborn male and female babies. (Source: AMAP, 2000.)

and hormone-disruptive effects, as well as immune system impairments and probably reproductive impairments.

According to data reported in *Persistent Toxic Substances, Food Security and Indigenous Peoples of the Russian North* (AMAP, 2004), the Indigenous residents of the Pacific coast of Chukotka, have been at higher risk of exposure to persistent contaminants than other Indigenous populations of the Russian Arctic (Figure 5.1), particularly to the group of PCBs that has originated mostly from local sources. Permafrost warming has enlarged the area of thawing permafrost soils, thus accelerating corrosion and leakage from old rusted drums and storage tanks scattered along Chukotka's coastal and inland river areas (Box 5.1). As tanks and drums rust, environmental contamination spreads and humans are increasingly exposed to its effects. Serious health risks are related to the warming-dependent remobilization of highly toxic persistent contaminants such as PCBs, which originate from spent lubrication and transformer oils at legacy waste sites. Temporal trends of the incidence rates of some diseases potentially associated with human exposure to PCBs, observed in the general population of Chukotka, are shown in Figure 5.2.

As a result of the implementation of Chukotka's Health Risk Reduction Plan in the villages of Lorino and Kanchalan, where PCBs have been the main local contaminant of health concern, a significant reduction of PCB serum concentrations in adult men was observed between 2001 and 2010. In the village of Lavrentia, in contrast, where clean-up operations were carried out to a lesser extent, there was no significant change in human exposure to PCBs, as indicated in PCB serum concentrations (Table 5.1).

Distinct from contamination due to local activities, an additional concern is the arrival of airborne contaminants from southern latitudes. Amplification of the concentrations of airborne contaminants during poleward transport appears to have compromised some Arctic subsistence foods (AMAP, 2010a, 2011a), leading to an increased risk of human health problems. Uptake of contaminants to humans via the subsistence food web is just one facet of the impacts of human activities on Arctic coastal communities of the Chukchi and Beaufort seas. An additional aspect, loss of confidence in the purity of subsistence foods, is a more insidious threat to Indigenous cultures and subsistence food security.

### Box 5.1 Clean-up of accumulated Soviet heritage

There has been growing concern that contaminated drums abandoned on the permafrost in Russia present a broad threat to the environment, to wildlife, and to the people who depend on Arctic subsistence food resources. Owing to limited understanding of the local and regional environmental health impacts of climate change, there was no comprehensive inventory of drum sites or systemic clean-up of contaminated villages until the Health Risk Reduction Plan, based on AMAP recommendations, was implemented in Chukotka between 2004 and 2006.


V. Chaschin

*Abandoned drums near the Indigenous coastal village of Lorino, Chukotka*


V. Chaschin

*Clean-up by trained local Indigenous volunteers near the Indigenous villages of Lorino and Kanchalan, Chukotka*

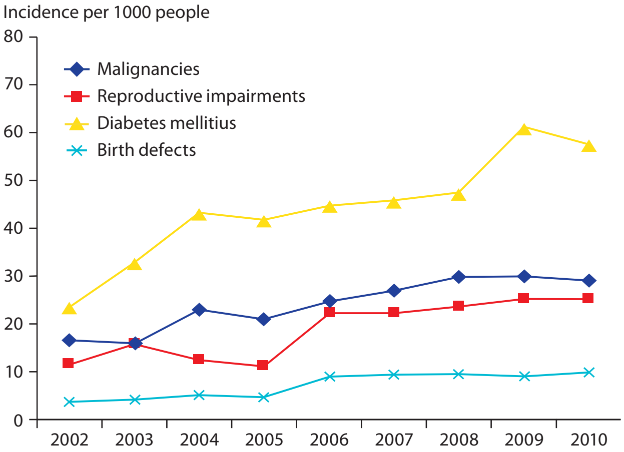

Figure 5.2 Incidence of diseases potentially associated with human exposure to PCBs in Indigenous populations of Chukotka (Russian Ministry of Public Health, 2011).

### 5.2.1.3 Water security

Water security – the reliable availability of and accessibility to an acceptable quality and quantity of water for health, livelihoods, and production – is an important challenge for the BCB region. For example, drinking water in the Canadian ISR and Kitikmeot Region, as elsewhere across the Canadian Arctic, is obtained either from municipal filtered water or from surface water gathered from the land (Martin et al., 2007). This water resource exists largely because of underlying permafrost and is shared by people, wildlife, and industry. It is consequently vulnerable to climate warming–related permafrost thawing as well as drainage, contamination, and overuse (White et al., 2007; Evengard et al., 2011).

Communities have reported that the availability of clean and safe water has become poorer in all Inuit regions of Canada due to recent environmental changes (Nickels et al., 2006). Residents of the ISR have reported that the natural sources of drinking water are different and have a worse taste and smell than in the past. Residents have also stated their concern about water supplied by the municipalities. The water treatment system in Aklavik, for example, has in the past frequently been clogged by increased algae and sedimentation linked to low water levels. There is also concern in Aklavik that *Helicobacter pylori* contamination of the water supply is adversely affecting the health of residents (Cheung et al., 2008).

In the US Arctic, community water supply is sensitive to impacts from thawing permafrost. Like Canada's ISR and Kitikmeot Region, Alaska's North Slope relies largely upon small tundra ponds for community water supply. Many of these ponds are changing as warming increases seasonal thaw, allowing lake drying to occur. As water levels drop, changes in the physical and biological conditions of the lakes also occur. For example, in Point Hope, warm conditions and a lower lake level resulted in algal blooms during July 2008. As a result, the labor required to maintain the water system increased from changing filters four times per day to almost 50 times per day (Brubaker et al., 2010). This water system was designed for conditions that no longer exist, at least not consistently; as a result, the lake environment brought about by a new climate has overwhelmed the capacity of the water systems to operate efficiently. This lesson probably applies to many communities throughout the Arctic. As long as infrastructure continues to be designed and constructed based on conditions and data from the past, there is likely to be a continuation of high maintenance costs, operational failure, or complete loss of systems from catastrophic events in the future.

Another example is the water distribution system for the village of Selawik, Alaska, built on the delta of the Selawik River. This region of ice-rich permafrost is thawing, subsiding, and eroding as warming temperatures destroy the icy foundations that designers have depended upon for generations. The water and sewer utilities in Selawik are located in an above-ground network of insulated utilidors (utility corridors) and Arctic (multilayer, insulated) pipe. These facilities are heavily insulated and must be heated in winter to prevent freezing. Still, freezing does occur, resulting in seasonal water distribution failures that affect entire sections of town. This freezing is in part due to the settling of supports and foundations in thawing soils; when settling occurs at different rates, the fittings that connect homes and other structures to the water system are stressed and damaged. Once a fitting is broken, cold air can infiltrate the seal and freeze the water in the pipes. During the winter of 2011–2012, repeated freeze-up caused many households to be without water service for most of the winter. Turning up the heat has resulted in high energy bills for both the water supplier and individual homeowners but still has not always been enough to prevent water lines from freezing (Brubaker et al., 2012). Adaptation to the changing conditions has included redesign of the community water distribution system, incorporating highly flexible pipe junctions that can accommodate dynamic movement.

In Chukotka, water resources are abundant. In 2013, annual river flows were higher than the multi-year annual average (up 15% from 2010 flow rates) (RF Ministry for Natural Resources and Environment, 2015). Chukotka is also characterized by high annual per capita water consumption. In 2014, average water consumption by Chukotka households was

Table 5.1 Serum concentrations (μg/L) of total polychlorinated biphenyl (PCB) and selected congeners in Indigenous cohorts of adult men (35–55 years of age) in Chukotka in 2001 and 2010 (Russian Ministry of Public Health, 2011).

| Village of cohort | Number of study subjects | 2001 | | | 2010 | | |
|---|---|---|---|---|---|---|---|
| | | ΣCB28–CB118 | CB153 | Total PCBs | ΣCB28–CB118 | CB153 | Total PCBs |
| Lavrentia | 40 | 1.61 ± 0.20 | 1.33 ± 0.15 | 6.66 ± 0.55 | 0.96 ± 0.40 | 1.75 ± 1.62 | 7.06 ± 2.36 |
| Lorino | 16 | 1.38 ± 0.51 | 3.22 ± 2.12 | 8.05 ± 4.60 | < 0.07[a] | 0.81 ± 0.33[a] | 2.37 ± 1.10 |
| Kanchalan | 24 | 1.09 ± 0.74 | 3.50 ± 1.41 | 7.85 ± 2.96 | 0.68 ± 0.12 | 0.24 ± 0.08[a] | 1.81 ± 0.22[a] |

[a] Difference from 2001 concentration is statistically significant

76 $m^3$ per person, which is higher than in most other regions of the Russian Far East. The major water supply source is surface waters, accounting for about 93% of total freshwater consumption (RF Ministry for Natural Resources and Environment, 2016). However, the water quality in Chukotka is poor, ranking first among the ten Russian Far East regions for poor quality of drinking water – both in centralized water supply networks and in decentralized systems, thus posing a serious risk to human health. In 2014, 51% and 36% of samples from centralized and decentralized water supplies, respectively, did not meet sanitary and chemical standards, and water quality appears to be still deteriorating further (RF Ministry for Natural Resources and Environment, 2015). However, the proportion of polluted drinking water that meets microbiological standards is steadily increasing. Poor drinking water quality can be partly attributed to the consequences of human pressures (although the annual level of polluted water discharge is not high) and accumulated damage to vulnerable natural systems. One important factor is the aged water supply infrastructure, which is becoming particularly sensitive to extreme northern conditions (Nikitina, 2011). Similar to the situation in Canada and Alaska, water supply and sanitation systems in the settlements of Chukotka are extremely vulnerable to permafrost degradation and thawing. In this context, integrated adaptive water governance options are increasingly essential for problem solving in the interest of enhanced water safety (Pahl-Wostl et al., 2012).

## 5.2.2 Local communities: housing, public services, and infrastructure

### 5.2.2.1 Permafrost

Permafrost thaw is already reshaping Arctic and near-Arctic landscapes, causing the ground to be less stable in some areas (Jorgenson et al., 2006; Zhang et al., 2008; Burn et al., 2009; Martin et al., 2009; Lamoureux et al., 2015). Such thawing may compromise the containment of contaminants in landfills, sewage lagoons, drilling waste pits, and tailings ponds, allowing those pollutants to migrate to nearby waterbodies (AMAP, 2011b). Thawing permafrost and milder winters are also negatively affecting winter road construction, thereby limiting access to isolated communities and industrial sites (Stephenson et al., 2011).

The sensitivity of infrastructure, including roads, housing, and other public services, to climate change depends on three key factors: permafrost, hydrology, and – where applicable – coastal conditions (Lamoureux et al., 2015). Reductions in the thickness and seasonal extent of river, lake, and sea ice will require adaptation for marine and freshwater transportation. Expansion of marine and land-based transportation will be required to support further resource exploration, as previously remote resources become more accessible and economically viable.

Permafrost presents challenges for the design, construction, and operation of infrastructure, as thawing of the ground can lead to loss of strength, settlement, and instability. The removal of insulating vegetation and other ground disturbances from human activity can also lead to warming and thawing of permafrost. Additional warming may occur due to heat generated by industrial developments and community facilities, such as heated buildings and water and sewage pipelines. For runways, roads, and pipelines, settlement and slope instability may occur. Another impact of climate change on permafrost is related to the ground stability of waste-rock piles, tailings piles, and tailings ponds, which depend on permafrost to ensure that contaminants are not discharged into the environment.

Permafrost thawing will likely affect hydrology, surface water availability, and landscapes. As shallow permafrost degrades, new pathways will open for surface water to drain from the landscape, thus reducing water availability for people and ecosystems. The precise nature of these changes is difficult to predict due to expected but unpredictable variability in snow depth, air temperatures, timing and amount of rain, and permafrost thawing rates (Martin et al., 2009). High-latitude northern lakes are already showing a trend toward increased duration of open water, earlier ice break-up, delays in freezing, and reduced ice growth (Magnuson et al., 2000; Dibike et al., 2012).

Permafrost is especially vulnerable to changing climate where near-surface excess ice occurs. The climate warming projected for 2050 in Canada's ISR and Kitikmeot Region will likely generate conditions that could enhance the warming of soil, deepening of the active layer, and thawing of the upper permafrost (Zhang et al., 2008). This vulnerability is particularly important in the southern margins of the regions, where the permafrost is already relatively warm and thin (Burn et al., 2009). Most of the northern part of the region has thick, continuous permafrost, and the projected temperature changes are unlikely to eliminate permafrost. Rather, the impacts of warming on infrastructure will be through subsidence, retrogressive thaw slumps, and active-layer detachment on slopes. These types of disturbance can rapidly affect infrastructure and represent a major hazard associated with climate change. Additionally, land-use and permafrost changes may alter drainage patterns, with effects on infrastructure that can range from expensive repairs to failure. Hydrological changes will alter seasonal streamflow peaks and stress drainage infrastructure.

In coastal areas of the ISR, decreased sea ice has already resulted in increased wave activity (Lamoureux et al., 2015). Projected changes in relative sea level (RSL) in the ISR and Kitikmeot may increase the impacts of wave erosion and thermal abrasion (e.g., Figure 5.3) on coastal infrastructure. Sea level is already

Figure 5.3 Effects of thermal abrasion on a coastline of unconsolidated, ice-rich sediments, example from Lorino, Chukotka Autonomous Okrug.


Accent Alaska.com / Alamy Stock Photo

*The northernmost point of North America is surrounded by ice, even in mid-summer. Chukchi Sea off Utqiagvik, Alaska*

rising in most coastal Inuvialuit communities, and a future switch from falling to rising RSL in the Kitikmeot region (as post-glacial landscape rebound is overtaken by rising sea levels) may increase coastal hazards there. Accelerated coastal retreat has been documented in parts of the Alaska North Slope, but evidence from the ISR and Kitikmeot remains unclear. New planning and design standards (e.g., CSA, 2010; TAC, 2010) are emerging to help local decision-makers improve the resilience of infrastructure, and educational initiatives are seeking to improve community knowledge of risks to infrastructure and other community assets (Government of Nunavut, 2013).

In Russia, current assessments indicate that climate change impacts have resulted in declining stability of permafrost support for buildings and infrastructure – by about 17% from indices of the 1970s, and in some locations a 45% decrease (Roshydromet, 2014). Today, about 50% of buildings and infrastructure in Pevek and Amderma have suffered permafrost-related damage, compared to 22% in Tiksi; 55% in Dudinka; 60% in Igarka, Dikson, Khatanga; and 100% in most of the settlements of the Taymir Peninsula. Serious deformations have been observed in railways, roads, and pipeline networks.

On the Chukchi Peninsula, the southern permafrost boundary has retreated northward by an average of about 80 km. Permafrost thaw as a result of climate warming and human factors, such as flaws in engineering design and poor maintenance (e.g., sewage and heating system leakages), has already affected and will likely continue to affect infrastructure, including housing, roads, and access to remote communities via winter roads (Anisimov, 2009; Kokorin et al., 2013; Streletskiy and Shiklomanov, 2013). According to projections for the mid-21st century, most of the territory of the Chukotka Autonomous Okrug will be subject to a high risk of destructive geomorphological processes linked to permafrost degradation (Anisimov, 2009; Roshydromet, 2014). Special attention should be paid to the Bilibinskaya nuclear power plant, which is built on permafrost (Anisimov, 2009) and is scheduled to be decommissioned soon.

#### 5.2.2.2 **Floods**

Flooding is a threat to many communities throughout the BCB region. Chukotka is highly vulnerable to floods and their potential impacts. Almost all river basins within its territory are flood prone in spring and early summer. A variety of factors define the risk of flooding, including the level of snow storage within a river basin, periods and intensity of snowmelt, technical conditions of dams, and riverbank stabilization. Among the major river basins with local settlements in flood-prone zones are the Anadyr, Mayn, and Eropol. During a number of recent years, warmer weather has contributed to an earlier ice break-up and more intensive ice drifting, ice jamming, and freshet flooding, compared to the multi-year average for this region. During the flood season, EMERCOM (the Russian Emergencies Ministry) and monitoring bodies in Chukotka regularly assess snow storage dynamics and produce forecasts and issue warnings to communities (http://chukotka.org).

In the western and central Canadian Arctic, the hydrology is highly seasonally variable, reflecting the landscape, snowpack, vegetation, and soil properties. To date, few studies have projected future changes in hydrology in the region. In one example from the northern islands of the ISR, Lewis and Lamoureux (2010) noted that future runoff is expected to come earlier due to warming, with increased snowpack generating greater spring runoff discharge (Figure 5.4). The runoff period is projected to be longer, but post-snowmelt low-flow conditions were not assessed.

In Alaska, 184 out of 213 (86%) of Alaska Native villages experience some level of flooding and erosion (US GAO, 2003). However, it is difficult to assess the severity of the problem because quantitative data are not available for remote locations. Villages on the coast and along rivers are subject to both annual and episodic flooding and erosion. Various studies and reports indicate that coastal villages in Alaska are becoming more susceptible to flooding – in part because rising temperatures cause protective shore ice to form later in the year, thus leaving the villages vulnerable to autumn storms. Villages in low-lying

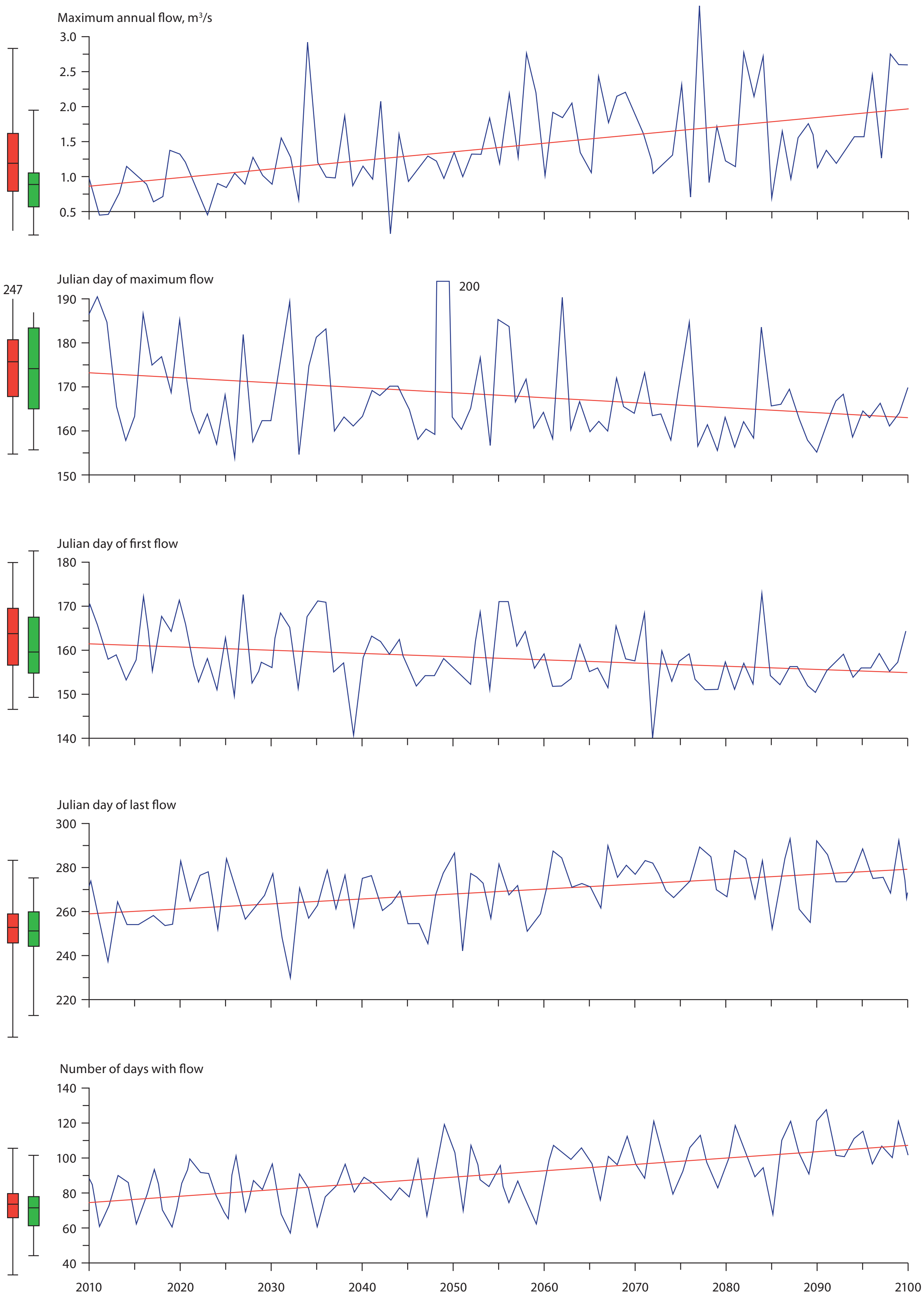

Figure 5.4 Projected 21st century runoff from the West River at Cape Bounty, Melville Island, in the High Arctic, based on the IPCC A2 scenario. Event timings are given in terms of Julian days. The box plots on the left indicate the ranges of modeled hydrological response based on measured meteorological data (red; 1949–1997, Mould Bay) and historical model data (green; 1961–1996, Canadian Global Climate Model v. 3) (Lamoureux et al., 2015, as adapted from Lewis and Lamoureux, 2010).

areas along riverbanks or in river deltas experience flooding caused by ice jams, snow and glacial melts, rising sea level, and heavy rainfalls. For many villages along the Kuskokwim and Yukon rivers, ice jams that form during the spring ice break-up cause the most frequent and severe floods by creating a buildup of water behind the jam; the resulting accumulation of water can flood entire villages, both when water is backed up behind the ice jam and when it is eventually released.

## 5.2.3 Food security

Ecologically-based change has been associated primarily with reduced confidence in food safety due to identified threats from contaminants such as mercury and POPs and, more recently, climate-related changes in wildlife distribution and availability (Douglas and Chan, 2015). Climate change also affects the accessibility and safety of hunting areas (e.g., from changes in the timing of ice freeze-up and break-up) and threatens the traditional food storage method of underground chambers cut into permafrost (Furgal and Seguin, 2006). Changes in lifestyles and socio-cultural behaviors also have impacts: new technologies such as video games, Internet access, and social media may have an additional effect on the practice of traditional harvesting, although these impacts remain poorly understood.

### 5.2.3.1 Subsistence fisheries, hunting, and gathering

With thawing and changes in precipitation, Arctic vegetation is adapting and these changes have implications for plant-related food security. Low snowpack, thawing permafrost, and warm temperatures are causing the landscape to dry, and tundra plants are losing ground to temperate species. In some cases, new species of plants with deeper root systems are moving northward into newly habitable regions. The harvest of wild berries, the only local source for fruit, has become unreliable in some areas (e.g., see Outridge et al., 2015). Like many Bering Sea communities, the US village of Pilot Point had no significant berry harvest in 2012 – no blueberries, crowberries, cranberries, or salmonberries. Such shortfalls have significant cultural, economic, and nutritional impact. Adaptation has included increased harvest levels and stockpiling, along with extended travel to productive areas and more purchases of canned fruit.

Permafrost thaw is also dramatically affecting food security through its impact on underground ice cellars, which are widely used to store harvested foods. A case in point is the coastal Chukchi Sea community of Wainwright, located in Alaska'a North Slope Borough. Ice cellars, a traditional method of storing whale meat and blubber, are used in Wainwright, as well as Kivalina, Point Hope, Point Lay, Utqiagvik (Barrow), Nuiqsut, and Kaktovik. The traditional cellars offer convenience, ample space, and an economical method for refrigeration. In April 2014, an inventory was made of all ice cellars in Wainwright. A total of 34 cellars were recorded – 15 in use and 19 abandoned. Several former cellars were gone altogether, having been lost to erosion over the last three decades. Many of the currently abandoned cellars are located along the shore. Yet others were found well back from the shoreline. Some had been affected by water and sewer line breaks, another casualty of the thawing permafrost (Brubaker et al., 2014). Adaptations have included increased usage of conventional freezers, which are more expensive and which compromise food taste and quality. Another adaptation is the relocation of ice cellars or the use of innovative systems that use active freezing to help preserve the permafrost. Also, changing weather patterns (i.e., overly wet or warm conditions) can prevent the proper drying of fish and seal meat.

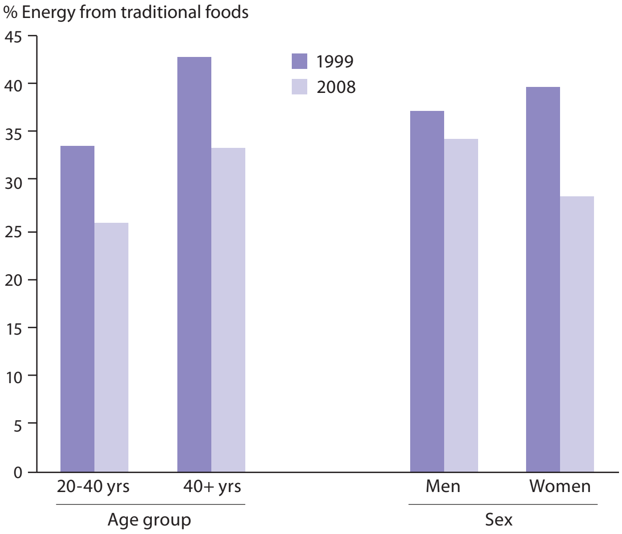

Figure 5.5 Proportion of energy derived from traditional foods among Inuit by age and sex. Data collected from the Inuit Health Survey, based on respondents' 24-hour recall of food intake. Redrawn from Young et al. (2015).

A disturbing recent finding in the western Canadian Arctic is that food insecurity is widespread and apparently increasing, while at the same time the quality of the diet is deteriorating (Huet et al., 2012; Douglas and Chan, 2015). In 2007–2008, 33% of households in the ISR (Egeland, 2010) and 35% in Nunavut, including Kitikmeot (Huet et al., 2012), experienced severe food insecurity, compared to 9% in the rest of Canada. In large measure, food insecurity can be attributed to a reduced reliance on traditional foods because of the move away from hunting, fishing, and gathering (Figure 5.5). This change is due to interrelated perturbations in northern ecological, climatic, social, political, and economic systems.

The Indigenous cultures (primarily Iñupiat and Inuit) have so far adapted to the introduction of non-Indigenous food and transportation technologies to maintain a traditional subsistence way of life to some extent. However, human health impacts from the mixture of subsistence foods and lifestyles with non-subsistence foods and non-Indigenous ways of life are apparent in US Arctic coastal communities. A long list of human health issues, including obesity, diabetes, and heart disease, has affected these communities due to loss of the subsistence lifestyle.

A way of life dependent upon the pursuit and harvest of subsistence resources is physically demanding for all involved. Hunters and fishers must travel to where the resources are located, with planning and equipment preparations required before embarking. Effort must be expended to deploy equipment; take resources; process and prepare product for transport in the field; transport product and process it further; distribute and store product; repair, maintain, and stow equipment; prepare product; and serve and consume product. It is important to note that subsistence activities can also be expensive, with rising costs for fuel and necessary equipment.

*Grocery store, Cambridge Bay, Nunavut, Canada*

The decreasing extent, thickness, stability, and predictability of landfast sea ice has limited seasonal access to bowhead whales (*Balaena mysticetus*) and some other marine resources (Callaway et al., 1999). These changes have also increased the risk of physical injury and loss of equipment, as hunters have more frequently found themselves stranded or set adrift when pans of ice have broken off from shore-connected ice (George et al., 2004).

In the open water season and autumn, bad weather in the form of high winds, large seas, and low-visibility conditions has the potential to swamp boats or reduce hunting success (George et al., 2004). Autumn open water conditions have become the 'new normal' and are less in line with longstanding traditional skill sets and patterns. Since about 2010, hunters at Utqiagvik appear to be responding by procuring larger boats (to 9 m) capable of handling larger seas.

Changing snow and ice conditions on land, rivers, and lakes are also altering longstanding travel and hunting patterns. Traditional inland travel in autumn has become increasingly dangerous due to late-season unpredictable ice conditions. Injuries and the death of experienced hunters due to breaking unexpectedly through thin ice have occurred. On the other hand, a longer sea ice-free season has extended the autumn whale-hunting season in some Arctic villages (e.g., Kaktovik, Nuiqsut, Utqiagvik, and Wainwright) and in Bering Sea villages by nearly 2-fold. Noongwook et al. (2007) described the first recent autumn hunts, which took place in 1990 as a result of ice retreat. Similarly, the first autumn whale taken in well over 70 years was at Wainwright just within the past five years (Suydam et al., 2014).

In Chukotka, the largest sector of agriculture is reindeer breeding (Gray, 2004), which has traditionally constituted the basis of community living. After the early 1990s, due to socio-economic shifts and a lack of financial resources, the reindeer herd drastically decreased because of overharvesting (Gray, 2000). This decrease continued into the 2000s, although less rapidly. From 2008 to 2014, the reindeer population dropped from 189,000 to 158,200 head – i.e., by nearly 16% (Federal State Statistical Service RF, 2015b). However, measures are currently being taken by the CAO government to reverse this trend (CAO, 2015a). Other important agricultural sectors are hunting, fur farming, and dog breeding (specifically, sled-dog breeds). These traditional sectors are highly sensitive to changes in climatic conditions as well as the consequences of human economic activity (Baskin and Miller, 2007).

### 5.2.3.2 Market foods from outside the Arctic

The corollary to a reduction in traditional food consumption in northern Alaska and the Canadian Arctic has been an increase in consumption of market foods imported into the North and sold in stores – the 'nutritional transition' of northerners (Egeland et al., 2011). In particular, high rates of consumption of sugared soft drinks, which are now consumed by about 80% of the population in the IHS, are believed to be contributing to an increase in type II diabetes among Inuit over recent decades (Young et al., 2015).

In northern Chukotka, food products as well as other consumer goods have historically been supplied to settlements under the framework of the Northern Deliveries program (*Severny Zavoz*) (Barsegov, 2002; Piliasov, 2008). The goods are delivered to the coast mainly by cargo ships from Vladivostok, then further by cross-country vehicles and helicopters. Deliveries by sea usually take place from mid-June to mid-November, depending on weather conditions. In 2014, more than 9000 tonnes of food products were brought to Chukotka from other regions. The list of food products included fruit and vegetables, grains, oil and fat, and flour. In 2013, the total cost of delivered food products reached RUB 500 million. The deliveries are organized through government agents, primarily by the state enterprise stock-holding company Chukotopttorg; deliveries are usually subsidized by the regional budget and are among the important items on the social agenda of the local government.

In 2014–2016, international economic sanctions against Russia over the Ukraine crisis and the response of the Russian Federation led to changes in the traditional Northern Deliveries pattern, with previous importers being replaced by new ones or by domestic producers. For example, potatoes that previously had been imported from the United States were in 2014 replaced by domestic deliveries. In 2015, more than 90% of vegetables were imported from other regions of Russia and from China; meat products, including chicken meat, were imported from Brazil, Argentina, and Belarus. Another factor influencing the food supply of Chukotka is price increases, for both imported foods (due to changes in the dollar/ruble exchange rate) and domestic food products (due to the economic situation in the Russian Federation). These increases might lead to a need for additional budgetary resources and subsidies to maintain an appropriate level of food supply.

There are some new trends in food consumption in Chukotka due to social change in the region. Over the period 2005–2014, the average annual per capita consumption of basic food products in the Chukotkan diet grew significantly (Table 5.2). Despite such change, the level of per capita consumption in the region remains markedly lower than in other regions of Russia. The gap is particularly significant for milk and dairy products – about 55% less consumption of milk and dairy; more than 45% less eggs, potatoes, and bread; and more than 30% less meat and meat products. (The Chutkotkan consumption of vegetable oil, on the other hand, exceeds the domestic average by nearly 29%.) The food consumption gaps are slowly diminishing but still result in serious problems for population health because of the damaging combination of nutritional imbalances (i.e., lack of proteins, vitamins, and minerals) and severe climatic conditions. The lower rate of consumption of market foods in Chukotka versus the rest of Russia could be either the cause of, or an effect of, the increased

Table 5.2 Annual average per capita consumption of food products, 2005–2014, for Chukotka Autonomous Okrug and for the Russian Federation (Federal State Statistical Service RF, 2015c).

| Food | Chukotka region | | | Russia | | |
|---|---|---|---|---|---|---|
| | 2005 | 2014 | Change in consumption 2005-2014 | 2005 | 2014 | Change in consumption 2005-2014 |
| Meat and meat products,[1] kg | 35 | 51 | +46% | 55 | 74 | +35% |
| Milk and dairy, kg | 59 | 109 | +85% | 234 | 244 | +4% |
| Eggs, pieces | 152 | 147 | -3% | 250 | 269 | +8% |
| Sugar, kg | 37 | 34 | -8% | 38 | 40 | +5% |
| Potatoes, kg | 65 | 59 | -9% | 109 | 111 | +2% |
| Vegetables and melons, kg | 15 | 26 | +73% | 87 | 111 | +28% |
| Vegetable oil, kg | 19 | 18 | -5% | 12 | 14 | +5% |
| Bread, kg | 58 | 61 | +9% | 121 | 118 | +8% |

[1] Including sub-products and fat.

importance of the subsistence economy in the region since the 1990s (Oparin, 2013). Among important factors contributing to the recent decline in consumption of market foods in Chukotka is the sharp increase of foodstuff prices, along with declines in per capita real income during 2010–2014. As a result, the purchase of market food dropped from 48% of consumer household expenditures in 2010 to 35% in 2014 (Federal State Statistical Service RF, 2015a).

## 5.2.4 Safety in travel and navigation

### 5.2.4.1 On land

The impacts of climate change on overland travel – including changing landscapes, increased frequency and intensity of storms, and changes in snow cover and levels of precipitation – have compromised safety, access (e.g., to camps, harvesting grounds, routes), and overall success of hunts in Canada's ISR and Kitikmeot Region (Clarke et al., 2015). In some cases, hunters have had to travel longer distances to find game or wait to travel later when conditions were safe. A major challenge is associated with unpredictable weather. Critical to a successful hunting trip are the knowledgeable forecasting skills that Inuit have developed over many generations. In recent years, due to sudden, unexpected weather, hunters have often had to return home prematurely or forgo trips altogether. Permafrost degradation and increased rain in the summer and autumn have softened and waterlogged the ground, discouraging ATV (all-terrain vehicle) travel (Pearce and Smit, 2010).

Climate change impacts on travel safety are also observed in Chukotka. These impacts are associated with changes in snow cover patterns, variations in precipitation, and overall increased volatility in major weather and climate characteristics – such as unpredictability in weather forecasts, abrupt changes or quite unstable weather, increase in snow storms and severe winds, and a decrease in duration of the winter period (Roshydromet, 2014). The degradation of permafrost, which covers the entire Chukotka region and is located very close to the ground surface, will increasingly affect road infrastructure in the future.

Ice-covered and snow-covered roads, as well as ice-covered river channels, have been traditionally used in Chukotka as the major means of transportation between towns and settlements – by the local population, by local hunters and harvesters, and by remote mining operations and commercial businesses. In 2014, the length of such routes accounted for about two-thirds of the total road network in the region. They are especially important for deliveries of food supplies to the distant settlements and have been traditionally used as a key means of transportation during the long winters. Shorter periods of snow cover and the destruction of iced routes negatively affect access to many destinations, as well as the safety of transportation. According to mid-term forecasts, by the mid-21st century, the accessibility of remote northern settlements in the Russian North, which are today connected with the mainland by ice roads, could decline by 13% (Stephenson et al., 2011). In total, the area of the northern territories served by this type of transport infrastructure might be reduced by 1 million km$^2$ (Roshydromet, 2014).

Although the linear extent of roads with hard surfaces has increased in Chukotka due to new construction in recent years (to about 660 km in 2014) (CAO, 2015b), the network is still not well developed. Many of the roads are of too poor a quality to provide safe land transportation. Proper road networks exist only in towns and adjacent settlements, whereas winter ice roads are used throughout the territory. There are no railway connections in Chukotka. Due to the combined impacts of various socio-economic factors (including increased gasoline prices, new patterns of economic activity, and environmental change), truck cargo deliveries decreased in Chukotka by 1.4-fold during a recent 10-year period (to 1.8 million tonnes in 2014) (Federal State Statistical Service RF, 2015c). Air transport is the key means of transportation in the extreme environment of Chukotka; nine airports operate in the region, providing local, regional, and international connections. Climate change impacts are associated with the risks of damage to runway infrastructure and other facilities, as well as risks of extreme weather.

### 5.2.4.2 At sea

Implications of climate change for transport safety at sea are becoming apparent for all areas of the BCB region. The implications for transport safety at sea are twofold. First, the increase in duration of ice-free waterways and the smaller extent of seasonal ice coverage provide broader access of marine transportation to specific destinations on the region's coastlines. Safe navigation in these waterways is important for various sectors of the subsistence economy as well as for local commercial and broader international activities and tourism. In the future, increased shipping traffic is expected through the Bering Strait and along the coastlines of Russia, the United States, and Canada. Second, increases are also expected in the frequency and magnitude of sea storms and severe winds and in the instability of weather patterns in marine and coastal areas. Such conditions, for example, are currently very typical for Chukotka. Today, marine transport is operating in the limited navigation period of several months on the Russian side of the BCB region; all cargo is delivered to the five major ports of Chukotka (Anadyr, Pevek, Beringovsky, Provideniya, and Egvekinot). In the future, the transportation network will be expanding, requiring additional investment in support infrastructure and the provision of accurate weather forecasts and climate services.

Longer ice-free seasons and less ice coverage, along with windier and stormier conditions, have made the sea rougher and more dangerous for small boat travel in the ISR and Kitikmeot, according to local Inuit (Clarke et al., 2015). Areas of the sea that have recently become free of sea ice are almost entirely uncharted, and only about 10% of the area that was previously (30 years ago) typically ice free is charted; this lack of reliable charts is a major hazard for commercial, tourist, and community supply shipping (Clarke et al., 2015).

The lack of port infrastructure, large regional hospitals, and sparse search and rescue capabilities are also major risk factors (PAME, 2009). The 2016 passage of the cruise ship *Crystal Serenity* is a good example of the increased passage of large numbers of ship-based tourists through the region, arising with less summer ice. The US Coast Guard was sufficiently concerned about the Arctic transit of this non-ice-strengthened vessel, with more than 1000 passengers, that it conducted tabletop exercises to review preparedness for an emergency response situation (Laursen, 2016).

## 5.2.5 Human security: extreme weather and natural disasters

### 5.2.5.1 Severe storms and natural disasters

The loss of sea ice, which affects average wave heights, and extreme variability in freeze-up and melt dates (see Chapter 4) affect marine access, regional weather, global climate, marine and terrestrial ecosystems, and coastal communities. Furthermore, severe ocean storm conditions due to the lack of sea ice, coupled with complex weather and oceanographic hazards, threaten mariner safety in the Bering, Chukchi, and Beaufort seas and the well-being of coastal communities.

Traditional knowledge interviews and feedback from communities and elders across the ISR and Kitikmeot indicate that one of the most profound impacts of climate change for all of the communities is the new unpredictability of the weather (Stern et al., 2015). Many Inuit have experienced unexpected changes in the strength and direction of winds and in the frequency and intensity of storms. Impacts of stronger winds include more dust in the air and associated respiratory illnesses, reduced drinking water quality on the land, hazards in communities (e.g., downed power lines), erosion, damaged infrastructure, and fewer opportunities for traveling on the land. Changing wind directions render snow drifts as unreliable navigational markers on the land and can also create hazards when they develop across airstrips or other main travel routes. With respect to thunderstorms, most communities have experienced more extreme or frequent storms.

Analyses of scientific data generally support the traditional-knowledge view of significant recent shifts in weather patterns and especially in storms, although confidence in conclusions and predictions is limited by the short time series data sets available for this region (Candlish et al., 2015). The Beaufort Sea experienced a statistically significant increase in wind magnitude during autumn (October) between 1981 and 2010, with an average increase of 0.83 m/s per decade, while most areas of the ISR and Kitikmeot experienced a decline in the frequency of east–west winds in summer (August). There is also evidence of a shift in storm event (cyclone) intensities in the ISR and Kitikmeot, with the previous usual winter peak shifting to larger peak intensities during autumn, with a slight increase in spring storm frequency.

Recent studies of storm trends, based on cyclonic activity for the period 1948–2002, further highlight a significant increase in the frequency of incoming cyclones through Bering Strait and western Canada (Sepp and Jaagus, 2011). Examples of severe storms are the so-called millennium storms of 1999, with large waves and storm surge impacting the Mackenzie Delta ecosystem (Pisaric et al., 2011). The Great Arctic Cyclone of 2012, described by Simmonds and Rudeva (2012), had high winds and waves that pummeled a mammoth zone of thin, fragmented ice.

In terms of environmental impacts, Arctic storms contribute significantly to the loss of sea ice, which in turn has a positive feedback on storm intensity and winds (Simmonds et al., 2008; Screen et al., 2011). Storm-generated winds enhance exchanges of momentum, heat, and moisture between the atmosphere and the ocean surface, thereby increasing the strength and size of Arctic storms (Simmonds and Keay, 2009). Long and Perrie (2013) used a coupled atmosphere–ocean–ice model system to simulate a storm that moved into the Beaufort Sea in 2008. In terms of the maximum wind associated with the storm, the loss of Arctic sea ice was shown to cause an increase of wind speeds by about 4 m/s, compared to conditions when this area was largely ice covered (typical of past decades), mostly due to enhanced momentum exchange between the atmospheric boundary layer and the troposphere.

Natural disasters in Chukotka are divided into two major categories, depending on the consequences they bring: those that affect local populations and settlements and result in damage to economic sectors, and those that have an impact exclusively on natural environments. Natural disasters of the first type require prevention or mitigation responses and institutional adjustments to reduce the vulnerability of society. Extreme weather events and natural disasters of the second type are of a much broader range, occurring in sparsely populated areas and regions without infrastructure, with minimal human impact.

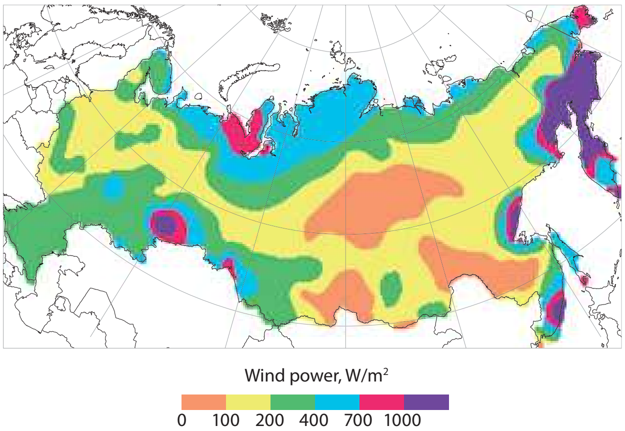

Figure 5.6 Zoning of the Russian territory according to specific power of the wind flow at a height of 100 m above the ground (Roshydromet, 2014).

Chukotka is prone to natural disasters. EMERCOM and its territorial branch in the CAO rank Chukotka within group ‘A’ of the Russian regions – i.e., vulnerable to a maximum extent to the risk of emergencies, both natural and human-induced (http://87.mchs.gov.ru). Low temperatures, storms, strong winds (Figure 5.6), heavy snowfalls, spring floods, and tundra and forest fires have major impacts on this environment and its people. The mountainous landscape in a seismically unstable zone poses an additional barrier to emergency rescue operations and to dealing with the consequences of natural disasters.

### 5.2.5.2 Coastal inundation and erosion

Coastal erosion rates in the Arctic over the past half-century have been among the highest in the world (Jorgenson and Brown, 2005). This is particularly noteworthy because marine waters that have typically remained frozen for nine months of the year are now rapidly trending toward longer open water periods, leading to increased wave action and still faster rates of erosion (Markus et al., 2009).

Coastal erosion in the US Arctic is increasing due to reduced sea ice, increased wave action, and permafrost degradation. Remarkably, the erosion rates of some coastal areas along the Beaufort Sea east of Point Barrow have doubled over the past half-century, from 6 m/y to 14 m/y (Figure 5.7) (Jones et al., 2009a,b). The coastline is thus being reshaped, with several attendant impacts on residents. Coastal villages, property, infrastructure, and livelihoods are being adversely affected, and the continued viability of some coastal villages is in doubt (Jorgenson and Brown, 2005; Larsen et al., 2008; Jones et al., 2009a,b). Erosion and other climate change impacts have the potential to increase the cost of maintaining infrastructure in Alaska by over USD 6 billion in coming decades. Shoreline fuel storage and delivery systems such as pipelines and tanks are also threatened (ACIAC, 2008; Larsen et al., 2008). Government agencies are preparing inventories of coastal areas and facilities whose deterioration from erosion and inundation may threaten waters, fish, wildlife, settlements and industrial facilities.

Of Alaska’s 213 predominantly Native villages, historically situated along rivers and coasts, 86% are now affected regularly by floods or erosion, and these impacts are expected to be greatly exacerbated by climate change (US GAO, 2004). Several Arctic communities in northwestern and western Alaska, including Shishmaref, Kivalina, and Newtok, have suffered substantial erosion; houses and buildings are falling into the sea, and landfills, archaeological sites, and other infrastructure are being lost.

In contrast to northern Alaska, there is no evidence overall for widespread acceleration of coastal erosion in Canada’s Mackenzie Delta area over the most recent 28 years of record (Solomon, 2005). However, the delta is one of the areas most susceptible to future erosion in the ISR (Figure 5.8), and it presently experiences among the highest erosion rates along the entire Beaufort Sea coast (Lamoureux et al., 2015). Current rates of coastal erosion have resulted in the loss of heritage sites and modern buildings on Herschel Island and in Tuktoyaktuk, as well as many hunting camps elsewhere (Lamoureux et al., 2015).

Sea level rise presents a serious threat for increasing frequency and extent of coastal erosion and inundation, especially during spring high tides and storm surges. For example, at Tuktoyaktuk, the return period for a 2.2 m water level (sufficient to inundate extensive coastal areas) is predicted to decrease from about 25 years today to 17–20 years by 2060 and to less than 10 years by 2100; the height of a 25-year flood event would rise from 2.2 to 3.0 m by 2100 and to 3.3 m if West Antarctic Ice Sheet ice loss adds another 30 cm to the global average sea level (James et al., 2014; Lamoureux et al., 2015). Evidence from dated lake sediment cores from islands in the outer Mackenzie

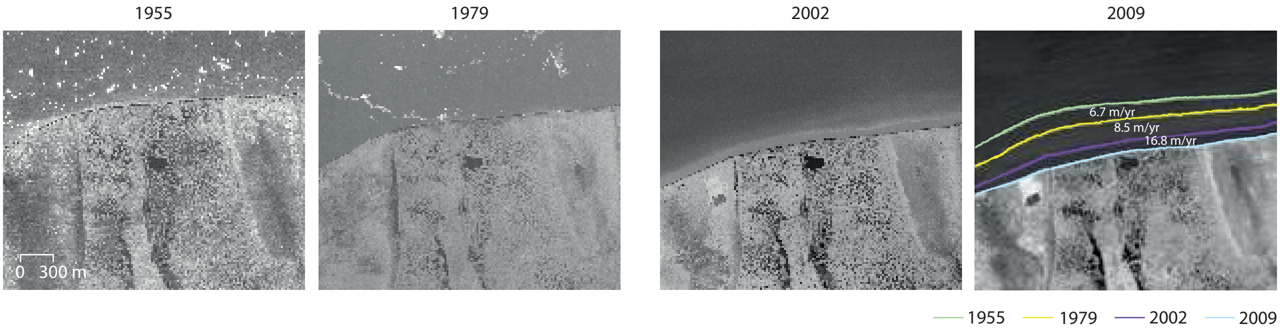

Figure 5.7 Aerial imagery of tundra and ocean, showing the impacts of coastal erosion near Drew Point, Alaska. Between 1955 and 2009, approximately 2800 ha of land were washed into the sea along a 64-km stretch of Beaufort Sea coastline that included the parts shown here. For the periods 1955–1979, 1979–2002, and 2002–2009, the annual rates of coastline erosion were 6, 8, and 17 m/y, respectively. For year-to-year reference, note the large lake near the center of the photo. The colored lines in the 2009 image outline the locations of the shoreline in the years indicated (Benjamin M. Jones, US Geological Survey).

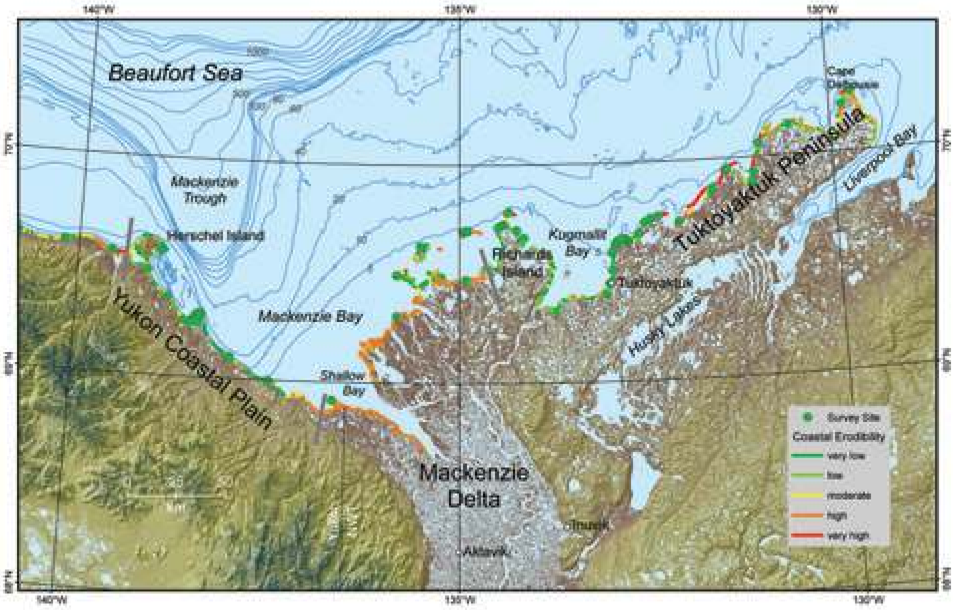

Figure 5.8 Topography and bathymetry of the Canadian Beaufort Sea region with physiographic subdivisions (gray bars), after Forbes et al. (2014). The green squares show the locations of Geological Survey of Canada coastal erosion monitoring sites. The color-coding along the coastline indicates erosion hazard index, after Solomon and Gareau (2004). (Modified from Lamoureux et al., 2015.)

Delta suggest that a 1999 storm surge and inundation of the lakes was unprecedented in the preceding thousand years; more than a decade after the event, there had been no recovery in diatom and terrestrial shrub vegetation to pre-surge states (Pisaric et al., 2011).

### 5.2.6 Cultural heritage and native cultures

Traditional ways of life in much of the Arctic are at risk. In the United States, Alaska Natives face a number of cultural and social challenges stemming from climate change as well as from economic and industrial development in rural areas (Nuttall et al., 2005). Physical impacts to villages from erosion, subsidence, floods, and storm surges often require emergency responses, infrastructure investments, and in some cases even full-scale community relocation. The subsistence way of life of many Indigenous people and other rural residents relies upon natural resources for food, shelter, clothing, transportation, and the maintenance of cultural traditions. While industrial development, new technologies, and changing climate all affect locally based practices, reliance on natural resources remains high. Deep-seated cultural values of family, sharing, tradition, and supportive social networks are important to maintain amidst the changing circumstances.

In Chukotka, as well as in Canada and the United States, retention of the native cultures of Indigenous peoples is carried out by families, within traditional livelihood activities, and within folk dances and singing exercises at village art centers (the art centers, which emerged in the Soviet period, are still popular) (Oparin, 2013). A serious challenge for the preservation of the native cultures is a 'cultural gap' between generations. One of the main drivers of rapid de-ethnicization is increasing loss of the native languages. According to 2010 census data, only 29% of the Chukchi population of Chukotka speak Chukchi. Among the Eskimo and the Evens of Chukotka, the proportion of those who speak their native languages is 28% and 14%, respectively. The use of native languages by the Chuvans, the Yukagirs, and the Koryaks of Chukotka has become less common. Indigenous children learn native languages at school, but these languages are taught as subject matter; they are not the languages of instruction. Russian is the language of education in all schools of Chukotka (Dann, 2008).

During the Inuit Health Survey in Canada, 26% of households reported the use of an Inuit language, which can be taken as one possible measure of the continuing retention of traditional Inuit culture (Young et al., 2015). Kitikmeot residents spoke an Inuit language on average three times more frequently than those in the ISR, which may reflect the more direct transport options into many ISR communities from southern centers, as well as the higher rate of traditional hunting and fishing among Kitikmeot families.

Many nationally and globally significant archeological sites, historic structures, and traditional cultural properties exist throughout the Arctic. In Alaska, this legacy bears witness to a record of remarkable achievement: the arrival of humans in the Western Hemisphere over 14,000 years ago; the development and spread of Eskimo, Aleut, Athabaskan-Eyak-Tlingit, and other cultures; and human ingenuity and tenacity in a forbidding environment. Traditional and historically significant places are essential to the practices that transmit culture from one generation to the next. These sites, which document a long record of human adaptation to environmental change, include camps of pioneering hunters from the Ice Age, remains of sod houses, long-abandoned camps of prospectors in search of gold, and other notable features. These unique cultural resources derive much of their significance from 'place'. When conditions change, these sites cannot be relocated and still retain the same degree of cultural significance. Environmental consequences of climate change and modern development are affecting many of these sensitive sites, and that trend is likely to accelerate.

## 5.3 Impacts on ecosystems

Natural and anthropogenic components of climate change may have origins far outside the BCB region, but they can have far-reaching effects on ecological conditions within the region. As an example, ocean–atmosphere forcing and related transfers of moisture, heat, low-salinity Pacific waters, and biogenic materials in flows through the Bering Strait have significant effects on the region's sea ice and marine ecology and, more broadly, on climate conditions and ocean circulation patterns in the Arctic and Atlantic oceans (Frey et al., 2015; Moore and Stabeno, 2015; Woodgate et al., 2015). The converse is also seen to be true, as new information and hypotheses are emerging about Arctic amplification and high atmospheric processes and circulation, as well as anomalous weather patterns in high and mid-latitudes (AMAP, 2012; Cohen et al., 2014; Gramling, 2015).

In the BCB region, where human dependencies on the natural world are great, the sustainability of the mixed cash/subsistence economy, food security, and quality of life can be closely tied to ecosystem condition and health. The vulnerability of marine mammals, on which many coastal communities depend for food and other purposes, was summarized in Chapter 3 (Table 3.9). Changes in ecosystem processes and mechanisms can be expected to vary with time, geography, and the environmental requirements and population dynamics of the region's living resources.

An assessment framework focusing on climate factors and potential system vulnerabilities in light of other natural and anthropogenic stressors (e.g., infectious diseases and oil spills, respectively) has yet to be developed for the BCB region. Considerable intergovernmental and partnership planning (e.g., Landscape Conservation Cooperatives; see Chapter 3) has, however, identified several ways in which the interplay between climate change and vulnerable ecosystems may lead to adverse impacts on human and wildlife health.

### 5.3.1 Ocean acidification

Ocean carbon chemistry is changing in response to increasing concentrations of atmospheric carbon dioxide ($CO_2$) (Caldeira and Wickett, 2003; Feely et al., 2004). Higher atmospheric $CO_2$ levels cause dissolved $CO_2$ in seawater to increase and seawater pH and bicarbonate ions to decrease, a process collectively called ocean acidification (The Royal Society, 2005). The Arctic Ocean is particularly prone to acidification because of its low temperature as well as its increasing freshwater supply from river runoff, ice melt, and Pacific water (AMAP, 2013; Chapin et al., 2014; Popova et al., 2014). Increased acidity and calcium carbonate undersaturation has been documented in the Bering, Chukchi, and Beaufort seas and the waters of the Canadian Arctic Archipelago (AMAP, 2013; Cross et al., 2013; Robbins et al., 2013; Miller et al., 2014). With relatively low diversity and relatively simple invertebrate-dominated food webs, BCB marine ecosystems are vulnerable to the effects of ocean acidification (Grebmeier and Maslowski, 2014; Grebmeier et al., 2015; Moore and Stabeno, 2015).

The rising acidity may have particularly strong societal effects in the Bering Sea because of its high-productivity commercial fisheries and in the northern BCB region because of its important subsistence fisheries (Doney et al., 2012; Mathis et al., 2015). Increases in meltwater and rising inventories of anthropogenic $CO_2$ in the water column have begun to drive saturation states below the threshold of calcium carbonate saturation, particularly for aragonite, and these low saturation states could be detrimental to some marine calcifiers, particularly the diverse benthic organisms that dominate the Chukchi Sea (Mathis and Questrel, 2013). The combined effects of high productivity and the intrusion of anthropogenic $CO_2$ will moreover exacerbate the effects of ocean acidification at depth (Mathis and Questrel, 2013). At a time when the Arctic Ocean and its adjacent lands are undergoing rapid change, it will be critical to maintain observations (seasonal and annual) of the extent of ocean acidification in this region (Fabry et al., 2009).

### 5.3.2 Contaminants

The BCB environment contains measurable concentrations of several groups of chemicals that have varying degrees of potential to pose toxicological risks for humans and wildlife (e.g., Macdonald et al., 2003). These chemicals include mercury, POPs, and petroleum hydrocarbons. The sources of these chemicals and the relative importance of anthropogenic (human-derived) versus natural emissions vary among the groups. Mercury and petroleum hydrocarbons come from both natural and anthropogenic emissions, whereas the extremely diverse group of chemicals known as POPs is entirely synthetic. Petroleum hydrocarbons are the only contaminants with known significant anthropogenic sources in the BCB region; anthropogenic mercury and POPs in the BCB environment come mainly from elsewhere via long-range transport by atmospheric, oceanic, and riverine pathways (AMAP, 2010a,b, 2011a).

Natural oil seeps from the intertidal zone along the Alaskan coastline, coastal erosion on the Beaufort Sea coast, and erosion of peat, coal, and petroleum outcrops along the Mackenzie River are believed to be the main natural petroleum hydrocarbon sources, which are greater than the relatively small anthropogenic emissions from minor shipping- and production-related spills (AMAP, 2010a). Current exploration and production activities in the BCB region, which are centered on the Alaskan North Slope and Norman Wells, NWT, have resulted in measurable petroleum hydrocarbon contamination of restricted terrestrial areas around land-based wells but have had negligible impact on marine levels.

Ongoing monitoring of POPs in the BCB environment is constrained to several biological time series on beluga and ringed seals (*Pusa hispida*) in the Beaufort Sea and beluga in the Bering Strait. In addition, sporadic or continuing monitoring of POPs occurs in human breast milk of Inuvik (NWT), Chukotka, and Alaskan Inuit mothers (AMAP, 2014). Early studies of maternal milk identified the Chukotka region as one of the world's most contaminated areas in terms of POPs concentrations, with a potential for adverse health effects (AMAP, 2004). Recent studies of marine biota show either declining or stable low levels of legacy POPs that were banned two to three decades ago, probably reflecting declines in emissions and the associated transport of these chemicals into the Arctic (AMAP, 2014). The present state of POPs in human breast milk in Chukotka is unknown. Interpretation of the reasons for the trends in POPs, many of which are volatile or soluble in seawater, is complicated by the complexity of environmental, industrial, biological, climatic, and cultural (traditional food consumption) factors in play.

Human health risks from mercury in the BCB region are primarily related to the consumption of traditional marine foods. Mercury concentrations in BCB marine ecosystems are significantly higher than in other parts of the Canadian Arctic, possibly associated with the riverine and coastal erosional inputs of mercury, organic matter, and nutrients from the Mackenzie River and the eroding Arctic coast (AMAP, 2011a). Unlike POPs, mercury concentrations are not declining in the Arctic atmosphere or in biological samples from the BCB region, despite declining global emissions over the past two decades. Climate warming and its attendant oceanographic effects on primary production, loss of sea ice, and elevated microbial activity, which promote increased production of the more bioavailable methylmercury form, may be causal factors for this dichotomy (Stern et al., 2012).

### 5.3.3. Wildfires

Tundra fires in the BCB area have been historically rare, but they are expected to increase under projected climate scenarios (Barney and Comiskey, 1973; Jones et al., 2009c; Hu et al., 2010). While models suggest that Arctic precipitation will increase, evapotranspiration and water drainage predictions indicate a drier tundra that will be susceptible to more numerous and intense tundra fires, releasing carbon and contaminants such as mercury into the atmosphere (Martin et al., 2009; Wiedinmeyer and Friedli, 2007; Mack et al., 2011).

For example, wildfire used to be rare around the village of Atqasuk on Alaska's North Slope (Brubaker et al., 2014), but thunderstorms have recently been occurring more frequently, increasing the risk for wildfires and infrastructure damage. Between 1950 and 2007, the number of wildfires increased significantly in northern Alaska (Joly et al., 2009), as a result of warmer and drier summer conditions, frequent lightning strikes, an increase in shrubs, and dry conditions on the tundra (Duffy et al., 2005). Poor air quality from wildfire smoke is now more frequent, bringing an increase in respiratory complaints. Adaptations have included increasing water access for firefighting and formulating emergency plans to evacuate sensitive community members during times of poor air quality.

In Chukotka, tundra and forest tundra covers about 82% of the territory, and it is vulnerable to wildfires, which are a serious problem for this region. A high level of fire risk is typical, especially for the Anadyrsky, Bilibinsky, and Chaunski districts. The number of summer and autumn wildfires spreading over large areas is reported to have increased in recent years. A combination of natural and human factors contributes to forest fires, and the negative consequences include threats to human health and life, the destruction of ecosystems and wildlife, air pollution and $CO_2$ emissions, and soil erosion. Wildfires in tundra areas negatively affect reindeer husbandry. Annually, the reindeer herding grounds are significantly damaged by fire, and about 10% of Chukotka's herding areas are covered by burnt-out sites of various ages. Sometimes in the fire zones, up to 1000 people are involved in the rescue of reindeer that might be at risk (http://чукотка.рф/region/protection). Climate change and increasing weather instability, and particularly the increase in wind velocity and annual number of windy days, are among the factors contributing to the growing risk of wildfires. The territorial distribution of wind characteristics is uneven across Chukotka: high wind activity is specific to the coastal areas. For example, the average annual number of days with strong winds (15 m/s and higher) in the vicinity of Beringovsky settlement is about 158 (CAO, 2015c).

### 5.3.4 Atmospheric deposition

Sources of nitrogen, metals, and sulfur in wet and dry deposition include point sources, regional sources, and trans-Pacific and trans-polar global pollution sources (NPS, 2016). Arctic and alpine communities of the BCB region are sensitive to increased atmospheric nitrogen input because within-system nitrogen retention is very efficient and is regulated via a network of temperature- and moisture-dependent processes (Linder et al., 2013). Increased nitrogen deposition to terrestrial and freshwater ecosystems can lead to eutrophication or acidification and can alter plant species composition through toxicity and increased competition from taxa that are more nitrogen dependent. Direct toxicity of nitrogen gases and aerosols and long-term negative effects of increased ammonium and ammonia availability are also noted, particularly in combination with other components of atmospheric aerosols such as sulfur oxides, whereby nitrogen deposition contributes to soil-mediated effects of acidification. Concentrations of nitrogen in the form of ammonium, nitrate, or inorganic nitrogen in wet deposition are relatively low (0.0–0.25 kg/ha/y) at the National Atmospheric Deposition Program/National Trends Network (NADP/NTN) monitoring stations of interior Alaska (Linder et al., 2013). These levels are consistent with much North American literature regarding nitrogen loads for relatively undisturbed habitats at high latitudes (Linder et al., 2013). The acidity (pH) of snow cover on the territory of Chukotka at the end of winter 2014–2015 varied between 5.0 and 5.5 (Roshydromet, 2016). These pH values are indicative of a low level of acidification, which is thought to be due to the remoteness of Chukotka from major industrial centers. Average sulfur deposition was less than 10 $kg/km^2$ and nitrogen deposition less than 7 $kg/km^2$ for this period (Roshydromet, 2016).

### 5.3.5 Disease and pests

Infectious and parasitic diseases can be responsible for population oscillations, extinction of endangered species, reduced host fitness (e.g., hair loss in polar bears), and increased susceptibility to predation, as well as natural mortality in wildlife populations (Atwood et al., 2015). Some of the mechanisms by which global warming can affect the severity and distribution of infectious diseases in wildlife species include changes in the growth rate of pathogens; types or strains of pathogens present; distribution or biological carriers and reservoirs of pathogens; density or distribution of susceptible species; diets that can alter resistance to disease; and physical habitat, in ways that affect disease ecology.

Environmental temperature is a controlling factor in the physiology and immunology of poikilotherms such as fish.

*Lupin mine and airport, Nunavut, Canada*

The emergences of *Ichthyophonus* infections in Chinook salmon (*Oncorhynchus tshawytscha*) in the Yukon River, Pacific halibut (*Hippoglossus stenolepis*) in the northeast Pacific, and herring (*Clupea harengus*) off Iceland and in the Pacific Northwest are examples of disease being linked to climate (e.g., Hershberger et al., 2013; Burge et al., 2014). With respect to endemic pathogens and parasites, climate effects such as warmer temperatures and changes in flow regimes can be expected to increase growth rates of pathogens, favor pathogens or strains that replicate at higher temperatures, and alter the strength and speed of host immune response diseases. In addition, altered freshwater and ocean conditions will change the distribution or density of hosts and their exposure to vectors, carriers, or reservoirs of infection. Species with wide-ranging migrations are potentially susceptible to exposures to infectious diseases and pathogens over large geographies (e.g., avian flu; Ip et al., 2008).

Insect harassment can have dramatic effects on caribou calf weight gain and survival (Helle and Tarvainen, 1984; Weladji et al., 2003). Longer growing seasons and warmer spring and summer temperatures are likely to increase the breeding production of many biting insects, thus leading to increased levels of harassment by warble flies (*Hypoderma tarandi*) and nose bot flies (*Cephenemyia trompe*), leaving caribou with less time to feed. If warmer conditions reduce the number of water bodies for mosquito larvae, harassment from mosquitoes might decline in some regions (Vors and Boyce, 2009). Caribou populations generally increased in abundance in the 20th century, especially on the southern tier of islands, such as Banks and Victoria islands (Fournier and Gunn, 1998; Gunn and Forchhammer, 2008). However, some of these populations have suffered substantial recent die-offs during hard winters, probably because they had reached such high densities that the effects of winter thaws and icing events severely reduced per capita food availability (Gunn and Forchhammer, 2008; Nagy and Gunn, 2009).

## 5.4 Economic development and opportunities

### 5.4.1 Energy and mining

Although the vulnerability and adaptive capacity of northern communities to climatic change has been extensively studied in recent years, the importance of resource extraction and shipping as climate-related sources of vulnerability in the region has not been thoroughly assessed (Cameron, 2011). This gap remains an important focus for future research. According to Lemmen et al. (2008), resource-dependent and Indigenous communities are the most vulnerable to the effects of climate change. Indigenous communities of the North that depend on resource development are especially vulnerable, as many communities shift to livelihoods that are less dependent on subsistence incomes (White, 2009). Boom and bust economic cycles, as mines open and close, and increasing interregional connections and mobilities present additional challenges to social, cultural, and economic cohesion. These changes are likely to interact in complex ways with climate and environmental change in the region, and the cumulative impacts of these changes are difficult to predict (Lockhart et al., 2015).

Resource extraction has been a key economic driver in Canada's ISR and the Kitikmeot region for generations; the discovery of oil and gas in the ISR and mineral deposits in the Kitikmeot region has generally led to many positive impacts for the communities, including improved transportation infrastructure and employment and the resolution of land claims (Lockhart et al., 2015). At the moment, the main activities are exploration projects; there are few producing projects active at this time. Thus, while the potential for future resource production is significant, the prospect remains largely potential rather than actual. The Kitikmeot region could see up to eight mines opened in the next five years, including a reopening of the Lupin gold mine near Contwoyto Lake, Nunavut (George, 2011), although projections change rapidly and frequently. Proposals for major road and port infrastructure are also under consideration in the Kitikmeot region. Mineral exploration in the Inuvialuit region has been steady, although no proposed Inuvialuit-region mines are currently under assessment at the NWT's Mackenzie Valley Environmental Impact Review Board. The earliest hydrocarbon development likely to come on stream is the Amauligak field, still the largest oil and gas discovery in the ISR, located 75 km northwest of Tuktoyaktuk, NWT. Offshore development will require onshore ports, shore-based facilities, and transportation infrastructure (Lamoureux et al., 2015).

Change to permafrost is perhaps the most significant impact and source of future uncertainty for mining operations and infrastructure. Indeed, mining operations in the Arctic rely on the predictability of permafrost temperatures for a number of reasons that are mainly related to the structural stability of operational facilities (including tailings ponds) and transportation routes. In the past, mines have been designed with the assumption that climate conditions would be stable (Pearce et al., 2011). As of 2000, there were 160 abandoned mines reported in northern Canada, with almost 70 sites showing physical instability or chemical contamination (Keeling and Sandlos, 2009). As permafrost thaws, shifting tailings containment dams and piles have the potential to collapse and leach toxins into the surrounding environment.

The Tibbitt to Contwoyto Winter Road (TCWR) is a major winter transport route over lake and river ice and permafrost terrain to several major operating or prospective mining operations. Privately owned and managed, the TCWR is the longest winter road in the NWT and is the main shipping and supply route for the Ekati and Diavik diamond mines, the Snap Lake and Jericho mine developments, as well as the Lupin gold mine (Furgal and Prowse, 2008). If the Bathurst Inlet Port and Road project proceeds, it will connect mines in the Kitikmeot region to the TCWR, further tying mineral development in the entire region to the stability and reliability of ice and all-weather roads.

Similar to northern Canada, Chukotka is characterized by narrowly based economies that leave only a small range of adaptive choices for its population. Mineral resources development is the key economic driver: mining is the main industry in Chukotka (Morozova, 2006), while other industrial sectors are undeveloped and the level of economic diversification is low. In particular, gold and nonferrous mining (see Chapters 3 and 4) constitute the leading source for gross regional product and for stable increases in the per capita income of Chukotka's residents (the growth rates of annual per capita income in Chukotka are higher than the national average) (CAO, 2015a). Future key strategic foci are linked to mineral resources development based on technological innovation and modernization (CAO, 2014).

Societal system change during the post-Soviet period – i.e., the transition from a command-based economy to a market economy and from a centralized state to a federal model – has probably had the most significant implications for Chukotka's economy and its specific sectors. System change established a new context for regional development and new challenges and opportunities for its residents, including the creation of new jobs (Nikitina, 2013). A number of important modernization projects are underway, including renovations in the mining sector, energy systems, and airport and seaport reconstructions.

Resource extraction and infrastructure modernization in Chukotka are particularly dependent on external sources of financing – both from the federal budget and from investments, domestic and international. Private investments are essential for regional economic development. According to the official development strategy of Chukotka through 2030, the essential capital needs are estimated at USD 3.6 billion, with equal proportions deriving from private and state investments. Development of the Baimskaya mining zone and the Beringovsky coal basin is a priority in attracting private investments in the mid-term future (CAO, 2014). Foreign investments play a significant role in the development of gold resources. The Chukotka government headed by Roman Abramovich emphasized attracting foreign investments for the modernization of technologies in this sector, and foreign investments peaked at USD 469 million in 2009 before gradually declining to USD 56 million in 2013 (Rosstat, 2014). The average annual level of gold production during 2008–2013 was 20 tonnes; in 2014, production increased significantly – up 1.5-fold from previous levels (Ernst and Young, 2015). Production is expected to grow to up to 35 tonnes in 2030 (CAO, 2014).

The local authorities and companies of Chukotka obtained licenses for export operations only under perestroika, after the previous state monopoly on foreign trade had been abolished. In recent years, Chukotka's annual foreign trade turnover has been USD 200–250 million – an almost 100-fold increase from 2000 (Rosstat, 2014). Due to recently increased exports of gold concentrate, the previously high foreign trade deficit (with fish and other seafood being the traditional export items) had by 2014 been reduced to an extent that the region's trade balance became positive. Since then, gold has become the main export item of Chukotka (Federal State Statistical Service RF, 2015c).

Federal financial transfers and investments are an important source for economic change: they are a key component in national policies aimed at supporting development of the northern territories. Financial transfers from the federal budget to Chukotka have significant impacts, annually contributing approximately 50% of the local budget (CAO, 2014). In addition to direct federal transfers, Chukotka's economy is also dependent on federal investment in mining industry projects and in geological surveys, and especially on support for regional energy and transportation infrastructure, including the construction of the 'transport corridors for exports' that are also essential for mineral resources development.

Mining in Chukotka is highly challenging due to extreme weather conditions and the harsh environment. When active gold mining started in Chukotka in the 1950s, the development of placer gold deposits was accompanied by the construction of huge processing plants (Bilibinsky, Poliarninsky, Komsomolsky) and large settlements for the miners (up to 5000 inhabitants). Gold production in Chukotka peaked in 1974 (at more than

36 tonnes) due to exploitation of the unique Riveemskoe placer deposit at the Ryveem River. Since then, production has been gradually declining, and many mining settlements have closed. Production of vein gold has been growing since the 2000s due to the interest of foreign investors, and modern settlements for fly-in workers have been constructed (e.g., the major Mayskoe and Kupol deposits).

Climate change has consequences for mining operations, and these consequences may vary according to the different types of mining activities. The implications for gold mining might be different, for example, depending on the type of deposit being worked (i.e., vein gold or placer gold deposits in the open; underground mining; hydraulic or drainage mining), the types of engineering and service infrastructure, and the types of worker settlements. The consequences of climate change would be significant for mine construction in areas with complicated hydrogeological conditions and for the technical safety provisions of engineering facilities. Permafrost regime fluctuations might contribute to ground instability, potentially affecting not only mine operations facilities but also housing in the miners' settlements and transportation and service infrastructure (Roshydromet, 2014). Climate change is expected to also affect Chukotka polymetallic ore development, including tin, tungsten, mercury, molybdenum, copper, and uranium. However, the mining sector in Chukotka has traditionally exhibited good practices in adapting to permafrost and snow conditions.

The forecasts for oil/gas sector development in Chukotka are promising, with vast prospective oil and gas resources being located both onshore and offshore (see Chapters 3 and 4) (Poussenkova, 2011b); the largest are in the Anadyrsky, West-Hatyrsky, South-Chukotky, and North-Chukotsky areas. It is expected that onshore reserves of the Telekayskaya province would be sufficient to meet the internal energy demand of Chukotka, while the rest could be used for external consumption. The largest reserves are in the Anadyrsky and Hatyrsky basins, which contain about 61% and 21%, respectively, of the onshore resources of Chukotka (http://chukotka.org). Chukotka offshore oil and gas resources are estimated at 10 billion tons of oil equivalent (CAO, 2015a), with most being located within the 12-mile (nautical mile) exclusive economic zone in the Chukchi and Bering Seas; the level of oil and gas exploration in CAO is still low, accounting for 3% (http://chukotka.org). Currently, natural gas production has started at the West Ozernoe field to cover internal energy demand. According to the Russian Federation national energy strategy, the development of Arctic petroleum projects could have significant impacts on economic strategies and focal points in regional economic growth (RF Ministry of Energy, 2016).

There is no direct evidence so far regarding adaptation challenges for oil and gas developments, but it is possible that adaptation costs for newly developed Chukotka oil fields might be lower than those of the traditional oil and gas northern provinces. For new developments, possible future climate change impacts could be taken into account in the initial technological planning and design of engineering structures. Future projects may therefore need comparatively smaller technological adjustments to accommodate future Arctic change. Much of the oil/gas development infrastructure is intended to be built on the basis of new technologies (Poussenkova, 2011a), taking into account the severe weather conditions of Chukotka. Today, damage from ice and flooding is typical for pipelines and drilling platforms, and these events generate major economic costs and risks. The oil and gas sector is highly vulnerable to environmental emergencies and natural disasters, as well as technological accidents. The wider access to offshore energy resources expected under climate change could in the future contribute to local development and global shipments, but prospects depend to a great extent on global energy market futures (Poussenkova, 2012). From a short-term perspective, the international sanctions imposed in 2014 (regarding restrictions on financial transfers to Russia and on the import of drilling equipment and technologies for Arctic projects, including hard-to-recover deep-water reserves) affects the development of Chukotka's offshore petroleum production.

Arctic mining is both challenging and expensive due to the region's remote and harsh environment, lack of roads, and potentially frozen shipping lanes. Nevertheless, exploration and development investment has increased in the last few years, driven in part by high commodity prices. The US Arctic hosts a variety of important mineral deposits. In Alaska, seven large mines currently operate statewide, and six more are in the exploration or permitting phases, along with thousands of smaller operations (Resource Development Council for Alaska, 2012). The Red Dog Mine, located within the BCB region, is the largest in Alaska in terms of production and reserves; it is currently processing zinc, lead, and silver ore from one of the largest zinc deposits in the world. This mine accounted for 49% of Alaska's total non-fuel mineral production in 2010, and it has produced ore worth over USD 1.5 billion. Further production of copper and zinc may develop from mineral deposits in the southern portion of the US Arctic. High gold prices have brought increased exploration activity for placer gold into Alaska's northern region in recent years, and gold production in 2010 totaled a reported 80,714 grams (Szumigala et al., 2011).

Other US Arctic industrial investments continue to increase and drive infrastructure expansion and modernization, which will affect additional industries. For example, Alaska's tourism industry is also based on natural resources (fish and wildlife), and its long-term profitability depends on the sustainability of those ecosystem services. Projected increases in permafrost thawing may further restrict land-based resource development, such as onshore oil and gas exploration and development, which affects fragile tundra landscapes but also depends upon the frozen ground for stability (Larsen et al., 2008).

### 5.4.2 Shipping and transportation

There are differences of opinion among experts as to whether or not the diminishing sea ice is likely to encourage the growth of commercial shipping via international trans-Arctic routes (Figure 3.10). On one hand, these routes reduce transit distances between Europe and Asia by as much as 8370 km (Humpert, 2011). The Marine Exchange of Alaska reports that commercial traffic through the US Arctic increased by 30% from 2008 to 2010, although the total number of transits remains small relative to other routes. Transits through the Bering Strait increased 25% during the same two-year period. As recorded by the Exchange's Automatic Identification System, there were 300 and 333 commercial-vessel transits of the Bering Strait in US Arctic waters in 2011 and 2012, respectively, with many other vessels transiting west of the maritime boundary with Russia.

Conversely, in the Russian Arctic the decline in ice cover is regarded by experts as having mixed implications for the development of marine transportation along the Northern Sea Route. Changes in ice cover and increased interannual variability in weather and sea conditions contribute to greater unpredictability for marine shipping. In the short term, the Northern Sea Route is expected to be navigable for at least six months of the year. A significant probability of adverse ice conditions is confined to several northern shipping routes, including Long Strait, between the northern coast of Chukotka and Wrangel Island. In order to ensure a high level of safety of marine navigation, the operation of icebreakers and ice-strengthened vessels, along with the development of ice and meteorological services, is essential. Among priority goals in the short term and long term is the development of effective service infrastructure and ports to ensure the operations of commercial shipping. In the future, it is expected that Chukotka will see increased transit transportation (Barsegov, 2002), especially under the influence of a warming climate and globalization of the world economy. At the same time, expected climate change in Chukotka would also bring greater transport accessibility and better conditions for inland shipping, which in turn would promote local economic development (Esykin, 2014).

The Northwest Passage shipping route along the Beaufort Sea coast (Figure 3.10) has seen a significantly slower increase in usage than routes along the Siberian coast, partly because the Beaufort Gyre keeps sea ice pushed against the Canadian coast; as a result, sea ice reduction in that area has been slower than elsewhere in the Arctic Ocean (Snider, 2013). Newly open, ice-free areas of ocean and coastal waters are mostly uncharted, which represents a major navigational hazard and impediment to further development of shipping in the area (Clarke et al., 2015).

Current shipping activity in the US Arctic is mostly regional, centered on the export of resources and the resupply of communities and facilities extracting natural resources. Most shipping is done with tugs and barges due to the absence of deep-water ports in the US Arctic. Current infrastructure includes capabilities to accommodate landings from cruise ships and lighter vessels. However, with the anticipated growth in ship traffic in the US Arctic, a major expansion of a deep-water port at Nome, Alaska, is currently under review. Oil and gas exploration and development continue to be the primary drivers for commercial maritime traffic in the region. Successful offshore oil and gas exploration and extraction ventures will depend heavily on safe marine transportation.

Plans for economic development in Chukotka, especially in the Anadyr industrial zone by 2020, would affect the design of commercial transportation networks in the future (Selin, 2013). Transportation infrastructure would be adapted to plans aimed at increases in (1) coal production (up to 12.7 million tonnes in 2030) (CAO, 2014), with expansion of coal domestic deliveries and also exports to Pacific countries, and (2) onshore petroleum production by 2020 (up to 500,000 tonnes of oil and 70 million m$^3$ of gas) for internal consumption in Chukotka. Plans for an increase of gold and silver production in the Chain-Bilibinsky fields (32 tonnes by 2020) may have an impact on new transportation capacity (RF Government, 2014). Transport infrastructure design and capacity are supposed to reflect the strategic plans of Chukotka for future expansion of its international trade operations, particularly in the Asia-Pacific region. Climate change factors should be taken into account in the development of new commercial transportation networks. Permafrost degradation, with increasing fluctuations in surface ground temperatures near the thawing threshold, will threaten the stability of support constructions for pipelines, potentially resulting in accidental oil leakages.

### 5.4.3 Tourism

Arctic change is affecting tourism in Chukotka. Tourism is starting to be actively developed, and it has a strong capacity for the future. Chukotka offers opportunities for expeditions, cruises, and ethnotourism. Chukotka is famous for its Nadezhda (Hope) dog sledge races (Bogoslovskaya, 2011) – an analogue to an annual Fairbanks–Whitehorse event, which has been attracting growing international attention. Sea cruises are quite popular, mainly among foreigners. Climate change impacts allow easier access to many tourist destinations and enhance their attraction; it will contribute to the growing tourist flows. There are, however, a number of limiting factors: poorly developed infrastructure and services, limited choice of transport options, inadequate public relations, and insufficient advertisement by tourist operators in Chukotka. Significant opportunities are opening up and are linked to the creation of additional jobs, external investments, and the development of infrastructure and services (Piliasov, 2009). It should also be noted that the expanding tourist industry should not challenge or interfere with the traditional lifestyles of Indigenous populations.

Recent innovations in environmental protection policies in Russia, with increasing attention to biodiversity conservation, particularly in the North (Nikitina, 2011), have had positive impacts on Chukotka tourism (Fomenko and Fomenko, 2011). Specially protected areas attract the attention of tourism business (UNEP, 2007). In Chukotka, more than 6.5 million hectares (9% of its territory) is specially protected, and there is the potential for further increase. The major natural reserve is the Wrangel Island Reserve, a UNESCO World Heritage site. This reserve, the recently established Beringia National Park, and a number of other specially protected territories (Lebediny, Avtotkul, Ust-Tanurersky, Chaynskaya Guba) are expected to be top tourist attractions in the near future.

In the western Canadian Arctic, some of the few positive impacts of climate change have included more fishing and boating opportunities and new tourism prospects through potentially better access to previously inaccessible coastal and riverine areas for longer periods each year (Thorpe et al., 2001; Stewart et al., 2007).

In Alaska's far North, tourism has a long history, but the total activity remains low compared to tourist visits elsewhere in Alaska. Data for 2011 provide an overview: the Arctic accounted for 2% of Alaska tourist destinations, down from 3% in 2006, while overnight stays in the region dropped from 2% to 1% of statewide totals. It is unknown if diminishing sea ice cover and longer, warmer summer seasons will be sufficient to drive


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*Provideniya, the nearest Siberian port to the Bering Strait, Chukotka*

an increase in Arctic marine tourism in the future (Ringer, 2006; Stewart et al., 2007; ACIAC, 2008), but with receding sea ice, there will likely be increased vessel-based tourism and associated economic opportunities for community-based businesses catering to tourists.

## 5.5 Conclusions

> *Who and what will be affected by or exposed to consequences of the changes occurring in Arctic environments, economies, and communities?*

Some ongoing changes in the Arctic environment are clear, and their impacts are predictable. These include sea ice reduction, increasing tundra thaw depth, increasing ocean acidification, increasing risk of river floods, increasing weather fluctuations, and increasing rates of erosion. Many other changes are more subtle and complex and will play out in unforeseen ways for generations to come. For instance, it is clear that some species' numbers and distributions are changing. But it remains to be seen exactly who and what may benefit or be harmed by such changes in both the short and long term; there will be 'winners' and 'losers.'

Among the key issues needing further assessment in the context of future impacts and consequences of Arctic change are the extents to which: essential subsistence foods may become less available, unavailable, or more abundant; industrial and municipal infrastructure may become less stable; seasonal tundra travel may become more difficult; commercial fishing and tourism may expand; new business opportunities may open up; human populations may grow or shrink; regulatory regimes may be scaled up or back; and a wide range of other direct or indirect impacts may materialize.

As described in the US National Climate Assessment (Melillo et al., 2014), "The small number of jobs, high cost of living, and rapid social change make rural, predominantly Native, communities highly vulnerable to climate change through impacts on traditional hunting and fishing and cultural connection to the land and sea. Because most of these communities are not connected to the state's road system or electrical grid, the cost of living is high, and it is challenging to supply food, fuel, materials, health care, and other services. Climate impacts on these communities are magnified by additional social and economic stresses. However, Alaskan Native communities have for centuries dealt with scarcity and high environmental variability and thus have deep cultural reservoirs of flexibility and adaptability." (Chapin et al., 2014, p. 514).

> *How are Arctic environments and ecosystems changing in ways that can be expected to directly affect Arctic residents and communities?*

The environmental drivers that have been increasingly shaping the lives of people in the coastal communities of the BCB region are expected to continue to grow in magnitude and effect during the 21st century. Impacts on the physiography of the coast will continue to direct the location of human habitations and the staging and feasibility of subsistence activities.

The loss of multi-year ice and changes in the duration and distribution of annual ice will also continue to circumscribe the availability of marine and coastal subsistence resources. When multi-year ice leaves the area completely, the resulting dependence on annual ice is expected to lead to profound changes in the mammal and bird sources of subsistence foods. The restructuring of Indigenous cultures in response to changes in the species composition and availability of subsistence food resources appears to be inevitable.

> *How will Arctic residents and communities be affected by environmental, economic, and social changes occurring in the Arctic?*

To understand the ongoing and potential future impacts of a changing climate on Arctic residents and communities, it is necessary to recognize the intimate and inseparable linkages between subsistence and the physical, economic, and socio-cultural well-being of those residents, their families, and communities. The connections and dependencies among these conditions extend in all directions, and each is seeing, and will continue to see, changes, challenges, and opportunities in the coming years. Arctic residents and communities will all be experiencing impacts in their everyday lives, associated with issues such as anthropogenic contaminants, food and water security, adequate housing, public services and infrastructure, human health, safety, coastal erosion and flooding, permafrost thaw, wildfires, and the preservation of cultural heritage.

> *How will economic development and opportunities in particular sectors be affected by multiple changes occurring in the Arctic, including climate, environmental, economic, and social change?*

The traditional subsistence economy is now intertwined with and is a component of a truly mixed subsistence/cash economy. Cash is needed for vessels and vehicles, fuel, weapons, appropriate clothing, communication devices, and safety gear (Poppel, 2006). Rising fuel and shipping prices have affected rural residents' ability to heat their homes and fund subsistence activities. More challenging travel conditions and increasing unpredictability in resource movements and availability can decrease harvest success and require additional hunting effort. Additional hunting effort entails additional fuel costs, time away from jobs and families, increased wear and tear on equipment, and increased risk of exposure and injury. The thawing of permafrost is affecting the integrity of homes, municipal buildings and essential facilities, and oil and gas industrial facilities (Instanes et al., 2005).

The Arctic remains a frontier economy. Many of the products and much of the value of commercial activities derive from natural resources. Economic activities in the Arctic are technically challenging and costly due to the harsh environment and limited transportation routes. Despite these challenges, industrial sectors operating in the Arctic can have major impacts. For example, in Alaska, the industrial sector generates, directly and indirectly, thousands of jobs, millions of dollars in personal income, billions of dollars in revenue (for federal, state, and local governments), and substantial industry profits (ADCCED, 2012). Revenue, employment, and personal income from these industrial activities can improve the quality of life for local residents and support the ability of regional and local governments to provide public services to communities.

## Acknowledgments

This chapter draws heavily from the following reports, which describe excellent examples of the impacts of ecological, economic, and cultural change taking place in the Canadian and US Arctic: *From Science to Policy in the Western and Central Canadian Arctic: An Integrated Regional Impact Study (IRIS) of Climate Change and Modernization* (Stern and Gaden, 2015) and *Managing for the Future in a Rapidly Changing Arctic: A Report to the President* (Clement et al., 2013). We wish to acknowledge the significant contribution made to this AACA assessment by the authors and coauthors of these reports.

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# 6. Resilience to rapid change in Bering, Chukchi, and Beaufort communities

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## Key messages

- ***Human and social resilience are dynamic outcomes of effective responses to all aspects of the changing Arctic system, including but not limited to climate change and extreme weather events.*** *Resilience describes the ability of a system to recover from some stress or injury. For social systems, resilience is oriented toward managing and improving well-being and is embedded within people's ability to work with and through change, while pursuing sustainable and healthy community outcomes.*
- ***Resilience is often relative to some undesirable threshold that, once crossed, leads to change, collapse, or reorganization.*** *In the North, multiple thresholds of concern exist, toward which climate change, in concert with numerous other direct and indirect drivers, is pushing rural peoples and communities. Examples of such undesirable thresholds include individual deaths, individual decisions to leave a community, the nutrition transition, school closures, fish and wildlife closures or collapse, and community demographic collapse. While these thresholds are not as frequently considered as some other thresholds in planning for resilience, they are nonetheless just as important.*
- ***Resilience can be relative to a desirable threshold that leads to change (transformation).*** *One important and more positive aspect of resilience is the ability that people (may) possess to 'bounce forward' through purposive transformation (desired thresholds). An important consideration when thinking about resilience and transformation is whether actions that people take to avoid undesirable thresholds improve or undermine their ability to work toward positive transformation.*
- ***Effective strategies for coping with change require identification of both the problem and a solution and must be dynamic rather than passive.*** *People of the North have multiple strategies they can enact to avoid reaching undesirable thresholds. These strategies for 'helpful resilience' include maintaining a diversity of livelihood strategies, openness to change, reserves of resources for coping during times of stress, tightness of feedback loops between people (social networks) and ecosystems, and social capital (essentially resources generated through participation in social networks across all scales, from households to communities to governments and international bodies). Over time, however, the cumulative effects of the various impacts of climate change, which interact with the historical legacies of the Soviet collapse in Russia and of colonialization and mission schools in Alaska and Canada, can erode people's ability to enact effective strategies for coping with change.*
- ***Effective regional planning platforms must be dynamic, iterative, and designed to incorporate multiple stakeholder perspectives and inputs.*** *Thinking about how climate change impacts interact over space and time is essential for effective policy formulation and implementation.*

## 6.1 Introduction

Resilience is described as the ability of a system to recover from some stress or injury while maintaining its structure, function, and identity. Resilience thinking in the context of social systems is an analytical approach that applies the concept of resilience to the understanding of societal challenges such as natural disasters and environmental change. When surprises happen, are people able to recover effectively from the impacts of unanticipated change? How do people cope, endure, and rebuild? When pressed by long-term change, how do people maintain the aspects of their lives and livelihoods they hold most important and avoid being pushed into some less equitable, less sustainable, or otherwise undesirable state? These are but a few of the key questions that researchers attempt to answer with social resilience thinking.

In this chapter, resilience thinking is applied to the question of potential or probable impacts of climate change on communities in the Bering, Chukchi, and Beaufort Sea (BCB) region of the Adaptation Actions for a Changing Arctic (AACA) project. These communities are small, rural, and remote: they generally have hundreds to a few thousand people, the majority of whom (in the Canadian and Alaskan sectors at least) are Indigenous. Settlements are generally accessible only by air, or for some communities, by river or ocean access in the summer. The focus here is on 'human resilience', which manifests in a multitude of relationships and interactions among individuals, collectives, and their social, cultural, and biophysical environs (Almedom, 2015). Discussion concerns what is known and what needs to be known in order to best help people and communities respond to the many changes and impacts that are discussed in the previous chapters of this report.

People will no doubt respond in *some* manner to the many direct and indirect impacts of climate change. Whether these responses are best characterized as suffering, coping, mitigation, resilience, adaptation, or some combination of all of these remains to be seen, and the answer depends as much on whether and how local people assign meaning to their responses as it does on abstract academic definitions. Nevertheless, the assumption is that the concept of resilience can at least highlight ways local people may be empowered to successfully manage change and surprise and to cope in a manner consistent with their values for self-determination, well-being, and the future. The goal of this chapter, therefore, is to lay out a framework for what is known, and what still needs to be known, about the resilience of northern communities. It is not possible to assess or measure resilience to specific challenges, whether a flood in one community or rapid coastal erosion in another, except perhaps in hindsight (McGovern, 1980; Hamilton et al., 2003). It is possible, however, to highlight socio-economic resilience strategies that can create space for communities to navigate and manage impacts when they occur.

The chapter takes an explicit policy focus in resilience thinking. It is important to note, however, that from a policy perspective, overemphasis on resilience alone is not a desirable approach. For example, a community may be in a 'trap' and therefore highly resilient to change that might otherwise move it from a dysfunctional state to conditions of greater well-being. Whether a person or community proves resilient to some harm is, therefore, irrelevant when evaluating the social justice implications of being harmed in the first place. As Almedom (2015) argued, human resilience must be about thriving and not merely surviving, or about 'bouncing forward' rather than back, as phrased by Manyena et al. (2011). Some, but not all, of this concern is captured in approaches to resilience that package vulnerability, resilience, and adaptation together.

Likewise, resilience should not be privileged over attention to the various other human rights dimensions of climate change or community development. As Standish et al. (2014) explained, resilience is not an end but rather a means by which desired and desirable outcomes are pursued. Resilience is thus not a static property of any system but rather an array of feedbacks and interactions that play out at different levels of organization. In short, emergent properties characterize resilient systems. When coping with change, people's actions are enhanced or constrained for multiple reasons (Beckley et al., 2008), and resilience in this sense is an important form of social and other types of capital, enabling people not only to cope but to remain on their chosen trajectories despite the interruptions and challenges posed by climate change (Nabhan, 2013; Loring et al., 2016).

### 6.1.1 What is resilience?

Resilience most commonly describes the ability of an otherwise stable system to absorb and recover from a stressor without changing in overall structure or function (Holling, 1973; Pimm, 1984). Stressors may be sudden or gradual, directional or randomly determined (Gould and Eldredge, 1977; Chapin et al., 1996; Collins et al., 2011). A system may undergo some level of change but remain resilient to a stressor or to an assemblage of stressors if it recovers from those stressors without passing a threshold or 'tipping point' that shifts the system into a different state (Groffman et al., 2006).

Resilience as it is widely used in sustainability and development research is typically linked with the concepts of vulnerability, adaptability, and transformation. This set of concepts is collectively known as 'social-ecological resilience' or 'resilience thinking' (Walker et al., 2004, 2006; Walker and Salt, 2006). Critics of this work raise concerns that this expanded resilience universe is unworkably vague (Brand and Jax, 2007; McGreavy, 2016), although recent attempts have been made to translate the normative aspects of social-ecological resilience into an applied system for 'resilience practice' (Walker and Salt, 2012; Standish et al., 2014). For example, the Resilience Alliance, a network of resilience thinkers and practitioners across the world, has released workbooks for those seeking to assess a system's social-ecological resilience in expert-driven or collaborative research where the emphasis is situated in community-based participatory research (Quinlan et al., 2016).

Resilience is also used with somewhat different meanings in fields such as psychology and community health. Understanding these definitions is essential for understanding how northern peoples and communities construct and implement responses to climate change, to extreme weather events and impacts, and to the interactions of climate change and social and economic limitations and opportunities at both the individual and community levels. At the individual level, 'psychological resilience' describes people's ability to normalize harm and return to a state of general 'happiness' following some disturbance or despite objectively poor circumstances (Diener, 2009). Psychological and psychosocial resilience are important coping mechanisms for individuals dealing with stress or loss (Almedom, 2015) but can differ from a social-ecological definition of resilience because psychological resilience may suggest that individuals have 'bounced back' when their circumstances, in fact, have not.

Social resilience is a broader concept that encompasses psychological resilience to describe the process by which people harness psychological, social, cultural, and ecological resources (including ecological resilience) to sustain their well-being (Adger et al., 2000; Coulthard, 2012; Panter-Brick and Leckman, 2013). Social resilience, or simply 'human resilience' as it has also been called (Almedom 2015), is not always linked with disturbances or impacts in the same way as ecological resilience, nor is it necessarily anchored to social or ecological stability (McCubbin et al., 2013). Continued quality of life and pursuit of life goals from a culturally embedded perspective are the features being sustained, rather than an equilibrium among specific structural, organizational, or behavioral aspects of the system (McCubbin et al., 2013). In other words, when people and communities are resilient, this is evident not in whether they appear to some outsider to have changed as a result of some stressor, but instead whether or not they are willing and able to do whatever is necessary to pursue their values and visions for the future.

Each of these nuanced definitions of resilience contributes different pieces at different levels and scales to the overall picture of how people respond to change. Further, this plurality of resilience concepts, involving individual, social, and ecological systems, interact in positive and negative ways across these different levels and scales over time (i.e., cumulative effects) (Gunderson and Holling, 2002; Masten and Cicchetti, 2010). As Almedom (2015) explained, elements of human resilience manifest in "the smallest social units of couples and families to the larger community organizations and social networks." Individuals can both contribute to and draw from the resilience of institutions at higher levels of organization. Finding the linkages and tensions among differing elements of resilience operating at different levels and scales remains an important area for continued research. Following the lead of Gunderson and Holling (2002) where possible, the following sections note examples of these cross-level and cross-scale interactions.

One additional challenge for policy-makers and communities seeking to implement resilience, whether in ecosystem management, disaster planning, or some other venue of governance, is that in order to be effective, frameworks and assessments using resilience and its associated concepts must be context-specific (Hinkel, 2011). As such, attempts to distill the inherent complexity of resilience, vulnerability, and ability to respond to change into indicators should proceed with caution. Unless developed in a participatory and decolonized way, indicator frameworks can easily encode notably materialistic or paternalistic values (Friedman, 1974; Reed et al., 2006; Haalboom and Natcher, 2012; Gadamus 2013). At best, these decidedly well-meaning frameworks will simply be wrong; at their worst, they may well inform policy actions that ultimately do people and communities more harm than good.

### 6.1.2 Chapter structure

The approach here is inspired in part by the 'resilience thinking' framework outlined by Walker and Salt (2012) and in part by the notions of 'helpful' and 'unhelpful' resilience as suggested by Standish et al. (2014). The goal is *not* to assess the resilience of individual communities and regions, nor is it to make predictions about their relative resilience or vulnerability moving forward. Such exercises would be both complex and unfruitful. The data are simply not available to answer these localized, place-based questions, even if strict definitions of resilience stability and disturbance could be established. Instead, the approach is to lay out questions that need to be asked in order to understand and identify sources of 'helpful resilience', which describes the means by which people can maintain some desired system feature or state (or return the system to that state) and 'unhelpful resilience', which describes system forces that hinder recovery or adaptation in some way (Standish et al., 2014).

Nor is it attempted to reconcile or unify the different frameworks and definitions of resilience as outlined above; multiple varied approaches to the study of resilience arguably make the concept more rather than less powerful (Miller et al., 2008; Almedom, 2015; Almedom et al., 2015). However, it is likely that the approach used here does rest on something of a common ground among these many disciplinary and academic differences about the concept.

Specifically, this chapter attends to the following questions:

> *What are the undesirable thresholds or regime changes that have been identified for communities in the three BCB subregions?*

The concept of resilience is generally (but not always) dependent on the identification of a recognizable state or regime, with the question of interest being how much the system can be pressured before it shifts into something fundamentally different. As such, the identification of possible but undesirable regimes and their associated critical thresholds for communities in the three BCB subregions is often a first step in assessing whether communities are or will be resilient to one or more stressors. It is important, given that human resilience is not always anchored to a stable state in the same way as ecological resilience, that people self-identify what thresholds are of importance. To the extent possible, literature is drawn on that has emphasized local voices and concerns. That being said, different communities are likely to put different emphasis on the different thresholds identified.

> *What strategies, or mechanisms of 'helpful resilience', are known that, in the past, have enabled households and communities to effectively cope with or otherwise respond to change?*
>
> *Conversely, what sources of 'unhelpful resilience' support the status quo such that they are limiting people's ability to recover and adapt?*

Change in the short and long term has arguably been the norm for the North as long as it has been peopled, and Indigenous northerners are well known for their adaptability, through their responses to social, ecological, and historical change (Berkes and Jolly, 2002; Binford, 2002; Forbes, 2008; Kofinas et al., 2010; Berkes, 2012). By examining the features and strategies of northern societies that, in the past, have contributed to people's ability to endure and respond to change, it is arguable that best practices can be identified for ensuring that people are similarly enabled for effective response to current and future changes. Likewise, it is essential to identify the ways in which people are 'locked in' and prevented from responding in ways that they deem most meaningful and effective (Allison and Hobbs, 2004).

> *What mental models or frameworks exist that can help us understand or anticipate how households and communities will respond to these multiple interacting issues?*

Numerous models and frameworks are available for thinking about how people and communities will be affected by and may respond to some external change or suite of changes, today and in the future. Vulnerability analysis is one example. It is known that the impacts of climate change and disaster are largely socially constructed and/or experienced (Oliver-Smith, 2013) and that the people most likely to experience harm from climate change are often those likely to have the least ability to respond effectively (O'Brien and Leichenko, 2000). Thus, it stands to reason that any framework for understanding how people will respond should explicitly account for the interaction of climatic and non-climatic stressors and variables over space and time.

> *What desired thresholds or regime changes (i.e., transformations) are people of the North actively working toward? How do the strategies that we discuss work with or against these goals?*

The matter to be highlighted here is that rural communities of the North are all engaged in their own 'future seeking' processes, not merely responding to change but pursuing a future that is improved in whatever ways they value. Strategically, resilience to surprise can propel people toward these goals, but in many cases the need to be resilient can be a setback. If people are coping with surprise, for example, can they leverage this toward existing community development goals or are they set back, locked into patterns of mitigation?

### 6.1.3 A caveat

One of the contradictions in resilience thinking is that the most stable, and therefore by definition most resilient, systems are often also likely to be the most degraded or impoverished, the least likely to innovate in a social sense (Weick, 1984; Suding et al., 2004). Another way of thinking about this is that resilience thinking focuses on thresholds or tipping points, but whether a tipping point is crossed or not is not always an accurate indicator of whether people are experiencing harm or injustice, directly or indirectly. Too much attention to tipping points may direct attention away from the challenges that people are enduring and the costs that they are absorbing as a result. Likewise, while individual, community, and collective responses to change are referred to as 'adaptation actions' throughout this report, not all responses to change at the community or regional level are necessarily adaptive, not all responses to change are effective, and not all support well-being in the short or long term (Barnett and O'Neill, 2010; Thornton and Manasfi, 2010).

From the perspective of rural BCB community residents, it is worth noting that the climate change narrative is sometimes negatively perceived (Marino and Schweitzer, 2009; Loring et al., 2016). Climate change – and all rural northern residents are quite aware of seasonal and annual changes in weather and ecosystems – is often of less immediate concern than other global challenges that interfere with local livelihoods and community development. Such challenges include nonrenewable resource development; the legacies of colonialism; food and water insecurity; increases in the costs of fuel, market foods and other supplies and commodities; a lack of rural infrastructure and employment opportunities; and social problems such as drug and alcohol use and addiction (see Section 2.3.1 for various related case studies). This said, resilience to climate change as framed in the previous questions provides a window into understanding where systems are strong (place-based and self-determined) and where they are vulnerable, with vulnerability linking directly to these many climatic and non-climatic issues over which there is generally little local or regional control.

## 6.1.4 Comparing North American and Russian settings

Speaking comparatively, far more research is available on resilience in Canada and Alaska than in Russia, which is evident throughout the chapter. In general, rural households in the BCB region share similar physical environments but are situated in dramatically different socio-economic and institutional contexts. Ongoing social and cultural trends such as globalization, modernization, and global activism are arguably having equal or greater impacts on people in these subregions than climate change alone (Gray, 2005; Crate, 2006; Lynch and Brunner, 2007; West, 2011; Loring and Gerlach, 2015), although climate change is surely an important aspect within the broad set of cumulative challenges. The many legacies of the former Soviet Union, for example, continue to have a huge effect on livelihoods and community resilience in the Russian North (Davies, 1996; Gray, 2000; Ziker, 2003; Crate, 2006). Population declined by more than 60% in Chukotka after 1990, for instance, following a rapid rise through immigration in the 1960s, 1970s, and 1980s (Thompson, 2002; Gray, 2005; see also Chapter 4), leaving abandoned and failing infrastructure and other hallmarks of a boom–bust age. So, while certain challenges are common to all three subregions, people's ability to endure or respond is quite different from place to place.

For instance, social resilience to environmental changes in the subregions is likely to be driven, at least in part, by financial limitations, policy dimensions such as legal land tenure frameworks, and political entitlements to subsistence resources (Keskitalo, 2008; Ford and Pearce, 2010; Kofinas et al., 2010; Gerlach et al., 2011; Loring et al., 2011; Berman et al., 2017). In Alaska, several pieces of legislation and court rulings at the state and federal levels have granted rights to subsistence harvests to Indigenous peoples: the Alaska Native Claims Settlement Act (ANSCA) in 1971, the State Subsistence Act in 1978, the Alaska National Interest Land Conservation Act (ANILCA) in 1980, and McDowell v. the State of Alaska in 1989 (Case, 1984; Sacks, 1995; Theriault et al., 2005). Collectively, these actions effectively extinguished Aboriginal land claims (Mitchell, 2003) and arguably eroded traditional sources of resilience, but they also established protections and a priority for subsistence and personal-use harvests of fish and game that today are essential to rural livelihoods in the state (see Gerlach et al., 2011, for a discussion). In some cases, they also provided access to financial resources through the establishment of village and regional corporations; this aspect is specific to Alaska for the most part. In Canada, several legal acts likewise establish protections for Indigenous Peoples' uses of subsistence resources, including multiple treaties, the Canadian Constitution Act of 1982 (Slattery, 1992), and case law including the *Delgamuukw* case of 1997, and *Tsilhqot'in* Nation v. British Columbia in 2014 (Nadasdy, 2002). The Beaufort coast in Canada makes up the Inivualuit Settlement Region (ISR), which was established in 1984 and affords self-government that, while limited, provides

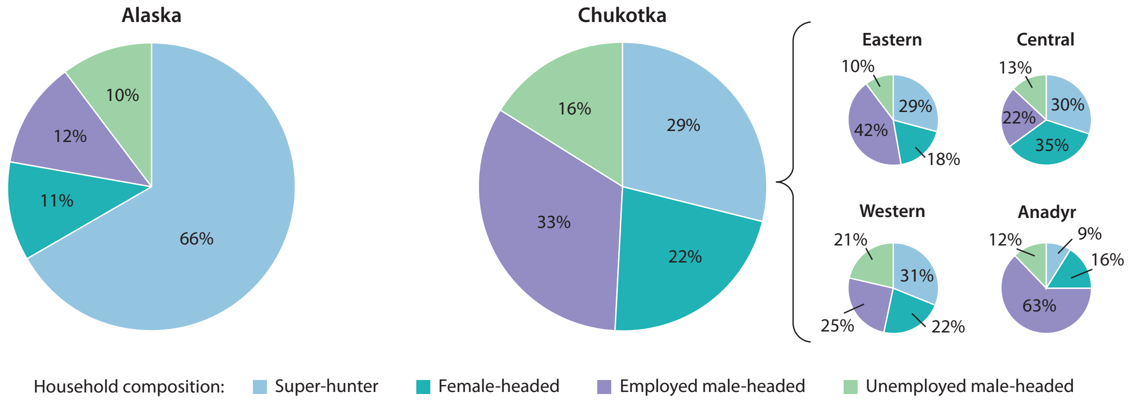

Figure 6.1 Comparison of household composition for Alaska and Chukotka (based on SLiCA data, as reported by West, 2011).

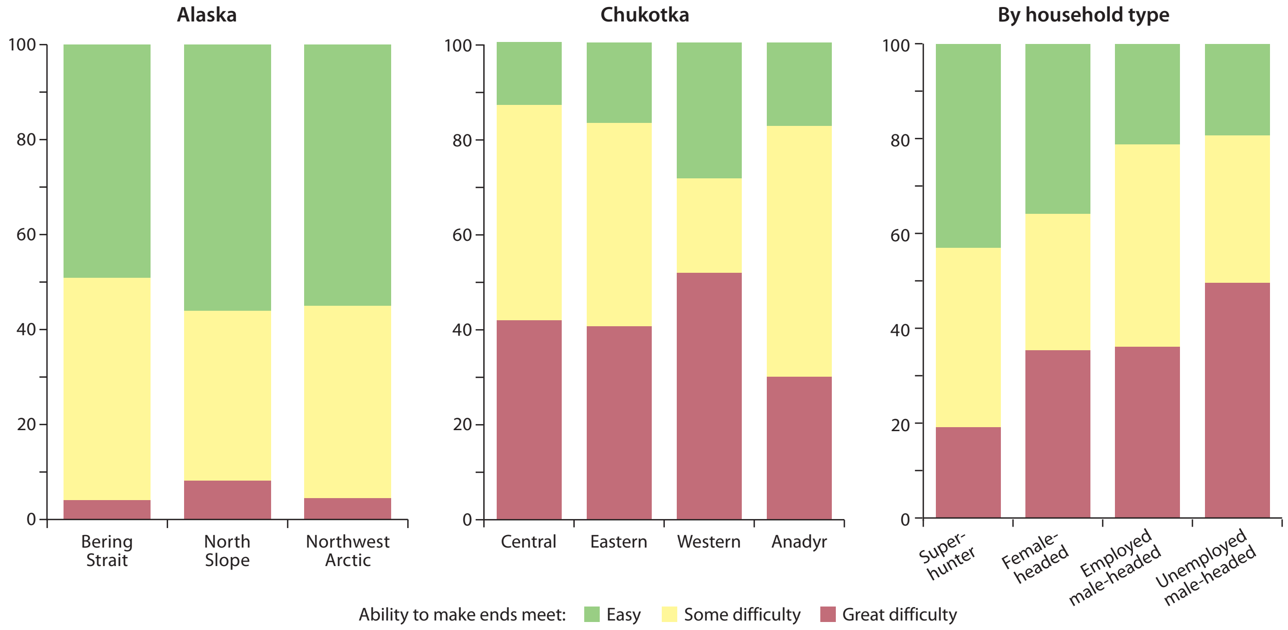

Figure 6.2 Self-reported ability to make ends meet, Alaska and Chukotka (based on SLiCA data, as reported by West, 2011).

rights that are in some respects more extensive than the rights available to Indigenous Alaskans.

In Chukotka, Indigenous peoples have few formal legal rights to subsistence resources, although in the last decade they have begun to assert their voices in regional decision-making and authority over natural resources (Gray, 2000, 2005). Using data from the Survey of Living Conditions in the Arctic (SLiCA), West (2011) offered a rare comparison and finds that Chukotka households and regions are constrained with respect to their ability to effectively respond to change as a result of a number of issues, including political histories, current policies regarding land claims and tenure, employment, and household dynamics. Unfortunately, West (2011) compared only Russia and Alaska, making it impossible to include the Canadian/Inuvialuit context in the following section.

West (2011) followed Chabot (2003) in focusing on household composition, and specifically household type as defined by the gender and occupational status of the head of household. Chabot (2003) identified four types of household heads: male unemployed, female, male employed, and 'super-hunter', listed here in the order of most to least vulnerable to some change, as argued by West. In West's words, "… household composition plays a central role in determining the vulnerability of households to shocks. Extending this argument to the level of regions, I contend that the relative proportions of household types within a region can serve as a measure of the overall sustainability of livelihoods within that region." (West, 2011, p. 229).

While West is not writing specifically about resilience, resilience is explicit in this author's definition of social vulnerability as "a function of the sensitivity of a livelihood system to a given shock and its resilience" (West, 2011, p. 220). While it is somewhat simplistic to assume such a linear relationship among household type and resilience (Friedman, 1974), those assumptions are not entirely unjustified and allow at least for the coarse level of analysis pursued here. The notion that super-hunter households (those associated with both high rates of subsistence expenses and high harvests) confer community and regional resilience is supported by multiple studies (e.g., Wolfe and Walker, 1987; Magdanz et al., 2002; Chabot, 2003; BurnSilver et al., 2016; Kofinas et al., 2016).

The SLiCA data for household composition show noteworthy differences among Alaska and Chukotka households (Figure 6.1). Two-thirds of Alaskan households are led by a super-hunter, compared to less than one-third in Chukotka. The two categories that are ostensibly least resilient, unemployed male and female-led, account for 38% of households in Chukotka but only 21% in Alaska. These numbers do not vary notably within Alaska, but do vary across regions within Chukotka. The Eastern and Western regions of Chukotka appear to have the lowest vulnerability. Interestingly, households with employed male heads are more common in Chukotka, especially in the Anadyr region, than in Alaska.

West (2011) also used a second piece of SLiCA data to estimate household and regional resilience – a question that asked respondents how easily they are able to make ends meet (Figure 6.2). These data reinforce some of the above findings – that households led by a super-hunter are the most resilient, while those led by an unemployed male are the most vulnerable. But the data also challenge West's assumption that female-led households are the second most vulnerable. These data also suggest that, overall, Chukotka households and regions will be less resilient to climate change-driven challenges than households in Alaska.

## 6.2 Thresholds and regime changes of concern

Identifying thresholds and regime changes of concern is a first step in understanding resilience and the role it plays or will play in how northern communities experience and respond to climatic and environmental change. As used here, the term *threshold* describes the point at which a system is no longer

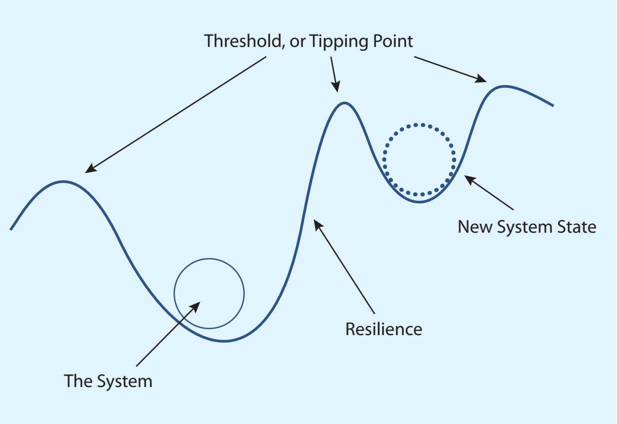

Figure 6.3 Heuristic presentation of thresholds and regime change in resilience. Resilience is represented by the height and slope of the 'hill' between the system's current state and an alternative stable state (Loring, 2017).

sufficiently resilient to withstand or recover from some stressor, and as a result the system 'tips' into a fundamentally new (and sometimes degraded) regime (Figure 6.3) (see also Scheffer and Carpenter, 2003). Thresholds are difficult to measure quantitatively unless they have already been passed (where 'measure' means to determine how much a person or community or ecosystem can be pushed before tipping over a threshold). Similarly, while it is relatively easy to discern between stability and change in ecological systems (Pimm, 1984), it is far more difficult to recognize change in social systems (Cumming and Collier, 2005; Loring, 2007a; Andrachuk and Armitage, 2015).

In other words, whereas regime changes can be defined and identified in objective ways for ecological systems (via such features as species composition or productivity), the same is not true for social systems. Stability and change in social systems are much more a matter of perspective: what an outsider sees as a fundamental change to a society may be perceived from within as a progression toward a person's or a community's ideal self. Also, conventional wisdom for social systems holds that there is 'no going back'; people naturally learn, grow, and change as a result of their experiences, both positive and negative, so while a tipping point may be avoided through some form of societal intervention, this does not mean that people are not irreversibly changed by the experience.

Research on thresholds and tipping points in Arctic social-ecological systems has focused on these concepts at regional or pan-Arctic levels and on biophysical changes; whether the Arctic Ocean will transition to a seasonally ice-free state, for example, is an important threshold (Overpeck et al., 2005; Duarte et al., 2012) and one that is likely to be accompanied by noteworthy geopolitical consequences (Ebinger and Zambetakis, 2009). It is unclear, however, what the changes at the pan-Arctic scale will mean for local communities. Nonetheless, local concerns about increased shipping, oil exploration, and fisheries exploitation shed light on possible thresholds or tipping points at local and regional scales that arguably have more meaning for local people.

The following sections provide additional detail on several thresholds (Arctic Council, 2016b) that are discussed in the social and environmental sciences literature: individual death; an individual's decision to leave a community; loss of traditional life-ways and knowledge; loss of transportation/travel routes; loss of language; fisheries closure or collapse; loss of grazing land; loss of critical mass in community population; community relocation; school closures; and relocation of local elders. These thresholds are often nested and may operate at different organizational levels and scales (Table 6.1).

### 6.2.1 Individual death

Death of an individual is a threshold of importance, especially when death is unexpected and premature. Accidental death has been and continues to be among the top causes of mortality in the rural North (Boyd et al., 1968; Pika et al., 1993; Prowse et al., 2009; Downing and Cuerrier, 2011). As climate changes, life in rural regions of the North is becoming more dangerous for a variety of reasons (Brubaker et al., 2011; Cozzetto et al., 2013). Changes in the landscape, river conditions, and sea ice dynamics (e.g., ice thickness, break-up, and freeze-up) increasingly make the land less safe for hunters and travelers who rely on generations of experience to read and understand whether or not conditions are safe (Laidler et al., 2009; Druckenmiller et al., 2010; Huntington et al., 2010; Ford et al., 2014; Schneider et al., 2015). To this, add individual death as a result of suicide, a problem of epidemic proportions across the North today. While suicide is not directly driven by climatic change or extreme weather events, the psychological traumas associated with change and uncertainty no doubt combine with other historical, social, and economic stressors to play a role (Downing and Cuerrier, 2011; Kral, 2012; Ford et al., 2014).

Resilience with respect to death likely plays out in at least two ways: first, resilience may be enhanced through development and transfer of new forms of knowledge and practice for improving safety in new and changing conditions, and second, it may be enhanced by infrastructure investments and improvements in search and rescue operations. Resilience at the family and community level becomes important when a death cannot be avoided, as those who remain must find ways to cope with loss – loss that cascades through small communities in terms of psychological impacts. Loss is also reflected in the cultural understanding that all individuals are important in unique ways, whether as traditional knowledge and wisdom carriers, current and future leaders, or young learners who represent the future of the community and culture.

### 6.2.2 Decision to leave the village

Rural outmigration is not a demographically uniform phenomenon, as specific groups of people are choosing to leave; one study identified young, working-age women as the largest group of people leaving the rural communities for urban areas or even other rural communities (Hamilton and Seyfrit, 1994). Outmigration by this group is often driven by a desire for educational and employment opportunities. People's reasons for leaving vary, and include food insecurity, high and rising costs of food and fuel, a lack of access to formal education, and a lack of employment opportunities (Huskey et al., 2004; Martin et al., 2008; Fazzino and Loring, 2009). However, circumstances for many are not necessarily improved when they arrive in urban communities (Fazzino and Loring, 2009), as there are likely to be multiple material, economic, and perhaps even psychological drivers pushing people beyond critical thresholds.

Table 6.1 Possible thresholds of concern.

| Threshold | Level | Cross-level(s) or scale(s) of interactions |
|---|---|---|
| Individual death | Individual | Impacts families and communities psychologically as well as socially through loss of important people, elders, and current and future leaders |
| Decision to leave | Individual | Similar to above, but can also affect the receiving community; double-edged since a move to an urban center may result in a source of money for those remaining in the village |
| Loss of traditional ways of life and knowledge | Individual, community, region | Individual and household changes may affect community food sharing and relations; losses may have intergenerational, regional consequences, including loss of essential ecological knowledge that could otherwise enable people to adapt to a changing climate |
| Loss of transportation and travel routes | Community, region | Changes in river, lake, and sea ice, permafrost thaw, erosion, wildfire, and other physical changes to the land can complicate travel for hunting, fishing, and socialization with neighboring communities |
| Loss of language | Region | For multiple reasons, Indigenous peoples around the North are no longer speaking their native languages as they once did; given how linked these languages are to geography, worldview, and ways of life, this loss interacts cumulatively with several of the other thresholds listed here |
| Fisheries closure or collapse | Community, region | Regional or community-level, depending on scale, closures of canneries and support businesses, etc. |
| Loss of grazing land | Community, region | Reindeer herders are reporting incremental losses of land to development activities such as mining; eventually, there will not be enough suitable land available for people to sustain a viable herd |
| Loss of critical mass in community population | Community | Can cascade through a region through outmigration and increased pressures on infrastructure elsewhere; can contribute to other thresholds such as the loss of traditional ways of life |
| Community relocation | Community | Can cascade through a region through outmigration and increased pressures on infrastructure elsewhere; can contribute to other thresholds such as the loss of traditional ways of life |
| School closure | Region, community | Community-level change that can contribute to outmigration and push a community in the direction of demographic collapse |
| Relocation of local elders | Individual, community | When elders move away for healthcare, this can fracture elder–youth pedagogy, which contributes to issues such as the loss of traditional ways of life and language |

As with individual deaths, when people leave a community it can affect resilience at the community or household level, both immediately and into the future, such as through a reduction in capacity to cope with change or to realize current and future plans. High rates of teacher turnover are also common in these remote communities; this phenomenon affects rural educational outcomes and can contribute to the school closure issue (see Section 6.2.10).

### 6.2.3 Loss of traditional ways of life and knowledge

Indigenous residents of the Russian and North American North value their customary and traditional ways of life, including hunting, fishing, and herding, as a cornerstone of their livelihoods; their cultural, spiritual and personal identities; and their community and individual health (Furgal and Prowse, 2007; Council of Canadian Academies, 2014; International Center for Reindeer Husbandry et al., 2015; Inuit Circumpolar Council, 2016). Challenges today are similar across the Alaskan and Inuvialuit Settlement Region communities, including but not limited to the Kitikmeot communities; there is more available research in North America than in Russia. The shared challenges include changes in the distribution and abundance of fish and wildlife, loss of grazing lands, changing weather and seasonal patterns, uncertainties from year to year about harvest and catch regulations, and the introduction of new and different tools and technologies, including cash, guns, and motorized transport – along with the historic shift across the region from seasonal residential mobility to permanent villages with limited mobility (see Ford and Pearce, 2010, for a comprehensive review).

Despite such challenges, many northern groups remain committed to harvesting country foods and to spending time on the land or sea. This commitment is not without constraints and problems, and increasingly these are climatic, ecological, social, economic, cultural, and legal or regulatory constraints. For example, it is now well documented that northern Indigenous communities of North America are experiencing a nutrition transition, with people increasingly relying on a limited array of imported, highly processed market foods in lieu of country foods from the land and sea (Kuhnlein et al., 2004; Furgal and Prowse, 2007; Ford, 2009, 2012; Loring and Gerlach, 2009; Findlay et al., 2013). This nutrition transition is accompanied by numerous biomedical, psychological, and social and cultural impacts (Bersamin et al., 2007; Loring and Gerlach, 2009; see also Chapters 4 and 5). Interestingly, in Chukotka, the reverse happened following the collapse of the Soviet Union when many Indigenous people returned to their traditional homes and ways of life (West, 2011).

Being able to rely on food from the land now and into the future is considered by many northerners to be a matter of self-determination, a venue for resistance to further colonial influence, and a means for building community self-reliance and security (Banerjee, 2012; International Center for Reindeer Husbandry et al., 2015; Loring and Gerlach, 2015; Inuit Circumpolar Council, 2016). Local northern food systems are situated in regional and global-level cultural, economic, political, and nutritional contexts, and thus feedbacks and interactions in food systems can strengthen or weaken household and community viability through diet and health (Ericksen, 2008). On the one hand, being able to rely on store-bought foods offers a source of resilience to variability in country foods (Ford and Pearce, 2010), but a northern community that depends too heavily on external inputs for a secure food supply is vulnerable to small perturbations, disruptions in economics and transportation, and market or regulatory failures that result in extremely high prices (Gerlach et al., 2011; Council of Canadian Academies, 2014; see Chapters 3, 4, and 5).

Rural residents are becoming more aware of and concerned with the economic costs of food from village stores and also about the health costs of overreliance on highly processed market foods. They also continue to be concerned with the unpredictability, uncertainty, and expense of relying too heavily on country foods, regardless of how culturally important subsistence activities continue to be. The nutrition transition is related to food security and health, but this is more than a simple one-size-fits-all nutritional relationship. This issue incorporates matters such as the cultural importance of certain foods, food choice, local perceptions of hunger, worry about food safety and shortages, and other psychosocial, socio-cultural, and environmental stresses resulting from the need to reliably put food on the table.

The flip side of food security, food *in*security, results from complex, synergistic interactions among a wide and disparate set of challenges (Beaumier and Ford, 2010; Ford and Beaumier, 2011). Recent studies indicate significant issues of food insecurity for northern Canada and Alaska, with communities reporting problems obtaining adequate food to meet basic household needs (Kofinas et al., 2016). Reported food insecurity in these contexts relates to obtaining both store-bought and harvested country foods. Contributing factors include regional and household vulnerabilities to external market shifts in the price or availability of imported foods and fuel; the cumulative effects of climate change and development of oil, natural gas, and mineral extraction on ecosystems and fish and game; and environmental pollution and bioaccumulation of heavy metal contaminants. Community-level food aid or food banks are rare, but where such programs do exist they are relied upon (Ford et al., 2013). Given problems with limited inventories and high prices in the village stores and given the new challenges for success with the country food harvest, villages from Kotzebue Sound in Alaska to Inuvik in the Northwest Territories and communities in Nunavut are in some cases reviving village gardens; in other cases, communities are experimenting with new approaches to food production (e.g., using greenhouses, aquaponics, and biodynamic systems; solar and wind power; and water conservation – all models borrowed largely from other areas) and are employing other innovative strategies for growing food (Inuit Circumpolar Council, 2016). These new strategies are not about replacing traditional country food harvesting but rather providing a complementary food supply with healthy, locally controlled garden and greenhouse produce. In combination with traditional harvesting, the use of local gardens is a good example of an effective response to climatic, social, cultural, economic, and ecological change. This approach represents an adaptation for avoiding a tipping point and moving toward a more stable, sustainable, and healthy rural northern future.

The specific location or timing of a discrete threshold or tipping point in this nutrition transition is likely to be difficult if not impossible to locate; in other words, it is unlikely that there is a fixed amount of time that must be spent on the land or a standard value for the number of calories that must come from country foods in order for local people to be healthy, nutritionally secure, and satisfied with their community and livelihood. Indeed, preferences may vary from individual to individual or among different generations. Nevertheless, the pace and impact of the nutrition transition are escalating in some places because of positive feedbacks, whereby less time on the land requires that more food be purchased from the store, which requires more cash, which means less time spent on the land in favor of earning wages, and so forth (Loring, 2007b). The reality of experiencing a complete socio-cultural regime shift, from livelihoods that are well in sync with and adjusted to the seasonal flows of local land and seascapes, to livelihoods that are entirely 'locked in' to dependence on imported food and fuel, troubles many northerners and drives opposition to development projects such as off- and onshore oil and gas activities, marine shipping, and more (e.g., Betcher, 2015).

Loss of traditional ways of life (time spent on the land, harvesting and processing foods, sharing) may also contribute to a long-term loss of traditional and local knowledge, with significant ramifications for resilience (Kofinas et al., 2010; Pearce et al., 2015). In the pioneering book *The Earth is Faster Now*, Krupnik and Jolly (2002) discussed how climate change is altering the environmental cues that Indigenous people use to observe, understand, and navigate their local and sometimes risky environments (Huntington, 2000; Bates, 2007; Ford and Pearce, 2010; Moerlein and Carothers, 2012; Pearce et al., 2015). If people are engaging less with the land, they may lose critical opportunities to learn about new conditions and to pass on their ways of knowing and understanding the environment to future generations.

### 6.2.4 Loss of transportation and travel routes

In the rural North, regional hydrological conditions, including water levels during the summer and lake, river, and sea ice conditions during the winter, are important for transportation. Other important hydrological system conditions include seasonal changes, such as the timing of ice break-up and freeze-up, and also the predictability of conditions throughout these changes, such as the duration of break-up and freeze-up. Because many remote communities are not connected by roads, changing conditions can affect travel by increasing the danger of ice use and restricting access to other communities and important places for hunting and fishing.

For coastal communities, changing coastal sea ice regimes, river runoff, and coastal erosion can impact community provisioning – for example, by blocking food and fuel shipments. This happened to the Alaska community of Nome in 2012, when

*Seawall and sewage pipe exposed due to beach erosion in Dillingham, Alaska*

sea ice barricaded the community much earlier than expected and while a fuel shipment was en route. A combined effort by Russian and US icebreakers was necessary to deliver fuel to the community (Ahlers, 2012). That the fuel ultimately arrived is a sign of resilience, perhaps, but the event also signals a vulnerability of existing purchasing and planning practices to unpredictability in sea ice conditions.

Ice roads are also an important aspect of transportation in the BCB region (see Chapter 3). Ice roads can be constructed to support development activities, such as mining and oil production, but are also used in some cases for provisioning communities. With warming and changes in seasonality, ice roads are becoming less reliable – both because the season during which they can be used is shortening and also because warm periods during their season can make them unsafe for heavy trucks (see Chapter 5).

As with several of the thresholds discussed in this section, loss of important transportation routes is a change that interacts with several other changes. Being cut off from important hunting and fishing grounds, for example, can contribute to the nutrition transition and loss of ways of life discussed in the previous section (Prowse et al., 2012) and can interfere with intergenerational teaching on such matters as important places, stories, and practices (Druckenmiller et al., 2010; Huntington et al., 2010). Where conditions are less predictable, impacts on travel safety can also result in increased injury and deaths – for example, if people expect the ice to be safe for their snow machines but it is not (Druckenmiller et al., 2010; Ford et al., 2014; Schneider et al., 2015).

### 6.2.5 Loss of language

Many Indigenous languages in the North are disappearing or have already disappeared as a result of colonial or state influences on, and interference with, traditional cultures. Twenty-one Arctic languages have become extinct since the 1800s, and ten of these were lost after 1990, which indicates an increasing rate of loss (Vakhtin, 1998; Morgounova, 2007; Dorais, 2010; Barry et al., 2013), with more to come, according to Larry Kaplan and Michael Krauss of the Alaska Native Language Center (personal communication). Another 28 Arctic languages are endangered, which Krauss (2007) defined as meaning that they are spoken only by a few grandparents and are no longer transmitted from parents to children through traditional means. Numerous programs for language learning and recovery now exist to mitigate or even reverse this trend (Morgounova, 2007; Arctic Council, 2016a).

Native language is important in multiple ways to Indigenous peoples and their cultures, including the maintenance of traditional ways of life and expression of worldview (Dorais, 2010). Native languages also provide a cognitive framework for how people think and learn about local and regional environments and geographies; that is, these languages encode in their vocabulary and grammar data about the environment as well as concepts and relationships for describing and understanding the natural and physical world (Kari, 1996, 2003, 2011; Barry et al., 2013). The loss of a language is thus not just a linguistic matter but also a loss of biocultural diversity that is akin to species extinction (Vakhtin, 1998; Maffi, 2001; Dorais, 2010), which can have significant ramifications for a people's sense of identity and, in turn, their resilience and sustainability.

### 6.2.6 Fisheries closure or collapse

Fisheries closures or the collapse of a stock's population is a dramatic example of a linked social-ecological regime change (Naylor, 2009) that can drive significant human impacts, including individual decisions to leave the community or, at worst, cumulative community collapse and village relocation (Hamilton et al., 2000; Himes-Cornell and Hoelting, 2015). With significant resident outmigration, communities are likely to lose canneries and associated businesses, meaning that the impacts of the closures cascade through the community's social networks through the loss of businesses that provide support to fishing fleets, from welders to bankers to grocers. In cases where fisheries generate tax revenue for local communities, people may lose this important source of financial capital as well. If people move away from the communities as a result, an amplifying feedback loop may emerge, leading more and more people to leave and further eroding the community.

## Box 6.1 Demographic evidence for resilience to fisheries closure

In 2000, the Norton Sound king salmon fisheries experienced a collapse and subsequent indefinite closure by the Alaska Department of Fish and Game (Kent and Bergstrom, 2012). Impacts on communities were evident in short-term outmigration (Figure 6.4), notably for Unalakleet, the fishing subdistrict arguably most heavily impacted by the closure (Kent and Bergstrom, 2012). Nearly 100 people left Unalakleet; noteworthy outmigration is also evident for Teller and Shaktoolik. However, some communities, specifically Golovin, Elim, and Koyuk, experienced in-migration during the same period, suggesting a possibility that people moved from one community to the next but did not leave the region outright. Unalakleet, the community most obviously impacted, may be showing recovery (resilience?) in recent years.

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*Salmon drying rack, Safety Sound, Alaska*

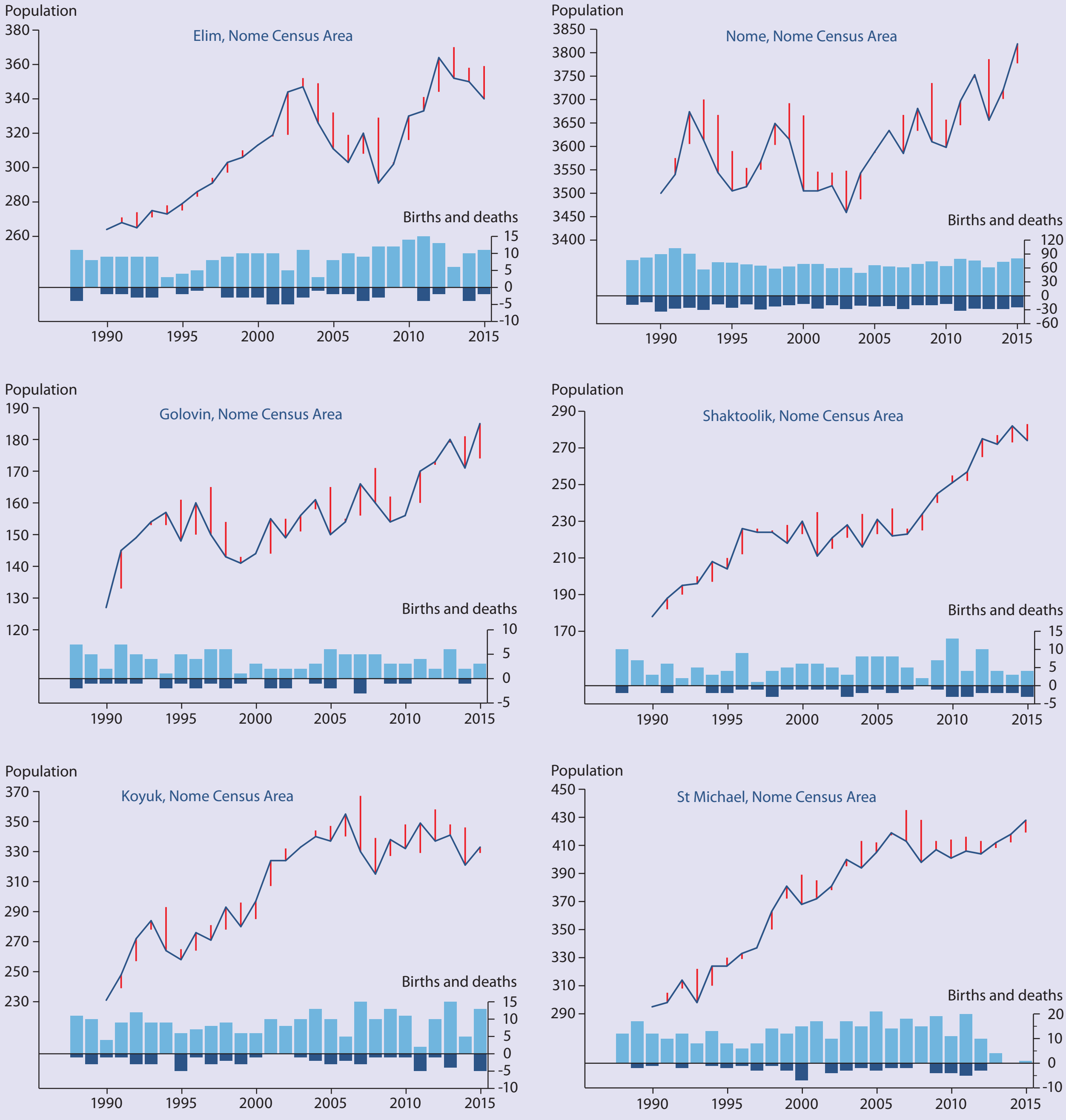
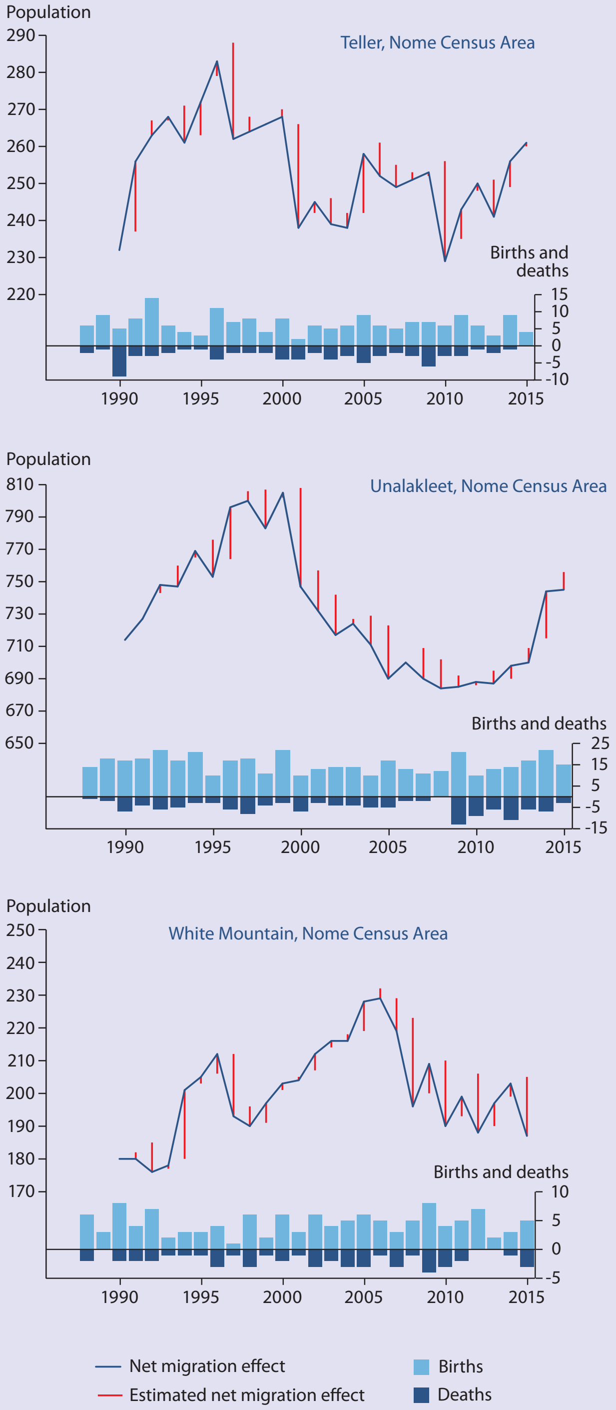


Figure 6.4 Population dynamics of nine communities along Alaska's Norton Sound, where king salmon fisheries collapsed in 2000 (population and birth/death numbers are graphed from different baselines but with comparable $y$-axis scales) (Hamilton et al., 2014).

Philip Loring

*Local communities showing resilience*



Whether people from rural communities of the North will indeed leave villages or rural regions as a result of fisheries closures or other dramatic changes in ecosystem services is not clear. It is also possible that people will remain, or move from one rural community to another in the same region, or simply stay where they are and direct fishing and hunting efforts to alternative fish and wildlife resources (Loring and Gerlach, 2010; Hansen et al., 2013). While there is some evidence that fisheries closure can drive outmigration as a resilience strategy for individuals (Himes-Cornell and Hoelting, 2015), there is also evidence that in some cases communities endure and eventually recover (i.e., they are resilient) (See Box 6.1).

### 6.2.7 Loss of grazing land

Reindeer herding is central to the livelihoods of many people in Chukotka and elsewhere in northern Russia, and this livelihood strategy in general can be quite resilient to change and beneficial to local biodiversity (Forbes et al., 2009; International Center for Reindeer Husbandry et al., 2015). However, for multiple reasons, reindeer herds are shrinking and fewer youth are taking up the lifestyle. This decline in reindeer herding has had ramifications not just for local people but also for biodiversity conservation and sustainable land management. Pastoralism in these regions has proved over the centuries to be a sustainable way of life that can strengthen local biodiversity (International Center for Reindeer Husbandry et al., 2015).

The most important environmental requirement for viable herding is grazing land, yet reindeer herders in Russia have few or no explicitly recognized rights to their traditional lands. Having adequate lands for herding is not just a matter of the total area available; herding requires a diverse portfolio of lands that can be utilized in different seasons and under different climatic conditions. Increased infrastructure development and landscape fragmentation are problematic, as are landscape conservation initiatives that seek to remove people from 'natural' lands (International Center for Reindeer Husbandry et al., 2015). If climate change creates additional landscape changes that either directly limit the lands available for grazing or indirectly affect grazing by limiting herders' flexibility and adaptability, a threshold may be crossed whereby herding is simply no longer feasible.

### 6.2.8 Loss of critical mass in community population

Another threshold of concern for rural communities in northern regions involves rapid demographic change, in part because of a trend of rural outmigration that is widespread across the North (see Box 6.2) (Huskey and Southcott, 2010; Rasmussen, 2011). In Chukotka, rapid outmigration followed the collapse of the Soviet Union and subsequent perestroika and economic changes. While many residents were recent and non-Indigenous immigrants, the dramatic boom–bust effect significantly impacted local populations and places (Thompson, 2002; West, 2011). In Alaska, many coastal and interior rural communities are experiencing population growth (Hamilton et al., 2014), with a large segment of the population being age 18 years and younger, but there is also evidence of a shift in demographics, with many rural residents, particularly young women, moving to urban areas for a variety of reasons (Hamilton and Seyfrit, 1994; Hamilton et al.,

## Box 6.2 Demographic evidence for community resilience in Alaska

Community demographic collapse, as a cumulative result of individuals deciding or being forced to leave because of environmental and economic stressors, is a threshold of concern for the North. Data are limited for evaluating resilience for northern communities to this and other thresholds, although detailed demographics (births, deaths, population) are available for 43 communities in Arctic Alaska from 1990 to 2014 (Hamilton et al., 2014). Similar data are not available for Arctic Canada or Arctic Russia (Hamilton and Lammers, 2011). These data can be explored visually for evidence of demographic collapse or trends of in- and outmigration (Figure 6.5).

One hypothesis for the growth trends shown in this graphic is that these communities are resilient in the sense of being affected by and then recovering from the cumulative impacts of climatic, environmental, and economic change. An alternative hypothesis is that people in these communities have no choice but to absorb, or cope with, these changes. These growth trends, however, may mask future tipping points at which people can no longer absorb the impacts of change.

These data clearly show no evidence of climate-driven rural outmigration (Hamilton et al., 2016). Economic perturbations, such as the food and fuel cost crisis in 2008, did not noticeably affect rural community demographics; indeed, net outmigration decreased in Arctic Alaska after 2008 (Hamilton et al., 2016), contrary to the hypothesis that rising fuel and food costs would push people out of rural villages (Martin et al., 2008). Median net migration rates during the period 2000–2014 are also not significantly higher for any of the communities identified as being most heavily affected by climate change (e.g., by coastal erosion or impacts on freshwater supplies) compared to other communities (Hamilton et al., 2016).

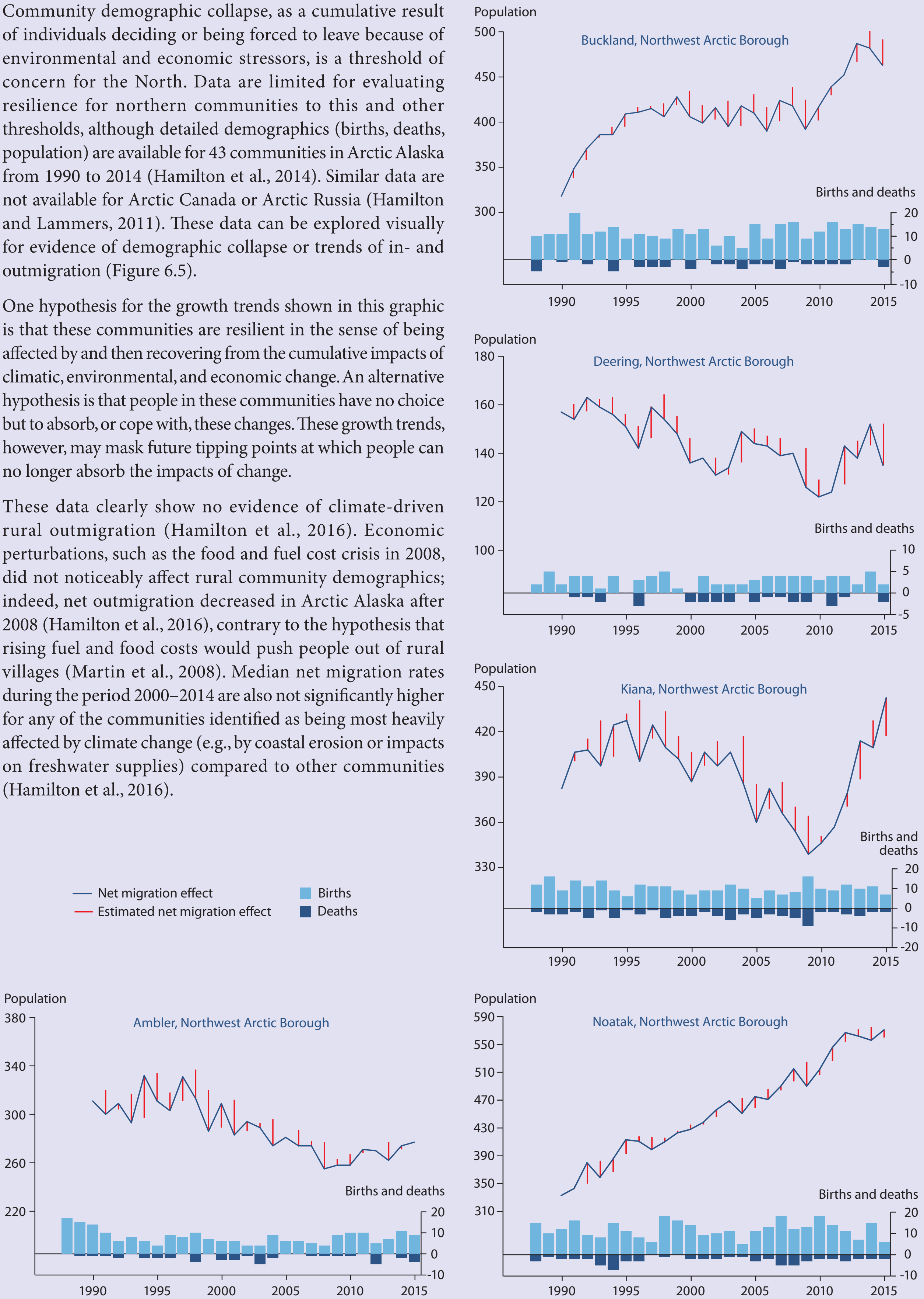
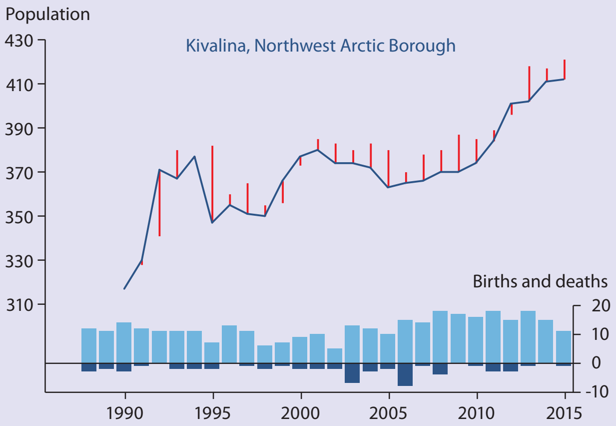
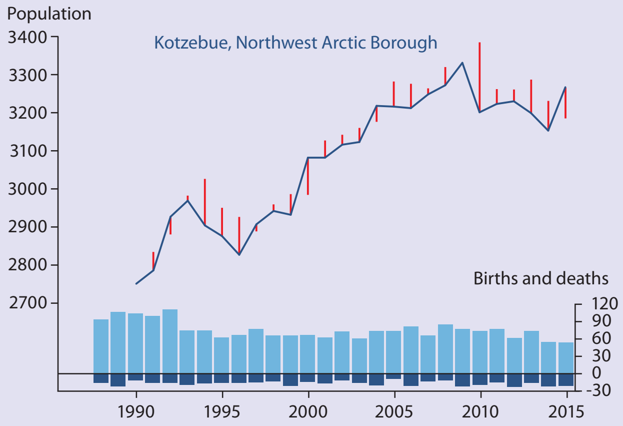
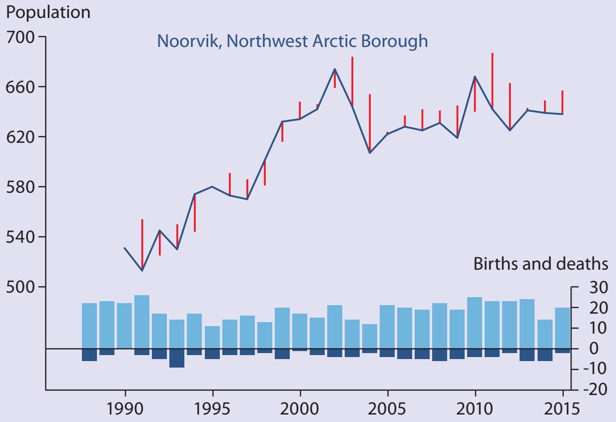
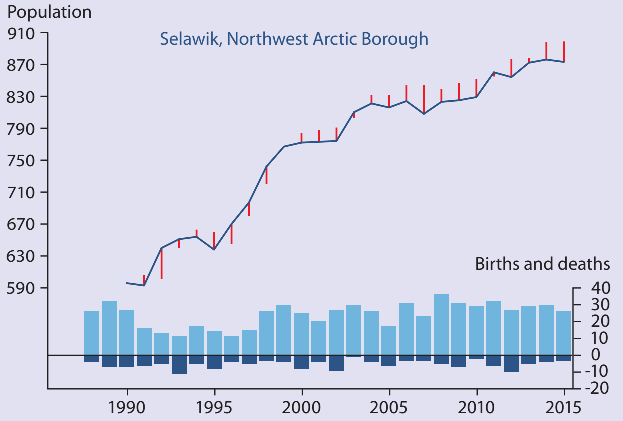


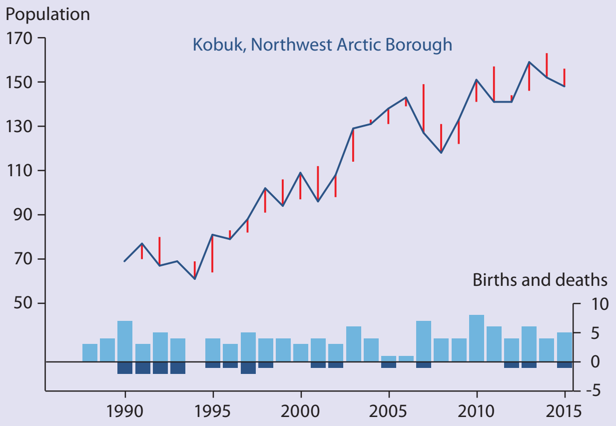
Figure 6.5 Population dynamics of 11 communities in Alaska's Northwest Arctic Borough, where food insecurity and the impacts of climate change are being actively experienced (population and birth/death numbers are graphed from different baselines, but with comparable $y$-axis scales) (Hamilton et al., 2014).

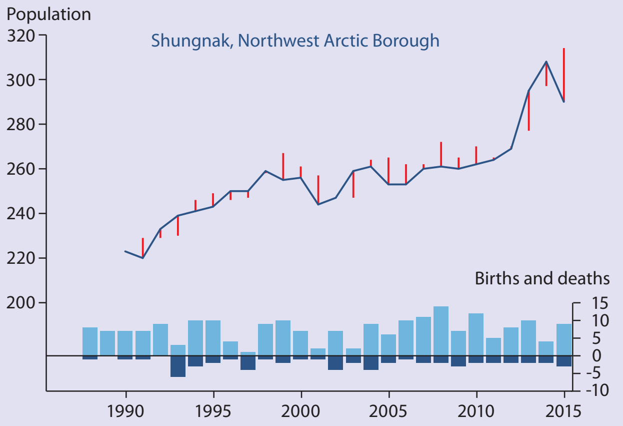










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*Aerial view of the town of Kotzebue, Kotzebue Sound, Alaska*

2014). Food insecurity, high and rising costs of food and fuel, and a lack of employment opportunities are among the primary drivers hypothesized (Huskey et al., 2004; Martin et al., 2008; Fazzino and Loring, 2009). Other thresholds are also likely to play a role, making community demographic collapse something of a complex emergent phenomenon that results from numerous interacting stressors.

In Arctic Alaska, outmigration from rural communities has been outpaced by local births (Hamilton et al., 2014), and only in extreme cases such as fisheries closures has outmigration dramatically remade community demographics (Hamilton et al., 2014; Himes-Cornell and Hoelting, 2015). Nevertheless, the changes in rural community demographics that result from outmigration can push a community past a tipping point, with one possible outcome being that the community is no longer viable (Martin et al., 2008). Even short-term outmigration, perhaps for seasonal jobs or healthcare (e.g., of expecting mothers and the elderly), can have notable impacts on local communities and cultures (Lewis, 2008; Schwarzburg, 2013).

### 6.2.9 Community relocation

In contrast to community demographic collapse, the forced or voluntary decision to relocate a community outright is a stark threshold and an extreme form of regime change, but one that is nonetheless being actively confronted by multiple communities across the North. Community relocation is not unprecedented, however, as communities have relocated in the past for a variety of reasons. The Seth-De-Ya-Ah Athabascan tribe, for example, relocated from ‘Old Minto’ to ‘New Minto’ on higher ground in Alaska’s interior in the 1950s, partially in response to repeated seasonal flooding of the Tanana River but also because of new developments such as construction of a new school in New Minto.

For Alsakan communities such as Kivalina, Shishmaref, and Newtok, relocation has a distinct character, coming as it does in response to coastal erosion resulting from rapid climate change and extreme weather events. Here, there is a discrete tipping point related to coastal geography and oceanic processes that in combination may drive communities beyond the point of habitability. From the perspective of these villages, resilience as a concept is more or less irrelevant, but from the perspective of the inhabitants, resilience emerging from relocation – and the ability to direct that process and decide where, when, and how to move – is of utmost importance (Bronen, 2011; Marino, 2012). Because government action on supporting community in general has been limited, and given the high and rising costs of relocation, it may very well be the case that people leave these communities individually and that some communities collapse (see Section 6.2.8) before any concerted effort to relocate them en masse ever materializes.

Despite the trends of change in Arctic Alaska discussed in Boxes 6.1 and 6.2, the impending need for relocation faced by many coastal communities is a clear example of a threshold. Unfortunately, governments have yet to act in many of these cases, thus delaying and increasing the magnitude of the costs and impacts. As these impacts accrue, people become less able to respond and adapt effectively (Huntington et al., 2012). Resilience in this context is somewhat irrelevant from a perspective of where the community will be, but psychological and social resilience are likely to be hugely important when relocation eventually happens. Being uprooted from a homeland is about the most dramatic form of environmental change imaginable, and it comes with numerous psychological and social stresses. Efforts to support people’s resilience in these regards will be an essential component of relocation.

### 6.2.10 School closures

Past research on Alaskan villages has shown that the presence of a public school is the single most important condition for retaining a village population. Thus, school closures are an informative example of an intermediate threshold, and perhaps a tipping point within community demographic collapse. Rural schools are a source of jobs and of food (through the school lunch program) for a community. In Alaska, for example, if a community does not have a minimum of eight school-age children, schools are forced to close, and this will arguably provide further incentive for people to leave their community for elsewhere. In general, this reflects the larger issue of the importance of critical mass for making modern services feasible in remote rural areas: making bulk fuel purchases, maintaining an air strip, attracting the service of a regional air carrier, and maintaining municipal infrastructure for water, wastewater, solid waste, and other municipal services such as schools and healthcare. All of these become difficult or impossible to manage when community populations dwindle.

Data for 43 rural villages in Alaska show that not all rural villages are presently facing demographic collapse (Hamilton et al., 2014), yet continued changes in age–sex composition may presage future problems or vulnerabilities to the impacts of climate change (Hamilton et al., 2016).

### 6.2.11 Relocation of local elders

Lack of healthcare infrastructure and family reorganization in many northern communities sometimes makes it impossible to locally care for ailing or aging elders. Assisted living facilities – facilities where the elderly can access healthcare services around the clock and live with supervision and help if needed – are available only in large urban centers. Regional corporations and their nonprofit partners are concerned about this and are taking steps to provide such facilities in communities, but the financial and professional costs are high and progress is slow. Most communities do have centers where elderly members are served daily meals, especially lunch, and as much as possible, these meals consist of traditional foods provided at little or no cost.

When elders are forced to relocate, to leave the community because of health or age, there is a significant social cost. The potential for older, experienced community members and leaders to connect with youth and the intergenerational transmission of local knowledge are both compromised. There is also a likely shift in the demographic profile, with younger people dominating and elders of both sexes becoming fewer in number. The implications of this trend for resilient community futures remain to be seen, although the emergent pattern is clear now in community demographics (Hamilton et al., 2016; see below).

## 6.3 Strategies and mechanisms for (helpful) resilience

This section examines helpful and unhelpful resilience strategies (see Section 6.1.2), identifying some of the approaches that people can employ and some of the societal mechanisms they can rely upon when responding to change, as well as some of the social or ecological barriers that may limit these actions.

The discussion is refined by invoking a set of categories suggested by Walker and Salt (2012) for mechanisms of resilience, including such items as diversity, feedback loops, and social capital. Thornton and Manasfi (2010) offered a second set of strategies that can confer resilience (Table 6.2). These are used in the sections that follow, to craft a combined and simplified set of resilience strategies: diversity, openness, reserves, tightness of feedbacks, and social and other forms of capital.

Table 6.2 shows a range of actions that people may take in response to climate change. These strategies are enacted within the context of local impacts – with the explicit purpose of maintaining community, culture, and so on. It is possible that adaptation or adjustment and effective response will happen over time as a result of the strategies being enacted, whether or not this will happen is not yet clear. Each of these strategies is explored in more detail in the sections that follow.

### 6.3.1 Diversity

Change has ostensibly been the norm for the biological and cultural geographies of the Arctic for as long as it has been peopled. Northern First Nations, Athabascan, Inuit, Iñupiaq, and other Indigenous residents have long coped with both social and ecological change – successfully in some cases, not so successfully in others. People have responded to the shortage or abundance of wildlife and other harvested resources through seasonal movements, high residential mobility, and social group flexibility. For northern foragers, food security and resilience have been found in mobility and social exchange, among other traditional practices and institutions (Binford, 2002; Kofinas et al., 2010). These peoples have also coped through experiential knowledge gained over generations about how to understand and plan for the vagaries of place, including social and economic issues, changes in seasonality, and changes in the distribution of wildlife. This 'traditional knowledge' – the wisdom and collective social action reflected in and by local knowledge about place – mistakes made, and lessons learned, on balance and when coped with effectively, contribute to resilience and sustainability (Nelson, 1986; Berkes, 2012).

In light of the thresholds of concern introduced above, diversity as a mechanism for resilience holds promise for several reasons. Managing for diversity in local subsistence food systems can continue to offer resilience to northerners who are seeking to maintain a traditional way of life where country foods will continue to play a strong role. Economic diversity – for example, through the creation of new jobs and through improved trades-based educational opportunities (e.g., training local teachers) – can improve the likelihood that people will choose, or be able to choose, to stay in rural communities. And finally, cultural pluralism, a societal value that recognizes and strengthens diversity in all forms, can be an important source of resilience that local people can draw from at state, provincial, and national levels (Kassam, 2010; Loring, 2016). In other words, if the dominant societal narratives about climate change emphasize the importance of local self-determination and human rights, people in northern communities will at least be socially and culturally empowered to respond effectively to change. Currently, however, dominant narratives about climate change for the North typically do not emphasize these issues (Parenti, 2011; Loring, 2013).

### 6.3.2 Openness

Whereas people in the North once had the flexibility to move across the landscape in response to changes in the distribution and abundance of fish and game, their subsistence systems are no longer as open. Today, people are constrained by land tenure, governance, fish and game management protocols, and a variety of other circumstances that are situated well outside local control (Huntington, 1992; Loring and Gerlach, 2009; McNeeley and Shulski, 2011). That northern people today live in permanent

Table 6.2 Strategies and mechanisms of response resilience.

| Strategy | Description (Thornton and Manasfi, 2010) | Categories of mechanisms (Walker and Salt, 2012) |
|---|---|---|
| Mobility | Traveling farther to hunt, fish, collect foods<br>Relocating or migrating away from land that is vulnerable to storms or thawing permafrost | Diversity, openness, reserves |
| Exchange | Transfer of traditional knowledge across generations | Social capital, feedback loops |
| Rationing | Caching foods in ice cellars, canning, smoking fish | Reserves |
| Pooling | Coordinated hunting, 'super-hunters' who procure country foods for multiple families | Social capital |
| Diversification | Altering prey choice and dietary breadth<br>Transitioning to a mixed subsistence/cash economy | Diversity |
| Intensification | Hunting or fishing more heavily in easily accessible areas | Intensification |
| Innovation | Regional coordination of healthcare, municipal services, fuel buying | Social capital, human capital |
| Revitalization | Restoration and reassertion of traditional ways of knowing, educating, healing, and governing; co-management | Social capital, human capital, feedback loops |


GM Photo Images / Alamy Stock Photo

*Walrus hunters, Cape Aachen, Chukotka*

settlements is one enduring legacy of a colonial past and present. This is also a powerful constraint on what residents can and cannot do and on how and under what conditions they may respond to any number of drivers of change (Eichelberger, 2011; Gerlach et al., 2011; McNeeley, 2012; Crate, 2012). This condition is important for understanding community resilience, as permanent settlement in fixed communities means the loss of the seasonal and residential flexibility that made life on the land possible and, more often than not, successful (Binford, 1978). While there are clearly benefits afforded to residents of permanent settlements, the legacies of colonialism and an unbalanced world economic system are many – so many that northern residents sometimes refer to their Arctic communities and regions as developing nations within an industrial world. The Indigenous world across all Arctic regions is dominated for the most part by national and international concerns about Arctic security, natural resource extraction by multinational corporations and governments, and little else (Osherenko and Young, 1989; Zellen, 2009).

### 6.3.3 Reserves

Many rural northerners describe their food security as being 'stored in the country' (Betcher, 2015), a reference to the various fish and animal populations on the land and seascapes. In addition, most rural communities also have commercial stores with some 'on shelf' storage capacity for highly processed and boxed or packaged market foods, although only rarely – if at all – for fresh produce, which is often wilted or wilting from long-distance transport by the time it reaches remote northern communities. While people do eat out of these stores on a regular basis (and this represents to some extent part of the nutrition transition discussed in Section 6.2.3), some view them as a measure of emergency food security. However, food security and nutritional security are not the same, and it is nutrition that is compromised in this context (Gerlach et al., 2011).

A changing climate is affecting some of the traditional ways that rural peoples preserve and store foods. Ice cellars, for example, are being compromised in some communities as a result of warming in general and permafrost thaw in particular (Brubaker et al., 2009; also see Chapter 5). Similarly, unseasonably wet conditions can interfere with fish smoking, which is extensively practiced across the North, and unseasonably warm autumn conditions can create a risk of large-mammal meat spoilage before it can be processed. Because of an increase in warm autumn temperatures and the late timing of freeze-up, at least in Alaska, people are now finding it difficult to preserve harvested meat without access to electricity and a bank of freezers and cold storage options. The days of being able to harvest caribou and moose in particular, just before the rut, then butchering, processing, and hanging the meat on racks outside houses or in outdoor meat caches seem be a thing of the past in many regions.

### 6.3.4 Tightness of feedbacks

One particularly important feedback loop among humans and the environment in the North is the ongoing maintenance and refinement of local environmental knowledge. In-depth knowledge of land and seascapes has been and still is essential for survival and self-reliance, and local people still hold a tremendous amount of relevant knowledge, although this is changing too as climate and weather change. Many say that the earth is changing in ways that make current environmental cues less effective predictors of the land and sea conditions (Krupnik and Jolly, 2002). Changing seasonality, an increase in extreme weather events, and changes in sea ice and ocean conditions, along with a shifting of co-occurring key environmental events, are all widely observed and well documented (Moncrieff et al., 2009). In combination, these changes undermine the reliability of natural indicators to forecast system condition or anticipated change. This is also true for local knowledge, especially so of the kind that traditional ecological knowledge proposes to capture. On many occasions, younger hunters and fisher folk in Alaska have been heard to say that the "*way the world was in our grandfather's time is not the way that it is now, and we don't always know from one season to the next, from one year to the next, what to do to make things work and feed our families*" (C. Gerlach, field notes, 2010).

Maintaining tight feedback loops so that people can continue to develop, test, revise, and enhance their local knowledge is essential, but it means ensuring that people have access to the land, as well as the time and the resources to spend on the land. It also means that interpersonal connections among youth and elders are preserved and perpetuated so that younger hunters can learn how best to incorporate new and novel observations into their existing system for knowing the land.

### 6.3.5 Social and other forms of capital

To varying degrees, rural communities are enriched with or impoverished by the capital resources available to them during times of stress. Most communities are rich in social capital in that they are members of regional tribal consortia and corporations, and this is especially true for Alaska, perhaps less so for northern Canada and Russia. While some consortia are better than others at fostering collaboration and coordinated outcomes, all provide some form of a social support network. Intervention by these groups through various kinds of support and capacity building perhaps represents the best chance for moving forward in positive directions.

Financially, much of the rural North is still heavily dependent on government transfer payments and grants from a variety of governmental and nongovernmental organizations. Federal disaster assistance also exists in various forms and has been drawn on in the past, with one example being funds to compensate for commercial fisheries failures in the US (Harrison and Loring, 2016). Such revenue streams are probably a source of both resilience and vulnerability, depending on economic and political circumstances at higher levels. The revenue sources do not necessarily serve all residents equally though.

## 6.4 Single stressors to cumulative effects

The extent to which people will be able to enact the resilience strategies outlined above in response to the varied impacts of climate change remains unclear. The ability to respond to some change is not uniform over space or time, and as impacts accumulate, and perhaps interact synergistically with one another, the feasibility of the above strategies will very possibly erode. For example, policy and land use change may erode the potential diversity from which local food systems presently derive their resilience (Loring and Gerlach, 2009; Loring et al., 2011; McNeeley and Shulski, 2011). Likewise, some thresholds of change operate at the individual level, such as decisions to leave a community, and thus entail different rationales and drivers from person to person. Developing and refining frameworks and models for tracking how and whether changes at one level will accumulate or ‘scale up’ to threshold crossings at higher levels remains a research need.

Besides resilience theories, another research platform that we find complementary and useful for this question of how people are cumulatively affected by multiple stressors operating at different scales is the cumulative effects (CE) framework (Smit and Spaling, 1995). The CE framework is designed for capturing the interaction of multiple variables through time and across space, whether in the context of gradual change, incremental change, surprise, or some combination of all three (Penn et al., 2016). Both resilience theory and CE analyses describe scaled feedbacks and interactions in social and ecological systems; both emphasize the dynamics of change and the effects of direct, indirect, and systemic or cumulative impacts; and both seek to identify and reduce the undesirable effects of interactions among perturbations and receptors (National Research Council, 2003). Both frameworks have the potential to provide useful information for policy-makers and planners, with the CE framework possibly stronger on the descriptive side and the resilience framework stronger on mapping community-based strategies for coping with social and ecological change and planning for surprise and uncertainty.

Cumulative effects analysis was originally developed in the United States by the White House Council on Environmental Quality, after passage of the National Environmental Policy Act of 1969. The CE framework is explicitly holistic and attends to the manner in which problems and surprises interact and how impacts accumulate, additively or synergistically, over time. The approach focuses on both short-term direct and long-term indirect and cumulative impacts. It not only accounts for proximate or immediate causes but also anticipates the accumulation of stressors toward the potential for thresholds and tipping points, beyond which an entirely new suite of negative impacts may appear (Walker et al., 1986; National Research Council, 2010). Cumulative-effects approaches are differentiated from traditional environmental impact assessment approaches in that the CE framework seeks to incorporate both the spatial and temporal dimensions of environmental perturbations, while also accounting for how they interact with a system’s ability to respond. In the simplest terms, cumulative effects arise from single or multiple drivers, whether climatic or non-climatic, which when combined may result in additive or interactive effects.

The CE approach requires the analyst to think in an integrative way about the various challenges described throughout this report. Just as importantly, in order to better understand how these challenges will interact in space and/or time, it is necessary to work in a collaborative and participatory way with local stakeholders – another important theme here. Ultimately, while climate-driven changes are important to rural peoples, climate change is sometimes perceived as a kind of background noise, against which the social and economic challenges of the day are directly experienced and, at times, exacerbated.

## 6.5 Transformation

This chapter has discussed transformations, thresholds, tipping points, change, and stability in rural northern communities. It has also discussed what is seen as a subtle but potentially important distinction between effective responses to change and adaptation action as it is conventionally used. Transformation also differs from adaptation in that it implies a human-navigated change to some desirable system state, a shift that results in a fundamental modification in the structure, function, or identity of a system (Olsson et al., 2004; Carpenter and Brock, 2008; Folke et al., 2010).

Transformational change is sought when current or anticipated future conditions are out of step with current human needs to the extent that even modest modifications (adaptation) are not sufficient. Facing an array of problems, many Indigenous peoples of the North have sought varying forms of transformation for improving individual, community, and ecosystem health and well-being (Pelto, 1973; Berger, 1985; Thornton, 1998; Marino, 2012). The abandonment of a village site, the implementation of a new property regime (such as the implementation of a land claims agreement), or a dramatic change in economy (such as the abandonment of a fishing economy and a shift to an alternative food production system) are a few examples of changes that people have pursued or must now consider. The Alaska Native Claims Settlement Act, the key piece of legislation that created village and regional Native corporations in Alaska, and the Nunavut Political Accord, which led to the creation of a sovereign Nunavut in Canada, radically changed the governance system for the region and showed how humans may dramatically modify aspects of their social-ecological systems to ensure sustainability and well-being.

Given the extent of changes that are likely to occur in the future, transformational change in high-latitude social-ecological systems of governance and, in some cases, northerners’ livelihoods may prove more important than simple acts of adaption. These actions may be initiated at any level, but regardless of the genesis, meaningful local involvement will be critical to ensure that community needs are not ignored and that local knowledge of change and its implications are not ignored.

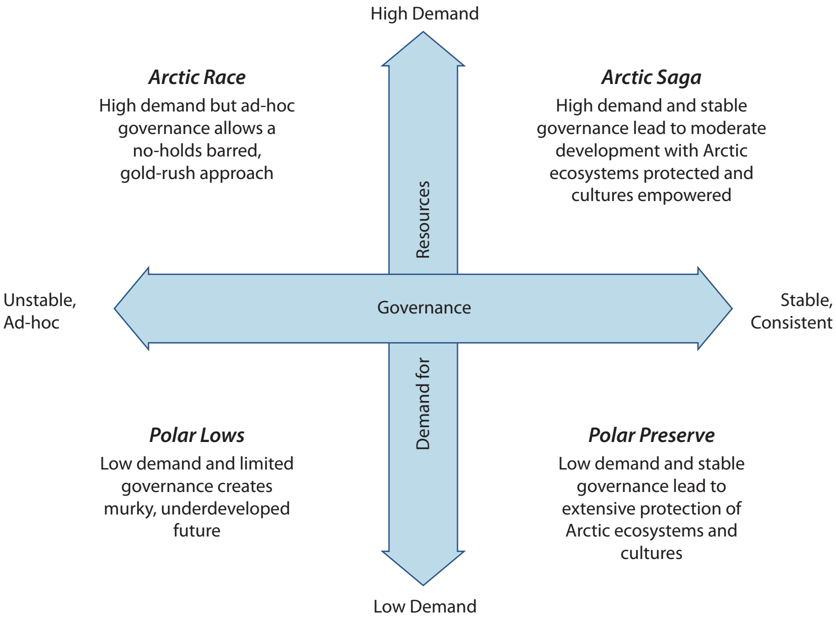

Figure 6.6 Four scenarios for the future of the Arctic, based on future demand for Arctic resources and the stability of Arctic governance (based on work by Brigham and colleagues: Brigham, 2008, and PAME, 2009). These scenarios are 'Arctic Race', in which ad hoc and poorly developed governance does not keep up with the high demand for Arctic resources, resulting in a gold-rush approach; 'Arctic Saga', in which high demand is tempered by stable governance structures, leading to development balanced with the needs of local peoples and ecosystems; 'Polar Lows', in which demand does not materialize and limited governance leads to little change or development for the region; and 'Polar Preserve', in which stable governance pursues extensive protection of Arctic ecosystems and peoples without external geopolitical pressure.

A recent meta-analysis on food security in northern North America provides an important case in point regarding this question of whether local communities can be active (self-determined?) architects of their futures (Loring and Gerlach, 2015). Four scenarios for the future of the Arctic have been proposed (Figure 6.6), based on the projected demand for Arctic natural resources and stability of Arctic governance; these scenarios are discussed in Chapter 8 as well. Extensive evidence indicates that climate change will continue to pose multiple challenges, and many national and international players have adopted an attitude of acquiescence to the resulting impacts, emphasizing economic development opportunities over social and environmental justice concerns (Loring, 2013; Loring and Fazzino, 2014). As such, only the two 'high-demand' scenarios are now likely: *Arctic Race* and *Arctic Saga*. The saga scenario could ensure a thriving and food-secure future for Arctic peoples, but the race scenario, an extreme example of which is provided by the environmental degradation and injustice found in the Niger River Delta, seems more likely given that existing legal protections for Indigenous rights already fail to ensure regional food security. Ideas for strengthening peoples' ability to self-determine through these challenges need to look past concepts such as adaptation and resilience and instead to rights-based reform around concepts such as food sovereignty, which implies the right of people to control their food supply (Via Campesina, 1996; Loring and Gerlach, 2015).

## 6.6 Conclusion

This chapter has sought to provide a perspective, informed by resilience thinking, about human resilience in the North. Participatory and community-initiated research is a good first step for improving knowledge about the resilience of northern peoples and communities to climate change. In arguing for a bottom-up rather than a top-down approach, it should be noted that only northerners themselves can accurately construct, identify, and locate the most pressing thresholds of concern or speak to what resources they need most in order to navigate, avoid, or cross those thresholds successfully.

For any theoretical framework to be useful for understanding how communities will be affected by change and how they should or will respond, the framework must be synergistic and powerful enough to incorporate aspects of economics, demography, ecology, climate, and meteorology into the social, cultural, political, and policy components of analysis and action. No one dimension should be elevated to priority status over the others in theory development or planning. Resilience thinking may satisfy this need to some extent, but it does come with limitations. In practice, not all adverse impacts are created equally: extreme weather events and natural disasters, for example, have both severe short- and long-term repercussions, thus requiring both short-term coping mechanisms and long-term adaptation strategies (Oliver-Smith, 2013). Likewise, not all responses to change need to be equal in magnitude or efficacy, but an effective local and regional planning platform must have a well-integrated set of dimensions as coping strategies are being mapped, designed, implemented, redesigned, and again implemented (McClanahan and Cinner, 2011). An effective regional planning platform must be dynamic and iterative, designed to incorporate multiple stakeholder perspectives and inputs (Walker et al., 2013).

It is impossible to anticipate all the ways that communities might be affected by the changes discussed in the earlier chapters of this report. Likewise, it is impossible to know definitively whether or not communities will prove resilient to these challenges. The goal with this chapter was to map out an understanding of what are the most likely mechanisms and strategies for resilience so that policy considerations now and in the future might better attend to stark deficiencies in those cases where negative impacts are impossible to avoid.

Concerns for promoting Indigenous community health and well-being or collaborative natural resource development strategies are sometimes part of a larger political narrative and justification for Arctic exploitation and natural resource extraction activities. Such concerns, however, are probably not the only motivation for expansion into new Arctic economic and military frontiers (Osherenko and Young, 1989). Among the increasingly normative themes emerging in resilience thinking, important questions remain: who is it that is resilient – the nation state, a collective of nation states, or local and regionally networked communities? And will decisions about community futures be made from the top down or the bottom up? Like sustainability, the questions of resilience – for whom, about whom, and for what? – are important if the goal is to improve planning for sustainable futures and to identify and promote new and effective strategies for coping with change (Yanarella and Levine, 2014). Effective strategies for coping with change require identification of both the problem and a solution and must be dynamic rather than passive.

Finally, it is essential to note that resilience to some identified harm, regardless of how severe, is and should not be the final concern for policy formulation; effort should be made to work toward planning for change rather than simply mitigating impacts. In recognizing that people of the North are being harmed by climate change – a product in part of activities in more economically privileged communities and nations, by policy-makers and policy actions – it is important not to lose sight of the social justice component in working collaboratively with local communities to craft new and more effective 'adaptation actions'. Helping people recover from a real or perceived harm is essential, but ensuring that it does not happen again and that people are at least adequately compensated for and/or are better prepared to cope with such harms must not be overlooked either (Bowles and Veltmeyer, 2014).

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# 7. Adaptation

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## Key messages

- ***Proactive adaptation in response to environmental and societal changes in the BCB region is imperative.*** *Primary concerns include impacts on ecosystems, infrastructure, and rural communities, particularly regarding food security and human health and safety.*
- ***Effective adaptation requires case-specific consideration of context as well as the interconnected environmental, cultural, social, and economic conditions of the BCB region.*** *Flexible governance structures and institutions are key in enabling effective adaptation.*
- ***There is a need to better understand the dynamics of multiple stressors, feedbacks, and synergies between and among social and environmental drivers of change and the associated cumulative impacts in the region.*** *The transdisciplinary research to understand the cumulative impacts of these drivers is still in its infancy.*
- ***Despite many examples of adaptation actions in the BCB region, the rate and extent of climate change necessitates increased attention to overcoming adaptation barriers.*** *Existing and potential barriers include resource constraints, ineffective institutional arrangements, and knowledge gaps.*
- ***Adaptation to climate change in rural communities is often combined with other initiatives*** *such as improving community health, self-reliance, and sustainability.*
- ***There are few documented adaptation actions directed at realizing potential new economic opportunities, particularly those initiated locally.*** *Many such development opportunities also present increased risks to the environment and traditional livelihoods.*
- ***Various tools, including codes, standards, and guidebooks, are available to support adaptation decision-making yet there are few documented examples of their use in the region.*** *Networking and exchange of practical adaptation experiences is an important tool for facilitating adaptation action.*
- ***An evaluation of existing adaptations is largely lacking.*** *There is a need to monitor and assess both the processes and outcomes of adaptation in light of the societal/environmental system complexity and the possibility of unintended consequences.*
- ***Boundary organizations can be important players in advancing adaptation by linking scientific, policy, Indigenous, and practitioner communities.*** *Boundary organizations act as intermediaries that interpret technical information for practical application and foster communication and relationship building among groups that would otherwise seldom interact.*

## 7.1 Introduction: conceptual framework

The goals of this chapter are to provide a contextualized overview of adaptation actions and options throughout the Bering-Chukchi-Beaufort (BCB) region, to discuss barriers to adaptation, as well as principles that lead to successful adaptation, and to provide guidance for adaptation planning and implementation. Thus, this chapter answers these underlying questions for the BCB region:

> *What adaptations have occurred and what are options for future adaptation?*
>
> *What barriers exist, how can they be overcome, and how can we build successful adaptation?*
>
> *What tools exist, and what concrete steps can be taken toward creating adaptation solutions?*

The chapter focuses on human adaptation to climate and associated environmental changes, and provides information specific to the region as well as more generalized information that can be applied in the context of the BCB region. For consistency and clarity, this work uses the definition of adaptation adopted by the Intergovernmental Panel on Climate Change (IPCC): 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, 2014a, p. 76).

This chapter is organized into three sections. The first provides a conceptual overview of adaptation and discusses links between social and ecological aspects of adaptation, different types of adaptation, incremental versus transformative adaptation, and the role of cross-scale interactions. Conceptual aspects of rural adaptation, community adaptation, and institutional adaption are also included. The second section presents examples and discussion of adaptation actions in specific sectors in the BCB region, including human health and well-being, rural communities and food security, commercial shipping and marine tourism, resource development, wildfire mitigation, and governance. The final section presents and discusses principles, mechanisms, and tools for promoting and supporting adaptation in the region. This section includes discussion of general principles of successful adaptation, an outline of barriers and limitations to adaptation, and a summary of available adaptation guidebooks in the region. It also discusses the importance and process of linking scientific knowledge to action, gives recommendations for evaluating adaptation, and outlines knowledge gaps identified in the literature. Throughout the chapter, boxes highlight relevant specifics, such as adaptations in Indigenous communities in Chukotka, decision tools for prioritizing adaptation options, and examples of boundary organizations that can help facilitate adaptation in the region.

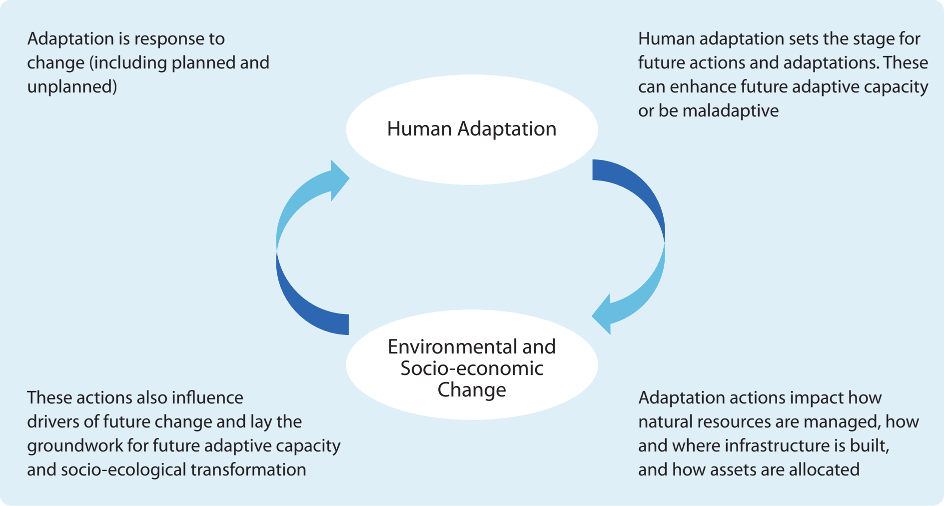

Figure 7.1 Feedbacks and interactions between adaptation and changing environmental and socio-economic conditions.

### 7.1.1 Why is adaptation needed?

The Arctic is warming faster than any other part of the planet, and impacts on people, cultures, economies, and industries in the region are already evident (ACIA, 2005; Chapin et al., 2014; Chapter 5). As temperatures rise, the resulting changing seasonality affects plant, insect, and migratory bird phenology; the availability of subsistence foods; and the incidence of wildfire, with its associated threats to life and property and smoke-related health hazards. Permafrost is warming, affecting surface water availability, ecosystems, traditional underground food storage, and infrastructure. Summer sea ice extent is decreasing, creating habitat decline for marine megafauna, hazards for Indigenous hunting and travel, hardships in Indigenous subsistence food harvest, and increased coastal vulnerability to extreme erosion. Declining summer sea ice also provides potential opportunity for increased offshore oil and gas development and trans-Arctic shipping and commercial marine traffic, both of which will require increased infrastructure development, spill response capacity, and provisioning for marine traffic safety. In addition, non-climate-related economic and social drivers are generating changes in population, governance structures, resource development, transportation, infrastructure development, and subsistence food harvest (Chapter 4).

Heat-trapping gases can remain in the earth's atmosphere for a century and beyond. Even if global greenhouse gas emissions are drastically curtailed, impacts from climate change will continue for decades (IPCC, 2014a). Similarly, socio-economic change in the region will continue (Chapter 4). It is therefore advantageous, if not essential, to provide forethought and to orchestrate efforts that assist in adapting to the changes underway (Chapters 2 and 8). These adaptations can take advantage of upcoming opportunities as well as help to lessen future hazards and risks (Chapter 8).

### 7.1.2 Links between social and ecological aspects of adaptation in the region

Impacts of and adaptations to environmental changes in the BCB region must be considered in the context of multiple drivers of change (Larsen et al., 2014b). These multiple, coupled drivers of change create complex feedbacks among the physical, natural, social, and economic spheres. Physical, biological, social, and economic changes occur simultaneously and influence each other. Often, complex feedbacks exist among these drivers of change and their cumulative impacts on community, regional, national and international levels. For example, diminishing summer sea ice and overall ice thickness offers trans-Arctic shipping and offshore oil and gas development opportunities, as well as challenges in the form of infrastructure development needs and potential environmental contamination from oil spills. This potential resource development provides economic opportunity to Indigenous communities, as well as challenges associated with impacts on subsistence food resources and food security (Cameron, 2012). Thus, socio-economic and environmental changes are linked, as are the adaptive actions and responses to these changes (Adger et al., 2005b). Because of these complex links and interactions, interdisciplinary perspective and analysis are required to identify, implement, and evaluate adaptation actions.

Adaptation actions influence how natural resources are utilized and managed; which policy incentives and regulations are established; and what skills, capacities, and social resources are developed by individuals, communities, and institutions. Current choices about adaptation thus set the stage for future environmental and socio-economic change (Garrelts and Lange, 2011) and create a cycle of interaction between human action and environmental and socio-economic change. These feedbacks are outlined in Figure 7.1. To achieve long-term success in adapting to changing environmental and social parameters, it is therefore necessary to consider adaptation within a larger temporal framework that includes interactions and dynamic influences among human adaptation actions and environmental/socio-economic change (Larsen et al., 2014b). It should be considered, for example, how current adaptation actions set the stage for future actions and build future adaptive capacity or, conversely, how current adaptations might limit future options (Barnett and O'Neill, 2010; Pahl-Wostl et al., 2012; Noble et al., 2014). It is therefore important to build an iterative, evaluative component into planned and proactive adaptations, as illustrated in Figure 7.2 (Adger et al., 2005b; Moser and Boykoff, 2013), and to consider potential social and environmental constraints on adaptation (Adger et al., 2009; Moser and Ekstrom, 2010).

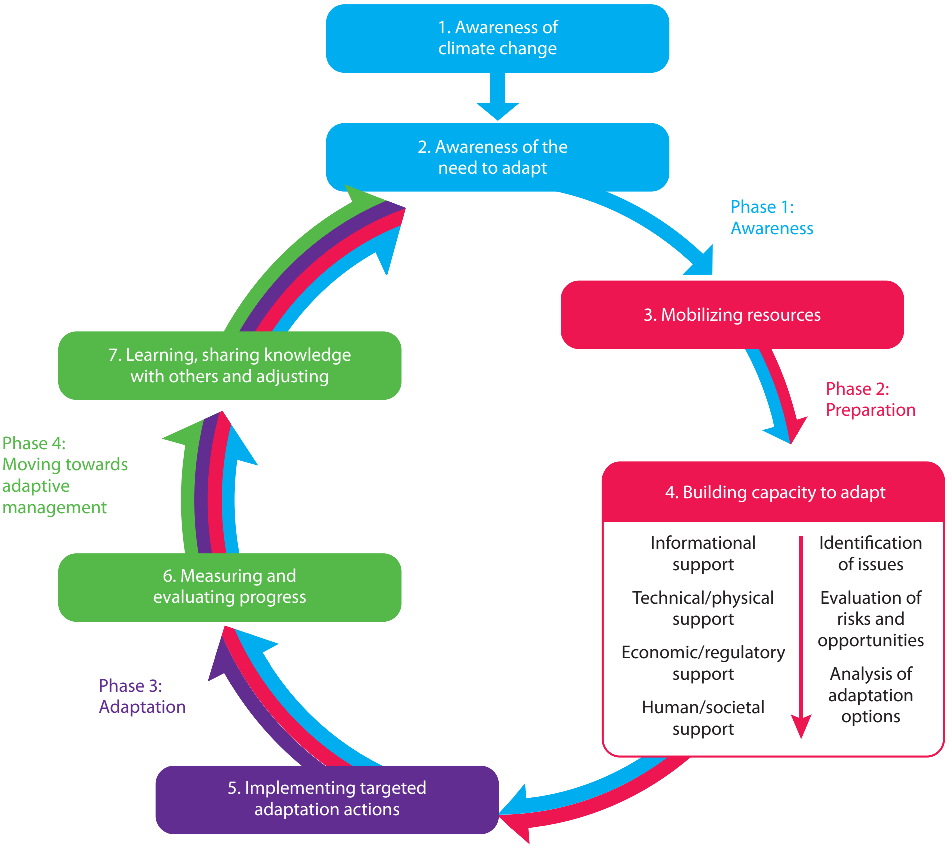

Figure 7.2 Stages and steps in the adaptation process (Eyzaguirre and Warren, 2014). The adaptation process involves deepening levels of engagement (phases), as well as actions that can be taken in support of decision-making (the numbered steps). While illustrated here in a sequential manner, organizations may take different pathways as they move through these phases and steps. This graphic was compiled by integrating common elements of different adaptation planning frameworks.

### 7.1.3 Perspectives on rural community adaptation in the North

Crate (2011) examined how people internalize adaptation in northern Russia by changing how they think about the land, themselves, environmental problems, and power. The author drew attention to the cognitive influence of the 'era of global climate change' and argued that research on climate change adaptation must take into account people's changing perceptions, the origins of these perceptions, and the power issues therein. Also commenting on the issue of power, Loring (2013) and Loring and Fazzino (2014) noted that a challenge with climate change adaptation programs and policies is that they have the potential to overshadow or even reproduce the social and environmental injustices that are at the root of climate change. Emphasis on directly engaging rural communities in adaptation policy and decision-making is thus particularly important (Chapin et al., 2014, 2016; Larsen et al., 2014b; ICC Alaska, 2015) (see Section 7.3.1.)

### 7.1.4 Institutional/governance adaptation

Governance and its related institutional arrangements are critical determinants in facilitating adaptation to climate change at specific levels and across levels of interaction (Dietz et al., 2003; Ostrom, 2005). Governance is defined here as the collective efforts of society to navigate and attempt to resolve social-ecological challenges, which may or may not involve government (Folke et al., 2005; Kofinas, 2009; Armitage and Plummer, 2010; Boyd and Folke, 2012; Nikitina, 2013; Young, 2013). Institutions, whether formal (e.g., government policies) or informal (e.g., culturally defined norms) shape human interaction and potentially serve as a means of generating innovation, mobilizing action, and facilitating the formation of networks within and beyond stakeholder groups (Light, 1998; Armitage et al., 2007; Hahn et al., 2008; Matous and Todo, 2015). Thus, both the *processes* of governance as well as the *structural/organizational features* of institutions can affect human responses to change.

Institutional learning is always a critical element of effective adaptation (Berkes et al., 2003; Biggs et al., 2012) but takes on special significance in the BCB region, given the increasing complexity of challenges facing the region (Folke et al., 2005; Chapin et al., 2006; Noble et al., 2014). Climate change is, of course, not occurring as a single driver but is concurrent with land use change, changes in economic conditions, and ongoing shifts in culture. In some cases adaptation will involve altering existing institutions, and in other cases there is a need for institutional transformation (i.e., the dismantling of old institutions and the creation and development of new ones) (Folke et al., 2009; Klein et al., 2014; Olsson et al., 2014).

Evaluating systems of governance with respect to potential adaptations to climate change requires a broad multidisciplinary lens that considers the past and possible future economic, social and cultural, and political contexts for decision-making. This process is made especially challenging because the future is not likely to duplicate experiences of the past and because human agency is highly unpredictable. But even with the uncertainty

**Box 7.1 Governmental approach to immediate needs related to climate change in Alaska**

The 2009 report of the Alaska Immediate Action Workgroup contains the following recommendations for successfully addressing immediate community hazards (IAWG, 2009) (see Section 7.2.6.3):

1. Begin by developing a collaborative organizational structure that can focus the combined capabilities of local, regional, state, and federal stakeholders on the problems at hand (see Section 7.3.1 regarding cross-scale coordination).
2. Discuss the nature and extent of the potential climate change impacts and create an applied approach to addressing significant impacts (see Section 7.3.6).
3. Identify the communities at risk, time frames, and the true needs of addressing climate change impacts (see Section 7.3.1 regarding consideration of short-term disaster risk management together with longer-term structural policy).
4. Develop measures that meet the stated needs and combine those measures into alternative plans for comparison.

The third item warrants more explanation. The majority of the residents in each of the villages looking at relocation are Indigenous Alaskans. Most rely on their intimate knowledge of their local environment to harvest local subsistence foods (see Section 7.2.2). This local and traditional knowledge might not be readily transferable to another location. The residents are also culturally and spiritually closely tied to the lands and waters near their villages, which would make moving very difficult (see Section 7.3.1). There are also other dynamics that could make one village's needs much different from the needs of another at-risk village.

Ingredients to success include coordination among agencies, close working relationships with the affected community, a thorough science-based hazard assessment, community consensus around the selected adaptation option, and strong leadership in the community and in state and federal agencies and a willingness for the agencies to look for creative solutions (see Section 7.3.1) – but these alone do not make for a successful project without sufficient funding (see Section 7.3.2).

To date, no Alaskan community has successfully relocated to a safer site. Securing federal funding for the coastal erosion and flooding protection and relocation projects needed in the at-risk villages continues to be very difficult. Such projects do not compete well for funding under existing federal programs due to mismatch between the grant award criteria and the needs and circumstances of specific villages. For example, villages in Alaska with relatively small populations (typically less than 1000 residents) and high construction costs (due to remote, off-road locations) do not rate well in a cost–benefit analysis. The villages might also lack, and have a hard time producing, hard data to support a funding request (US Government Accountability Office, 2009). This points to an increasing need for building bridges between scientific and local communities (see Section 7.3.6). A clear and achievable path to federal funds for these relocation and protection projects would be a major step forward (see Section 7.3.2).

that comes with responding to climate change, there are known characteristics of institutions that support adaptation and ultimately contribute to social-ecological resilience (Dietz et al., 2003; Folke et al., 2005; Brunner and Lynch, 2010; Biggs et al., 2012; Boyd and Folke, 2012; Young, 2013). These characteristics include (but are not limited to): responsiveness, flexibility, diversity and cross-scale interactions.

*Responsiveness.* The ability to respond to change in a timely fashion is a foundational characteristic of adaptive governance (Folke et al., 2002, 2003). In practice, however, being responsive is extremely challenging because conflicting political interests can delay or stall action. The consequence of inaction can include greater impacts and unanticipated outcomes, which can in turn lead to further difficulty in adapting to change. Responsive institutions are built, in part, through developing open and clear communication across organizational boundaries and striving to identify shared goals (Clark et al., 2008). Identifying and tracking indicators of change and establishing regular monitoring and assessment processes can supply vital information in support of responsive institutions (Lee et al., 2015). The integration of knowledge systems adds to the effectiveness of these processes, but implementation of the adaptive management learning cycle (i.e., monitor → understand → implement → reflect on outcomes → repeat) requires strong linkages between observing systems, research, and policy-making (Kofinas, 2009; Berkes and Armitage, 2010).

*Flexibility.* While much is known about the general trajectories of environmental change, understanding of how change will unfold in specific social, economic, and human contexts is limited by uncertainties (see Section 7.3.6). Building flexibility into governance systems allows groups to respond more quickly and effectively to both anticipated and unanticipated change (Gunderson, 1999). While accepted and established ways of conducting business can provide much-needed trust among parties, integrating flexibility into institutions expands the choices of society for responding to surprise. Achieving flexibility is especially challenging in a world of highly routine bureaucracies. Polycentric institutions (i.e., decentralized, multi-scaled, and interconnected institutions) provide one approach for achieving flexibility and responsiveness (Ostrom, 2010; Biggs et al., 2012). Spontaneity in evaluating emerging situations and a willingness to modify established protocols are also important. The capacity to be flexible (and responsive) is highly dependent on both overcoming barriers (see Section 7.3.2) and having adequate resources to act (i.e., knowledge base and human, financial, and social capital) (Berman et al., 2017).

*Diversity*. The importance of maintaining and even building diversity is well recognized in the literature of adaptive governance, and diversity can take many forms (Berkes et al., 2003; Walker and Salt, 2006; Chapin et al., 2009; Biggs et al., 2012). Cultural and social diversity can be a resource for problem solving, such as drawing on different systems of knowledge (e.g., Western science and traditional knowledge) (Reid et al., 2006). Working with this kind of diversity requires time and effort to develop relationships of trust and meaningful partnerships but, once established, can support improved understanding and the production of robust solutions (Berkes et al., 2003). There is also a power dimension to diversity, requiring stakeholders to be sensitive to how policies affect livelihoods and may result in winners and losers (Adger et al., 2005a). The benefits of social diversity (economic and cultural) are realized when institutions operate with adequate social capital and value diversity rather than fearing it as a threat and source of conflict (Adger, 2003).

*Cross-scale interactions.* Social-ecological systems interact across scales (Gunderson and Holling, 2002). Global-scale processes of climate change can cascade to have dramatic implications for local communities, and local actions can accumulate to affect regional-to-global processes. Institutional systems, such as co-management, informal networks, and other bridging arrangements, can help avoid policies that resolve a problem at one scale yet ultimately result in unintended consequences at another (Armitage et al., 2007).

Moving from the general principles of flexibility, diversity, and cross-scale interactions to effective adaptation planning is not mechanical but is instead a complex, nonlinear social process involving groups and personalities with needs and fears. Ultimately, making that move requires good leadership and the committed engagement of stakeholders through institutions that build knowledge, openly reveal biases, explore options, and engage actively in adaptation planning (Olsson et al., 2004). Some of the novel approaches currently being explored in the Arctic to support institutions for adaptive governance (Kofinas et al., 2016) include self-assessments of a group's adaptive capacity and resilience (Quinlan et al., 2016), participatory scenario analysis (Peterson et al., 2003), construction and use of simulation models by stakeholders (Holling and Chambers, 1973; Walters et al., 2000; Kruse et al., 2004), and data visualization (Swaab et al., 2002) (see Box 7.1, as well as Chapter 8). While these activity areas addressing climate change are indeed promising, they are occurring as stakeholders juggle multiple competing demands, many of which are perceived as more pressing (e.g., economic aspects of well-being). Thus, to avoid maladaptive policies and support sustainability, institutions should be sensitive to and highly supportive of local communities' priorities, working in direct and equal partnership whenever possible.

## 7.1.5 Types of adaptation

This section provides a brief overview of the different types of adaptation as they have been described in the literature and identified on the ground. Specific examples of adaptation in the BCB region are provided in Section 7.2. Changing climatic and social-economic parameters in the Arctic are prompting planned and unplanned, deliberate and spontaneous, proactive and reactive adaptations (Arctic Council, 2013; Ford et al., 2014a; Trainor et al., 2017). Adaptation can take many forms and the literature to date has identified several different structures for understanding and classifying adaptation. The IPCC distinguishes (a) *structural adaptation*, which includes engineered solutions and the built environment, technological actions, and ecosystem-based actions; (b) *social adaptation*, including education, information sharing, and training; and (c) *institutional adaptation*, encompassing economic solutions, legal and regulatory actions, and government policy and programs (Noble et al., 2014) (see Section 7.2).

Table 7.1. Adaptation variables and associated types of adaptation (based on Pelling, 2010, and Field et al., 2014).

| Adaptation variable<br>Adaptation type | Characteristics |
|---|---|
| Motivation | |
| Purposeful | Response to climate driver as a primary motivation |
| Incidental | Response to climate driver as a secondary motivation |
| Degree of forethought and planning | |
| Planned | High degree of forethought or planning |
| Spontaneous | Little forethought or planning |
| Action in preparation or response | |
| Proactive | Anticipating a driver, hazard, or threat |
| Reactive | Responding to driver, hazard or threat |
| Overall system change | |
| Incremental | Central aim is to maintain the essence and integrity of a system or process at a given scale |
| Transformational | Changes the fundamental attributes of a system in response to drivers of change and their effects |

Adaptation has been identified to include activities such as planning and strategic management, creating decision support tools, developing technological approaches, conducting research, building and engaging networks, enacting legislation, creating financial incentives, raising awareness, conducting training and education, participating in advocacy actions, and mainstreaming climate adaptation with other activities (Scientific Expert Group on Climate Change, 2007; Tompkins et al., 2010; Arctic Council, 2013). These activities can be motivated by goals of managing risk, reducing vulnerability, enhancing resilience, facilitating transition, initiating transformation, and benefiting from new opportunities (Eakin et al., 2009; Pelling, 2010; Kates et al., 2012; Nikitina et al., 2015).

Some adaptations in human and managed natural systems are planned and proactive, such as government policy and planning and the establishment of Indigenous joint management (or co-management) structures that incorporate adaptive responses to climate change. Other adaptations are incidental, spontaneous, and reactive, such as the changing of Indigenous subsistence hunting practices in response to changing environmental conditions. Table 7.1 outlines these different types of adaptation.

There is a growing concern about the need to understand and avoid ways in which beneficial adaptation in one location, sector, or population may lead to increased vulnerability or reduced adaptive capacity elsewhere. For example, Barnett and O'Neil (2010) described how site selection for construction of a desalinization plant to address long-term drought in Melbourne, Australia, overlooked Indigenous sacred-site designation and how project financing disproportionately affected people with low incomes. As adaptive solutions are promoted and implemented it is necessary to ensure that the

Table 7.2. Examples of existing and potential future adaptation in the BCB region (modified from IPCC, 2014b, p. 27).

🟦 Vulnerability and Exposure Reduction 🟩 Adaptation 🟨 Transformation

| Overlapping approaches | Category<br>*Sub-category* | Existing adaptations (and source, if available) |
|---|---|---|
| **Vulnerability and Exposure Reduction**<br>Through development, planning and practices including no-regrets solutions | **Human development** | Improved education, housing, and health services; suicide prevention; self-government (Larsen and Gail, 2015; Larsen et al., 2010, 2014a) |
| | **Poverty alleviation** | Improved education; economic diversification and development (Larsen and Gail, 2015; Larsen et al., 2010, 2014a) |
| | **Livelihood security** | Shifting subsistence harvest patterns (Alaska, Canada) (Sakakibara, 2010); Technical renovation and construction of modern utilities at staging posts along reindeer-herding routes (Chukotka) (www.arctic-info.ru); Construction (2016) of innovative technical 'secure town' complex aimed at enhancing safety of local population under extreme natural events (Chukotka) (www.arctic-info.ru/news/23-09-2015/mcs-ysilit-prisytstvie-na-cykotke/); Strengthened recognition of value of traditional knowledge (Multiple sources); Technology to improve safety of travel on land and sea ice (e.g., SmartICE) (Bell et al., 2014) |
| | **Disaster risk management** | Shoreline reinforcement (Alaska) (Trainor et al., 2017); Wildfire protection plans (Alaska) (Trainor et al., 2017); Expanded coast guard coverage (Alaska) (Trainor et al., 2017); Hazard and vulnerability mapping (Alaska) (Trainor et al., 2017); Development of special schemes for operational management of freshet floods by CAO (EMERCOM, lead management authority) (Chukotka) (www.mchs.gov.ru); Development of coastal erosion forecasts for coastal communities of Chukchi Peninsula (Chukotka); Building codes related to permafrost, snow loads, etc. (Canada), (CSA Group, 2014a,b,c, 2015), (Maskalov and Kraev, 2014); Improved navigational charts for marine traffic (Canada); Enhanced search and rescue capacity (Canada and Alaska) (www.uscg.mil/D17/Arctic Shield/ArcticShield.asp) |
| | **Ecosystem management** | National Park Service scenario planning (Alaska) (Weeks et al., 2011); Marine protected areas; development of a new national park (Canada) |
| | **Spatial or land use planning** | Schemes of territorial planning for Anadyr Municipal District, CAO (Chukotka) (OOO NPC IIR, 2013); Schemes of territorial planning for Chaunsky Municipal District, CAO (Chukotka) (OOO NPC IIR, 2014); Community adaptation plans (Alaska, Canada) (Trainor et al., 2017) |
| **Adaptation**<br>Including incremental and transformational adjustments | **Structural/physical** | |
| | *Engineered/built environment options* | Coastal village hazard reduction (Alaska) (Trainor et al., 2017); Adjustments to ice road construction (Chukotka, Canada, Alaska); Changing materials and construction design for roads, runways (Canada); Innovative building foundations (Canada) |
| | *Technological options* | Operational processing and regular upgrade of detailed maps of maximum snow load distribution (by EMERCOM) (Chukotka) (www.mchs.gov.ru); Use of thermosyphons to preserve permafrost (Canada); Sea ice monitoring (Canada) |
| | *Ecosystem-based options* | |
| | *Services* | |
| | **Institutional** | |
| | *Economic options* | Alaska Climate Change Impact Mitigation Program (ACCIMP) (Trainor et al., 2017); Regional government subsidies for processing the products of reindeer husbandry, hunting (Chukotka); Arctic Economic Council (arcticeconomiccouncil.com/) |
| | *Laws and regulations* | Change in statutory start date of wildfire season (Alaska) (Trainor et al., 2017); Upgraded guidelines for emergency forecasts of fires, floods, avalanches by the CAO EMERCOM center for monitoring and assessment of natural disasters (Chukotka) (www.mchs.gov.ru); Regulatory instructions for reduction of cargo load capacity per vehicle on the winter road of the Anadyr Estuary (Chukotka) (www.arctic-info.ru) |
| | *National and government policies and programs* | Denali Commission (Alaska) (www.denali.gov/, www.whitehouse.gov/the-press-office/2015/09/02/fact-sheet-president-obama-announces-new-investments-combat-climate); Interagency coordination of climate change adaptation policy (Chukotka); Regional program: Prevention of extreme natural and technological disasters and enhancing fire safety in CAO 2015–2019 (Chukotka); Regional program: Transport infrastructure development in CAO 2014–2018 (Chukotka); Pan-territorial adaptation strategy and partnership (Governments of Nunavut, Northwest Territories, and Yukon, northernadaptation.ca/about-partnership); Climate Change Impacts and Adaptation Program of Indigenous and Northern Affairs Canada (www.aadnc-aandc.gc.ca/eng/1100100034585/110 0100034586); Adaptation Platform: Northern Working Group (Canada) (www.nrcan.gc.ca/environment/impacts-adaptation/adaptation-platform/17176, Trainor et al., 2017) |
| **Transformation** | **Social** | |
| | *Educational options* | Rural community climate adaptation trainings (Alaska) (Trainor et al., 2017); Institute for Tribal Environmental Professionals; Alaska Center for Climate Assessment and Policy; Alaska Native Tribal Health Consortium); Wildfire crew training (Alaska) (Trainor et al., 2017); Training for policy-makers (Yukon, Nunavut, Canada) (Northern Climate ExChange) |
| | *Informational options* | Networking hubs (Arctic Adaptation Exchange; Northern Climate ExChange);<br>ArcticNet (www.arcticnet.ulaval.ca/) |
| | *Behavioral options* | Coastal village relocation (Alaska) (Trainor et al., 2017); Preservation of traditional knowledge |
| | **Spheres of change** | |
| | *Science* | Linking traditional knowledge and other science knowledge (Nickels et al., 2005) |
| | *Political* | |
| | *Governmental* | Devolution – strengthening autonomy of local and regional governments |
| | *Personal* | |

| Potential future adaptations (and source) |
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| Hazard and vulnerability mapping (Smith and Forbes, 2014; Smith et al., 2014) |
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| Economic assistance programs for traditional subsistence food harvest (Canada) (Fillion et al., 2014; Ford et al., 2010b) |
| Flexibility in state subsistence harvest regulations (Alaska) (Loring et al., 2011; Marino, 2012; McNeeley, 2012) |
| Federal agency coordination and assistance for community relocation (Alaska) (Bronen and Chapin, 2013; Clement et al., 2013) |
| |
| |
| |
| Shift to use-inspired science, knowledge to action, community science partnerships (Knapp and Trainor, 2013; Chapin et al., 2016); Community networking to share adaptation options (Knapp and Trainor, 2013) |
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adaptive capacity and well-being of low-income, Indigenous, and other vulnerable peoples are not compromised. Similarly, paying attention primarily to short-term outcomes may lead to increased vulnerability to longer-term threats. This phenomenon is known as maladaptation (Noble et al., 2014). Little research has been done on maladaptation in the BCB region. Failing to consider the regional distinctions across the Arctic has been identified as a potential source of maladaptation (Keskitalo, 2004).

There is a growing recognition that, due to the size, rate, and consequences of change taking place, some situations will require incremental adaptations while adjustments to other situations will require systemic transformation, either actively navigated or unplanned (Field et al., 2014). The IPCC distinguishes incremental from transformational adaptation as follows: incremental adaptation occurs "where the central aim is to maintain the essence and integrity of a system or process at a given scale" (Field et al., 2014, p. 40), whereas transformational adaptation, in contrast, "changes the fundamental attributes of a system in response to climate and its effects" (Field et al., 2014, p. 40). Rather than establishing percentages of change in specific metrics, transformation can be identified when a system operates in an entirely new way, including new system interactions and feedbacks.

Transformations can occur in biological systems (e.g., tipping points; see Chapter 6), with technological innovation (e.g., advances in communication technology or scientific imagery or monitoring), or within institutions or governmental arrangements (e.g., financial structures and regulatory, legislative, or administrative regimes), and they may be associated with fundamental changes in how a situation is viewed (e.g., altered paradigms, goals, or values) (Field et al., 2014). Some scholars have suggested that the relocation of coastal villages in Alaska due to severe erosion is an example of transformation (Kates et al., 2012).

## 7.2 Adaptation in the BCB region

This section provides examples of adaptation efforts in the BCB region (see also Chapter 2). Modeled after a similar table in the latest IPCC assessment, Table 7.2 outlines the overlapping approaches to managing the risks of climate change, including vulnerability and exposure reduction, adaptation, and transformation. Examples and source references for existing and potential future adaptations in the BCB region are provided. This list is not exhaustive, as new initiatives and publications are continually arising. The categories and subcategories outline and highlight the range of possible adaptations, including structural/physical, institutional, and social adaptations (Section 7.1.5). Gaps in the table represent areas where – although possibilities exist – adaptation has not yet been documented or otherwise formally identified in the literature.

The topics discussed in the rest of this section were selected by a team of the report's lead authors to be (a) representative of key areas in the BCB region where adaptation is occurring or will need to occur in response to changing environmental and social parameters and (b) consistent with other chapters of this report.

### 7.2.1 Planning and monitoring climate change adaptation to reduce adverse health outcomes

The environmental effects of climate change in the Arctic include the degradation of permafrost, loss of sea ice, and warming and acidification of seawater (Hinzman, et al. 2005; Huntington et al., 2005). Although scientific understanding is still emerging, there is evidence that these effects currently pose substantial risk to human health and well-being and will in the future represent even greater threats, especially for Indigenous communities (Larsen et al., 2014b).

Contemporaneous with mitigation, early adaptation is essential to reducing the adverse health effects of climate change. This section explores some strategies for planning and monitoring climate change adaptation to reduce adverse health outcomes associated with climate change among Arctic peoples and communities.

#### 7.2.1.1 Building resilience against climate effects

The modern epidemiologic methodology is particularly well suited for studies of associations between discrete exposures and health outcomes. However, challenges exist in applying this methodology to research related to climate change impacts. This difficulty is due in large part to the emphasis placed on randomized, controlled trials as the gold standard in epidemiological research design. These designs require researchers to control and selectively assign specific exposures potentially associated with adverse health outcomes and to measure those outcomes over time. However, the causal pathways through which climate-related exposures are associated with adverse health outcomes can be complex, interrelated, and widely separated in time. These causal pathways can be direct, such as unanticipated accidents during extreme weather, or indirect, such as food contamination associated with warming and thawing food cellars that are built in permafrost.

An additional challenge for modern epidemiological studies of the health effects of climate change is that few, if any, of the prospective adverse health outcomes are unique to environmental drivers (Samet, 2010). For example, an increase in cardiovascular complications may be associated with a heat wave but may also be associated with a host of social and physical determinants that precede such an event. For these reasons, the most intuitive health consequences of a warming climate, such as thermal stress, floods, and infectious diseases, have been the most amenable to conventional epidemiological studies of climate change (McMichael et al., 2006).

The US Climate and Health Program at the Centers for Disease Control and Prevention (CDC) has proposed one strategy for assessing the adverse health outcomes of climate change in order to develop and evaluate efforts to reduce them. The Building Resilience Against Climate Effects (BRACE) framework is a five-step process (Figure 7.3) intended to help health departments understand adverse health outcomes from climate change and to develop their responses (Marinucci et al., 2014).

The first step of the BRACE process involves identifying climate-related exposure and climate-sensitive health outcomes of concern. In the BCB region, second-, third-, and fourth-order impacts of climate change are particularly relevant – for example, smoke from increasing wildfire occurrence, travel and transportation safety hazards from thinning river and sea ice, and increasing exposure to persistent organic pollutants and toxic waste (Chapin et al., 2014; Trainor et al., 2009b). The second step of the BRACE process involves identifying the known risk factors, other than climate, for the health outcome of concern. This important step may allow the researcher to assess and integrate the various determinants of these adverse health outcomes, as well as to identify subpopulations that may be particularly at risk from the combination of climate change and these other determinants. Local residents and health experts, including experts from the US Centers for Disease Control and Prevention, met in October 2010 at the University of Alaska Anchorage to identify the known risk factors for health effects of climate change in Alaska (Marinucci et al., 2014). Participants agreed that subsistence-related activities, including travel and transportation across sea ice and surface (freshwater) ice, represented an important risk factor that must be captured in any study of the health effects of climate change in the region. The third step of the BRACE process is to acquire spatial information on health outcomes and risk factors for analysis. This step is problematic for many rural and remote communities in the circumpolar North, and particularly those with a large percentage of Indigenous or Aboriginal residents. These communities are often characterized by greater levels of poverty, limited technological capacity, inequality in socio-political influence, limited institutional capacity, and informational deficits (Ford et al., 2010a). Informational deficits may include a lack of data on climate change health outcomes and risk factors needed for the BRACE framework. Figure 7.3 outlines these initial steps, showing how they serve as a precursor to adaptation planning (fourth step) and the evaluation of implemented activities (fifth step). Outcomes

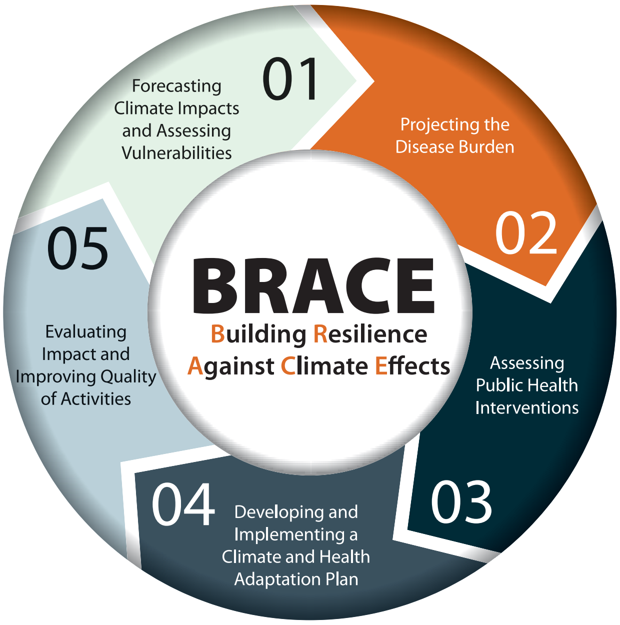

Figure 7.3 The Building Resilience Against Climate Effects (BRACE) framework (Marinucci et al., 2014).

of these evaluations then serve as inputs to ongoing climate-related health assessments. This process parallels the cyclical process of awareness, preparation, adaptation, evaluation, and ongoing assessment illustrated in Figure 7.2.

### 7.2.1.2 Human health adaptation in Canada

Inuit in northern Canada are already experiencing health effects from climate change and the resulting environmental changes, and weather and climate models indicate that these changes are expected to continue into the future. Impacts on human health are associated with changing temperature and precipitation regimes, which increase the probability and severity of extreme weather events, and with related flooding and erosion, with implications for water quality, food security, and the physical and mental health effects of population displacement (Warren et al., 2005; Furgal and Seguin, 2006; Martin et al., 2007; Furgal and Prowse, 2008; Furgal et al., 2008; ITK, 2014). Warmer and wetter summers also have the potential to increase the risk and incidence of waterborne, food-borne, and vector-borne disease (e.g., *Escherichia coli* infection, campylobacteriosis, giardiasis, salmonellosis, botulism) (Parkinson and Butler, 2005; Martin et al., 2007; Hennessy et al., 2008; Parkinson et al., 2008; Evengard and Sauerborn, 2009; Harper et al., 2011a,b). These risks are serious in an Inuit context, given the nutritional and cultural importance of country foods as well as the long distances that retail food must travel. Indeed, small changes in storage and transport temperatures for both country and retail foods can increase the risk of food-borne diseases (Parkinson and Butler, 2005; Parkinson et al., 2008; Furgal et al., 2008; Harper et al., 2015a,b). For instance, in Nunatsiavut, periods of heavy rainfall and rapid snowmelt – conditions that are expected to increase under climate change – have been associated with significant increases in indicator bacteria in drinking water, as well as significant increases in health clinic visits for diarrhea and vomiting (Harper et al., 2011b). Warming temperatures also affect snow patterns and sea ice thickness, extent, reliability, and the timing of freeze-up and break-up, leading to increased morbidity and mortality from unsafe and uncertain travel conditions (Ford et al., 2008). Climate change has also been linked to direct and indirect impacts on mental health and well-being, including increased emotional responses, elevated mood and anxiety disorders, increased family stress, increased addictions and suicide ideation, loss of connection to place and cultural identity, and mental health stress from these physical health impacts (Cunsolo Willox et al., 2013a,b, 2015; Bourque and Cunsolo Willox, 2014).

Research indicates that social gradients in health, the ongoing effects of colonization and intergenerational trauma, and a continued reliance on land-based living for food and culture continuity increase Inuit sensitivity to the health effects of climate change (Young, 2003; Ford et al., 2010a; Cunsolo Willox et al., 2015). For instance, overcrowded housing, which is common in many Inuit communities, can increase the risk of climate-sensitive communicable diseases, including acute respiratory and gastrointestinal disease. Moreover, Inuit maintain a close relationship with and dependence on the land, sea, ice, and natural resources for their livelihoods and culture, thus increasing their sensitivity to climate-related risks that affect subsistence hunting and travel (Pearce et al., 2015). For instance, in northern Canada, changing weather and ice conditions are associated with increased search and rescue incidents, self-reported stress, and unintentional injury – demonstrating how changing environmental conditions are critical factors affecting physical, emotional, and mental health and well-being (Durkalec et al., 2014, 2015; Clark et al., 2016). In some instances risks are associated with changes in the land–sea–ice interface, yet at the same time, it is from their connection to the land that Inuit derive their social and cultural strength, which is recognized as a key factor underpinning the capacity of northern communities to adapt to climate change (Cunsolo Willox et al., 2013b; Pearce et al., 2015; ITK, 2014).

Although adapting to the health effects of climate change is a daunting task, Inuit are active players, and many responses are rooted in Inuit knowledge and wisdom regarding climate and environmental change and health. Inuit have a holistic view of health, in which physical, mental, and spiritual well-being are considered together and as interconnected with the natural environment (Wenzel, 1981; King et al., 2009; Kral et al., 2011; Jasiuk, 2016). Effective responses to the health effects of climate change will involve a holistic view of health, in which climate change is considered in the broader context of the multiple factors affecting Inuit health (Ford et al., 2014b; Jasiuk, 2016).

Notably, adaptations to the health effects of climate change are unlikely to be undertaken for climate change risks alone but are more likely to be made in response to existing health concerns and underlying factors. Supporting efforts that enhance health and local capacity to manage health risks will often inadvertently enhance Inuit capacity to deal with current and expected future climate-related health risks (Pearce et al., 2010; Ford et al., 2014b). For example, supporting the transmission of environmental knowledge and land skills to younger generations is not only about sharing hunting skills; it also encompasses many of the teachings needed to survive in a modern world: patience, forbearance, observational skills, control over physical reactions and emotions, the ability to maintain self-control under pressure and overcome adversity, and the ability to develop and efficiently execute strategy (Pearce et al., 2011). These teachings help prepare younger Inuit to cope with and adapt to the climate risks that affect travel and hunting on the land, sea, and ice, and provide them with the opportunity to engage in productive activities that continue to have economic and social value, while simultaneously enhancing physical, mental, emotional, and spiritual health and well-being (Pearce et al., 2015).

Additionally, health systems and health services across the North need to adapt, continuing to shift to provide locally appropriate and culturally relevant health supports that are responsive to and premised on Inuit-identified attributes of wellness, including land-based programming, community freezers to support country food intake, intergenerational learning opportunities, the teaching of cultural skills, and enhanced and integrated health and environmental monitoring and response. Adaptation will also necessitate that health planning at all scales considers the potential impacts of climate change, which has the potential to compromise existing policies and programming and to create new risks; there is limited evidence that this type of health planning is being achieved at present (Furgal and Sequin, 2006; Ebi and Semenza, 2008; Ford et al., 2014b). Efforts to identify and examine future health risks in light of climatic and socio-economic change can help in this process (Ford et al., 2014b; ITK, 2014).

The issues described here for Canada also apply in both Alaska and Chukotka. The following two sections focus on additional issues that have been well documented and are particularly critical in these regions: health planning and wind-related allergies in Alaska and environmental contaminants in Russia.

### 7.2.1.3 Human health adaptation in Alaska

Researchers from the Institute of Circumpolar Health Studies at the University of Alaska Anchorage, in collaboration with researchers from the Alaska Native Tribal Health Consortium and the University of Alaska Fairbanks, recently sought to implement the BRACE framework (Figure 7.3) in Alaska. Due to the paucity of public health data on health outcomes from the environmental effects of climate change in the BCB region, these researchers conducted the first three steps of the BRACE framework by collecting surveillance data on local health outcomes and risk factors associated with climate change in the Chukchi Sea coastal communities of Kivalina and Noatak and the city of Point Hope. Study investigators worked with local residents to develop a sentinel surveillance survey of the likely environmental effects of climate change in their areas. Community residents then completed monthly structured surveys of local environmental events and the health impacts of these events in two year-long periods: from May 2010 to May 2011 and from May 2013 to May 2014.

Allergic asthma and pollen allergy symptoms were the most frequently mentioned adverse health outcomes among surveyed residents of these communities, followed by frostbite and other cold-related injuries. Participants described air quality as poor most often in the spring and summer due to windblown dust and pollen. While thermal inversions in autumn and winter can lead to poor air quality from wood smoke in some locations, this phenomenon was not mentioned by study participants as causing local concern. During community meetings, residents connected the prevalence of asthma and other respiratory illnesses to the dusty air. Unintentional injuries were 2.8 times more likely during months in which environmental conditions were perceived as different than expected for that time of year, and 4.5 times more likely in months when community members changed travel plans due to unusual environmental conditions such as warmer-than-average temperatures. Certain types of injury were more likely to occur only in months when travel plans needed to be changed due to unusual weather: hypothermia and frostbite were 3.5 times more likely and mortality was 3.7 times more likely.

These findings can inform implementation of the final two steps of the BRACE framework outlined in Figure 7.3. First, based on these findings, residents assessed their capacity to develop and implement adaptations to reduce vulnerability to these adverse health outcomes, and then they assessed their vulnerability to adverse health outcomes in light of this capacity. In community hearings with researchers, local residents discussed local adaptation strategies they felt could be implemented with current resources. These strategies included dust suppression and improved aeroallergen monitoring and forecasting, as well as the implementation of better disaster and accident response strategies (e.g., early warning of severe storms or unusual weather and improved access to emergency locator beacons).

### 7.1.2.4 Human health adaptation in Chukotka

According to a Russian Arctic health survey (AMAP, 2004), the highest concentrations of persistent toxic substances in the blood of Indigenous residents of the northern regions of Russia was measured in Chukotka. Past economic activities in the region resulted in heavy contamination of populated areas with abandoned hazardous wastes. In local villages, a lack of bulk fuel storage infrastructure resulted in the accumulation of thousands of metal drums containing spent oils and other waste products (1950–2000), including persistent toxic substances – in particular, polychlorinated biphenyls (PCBs). Climate change impacts – i.e. increases in air temperature and precipitation – aggravated the problem by destroying the permafrost layer and accelerating corrosion and leakage from old rusted drums and storage tanks scattered along the thawing coastal and inland river areas of Chukotka (see Chapter 5).

There has been a growing concern that contaminated, abandoned drums in Russia present a serious threat to the environment, to wildlife, and to those people who depend on Arctic subsistence food resources. Due to little knowledge about local or regional environmental health impacts of climate change, there was no comprehensive inventory of the drum sites nor a systemic clean-up of contaminated villages until the health risk reduction plan, which was based on AMAP recommendations on adaptive management, was implemented in Chukotka during 2004–2006. Concrete actions were undertaken in the Indigenous villages of Kanchalan and Lorino, including an inventory of drum contents, with estimates of volumes and types of waste (e.g., spent oils, lubricants, paints, insecticides, fuels); collection of the drums; incineration of drum contents; and drum cleaning, compaction, recycling, and disposal. As a result of this program, a monitored cohort of adult men exhibited a significant reduction of serum concentrations of PCBs, the main local contaminant of health concern. In contrast, in a parallel cohort in the village of Lavrentiya, where cleaning operations were carried out to a lesser extent, no significant change in blood serum PCBs was found. Major health effects associated with human exposure to PCBs include toxic, mutagenic, carcinogenic, and hormone disruptive effects, as well as immune system impairments and probably reproductive impairments.

The health risk reduction program implemented in Chukotka has had far-reaching effects in terms of supporting adaptive capacities in the Russian North. This program has been used, for example, as a template for the design of a new national-level model of healthy Arctic communities that takes into account future climate change impacts on Indigenous communities. In addition, a national information network on Indigenous health statistics and web-based consultancy resources is being developed. Priority has been placed on health risk factors and the specification of public health policy and practice needs associated with delivering comprehensive education for professionals working in Arctic Indigenous communities, including increasing the rate of Indigenous graduates nationally awarded a Master of Public Health degree.

## 7.2.2 Rural communities, adaptation, and food security

### 7.2.2.1 Adaptation in northern communities

In rural communities in the Alaskan and Canadian parts of the BCB region, Indigenous peoples constitute about half the local population. These peoples are disproportionately vulnerable to socio-economic and environmental change; however, they also have rich cultural traditions of resilience and adaptation (Trainor et al., 2007; Cochran et al., 2013; Chapin et al., 2014; Larsen et al., 2014b). While adaptations to the cumulative effects of climatic and socio-economic change are occurring at individual, community, tribal, and other institutional levels (Armitage, 2014), the majority of the relatively few peer-reviewed publications analyzing climate adaptation in the Arctic have focused on Indigenous adaptations at individual, household, and community scales (Ford et al., 2014a; Larsen et al., 2014b). In many cases, the people confronted with challenges associated with climate change already face a myriad of other societal and environmental challenges, including issues with clean water and environmental quality, high costs of fuel and supplies, alcoholism and domestic violence, and an increasing incidence of health issues such as diabetes and cancer (Lynch and Brunner, 2007; Ford, 2009; Beaumier and Ford, 2010; Gerlach et al., 2011; Moerlin and Carothers, 2012; ITK, 2014). In some cases, people's actions focus explicitly on climate change; in the majority of cases, however, people are simply continuing to pursue goals such as improving community health, self-reliance, and sustainability – incorporating the new conditions presented by climate change as best they can into ongoing initiatives and visions for the future (ITK, 2016; Loring et al., 2016).

### 7.2.2.2 Individual and household responses and food security

Subsistence hunting and fishing has long been the foundation of Inuit lives and economies. Today, residents of most Arctic communities in all three BCB subregions still rely extensively on wild, country foods, although the means by which these foods are obtained has changed, and people in many communities rely more heavily on store-bought supplies as well (Ford, 2009; Loring and Gerlach, 2009; Egeland et al., 2011). Climate change is affecting the distribution and abundance of wild fish and game populations across the North, and people are responding in various ways – some that may be considered adaptive and some not, although how the benchmark should be set for this determination and by whom is not clear (Loring et al., 2016).

In some cases adjustments are very small, taking the form of changes in where and when people hunt or fish (Gearheard et al., 2006; Loring et al., 2011; Moerlin and Carothers, 2012; Brinkman et al., 2014). This is not a new adaptation but simply the continuation of a long tradition of flexibility and diversity in local food systems. However, some northern residents are constrained in their flexibility by state-imposed policies and changes in land tenure that limit people's options (Loring et al., 2011; McNeeley and Shulski, 2011; Brinkman et al., 2014).


Daniel White

*Salmon drying*

Another change is that many hunters are taking fewer trips, in some cases shorter and in some cases longer, in response to both the high costs of fuel and the changes to game populations that take them farther afield from their communities (Gearheard et al., 2006; Ford and Beaumier, 2011; Brinkman et al., 2014). Hunters on the ocean are also relying more heavily on new technology – buying larger and faster boats, for example, to cope with changes in the extent of sea ice (Gearheard et al., 2006). Some hunters are often hunting for more than one family – these are the so-called 'super-hunters', in whom communities invest support and resources rather than hunting individually. Another way that individuals and households respond to changes in the availability of fish and game is through prey-switching, a long-held adaptation wherein people switch to alternative resources when primary ones are scarce or in decline (Loring and Gerlach, 2010; Hansen et al., 2013). However, people are also increasingly reliant on store-bought foods to supplement or replace country foods, and climate change is clearly one of the many drivers of this 'nutrition transition' (Chapters 4, 5, and 6).

Changing ice and permafrost creates similar impacts and resulting adaptations in Alaska, Canada, and Russia (e.g., Gearheard et al., 2006; Laidler et al., 2009; Huntington et al., 2010; Crate, 2012). In Siberia, for example, Crate (2012) discussed responses by local people who continue to rely on historically based subsistence practices but must do so with increased effort and cost due to the increased amount of fuel and supplies needed to access remote resources. Elsewhere in the Russian North, local experts interviewed from Chukotka Indigenous communities have identified a number of concrete actions taken in response to climate change. For example, the thickness of ice cover on water reservoirs has been steadily declining. The reindeer herders note that their traditional pathways, used for generations, are now becoming more dangerous as the ice is more fragile. In the local villages, the fishers or herders post special signs to warn about the thickness of the ice cover (Sanborn and Hinzman, 2016). More adaptations of local communities in their agricultural practices are expected to take place in the future. This anticipated change can be attributed to increasing climate change impacts on pasture growth, animal breeding, and agricultural crop production (Roshydromet, 2014).

The major concerns of the local Indigenous populations of Chukotka, as noted in interviews conducted for this report, include risks that urgently necessitate adaptations by communities and households in order to ensure food security. These concerns include (1) sharp temperature fluctuations that result in the icing of reindeer herding grounds, causing significant damage or mortality to the animals; (2) severe storms, deteriorating weather conditions, and unpredictability of weather; (3) the spread of new types of insects and wildlife; and (4) a decline in seal populations and seal weight, with many migrating to more northerly areas; seal meat that has acquired a specific unpleasant taste; and the possibility that traditional seal hunting might disappear in the near future as a result of warming (Sanborn and Hinzman, 2016).

Chukchi Indigenous populations have accumulated a great deal of adaptation knowledge that has been applied by several generations. For example, one of the local respondents, a reindeer herder who lived in the village of Neshkan in the eastern part of Chukotka, indicated that the climate there has become milder and more comfortable, which makes tundra herding easier (Sanborn and Hinzman, 2016). About 30 to 40 years ago, winter storms were severe, lasting up to 20 days; there was no visibility; sometimes it was difficult to breathe outdoors; and it was difficult to support the herds (MCNC, 2016). Still, the local people had special means and knowledge to keep reindeer safe, including special preparations made in advance of the upcoming winter storms (e.g., additional insulation, ice storage, rope marks along the roads). Such adaptive-management knowledge could be used broadly under deteriorating weather due to climate change. According to expert evaluations, wind velocity in Chukotka coastal areas, in a mid-term perspective, is projected to increase by 5–10% (Roshydromet, 2014).

#### 7.2.2.3 Community and regional responses

The impacts of climate change on community infrastructure in the North are relatively direct, with coastal erosion, thawing permafrost, and changing hydrology affecting everything from residences to water and wastewater and solid waste management. 'Climigration' (i.e., population movements driven by climate change) is widely anticipated, although current demographic patterns in Alaska do not support this prediction (Hamilton et al., 2014). Some communities are actively pursuing complete relocation due to the significance of ongoing impacts (Bronen, 2011; Marino, 2012), but populations in many 'at risk' communities are still growing (Hamilton et al., 2014). In other communities, responses are more nuanced; increased monitoring of change, both formal (e.g., science-based and data-generating) and informal (e.g., educational, information-sharing networks), is prevalent. The Local Environmental Observer (LEO) program of the Alaska Native Tribal Health Consortium (ANTHC) is an example of the latter, whereby local people from across Alaska have developed a community of practice around the need to monitor, report, and understand change. ANTHC also provides an example of the former (i.e., more formal monitoring) – the group has completed multiple climate change health impact assessments (as of the writing of this report, for 24 Alaskan communities). Yet another example is provided by Alaska's Northwest Arctic Borough, which recently completed a multi-year Subsistence Mapping Project to document local knowledge of important places on the land and sea, as a way to better understand and respond to change.

Finally, some communities and larger groups are responding to these challenges by communicating the impacts they are experiencing to broader national and international audiences. In northern Canada, the 'Feeding My Family' group is using social media and other online venues to highlight issues with food security and climate change.

Figure 7.4, which was produced as an outcome of a series of regional workshops hosted by the Inuit Tapiriit Kanatami in Canada, provides a schematic representation of how changing weather patterns – a key concern associated with changing environmental conditions – affects a range of community members, from elders to youth, in a variety of ways, including food security, health and safety, intergenerational learning of traditional knowledge, and mental and physical health. These various impacts have led to spontaneous adaptations, such as increasing use of GPS, satellite imagery, and Western science and technology for weather forecasting. The graphic also includes other proactive adaptations that can provide opportunities to enhance communication networks and build intentional cross-generational learning and information exchange.

### 7.2.3 Shipping and marine tourism

Circumpolar and national assessments highlight the potential for increased marine transport in the Arctic as a consequence of decreasing sea ice (e.g., ACIA, 2005; US Committee on the Marine Transportation System, 2013; Larsen et al., 2014b). The majority of models project decreased shipping costs along Arctic routes; however, assumptions vary widely and some modelers disagree (Lasserre, 2015). While interest from shipping companies remains, there are many environmental and economic factors that determine the viability of trans-Arctic shipping (Arctic Council, 2011). Ultimately, the feasibility of trans-Arctic shipping will be determined by the global market and may not materialize (Young, 2015).

Increased marine transport would provide opportunities for economic development while also presenting environmental and security risks (Furgal and Prowse, 2008; Warren and Lemmen, 2014; Ford et al., 2016). Given the local experience of increased shipping to date and the potential for environmental and safety risk, regional stakeholders emphasize the following needs to prepare and adjust for potentially increased shipping: government vision, regulations, and enforcement (Dawson et al.,

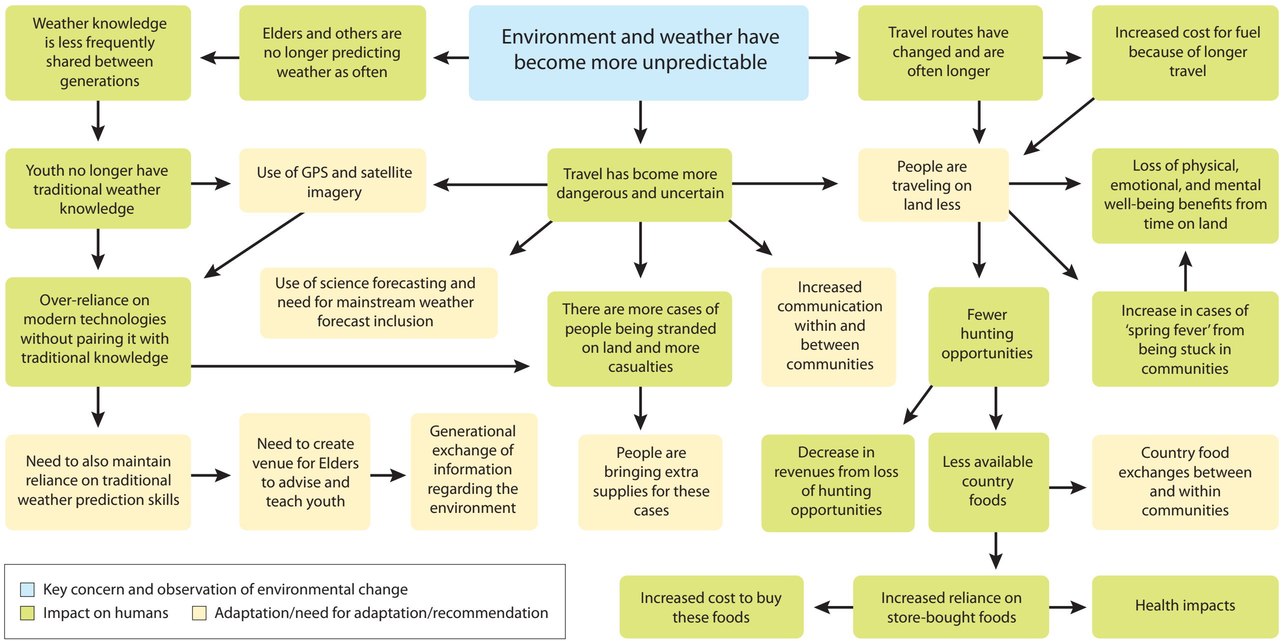

Figure 7.4 Links between increasing unpredictability of weather and human impacts and adaptation among Inuit Nunangat communities in Canada (Nickels et al., 2005).

2014); supporting infrastructure; improved weather and hazard communication warnings and responses; and cross-scale and international coordination and collaboration (Chapter 2). Highlighting the risks is the fact that only about 1% of Canadian Arctic waters are currently surveyed to modern standards (OAG, 2014). The Alaska Center for Climate Assessment and Policy (see Box 7.2) has produced historical sea ice atlases for Alaska and pan-Arctic waters as a reference for past observations of seasonal ice extent and thickness (seaiceatlas.snap.uaf.edu/; Walsh et al., 2015, updated 2016; NSIDC, 2016).

Adaptation approaches in marine transportation frequently involve additional navigation and communications equipment to monitor ice conditions, including IceNav$^{\text{TM}}$ systems, which incorporate advanced marine radar, enhanced target detection radar, and satellite communication technologies for acquiring ice charts. SmartICE (Sea-ice Monitoring and Real-Time Information for Coastal Environments) is a new initiative designed to address potential conflicts where traditional Inuit and marine shipping routes overlap and to assist safe and efficient winter travel for both sets of users. SmartICE utilizes in situ sensors, remote sensing data, and traditional Inuit knowledge to generate processed digital products customized to the needs of various users (Bell et al., 2014; Nain Research Centre, 2015).

In Canada, priority adaptation needs for Arctic shipping include modern hydrographic surveys and the production of nautical charts, deployment and maintenance of navigational aids, enhanced provision of weather and ice information and ice-breaking services, and surveillance and monitoring of marine traffic and spills (OAG, 2014).

In the United States, the US Coast Guard has conducted risk assessments, regional planning, and training exercises in Alaska (Trainor et al., 2017), and similar activities are occurring in Canada (see Chapter 2). The Government of Canada, through Transport Canada, the Canadian Coast Guard, and the Canadian Hydrographic Service, in consultation with other federal organizations, recently began working on the Northern Marine Transportation Corridors Initiative (Dawson et al., 2016). This initiative is a first step toward focusing and coordinating resources in the development of safe and efficient marine transportation corridors in the Arctic. The planning phase will end in 2017, with a multi-year operational plan to be put in place in 2018. Chart development and production will start immediately after the completion of each field survey.

The Sustainable Model for Arctic Regional Tourism (SMART) project set forward a strategy for sustainable tourism in the Arctic (Vaarala, 2006). The Protection of the Arctic Marine Environment (PAME) Arctic Marine Tourism Project (AMTP), formerly named the Arctic Shipborne Tourism Initiative, was part of an ongoing effort by the Arctic Council to analyze and promote sustainable tourism across the circumpolar Arctic (PAME, 2015). For the BCB region, sustainable tourism is relevant as an economic approach that can include an understanding of climate impacts and can incorporate both low-carbon measures and a transition away from non-renewable resource extractive economies. Sustainable tourism is also consistent with the Inuit expectation for a just and reasonable transition to a low-carbon economy, as described in the 2016 Inuit Tapiriit Kanatami report, *Inuit Priorities for Canada's Climate Strategies* (ITK, 2016).

Regional governments in the BCB region are also interested in sustainable Arctic tourism. The Sustainable Arctic Tourism Association includes the participation and support of the State of Alaska, the Northwest Territories, and the territory of Nunavut, who also collaborated in the design of tourism principles, guidelines, and best practices under the SMART project. In 2016, the Mackenzie Delta, in Yukon and the Northwest Territories and including adjacent coastal and marine regions, was recognized as one of the 2016 Top 100 Sustainable Destinations in the world by Green Destinations, in part due to ecosystem-based adaptive management processes (Green Destinations, 2016; Salman, 2016).

**Box 7.2 Examples of boundary organizations that support the knowledge-to-adaptation-action process**

*United States Forest Service, workshop held in 2009*

*Alaska Center for Climate Assessment and Policy (ACCAP), University of Alaska, Fairbanks, United States.* Funded by the US National Oceanic and Atmospheric Administration (NOAA) since 2006 as one of ten Regional Integrated Sciences and Assessment (RISA) programs, ACCAP is a boundary organization with the mission of improving the ability of Alaskans to respond to a changing climate. ACCAP works directly with communities to build community-based adaptation plans and conducts relevant use-inspired climate and social science, partnering directly with tribal, local, state, and federal organizations and agencies to bring science to bear in solving problems. Key foci are building climate adaptation capacity in coastal communities and conducting research on societal impacts of extreme events.

*Alaska Fire Science Consortium (AFSC), University of Alaska, Fairbanks, United States.* The primary purpose of the AFSC is to strengthen the link between fire science research and on-the-ground application in Alaska by promoting communication between managers and scientists, providing an organized fire science delivery platform, and facilitating collaborative scientist–manager research development. Funded by the federal interagency Joint Fire Science Program as part of their network of regional knowledge exchanges, the AFSC has been building relationships and conducting knowledge exchange activities between scientists and managers in Alaska since 2010.

*Alaska Native Science Commission (ANSC), United States.* Established in 1994, the ANSC works to create partnerships between scientific researchers and Native communities by providing referral and networking support. The commission also serves as a clearinghouse, information base, and archive for proposed, current, and past research. Core issue areas include avian bird flu, Arctic contaminants, climate change, subsistence and traditional foods harvest and sustainability, traditional knowledge, and snow change.

*ArcticNet, Université Laval, Quebec City, Canada.* With a focus on the study of climate change impacts in the coastal Canadian Arctic, ArcticNet builds partnerships between scientists in natural, human health, and social sciences and diverse stakeholders, including Inuit organizations, communities, federal and provincial agencies, and the private sector. The goal is to create partnership in science and in building a network of Canadian Centres of Excellence.

*Cold Climate Housing Research Center (CCHRC), Fairbanks, Alaska, United States.* Conceived and developed by members of the Alaska State Home Building Association, the CCHRC is an industry-based nonprofit corporation that develops and tests energy-efficient, durable, healthy, and cost-effective building technologies, with a focus on the circumpolar region. The center brings together innovation in engineering and building to meet the needs of northern communities.

*Community Partnerships for Self-Reliance (CPS), University of Alaska, Fairbanks, United States.* The CPS is a capacity-building boundary organization whose mission is to enhance collaboration between university researchers and Alaska communities in order to address community-identified research priorities related to self-reliance and sustainability. CPS connects local Indigenous knowledge and community information needs with university scientists conducting relevant research, thereby fostering use-inspired science. Leveraged with funding from the National Science Foundation (NSF) and the National Aeronautics and Space Administration (NASA) and focusing on the integrated factors of climate, energy, economics, environmental change, policy, and subsistence practices, this program works closely with rural Indigenous communities in Alaska to bridge top-down and bottom-up adaptation planning (Chapin et al., 2016).

*Northern Climate ExChange (NCE), Yukon College, Whitehorse, Yukon, Canada.* Situated within the Yukon Research Centre at Yukon College, the NCE focuses on the study of climate change in Yukon and the North. It provides a credible, independent source of information, develops shared understanding, promotes action, and coordinates research on climate change in Yukon and across northern Canada. The NCE promotes and coordinates research on impacts and adaptations (including risk and vulnerability assessments), coordinates the exchange of scientific and local knowledge and expertise, and provides mainstreaming and decision-making support, policy alternatives, and climate change education for a wide range of partners and audiences. The NCE works with federal, territorial, municipal, and First Nations governments, along with academic institutions, industry, and communities to respond to northern needs. The NCE recognizes that community participation in research and decision-making is essential to long-term resource, environmental, and cultural sustainability in the North. Its work emphasizes the collection of local and scientific knowledge and expertise in order to reflect northern perspectives, priorities, and needs. The NCE also runs the Climate Change Information and Mainstreaming Program, through a partnership with Government of Yukon's Climate Change Secretariat, and teaches a *Decision Making for Climate Change* course to assist with mainstreaming climate change into government decision-making.

Huntington et al. (2015) noted the work of the Arctic Waterways Safety Committee to protect communities and the environment and to create a safe and attractive environment for the shipping industry. Highlighting that strong regional and national governance is mutually beneficial to local communities and the shipping industry, the authors recommended ways to reduce risks potentially associated with increased marine traffic in the BCB region, including improved charting, the establishment of designated shipping routes, the delineation of areas to be avoided, and the adoption of speed restrictions. Additional recommended regulatory needs include: a suite of regulatory and governance measures to address all shipping-related risks and threats, implementation and enforcement of these measures, international communication and collaboration, and forethought and cooperation at the outset of increased shipping in the region (Huntington et al., 2015).

The Arctic Council's *Status on Implementation of the AMSA 2009 Report Recommendations* (2011, 2015) noted these additional recommendations as presented in the original Arctic Marine Shipping Assessment report (PAME, 2009): include all relevant stakeholders in decision-making, increase communication and international linkages, engage the International Maritime Organization, approve the Polar Code (the Polar Code entered into force in January 2017), ensure uniformity of governance across the region, strengthen safety and search and rescue capacity, and survey local and Indigenous use. The first two Arctic Council recommendations fit with the general recommendations in Section 7.3.1; the remaining items are specific to shipping and maritime safety.

### 7.2.4 Resource development in hydrocarbons, mining, and infrastructure

Similar to trans-Arctic shipping, resource development in the Arctic is driven in large part by global markets (Poussenkova, 2011; Young, 2015). Natural resources, including mining and energy resources, are seen as a major component of economic development in Arctic Canada (Government of Canada, 2009; Government of the Northwest Territories, 2015), and in Arctic Russia they are regarded as focal points for future economic growth and sustainable development of the northern regions (RF Ministry of Energy, 2016). As with most development initiatives, resource development presents both economic opportunities for Arctic communities and increased risks to the environment and traditional livelihoods (Cameron, 2012). To date, adaptation has generally not been given a high profile in the mining and oil and gas sectors in Canada (Ford et al., 2010a, 2011). However, Dell and Pasteris (2010) have conducted an assessment of vulnerability in Alaska and they present recommended adaptation actions. The fact that these industries already work in a wide range of climate extremes likely makes them reasonably resilient to projected climate changes (Lemmen et al., 2014). Barriers to progress on adaptation that have been cited in the literature include limited awareness of the potential scope, scale, and business relevance of climate change impacts, as well as uncertainties regarding climate projections (NRTEE, 2012; Navius Research, 2013). Regulations are seen as a key mechanism to advance adaptation in Canada's North (Navius Research, 2013). In addition, environmental assessment and public risk disclosure are emerging as key processes to encourage adaptation action in the natural resource sectors, especially in the North (Lemmen et al., 2014). There is also a need for updated and strengthened guidance on how climate change impacts and adaptation issues can be integrated into the environmental assessment process (e.g., EIRB, 2011; Navius Research, 2013). Initiatives such as CDP (formerly the Carbon Disclosure Project), which includes material risks related to climate impacts, inform investors on how publicly traded companies evaluate and manage risks from climate change.

Adaptation in the mining sector is needed both for designing new facilities and for undertaking remedial work at existing mines and post-operational mines to ensure structural integrity of infrastructure in light of changing climate and permafrost conditions. Technical guidance for this type of analysis is provided by Auld et al. (2010). Particular importance needs to be placed on waste containment facilities that must function for decades beyond the operational life of a mine (Ford et al., 2016). Failure of frozen-core dams on tailings ponds at some sites has already resulted in contaminants being released into the environment (Stratos, 2011). Examples of engineering solutions to protect infrastructure from permafrost degradation include the use of deeper pile foundations, thicker gravel pads, adjustable foundations, artificial cooling (e.g., through the use of thermosyphons), clearance of snow from around foundations, and modification of tailings covers to ensure that below-ground materials stay frozen (Pearce et al., 2011; Prowse et al., 2009). Monitoring the performance of engineering measures is a critical aspect of effective adaptation (Lemmen et al., 2014). Adaptation in northern mines also includes enhancing resilience through the use of locally derived renewable energy, such as the use of wind turbines for the Diavik diamond mine project in the Northwest Territories (Muir, 2012).

For oil and gas exploration, some of the most significant impacts may be related to the use of in-ground sumps for drilling wastes, especially where these sumps rely on the presence of permafrost to prevent subsurface movement of contaminants (Prowse et al., 2009). Comparatively little information is available regarding adaptation of offshore operations, with the general expectation that engineering solutions will dominate as infrastructure design is modified on the basis of projected climate conditions (Stantec Consulting, 2013). Most existing regulations, guidelines, and best practices for the Beaufort Sea region do not take climate change impacts into consideration (Stantec Consulting, 2013).

The application of climate-risk screening tools represents an important step for informing infrastructure investment, whether it is in the design of new infrastructure or the making of adaptive modifications to the design, operation, or maintenance of existing facilities (e.g., Prowse et al., 2009; Andrey et al., 2014). One example is the Public Infrastructure Engineering Vulnerability Committee (PIEVC) Engineering Protocol (Engineers Canada, 2013), which incorporates both historical climate information and projected future climate changes to estimate the severity of climate impacts on infrastructure components and identify those elements at higher risk. The protocol, which involves a five-step procedure supported by worksheets, has been successfully applied in more than 40 case studies across Canada. These case studies include an assessment of the suitability of flat loop thermosyphon foundations for a 50-year life-span building on warm permafrost (Holubec, 2008), which involved site analysis of three large buildings in Inuvik, NWT. The protocol has also been applied to transportation infrastructure (all-season roads and winter roads) and mining infrastructure in Arctic sites outside of the BCB region (Engineers Canada, 2016).

### 7.2.5 Wildfire

The combined effects of increasing wildfire risks in the circumboreal and Arctic tundra regions (Chapter 5) will significantly challenge existing fire management and suppression institutions in the BCB region. Tundra communities are unaccustomed to anticipating and responding to wildfire risks. This lack of familiarity creates additional challenges for fire and risk management (McCaffrey et al., 2015).

Scientific research on tundra fire in the BCB region is increasing, although significant gaps in knowledge exist (IARPC, 2014; French et al., 2015). These gaps include the need for better observations of weather and long-term weather patterns, characterization of tundra fuel loading and seasonal fuel moisture trends, and assessment of fire effects on wildlife (IARPC, 2014). Researching and monitoring of tundra and forest response after fire disturbance and the development of measures to reduce fire impacts have been identified as priority areas in Alaska, along with expanded modeling of wildland fire, fuel, and smoke and coordination of wildland fire policies with Canadian counterparts (Alaska Department of Environmental Conservation, 2010). Interdisciplinary assessment of current and future fire regimes and the development of innovative new management regimes have also been suggested as areas of research (Shvidenko and Schepaschenko, 2013). Filling these research gaps will be an important precursor to both long- and short-term adaptation actions in wildfire management, suppression, and risk reduction in the BCB region.

Evidence is increasing to demonstrate how fire management activities influence wildfire incidence in combination with climatic factors. For example, Calef et al. (2015) document an overall decrease in area burned in Alaska's boreal forest in areas of high suppression since the late 1980s. However, the rate of increase in area burned over that same time period has increased more rapidly in areas of suppression relative to areas of non-suppression (Calef et al., 2015).

Owing to remote location, lack of access to resources, and dispersed institutional connections, isolated rural communities in the boreal region are more sensitive to increasing incidence of wildfire than are centralized urban areas, especially in combination with other socio-economic stressors (Trainor et al., 2009a). Key features affecting a community's capacity to adapt to increasing wildfire risk include communication and institutional links with fire management, community leadership and organizational capacity, regional networks, and access to both resources and information (Trainor et al., 2009a; Newman et al., 2014).

In Russia, recommendations for adaptation in boreal forest management include: managing for identified forest risks, expanding infrastructure and transportation systems to take commercial advantage of projected expanded boreal forest, alternative processing of forest and non-forest timber products, artificial forestation, and innovative silviculture techniques (Krankina et al., 1997). It has been recommended that fire risk management should account for climate change, increasing human risk factors, and state politics in forestry (Ponomarev et al., 2015).

Recommendations for wildfire risk reduction throughout Alaska include: increasing the capacity of communities to initiate, complete, and implement Community Wildfire Protection Plans (CWPPs); reviewing selected wildland fire management practices; and developing a comprehensive fuels management program to treat high-risk areas (Alaska Department of Environmental Conservation, 2010). Statewide wildfire planning in Alaska explicitly acknowledges increasing wildfire risks from climate warming (State of Alaska, 2010). In 2009, the statutory start of the wildfire season was moved from the first day of May to the first day of April, in order to increase preparedness for more frequent early-season fires. In more recent years, efforts have increased to create and implement community wildfire protection plans and increase fire suppression capacity by initiating advanced firefighting training opportunities (Trainor et al., 2017).

International communication, collaboration, and networking regarding wildfire risk and adaptive measures can help build adaptive capacity throughout the BCB region (Volokitina et al., 2008; Trainor et al., 2009a; Alaska Department of Environmental Conservation, 2010; Shvidenko and Schepaschenko, 2013).

### 7.2.6 Governance, institutional adaptation, and cross-scale interactions

Given the dynamic regional environmental and socio-economic conditions, Arctic governance systems will need to remain flexible and adaptive to meet future challenges (Young, 2015). Environmental, economic, social, and political drivers of change in the Arctic are closely interlinked, and adaptation in the region will be influenced by global markets and politics. It will also be necessary for non-Arctic institutions with interests in the region to engage in adaptation and take responsibility for the future of the region while remaining sensitive to the priorities and concerns of Arctic residents (Young, 2015). Place-based, regional adaptations, as described in this chapter, and Arctic Council activities can be supplemented by institutional initiatives including global agreements, public–private partnerships, and informal venues (Young, 2015).

It is clear that governance structures play a key role in adaptation. Indeed, successful adaptation may require flexibility or evolution in these structures. Governance systems currently in place in the BCB region vary substantially from one country to another, and aspects of these governance structures are changing. The roles and capacities for governance to guide and implement successful adaptation will vary within subregions of the BCB. One aspect is the result of shifting internal processes and actors, such as the ongoing decentralization of responsibilities from federal to regional levels of government in Canada and Russia. Another aspect is the evolution of new actors and regulatory frameworks as a result of negotiation and implementation of northern land claims and self-government agreements in northern Canada and the evolving development of the Inuit Nunangat, or the

Inuit homeland in Canada (ICC Canada, 2016). Governance is also changing on a regional, national, and local basis as a result of the recognized need to ensure sustainable development in the BCB region in the face of changing climate and changing socio-economic conditions. All of these changes in governance will be important elements of adaptation in the region.

### 7.2.6.1 Chukotka

Arctic change has consequences for the governance and institutional frameworks of Chukotka. Such change affects strategic planning and regional sustainable development agendas. During the last two decades, there have been serious reforms in governance systems to deal with environmental and climate change risks; these reforms have resulted from recent changes in the governance of Chukotka, in a course of decentralization and enactment of the federal model in Russia. As a part of the new policies, many functions and competences in environmental, climate change, and natural resource management were transferred from the federal level to the regional and local governments of Chukotka (Chapter 3).

Following the 'standard' design of regional institutional structures throughout Russia, Chukotka has regional affiliations with major domestic bodies dealing with environmental and climate issues. For example, the Chukotka Committee of Natural Resources is a territorial organ of the federal environmental ministry, and it has a full range of competences to perform its functions within the territory in environmental and natural resources management and coordination with other executive authorities. Prevention, reduction, or adaptation to natural disaster risks have become an integral part of Chukotka regional sustainable development strategies. Subdivisions of EMERCOM (the lead emergency management authority in Russia) were created in the municipalities of Chukotka in 2005 with the goal of providing services in forecasting and operational emergency response. The Center for Monitoring and Assessment is responsible for regular operational data processing and emergency forecast of fires, floods, avalanches, and other natural disasters. The network of hydro-monitoring sites has been consolidated, special schemes for operational management of freshet water flows have been developed, and rescue groups of professionals have been organized; detailed maps of the distribution of maximum snow storage across the region are regularly updated.

Recently, a set of regional government programs[2] covering certain aspects of climate change risk management was adopted by Chukotka (CAO Government, 2016). The programs, which contain detailed provisions for short-term strategic planning and action plans, are an element in regional adaptive capacity building. However, regional programming and planning in Chukotka faces the same challenges typical of other circumpolar regions – lack of fiscal resources to cover multiple programs and services for which the local governments are responsible, as well as challenges related to the deficit of infrastructure to ensure operational services.

### 7.2.6.2 Canada

In northern Canada, adaptation planning and implementation for climate change is occurring at federal and territorial governmental levels as well as within communities. For example, territorial collaboration is underway with the Pan-Territorial Adaptation Partnership, and communities and First Nations are creating adaptation plans. Despite key knowledge gaps and limited technical and financial resources, it is felt that the management structures and policy and regulatory frameworks needed to advance adaptation already exist (Cobb et al., 2008).

Three initiatives, frameworks, and concepts are particularly relevant to ecosystem-based adaptation for that part of Canada within the BCB region. The first is the Beaufort Sea Large Ocean Management Area (LOMA). The second is the Mackenzie River watershed (ecosystem-defined), the Mackenzie Valley (defined under land claims and limited to Northwest Territories), and the Mackenzie River Basin Board (whose jurisdiction extends outside the northern Canadian territories to include more southern provinces). The third is the Nunavut Marine Council, as defined under the Nunavut Final Agreement and only recently formed.

The Beaufort Sea LOMA is the most advanced of the three and is very important for environmental measures and ecosystem-based management, including climate adaptation; this priority area was established in part with this adaptive intent in mind for the Inuvialuit Settlement Region (Cobb et al., 2008). The Beaufort Sea LOMA has legal and political designation but was designed with Inuvialuit, Inuit (Nunavut), and Gwich'in First Nation (Mackenzie Valley) participation. Research was implemented under Inuvialuit processes and structures such as the Fisheries Joint Management Committee and the Inuvialuit Game Council (Cobb et al., 2008).

### 7.2.6.3 Alaska

In 2007, the State of Alaska began a major effort to assess its vulnerabilities to climate change and develop adaptation options. Then-governor Sarah Palin established the Alaska Climate Change Sub-Cabinet (climatechange.alaska.gov), with responsibility for developing adaptation and mitigation options for the state (Governor Palin, 2007). Advisory and technical workgroups, comprising a broad cross-section of Alaskans, made crosscutting recommendations, including: establishment of a 'knowledge network' to facilitate the public's access to climate information; enhanced coordination among government agencies, including the designation of a single government entity with responsibility to coordinate and prioritize adaptation work; and inclusion of climate change science curriculum in Alaska's schools (Alaska Adaptation Advisory Group, Appendix I, September 2009; climatechange.alaska.gov/aag/aag.htm). These recommendations emphasized the need for federal and state agencies and institutions to take responsibility and show leadership in helping their communities adapt to physical, biological, economic, and social changes in Alaska relating to climate change. To date, however, these recommendations have not been enacted.

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[2] These programs include, among others, Forestry Development in CAO 2014–2018, Prevention of Extreme Natural and Technological Disasters and Enhancing Fire Safety in CAO 2015–2019, Development of Healthcare in CAO 2014–2020, Transport Infrastructure Development in CAO 2014–2018, Development of Agro-industrial Complex in CAO 2014–2018, and Support for the Russian Nation Consolidation and Ethno-cultural Development in CAO 2014–2020.


Photo by Andrew Burton/Getty Images

*The Alaskan community of Newtok is one of several vulnerable Alaskan communities in need of relocation*

The sub-cabinet also formed the Immediate Action Workgroup (IAWG) in autumn 2007 to assess vulnerabilities and develop the action plan for communities identified to be in imminent danger from flooding and coastal erosion, due in part to climate change: Kivalina, Koyukuk, Newtok, and Shishmaref (US Government Accountability Office, 2003). These communities face two options: relocate the village, or stay and 'protect in place.' A 2009 IAWG report included the following projects that had been completed, begun, or for which funding was being secured to help these villages and others at risk (IAWG, 2009). These accomplishments fall into four categories:

1. Working with at-risk communities to develop or update local emergency plans (primarily to deal with extraordinary flooding risks) and to conduct training and drills on those plans.
2. Constructing rock revetments in Kivalina and Shishmaref to provide temporary protection from erosion while more permanent solutions are explored.
3. Conducting design and planning work, along with securing funding for a barge and landing site needed to completely relocate the village of Newtok to Mertarvik, a safer location about 12 miles away by river.
4. Planning, engineering, and other preliminary work to either protect in place or move infrastructure to a safer relocation by road (Unalakleet and Shaktoolik).

No at-risk communities have the same needs or are at the same point in the process of vulnerability assessment, identification of erosion and flood risk, consideration of options, and implementation.

To assist communities, the Alaska Department of Commerce, Community, and Economic Development established the Alaska Climate Change Impact Mitigation Program (ACCIMP), which provides funding and technical assistance for science-based community hazard assessments and recommended options to address impacts. The ACCIMP assists in pursuing one or more of these recommended options. For example, if a recommendation coming out of the hazard assessment is to relocate, the ACCIMP could provide a Community Planning Grant to help the community develop criteria for the selection of a new village site (e.g., good drinking water source, barge landing site, sufficient developable land) and plan for the move itself. More information about the ACCIMP can be found on the department's website. Specific recommendations by the IAWG for additional work are outlined in Box 7.1. These recommendations may be helpful as governments continue to address immediate threats from coastal erosion.

### 7.2.6.4 Cross-scale interactions

The stakeholder perspectives presented in Chapter 2 emphasize the need to better address cross-scale interactions and international cooperation (Canada, United States, Russia, other Arctic countries, and China). Adaptation decisions are made and adaptive actions are taken across a spectrum of organizational scales. International agreements can be implemented on an Arctic-wide scale; national governments can institute adaptation policy and planning; and regional governments (i.e., territories, provinces, states, and prefectures) can facilitate, mandate, or support adaptation, as can governments on smaller scales, including tribal and municipal governments. For example, the implementation of Inuit Nunangat agreements and comprehensive land claims agreements and their joint Indigenous-government institutions of public government in northern Canada are creating new frameworks and mechanisms for adaptation action.

Communication, collaboration, and partnership across scales and levels of governance and decision-making is an important way to facilitate adaptation and build adaptive capacity. This is true whether starting at the local level (bottom up) or at larger national or international levels (top down); see also the discussion in Section 7.3.6.3 regarding the role of boundary organizations and governance (Cash et al., 2006a; Wilbanks, 2007; Chapin et al., 2016). In cases such as vulnerable Alaskan coastal communities in need of relocation, for example, it has been imperative to fully engage local tribal governments, state agencies, and federal agencies (Community of Newtok and the Newtok Planning Group, 2011). Similarly, national-level initiatives, such as infrastructure development for trans-Arctic shipping or offshore resource development, need to engage local knowledge and priorities (Clement et al., 2013). In addition to governmental policy, regulation, and resource management, other entities (e.g., industry representatives, trade organizations, civil society, research scientists) can also be actors in adapting to changing environmental and social conditions (Knapp and Trainor, 2013). More research is needed across scales and on the engagement of changing economic opportunities through shipping and resource development in addition to impacts on traditional and local Indigenous practices (Cameron, 2012).

## 7.3 Principles, mechanisms, and tools for promoting adaptation

This section aims to provide practical guidance for planning and implementing adaptation in the BCB region. The term 'decision-maker' is used to refer to any individual or organization faced with planning, developing, or implementing adaptation. The section begins with a summary of principles of successful adaptation, followed by an overview of overcoming barriers and limitations to adaptation. Overcoming barriers may necessitate transformative adaptation, and this is also discussed. Existing adaptation guidebooks relevant to the region are reviewed and summarized. This is followed by an overview of literature on evaluating adaptation actions and identified knowledge gaps.

A growing body of literature documents the need to explicitly and comprehensively bridge the realms of science and decision-making and investigates the effectiveness of this process, sometimes known as co-production of knowledge or use-inspired science in the context of adapting to change. This section reviews this literature with specific application to adaptation in the BCB region. The uncertainties inherent in scientific models of future conditions can confuse decision-makers and stall adaptation decisions. A discussion is therefore provided on these uncertainties and how they can be managed in the adaptation decision process, followed by a brief discussion of addressing extreme events. An in-depth review of the process of bringing scientific knowledge to bear on adaptation decisions in the BCB region, including a summary of suggestions from the literature is also given.

### 7.3.1 Principles of successful adaptation

There is no 'one-size-fits-all' solution for adaptation across sectors or geographic subregions in the BCB region (Larsen et al., 2014b; Mimura et al., 2014). Adaptation will require case-specific consideration of contextual and interconnected environmental, cultural, social, and economic conditions. There are, however, some basic principles for building adaptive capacity and maximizing the chance of success of adaptive actions.

*Cross-scale coordination, integration of local knowledge, and partnership with local and Indigenous communities.* Adaptation to regional environmental and socio-economic change will require coordination, knowledge sharing, and collaboration across scales from the individual to the community, borough or prefecture, state or territory, and national levels (Eriksen et al., 2011; Knapp and Trainor, 2013; Mimura et al., 2014). Higher levels of government play critical roles in establishing legal, regulatory, and policy frameworks; protecting vulnerable groups; and providing funding. Collaboration at the local level is essential to ensure relevance, feasibility, and broad stakeholder engagement (Mimura et al., 2014) (see Box 7.1 for an example of cross-scale coordination in Alaska). Integrating local knowledge is vital for ensuring that adaptations meet local needs and priorities (Eriksen et al., 2011; Aslaksen et al., 2012; Armitage, 2014; Blair et al., 2014; Pearce et al., 2015; Lamers et al., 2016) (see Section 7.2.6.3 for an example related to coastal erosion hazards and village relocation in Alaska). To assist local communities in adaptation, scientists, managers, and decision-makers will need to engage communities in designing adaptation solutions that directly assist in achieving their self-identified adaptation goals, challenge historically entrenched inequalities, and engage in mutually respectful partnership with Indigenous peoples (Cameron, 2012; Cochran et al., 2013; Knapp and Trainor, 2013).

*Networking and information sharing that recognizes differing values and priorities.* It is especially important in the BCB region to create an environment of mutual respect for multiple ways of knowing, to promote partnerships that foster solutions from both Western and Indigenous perspectives, and to foster regional and international networking to share solutions (Cochran et al., 2013). It is particularly important for knowledge exchange to occur. This exchange includes enhanced communication and partnerships between scientists and local communities, as well as among scientists, among communities, and across government bodies at multiple levels (Knapp and Trainor, 2013; Newman et al., 2014; Chapin et al., 2016). Analysis of self-reported existing adaptation occurring Arctic-wide underscores the importance of partnership and cooperation in successful adaptation. This includes partnership internationally across government entities, among scientists, and between Western scientists and local holders of traditional knowledge (Arctic Council, 2013) (Chapter 2). The ArcticNet climate science network in Canada provides a long-standing example of just such a partnership (see Section 7.3.6). Successful information-sharing for building adaptation solutions will require acknowledging differing values and priorities in the adaptation process (Eriksen et al., 2011; Aslaksen et al., 2012; Armitage, 2014). One example from the Barents Region includes youth and innovative video technology to build information exchange (Pearce et al., 2015).

*Consideration of short-term disaster risk management together with longer-term structural policy.* With the rate and projected magnitude of climate-related environmental change combined with stressors of socio-economic change in the BCB region, there is a need to simultaneously consider and plan for short- and long-term change (Fankhauser et al., 1999; Horton et al., 2011). One way to approach this need is through a two-tiered strategy that coordinates actions to simultaneously address immediate disaster risk management and build integrated long-term adaptive capacity (Lemos et al., 2007). This approach includes establishing policy that builds mechanisms for incorporating local risk perception, for establishing co-management and cross-scale interactions, and for correcting inequalities that can be the root of local vulnerabilities (Lemos et al., 2007; Armitage, 2014; Blair et al., 2014). This approach can help to both build adaptive capacity and reduce the likelihood of maladaptation (Section 7.1.5). It is important to view adaptation as an iterative, ongoing process that involves assessment and redirection as

*Bulldozer on beach attempting to build levees against an approaching storm, Utqiagvik, Alaska*

needed (see Figure 7.2 and Sections 7.3.3 and 7.3.6). This will make it possible to address immediate disaster risk management together with longer-term policy strategizing (see Section 7.2.6 and Box 7.1, for an example of addressing immediate disaster risk management).

*Recognition of the larger context, including multiple stressors and cumulative effects.* As this report emphasizes, the BCB region is subject to both environmental and social drivers of change, which work together to create both opportunities and challenges to adaptation. The larger context of adaptation actions and these multiple stressors needs to be recognized in order to take advantage of assets and synergies as well as to avoid maladaptation and potential barriers (Eriksen et al., 2011) (see also Section 7.3.2). Recommendations for mainstreaming climate adaptation into other planning efforts and for integrating responses to multiple drivers have been suggested, but challenges remain in cross-scale integration of implementation (Bierbaum et al., 2013; Mimura et al., 2014).

*Engagement of an adaptive, co-management governance framework.* Due to changing conditions, feedbacks, and the complexity of the system of drivers and potential responses, adaptation practice should include a process for monitoring, assessing, and revising action as needed (see Figure 7.2 and Sections 7.3.3 and 7.3.4.). This is especially true in vulnerable coastal communities (Armitage, 2014; Bronen, 2015).

### 7.3.2 Overcoming barriers and limitations to adaptation and system transformation

Given the rate and impacts of change in the BCB region, there are ample instances in which households, communities, and organizations can adapt to changing climatic conditions (Trainor et al., 2009a; State of Alaska, 2011; Klein et al., 2014; Ford et al., 2014b, 2016). However, adaptation barriers can hamper opportunities presented by climate change and impede implementation of adaptation options that could potentially be effective in reducing climate risk (Adger et al., 2009; McNeeley, 2012; Klein et al., 2014). Also, it has been suggested that the rate and extent of climate change in the Arctic may, in some cases, surpass adaptive capacity (Larsen et al., 2014b). Barriers to adaptation can stem from a variety of sources and can be categorized into four different types.

First, *the rate and magnitude of climate change and its impacts* may pose a barrier to adaptation by exceeding critical ecological thresholds (Klein et al., 2014). Human systems such as subsistence hunting, fishing, and gathering are affected by processes such as declining sea ice causing habitat degradation or loss for marine mammals, changing ocean temperatures and chemistry causing system shifts from benthic to pelagic dominance and impeding crustacean and mollusk shell formation, and changing seasonality causing mismatched timing in availability of fish and wildlife at critical life-cycle phases (Chapin et al., 2014; Larsen et al., 2014b) (Chapter 5).

Second, *deficits of knowledge, both technical and traditional, about climate change, its consequences, and appropriate response options* are often identified by practitioners as an obstacle to the effective pursuit of adaptation (Berkes and Jolly, 2001). This barrier can include changes that occur beyond the scope of traditional knowledge (Krupnik and Jolly, 2002), lack of access to scientific knowledge, lack of trust in scientific projections, or misunderstanding of the scientific information and associated uncertainties (Morss et al., 2005; Mearns, 2010). However, scientific uncertainty need not pose a barrier to effective adaptation (Adger et al., 2009). Hence, research as well as science translation, improved communication and coordination among scientists, and enhanced collaboration and partnerships with communities continue to be important activities for enabling adaptation action (State of Alaska, 2011; Clement et al., 2013; Knapp and Trainor, 2013).

Third, *practical constraints such as access to capital – financial, social, human, physical, and natural* – as well as technological constraints are among the more commonly cited barriers to adaptation (Berkes and Jolly, 2001; Klein et al., 2014; Noble et al., 2014). Social limits to adaptation, such as values and individual and social parameters (legacies, path dependencies, and risk perception), can pose additional limits to adaptation (Adger et al., 2009).

Finally, *lack of effective institutions and governance arrangements* among stakeholders can slow adaptation responses (Berkes and Jolly, 2001; Biesbroek et al., 2013). This type of barrier can include regulatory schemes as well as lack of cooperation among federal, state/territory, local/Native, and private institutions. Cross-scale dynamics, particularly in governance and regulation, are important in adaptation planning, implementation, and assessment (Berkes and Jolly, 2001; Adger et al., 2005b; Cash et al., 2006a). For example, adaptation often occurs on a local scale but can be constrained by policy, regulation, or lack of funding at higher institutional scales (Bronen, 2011; Loring et al., 2011; Marino, 2012; McNeeley, 2012). The relocation of the village of Newtok to Mertarvik to escape severe erosion is one example of cross-scale interaction in Alaska (Community of Newtok and the Newtok Planning Group, 2011, 2012).

Barriers to adaptation vary with scale (Klein et al., 2014). For example, the barriers encountered at the household level will differ from those encountered at the federal level, owing to differences in responsibilities, jurisdiction, and resources at these different scales of decision-making. Actors at different scales may have different perceptions of the need for adaptation as well as the factors that constrain or enable adaptation (Biesbroek et al., 2011; Klein et al., 2014). Scale can also be considered in the context of the magnitude of the response needed to achieve adaptation objectives.

Key features for overcoming barriers to adaptation include: strong cross-scale coordination in adaptation, strong leadership, communication and collaboration at similar administrative levels, and coordination between formal and informal institutions and stakeholders (Mimura et al., 2014). Overcoming barriers to adaptation may require novel institutional arrangements (Klein et al., 2014).

The existence of social and ecological tipping points suggests that there are limits to incremental adaptation and that *transformational adaptation* will be required in some circumstances, to address some climate risks (see Table 7.2) (Kates et al., 2012; Klein et al., 2014; Noble et al., 2014). Transformation can be planned and intentional or unplanned and unintentional (Chapin et al., 2010). For example, sustaining Native Alaskan communities threatened by coastal hazards may require more than simply enhancing coastal defenses. Rather, relocation of entire communities may be necessary (Kates et al., 2012). In some cases, the barriers associated with implementing such large-scale adaptation efforts may prevent their implementation. This suggests there are limits to the extent to which adaptation can prevent or adequately reduce climate change risk (Adger et al., 2009; Dow et al., 2013).

Given the importance of adaptation for reducing risk in the BCB region, as well as the broad range of barriers that can slow or prevent effective adaptation responses, addressing these barriers is a key aspect of adaptation that may require transformative action. Building capacity of households, communities, government institutions, and the private sector can be an effective process in addressing adaptation barriers (Ford, 2009; Ford et al., 2011; Klein et al., 2014).

### 7.3.3 Summary of adaptation planning guidance

A number of climate adaptation guidebooks focus on the Arctic region of Alaska and Canada (Table 7.3). Universities, governments, and nongovernmental organizations produced these guidebooks for a range of audiences, including rural Native Alaskan and Canadian Indigenous communities, local governments, and state or territorial governments. This section reviews available resources for climate adaptation planning and identifies the key themes from these resources.

Table 7.3. Adaptation guidebooks for Alaska and Canada, of potential use to practitioners and decision-makers in adaptation planning. Only one focuses specifically on the BCB region.

| Title | Author(s) | Target audience | Scale of focus | URL |
|---|---|---|---|---|
| *Adapting to Coastal Climate Change: A Guidebook For Development Planners* (2009) | United States Agency for International Development (USAID), Coastal Resources Center – University of Rhode Island, and International Resources Group | Professional planners and development specialists working in coastal communities, especially in developing nations | International | adaptation-undp.org/sites/default/files/downloads/usaid_adapting_to_coastal_climate_change_-_a_guidebook_for_development_planners.pdf |
| *Canadian Communities' Guidebook for Adaptation to Climate Change: Including an Approach to Generate Co-benefits in the Context of Sustainable Development* (2008) | Livia Bizikova, Tina Neale, and Ian Burton<br>University of British Columbia and Environment Canada | Planners, decision-makers, local practitioners, and investors in Canada | Canada | www.fcm.ca/Documents/tools/PCP/canadian_communities_guidebook_for_adaptation_to_climate_change_EN.pdf |
| *Climate Change Adaptation Planning: A Handbook For Small Canadian Communities* (2011) | Canada Institute of Planners | Small communities | Canada | www.cip-icu.ca/Files/Resources/RURAL-HANDBOOK-FINAL-COPY |
| *Changing Climate, Changing Communities: Guide and Workbook for Municipal Climate Adaptation* | Local Governments for Sustainability (ICLEI) - Canada with Natural Resources Canada | Local or municipal governments | Canada | www.fcm.ca/Documents/tools/PCP/changing_climate_changing_communities_guide_for_municipal_climate_adaptation_EN.pdf |
| *Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments* (2007) | Climate Impacts Group – University of Washington and King County, Washington, in association with ICLEI[1] | Local, regional, and state governments | United States | cses.washington.edu/db/pdf/snoveretalgb574.pdf |
| *Climate Change Planning Tools for First Nations* (2006) – a series of 6 guidebooks, from *Starting the Planning Process* (1) to *Monitoring Progress and Change* (6) | Centre for Indigenous Environmental Resources Inc. and Indian and Northern Affairs Canada | First Nations | Canada | www.yourcier.org/climate-change-planning-tools-for-first-nations-guidebooks-2006.html |
| *Promoting Generations of Self-Reliance: Stories and Examples of Tribal Adaptation to Change* (2011) | Environmental Protection Agency (EPA) | Indigenous communities | United States | accap.uaf.edu/sites/default/files/resources/epa_tribal_adaptation.pdf |
| *Tribal Climate Change Adaptation Toolkit* (2013) | Institute for Tribal Environmental Professionals (ITEP), Northern Arizona University | Indigenous communities in developed nations | United States | www7.nau.edu/itep/main/tcc/Resources/adaptation |
| *Climate Change Adaptation Planning Manual: For Coastal Alaskans and Marine-Dependent Communities* (2011) | Terry Johnson, Alaska Sea Grant Marine Advisory Program, University of Alaska Fairbanks | Indigenous communities, especially Alaska Native communities and marine-dependent coastal communities | BCB region – United States | seagrant.uaf.edu/map/climate/docs/climate-change-adaptation-manual.pdf |
| *Climate Change Adaptation Planning: A Nunavut Toolkit* (2011) | Canada Institute of Planners and Government of Nunavut | First Nations communities in Nunavut | BBDS region – Canada | www.cip-icu.ca/Files/Resources/NUNAVUT-TOOLKIT-FINAL |

Key phases in the adaptation planning process that are consistent across the majority of the guidebooks (Table 7.3) include the following: building partnerships and networks of stakeholders; conducting vulnerability and risk assessments; establishing priorities, options, and an implementation plan and evaluation metrics; implementing the preferred option; and conducting ongoing monitoring and adjustment of activities (Table 7.4). A synthesis of the steps in adaptation planning from a review of 11 adaptation guidebooks specific to Alaska and the Canadian Arctic is presented in Figure 7.5: Steps A through E. These steps are superimposed on the steps of Figure 7.2 to illustrate how the more generalized stages presented earlier can be implemented in more concrete terms and how the steps of adaptation planning summarized by practical guidebooks map to the more theoretical framework. *Step A. Start* (identifying stakeholders and establishing support, plus other start-up activities) matches with Step 3 (mobilizing resources) of the more general framework. *Step B. Research* (conduct risk and vulnerability assessment, plus other research-related activities) corresponds to Step 4 of the more theoretical framework (building capacity to adapt). *Step C. Plan* and *Step D. Execute* both line up with the more general Step 5 (implementing targeted adaptation actions). Lastly, *Step E. Monitor, Evaluate and Adjust* is consistent with both Step 6 (measuring and evaluating progress) and Step 7 (learning, sharing knowledge with others, and adjusting) of the inner diagram. By viewing these two sets of processes in tandem, it is clear that while there are different ways to describe adaptation planning, the steps that take place are consistent.

In addition, there are common themes throughout all of the reviewed guidebooks. The guidebooks specific to Alaskan Native and Canadian Inuit and First Nations peoples emphasize the importance of community support and participation in the adaptation planning process. Similarly, the guidebooks strongly encourage the involvement of a wide range of community ages and demographics. Elder involvement and support is particularly critical to the success of adaptation planning in Indigenous communities. Elders are held in the highest regard in many Indigenous communities; therefore, they should be sought out to participate throughout the process. When professional planners or outside consultants are involved in planning with Native Alaskan and Canadian Inuit and First Nations communities, it is beneficial to elect a liaison to facilitate communication between the community and the outside consultants. All of the guidebooks are consistent in emphasizing the importance of prioritizing win–win and no-regrets activities and the necessity of communication amongst the various stakeholders. Including a process to evaluate activities and outcomes is also recommended (see Section 7.3.4).

The adaptation planning guidebooks also identify potential obstacles, which may be anticipated and addressed in the planning process (see also Section 7.3.2). Financial capacity is a significant barrier that can be overcome by engaging stakeholders, gathering community support, and making adaptation planning a government priority. Scientific uncertainty about climate futures can also impede planning decisions. A key recommendation is to make the most informed decisions possible with all available information, without letting scientific uncertainty stall the process.

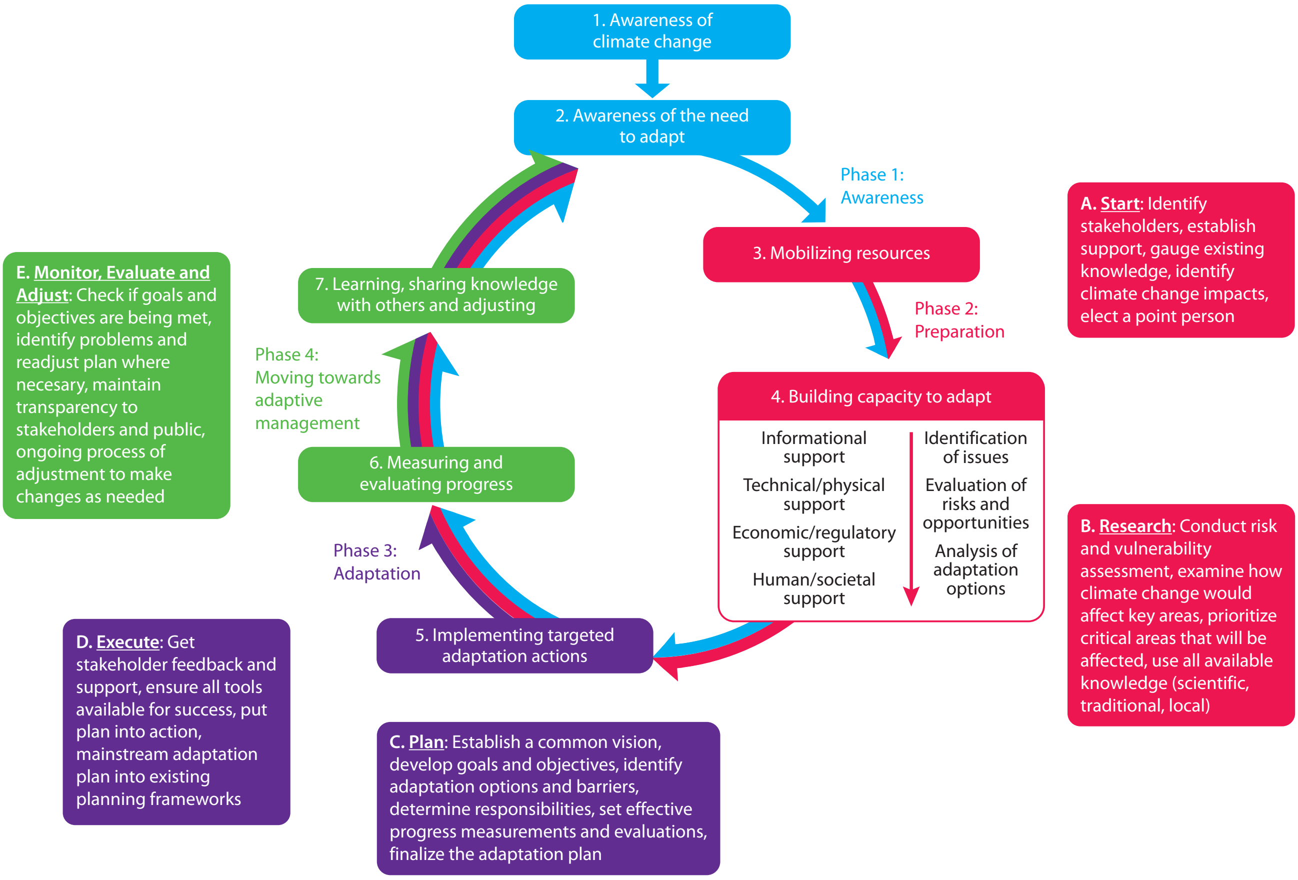

Figure 7.5 Step-by-step process of adaptation planning (Steps A through E, as in Table 7.4), overlain with the more general adaptation steps shown in Figure 7.2 (based on Eyzaguirre and Warren, 2014).

Table 7.4 Step-by-step process for climate adaptation planning

| | |
|---|---|
| A. Start | Identify stakeholders, establish support, gauge existing knowledge, identify climate change impacts, elect a person to act as a point of contact |
| B. Research | Conduct risk and vulnerability assessment, examine how climate change would affect key areas, prioritize critical areas that will be affected, use all available knowledge (scientific, traditional, local) |
| C. Plan | Establish a common vision, develop goals and objectives, identify adaptation options and barriers, determine responsibilities, set effective progress measurements and evaluations, finalize the adaptation plan |
| D. Execute | Get stakeholder feedback and support, ensure all tools available for success, put plan into action, mainstream adaptation plan into existing planning frameworks |
| E. Monitor, Evaluate, and Adjust | Check if goals and objectives are being met, identify problems and readjust plan where necessary, maintain transparency to stakeholders and public – an ongoing process of adjustment to make changes as needed |

### 7.3.4 Evaluating adaptation

Evaluation of adaptation actions is an important element of adaptive management and the adaptation planning and implementation process (see Figures 7.2 and 7.5). Once adaptation action is taken, the outcomes must be monitored and evaluated against overall environmental and societal goals. Evaluating climate adaptation enables decision-makers to assess the *process* of how decisions were made (e.g., was the process inclusive, legitimate, and relevant?) as well as the *outcomes* of the project (e.g., was the project effective, efficient, and equitable?) (Pringle, 2011). Outcomes are typically the aspect most relevant to policy (Noble et al., 2014). Evaluating the process of linking scientific knowledge with adaptation action (see Section 7.3.6) is also an important component of facilitating adaptation and building adaptive capacity (Meadow et al., 2015). Such evaluations provide information that can legitimize efforts, increase funding opportunities, increase procedural efficiency, promote innovation, and enable course correction, which is an essential component of adaptive management (Walder, 2004). Evaluation also produces information that may be shared with other communities, so as to facilitate learning from each other's experiences.

Preparing for climate adaptation evaluation involves clarifying why and for whom the evaluation is taking place, involving key stakeholders, cultivating support, discussing adaptation outcomes, and agreeing on principles that will guide the evaluation (Horton et al., 2003). These steps inform what information to collect and what data are relevant. Careful attention to each of these steps early in the design, implementation, and monitoring of climate adaptation will help to establish funding for monitoring and evaluation, baseline conditions, and criteria to measure progress. For example, engaging key stakeholders early in the adaptation planning and implementation process will help build agreement on what indicators should be measured to assess progress.

Adaptation evaluation challenges include the long time horizons potentially required to effect change, the possibility of shifting baselines and decision contexts, and the question of the extent to which observed outcomes can be exclusively attributed to adaptation actions (Bours et al., 2015). However, mixed methods approaches and trend analysis are two options for overcoming these challenges (Lennie and Tacchi, 2015; Schonthaler et al., 2010). Several resources are available for decision-makers interested in evaluating climate adaptation, including checklists of issues to consider (Weiland and Tröltzsch, 2015) and databases of existing climate evaluation efforts (CAKE, 2015).

Evaluation of adaptations on the provincial and territorial levels has not yet occurred in Canada (Eyzaguirre and Warren, 2014), and no evidence currently exists on adaptation evaluation in other parts of the BCB region. The process of developmental evaluation is explicitly designed to directly engage stakeholders and to assess outcomes in complex systems, such as the system of combined social and environmental change in the BCB region. As such, this approach offers a promising direction for filling this evaluation need (Patton, 2011).

### 7.3.5 Knowledge gaps

This section describes adaptation-related research and information needs that have been identified in the peer-reviewed literature. However, at least as important as filling scientific knowledge gaps with new information is making available the existing knowledge that is relevant and applicable to policy, planning, management, and other decision contexts for the implementation and assessment of adaptation actions and measures (see Section 7.3.6) (Knapp and Trainor, 2015). It is thus necessary to emphasize the need to place time, attention, and resources on building the capacity to bridge science and application – a process sometimes referred to as 'use-inspired science' (Stokes, 1997; Clark and Dickson, 2003; Clark and Holliday, 2006). This bridging can be accomplished in several ways, including the fostering and development of knowledge networks, embedded institutional capacity, and knowledge brokers (see Box 7.2) (Dilling and Lemos, 2011; Lemos et al., 2012). Existing local knowledge and local knowledge needs are not necessarily represented in the peer-reviewed literature (Krupnik and Ray, 2007; Ford and Pearce, 2010).

Overall, this chapter reveals a gap in the published literature on regional application and use of decision tools for prioritizing adaptation options in the BCB region (see Box 7.3). Another significant gap is the lack of integrated, interdisciplinary assessment of adaptation to the complex, combined, and synergistic environmental and social drivers of BCB change (see Chapters 4 and 6). While most residents face these changes within the larger, holistic context of their lives (see Chapter 2), the nature of scientific disciplinary expertise has led to a preponderance of research focused exclusively on climate adaptation or on the social, health, or educational well-being of Arctic residents (Larsen et al., 2010, 2014a; Larsen and Gail, 2015). More solutions-based research is needed in partnership with regional residents to address adaptation and response to the combined social and environmental drivers of change (Huntington et al., 2012; Nilsson et al., 2013; Noble et al., 2013).

## Box 7.3 Decision tools for prioritizing climate change adaptation options

A wide variety of adaptation options are available to decision-makers to address the potential risks posed by climate change. However, it may often be infeasible for decision-makers to implement some plausible options due to technical challenges, resource limitations, regulatory barriers, or established practice (Chambwera et al., 2014). Prioritizing adaptation options through decision-analysis mechanisms is therefore an important component of adaptation planning. This box provides an overview of decision tools that can be used in evaluating and prioritizing climate change adaptation options. Table 7.5 gives a brief description of each technique, references that provide specific guidance in how to use the tool, and references with examples of how the tool has been used in practice, including examples specific to the BCB region.

Assessment of the potential impacts, vulnerabilities, and risks related to climate change is often an entry point for adaptation planning. However, evaluation and prioritization of possible options for adapting to change is often required in managing risk.

Various decision-analysis tools are available to facilitate the evaluation and prioritization of adaptation options. High-level frameworks for adaptation planning and implementation can help guide the adaptation process. For example, the *precautionary principle* has been used for several decades as a simple heuristic that calls for new technologies or practices to be presumed harmful until evidence indicates otherwise (Aslaksen et al., 2012). In the BCB region, the North Pacific Fishery Management Council has engaged the precautionary principle in fisheries management to buffer against unknowns about future marine conditions and related cascading impacts to the marine food web. Their 2009 fisheries management plan closed the Arctic Ocean to commercial fishing, pending further research on potential ecosystem impacts, and instituted adaptive management procedures in instances where changing climatic variables were linked to changing fish and shellfish distributions. More recently, the *risk management paradigm* has seen increased use as a structured framework for adaptation planning (Willows and Connell, 2003; Jones and Preston, 2011; IPCC, 2012; Bowyer et al., 2015) that focuses on identifying and implementing risk treatment options under uncertainty. For example, Karvetski et al. (2011) used scenario analysis to prioritize the vulnerability of Alaskan communities to climate change in order to identify those in greatest need of infrastructure and other interventions.

*Risk management* can accommodate a number of more focused appraisal and decision tools**.** *Cost-benefit analysis,* which compares the economic costs of implementing an option with its anticipated benefits, is one of the most common decision tools for the appraisal of policy options. Total costs and benefits of implementation over a specified time period are calculated and discounted to reflect social preferences for near-term costs and benefits over the long term. Larsen et al. (2008) used climate change projections to estimate the impacts of climate change (expressed as replacement costs) on infrastructure for multiple locations in the BCB region, as well as the benefits of adaptation in terms of avoiding damage. However, the economic evaluation of adaptation benefits can be difficult to rigorously quantify, particularly for benefits that are not readily captured by economic or financial metrics (e.g., quality of life).

Technology and product appraisal is often undertaken using *life cycle assessment* (LCA), which assesses 'cradle-to-grave' environmental impacts – often with a focus on energy and natural resource use during production, use, and disposal. Although potentially informative for structural adaptation options involving technology fixes, infrastructure, or buildings

Table 7.5 Summary of decision frameworks used in the appraisal of adaptation options.

| Decision framework | Description | Guidance for getting started |
|---|---|---|
| Precautionary principle | When applying the precautionary principle, precautionary measures should be taken to mitigate the risks of an activity that potentially poses threats to human health or the environment, even if some cause-and-effect relationships are not fully established scientifically. Therefore, the proponent of an activity, rather than the public, should bear the burden of proof (Lougheed, 2009). | O'Riordan and Jordan (1995); Kriebel et al. (2001) |
| Risk management | Risk management refers to a coordinated set of activities and methods used to direct an organization and to control the risks that can affect its ability to achieve objectives. The risk management process includes the identification, analysis, treatment, and evaluation of risk (ISO, 2009). | Willows and Connell (2003); Jones and Preston (2011); Kunreuther et al. (2013) |
| Cost–benefit analysis | Cost–benefit analysis is a tool for weighing the costs of an investment decision against the benefits; this approach involves some form of calculation over time to compare the former with the latter when they accrue over time (European Commission, 2008). | UNFCCC (2011); Kull et al. (2011); Ciscar et al. (2011); AECOM (2012a); Nassopoulos et al. (2012); OCCIAR (2015) |
| Life cycle assessment (LCA) | Life cycle assessment is a tool for evaluating the environmental impacts of a product or service through all stages of its life cycle, including the inputs and processes used in product development and delivery as well as disposal (Jensen et al., 1997) | Jensen et al. (1997); ISO (2006); Guinee et al. (2010) |
| Multi-criteria decision analysis (MCDA) | Multi-criteria decision analysis uses multiple monetary and non-monetary criteria for the appraisal of investment options or decisions. The process integrates decision-makers' alternatives and criteria with required characteristics (Department for Communities and Local Government, 2009). | Linkov et al. (2006); Department for Communities and Local Government (2009); Huang et al. (2011); Zarghami and Szidarovszky (2011) |

– all of which may have significant material components or require intensive manufacturing or construction processes – LCA may be less informative for non-structural adaptation options associated with education or capacity building activities, community or land use planning, or economic diversification.

There may not be a single indicator or metric that can be used to prioritize alternative adaptation options. *Multi-criteria decision analysis* (MCDA) is a tool that seeks to directly incorporate multiple interests and beliefs into the analysis of adaptation alternatives. In MCDA, stakeholders establish the criteria by which adaptation options should be assessed, as well as how much importance or weight should be given to each criterion. An advantage of MCDA is that it can be used in conjunction with other tools (such as cost-benefit analysis or life cycle analysis). However, the MCDA approach has also been criticized because it involves significant inputs of subjective information, which makes it sensitive to the judgments of those undertaking the analysis. Several studies have applied MCDA methods in the assessment of adaptation options in the BCB region. For example, Champalle et al. (2015) applied MCDA techniques in conjunction with stakeholder participation to prioritize adaptation options for Nunavut communities.

Of course, many adaptation decisions will be made independent of formal adaptation planning or decision analysis. This is particularly true for decisions made by individuals or households and for decisions regarding actions with little ambiguity or uncertainty regarding their necessity. Nevertheless, for large public and private organizations engaged in *long-term strategic planning* or seeking transparency in the development of adaptation policy agendas, decision tools such as these – either alone or in combination (Linkov and Seager, 2011) – may be a useful entry point.

| Applications from adaptation practice (* marks those specific to the BCB region) |
|---|
| Fisheries management: Garcia (1994), Darcy and Matlock (1999), North Pacific Fishery Management Council (2009)*, Stram and Evans (2009)*; National security: Dabelko (2009); Conservation of coastal salt marshes: Simas et al. (2001) |
| Coastal infrastructure: ADB (2005), Karvetski (2011)*; Urban adaptation: NYCPCC (2010); Transportation planning: TRB (2013) |
| Public infrastructure: Larsen et al. (2008)*; Water resources management: AECOM (2012b); Mining assets: MIRARCO (2015); Transportation infrastructure: AECOM (2012c); Coastal inundation: AECOM (2013) |
| Land use planning: Andersson-Sköld et al. (2016); Urban water resources management: Spatari et al. (2011), Scott (2013), Zahmatkesh et al. (2014); Building design: Saiz et al. (2006) |
| Community-based adaptation: Champalle et al. (2015)*; Forest management: Wolfslehner et al. (2005), Wolfslehner and Seidl (2010); Water resources management: Weng et al. (2010), Straton et al. (2011), Yang et al. (2012); Coastal infrastructure assessment: Karvetski et al. (2011)*; Flood risk management: Jun et al. (2013); Household vulnerability: Eakin and Bojorquez-Tapia (2008); Coastal pollution: Greiner et al. (2005) |

### 7.3.5.1 Adaptation in general

While multiple stressors and cumulative impacts are widely acknowledged in the context of social and ecological change in the BCB region, there is a lack of structured frameworks for evaluating, assessing, and comparing the complex dynamics across multiple sectors and international governance systems (Gunn and Noble, 2009). There are methodological and knowledge gaps in evaluating the efficacy of adaptation actions over time (Bierbaum et al., 2013). This includes a need to better understand how adaptive actions guide towards pathways or trajectories that can constrain or facilitate future adaptive capacity (Barnett and O'Neill, 2010; Garrelts and Lange, 2011). There is a need for explanatory (versus descriptive) social science approaches to adaptation, including behavioral sciences, institutional analysis, and policy analysis (Hinkel and Bisaro, 2015). Similarly, there is a knowledge gap in interdisciplinary research that engages social sciences – especially psychology, communication, and decision sciences – in adaptation research (Adger et al., 2010; Pidgeon and Fischhoff, 2011). For example, there is a need for analysis of how different audiences perceive and understand climate adaptation and how these perceptions change over time, in-depth analysis of media coverage of climate adaptation, analysis of the psychological dissonance of climate change denial and impacts, and investigation of the roles of place attachment and place identity (Moser, 2014).

### 7.3.5.2 Adaptation specific to the BCB region

Many of the knowledge gaps in the BCB region emphasize a need for procedural innovation in partnering directly with local communities and building adaptive capacity. Specifically, there is a need for scientific processes that are transparent, collaborative, and accessible to communities and stakeholders, especially in integrating traditional, local knowledge (Ford and Pearce, 2010; Knapp and Trainor, 2013; Arctic Observing Summit, 2016). Suggestions to fill this need include direct engagement with communities, assistance in helping them achieve their self-identified adaptation goals, and the creation of international networks to share adaptation solutions (Forbes and Stammler, 2009; Cochran et al., 2013; Chapin et al., 2016). In Canada, ArcticNet has been established to foster collaboration between scientists and Inuit organizations and communities (Box 7.2), but similar institutional infrastructure does not exist in Alaska or Chukotka. Especially important in adaptation research is the need to acknowledge the full spectrum of contemporary Indigenous identity, including the complexities and juxtapositions of economic opportunities, environmental risks, subsistence food harvests, and traditional Indigenous lifeways (Cameron, 2012).

In addition to a need for baseline data (Knapp and Trainor, 2015) and documentation of adaptation actions across multiple sectors, including those not reported in the peer-reviewed literature, there is a regional need for longitudinal studies, for assessment of the effectiveness of adaptive actions, and for international comparison with other regions (Ford et al., 2014a). Research in the forestry sector south of the BCB suggests that gender gaps in decision-empowered positions and gender differences in access to financial, human, and social capital play a role in adaptive capacity. This research points to the possibility that gender research on adaptation and adaptive

*Catching fish at the Chukotrybpromkhoz fish processing plant in the village of Shakhtersky, Chukotka*

capacity in sectors within the BCB region may prove a fruitful avenue for building regional strength in adaptation (Reed et al., 2014). Significantly, little evidence exists for the application of decision tools for prioritizing adaptation options in the BCB region (Box 7.3).

## 7.3.6 From science to knowledge to adaptation action

### 7.3.6.1 Interpreting the scientific uncertainty inherent in climate models

Uncertainties are inherent in scientific projections of future conditions, as well as in many other elements that inform the adaptation decision process. Factors that contribute to uncertainties inherent in modeled projections of future climate conditions include the magnitude and trajectory of future anthropogenic greenhouse gas emissions, the natural sensitivity and variability of the climate system, and assumptions about how the global climate system will respond to future emissions. The process of downscaling global models to finer regional and local spatial dimensions creates additional uncertainties (Mearns, 2010). Feedbacks of uncertainties then arise because the global climate system's response to future emissions depends on how regional and local environmental and ecosystem conditions (e.g., spatial distribution of snow, hydrology, ecosystem species composition, and sea ice dynamics) will respond to changing climatic parameters (e.g., temperature, precipitation, winds) (Yeomans, 2004) (see Chapter 4).

Although uncertainties in future projections are inevitable, they should be less of a barrier to action at high northern latitudes than elsewhere. Continued climate warming and its well-known consequences are virtually certain over the most relevant time horizons for planning, given their strong recent trends and the dependence of continued warming on the legacy of carbon dioxide in the atmosphere from past anthropogenic emissions. There is a very high likelihood of continued warming, sea ice decline, permafrost thaw, and increases in wildfire extent, as well as the well-known consequences of these environmental changes (Chapin et al., 2014). Because it is often extreme events (e.g., storm surge, flooding, wildfire) that have the greatest social, human, and economic impacts yet also the highest uncertainty of occurrence in terms of their precise timing and location, a focus on planning for these extreme events should not be overlooked in adaptation planning. Thus, in some areas, climate adaption planning can and should occur in conjunction with hazard mitigation planning or disaster risk management (Birkmann and von Teichman, 2010; Bronen and Chapin, 2013; Eicken and Mahoney, 2015).

Uncertainties in global market dynamics, future politics and political conditions, and local and regional demographics add additional layers of unknowns to the adaptation process (Trainor, 2012). Refinements of analyses of scientific uncertainty (although scientifically useful) do not necessarily improve the ability of decision-makers to apply information to adaptation decision-making. Often what is most needed are individuals or boundary organizations to help interpret projected future climate scenarios for stakeholders and to assist in identifying how projected future conditions will affect elements that stakeholders care most about (Lemos and Rood, 2010; Mearns, 2010; Trainor, 2012). The strong dependence of rural communities on nutritional and cultural connections to the land and sea through subsistence harvest is also highly likely to continue. Given these high likelihoods, adaptation planning can start from a foundation of climate warming and consider scenarios related to less certain socio-economic and institutional changes (see Chapter 8).

Different problem framings and decision processes offer alternative approaches to managing uncertainties (Jones et al., 2014). One approach presents generalized probabilistic projections of future conditions (e.g. for example, climate conditions) based on expert analysis. Application of the information to specific situations or contexts is then handled separately by a second set of experts, and this applied information is communicated to decision-makers. This is the approach taken by the IPCC (Jones et al., 2014). A second approach engages scientific experts with decision-makers at the outset in order to ensure that information and scientific knowledge are appropriately scaled and applicable to specific decision contexts. This approach is more time consuming, is more appropriate in complex systems (Jones et al., 2014), and is consistent with the knowledge-to-action framework (Collier et al., 2009).

Specific decision tools to manage uncertainties are presented in Box 7.3, and aspects of adaptive governance that are particularly adept at dealing with uncertainty are presented in Section 7.1.4. Scenario planning (see Chapter 8) is also an effective mechanism for managing uncertainties in the decision process (Jones et al., 2014). Adaptation planning guidebooks emphasize the importance of managing uncertainties so as to prevent them from stalling or impeding the planning and implementation process (Section 7.3.3). Additional strategies for managing uncertainties about future conditions are to increase flexibility in the decision process and to plan with a view of the long-term time horizon (Fankhauser et al., 1999).

### 7.3.6.2 Extreme events

In the BCB region, projections of future climate conditions are most frequently presented as annual or seasonal averages. However, the most severe human impacts from environmental change – and therefore the most urgent needs for adaptation – are often generated by extreme events such as severe storms, flooding, wildfire, and sea ice minima. In many of these cases, longer-term adaptation will need to be coordinated with shorter-term disaster risk management (Collier et al., 2009; IPCC, 2012). Taking action to decrease exposure and reduce vulnerability are key components to both strategies (IPCC, 2012).

### 7.3.6.3 From knowledge to adaptation action

Although adaptive actions are underway (Section 7.2), there is need for a new model for linking science and adaptation action in the BCB region (Knapp and Trainor, 2013, 2015; Armitage, 2014; Wyborn, 2015). Adaptation requires financial resources and often technological solutions. There is also need for scientific research, observation and monitoring, data sharing regarding the drivers of change and societal impacts of change, and the establishment of indicators (Aslaksen et al., 2012; Knapp and Trainor, 2015; Young, 2015; Sanborn and Hinzman, 2016). However, information, funding, technology, scientific monitoring, research, and synthesis alone are often not sufficient to facilitate adaptation. There is a need for better communication and collaboration between scientists and decision-makers as well as a need for processes and tools that can facilitate the application of science within a specific decision context (Cash et al., 2006b; Dilling and Lemos, 2011; Aslaksen et al., 2012; Jones et al., 2014; Knapp and Trainor, 2015; Wyborn, 2015; Young, 2015; Arctic Observing Summit, 2016; Sanborn and Hinzman, 2016).

While the 'usability' of scientific research is increasingly valued by funders, gaps remain in incorporating stakeholder needs and perspectives into the research process (Weichselgartner and Kasperson, 2010; Ford et al., 2013; Knapp and Trainor, 2013). Differing objectives, needs, values, priorities, time frames, and problem framing among scientists and decision-makers can pose barriers to closing the knowledge-to-action loop. Strong communication and trust-building are important components of the process of bridging knowledge and action (Vogel et al., 2007; Weichselgartner and Kasperson, 2010; Dilling and Lemos, 2011; Knapp and Trainor, 2015).

Adaptation can be facilitated by the work of boundary or bridging organizations or other intermediary entities (Dilling and Lemos, 2011; Armitage, 2014; Jones et al., 2014). This process, known as knowledge co-production, is illustrated in Figure 7.6, which highlights the importance of two-way, iterative communication. Boundary organizations serve to build communication and foster knowledge exchange between scientists and decision-makers (Buizer et al., 2010; Guston, 2001). For example, in the BCB region, the Alaska Center for Climate Assessment and Policy (see Box 7.2) is working directly with tribal governments to bring the most up-to-date, relevant science to bear on adaptation planning that is anchored in community values, needs, and priorities (Kettle et al., in press). Because of the informal nature of boundary-organization linkages, such groups are often able to adjust nimbly to changing environmental or political landscapes and to foster communication among groups that would otherwise seldom communicate. Other institutional arrangements such as embedded capacity, information brokers, knowledge networks, and collaborative processes can also promote knowledge exchange and social learning related to adaptation (Dilling and Lemos, 2011; Meadow et al., 2015). In many cases, these intermediary organizations are essential for bridging the gap between science and action (Clark and Holliday, 2006). The process of integrating science with the needs of stakeholders requires specific skills and personal characteristics, including humility, patience, curiosity, self-reflexive thinking, strong communication skills, respect and willingness to listen to different perspectives and values, and an ability to understand the decision context (Brugger et al., 2016).

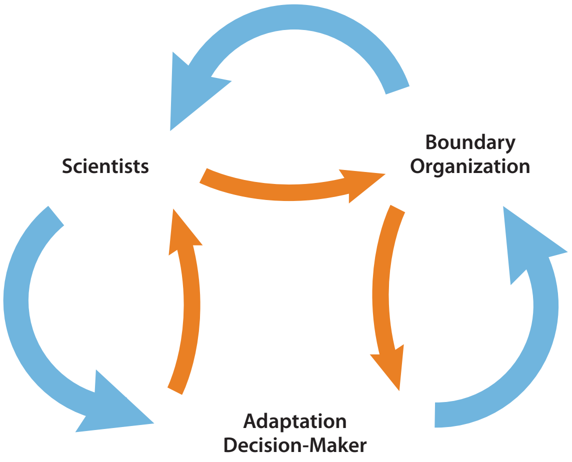

Figure 7.6. Knowledge co-production (adapted from Knapp and Trainor, 2015). Two-way, iterative communication is an important feature of knowledge co-production. In some cases, scientists and decision-makers communicate directly. Boundary organizations can facilitate this communication as well as the transfer of knowledge from scientists to decision-makers.

The peer-reviewed literature contains two main suggestions to advance the bridging of science and adaptive action in the BCB region:

1. *Engage stakeholders from the beginning of the research process, and engage in iterative, ongoing dialogue between scientists and stakeholders* (Clark and Holliday, 2006; Dilling and Lemos, 2011; O'Brien, 2013; Knapp and Trainor, 2015). This partnership model includes respect for multiple ways of knowing (values) (Knapp and Trainor, 2015) and could also be effective in overcoming barriers to adaptation (see Section 7.3.2). Boundary organizations can often provide effective assistance (see Box 7.2). The largest and earliest example of this partnership model in the Arctic is ArcticNet (a Network of Centres of Excellence in Canada; www.arcticnet.ulaval.ca). Since 2004, ArcticNet has been bringing together northerners and scientists in designing, approving, managing, and disseminating the results of climate-related science in Canada's North. Inuit and northern industry representatives sit on ArcticNet's Board of Directors and Research Management Committee, and ArcticNet's Annual Science Meeting

brings hundreds of northerners and scientists together to present and discuss the latest results of dozens of research projects from across the spectrum of natural sciences and humanities.

2. *Create decision support tools and establish climate services, knowledge networks, and data sharing* (Alaska Department of Environmental Conservation, 2010; Jones et al., 2014; Knapp and Trainor, 2015). The partnership model of iterative, ongoing dialogue between scientists and decision-makers (see previous suggestion) can be used to create context-relevant climate services and decision support tools for bringing science to bear on decision-making (McNie, 2012; Vaughan and Dessai, 2014). Tools that can identify and evaluate policy options under a range of scenarios of future conditions will be beneficial in the BCB region (Young, 2015).

Examples of decision-support tools in the BCB region include the Historical Sea Ice Atlas, created by ACCAP in collaboration with the Alaska Ocean Observing System, and the climate-outlook community charts of projected temperature and precipitation, created by the Scenarios Network for Alaska and Arctic Planning (SNAP). Boundary organizations and the use of technology can facilitate the creation and expansion of knowledge networks through events such as webinars (Kettle and Trainor, 2015; Trainor et al., 2016). Data sharing can be accomplished with online tools such as portals and data hubs, but these alone are insufficient to fully meet the information needs of rural communities in the region (Knapp and Trainor, 2013, 2015). Decision-support tools should be evaluated periodically to ensure their usefulness to stakeholders in practical decision contexts (Ferguson et al., 2016).

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# 8. Scenarios thinking for the Bering-Chukchi-Beaufort Region

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## Key messages

- ***The future of the BCB region is one of significant socio-economic and climatic changes.*** *The consequences of climate change as well as the capacity of communities within the region to respond effectively will be contingent on the suite of social and environmental changes facing the circumpolar North. Over long timescales, such change is inherently uncertain. Scenarios provide a mechanism for representing that uncertainty, incorporating alternative socio-economic futures into climate change assessment, and identifying key opportunities for future investigations.*
- ***The evolution of governance systems as well as global demands for energy and the exploitation of Arctic resources are key uncertainties affecting future socio-economic pathways in the BCB region.*** *Global energy demand will affect future investments in the exploitation of Arctic energy resources. Meanwhile, the strength and level of cooperation among different government institutions and non-state actors will affect how well the BCB region addresses change and balances the benefits and costs. The potential for quite distinct futures across social, economic, and cultural dimensions also has implications for the adaptation experiences of communities and ecosystems in relation to the type and severity of climate change impacts.*
- ***Scenarios for different communities illustrate how the opportunities and challenges associated with climate change will vary significantly over time and place.*** *Different communities face different risks from a changing climate and have different perspectives regarding the implications of those risks and the most appropriate response options. As a result, it may be difficult to align decision-making at different levels, from local to international, to effectively address challenges across diverse communities, ecosystems, and stakeholders. Cross-scale research and collaboration in governance can mitigate disconnects. Participatory scenario processes can identify those aspects of human and natural systems that are most relevant to the sustainability of BCB communities.*
- ***Scenarios can be useful for navigating the interface between Arctic science and policy.*** *Thinking deliberately about the future can provide a vehicle for integrating multiple sources of knowledge into assessment and decision-making. This includes both technical and scientific knowledge, such as model projections of a changing climate, as well as the knowledge of Indigenous peoples. Scenario processes can reveal critical uncertainties that are directly relevant to stakeholder needs and livelihoods, which can then become targets for future research and monitoring of early warnings of change to enhance the social impact of science investments.*

## 8.1 Introduction

A number of biophysical and socio-economic drivers will have a significant influence on future vulnerability, risk, resilience, and adaptation planning in the Bering-Chuckchi-Beaufort (BCB) region (Chapters 4–7). The trajectories of some of those drivers are amenable to modeling, forecasting, or projection. However, the future is inherently uncertain, particularly over long time horizons. Scenarios have been used for over 50 years as a tool for exploring such uncertainty in order to identify key driving forces and critical unknowns, as well as to generate shared understanding among stakeholders regarding the potential for, and implications of, alternative futures (van Notten et al., 2003; Bishop et al., 2007; Avango et al., 2013).

This chapter provides a general overview of scenarios and their value for understanding the implications of a changing climate within the broader context of global change. The chapter includes a review of how scenarios have been used previously to understand climate change vulnerability, risk, and resilience, with a particular emphasis on the Arctic. It also introduces a new series of qualitative regional and subregional socio-economic scenarios for the BCB region, peering into the future to 2050, and discusses their implications for climate change impacts as well as adaptation planning and implementation.

## 8.2 Background on scenarios

### 8.2.1 What are scenarios?

For the purposes of this chapter, scenarios are narratives of plausible future worlds. Scenarios and methods for scenario development have been used for analysis and planning in a wide range of settings (Peterson et al., 2003; Kok et al., 2006a,b; Andrew, 2014). They have been successfully employed by governments, industry, researchers, and community-scale organizations (e.g., school systems, natural resource management groups), all of which face the common challenge of responding to uncertain futures during periods of rapid change.

> *"They [scenario development processes] introduce discontinuities so that conversations about strategy – which lie at the heart of any organization's capacity to adapt – can encompass something different from the present. Storytelling is key to making this process work."* Wilkinson and Kupers (2013, p. 124) on Royal Dutch Shell's scenario process

> *"In addition, the process of scenario development offers a variety of ancillary benefits, notably raising awareness, learning from past experiences and reconsidering the validity of policy assumptions. Engaging stakeholders and policy-makers directly in development also boosts the validity and credibility of outputs."* EEA (2009, p. 5)

**Box. 8.1 Definitions of concepts used in exploring future states**

*Based on Andrew (2014) and Lindgren and Bandhold (2009).*

**Projection** – A projection is a parametric description of a future time and possibly also the pathway to that time. For example, "the world's population in 2100 is projected to be 29 billion if fertility remains high".

**Forecast** – *"What do I predict will happen?"* A forecast is a projection that is considered most likely among other projections. While a projection can be simply a trajectory of a particular parameter (e.g., global population growth or decline), the process of forecasting additionally assigns some likelihood to various projections and highlights the most likely among them. For example, "the world's population in 2100 is likely to be 29 billion because fertility is expected to remain high".

**Scenario** – *"What would happen if?"* A scenario is a coherent narrative describing a future and often the pathway to that future and the drivers of changes along the way. Scenarios are often accompanied by projections, but not always. For example, "developed nations step up their ambition to eradicate common diseases in developing nations". This would be a valid scenario because the key drivers and their trajectories to create it are grounded in data that explain a trajectory to this outcome.

**Visions** – *"What do I want to happen?"* Visioning exercises address desired futures and specifically include values held by participants while purposefully discounting risks. They are usually qualitative, and often the goal is to trigger voluntary changes. Visioning may use projections, models, and forecasts, but only after determining the desired future state. For example, "we desire to have renewable energy widely available across the Arctic by 2040".

**Sensitivity analysis** – Some projections are presented as sensitivity analyses, where the uncertainty of the forecast is investigated by varying the assumed values of key parameters. Effectively this results in a number of additional projections with no change in the forecast (the most likely projection). This practice is particularly common in economic projections.

**Models** – Models formalize relationships between drivers and outcomes as a way to represent reality. Usually greatly simplified compared to the real world, models can be quantitative or qualitative, deterministic or stochastic (random), process-based or empirical, spatial and/or temporal. A model can be used to develop components of a scenario or assess the outcomes of a scenario.

Scenarios provide a flexible but informed perspective on a range of plausible socio-economic and environmental outcomes, which explains their wide use as a planning tool (Schwartz, 1996; Lindgren and Bandhold, 2009).

Although inherently forward-looking, scenarios are not explicit models of the future. While models can help inform scenario creation, scenarios are neither forecasts nor predictions (see Box 8.1 on definitions). Using scenarios is often a process of asking *what if?* This process can be implicit and informal, as individuals or organizations contemplate possible future events, consequences, and responses. In contrast, a range of formal scenario development processes have been designed to explicitly articulate alternative future development trajectories, states, and associated uncertainties. Scenario development processes can be used to bring together a wide variety of expert and lay perspectives to examine social, economic, and environmental processes. In general, participants identify drivers or key factors related to a question about the future (i.e., the 'focal question'), then examine current data, knowledge, and understanding around these drivers. Scenario participants can hypothesize how the most important drivers will interact in the future – typically over a time horizon of at least 20 years.

The long-term time horizon associated with scenarios hints at their key utility. Scenarios are used to explore possible futures that lie beyond forecasts or predictions where there is reasonable confidence about trajectories, outcomes, and uncertainties. Hence, scenarios are often described as plausible futures of unknown probability. For example, while demographic models are commonly used to develop population forecasts, the longer into the future those forecasts are made, the less reliable they are due to the accumulation of unforeseen and random events. Eventually, the forecasts become largely speculative. Thus, switching to a scenario mode of thinking can be helpful for exploring a range of alternative population trajectories and associated driving forces while explicitly acknowledging inherent uncertainties. Scenarios have also proven valuable as tools for exploring low-probability, high-consequence events that may not be readily identified or anticipated through management processes focused on the status quo, the foreseeable future, or the most likely trajectory (see Section 8.2.4).

Furthermore, because scenario exercises rest on an understanding of information pertinent to answering key questions tailored by those using the process, the data used can come from a variety of sources, such as climate change models, Indigenous knowledge, practitioner experience, or community values. In this sense, scenario development is based on science – established facts about how the world works – but the process of using science and values is flexible to the knowledge needs and expertise of participants. For example, a scenario process based on the question "What is needed to maintain subsistence hunting and gathering across the Arctic Slope of Alaska in 2050?" would rest on data that spans a variety of sources. A different question "How can infrastructure for cities in the High North be sustained in 2050?" would use different perspectives and information. The blend of imaginative thinking and tangible data is what makes scenarios such a powerful tool for society.

To the extent that scenarios engage a range of different experts and stakeholders, the scenario development process itself can significantly benefit those preparing for the future by enabling conversations among affected parties, introducing and sharing new information sources, and indicating the interconnected aspects of shared problems. Moreover, the identification and exploration of key uncertainties identified in the process can lead to the development of early indicators of challenges and opportunities. These indicators can be observed over time in order to track, at the community or regional level, a trajectory toward a desirable or undesirable future (see Section 8.6.3). The use of long time horizons also lets participants think outside their short-term budgetary, political, or research constraints, thus enabling participants to freely communicate and consider multiple options. Ultimately, the selection of experts and stakeholders for participation in the scenario process is contingent upon the goals of scenario development, the questions around which insights are being sought, and who is seeking those insights. As illustrated in this chapter, a range of approaches to the development and use of scenarios are evident in the BCB region, all of which have potential applications for the assessment of vulnerability, risk, resilience, and adaptation planning.

### 8.2.2 Scenario methods and objectives

A wide variety of methods have been used in scenario development processes (Bishop et al., 2007; Rounsevell and Metzger, 2010). Börjeson et al. (2006) and Rounsevell and Metzger (2010), for example, identified three general approaches to scenario development often used in environmental assessment, which vary with respect to the intended application:

- *Exploratory* scenarios describe plausible but alternative development pathways
- *Normative* scenarios represent series of events and causal relationships that lead to desirable or undesirable futures or outcomes
- *Business-as-usual* scenarios explore the consequences of relatively well-known, near-term changes, and thus are often associated with shorter time horizons.

Other authors have identified a range of distinguishing characteristics associated with scenarios, including whether they are oriented toward actors or problems, use qualitative or quantitative data, span short or long time horizons, or are local versus global (van Notten et al., 2003; Chaudhury et al., 2013).

This diversity in approaches to scenario development offers a rich toolkit that enables scenarios to be developed and used for a wide variety of purposes, with varying levels of investment and intended outcomes. Van Notten et al. (2003) suggested that this diversity can be organized around three primary themes: scenario goals, scenario design, and scenario content. This heterogeneity in scenario approaches is apparent in the different BCB region scenario activities described in Section 8.3.

### 8.2.3 Scenarios across different scales

Scale is highly important to the development of any scenario process and can be defined as "the spatial, temporal, quantitative, or analytical dimensions used to measure and study any phenomenon" (Gibson et al., 2000, p. 5; Cash et al., 2006). In scenario processes, scale often refers to hierarchies of space and organization or time, each of which may encompass multiple levels (e.g., local to global, household to international institution, or near-term to long-term). The issue of scale matters in terms of which problems are considered, which participants are included, and what types of information are used. The scale of any scenario activity results from the questions and uncertainties around which insights are sought, as well as the manner in which scenarios will be used to achieve those insights.

One common scale dichotomy describes scenarios as being generated either from the 'bottom up' or the 'top down'. Top-down scenarios tend to be expert driven, developed at aggregate (e.g., global or national) scales for the purpose of generating a consistent set of driving forces for other applications. For example, investigating the key drivers of extractive industries in the Arctic to consider impacts on national economies would produce scenarios of production from sets of economic, demographic, geographic, and industrial data. Meanwhile, bottom-up scenarios tend to be developed at a local or regional level using participatory methods in order to target concerns of stakeholders at these local scales. For example, planning for the provision of clean water to a small rural community in the Arctic would require data from global and regional models of weather and climate, but one would desire for the majority of participants to be people involved in that provision. Although scenarios can be applied in subsequent analyses or planning, the scenarios themselves and the processes by which they are generated can be quite informative in their own right. The process of coming together with other experts, either from a technocratic or a citizen science perspective, learning from one another, and considering long-range uncertainty can prompt new thinking about problems and their policy components. It should be noted, however, that the dichotomy between top-down and bottom-up is subjective and not entirely clear-cut, and therefore the labels of 'top-down' and 'bottom-up' are simply convenient shorthand to describe different approaches to scenario development.

Top-down approaches are represented by the Millennium Ecosystem Assessment (Carpenter, 2005; Raskin, 2005), Global Environmental Outlook (Raskin and Kemp-Benedict, 2002), Foresight (DTI, 2002) and, more recently, the parallel scenario process (Moss et al., 2010), which is a key scenario framework currently supporting the climate change community. Within the parallel process, the representative concentration pathways (RCPs) used in modeling to support scientific assessments, such as those of the Intergovernmental Panel on Climate Change (IPCC), represent alternative global greenhouse gas trajectories and land use change projections over the 21st century. Because the objective of the RCPs was to generate scenarios to use in climate change projections rather than to describe alternative socio-economic states, the underlying socio-economic trends have not been extensively analyzed. Instead, the alternative socio-economic futures under the parallel scenario process have been represented by the Shared Socio-economic Pathways (SSPs), which describe alternative global development narratives framed around socio-economic challenges for mitigation and adaptation (O'Neill et al., 2017). In addition, a limited set of quantitative projections for population, gross domestic product (GDP), and urbanization have been developed for each of the SSPs at the national level. However, because the SSP narratives are at the global level, they lack detail regarding many aspects of future socio-economic systems that might be of interest to communities, decision-makers, and stakeholders in the BCB region. Hence, the SSP framework was developed with the intent of developing storyline extensions and downscaled quantitative indicators to provide context for various sectors and regions (Ebi et al., 2014; Absar and Preston, 2015).

At the opposite end of the scenario development spectrum is a range of bottom-up scenario approaches (Rotmans et al., 2000; Kok et al., 2006a,b, 2007; Harrison et al., 2013; Beach, 2015). A key characteristic of these approaches is the participation of stakeholders drawn from the system of interest. Stakeholders provide contextual expertise and experience regarding the system and are also the actors potentially in a position to facilitate or be affected by change. Participation can be enabled through workshops, focus groups, interviews, surveys, or other deliberative techniques. Of these, the scenario workshop is perhaps among the most common. For example, participatory workshops have been used to develop local scenarios for communities in the Mediterranean (Kok et al., 2006b) and East Africa (Chaudhury et al., 2013). They have also been used at national or continental scales as part of integrated modeling efforts (Harrison et al., 2013). In addition to producing beneficial scenario outcomes, the scenarios process itself has ancillary benefits. Scenario workshops enable discussions among participants who may not normally interact, and they facilitate discussions around futures that are seldom considered. Engaging stakeholders and treating them all equally as experts in the process boosts the credibility, relevance, and legitimacy of outputs (Chaudhury et al., 2013).

Although scenarios can be developed at a single level of organization, often there is a need for, or value in, linking scenarios across levels. Top-down scenario processes can be used to provide context or 'boundary conditions' for scenarios at more local levels. Some efforts have focused on downscaling quantitative projections generated by scenarios to more local scales (van Vuuren et al., 2007). For example, the *Special Report on Emissions Scenarios* (Nakićenović and Swart, 2000) generated socio-economic scenarios for use with the IPCC's Third and Fourth Assessment Reports. A number of quantitative indicators were developed as part of that scenario process, but they were confined to large regional aggregations. These indicators were subsequently downscaled to higher spatial resolutions (Gaffin et al., 2004; Bierwagen et al., 2010). Similarly, a number of quantitative indicators have been developed at the national level, consistent with the global SSP storyline (Samir and Lutz, 2017). Other efforts have focused on developing nested narratives that articulate how high-level narratives might manifest at local levels. For example, nested sub-global narratives were developed as part of the Millennium Ecosystem Assessment for 18 locations around the world (Lebel et al., 2005). Similar approaches have been applied to the SSP narratives (Absar and Preston, 2015). Rather than starting from high-level scenarios and working down, it is also possible to conduct a bottom-up, participatory scenario process and then map the resulting scenarios back to other scenarios at higher levels that appear consistent (Absar and Preston, 2015). Such methods enable scenarios that span multiple levels or organizations without placing a priori constraints on bottom-up scenario development.

### 8.2.4 Scenarios in the context of vulnerability, risk, and uncertainty

Scenarios are a particularly valuable method for the Arctic because their focus on the future engages key streams of enquiry related to vulnerability, risk, and resilience (Ford and Smit, 2004; Preston et al., 2011; Absar and Preston, 2015). Such knowledge can subsequently assist in adaptation planning and in the analysis of opportunities and constraints that may influence adaptation processes under conditions of uncertainty (see Section 8.2.4.2). When actors seek to explore future vulnerability, risk, and resilience over the long term, two interacting elements pose challenges that scenarios can address. The first element is that community or ecosystem vulnerability, risk, and resilience are determined by social values and perceptions. Therefore, knowledge of how climate and other environmental conditions could change in the future is often insufficient for understanding community risk and resilience. The second element relates to the inherent 'deep' uncertainty regarding the future, which limits the utility of using prediction to understand risk. In both cases, by expanding the view of possible futures, people today can plan more proactively for adaptation, rather than viewing adaptation as a reactive response to the unknown.

#### 8.2.4.1 Vulnerability, risk, and resilience as social processes

Formal, institutionalized assessments and management of vulnerability and risk have generally followed an expert, science-based regulatory model in which discrete actions are proposed to mitigate against specific risks. For climate change, this approach often manifests as analyses of system responses to different projections of changes in climate variables (e.g., temperature, precipitation, or sea level rise). However, risk and risk management are fundamentally social processes. At a global level, changes in the climate system are a function of the energy use and consumption that contribute to greenhouse gas emissions. Meanwhile, climate vulnerability and risk at the local level are influenced by social, cultural, economic, and institutional contexts and drivers. Hence, climate risk management increasingly recognizes the importance of trade-offs and conflicts among the diverse needs and interests of the public and decision-makers regarding appropriate responses to risk (Klinke and Renn, 2002; Renn, 2008). From a social justice perspective, this recognition is important. Scenarios promote discussion and can also enhance democratic practices by bringing together competing interests to analyze and debate trade-offs related to planning for the future (Box 8.2). This feature of scenarios matters when considering risks and vulnerabilities to climate change or disaster, because the social nature of these challenges is tightly tied to the kinds of information and values used for future planning (Hewitt, 1998; Marino, 2012). The more engaged those affected by decisions across scales are in the process of exploring various *what ifs,* the more likely it is that sustainable and just policies can be crafted.

Accordingly, scholars have attempted to develop guidelines for holistic risk management practices based on distinctions such as type of uncertainty, level of conflict regarding preferred method of prevention, acceptability of outcome, and the actors involved,

**Box 8.2 Scenarios as a tool for enhancing deliberation and democratic practices**

Participatory tools can add value to environmental decision-making processes by increasing their legitimacy and scientific accuracy (Wesselink et al., 2011). Practitioners of social-ecological resilience should seriously consider participatory tools – such as scenario-building workshops – in their efforts to promote resilience in regional systems. This box explores the potential roles of deliberative democratic practices in promoting the social-ecological resilience of rapidly changing regions through participatory tools for futures thinking.

***What is deliberative democracy?***

Deliberative democracy is a framework for decision-making that emphasizes discussion, debate, open-mindedness, and mutual consideration among the individuals who might be affected by a decision at hand. Baber (2004, p. 332) stated that deliberative democracy commonly means "a school of political theory that assumes that genuinely representative public participation in decision-making has the potential to produce policy decisions that are more just and more rational than actually existing representative mechanisms". Gutmann and Thompson (2009) expanded on this definition by offering three specific requisites: deliberators must be free and equal citizens in terms of power and knowledge; deliberators must justify their preferences to one another by giving reasons that all others find acceptable; and the deliberations must reach conclusions that are binding but also open to future deliberation. Deliberation about particular problem domains is often achieved through specific local events or deliberative fora such as citizen panels, deliberative polls (Goodin and Dryzek, 2006), and scenario workshops.

***What are the challenges of deliberative democracy?***

Irvin and Stansbury (2004) used a failed deliberative process to illustrate seven disadvantages of civic participation that can also serve as cautions in designing participatory scenarios processes: (1) financial cost to the organizers and participants, (2) the difficulty of diffusing citizen goodwill (i.e., the resultant policies may be legitimate only to those who participated in the process), (3) the complacency of many citizens and a common aversion to actually deliberating public policies, (4) patrician domination of the deliberative process, (5) the lack of authority to turn deliberative results into policy, (6) the power of wrong decisions (e.g., government representatives may be politically obliged to accept the results of a public panel even if the panel was hijacked by special interests), and (7) the persistence of selfishness (i.e., participants seek only their own self-interest rather than entering deliberations with some openness to changing their minds).

***What are the benefits of deliberative democracy?***

In spite of these challenges noted above, Reed (2008, p. 2,417) found that "there is evidence that stakeholder participation can enhance the quality of environmental decisions by considering more comprehensive information inputs". Baber (2004) argued that special interests (namely large corporations) tend to dominate existing representative mechanisms and that such interests may lack ecological rationality due to their profit-maximizing imperative. In contrast, the general public *does* possess ecological rationality, the author contended, which is engendered by the collective desire for survival. This is particularly true for many Arctic locations where residents rely on subsistence practices, and even those who may not themselves hunt or gather generally remain highly aware of their environment and its effects on well-being (e.g., costs and availability of goods, mobility, or communication). Therefore, deliberative democratic processes can create more ecologically and politically sustainable policies by channeling a public's ecological rationality into government decision-making at a scale appropriate to policy needs.

(see, for example, Klinke and Renn, 2002). Navigating the risk management process is contingent on public engagement and input as well as incorporation and reconciliation of a broad range of values and knowledge systems (Petts and Brooks, 2006; Gooch, 2007). Others have suggested shifting from risk-avoidant formal management processes toward processes that manage risks for resilience when current management practices cannot handle complex issues. Stated differently, new innovative approaches are needed to explore risks and sensitivities when outcomes are uncertain and understanding is lacking on how societies may address both known uncertainties and surprises (Vis et al., 2003; Twigg, 2009; Cardona et al., 2012; Mitchell and Harris, 2012).

These various social dimensions of vulnerability, risk, and resilience highlight the value of scenarios. While biophysical changes in the Earth system are an important driver of future climate impacts, socio-economic changes are also important, perhaps more so when it comes to deciding how to manage socio-ecological change that is rapid and complex. Therefore, alternative narratives about future societal development provide important context for considering the risks of climate change as well as the capacity to manage that risk (see Section 8.5). For example, the SSPs use challenges to mitigation and adaptation as key uncertainties constraining alternative development pathways (O'Neill et al., 2017). This approach reflects the importance of considering not only demographic and economic changes as climate change consequences and responses, but also changes to institutions, governance, and societal preferences for different behaviors and livelihood strategies.

#### 8.2.4.2 Using scenarios to address deep uncertainty

Scenarios are particularly useful for decision-makers when uncertainties about drivers of natural systems or patterns of human development are high relative to stakeholders' abilities to predict or adjust (Schoemaker, 1995; Cavana, 2010); scenarios are also particularly useful when there are strong differences of opinion, with multiple opinions having merit. These circumstances lead to conditions where knowledge regarding both the scale of the problem and the scale and efficacy of potential solutions is limited and even ambiguous. Such conditions are often characterized as deep uncertainty (Kandlikar et al., 2005) or complex risks (Sachs and Wadé, 2013). Forecasts or predictions of such complex risks may be of limited value due to the inherently low confidence in the information. Rather than attempting to predict risks that might arise in the future, scenarios aim to span a range of possible alternative futures and their implications (Duinker and Greig, 2007). Hence, while scenarios do not eliminate uncertainties (Walker et al., 2003), they can help to make uncertainties explicit and to prioritize key uncertainties of particular relevance, thereby assisting in the design of robust strategies for addressing them (Schoemaker, 1995; Klinke and Renn, 2002; Petts and Brooks, 2006; Cavana, 2010). Hence, by using scenarios, "the analytical focus is shifted away from trying to estimate what is most likely to occur toward questions of what are the consequences and most appropriate responses under different circumstances" (Duinker and Greig, 2007, p. 209), and "scenario planning attempts to compensate for two common errors in decision-making – under-prediction and over-prediction of change – allowing a middle ground between the two to be charted" (Duinker and Greig, 2007, p. 210).

A specific category of complex risks relevant to scenarios are those perceived as a surprise relative to available knowledge, evidence, and experience (Aven, 2013). These 'black swans', often called 'wild cards' in scenario development, pose a particular challenge for risk assessment and management because such futures are not necessarily expected or considered likely and statistical information regarding such events may be limited or absent – which means the risk may go unrecognized. Scenario development therefore represents a deliberative process that enables both the identification of potential wild card events and the analysis of their potential implications. This element of surprise is one reason why a diversity of participants in a scenario development process is valuable. Participant diversity can significantly expand the set of futures developed and thus enable exploration of a wider range of risks, planning options, and adaptation strategies.

## 8.3 Overview of scenarios and futures thinking in the BCB Arctic

Scenarios have been used in the BCB region for several decades, including scenario exercises over different spatial and temporal scales as well as for different industry, government, and community-based stakeholders. These prior efforts provide valuable context for understanding the driving forces and uncertainties that are important to different stakeholder communities in the region. Driving forces and uncertainties have important implications for the timing, nature, and magnitude of climate change impacts as well as ecological and societal adaptation. For example, scenarios have been used to identify adaptation options for US National Park Service facilities in Alaska (Winfree et al., 2014a,b) and to help plan the proposed Mackenzie Gas Project in Canada's Northwest Territories (Cizek, 2005; Holroyd et al., 2007). Scenarios were also a key element of the Arctic Marine Shipping Assessment (AMSA) (Arctic Council, 2009), which presented examples of rigorous futures thinking about the Arctic.

This section synthesizes a number of these prior scenario activities to further illustrate how scenarios have been used in different geographies and sectors in the BCB region. In addition, this section identifies common driving forces and uncertainties among different scenario activities that can be instructive for the consideration of climate impacts, resilience, and adaptation elsewhere in this report (Chapters 5–7). In so doing, this discussion relies on publicly available scenarios and thus cannot capture the use of scenario methods in private or corporate settings where the methods and results are proprietary and confidential. However, the synthesis demonstrates the breadth and significance of research and participation in thinking about the future of the BCB region.

### 8.3.1 Pan-Arctic scenarios

Multiple interdisciplinary scenario efforts have targeted broad geographic areas of the Arctic that overlap with, and are therefore relevant to, the BCB region but are not necessarily confined within the BCB regional boundaries (see Section 1.2). Because such pan-Arctic scenarios span large and heterogeneous areas, they often capture high-level driving forces and trends. While useful for identifying global drivers and uncertainties that have regional implications, such scenarios may be less informative for exploring place-based futures for specific locations or communities.

*Arctic Business Scenarios 2020* (Loe et al., 2014) was commissioned by the Norwegian Shipowners' Association and the Arctic Business Council. A second activity (Goldsmith, 2011) was funded by Northrim Bank as part of the Investing in Alaska's Future research initiative led by the University of Alaska Anchorage. Both scenario development processes pursued an expert-judgment approach led by private consultancies and university researchers. As such, the resulting scenarios were largely top-down scenarios, with a strong emphasis on interpreting global energy and economic driving forces in the context of the Arctic, with little bottom-up participation by local communities and stakeholders.

The scenarios of Goldsmith (2011) all explore similar themes. Three of the scenarios represent alternative futures characterized by the ebb and flow of oil revenue. Either fossil energy extraction continues to expand, driving economic development, or fossil-fuel development declines – slowly or in an acute crash. In both cases – expansion and contraction – Alaska's future economy is driven by outside market forces. A fourth scenario articulates a future where Alaska's economy is less tied to trends in global energy markets, as a result of strategic planning by the state to steer development in a way that maximizes benefits for Alaskans.

AMSA stands out as a comprehensive navigation and shipping assessment that extensively applies scenarios and narratives. Partnering with Global Business Network (GBN), the Arctic Council's Protection of the Arctic Marine Environment (PAME) created the AMSA to "systematically consider the long-term social, technological, economic, environmental, and political impacts on Arctic Marine Navigation" (PAME and Global Business Network, 2008). Modeled after GBN's scenario-planning process and facilitated by the GBN, the AMSA involved a diverse set of Arctic maritime experts in scenario planning workshops that served as the basis for the development of scenarios and, later, narratives.

Brigham (2007) described a set of scenarios for the Arctic in 2040, with an emphasis on Alaska. These scenarios reflect future prospects for a number of sectors, including fisheries, oil and gas, and tourism. The four different futures are largely

*Changes in the timing of ice break-up in spring have major consequences for coastal settlements such as Uelen, Chukotka*

distinguished by three factors – the degree of international cooperation in Arctic governance, the degree of local versus global control over decision-making, and a varying emphasis on the principles of sustainability.

### 8.3.2 Place-based and regional scenarios

In contrast to the pan-Arctic scenarios, place-based, local scenario activities have also been pursued within or near to the BCB region. Such scenarios often use local context and concerns as a starting point for bottom-up scenarios development. These efforts may focus on a particular community (e.g., town or village) or a specific ecosystem or landscape.

Working with the Indigenous community of Old Crow, Yukon, Canada, Berman et al. (2004) utilized a hybrid of agent-based modeling and scenarios. Their objective was to determine how climate and economic changes could influence the community's future wages, subsistence, and well-being. The two key factors considered were tourism and government spending, which yielded eight scenarios looking over 40 years ahead. The authors explained that while these eight "job scenarios bracket the likely range of future economic opportunities for Old Crow, the ultimate effects of climate change in the region are highly uncertain" (Berman et al., 2004, p. 409). They go on to point out one clear advantage of a scenarios process: the integration of data from multiple sources and perspectives through community engagement, which does not often happen in disciplinary studies.

Another local-scale participatory research project used qualitative scenarios to address vulnerability and adaptation for the rural, mostly Indigenous, natural resource–dependent community of Fort Resolution, Northwest Territories (Wesche, 2009). The researchers developed a set of four storylines based on the two axes of 'climate change' and 'resource development' – a standard four-quadrant scenario process (Wesche and Armitage, 2014). The scenarios integrated data from multiple sources, including local knowledge about past and current socio-economic and cultural trends, scientific data on past and anticipated climate trends, and accounts of past and prospective resource development projects in the area. This 'actor-oriented' scenario process engaged stakeholders through focus groups, interviews, and an adaptation workshop to identify vulnerabilities and corresponding anticipatory adaptation options. The authors noted that the workshop enabled the participants to better understand their levels of preparedness in terms of adapting to change and identifying barriers to overcome. The scenarios methodology proved useful in shaping a better understanding of the nuances of vulnerability of local stakeholders; incorporating multiple forms of knowledge and perspectives, including Indigenous knowledge; and enabling co-production of knowledge to better inform and develop bottom-up adaptation strategies to address imminent change. Such participatory processes have the potential to enhance Indigenous engagement in environmental governance processes, which is key to achieving a sustainable future for the Arctic.

Multiple place-based scenario development activities can be integrated to provide a regional perspective that captures underlying contexts at more local scales. For example, as part of the US National Park Service's Climate Change Response Program, the agency's Alaska Region led a scenario-based planning activity in natural resources and conservation management (Winfree et al., 2014a,b). This activity included five climate change scenario planning workshops conducted between 2010 and 2012, three of which included a focus on Arctic regions – the Interior Arctic, Northwest Coast, and Central Alaska Parks scenarios workshops (Moore et al., 2013; NPS, 2014).

Resource development scenarios are frequently described in permitting and environmental compliance assessments by regulatory agencies to investigate the potential cumulative impacts of resource developments that may occur in the future. For example, scenarios are often used in environmental impact statements, specifically for their utility in cumulative effects assessments to explore uncertainties and consequences of alternative futures (Duinker and Greig, 2007; Greig and Duinker, 2007). It is important to highlight that in such cases, even though low-development scenarios are possible, more emphasis is placed on considering a broad range of development activities in a region and their potential impacts. The use of the term scenarios in this sense may also be misleading, as the outcomes may be more accurately described as projections (see Box 8.1) of, for example, numbers of wells and drilling pads or lengths of new roads built (National Research Council, 2003; BLM, 2012; BOEM, 2015). Technical innovations and estimated geological distributions of resources may also be considered in the generation of these scenarios, but rarely is the full range of drivers explored, and as a result, broader narrative discussions are not provided. However, the Mackenzie Gas Project (Canada) is one example where experts advocated extensively for scenario analyses during the review process to explore possible development trajectories and socio-economic and environmental impacts (Greig and Duinker, 2007; Holroyd et al., 2007).

More recently, the North Slope Science Initiative (NSSI) used a scenarios approach to determine a range of plausible resource extraction activities and supporting activities on Alaska's North Slope and adjacent seas through the year 2040. Twenty-five years was chosen as a reasonable future time frame – one in which uncertainties make resource extraction activities difficult to predict, but not so far into the future as to render the scenarios ineffective at helping resource managers to address strategic research and monitoring needs. A spatially explicit component of the NSSI scenarios project was important to help member agencies plan research and monitoring needs into the future. Such science-based research prioritization was recognized following an assessment of more than a dozen emerging issues relevant to North Slope resource managers (Streever et al., 2011). The NSSI project used a participatory scenarios process that incorporated multiple views from a range of experts and stakeholders from local communities, nongovernmental organizations, industry, academia, and federal, state, and local agencies. The first step involved obtaining feedback from a range of experts and stakeholders on key drivers of change. Given the range of interests and stakeholders consulted in the iterative survey process, the list included not only economic drivers (e.g., the price of oil and gas) but also socially relevant drivers (e.g., community environmental health), biophysical drivers (e.g., sea ice change, climate change, and erosion), and political and regulatory drivers (e.g., global political stability and the regulatory environment). Outcomes from this scenarios work included the public release of scenario narratives and the corresponding spatial data that describe the implications of the scenarios, as well as the research and monitoring needs related to scenario implications (Vargas Moreno et al., 2016).

The Northern Alaska Scenarios Project (NASP) was developed to help identify and synthesize input related to the future of healthy sustainable communities by engaging expert residents of the North Slope and Northwest Arctic boroughs (University of Alaska Fairbanks, 2016). This project used a participatory scenario workshop process to foster effective communication among these experts across different interests, such as education, justice, mental and physical health, subsistence, Iñupiaq values, and business development. A series of three workshops in 2015–2016 brought people together from both boroughs to share creative strategies for the next few decades so that those living in Arctic Alaska can proactively shape their futures.

### 8.3.3 Synthesis of BCB scenarios

Among the aforementioned scenario activities, the top-down scenarios of Goldsmith (2011) and Brigham (2007) sought to be comprehensive by addressing multiple economic sectors and governance arrangements. However, the majority of scenario development processes have been more focused, in order to address a particular stakeholder community at the scale of its concerns. For example, several sets of scenarios have targeted the issues of energy and resource development or Arctic navigation. Other scenario activities have focused on specific communities within the region, rather than a particular economic sector. Community-focused scenarios therefore provide more place-based insights regarding what aspects of change are perceived as being particularly important or uncertain relative to large-scale, top-down scenarios.

Existing BCB scenarios reflect a range of methodological approaches. For example, participatory scenario development processes (e.g., NSSI and NASP) have been used to engage sector or community stakeholders. Such scenarios are consistent with the bottom-up approaches discussed in Section 8.2.3. Other BCB scenario activities have been top-down in that they were developed largely by sectoral, often non-resident, experts and may lack a diversity of perspectives or local context. For example, scenarios for the Alaska business environment (Goldsmith, 2011) have been generated by teams of experts. Still other scenarios have been generated largely through the use of quantitative models. Berman et al. (2004) used agent-based modeling in conjunction with qualitative scenarios to determine how climate and economic changes could influence local wages, subsistence, and well-being. Meanwhile, Mueller-Stoffels and Eicken (2011) used computer software designed for scenarios to perform robustness analysis on the AMSA workshop process after it ended. The goal was to create a more informative set of data than a four-quadrant analysis alone could provide. They were able to refine, through an examination of the plausibility and consistency of key factors, the narratives and possible scenarios that AMSA produced, thus demonstrating the important role of regional factors in the discussion of global shipping.

Each BCB-relevant scenario activity identifies driving forces or uncertainties that are key shapers of the region's future socio-economic systems. Despite using different methods and focusing on different sectors and stakeholder communities, the different scenario activities identified a number of common drivers. In particular, future demands for Arctic energy resources were identified as a key factor affecting the future of the energy sector as well as future shipping and navigation and environmental sustainability. Regional economic development and globalization, another common theme across scenarios, were closely tied to energy demand. Governance and the role of institutions were also frequently identified as important drivers of the future of national security, marine navigation, local community capacity, future business activity, and environmental sustainability. In addition to key driving forces, the Arctic marine navigation scenarios (Arctic Council, 2009) identified a range of 'wild cards' to consider – natural disasters, shifts in geopolitics, abrupt climate change, or technology breakthroughs (Section 8.2.4).

**S1: Regional Development**

- Global energy demand drives growth in oil and gas extraction in the Bering and Chukchi Seas
- Revenue from energy resources and mining supports community development and infrastructure that are accompanied by population growth and economic diversification
- National, bi- and multi-lateral agreements increase and open up the region for global investment while modest environmental protections seek to avoid significant externalities
- Strong environmental regulations exist, but there is increasing pressure for exploitation of fisheries in the warming Bering and Chukchi seas
- Indigenous communities have greater autonomy in local and regional governance, but coastal communities along the Chukchi and Beaufort Seas are increasingly at risk from sea-level rise
- Economic growth enables public and private investments in adaptation planning and implementation that enhance community resilience and the capacity of natural ecosystems to adapt naturally to the changing climate

**S2: Regional Inequality**

- High energy prices drive continued expansion of regional energy extraction including offshore development in the Bering and Chukchi Seas and opening of the Arctic National Wildlife Refuge
- Economic boom creates jobs and provides revenue for state/provincial/district and municipal governments
- Competition for access to marine resources drives conflicts between Russia, Canada, and U.S.
- Environmental protections are rolled back to enable resource extraction to proceed unimpeded, resulting in increasingly vulnerable fisheries and wildlife
- Indigenous communities benefit from economic growth at the expense of autonomy, traditional livelihoods and knowledge
- Adaptation efforts focus on maintaining the continuity and productivity of the energy sector, resulting in positive spillover effects for communities, but significant reduction in the adaptive capacity of natural ecosystems

**S3: Regional Sustainability**

- Climate change and technological changes in the global energy sector slow investments in the region's oil & gas resources
- Modest but steady, economic growth, with particularly rapid expansion of the tourism sector
- National, bi- and multi-lateral agreements increase environmental protections associated with oil and gas exploration, mining, navigation, and fisheries
- Commercial fishing opportunities in the Bering and Chukchi Seas are curtailed and increased land is set aside for protection and conservation
- Increased opportunities for indigenous communities to influence decision-making spurs calls for greater autonomy, community-based economic growth, and a resurgence of traditional livelihoods
- Modest economic growth and modest climate change impacts drive attention toward ecosystem-based adaptation as a mechanism for jointly increasing the resilience of natural and human systems

**S4: Regional Fragmentation**

- Lower energy and resource demand suppresses energy prices and regional investment in oil and gas extraction
- Economic growth is slow due to low energy and commodity prices while attempts at economic diversification are largely unsuccessful
- Regional tensions among governments are high as nations are unable to resolve disputes over resource access, which further discourages private investment
- Environmental protections are poorly enforced and uncoordinated with some protections suspended in the interest of economic development
- Opportunities for indigenous communities deteriorate as they are marginalized from both the larger economy and decision-making by formal governments
- Public and private actors are quite limited in their capacity to adapt in the face of multiple environmental and socioeconomic risks, resulting in short-term decision-making and maladaptive behaviors

Figure 8.1 Summary of socio-economic scenarios for the BCB region, based on a synthesis of prior scenario activities from the region.

## 8.4 Framing scenarios for the BCB region

The existing BCB scenarios provide a useful foundation for developing a coherent set of new scenarios to inform discussions of impacts, resilience, and adaptation. For example, the key dimensions of *global energy demand & economic growth* and *institutions & governance* can be used as axes to define four alternative future socio-economic states (Figure 8.1). These axes can be thought of as 'axes of uncertainty'. It is important to remember that plausible futures need not be a result of only two axes and their four quadrants, but this method is a commonly used one. Furthermore, different scenarios methods may produce more or less plausible and more or less internally consistent results, depending on the goals (Walsh et al., 2011). For example, the ongoing NASP work on healthy sustainable communities (Section 8.3.2) is using 21 key factors derived from resident expert participation and does not reduce them to two axes. When the data are fully analyzed, the plausible futures produced will be rich and, compared to an outcome based on fewer key factors, will provide more information about the plausibility of each factor and the relationships of different uncertainties to one another.

Figure 8.1 presents a simple four-quadrant scenario for the BCC region using two themes emphasized by Arctic experts and stakeholders from various sectors: energy demand and governance. This is then down-scaled for each subregion to illustrate the importance of scale to futures thinking. Different combinations of the two elements can be used to explore alternative plausible socio-economic futures relevant to BCB regional and local concerns.

### 8.4.1 Focal questions for the BCB scenarios

For the purposes of developing scenarios relevant to the BCB region, the following focal questions were considered:

> *What do regional and subregional scenarios reveal about the influence of socio-economic factors on the future of the BCB?*
>
> *What are the implications of BCB scenarios for regional impacts, resilience, and adaptation?*

The first question is addressed in Section 8.4.2 through a suite of illustrative scenarios based on prior and ongoing scenario activities at both the regional and local/place-based levels. These scenarios describe the key social, economic, and environmental factors that will shape the future of the BCB region, as well as the uncertainties associated with how those factors may evolve over time. The second question is addressed in Section 8.5.

In designing scenarios processes and using their outputs, careful attention must be paid to the focal question and the scale of the inputs. Scenarios processes designed primarily to stimulate narratives about what the world may look like and to get people thinking may not be appropriate for siting observational equipment, organizing monitoring schemes, or formulating policy. As noted in Section 8.2, scenarios come in many forms. The research and policy planning needs of the Arctic can draw on many different types of futures thinking, but the scale must match the research question, especially if adaptation planning is the primary concern. The focal question serves as a research question for the participants, whether they are distant experts working with data sets or community participants addressing local concerns. It is through this singular question that key factors – system drivers – are evaluated.

The scenarios presented in Section 8.4.2 did not stem from a participatory process, but are illustrative of how regional uncertainties can be evaluated to explore possible futures. Consequently, the two questions at the start of this section were used as focal aids. This focus led to the identification of two key uncertainties that became the axes for the scenarios. The same axes are used for the regional scenario (shown in Figure 8.1) and the subregional scenarios (presented in the following section), yet the content of the scenarios changes with the focus on more levels. While this is an informed thought experiment, it should be noted how the scenarios differ and that results from participatory or industry-expert scenarios processes would offer those concerned with energy production a much more robust view of possible futures for the region.

### 8.4.2 BCB regional scenarios for 2050

At the scale of the BCB region, two key socio-economic uncertainties appear to be critical for shaping the future: (1) global energy demand and economic growth and (2) institutions and governance. The resulting scenarios are tightly tied to climate-related changes as well as other social, cultural, and economic changes that are ongoing in the circumpolar North. For simplicity, however, this exercise uses two axes that are socio-economic (Figure 8.1) to make explicit the policy and planning value of scenarios for the Arctic, within the context of environmental changes reported in the other chapters. A key utility of scenarios is the ability to shift the perspective on the future. For example, it would be possible to replace either axis with 'climatic changes' and reveal a different narrative about the possible futures of the BCB region.

The first uncertainty is the global demand for energy and other resources (Figure 8.1, vertical axis), which is largely a function of the future evolution of global energy technologies and markets (Sections 4.5.3–4.5.4). This uncertainty was highlighted in several BCB scenario activities. At the upper end of this axis of uncertainty, higher global demand and prices, particularly for natural gas and oil resources, are assumed to drive greater investments in extracting BCB resources, particularly offshore oil and gas in the Bering and Beaufort seas around northern Alaska and Canada. However, the volatility of demand, as well as shifts to alternative sources of energy, could slow the development of offshore resources, increasing pressure to exploit onshore resources. In addition, global demand for energy resources is likely to be accompanied by greater demand for commodities more generally (Section 4.5.4), suggesting growth in investment in mining in both Chukotka and Alaska. Because energy resources and commodities are important drivers of BCB regional economies, higher demand for energy is anticipated to be accompanied by more rapid rates of economic growth. In contrast, lower global demand for energy, due to shifts away from fossil resources or overall slowing of the global economy (lower end of the vertical axis), would reduce investment opportunities for energy and other commodities in the BCB region – which would have direct implications for the overall economy of the region, even with efforts toward economic diversification. The unexpected 2014 crash of the oil market has already caused changes in industry production, government budgets, and regulatory frameworks.

The other key uncertainty that arises from prior BCB scenario activities is associated with the role of institutions in governing the BCB (horizontal axis in Figure 8.1) – such as national governments, state/territory/district governments, Indigenous organizations, tribal and municipal governments, and individual communities (Section 4.5.2). Furthermore, the private sector plays an important role in influencing investment, infrastructure development, and strategic planning. Most of the prior BCB scenario activities make a clear distinction between futures based on collaborative governance arrangements and those based on more competitive outlooks. Collaborative governance includes cooperation among national governments to resolve disputes regarding territorial boundaries, rights-of-way for shipping, and transboundary externalities of natural resources management practices. At its strongest, collaborative governance also includes the sharing of power among different levels of government within nations, including participation of Indigenous communities and organizations. Such forms of governance are often based on suites of regulations and are enforced by formal rules such as treaties, legislation, and policies that specify actions, responsibilities of different actors, and sanctions in the event of non-compliance. In contrast, governance based on competition generally precludes such cooperation except to establish market conditions. In general, institutions in a competitive system operate with a strong aversion to risk, which inhibits sharing of power, behavioral change, and possibly investment, even when such decisions could create positive benefits. At its strongest, competitive governance is a regime with few regulations across levels of governance and with low levels of concern about regulatory enforcement.

As with a number of the earlier BCB scenario activities, these two axes of uncertainties can be used to frame future scenarios for the BCB region as a whole. At this aggregate scale, such scenarios are quite general, focusing on a common set of key issues that are strongly connected to these uncertainties. These issues include regional energy futures, economic development, the environment, governance, and Indigenous communities. The four resulting scenarios, which are largely informed by aspects described in prior studies relevant to the region, reflect quite disparate socio-economic futures. Each scenario suggests different upsides, downsides, and trade-offs, but each can be considered plausible given historical events and the inherent uncertainty of the future. More importantly, the consequences of climate change in each of these futures would also vary, because the futures differ in their implications for vulnerability, adaptive capacity, and resilience.

The BCB region is not, however, homogenous in terms of its climate, natural resources, landscapes, or people. Therefore, the driving forces, values, and uncertainties that emerge from considering scenarios at the scale of the BCB region are not necessarily the same as those that emerge at local levels. It is therefore important to explore how the same axes in different geographic areas produce different outcomes. This utility is illustrated for the three different subregions of the BCB: Chukotka, Russia (Section 8.3.2.1); northern Alaska, United States (Section 8.3.2.2); and Beaufort, Canada (i.e., northwestern Canada; Section 8.3.2.3). For each subregion, current conditions are summarized based on the preceding chapters (particularly Chapters 3 and 4) to provide context, and each is accompanied by a graphical representation of the scenario outcomes that provide a forward-looking subregional perspective. Throughout, the key axes of uncertainty are preserved in order to maintain some internal consistency in scenarios across the different levels and different locations.

### 8.4.2.1 Subregional scenarios: Chukotka, Russia

Chukotka Autonomous Okrug (CAO) is situated in the northeast of Russia. The geography of Chukotka, with its far north location and severe climate, to a large extent defines the past and future socio-economic development patterns of this area of Russia.

In 2014, the population of Chukotka was 50,555 (CAO, 2015). At the end of the 1980s, it had exceeded 150,000 but then declined rapidly during the post-Soviet era. According to current forecasts, the population of Chukotka is expected to decline to 36,000 by 2030 (Section 4.5.1). About 70% of the Chukotka population resides in the cities. During the 2000s, an upward trend in the proportion of the population living in urban areas was reported (CAO, 2015), and this trend is forecast to continue into the future.

The Indigenous population in Chukotka constitutes about 35% of the region's total population (CAO, 2014b). The main occupations of the local Indigenous people are reindeer herding, fishing, and hunting. Although the number of reindeer has declined sharply – from 500,000 in the Soviet period to less than 200,000 currently (Section 5.2.3) – the prospects for processing and selling reindeer products such as meat, leather, cheese, and clothing are encouraging, as are the economic prospects associated with fisheries and fish processing. In 2013, total Chukotka exports were approximately USD 90 million, with exports of fish products (40% of total exports) almost equal in value to the export of mineral resources (mostly gold-containing concentrates). In 2014, total exports increased to USD 138 million, with the dominant share (95%) coming from gold-containing concentrates from high-grade deposits at the Mayskoe mine (CAO, 2014a); in 2015, gold accounted for more than 98% of Chukotka's total exports.

Today, the stability of Chukotka's energy sector is provided by the Bilibino nuclear power station, which has a capacity of 48 megawatt electric (MWe) (International Nuclear Safety Program, 2004). This plant is planned to be decommissioned by 2020. In 2016, construction began on coastal infrastructure for a new floating nuclear station (70 MWe and 50 gigacalories per hour) that is planned to go into operation in 2019 (Rosatom, 2016). For areas outside the Bilibino grid, local heat and electricity suppliers use local coal deposits to cover current demand; these supplies are expected to also meet future demand over the next decade.

The mining industry is the leading economic sector in Chukotka, owing to large deposits of oil and gas, coal, gold, copper, tungsten, and other minerals. Gold mining alone generated approximately 20 tonnes annually from 2008 to 2013, and over 30 tonnes in 2014 (Ernst and Young, 2015). Production of tungsten and tin stopped during the post-Soviet period. Taking into consideration current trends in the world oil and gas market, increased oil and gas development is anticipated for the polar areas of Chukotka. Other types of mining are highly contingent upon progress in transport infrastructure development, which could significantly reduce the costs of delivering product to consumers. In 2012, construction began on a new Kolyma-to-Anadyr highway, which is expected to provide an important land-based connection between Chukotka and the rest of Russia's Far East and with future Asia-Pacific export markets.

Investments in the economic development of Chukotka are channeled through a number of federal programs and foreign investors. During Roman Abramovich's tenure as governor of Chukotka (2000–2008), foreign investments into Chukotka's regional economy increased by up to USD 200 million. The major investments were channeled from the United States, Canada, South Korea, and Cyprus. If recent Western economic sanctions against Russia are continued, then the profitability of economic development in Chukotka will be undermined due to reduced foreign investment and disruption of supply chains. In recent years, foreign investment has declined to several million dollars from its high levels of a decade ago. In 2014, foreign investments constituted about 11% of the investments in fixed capital (CAO, 2015).

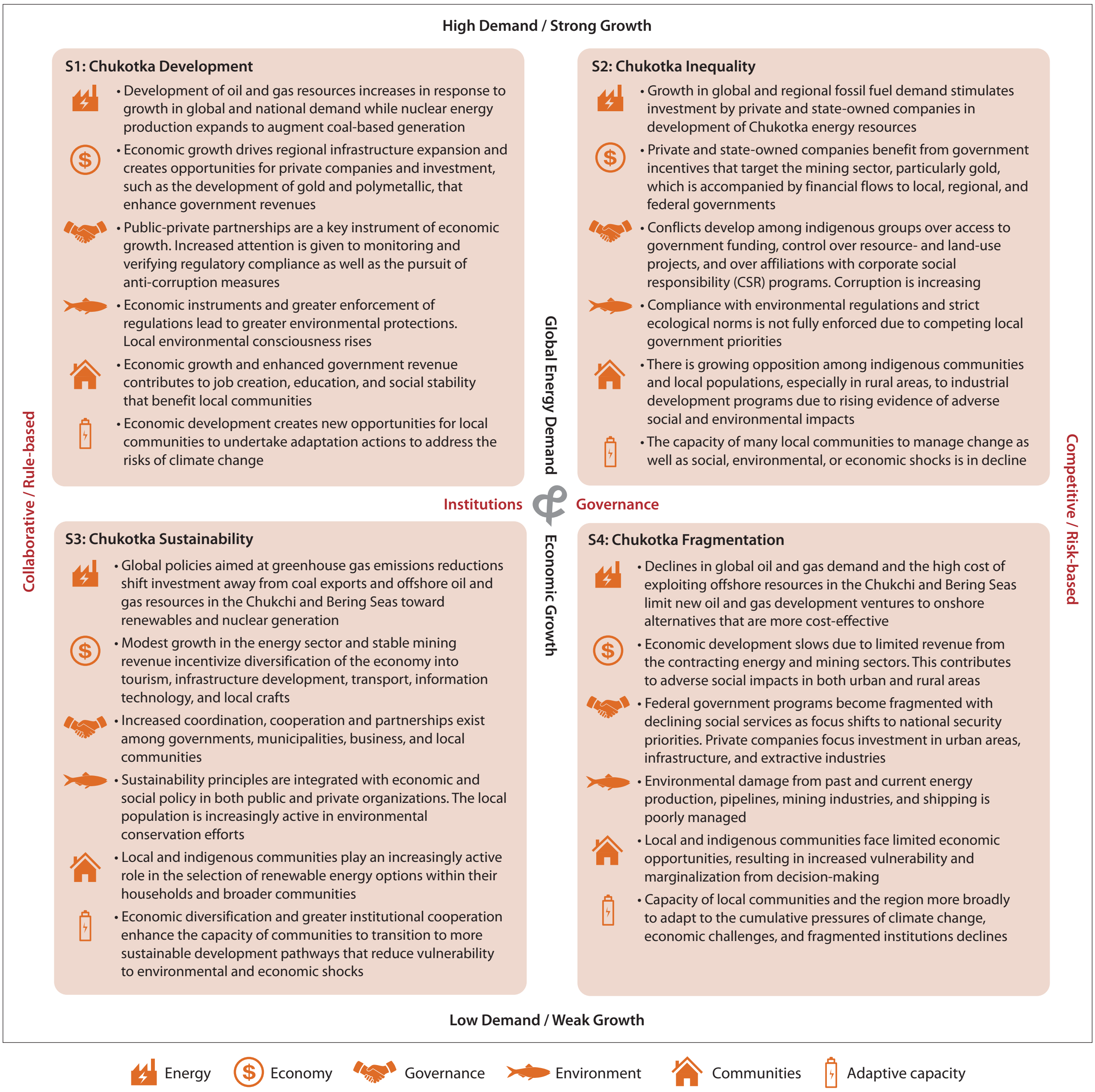
Currently, a fragile balance is maintained between the natural systems and economic development of Chukotka. Regular monitoring and scientific assessment of a range of challenges related to Chukotka's development is essential to avoid negative consequences of climate change.

The AACA illustrative socio-economic scenarios for the Chukotka subregion are shown in Figure 8.2.

### 8.4.2.2 Subregional scenarios: Arctic Alaska, US

The Arctic in the United States is located entirely in the state of Alaska, which borders the territory of Yukon, Canada, to its east and shares the Bering Strait with Russian Chukotka to its west. Communities in the Alaskan Arctic are defined primarily as coastal but do include inland populations on tundra and the edges of the taiga. The subsistence livelihood activities that continue to be important in these areas are influenced by the physical geography. Thus, the Iñupiat on the coasts rely on whaling (e.g., bowhead, beluga) and other marine resources, while inland communities rely more heavily on caribou. To the east, around the Seward Peninsula, walruses account for the majority of marine harvests.

This subregion is made up of two public governments or boroughs, whose populations are predominantly Indigenous, mostly Iñupiat, plus an unincorporated census area. The North Slope Borough, with a population of approximately 9600 (US Census Bureau, 2015), has its hub in Utqiagvik (Barrow) and is home to the massive infrastructure surrounding the Prudhoe Bay oil fields. The Northwest Arctic Borough, with about 7700 residents (US Census Bureau, 2015), is home to the Red



**S1: Chukotka Development**

- Development of oil and gas resources increases in response to growth in global and national demand while nuclear energy production expands to augment coal-based generation
- Economic growth drives regional infrastructure expansion and creates opportunities for private companies and investment, such as the development of gold and polymetallic, that enhance government revenues
- Public-private partnerships are a key instrument of economic growth. Increased attention is given to monitoring and verifying regulatory compliance as well as the pursuit of anti-corruption measures
- Economic instruments and greater enforcement of regulations lead to greater environmental protections. Local environmental consciousness rises
- Economic growth and enhanced government revenue contributes to job creation, education, and social stability that benefit local communities
- Economic development creates new opportunities for local communities to undertake adaptation actions to address the risks of climate change

**S2: Chukotka Inequality**

- Growth in global and regional fossil fuel demand stimulates investment by private and state-owned companies in development of Chukotka energy resources
- Private and state-owned companies benefit from government incentives that target the mining sector, particularly gold, which is accompanied by financial flows to local, regional, and federal governments
- Conflicts develop among indigenous groups over access to government funding, control over resource- and land-use projects, and over affiliations with corporate social responsibility (CSR) programs. Corruption is increasing
- Compliance with environmental regulations and strict ecological norms is not fully enforced due to competing local government priorities
- There is growing opposition among indigenous communities and local populations, especially in rural areas, to industrial development programs due to rising evidence of adverse social and environmental impacts
- The capacity of many local communities to manage change as well as social, environmental, or economic shocks is in decline

**S3: Chukotka Sustainability**

- Global policies aimed at greenhouse gas emissions reductions shift investment away from coal exports and offshore oil and gas resources in the Chukchi and Bering Seas toward renewables and nuclear generation
- Modest growth in the energy sector and stable mining revenue incentivize diversification of the economy into tourism, infrastructure development, transport, information technology, and local crafts
- Increased coordination, cooperation and partnerships exist among governments, municipalities, business, and local communities
- Sustainability principles are integrated with economic and social policy in both public and private organizations. The local population is increasingly active in environmental conservation efforts
- Local and indigenous communities play an increasingly active role in the selection of renewable energy options within their households and broader communities
- Economic diversification and greater institutional cooperation enhance the capacity of communities to transition to more sustainable development pathways that reduce vulnerability to environmental and economic shocks

**S4: Chukotka Fragmentation**

- Declines in global oil and gas demand and the high cost of exploiting offshore resources in the Chukchi and Bering Seas limit new oil and gas development ventures to onshore alternatives that are more cost-effective
- Economic development slows due to limited revenue from the contracting energy and mining sectors. This contributes to adverse social impacts in both urban and rural areas
- Federal government programs become fragmented with declining social services as focus shifts to national security priorities. Private companies focus investment in urban areas, infrastructure, and extractive industries
- Environmental damage from past and current energy production, pipelines, mining industries, and shipping is poorly managed
- Local and indigenous communities face limited economic opportunities, resulting in increased vulnerability and marginalization from decision-making
- Capacity of local communities and the region more broadly to adapt to the cumulative pressures of climate change, economic challenges, and fragmented institutions declines

Figure 8.2 Socio-economic scenarios for the BCB subregion: Chukotka.

Dog zinc mine, which is its major industry. In each borough, there are fewer than 20 small, primarily Indigenous, villages. The Nome Census Area, which encompasses much of the Seward Peninsula on the Bering Strait, is unincorporated, with a population of roughly 9800 people (US Census Bureau, 2015).

Land ownership in this subregion is mixed: state government, Alaska Native Corporations and other private landholders, and federal government. The result is a complex patchwork of governance related to social policies, environmental management, and extractive industries and other economic development. In 1971, the Alaska Native Claims Settlement Act (ANCSA) was passed in response to the combined pressure of mounting Native land claims and the desire to settle land disputes to encourage construction of a trans-Alaska oil pipeline. Rather than designating reservations, the passage settled claims to the land through the creation of 12 regional corporations and a 13th at-large corporation in addition to over 200 village corporations, which collectively received roughly 45 million acres of land and a billion US dollars (Linxwiler, 2007). Village corporations received surface rights to their land while regional corporations received surface and subsurface rights – a differentiation that has proven to be significant. Because regional corporations own the resources under their lands (e.g., oil and gas), they can profit accordingly. Village corporations, on the other hand, are restricted to taxing the industrial activities that occur on the surface of their lands (e.g., mining, oil and gas infrastructure).

After ANCSA, the next major shift in land management occurred in 1980, with Congress's passing of the Alaska National Interest Lands Conservation Act (ANILCA), which appropriated 104 million acres of federal land for the US conservation system, with 56 million of those acres being designated as 'wilderness', the most protected federal status. This law, as well as those that preceded it, however, has left many stakeholders unsatisfied with land ownership and management in Alaska. Currently, about 60% of Alaska is under federal ownership and 28% is owned by the State of Alaska; Native corporations own 12%, and other

**S1: Alaska Development**

- Global demand for energy drives technological innovation, expansion of offshore oil and gas development as well as increased pressure to exploit onshore resources
- The competitiveness of the Arctic Alaska energy sector generates large economic benefits for boroughs and Alaska native corporations as well as the state and federal governments
- Public-private partnerships and streamlined regulations with participation by local and tribal governments accelerate investment and economic benefits
- Safety and sustainability are top priorities for the oil and gas industry, which helps to minimize environmental impacts
- Economic development enables indigenous communities to pay for expensive remedial adaptation actions in response to climate change, but communities are divided regarding the costs and benefits of the oil and gas industry
- Generally, adaptive capacity of many communities expands with regional economic success, yet some actors worry about long-term sustainability

**S2: Alaska Inequality**

- Growth in the global demand for fossil fuels stimulates significant private investment in Alaskan energy development and the opening of the Arctic Natural Wildlife Refuge to development
- Private industry benefits from state and federal incentives with revenue from oil and gas leases flowing back to state and federal government
- The state of Alaska and native corporations scramble to entice private industry to continue development on their land rather than taking advantage of federal leases
- Environmental protections are eroded over the objections from Alaskans, indigenous communities, and environmental organisations
- Native communities voice strong opposition to development trends that are perceived to offer little in the way of economic benefits that can assist with adapting to the impacts of extractive industries and climate change impacts
- Although the energy boom enhances capacity of private firms and government institutions, that capacity is not consistently applied to the benefit of all, and natural ecosystems lose capacity

**S3: Alaska Sustainability**

- Global policies favoring greenhouse gas mitigation reduce the profitability of Arctic Alaskan resources and limit industry interest to Prudhoe Bay and areas with existing infrastructure
- Declining revenues, outmigration, and the costs of climate change impacts force Alaska to explore other industries such as tourism and information technology
- With the decline of the oil and gas industry, the U.S. government's interest in Alaska is confined to Arctic security. This catalyses a collaborative approach to governance among state, regional, indigenous, and local institutions
- The reduced importance of oil and gas and the desire to conserve other natural resources incentivizes strong environmental protections
- Indigenous communities establish a strong role in the energy regulatory process that generates new opportunities for renewable energy enterprises
- Economic diversification increases opportunities for climate-resilient development pathways that integrate economic growth and environmental protection

**S4: Alaska Fragmentation**

- With a waning global demand for fossil fuels, Alaska Arctic oil and gas development is no longer seen as a viable industry, with developments in the continental U.S. being cheaper to operate
- Reduced oil revenues slow economic growth and adversely affect abilities to adapt to climate change. This leaves the state of Alaska and indigenous communities vulnerable to climate variability and change
- Private industry seeks new opportunities in renewable energy with a focus on first serving highly populated urban areas where demand will likely generate the greatest return on investment
- Increasing, but poorly regulated, marine shipping traffic adversely affects subsistence hunting
- Indigenous communities are harmed by the slowing economy and their marginalization from the limited economic opportunities
- Both native Alaskans and natural ecosystems and resources are increasingly vulnerable to climate change as well as socioeconomic trends that encourage opportunistic exploitation of resources and discourage cooperation

Figure 8.3 Socio-economic scenarios for the BCB subregion: northern Alaska.

private owners hold 1% (Hull and Leask, 2000). Because ANCSA conveyed corporate land instead of reservation land, the option of tribal jurisdiction was extinguished. The inherent rights of individuals have remained protected through Congressional and federal court action, and there is a 'rural preference' for subsistence on federal lands. Most recently, in 2014, the Department of the Interior's Bureau of Indian Affairs issued final rule 25 CFR (Code of Federal Regulations, Title 25), which deletes the 'Alaska Exception' and permits land to be taken into trust through the Secretary of the Interior, essentially permitting the creation of 'Indian Country' in Alaska (BIA, 2014).

The dominance of extractive resources for the Arctic boroughs' revenue means heavy reliance on the prices of minerals and the demand for oil and gas products on the world market. For example, in 2006, the North Slope Borough revenue from local taxes was USD 189 million, and Red Dog Mine paid USD 8.6 million into the Northwest Arctic Borough (Goldsmith, 2008). These revenue streams tie these boroughs tightly to regulatory regimes related to extractive industries and the affiliated concerns of environmental quality, jobs development, and coastal management.

The AACA illustrative socio-economic scenarios for the northern Alaska subregion of the BCB are shown in Figure 8.3.

### 8.4.2.3 Subregional scenarios: Beaufort, Canada

The western Canadian Arctic encompasses the Northwest Territories (NWT) and the smaller territory of Yukon, which borders Alaska to its west. Of Yukon's 37,642 total population, approximately 21% are Indigenous (Yukon Government, 2016); of the NWT's 44,469 population, approximately 50% are Indigenous (Government of the Northwest Territories, 2016). This subregion of the BCB includes a significant number of small, primarily Indigenous (Inuit, First Nations, and Métis) communities. Communities in the northern tundra region of the NWT are primarily coastal and are predominantly inhabited by Inuit, whereas those located inland in taiga and boreal ecosystems – including the entire territory of Yukon and much of the NWT – are predominantly inhabited by First Nations and Métis. Subsistence livelihood activities continue to be important in these regions and are linked to ecological conditions. As such, Inuit communities rely heavily on marine systems for harvesting and travel, while First Nations and Métis rely on forest and freshwater systems.

Since Yukon and NWT are not fully-fledged provinces, the Government of Canada has long played a dominant role in territorial decision-making. However, many responsibilities have been devolved over the past decades, including significant authority and responsibility for public lands, water, and resource management. While the Government of Yukon has held some control and garnered revenues from the oil and gas sector since 1993, the territorial government formally took over responsibility for land, water, and resource management in 2003 when the Yukon Act came into effect (INAC, 2013). In the NWT, a similar devolution of responsibilities took effect in 2014, including stipulations for resource revenues for both the NWT and Indigenous government signatories (primarily those with settled land claims) (Government of the Northwest Territories, 2015).

Indigenous rights and title to land are increasingly being recognized, and this subregion includes a patchwork of Indigenous cultures and associated land claims. In Yukon, an overarching Umbrella Final Agreement of the Yukon Land Claims package was finalized in 1990 among the governments of Canada and Yukon and the territory's 14 First Nations. To date, 11 of the 14 First Nations are self-governing (Council of Yukon First Nations, 2016). In the NWT, negotiations among Indigenous groups and the federal and territorial governments around land, resources, and governance began in the 1970s (INAC, 2007). To date, three comprehensive land claims have been settled, including Inuvialuit (1984), Gwich'in (1992), and Sahtu Dene and Metis (1993); however, negotiations regarding self-government provisions are ongoing in these areas (with the exception of one Sahtu district, Deline, which ratified a self-government agreement in 2014). An additional comprehensive claims agreement that includes self-government provisions was completed in the Tlicho region in 2003. Other groups' claims in the central and southern NWT are still under negotiation (INAC, 2007).

As such, there is a growing awareness of propriety, and efforts are being made to effectively consult and incorporate all stakeholders, including Indigenous peoples, in strategic planning for various sectors of the Northwest Territories (e.g., water, poverty alleviation, economic development). Indigenous governments are becoming more assertive in demanding that their rights be considered and implemented, and Indigenous groups are forming around specific business and development opportunities (e.g., Aboriginal Pipeline Group, Northern Aboriginal Business Association).

The AACA illustrative socio-economic scenarios for the Canada subregion of the BCB are shown in Figure 8.4.

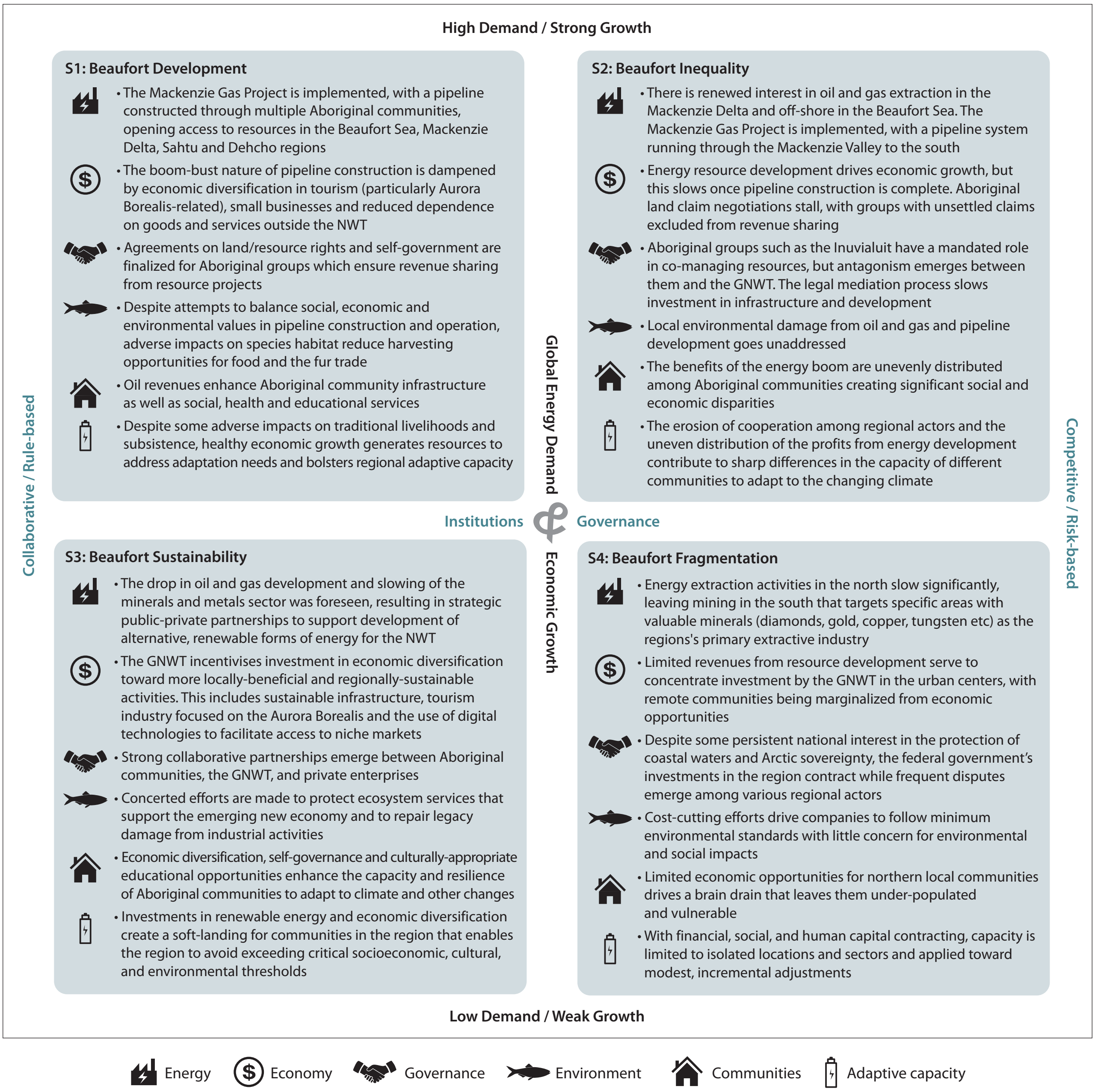
## 8.5 Scenario implications for impacts, resilience, and adaptation

The Arctic is currently facing, and will continue to face, unprecedented rates of environmental and social change in the near future as well as over the long term. The various socio-economic scenarios outlined for the BCB region as a whole (Figure 8.1) and the BCB subregions of Chukotka, Alaska, and Beaufort (Figures 8.2–8.4) reflect alternative trajectories along which these regions and communities could plausibly evolve. Such alternative futures reflect the potential for quite disparate consequences of future climate change as well as disparate capacities of regions, states, and local communities to adapt in order to avoid or reduce those consequences. In addition, such scenarios can be used independently or in conjunction with projections of future climate change (Box 8.3 and Chapter 4) in an integrated assessment of future biophysical and socio-economic change.

As discussed in Chapter 5 (Section 5.4), the impacts of climate change on BCB residents and communities are strongly shaped by interactions between climate, subsistence, and the physical, economic, and socio-cultural well-being of those residents. Although climate change can adversely affect the quantity, distribution, accessibility, and abundance of subsistence resources, those impacts can be ameliorated or exacerbated by socio-economic trends that enhance or degrade the value of subsistence livelihoods and traditional knowledge within Indigenous communities (Sections 4.5.2, 4.5.5, and 5.2.3). Similarly, the implications of climate change for housing and infrastructure will be contingent on changes in population, migration, and demography, which all affect housing and infrastructure demand, as well as on the extent of new or declining investment in housing and infrastructure development and maintenance (Section 5.2.2). All of the consequences of climate change will also be influenced by public policy and private decision-making at multiple scales – local to international.

The scenarios presented in Section 8.4 explore alternative trajectories along which some of these driving forces could evolve. Scenarios associated with high rates of economic development (e.g., the S1 and S2 series of the scenarios; Figures 8.1–8.4) imply growing pressure on natural resources in the BCB region and within specific subregions and communities. However, in the S1 series, strong, collaborative institutions help to reduce the adverse impacts of development. This collaboration limits the potential for adverse impacts of climate change on social and environmental systems. In contrast, the S2 series implies significant trade-offs between development and the protection of vulnerable social and ecological systems. With the S3 and S4 series, the lower rates of economic development pose different challenges for managing the risks of climate change. Lower growth reduces the flow of financial capital into the region, which reduces overall financial resources available for funding adaptation. However, under the S3 series, strong institutions help to maintain environmental quality and promote diversification of the economy. This emphasis on a smaller but sustainable economic footprint could ultimately offer benefits for adaptive capacity. Under the S4 series, lower growth has more adverse effects, with different stakeholders vying for the few resources that can be economically extracted. In such a future, stakeholders may have significant difficulties pursuing effective adaptation strategies.

These different scenarios also reflect fundamental differences in the resilience of BCB ecosystems and subregions, particularly regarding the risk of exceeding critical thresholds (see Chapter 6). For example, socio-economic trends that undermine the autonomy of Indigenous communities and the value of traditional knowledge may increase the likelihood that climate change could contribute to the failure of subsistence livelihoods (Sections 5.2.1 and 5.2.3). Similarly, fisheries management policies and practices that enable overexploitation of resources could enhance the risk of fisheries collapse if climate change drives changes in the distribution of fisheries or degrades fish



**S1: Beaufort Development**

- The Mackenzie Gas Project is implemented, with a pipeline constructed through multiple Aboriginal communities, opening access to resources in the Beaufort Sea, Mackenzie Delta, Sahtu and Dehcho regions
- The boom-bust nature of pipeline construction is dampened by economic diversification in tourism (particularly Aurora Borealis-related), small businesses and reduced dependence on goods and services outside the NWT
- Agreements on land/resource rights and self-government are finalized for Aboriginal groups which ensure revenue sharing from resource projects
- Despite attempts to balance social, economic and environmental values in pipeline construction and operation, adverse impacts on species habitat reduce harvesting opportunities for food and the fur trade
- Oil revenues enhance Aboriginal community infrastructure as well as social, health and educational services
- Despite some adverse impacts on traditional livelihoods and subsistence, healthy economic growth generates resources to address adaptation needs and bolsters regional adaptive capacity

**S2: Beaufort Inequality**

- There is renewed interest in oil and gas extraction in the Mackenzie Delta and off-shore in the Beaufort Sea. The Mackenzie Gas Project is implemented, with a pipeline system running through the Mackenzie Valley to the south
- Energy resource development drives economic growth, but this slows once pipeline construction is complete. Aboriginal land claim negotiations stall, with groups with unsettled claims excluded from revenue sharing
- Aboriginal groups such as the Inuvialuit have a mandated role in co-managing resources, but antagonism emerges between them and the GNWT. The legal mediation process slows investment in infrastructure and development
- Local environmental damage from oil and gas and pipeline development goes unaddressed
- The benefits of the energy boom are unevenly distributed among Aboriginal communities creating significant social and economic disparities
- The erosion of cooperation among regional actors and the uneven distribution of the profits from energy development contribute to sharp differences in the capacity of different communities to adapt to the changing climate

**S3: Beaufort Sustainability**

- The drop in oil and gas development and slowing of the minerals and metals sector was foreseen, resulting in strategic public-private partnerships to support development of alternative, renewable forms of energy for the NWT
- The GNWT incentivises investment in economic diversification toward more locally-beneficial and regionally-sustainable activities. This includes sustainable infrastructure, tourism industry focused on the Aurora Borealis and the use of digital technologies to facilitate access to niche markets
- Strong collaborative partnerships emerge between Aboriginal communities, the GNWT, and private enterprises
- Concerted efforts are made to protect ecosystem services that support the emerging new economy and to repair legacy damage from industrial activities
- Economic diversification, self-governance and culturally-appropriate educational opportunities enhance the capacity and resilience of Aboriginal communities to adapt to climate and other changes
- Investments in renewable energy and economic diversification create a soft-landing for communities in the region that enables the region to avoid exceeding critical socioeconomic, cultural, and environmental thresholds

**S4: Beaufort Fragmentation**

- Energy extraction activities in the north slow significantly, leaving mining in the south that targets specific areas with valuable minerals (diamonds, gold, copper, tungsten etc) as the regions's primary extractive industry
- Limited revenues from resource development serve to concentrate investment by the GNWT in the urban centers, with remote communities being marginalized from economic opportunities
- Despite some persistent national interest in the protection of coastal waters and Arctic sovereignty, the federal government's investments in the region contract while frequent disputes emerge among various regional actors
- Cost-cutting efforts drive companies to follow minimum environmental standards with little concern for environmental and social impacts
- Limited economic opportunities for northern local communities drives a brain drain that leaves them under-populated and vulnerable
- With financial, social, and human capital contracting, capacity is limited to isolated locations and sectors and applied toward modest, incremental adjustments

Figure 8.4 Socio-economic scenarios for the BCB subregion: Beaufort in the western Canadian Arctic.

stocks (Section 5.2.3). In contrast, socio-economic trends that enhance the capacity of stakeholders to manage resources under stress can enhance resilience and thereby prevent systems from encountering critical thresholds. At the same time, however, system resilience can be maladaptive if it acts to maintain conditions or trends that degrade natural or social systems. Efforts to maintain the resilience of the energy resource economy in the BCB region, for example, could destabilize natural ecosystems, populations, or species. Scenarios can therefore be useful in identifying, or at least exploring, such trade-offs.

The BCB socio-economic scenarios (Figures 8.1–8. 4) also reveal that the climate change impacts of concern at the regional level may vary from those of concern at the local level. Local economic activity, livelihoods, and ecosystems may have their own distinct vulnerabilities to a changing climate (Sections 5.2 and 5.3). For example, in Canada's Beaufort region (Figure 8.4), future development of the Mackenzie Gas Project is a key factor affecting local economic development and pressures on natural ecosystems and their services. In Alaska (Figure 8.3), some scenarios suggest the possibility of opening the Arctic National Wildlife Refuge to energy development, which raises concerns regarding trade-offs between development and the maintenance of ecosystem integrity and ability to naturally adapt to the changing climate. The effectiveness of efforts to manage the impacts of climate change and development are contingent on the balance of power among federal and state governments, the private sector, and Native Corporations.

Given that the various scenarios presented in Section 8.4 demonstrate the possibility of disparate socio-economic futures for the BCB region and its communities, the inherent uncertainty about the future is an important element to consider when reading the material presented in other chapters of this report – on impacts (Chapter 5), resilience (Chapter 6), and adaptation (Chapter 7). Many of the studies reviewed in these chapters do not directly incorporate socio-economic scenarios or a common scenario framework in their treatment of climate

**Box 8.3 Integrating socio-economic scenarios and climate projections**

Socio-economic scenarios can be usefully integrated with projections of future climate change to explore the joint implications of both climatic and socio-economic change for impacts, adaptation, and vulnerability. Scenarios can be developed with explicit assumptions regarding both socio-economic and biophysical (i.e., projected changes in climate) futures. However, in other instances, future changes in socio-economic conditions are treated as being independent of changes in the climate. For example, the 'parallel process' has been developed as a new scenario framework for integrated assessment modeling, Earth System Modeling, and explorations of climate change impacts, adaptations, and vulnerabilities. The representative concentration pathways (RCPs) were developed to represent alternative greenhouse gas forcings to drive Earth System Models and their projections of climate change. The shared socio-economic pathways (SSPs) were developed to provide richer socio-economic understanding of the driving forces that are consistent with the RCP forcings (Moss et al., 2010; Kriegler et al., 2012).

The scenario matrix architecture (SMA) provides the framework for the integration of RCPs and SSPs for integrated impact assessment (Moss et al., 2010; van Vuuren et al., 2012, 2014; Eom et al., 2013; van Ruijven et al., 2013; Ebi et al., 2014). There is a range of pathways by which such an SMA can be implemented, depending on the objectives of researchers or practitioners. For example, socio-economic storylines could be coupled with climate scenarios within a qualitative vulnerability assessment or risk assessment that explores the potential or likelihood for harm to different sectors given alternative climate futures and socio-economic conditions. Such an application would largely rely upon normative judgments in order to posit the future implications of alternative climate and socio-economic futures. Such an approach may be particularly useful for participatory visioning and assessment exercises with stakeholders (Carlsen et al., 2012; Harrison et al., 2013). Alternatively, socio-economic scenarios could be used to parameterize quantitative inputs for biophysical or economic impact models or integrated assessment models.

An additional step in the parallel scenario process is the integration of assumptions about the climate policies (mitigation and adaptation) that would be required to reduce the risks of climate change to a certain level. Not all types of climate policy are equally likely under each of the socio-economic pathways. To this end, a small number of shared (climate) policy assumptions (SPAs) has been developed (Kriegler et al., 2014), describing combinations of policies that are compatible with the shared socio-economic pathways. Consistent with this framework, BCB-relevant SPAs could be developed to reflect policy mitigation and adaptation options at different levels of governance (international, national, or regional), as well as their implications for risk reduction. When used within this framework, BCB socio-economic scenarios could include a set of policy assumptions related to adaptation. Hence, scenarios have potential value not only for outlining alternative development pathways and their implications but also for exploring the costs and benefits of policy responses.

change impacts, resilience, or adaptation opportunities in the BCB region. Hence, particularly for projections of climate change impacts that are likely to be contingent on future socio-economic trajectories or decision-making by actors across different scales, it is useful to consider the role of socio-economic uncertainty in evaluating that information. In addition, it is useful to consider how deliberate choices regarding economic development and environmental management could enable or constrain efforts to adapt to a changing climate.

## 8.6 Engaging the science/policy interface

Proactive adaptation requires a balance of those organizational forces that shape human behaviors through rules, values, and science. Such forces are generally discussed as 'institutions' by social scientists and are connected to governance by suites of rules and their institutional mandates (e.g., the 1973 Agreement on the Conservation of Polar Bears, the Arctic Council, the Chukotka Autonomous Okrug). When considering how top-down or bottom-up scenarios may create connections between science and policy, it is generally through such institutions. When it is necessary to know how institutions may shape the Arctic environment and the behavior of its inhabitants, the discussion concerns governance. Institutions of governance across the Arctic (e.g., governments, self-governing municipalities, and non-profit, Indigenous and other organizations) and at different levels of organization will need to be both nimble and robust enough to adapt to rapid changes (Figure 8.5). As such, these

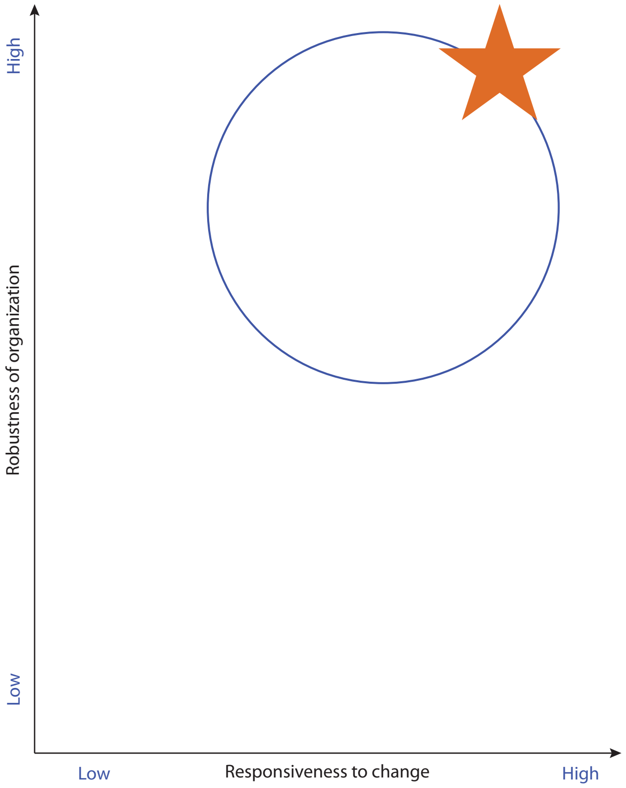


Figure 8.5 Effective institutions must be resilient but also nimble. Adaptive institutions should therefore occupy the space within the circle. Ideal institutions (orange star) perform optimally in robustness and responsiveness (adapted from Lindgren and Bandhold, 2009).

institutions cannot be so responsive that they lack consistency in research, application, or policy or so rigid that their mandates and practices resist change.

The relationship between the science of scenarios (the research that goes into identifying and prioritizing system drivers and their effects) and the potential for policy outcomes (planning for possible futures) produces four important interrelated aspects: integrating multiple sources of knowledge, guiding science investment, developing early warning systems, and problem framing and communication.

### 8.6.1 Integrating multiple sources of knowledge

The scenarios process, due to its interdisciplinary nature and open-ended focus on *what if?* inherently welcomes multiple sources of knowledge. Also, the narrative nature of scenarios can be congruent with Indigenous oral traditions and the human storytelling impulse to make meaning. To be fully effective, scenario development requires the integration of multiple sources of knowledge to form multiple comprehensive narratives (Bennett and Zurek, 2006; Bohensky et al., 2011). The BCB region has a mixture of Western and Indigenous knowledge systems that interact in varying ways through co-management of resources, formulation of social policy, education, and in some cases governance. It has been repeatedly demonstrated that Indigenous and local knowledges can provide insights, research methods, and data that enhance understanding of social-ecological systems and complement Western investigatory methods. It is only through acknowledging and engaging multiple sources of knowledge, in particular those that have been marginalized, that society can be sure it is considering the full range of future possibilities. By including multiple knowledge standpoints, 'less partial and distorted accounts of the entire social order' are produced (Harding, 1992, p. 583). This clearer view can be of particular importance when considering black swans or outlier variables that may unexpectedly drive a system. Different sectors of society may have access to information that is beneficial for planning, but their knowledge often exists in relative isolation (e.g., business, government, tribal organizations, Arctic residents). Scenarios can bring these sectors and their data together to bear on the future and thus create a knowledge base around a focal question that not only identifies different kinds of information but also can synthesize and examine their interactive effects (e.g., through knowledge co-production).

### 8.6.2 Science investment

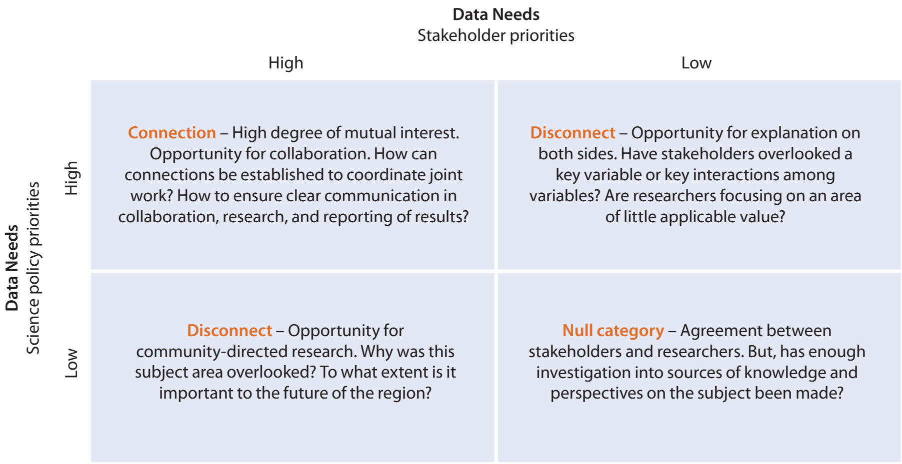
Because scenarios provide insights regarding stakeholder values and priorities (Chapter 2), they can be used to direct future research investments toward those areas that are likely to have the greatest impact on people's lives. National, subregional, and local governments have recognized the need for long-term observations to track a rapidly changing Arctic. This recognition has created funding opportunities in the US and Canada through research communities (e.g., National Science Foundation, Natural Sciences and Engineering Research Council of Canada) whereby government agencies and other organizations identify priorities, measurement sites, and methods for such observations (e.g., Arctic Observing


Martin Shields / Alamy Stock Photo

*Measuring carbon dioxide exchange between thawing permafrost and the atmosphere, Alaska*


© B&C Alexander / ArcticPhoto

*Reindeer at a winter camp on the tundra, Chukotka*



| | | | |
|---|---|---|---|
| | | **Data Needs**<br>Stakeholder priorities | |
| | | High | Low |
| **Data Needs**<br>Science policy priorities | High | **Connection** – High degree of mutual interest. Opportunity for collaboration. How can connections be established to coordinate joint work? How to ensure clear communication in collaboration, research, and reporting of results? | **Disconnect** – Opportunity for explanation on both sides. Have stakeholders overlooked a key variable or key interactions among variables? Are researchers focusing on an area of little applicable value? |
| | Low | **Disconnect** – Opportunity for community-directed research. Why was this subject area overlooked? To what extent is it important to the future of the region? | **Null category** – Agreement between stakeholders and researchers. But, has enough investigation into sources of knowledge and perspectives on the subject been made? |

Figure 8.6 Implications of agreements or disagreements among stakeholders and the scientific community regarding the value of different kinds of data. The data needs of stakeholders for decision-making are compared against data availability, which is a function of research priorities and investments defined by science policy.

Network, Study of Environmental Arctic Change, ArcticNet). It is reasonable to assume that over the course of the next decade or so, several tens of billions of dollars will be spent in the Arctic to put into place and sustain long-term observing networks for a variety of indicators of ecosystem and climate system change. But what matters the most to residents and communities in the Arctic? In times of changeable budgets, it is vital that investment in science matches the adaptation information needs of people across different scales in a manner that can be sustained (Lovecraft et al., 2012). The types of information and exchange that scenarios processes develop can help to direct investment by identifying and prioritizing areas of socio-economic uncertainty that are key to successful adaptation.

### 8.6.3 Early warning systems

Because scenarios help to identify key sources of uncertainty critical to future conditions, they may suggest important areas for monitoring in order to receive advanced warning of system trajectories. This benefit relates directly to the opportunities discussed in Sections 8.6.1 and 8.6.2. By engaging multiple sources of knowledge and sifting through what remains uncertain, scientists, decision-makers, and Arctic residents can design and be a part of early warning systems that leverage the power of local observations in tracking key uncertainties in the social-environmental system.

### 8.6.4 Problem framing and communication

Scenarios processes that are participatory or collaborative in nature can enable the communication of significant information among people (e.g., scientists, decision-makers, stakeholders, residents) bound by a shared problem. The participatory approach, both qualitative and quantitative, enables those most keenly affected by the future to identify key drivers of change and participate in data collection and review. This approach also begins a process of evaluation that can provide context for the data used by modelers. During and after a scenarios process, as participants determine what they view as the key factors and prioritize them, there is a knowledge exchange that informs both the investigators using the scenarios process and its participants. For example, in a standard four-quadrant scenario of climate change and extractive resources with a focal question of "*How does a small community in Russia maintain its watershed in 2050?*" the information about water quality, flow rates, important species, and usage will be of use to the community, but the participants may also be able to communicate significant data to researchers about important recreational or spiritual uses for the water, or that they no longer rely much on a particular fish. Because scenarios focus participants on how to maintain, develop, or avoid some attribute for the future, they rely on participants to focus on normative values and core system functions. These exchanges are informed by what science can bring to the participants, but participants also inform scientists about what matters to them; what questions need to be answered? The power of this communication can be visualized in four possible outcomes related to data needs and availability in a system (Figure 8.6). Each outcome, as perceived by researchers and community members (and other stakeholders), poses significant questions whose answers are highly pertinent to future outcomes. Furthermore, significant disconnects can inform institutions of unclear or contested definitions of policy problems. Policies for Arctic regions, due to the general nature of these regions at the peripheries of national cores, are especially susceptible to misunderstandings when social problems, their attributes, and solutions are being defined. In Arctic communities, such misunderstandings are routinely observed at the local level because their concerns are not broken into disciplinary pieces – they are lived realities.

The split between pure and applied science can be problematic. For example, depending on research goals, scientists often make ice measurements some distance from communities in order to obtain samples or data free of the artifacts of human influence. But another observational perspective of ice is at the household level where ice cellars have experienced increased flooding over the last decade, posing a major threat to community food security. From both community and researcher perspectives, the melting and thawing of the Arctic cryosphere is a core investigatory concern, but what that means to the future may be different for one that relies on an ice cellar for one's livelihood versus a researcher who ultimately flies home to a refrigerator.

## 8.7 Conclusions

Socio-economic trajectories are often associated with significant path dependence, but changes in policy, technology, economic systems, and perceptions of risk contribute to inherent and irreducible uncertainty regarding the future of human systems and communities. The challenges that such uncertainty poses to adaptation decision-making and planning have been well documented; yet, various tools exist to help manage that uncertainty, and scenarios are a common one. Scenarios have been developed and applied using a range of methods, across different scales and contexts – both in the Arctic generally and in the BCB region specifically. When developed using a participatory process, scenarios can be a powerful tool for eliciting insights from a range of perspectives regarding key drivers and uncertainties of the future.

Scenario activities in the Arctic and BCB region over the past decade have consistently identified uncertainties regarding the future evolution of global energy demand, extraction of Arctic energy resources, and Arctic regional governance as critical to understanding future socio-economic development pathways. Moreover, those uncertainties have important implications for the consequences of climate change, the resilience of BCB ecosystems and communities, and the capacity of decision-makers and stakeholders to adapt to a changing climate. Hence, continuing to assess the potential impacts of climate change under different scenarios of climatic and socio-economic change will be an important component of problem framing and of developing a robust adaptive response within the BCB region. In addition, scenarios can contribute to the development of early warning systems and the prioritization of regional research needs to enhance social benefits.

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# 9. Synthesis

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## 9.1 Introduction

The goal of this report is to examine changes in the current environment and living conditions of the coastal and tundra communities of northwestern Canada, northern Alaska, and the northern Far East of Russia – the Bering-Chukchi-Beaufort (BCB) region – and to understand how people are coping and adapting to these changes. The report seeks to describe how life in this region is changing in the context of the recent past; to project the likely future changes in the environmental, economic, and social systems; and to provide information for northern residents in preparing for and adapting to an uncertain future.

This effort began in 2011, when the Arctic Council requested its Senior Arctic Officials "to review the need for an integrated assessment of multiple drivers of Arctic change as a tool for Indigenous Peoples, Arctic residents, governments and industry to prepare for the future" (Nuuk Declaration, 2011, p. 4). In order to assess how these changes will affect the lives of northern residents, it was first necessary to characterize the land, climate, ecosystems, economy, and people. It was essential to view these characteristics of place through the lens of time, to see what has recently changed and what remains constant. In many respects, the environment of the BCB region has remained quite stable for the past 10,000 years, since the end of the last ice age, and only now faces rapid transformations. From other perspectives, such as the human occupation and utilization of the resources, the region has been in a perpetual state of flux. It was also necessary to view the changes in this region in the context of the global drivers of that change. Although responses may be amplified in the Arctic, the most influential drivers usually have a global nature. It was then necessary to consider the consequences for ecosystems, landscapes, and socio-economic systems.

In this study of impacts and responses, the intertwining of multiple drivers has been noted, since this complicates attribution of change as well as adaptation to change. The report considers impacts and adaptation in multiple sectors, including shipping, natural resource extraction, fisheries, transportation, tourism, human health, and subsistence food harvest. Key to promoting effective adaptation and building regional resilience is understanding the adaptation decision-making context within each sector, as well as the many feedbacks, influences, and impacts across these sectors.

In many respects, the Indigenous peoples of the Arctic have displayed remarkable resilience and adaptation capacity as inherent and cherished characteristics of their cultures. In other ways, they remain challenged in operating within governance and institutions which tie communities to established infrastructure and promote reliance on non-local food sources and fuel types.

Adaptation is both difficult and yet natural. Individuals who value their homes and lifestyles will seek or create solutions to new challenges that arise from evolving conditions. Indigenous peoples will need support to maintain traditional practices in the face of these environmental and social changes. Maintaining networks of communication and information transfer can strengthen the capacity for adaptation. Safeguarding ties to community and family, with the responsibilities to contribute and the benefits of mutual support and protection, enhances resilience and thus ability to adapt. Preserving strong, healthy, functional families and communities – despite stresses introduced through downturned economies or difficulties in conducting traditional activities – yields the benefits of health and well-being, as well as the benefits of participating in community and family, thus enhancing the capacity for innovation and adaptation. The current mixed subsistence/cash economies of rural Indigenous communities stand as an example of the adaptation of traditional lifeways to the non-Indigenous economic structure that has been a driver of change for at least a century in the BCB region.

The geographic area of the BCB region encompasses lands and people that are largely peripheral, remote, and otherwise geographically isolated from the main populations of their respective countries (Canada, United States, Russia). National-level attention and support for this region is therefore especially important, as its people may be easily marginalized. Simultaneously, however, the region has significant strategic importance for each country, especially in terms of offshore oil and gas development, shipping, and border defense.

Although it is difficult to make broad generalizations across the various BCB subregions, in some places the warming climate has caused environmental changes that have led to an influx of new species (e.g., salmon and beaver) or a reduction (or risk of reduction) of other species (e.g., polar bear, walrus, ringed seal, and caribou). Summer access has been enhanced for ship traffic, but winter access via ice roads has become more challenging. The region's low population density, the relatively high proportion of the population that still engages in some form of traditional lifestyle, and the cyclic expansion and loss of some industrial activities present a highly dynamic society that expresses both vulnerable and adaptive characteristics. The rapidly evolving system offers a unique opportunity to observe adaptive practices.

In general, the people of the Arctic are highly capable and motivated to defend their lifestyles and protect their social and cultural heritages. However, in some communities, the challenges may be too great without national or regional government intervention. Communities threatened by coastal erosion or the eventual failure of civil infrastructure due to degrading permafrost will require assistance if they decide to sustain their current facilities or to relocate to a new community site. In either scenario, the community and the nation must engage in planning on multi-generational time frames. Upkeep and maintenance of facilities is crucial in these extreme environments. However, maintenance and new development

*Storms erode the permafrost along the fragile Arctic coast, Alaska*

expenditures must be used wisely if the community faces eventual relocation. The scenario analyses presented in Chapter 8 offer insight into how such considerations may be approached in times of uncertain futures.

This final chapter of the report attempts to synthesize the complex information and interacting dynamics between the natural and human systems that were presented in the previous chapters. The chapter begins with a summary of the priority theme areas that emerged from all chapters, with a specific focus on food security/insecurity, environmentally sustainable economic opportunities, and social/cultural cohesion. This includes a description of the processes that have worked, and those that did not work, in terms of adaptation planning. Consideration is also given to what actions are needed to support future adaptation planning, and what actions are needed to initiate and extend that planning. The chapter concludes with an examination of the science/policy interface and specific actions required to promote adaptation within this rapidly changing region.

It is necessary to highlight, as have others (e.g., Dow et al., 2013), that adaptation has its limits. The evolutionary and historical records are replete with examples of extinct species and human civilizations that could not adapt rapidly enough, or completely enough, to climate change. Thus, the focus here on adaption actions and potentialities should not be construed to mean that adaptation is an effective substitute for mitigation of greenhouse gas emissions. The two processes – adaptation and mitigation – must proceed in parallel. Mitigation actions at national and international levels will improve the chances of successful adaptation to Arctic climate change by local/regional actors, by decreasing the rate of change to which ecosystems and human systems must adapt and by eventually limiting the ultimate amplitude of that change.

## 9.2 Priority theme areas

The information reviewed in previous chapters described the many broadly based, interlinked chains of *cause – effect – cause* that are irreversibly altering the physical environment, the ecosystems supported by this environment, and the impacts and responses of the human communities to these dynamics. Although climate warming may be a primary agent of ecosystem change, the secondary environmental and human impacts of that change can themselves become drivers of other, often unpredicted effects in a cascade of causation. BCB ecosystems are complex and interconnected across multiple temporal and spatial scales, and the effects of major ecological change (for example, from extreme weather events, pollution, land and resource use, and permafrost thaw) are often interdependent, nonlinear, cumulative, and difficult to predict within the limits of existing understanding. Similarly, stressors and drivers of social and economic change influence the capacity of human response to environmental change and can also create path dependencies, as well as legacies that can limit future adaptive response. Understanding the impacts of a rapidly changing Arctic environment is complicated by the dynamics of changing economies, demographics, and social structures and conditions. A suitable metaphor may be the effect of many small stones thrown into a calm pond, with the expanding ripple from each individual stone meeting other ripples, sometimes canceling each other out and sometimes multiplying together to form larger ripples that then go on to meet other ripples. In scientific terms, these patterns are equivalent to destructive and constructive interactions or to antagonistic and synergistic effects, respectively. Combined effects may be greater or lesser than the sum of the individual effects. How does one make sense of those seemingly chaotic, interlinked series of causes and effects?

The choice made here has been to focus the synthesis on crosscutting, integrative issues that are often identified by northerners and by northern governments as among the most immediately important and complex. These priority themes are food security (particularly with respect to subsistence resources), social/cultural cohesion, and environmentally sustainable economic growth. Like a magnifying glass that gathers light from diffuse sources and focuses it onto other areas, each of these integrative issues can be regarded as the culmination of multiple contributing causes, and each in turn strongly influences other important human issues. In BCB communities, there is a strong dependence on the natural world, and these themes acknowledge the central placement of Arctic human society within ecosystem structure and function. Many studies have shown that subsistence hunting and gathering activities are essential to the sustenance of families and communities, especially Indigenous peoples, and to the maintenance of Indigenous culture in the BCB region (see Chapters 3, 5, and 6). Subsistence harvesting activities buttress social and cultural cohesion, as well as traditional lifestyles. Therefore, these two crosscutting themes are considered together here. Similarly, while economic opportunity can be necessary to purchase guns, fuel, snow machines, and other items required for hunting, the subsistence species that Indigenous peoples rely on for food security can be threatened by resource development and enhanced harvest tools and techniques. This interdependence underscores the overlap of themes and complexities entailed in understanding trajectories of change and charting equitable and sustainable paths for the region's future. It should be noted that this discussion of these integrative priorities does not imply that these are the only priority issues for the BCB region.

## 9.2.1 Food security and social/cultural cohesion

Food insecurity can be defined as disrupted eating patterns, chronic hunger, or nutritionally inadequate food intake, which may have a variety of both local and global causes (Douglas and Chan, 2015). While there is seasonal and geographic variation in subsistence practices across the BCB region, a reliance on local biological resources for food is common for all Indigenous peoples. The fact that the nature of subsistence hunting (e.g., harvested species selection, balance between subsistence and market foods, ease of access, travel hazards) varies greatly among the communities of the BCB region underlines just how much the efficacy of adaptation planning related to food security will require local information to best inform policy and assistance initiatives (see, for example, Inuit Circumpolar Council-Alaska, 2015).

Despite this variability, given the number and diversity of causation chains that affect the endpoint of food security, and the fundamental role that food plays in people's well-being, the percentage of families in a community who experience food *insecurity* may serve as a practical proxy indicator of how successfully those communities are adapting overall to the current suite of challenges posed by climate change and modernization. Food security can be taken to indicate the overall state of natural ecosystem health, at least in places where people are still heavily dependent on natural food systems. Serious degradation of ecosystems immediately affects people's ability to access, harvest, and prepare traditional foods. Food insecurity can also reflect another suite of challenges such as lack of employment opportunities, income instability, and the limited availability and affordability of store foods.

The food security indicator could be applicable to Indigenous and non-Indigenous families alike. But almost half of the Inuit families in the Inuvialuit Settlement Region of the Northwest Territories have reported moderate or extreme levels of food insecurity, with similar levels of insecurity in parts of northern Alaska and Chukotka (Chapter 5). Thus, for many Indigenous communities, it appears that the current challenge of inadequate nutrition is substantial and the issue would benefit from some form of government attention and support. Food insecurity therefore should receive a higher profile and be more regularly monitored with a standardized methodology by government agencies across the BCB region. However, stakeholder surveys and future scenarios exercises conducted in different BCB communities show that the opportunities and challenges associated with climate change and modernization are experienced and perceived differently within and between communities and by different sectors of the economy (Chapters 1, 2, 8). Local assistance and adaptation strategies informed by local residents, rather than region-wide solutions imposed by governments, are more likely to be effective.

The causes of food insecurity and threats to food security, which occur on many levels, include physical, environmental, ecological, and biological changes, as well as technological, cultural, economic, and social alterations in communities and families. Key physical processes underpinning ecological and biological changes include loss of sea ice and river/lake ice, ocean acidification, thermokarst destabilization of landscapes, abnormal extreme weather events, and ice encrustation of terrestrial forage vegetation (Chapters 3, 4, 5). These physical changes lead to secondary effects. For example, the availability of subsistence food species to hunters may shift due to more difficult/hazardous travel to traditional hunting areas, altered


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*Market in Anadyr, Chukotka*

wildlife habitats, changing migration routes and distributions, local extinction of food plants, or the spoilage of meat in food cellars built into thawing permafrost. Furthermore, by altering the natural environment in unpredictable ways, climate change challenges the applicability of existing traditional knowledge to the new conditions by undermining its reliability (Power, 2008; Prowse and Furgal, 2009). One example often cited by elders and hunters is the recent unpredictability of weather patterns and sea and river/lake ice conditions, which makes overland and over-ice travel more hazardous (Chapter 2). This disconnect is causally related to both food insecurity and familial, intergenerational, and community tensions, which impede the transmission of knowledge from elders and hunters to young people, in some cases undermining cultural and social cohesion. However, the ability of communities and hunters to closely observe and learn about new environmental conditions, and to incorporate this knowledge into traditional knowledge, allows that knowledge to be adaptive to what *is*, and not only reflective of what *was* (Cochran et al., 2013). This important distinction supports consideration of not just traditional knowledge or just scientific data analyses – but of Indigenous and local knowledge being respected as having equal status with modern scientific studies in current land and resource management.

Climate change has already affected the range and abundance of important marine and terrestrial food sources (e.g., salmon, herring, char, cod, walrus, seals, whales, caribou, moose, and some species of seabirds), with atypical southern species now migrating to northern areas; these changes have both ecological and food security implications (Markon et al., 2012; Chapter 5). Changes in the availability of subsistence foods can also be attributed to concerns about food safety (contaminants, spoilage) and to weather conditions that interrupt traditional food preparation or preservation methods (Markon et al., 2012; Douglas and Chan, 2015). Adequate safe drinking water supplies may be considered part of food security. For many BCB communities, these supplies are natural surface features (ponds, streams, lakes), which are vulnerable to thermokarst disturbance and drainage as well as bacterial contamination (Chapter 5).

Mixed subsistence/cash economies in many communities have both positive and negative impacts on food security. On the one hand, cash income is essential for paying for gas for snow machines, four-wheel vehicles and boats, guns, bullets, camping supplies, and so on. Cash income is also required to pay for electricity and heating fuel. On the other hand, full-time employment makes it difficult to find time for seasonal hunting and fishing (Douglas and Chan, 2015; Chapters 5 and 6). Together, the trends in environmental, biological, and cultural factors have created the current 'nutrition transition' situation in Alaska and western Canada, in which many northern communities are increasingly relying on imported processed foods rather than local, traditional subsistence foods (Chapters 5–7). The reverse trend is occurring in Chukotka, where, following the collapse of the Soviet Union, traditional subsistence foods have become more important than previously. It is important to note that presently the central Russian government and local government policies exert more influence on the food and lifestyle choices of local people (both native and Russian) than do the dynamics of climate change (Nemirovskaya, 2015).

The effects of food insecurity impact a variety of other major endpoints at individual, family, and community scales (Loring and Gerlach, 2009; Chapters 5 and 6). These include poor nutrition, increased diabetes and obesity, general physical and mental health, and family relationships. Psychologically, food security means being able to depend on a locally sourced food supply, which in turn provides feelings of self-determination, self-reliance, and a degree of insulation from external economic forces that are beyond the control of northerners; food insecurity brings the opposite (Chapter 6). In some cases, the mixed subsistence/cash economy has resulted in a behavioral feedback loop that reinforces the relative importance of cash and reduces the importance of subsistence practices, thereby decreasing family self-reliance and diminishing the role of traditional knowledge holders and elders within families and communities. Alternatively, in other situations, wages provide a means to continue subsistence lifestyles and enable a connection to traditional practices in a modern world. Some communities have described less interest by young people in learning traditional practices, possibly because of the allure of Internet-based recreation and learning, as well as easier travel access out of the community and region.

Adaptation actions or options already taken by northerners to address food insecurity include both small and large changes in the timing and location of hunting practices and harvest species selection; some communities have been able to adapt more successfully to change than others (Chapters 2 and 7). Suggested adaptation strategies to improve food security and address some of the deleterious side effects of the nutrition transition in the western Canadian Arctic include greater government and community support for traditional food-sharing networks and community food freezers; increased access to and provision of hunter-support programs, including safety equipment, especially in more isolated communities; and increased educational outreach about nutrition and the important health role that traditional subsistence foods play in diets (Stern and Gaden, 2015). These strategies could also be applied in other parts of the BCB region. Making traditional land and ocean knowledge, subsistence skills learning, and Indigenous languages a part of school curricula within the region, together with a community-wide re-emphasis on subsistence skills as a strategy to bestow adaption capacity and self-reliance, have been recommended as responses to the cultural challenges posed by climate change and modernization (Douglas and Chan, 2015).

The Alaskan Inuit define food security as "the natural right of all Inuit to be part of the ecosystem, to access food and to care-take, protect and respect all of life, land, water and air" (Inuit Circumpolar Council-Alaska, 2015, p. 5). The 'One Health' paradigm is based on the recognition that the health of humans, animals, and the environment are inextricably linked (Bright et al., 2012). In this model, science at the environment/health interface addresses the quality of the physical environment, the health of the living environment, and human health. The quality of the physical environment includes the physical, chemical, and aesthetic characteristics of both natural environments (including those affected by human activities) and built environments (such as homes and workplaces). Recognition or acceptance of these qualities enhances an individual's or community's resilience and thus adaptive capacity. The health of the living environment

*The Inuit village of Ulukhaktok with ice floes, Victoria Island*

reflects the health of all organisms, from microbes to fish – all wildlife and all plants. People's health (Chapters 3 and 5) and well-being are affected by both the quality of the physical environment and the health of the other living organisms with which they interact.

### 9.2.2 Sustainable economic activities

Economic development in the region is one of the main drivers of social and economic regional change. The widely accepted definition of sustainable economic development is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987, Ch. 2). In the BCB region, numerous factors complicate the pursuit of sustainable development. Shipping, natural resource extraction, tourism, and commercial fishing are all sectors with dual relationships to regional adaptation. They are all simultaneously driving economic change and being affected by climate-related environmental change and are therefore sectors in which adaptation will be required.

Small communities in the region are likely to comprise a large percentage of Indigenous residents, and Indigenous people are likely to be more dependent than non-Indigenous people on a mixed-subsistence economy. These cultural differences may mean that types of development that might be appropriate in non-Indigenous communities will be inappropriate for Indigenous communities, or some developments may require special provisions to account for culture and subsistence. However, for the small communities in the BCB region (which are often not on a road or railway system), appropriate and sustainable economic development is a key factor in the capacity of the community and its people to respond to change. This assessment focuses on three types of industry that have made significant economic contributions to different parts of the BCB region or will have the potential to do so in the future: tourism, commercial fisheries, and the extractive resource industry. Each of these sectors also affects local communities and their ability to harvest subsistence foods.

Tourism is often considered to have many promising options for long-term sustainability (Chapter 7). 'Sustainable Arctic tourism' is defined by the Arctic Council's Sustainable Development Working Group (SDWG) as "tourism that minimizes negative impacts and maximizes socio-cultural, environmental and economic benefits for residents of the Arctic" (Vaarala, 2006, p. 6). When accomplished through local direction and with local ownership, tourism activities can bolster local economies and cultural pride, while at the same time educating outsiders. Key to accomplishing sustainable tourism will be local decision-making power and direct return of profits to the community. Some parts of the BCB region have experienced tourism activities for some time, but these activities have been primarily land-based. As other parts of the world continue to grow more volatile and dangerous and as access to the Arctic becomes easier, the Arctic is likely to become more attractive as a tourist destination.

Cruise ship tourism is likely to increase in the near term, and sustainable cruise ship tourism will require close collaboration and shared decision-making across levels from local to regional, national, and international. As access to coastal communities increases, communities have the opportunity to shape future benefits and and minimize potential negative impacts through local permit requirements (Chapter 2). Tourism depends on infrastructure, and this is particularly true for cruise ship tourism. Port reception facilities do not currently exist in the region, and sustainable cruise ship tourism will need major port construction, which will require collaboration and partnership on local, regional, and national levels. Similarly, search and rescue capabilities are also lacking or underdeveloped in Arctic communities and will require cross-scale collaborations. The viability of trans-Arctic shipping and tourism depends strongly on market and political forces outside the communities themselves, so aspects of the sustainability of a tourism enterprise may be largely outside community control. However, as communities plan for adaptation or engage in scenario-building exercises (Chapters 7 and 8), they can take a proactive stance to help maximize benefits and reduce negative social, economic, and environmental impacts. In general, early and close collaboration between tour operators and communities is vital (PAME, 2015), and in the case of predominantly Indigenous communities, special care needs to be taken to directly engage communities in the decision process and to guard against negative cultural impacts.

In the Bering Sea, the seafood industry is a significant potential or actual driver of the economy for Alaskan and Chukotkan communities. As with any commercially valuable activity, there is competition for the opportunity to exploit marine biological resources. In 2011 the total estimated labor income of the Alaskan Bering Sea fisheries was nearly USD 800 million (ASMI, 2013), yet only about USD 125 million, or 15%, of that income, went to regional residents; most jobs were filled by people from other areas. There are, however, other fishing regions where a dominant percentage of jobs go to local residents. In the Russian Federation, there is a significant but less well-documented fishery in the Anadyr River basin, which likely rivals the Alaskan fishery in the southern Bering Sea, off the Kamchatka Peninsula into the North Pacific. Small but locally significant fisheries are found in the Kotzebue/Norton Sound area of Alaska (Chapter 3).

The sustainability of marine resource production depends on a wide variety of factors, including traditional knowledge of harvested species, local governance and regulatory mechanisms, market prices, climate change impacts on ecosystems, and natural species variability. In addition, access to the possible economic benefits that fisheries might bring to a community can depend on investment in certain infrastructure, such as fishing vessels or processing facilities. Institutional arrangements that foster or constrain access to markets and sustainable harvest play a critically important role in the success or decline of local fishery industries. This wide range of factors makes projecting potential income from marine activities very difficult. It is critically important and in the best interests of local residents, the extended market, and the North Pacific fishing industry that ecological limits on stocks and productivity be understood and that appropriate regulations be implemented to build sustainable fisheries and prevent overfishing. Similar knowledge is required for the Chukchi and Beaufort seas.

Commercial marine fishing has some commonalities with subsistence activities, and so they often take place simultaneously. The complementary nature of the two activities can provide benefits outside the economic sphere, with additional positive effects for Indigenous peoples and their cultural practices. The Health Care Department of the Aleutian Pribilof Islands Association has speculated that one explanation for the extremely low suicide rate of the Aleut people of the southern Bering Sea (Alaska Suicide Follow-back Study; Alaska Injury Prevention Center, 2007) compared to other Alaska Natives and to Alaskans in general (Strayer et al., 2014) is their access to the relatively lucrative fishing industry jobs that are also culturally close to traditional Aleut practices. In addition, if local commercial fisheries activities encourage the consumption of local 'traditional' fish species by all people in northern communities, the outcome is likely to be healthier; for Indigenous peoples, it will promote a healthy diet and the cultural practices of food preparation and community sharing (Chapter 6). Opportunities for commercial fisheries activities farther north are limited by the US moratorium on commercial fishing north of the Bering Strait; there are no commercial fisheries in the Canadian Beaufort Sea (Chapter 3). This may change over time, depending on how climate change might affect the migration of fish stocks (Chapters 4 and 5). Regardless of the complexities of commercial fishing regulations and uncertainties relating to access to sustainable and economically viable fish populations, fisheries have significant potential for sustainable economic development in BCB communities, particularly where there exists a co-management structure that takes into account all potential users and ensures that the community is closely involved in the management of the resource (Chapter 2).

There can be no doubt that all countries of the BCB region have derived significant economic benefit from the extractive resources industries. The region has a long history of major mining and hydrocarbon operations, going back in some cases nearly a century (Chapter 3). Despite what might be considerable short-term economic benefits for communities and despite the current trend among companies working in these industries to coin terms such as 'green mining' or 'clean coal,' these industries cannot be said to be sustainable. In fact, the well-known boom and bust cycles that these industries tend to produce can worsen community problems over the long term when the jobs, whose incomes families have become accustomed to receiving, disappear. The very training and new skills that local workers receive as a benefit of development in the area may also encourage outmigration from the community, with locals leaving to seek new employment, along with the exodus of non-resident workers (Chapter 5). In addition, the influx of temporary, non-resident workers to a community can have negative cultural implications and could further stress community services that are already thinly stretched.

There are, however, examples of extractive industry activities in the BCB region that can be considered success stories in terms of supporting local economic development. Mining in Chaun-Chukotka, for example, is viewed very favorably by the region's Chukchi people, who support the mining companies' corporate social responsibility programs that provide funding for local cultural events (Chapter 2). In Alaska, Arctic Slope Regional Corporation (ASRC), an Inuit (Iñupiat) regional corporation, owns oil leases on Inuit land. Oil exploration and production on these leases takes place through contracts with oil companies, and Inuit maintain a high degree of control of the process; they also negotiate their own royalty arrangements. Red Dog Mine, one of the largest zinc mines in the world, has operated under a collaborative agreement with NANA Regional Corporation, near Kotzebue, Alaska, since 1989, employing a large number of local residents. Elder hunters from Noatak and Kivalina periodically meet with mine representatives to discuss subsistence and environmental issues (NANA Regional

Corporation, 2016). Operations that are well designed and managed, with community input to the process at all levels, can make for effective partnerships that benefit all parties.

Still, the nature of extractive industries activities is such that they seek to exploit and maximize return from a finite resource, and community input and planning for the economic and environmental impacts of when that resource is exhausted need to be a part of the process. Company responsibilities could include things like remediation plans for when operations conclude, as well as legacy infrastructure that would benefit the community after extraction operations cease. For communities, planning involves the more complex question of how to use present income to fund future community wellness and sustainability. How this can be accomplished will vary by community. There may be opportunities for infrastructure projects that would benefit the community after industrial activities have ceased and that are designed to adapt to environmental change – for example, improvements to airports and water and sanitation systems, incorporation of educational programs, or development of renewable energy systems. In addition, for Indigenous communities, it is especially important that industrial activities do not interfere with subsistence and cultural activities because these factors are important for food security and will cushion the shock of transition when industrial activities cease (Chapters 6 and 7). Planning ahead for transitions is another example in which communication, collaboration, and networks of knowledge exchange across local, regional, national, and international levels will help create sustainable solutions.

As with virtually all initiatives that take place in the Arctic, economic development activities should require that Indigenous and local community opinions be brought to the table early, often, and substantively. Where ongoing management activities are required, this management should be a collaboration among all entities involved – community, business, and government, as appropriate. Indigenous cultures have a strong grasp on how to manage environmental activities on the local scale; however, local communities often want to see economic development and may be willing to ignore impacts to some degree.

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*Wind turbines in summer on Wind Mountain above Nome, Seward Peninsula, Alaska*

## 9.3 The adaptation process: successes, challenges, and the way forward

Some adaptations will lead to incremental changes in policy, procedures, and modes of communication. These adaptations might also include concrete steps, such as building shoreline reinforcement against coastal erosion or adjusting the timing and location of subsistence food harvest. Other adaptations will require more substantive transformation of governance regimes, networks of communication, or fundamental values and priorities. Examples of such transformation include co-management decision bodies, new channels of cross-scale cooperation, explicit awareness of cross-sectoral feedbacks, and emphasis on sustainability.

### 9.3.1 Past successes in adaptation planning

The AACA-B report, *Taking Stock of Adaptation Programs in the Arctic* (Arctic Council, 2013), identified a number of factors that have contributed to success in adaptation planning in the Arctic. These factors include:

*Positive partnerships,* in which diverse groups (community or local participants, funders, external and internal experts, and other stakeholders both within and beyond the region) develop a shared vision for an initiative and work cooperatively to meet common objectives. Such partnerships include the sharing of resources (e.g., financial, personnel, data) as well as the qualities of open-mindedness, sensitivity, flexibility, and innovative thinking.

*Incorporation of local and traditional knowledge,* which is often essential for accurate information on local conditions (e.g., environmental factors, land use, planning policies, infrastructure quality, social change) and, overall, to fully understand the reality of climate change impacts at the community level. Local and traditional knowledge is seen as pivotal for initiatives pertaining to traditional livelihoods, such as subsistence economies, commercial fishing and hunting, and reindeer herding. Local expertise can be especially valuable.

*Effective communication for target audiences*, such as using easily understood messages and communicating in Indigenous languages, has contributed to successful awareness-raising activities. A community-based study design has been effective, as have a variety of communication methods (including the use of social media and YouTube videos).

*Learning from others' experiences* can prompt an adaptation activity and provide helpful background and information. The transfer of knowledge can be from other communities, boundary organizations, agencies, and even other Arctic nations.

#### 9.3.1.1 Components of successful adaptation

There is no 'one size fits all' solution for adaptation across sectors or geographic subregions in the BCB region (Field et al., 2014; Larsen et al., 2014; Mimura et al., 2014). Adaptation will require case-specific consideration of contextual and interconnected environmental, cultural, social, and economic conditions. However, general principles for successful adaptation include the following:

- Cross-scale coordination and incorporation of local knowledge, networking, and information sharing that recognizes differing values and priorities
- Consideration of short-term disaster risk management together with longer-term structural policy
- Recognition of the larger context, including multiple stressors and cumulative effects
- Engagement of an adaptive, co-management governance framework that includes traditional (Indigenous) knowledge and science in community-driven networking and information sharing (Chapter 7)
- Establishment and support for two-way communication between scientists and decision-makers as well as for science outreach and education.

#### 9.3.1.2 Evaluating planned adaptation

While many adaptations to changing environmental and social conditions occur spontaneously, without a formal planning process, planned adaptation to changing environmental and social conditions is most productively viewed as an ongoing, iterative, inclusive process in which the evaluation of implemented activities informs future action (Figure 7.2) (Eyzaguirre and Warren, 2014). The overall societal and ecological goals of adaptation planning and action should be identified early in the process with the equitable inclusion of all affected parties, including communities (Adger et al., 2006). Monitoring, evaluating, and revising both the process and the outcomes of adaptation actions to meet these goals is an important part of the adaptation process (Figure 7.2) (Moser and Boykoff, 2013; Eyzaguirre and Warren, 2014).

Preparing for climate adaptation evaluation involves clarifying why and for whom the evaluation is taking place, involving key stakeholders, cultivating support, discussing adaptation outcomes, and agreeing on principals that will guide the evaluation (Horton et al., 2003). Long time horizons for effecting change, shifting baselines and decision contexts, and attribution of outcomes (e.g., exclusively or in part to the actions taken) all present challenges to adaptation evaluation (Bours et al., 2015).

Evaluation of adaptations on the provincial or territorial levels has not yet occurred in Canada (Eyzaguirre and Warren, 2014), and no evidence exists at this time of adaptation evaluation in other parts of the BCB region either. Opportunities exist for network building to facilitate international knowledge sharing and cross-regional learning in identifying adaptation goals, establishing evaluation metrics, and comparing evaluation outcomes, especially pertaining to the themes of food security, social/cultural cohesion, and environmentally sustainable economic opportunities.

### 9.3.2 Key challenges

The following list of key challenges represents the overarching, regional-scale issues facing adaptation to change in the BCB region as a whole, to which must be added local-scale problems that vary in their nature between different communities and are not necessarily common to all.

*The rate and magnitude of climate change* and its impacts in the BCB region may pose a barrier to incremental adaptation if critical ecological thresholds are crossed. Human systems such as subsistence hunting, fishing, and gathering could be affected by changes such as the reduction of habitat for marine mammals, changing ocean temperatures and chemistry (ocean acidification), and changing seasonality (causing mismatched timing in the availability of food at critical life-cycle phases). The crossing of critical ecological, social, and economic thresholds will require substantial transformations in social, economic, and institutional structures.

*Lack of collaborative institutions and governance arrangements* between stakeholders and policy and regulatory regimes can slow adaptation responses on the community-to-regional scale. This includes regulatory schemes as well as coordination and cooperation among federal/state/territory, local/native, and private institutions. Cross-scale dynamics, from the local to the territorial/state/prefect and national and international levels – particularly in governance and regulation – are important in adaptation planning, implementation, and assessment. For example, adaptation often occurs on a local scale but can be constrained by policy, regulation, or lack of funding at higher institutional scales. The relocation of the Alaskan village of Newtok to Mertarvik to escape severe coastal erosion is one example of cross-scale interaction, as a lack of funding from the state and federal levels has been problematic. This key challenge opens opportunities for international collaboration and information exchange to promote adaptation.

*Challenges with project implementation* include limited funding resources, high staff turnover rates, inaccessibility of expertise to stakeholders, and absence of data/information. When ongoing resources are lacking, projects are often initiated for short periods and then lose momentum. Related challenges to implementation include coordinating schedules and aligning visions and expectations, especially for large projects with several partners from different sectors or different locations. Another facet of this challenge is insufficient capacity, especially for smaller or isolated communities that do not have the necessary skills or ability to obtain training and relevant information to plan and implement adaptation actions.

*Convincing decision-makers of the need for action* is a challenge that manifests itself in several ways. For decision-makers at the community or regional level, addressing climate change adaptation can become a lesser priority relative to more immediate needs such as housing, employment, and economic development. In some larger municipalities, it has been difficult to convince decision-makers to trust climate models and plan for several decades into the future when this long-term perspective could mean limiting revenue-generating activities. In some Indigenous communities, there is the perspective that they have adapted to many changes in past generations, and climate change represents just another challenge to which they will adapt over time as it occurs. More generally, the fact that climate changes more slowly than other socio-economic drivers contributes to a tendency to regard a concerted plan as less essential than if climate were the only driver of change. Still, increasing numbers of rural Indigenous communities in Alaska are seeking funding and assistance in creating climate adaptation plans. In considerations of long-term, gradually changing environmental conditions, it would be a critical mistake to ignore the immediately pressing social, cultural, and economic issues. The need for a comprehensive view underscores the importance of cross-scale interactions, dialogue, and collaboration. Rational conversations among local and national leaders must balance the urgency of pressing needs versus long-term needs.

*Communication among partners and with adaptation implementers* presents several challenges, including 'bridging lexicons' between scientists, Indigenous knowledge holders and practitioners, and other stakeholders and community members. The integration of scientific knowledge and traditional knowledge is also difficult when variables, scales, metrics, and priorities combine into 'different ways of knowing.' The number of conversations and the amount of effort required to achieve a common vision and a commitment to an initiative's objectives can run counter to the limited duration of a particular project or the available funding. While bridging traditional ecological knowledge and scientific knowledge has been acknowledged as a critical need, there is little guidance for how it may be accomplished (Knapp and Trainor, 2013).

*Lack of climate, environmental, and other data* can hinder adaptation efforts, especially in large and sparsely populated areas where monitoring networks are inadequate or nonexistent. Deficiencies in socio-economic data to enable climate change impact and risk assessments are especially notable hindrances to effective decision-making. Infrastructure-related activities have been hampered by the lack of historical design, construction, and maintenance records. In addition, regional consistency of geographic and topical coverage in regional and subregional climate assessments is severely limited by information gaps. Communicating existing data to decision-makers on local and community scales is also needed (Knapp and Trainor, 2013).

*Obtaining and selecting the right tools*, such as protocols, guidelines, mapping techniques, and databases, can be an obstacle to adaptation planning. These tools are often not disseminated to practitioners or to the appropriate people at the community or municipality level where they could be applied. Availability and guidance for use are problematic, especially when tools are highly technical or not appropriately targeted to the particular community for which they were developed.

### 9.3.3 Ways forward

Section 9.2 identifies priorities for adaption planning and action in the BCB region. Given these priorities, there are several directions for further work on climate change adaptation by the Arctic Council as well as governmental entities at various levels.

*Assess the usefulness and specificity of BCB scenarios.* Chapter 8 presented examples of scenarios for the BCB region. These examples are intended to illustrate the scenario process as a tool for planning, and they can be refined or extended for application to actual planning activities. An initial step would be to apply this approach to more specific adaptation activities through prototype planning efforts in subregional or local areas. Participation of scenario experts as well as community/sector representatives would facilitate the optimal use of the scenarios process. Some coordination of such efforts would enable feedback on lessons learned, in order to streamline the process for further use by other sectors and locations.

*Establish a framework for each community or socio-economic sector under which adaptation planning could occur.* While an overall process for adaptation planning was outlined in Chapter 7, there is no one-size-fits-all process or solution for adaptation in the BCB region. The process suggested by Pearce et al. (2012), for example, is specifically tailored for small, remote, subsistence resource–dependent communities. Six steps are involved: an analysis of documentary sources of information related to risks and adaptations already considered for the community; community engagement and partnering with external experts; local workshops on adaptation planning; development of an adaptation plan informed by community (i.e., local) concerns, priorities, and available resources; ongoing review of the plan by key contributors and local decision-makers; and initiation of pilot adaptation actions based on the identified priorities and action feasibility. Specific resources and guidance documents are also listed in Chapter 7. The choice of which framework to use should be left with the communities or sectors involved.

*Promote utilization of and contributions to a database of adaptation activities.* A comprehensive database of adaptation activities can inform adaptation planning in the BCB region. Benefits include coordination, synergies, and efficiencies across different locations; the sharing of 'lessons learned'; and greater leverage for funding from regional and national sources. This database should include efforts in the three BCB countries (Russia, United States, Canada). Outreach and communication on regional, local, and individual scales is a critical complement to such a database in order to ensure that the information is up-to-date and relevant. An example of an effort along these lines is the Arctic Adaptation Exchange portal (www.arcticadaptationexchange.com). This online portal is a project of the Arctic Council SDWG and was officially launched in 2015. Its stated goal is to build connections in the Arctic for climate change resiliency and adaptation. The portal contains significant information related to the BCB region and, with further development, could serve as an 'innovation space' to allow communities to collaborate on issues of common concern.

*Establish and foster networks for sharing information and expertise.* These envisioned networks would play a facilitative role to support capacity building, knowledge development, and the exchange of experience related to adaptation. The Arctic Adaptation Exchange is one example of a web-based portal that provides access to adaptation activities, tools, and links to other resources. Other complementary options would be to facilitate the development of networks of sector-relevant practitioners who could learn from each other, build local and regional capacity, and be utilized directly or indirectly in specific adaptation efforts. In-person workshops or virtual meetings could be a way to build international communication and collaboration. Another aspect of this activity could be ongoing assessment of other international or regional organizations' treatments of adaptation. This assessment could build on the AACA-A survey of organizations that provide data, strategies, advice, and general information for a variety of target audiences (Arctic Council, 2013).

*Focus on concrete adaptation practice.* An initiative to focus on concrete adaptation practice could, for example, center around dissemination and training in the use and application of specific tools. Several options are presented and described in Chapter 7. Tools could include guidelines, protocols, processes, and techniques to implement adaptation activities. A key feature is the establishment of networks and training to directly assist practitioners and decision-makers at the community level in selecting and using appropriate tools for their particular circumstances.

*Adopt a sector-focused approach.* Approaching adaptation on a sector-by-sector basis could assist in targeting resources, building networking capacity, supporting in-depth analyses, and identifying relevant experts and practitioners to contribute to an issue of broad relevance across the BCB region. Sectoral areas of particular relevance in the region include subsistence food harvest, trans-Arctic shipping, mining and resource extraction, fisheries, transportation, tourism, governance, and institutional adaptation. With such an approach, however, it is particularly important to note the feedbacks and interactions between sectors. As previously noted, shipping, resource extraction, transportation, tourism, and governance all affect subsistence food harvest. Similarly, adaptation in shipping, resource extraction, and transportation will all require some degree of action in governance.

*Focus on training and education.* Like other Arctic regions, the BCB region is changing more rapidly than other parts of the world. People in rural Arctic Indigenous communities are requesting access to training and education not only to promote economic development but also to support and bolster adaptation planning and implementation. In addition, access to education creates a more informed and more resilient workforce. Traditional and local knowledge will always be important, and sharing that understanding enhances cultural ties and stability. As local economies change, additional formal education and training will also play a role in enabling local residents to acquire new skills and the ability to adapt to conditions outside the range of their prior experiences.

### 9.3.3.1 Adaptive governance

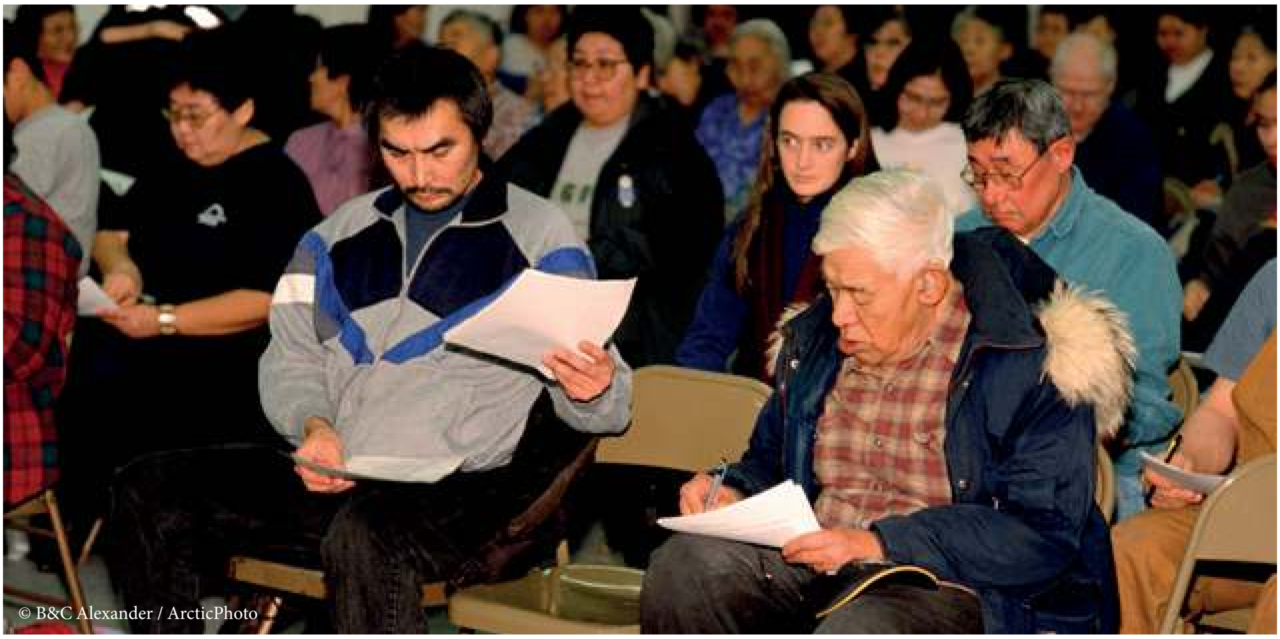
Given the dynamic regional environmental and socio-economic conditions, Arctic governance systems and institutions will need to remain flexible and adaptive to meet future challenges (Young, 2015). This is true on levels from local to international. The environmental, economic, social, and political drivers of change in the Arctic are closely interlinked, and adaptation in the region will be influenced by global markets and politics. It will also be necessary for non-Arctic institutions with interests in the region to engage in adaptation and to take responsibility for the future of the region while remaining sensitive to the priorities and concerns of Arctic residents (Young, 2015). Place-based, regional adaptations, described in Chapter 7, and the activities of the Arctic Council can be supplemented by institutional initiatives including global agreements, public–private partnerships, and informal venues (Young, 2015).

Characteristics of institutions that are particularly adept at facilitating adaptation include responsiveness, flexibility, diversity, and ability to foster cross-scale interactions. Governance systems currently in place in the BCB region vary substantially from one country to another, and aspects of these governance structures are changing. One such aspect is the result of shifting internal processes and actors, such as the decentralization of responsibilities from federal to regional levels of government in Canada and Russia. Another aspect is the evolution of new actors and regulatory frameworks as a result of negotiation and implementation of northern land claims and self-government agreements, such as in northern Canada with the evolving development of Inuit Nunangat, the Inuit homeland. Governance is also changing on a regional, national, and local basis as a result of the recognized need to ensure sustainable development in the region in the face of changing climate and changing socio-economic conditions. All of these changes in governance will affect local, regional, and national capacities for supporting and promoting adaptation actions.

The stakeholder perspectives presented in Chapter 2 of this report emphasize the need to better address cross-scale interactions and international cooperation (Canada, United States, Russia, and other Arctic states, as well as non-Arctic states such as China and others). Communication, collaboration, and partnership across scales and levels of governance and decision-making is an important way to facilitate adaptation and build adaptive capacity. This is true whether starting at the local level ('bottom up') or at larger national or international levels ('top down'). One example of cross-scale collaborations is the Newtok Planning Group, which has been working for over a decade to relocate Newtok, an Alaskan village threatened by riverine erosion (Alaska DCCED, 2012).

### 9.3.3.2 Scenarios planning

Developed initially in business and the private sector, scenarios planning has been used for over 50 years, as a tool for visioning and preparing for rapid change that involves a range of potential impacts and uncertainties (from high to low). The process identifies key drivers of change and critical unknowns while generating shared understanding among stakeholders regarding the potential for, and implications of, alternative futures (Bishop et al., 2007; Avango et al., 2013). Scenarios are often used to explore possible futures that lie beyond forecasts or predictions (i.e., beyond the horizon of reasonable confidence about future trajectories, outcomes, and uncertainties) and have also proven valuable as tools for exploring low-probability, high-consequence events. When employed skillfully, the process can incorporate local traditional knowledge alongside scientifically derived knowledge – an important element in the BCB region. Scenarios planning can also identify communication gaps and divergent approaches to problem framing.



*Villagers consider the agenda at a Wheeler-Howard Act meeting in Shishmaref, Alaska*

Regionally, scenarios have been used to identify adaptation options for US National Park Service facilities and to plan activities of the North Slope Science Initiative, both in Alaska. Scenarios were also used in the Mackenzie Gas Project pipeline planning in Canada's Northwest Territories (Cizek, 2005; Holroyd et al., 2007). The Arctic Council's Arctic Marine Shipping Assessment (Arctic Council, 2009) is one example of rigorous futures thinking, with scenarios planning being a key element.

One advantage to the scenarios planning approach is that it can explicitly address the combined effects of economic and resource development as well as environmental and social change. It can also incorporate cross-scale interactions, such as accounting for local impacts of and responses to resource development involving global markets and global-scale industry. The process may be highly participatory, so outcomes are directly contingent on which stakeholder groups are involved – a characteristic that emphasizes the need for broad inclusion and equitable participation of all interested and affected parties.

## 9.4 The science/action interface and gaps in knowledge

Although adaptive actions are already underway in the BCB region, a new model is needed for linking science and adaptation action. This can be accomplished in several ways, including fostering and developing knowledge networks, embedding institutional capacity, and engaging knowledge brokers (Chapter 7).

The 'usability' of scientific research is increasingly valued by funders; however, gaps remain in incorporating stakeholder needs and perspectives into the research process (Chapters 2 and 7). Strong communication and trust-building are important components of bridging knowledge and action.

Adaptation has been shown to be facilitated by the work of boundary or bridging organizations or other intermediary entities that can build communication, foster knowledge exchange between scientists and decision-makers, adjust nimbly to changing environmental or political landscapes, and foster communication among groups that seldom communicate. The process of integrating science with the needs of stakeholders requires specific skills and qualities, including an ability to understand the decision context, plus humility, patience, curiosity, self-reflexive thinking, strong communication skills, and respect for different perspectives and values (Brugger et al., 2015).

Recommendations for bridging science and action include the following:

- Engage stakeholders, including Indigenous peoples, from the beginning of the research process and engage in iterative, ongoing dialogue between scientists and stakeholders
- Create decision support tools and establish climate services, knowledge networks, and data-sharing platforms and procedures
- Improve the interdisciplinary aspects of scientific research and reflect on the process of how science is conducted, including addressing the subjective factors of adaptation (e.g., values, identities, and emotions) in addition to objective measurable indicators.

At least as important as identifying research needs and filling scientific knowledge gaps is making existing knowledge available in a form that is relevant and applicable to policy, planning, management, and other decision contexts for the implementation and assessment of adaptation actions and measures.

While growing quickly as a field of scholarly inquiry, adaptation research overall has significant research gaps, and thus significant opportunities for future work. These opportunities include addressing methodological and knowledge gaps in evaluating adaptation actions over time and better understanding how adaptation actions may set up path dependencies by facilitating or constraining future action. As previously noted, there is also a need to better understand the cumulative impacts of climate change, industrial development, and societal change, including the complex dynamics of cross-scale and cross-sector comparisons. A need exists for explanatory (versus descriptive) social science approaches to adaptation, including behavioral sciences, institutional analysis, and policy analysis. Similarly, a knowledge gap exists in interdisciplinary work that could better engage the social sciences in adaptation research, especially psychology, communication, and decision sciences.

Specific to the BCB region is an identified need for innovation in the process of conducting scientific research that genuinely engages and partners with Indigenous communities in a way that substantively builds adaptive capacity to multiple stressors and achieves locally defined goals. More research is needed across scales, and more is needed on engaging the changing economic opportunities associated with shipping and resource development, in addition to impacts on Indigenous practices. There is additional need for longitudinal studies, for assessment of the effectiveness of adaptive actions, and for international comparisons with other regions. Finally, to live efficiently and sustainably in these northern regions, it is important to establish and maintain cooperation and collaboration among the national and regional governments in Canada, the United States (Alaska), and Russia (Chukotka).

## 9.5 What have we learned?

For the BCB region, this report is the first synthesis of environmental and social/cultural information to include marine, terrestrial, and freshwater environments as well as the social impacts and perceptions of this rapidly changing region. Much of the existing information from the United States and Canada was collected preparatory to offshore oil and gas development and in many instances is of an inventory quality. Information from Chukotka, Alaska, and Canada was also obtained through the published literature and through interviews with scientific experts and local residents. Available data are sometimes scattered and fragmented (especially in Chukotka), but long-term data sets are developing in many disciplines and the ability to conduct comparative analyses is improving. There is considerable historical and ongoing research in the region, allowing for good insights into what is currently changing, what may change in the future, and how people have responded or will respond.

Several important lessons emerge from these analyses. For the most part, people throughout the region were more concerned with immediate needs, such as local politics, the economy, or the price of fuel, as compared to the longer, slower consequences of a changing climate. There was great concern over availability and access to subsistence food resources, although academic or policy phrases such as 'food security' were seldom mentioned. It is important to remember that there are opportunities as well as challenges, and individuals are keen to make their lives and communities more stable. Communities are facing a wide array of challenges and are dealing with them in various ways. There were remarkable similarities and differences among the communities across the region. Indigenous people are quite dependent on the natural world for food and other products to assist in their daily living. The traditional economy is very strong throughout the BCB region. In Chukotka, many people returned to this form of living during the post-Soviet period. The common importance of caribou/reindeer and marine mammals (bowhead whales, beluga and ice seals) emphasizes the importance of the coast. In many instances, especially in northern Alaska, participation in the cash economy actually allows many villagers more access to subsistence hunting, fishing, and trapping. This is because they have more disposable income to invest in technologies that help them to be successful in their subsistence activities. However, another important similarity is that opportunities for employment are quite limited for villagers, thus constraining their incomes and abilities to afford transportation and supplies required for subsistence food harvest. The employment opportunities associated with extractive natural resource industries benefit non-local and local non-Indigenous workers more than Indigenous residents. The regional and national governments in the BCB region appear to be poorly equipped organizationally to deal with even the most urgent needs (e.g., threatened coastal villages) in ways other than emergency responses and piecemeal approaches; regional strategic planning is not really in place.


LOETSCHER CHLAUS / Alamy Stock Photo

*Skinboat used on bowhead whale subsistence hunt, St. Lawrence Island, Bering Sea, Alaska*

One surprise was that at-risk communities in Alaska are growing demographically, despite some outmigration, including those on the coast threatened by dramatic erosion. This growth does not necessarily mean that these communities are resilient, but that there may be something locking people in or out of a systematic response. There may also be ways in which the impacts are being temporarily buffered, which is not necessarily a good thing as buffering could delay the need for action and potentially worsen impacts in the future.

The Survey of Living Conditions in the Arctic (SLiCA) was extensive in its coverage of different aspects that relate to satisfaction of life and living conditions in the Arctic (Poppel et al., 2007). The Chukotka response was almost the exact opposite of what respondents reported for Alaska and western Arctic Canada. In Chukotka, more than 80% of those surveyed were dissatisfied with their lives, how and where they lived, and about their future prospects (Chapters 2 and 3). In Alaska and Canada, between 7% and 19% of respondents reported dissatisfaction. Although these rates are lower than in Chukotka, they are significant and may play a role in the high rates of drug abuse and suicide in the BCB region.

Climate adaptation planning needs to be improved and needs to consider local inputs at much smaller scales (village-by-village or within a network of villages). This level of local input could be based on urgency of threat, which might vary geographically or by different subsistence practices. Numerous signals of climate-related change are present, extending beyond the classic example of sea ice loss. Other important characteristics of the changing system include degradation of permafrost; changes in hydrology and freshwater availability; dynamics of plant growth, migration, and succession; and the movements and behavior of walruses, polar bears, and caribou. Marine species that rely on pelagic ecosystems may benefit or be otherwise impacted from potential changes in benthic–pelagic coupling. Increasing wildfires may affect access to subsistence resources by locals (to caribou and reindeer, for example). Freshwater corridors for humans are changing in summer (low flows) and winter (unsafe ice conditions). Primary production and herbivory are especially important in the region, in both marine and terrestrial systems. Adaptations in fish species that migrate from freshwater to brackish or marine habitats due to their greater food resources will slow the changes in marine food webs.

## 9.6 What does that tell us about the future?

Adaptation actions taken now on local, regional, national, and international levels will affect future economic, social, and environmental trends and conditions. There is an opportunity to set a course for local, regional, national, and international cooperation and networking that can promote healthy communities and effective adaptation. However, overlooking key elements of success and ways forward, many of which are outlined in this report, may have detrimental outcomes for community, environmental, and social well-being in the region. It is important to pay closer attention to the way the world looks from the community perspective, rather than asking northern residents to say what they think about the latest area of interest. Much can be learned by studying what people in communities are already doing to adjust to change. It should be remembered that for communities, the time scale of climate impacts may be longer than many major concerns, each of which could determine the survival of the community. Pressure for oil and gas production and hard-mineral mining (e.g., diamonds, gold, zinc) is likely to remain, with access to extended continental shelves (i.e., beyond 200 nautical miles from shore) and deep water increasing as ice recedes. Commercial fishing in the Chukchi and Beaufort seas is unlikely to be viable in the near term, but with good management, this industry will remain important in the Bering Sea. As a result of these many considerations, adaptation planning on multiple levels needs to account for the feedbacks and interactions between sectors and to promote cross-scale institutions and communication.

Training and educational opportunities should be an emphasis of integrated planning at all levels of governmental organization. Within the BCB region, there are few examples of economic developments that have integrated local communities into their planning, but local perspectives must be incorporated through strategic planning in order to create robust, diverse economies. Native corporations and regional governments must become involved in potential new developments in order to ensure opportunities for local employment and the protection of important subsistence food sources. The BCB nations must make sure local Indigenous values and issues are known to their respective governments and people. Trends in emigration must be monitored as part of ensuring economic and cultural sustainability. Regional and national governments, which tend to be far removed from the BCB region, must become more effective in actively engaging local officials, who have vital perspectives and contexts for effective adaptation.

This BCB analysis provides a benchmark that should be updated at regular intervals (perhaps every five years), with a focus on ensuring that communities and regional and national governments are aware of evolving challenges and opportunities. Landscape and seascape evolution should be monitored and quantified to facilitate the communication of environmental/ecosystem understanding. The health of communities, families, and individuals must also be considered, and strategic planning should actively address the social concerns identified here.

## 9.7 Closing comments

This report describes important considerations for adaptive governance and discusses the process of scenarios planning. These frameworks are highlighted because of their potential to bring adaptation to new levels of effectiveness in the BCB region. Successful implementation of these recommendations requires consideration to how and where local residents and community leaders can effectively interface in adaptation planning with governments in the BCB region (thus enhancing top-down participation). It is also necessary to increase funding for local stakeholder participation in entities such as the Arctic Council working groups, the Landscape Conservation Cooperative network, and others (thus enabling bottom-up participation). It is critically important to view the dynamics of the BCB region as responding to multiple drivers that interact and create confounded, interwoven responses with sometimes unexpected and possibly amplified consequences. It is necessary to ensure that adaptation planning groups conduct some business outside of major municipal hubs to ensure on-site participation, enhance community awareness, and engage in information sharing. There is a need for increased effort toward developing community-based climate and economic scenarios to assist adaptation planning and coordination at multiple levels. Local and federal governments should assist in education and training for community planners to help make them more aware of and better able to respond to proposal calls and specifications. And finally, it is essential to recognize the importance of traditional and local knowledge – incorporating that understanding into the planning process.

Becoming more adaptive will require a stronger focus on renewable rather than finite resources. When development of non-sustainable resources takes place, planning for the cessation of benefits from that development should also take place at the earliest stages. Environmental impact assessment and economic impact assessment should be complementary, concurrent, and prerequisite to development approval. Economic opportunity can be a powerful force to improve the capacity of BCB communities to adapt to change; consequently, there should be effective and well adopted best practices in place to give economic development activities the greatest possible chance to benefit Arctic communities.

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# Acronyms and abbreviations

| | |
|---|---|
| $\Omega$ | Saturation state |
| AACA | Adaptation Actions for a Changing Arctic |
| AMAP | Arctic Monitoring and Assessment Programme |
| AMSA | Arctic Marine Shipping Assessment |
| ANILCA | Alaska National Interest Lands Conservation Act |
| ANSCA | Alaska Native Claims Settlement Act |
| AR5 | IPCC fifth assessment report |
| BCB | Bering-Chukchi-Beaufort (region) |
| BRACE | Building Resilience Against Climate Effects |
| CAD | Canadian dollar |
| CAO | Chukotka Autonomous Okrug |
| $CO_2$ | Carbon dioxide |
| EMERCOM | Russian Emergencies Ministry |
| ESM | Earth System Model |
| GBP | Global Business Network |
| Hg | Mercury |
| IHS | Inuit Health Survey |
| IPCC | Intergovernmental Panel on Climate Change |
| ISR | Inuvialuit Settlement Region |
| IWC | International Whaling Commission |
| MDE | Mercury depletion event |
| MW | Megawatt |
| NASP | Northern Alaska Scenarios Project |
| NDVI | Normalized difference vegetation index |
| NSSI | North Slope Science Initiative |
| NWT | Northwest Territories, Canada |
| PCB | Polychlorinated biphenyl |
| POP | Persistent organic pollutant |
| RCP | Representative concentration pathway (IPCC) |
| 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 |
| RIA | Regional impact assessment |
| RUB | Russian ruble |
| SLiCA | Survey of Living Conditions in the Arctic |
| SRES | Special Report on Emissions Scenarios (IPCC) |
| SSP | Shared socio-economic pathway |
| SWE | Snow water equivalent |
| SWIPA | Snow, Water, Ice, and Permafrost in the Arctic |
| USD | United States dollar |

**Arctic Monitoring and Assessment Programme**

The Arctic Monitoring and Assessment Programme (AMAP) was established in June 1991 by the eight Arctic countries (Canada, Denmark, Finland, Iceland, Norway, Russia, Sweden and the United States) to implement parts of the Arctic Environmental Protection Strategy (AEPS). AMAP is now one of six working groups of the Arctic Council, members of which include the eight Arctic countries, the six Arctic Council Permanent Participants (indigenous peoples' organizations), together with observing countries and organizations.

AMAP's objective is to provide 'reliable and sufficient information on the status of, and threats to, the Arctic environment, and to provide scientific advice on actions to be taken in order to support Arctic governments in their efforts to take remedial and preventive actions to reduce adverse effects of contaminants and climate change'.

AMAP produces, at regular intervals, assessment reports that address a range of Arctic pollution and climate change issues, including effects on health of Arctic human populations. These are presented to Arctic Council Ministers in 'State of the Arctic Environment' reports that form a basis for necessary steps to be taken to protect the Arctic and its inhabitants.

This report has been subject to a formal and comprehensive peer review process. The results and any views expressed in this series are the responsibility of those scientists and experts engaged in the preparation of the reports.

The AMAP Secretariat is located in Oslo, Norway. For further information regarding AMAP or ordering of reports, please contact the AMAP Secretariat (Gaustadalléen 21, N-0349 Oslo, Norway) or visit the AMAP website at www.amap.no.

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ISBN 978-82-7971-103-2

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Assessment Programme