Arctic Resilience
Interim Report 2013


Aleutian Islands
PACIFIC OCEAN
Bering Sea
Petropavlovsk-Kamchatsky
Kamchatka
Sea of Okhotsk
Amur
Gulf of Alaska
Koryaks Mts.
Anadyr
Anchorage
Yukon River
Alaska Range
ALASKA (USA)
Kolyma Mountains
Kolyma River
Juneau
Whitehorse
Fairbanks
Bering Strait
Teslin
Dawson
Brooks Range
Chukchi Sea
Wrangel Island
Chersky Range
Yakutsk
Rocky Mountains
Mackenzie Mountains
Barrow
Prudhoe Bay
East Siberian Sea
Verkhoyansk
Verkhoyansk Range
Mackenzie River
Inuvik
Northwest Territories
Beaufort Sea
New Siberian Islands
Tiksi
Lena River
Lake Baikal
Great Bear Lake
Great Slave Lake
Yellowknife
Saskatchewan R.
Lake Athabasca
Canada Basin
Banks Island
Laptev Sea
Central Siberian Upland
CANADA
ARCTIC OCEAN
Victoria Island
Nunavut
Lake Winnipeg
Makarov Basin
Taimyr Peninsula
Churchill
Arviat
Rankin Inlet
Resolute
Alpha Ridge
Lomonosov Ridge
North Land
RUSSIAN FEDERATION
Norilsk
Hudson Bay
Naujat
Ellesmere Island
Alert
Amundsen Basin
Nansen-Gakkel Ridge
Yenisey River
Foxe Basin
Baffin Island
Qaanaaq
Nansen Basin
Franz Josef Land
Novaya Zemlya
West Siberian Plain
Ob River
James Bay
Ungava Peninsula
Hudson Strait
Baffin Bay
Yamal Peninsula
Kara Sea
Salekhard
Québec
Iqaluit
GREENLAND (DENMARK)
SVALBARD (NORWAY)
Vorkuta
Ob River
Khanty-Mansiysk
Irtysh
Longyearbyen
Fram Strait
Sisimiut
Ilulissat
Davis Strait
Barents Sea
Naryan-Mar
ARCTIC CIRCLE
Bjørnøya
Ural Mountains
Nuuk
Greenland Sea
Labrador
Murmansk
Syktyvkar
Perm
Kama River
Ammassalik
Jan Mayen
Tromsø
Kola Peninsula
Arkhangelsk
White Sea
N. Dvina
FINLAND
Norwegian Sea
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Lake Ladoga
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Helsinki
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North Sea
Baltic Sea
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DENMARK

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Interim Report 2013

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The Arctic Resilience Report (ARR) is an Arctic Council project led by the Stockholm Environment Institute and the Stockholm Resilience Centre. It builds on collaboration with Arctic countries and indigenous peoples in the region, as well as several Arctic scientific organizations.

The ARR was approved as an Arctic Council project at the Senior Arctic Official's meeting in November 2011. The ARR was initiated by the Swedish Ministry of the Environment as a priority for the Swedish Chairmanship of the Arctic Council (May 2011 – May 2013) and continues until May 2015.

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The ARR project is governed by a Project Steering Committee, which consists of representatives of Arctic Council Member States, Permanent Participants and Working Groups, as well as representatives of collaborating organizations. PSC members are listed below.

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Preface

The Arctic is one of the most rapidly changing regions on the planet. These changes are taking place with striking breadth and diversity, and in ways that fundamentally affect the Arctic's ecosystems and the lives of its inhabitants. While climate change is the most prominent driver of change, many other environmental changes are taking place alongside rapid social and economic developments. In some contexts, social, political, economic and ecological drivers may be of greater significance than climate change. Social processes driving Arctic change include increasing demand for resources and for transportation, migration, geopolitical changes and globalization. Ecosystem changes include, for example, drawdown of fish resources and degradation of Arctic landscapes. As a result, the Arctic faces multiple and simultaneous social and environmental stressors. An integral part of the assessment is to identify policy and management options.

This Arctic Resilience Interim Report 2013 marks the halfway point in a process set in motion at the start of the Swedish Chairmanship of the Arctic Council. It aims to better understand the nature of critical thresholds in the Arctic and the sources of resilience in the face of environmental and social pressures, including choices that strengthen capacities to adapt and transform in the face of change. Because local changes are nested in larger-scale processes, it investigates the important interactions across scales. A core goal of this project is to better understand the combined impacts of change in the Arctic, focusing on the risk of large shifts in ecosystems services that affect human well-being. By taking an inter-disciplinary approach and analyzing the dynamics of change, the report generates crucial knowledge to inform decision-making regarding adaptation and transformation.

The project has been led by the Stockholm Environment Institute and the Stockholm Resilience Centre in collaboration with the Resilience Alliance. Importantly, the project has built on collaboration with other Arctic states and the indigenous peoples in the region, as well as with several Arctic scientific organizations.

We are looking forward to the final report in the spring of 2015 and anticipate further valuable insights into options for policy and other action and for understanding resilience and the risks associated with crossing thresholds of change.

Lena Ek
Swedish Minister
of the Environment

Johan Rockström
Executive Director of
Stockholm Resilience Centre
Chair of the ARR Project
Steering Committee

Glossary of terms

Adaptive capacity: The ability of a system or individual to adjust to changing conditions or recover from the impacts of change. In ecological systems, adaptive capacity is influenced by the biodiversity and the degree of redundancy in the system. In human social systems, it is determined by the structures and processes that enable or constrain choices for action and that shape people's ability to anticipate and plan for future change.

Agency: The capacity of individual and groups to act and make choices.

Controlling variable: A system component that has a dominant influence on the functioning of the system. Often, these are slowly changing components that trigger fast changes in other variables.

Cultural ecosystem services: The cultural values and benefits provided by ecosystems, including values such as recreation opportunities, aesthetic inspiration and spiritual values.

Driver: A natural or human-induced factor that causes a change in a system. Note that a driver that is seen as an external process when viewed from one scale may be seen as an internal process when viewed from another.

Ecosystem services: The benefits to human society that arise from ecosystem processes.

Feedback: A change within a system that occurs in response to a driver, and that loops back to control the system. A feedback can help to maintain stability in a system (negative or balancing feedback), or it can speed up processes and change within the system (positive or enhancing feedback). Feedback processes play a very important role in determining system thresholds and in maintaining system resilience.

Forcing: In climate science, forcing refers to an external driver of change in the physical climate system.

Function: The activities that are characteristic of a system, and that maintain its structure and services.

Provisioning ecosystem services: The goods directly obtained from ecosystems, such as food, fibre, fuel, and fresh water.

Regime shift: For complex systems, a substantial and enduring reorganization of the system, where the internal dynamics and the extent of feedbacks undergo change.

Regulating ecosystem services: The beneficial ecosystem processes that help to maintain ecosystem function. These services provide indirect value to people. They include pollination, erosion control, carbon sequestration, water filtration, etc.

Resilience: The capacity of a social-ecological system to cope with disturbance, responding or reorganizing in ways that maintain its essential function, identity and structure, whilst also maintaining the capacity for adaptation, learning and transformation.

Social-ecological system: An integrated system that includes human societies and ecosystems. The functions of such a system arise from the interactions and interdependence of the social and ecological sub-systems. Its structure is characterized by reciprocal feedbacks.

Structure: The web of interactions that link a system's key actors or processes.

System state: The configuration of a system defined by its structure, function, and feedbacks.

Threshold: An abrupt breakpoint between alternate states of a system, where a small change in the controlling variable produces a large change in the characteristic structure, function and feedbacks of the system.

Tipping point: A specific kind of threshold, characterized by bifurcation in a system, often recognized in systems that show oscillations between alternative states.

Transformation: A fundamental change to the coupled social-ecological system. It can be unintended or actively navigated through the alteration of a system when current ecological, social, or economic conditions become untenable or are undesirable.

Further explanations of key concepts in resilience thinking can found in Chapter 2 and at *www.resalliance.org/index.php/key_concepts*

Summary for policy-makers

Societies and ecosystems are interdependent, but they are often analyzed separately and managed as if they were distinct systems. The Arctic Resilience Report (ARR) is an Arctic Council project that analyses the resilience of these closely coupled social-ecological systems in the Arctic. The following are the key messages from the ARR Interim Report.

1. The Arctic is subject to major and rapid changes in social and economic systems, ecosystems and environmental processes. These interact in ways that have profound implications for the wellbeing of indigenous and non-indigenous peoples.
2. A resilience framework provides an integrative approach for assessing linked social and ecological changes across scales, identifying the risk of threshold effects, and building capacity to respond.
3. Abrupt changes have been observed in the environment across the Arctic. Such changes risk crossing environmental thresholds, which can have long-term consequences that affect options for future development.
4. Arctic change has global effects, with potential impacts on societies, ecosystems and options for development across the world.
5. Options for responding to change may be compromised by past decisions and interventions, particularly those that have eroded traditional safeguards of resilience.
6. Rapid Arctic change is likely to produce surprises, so strategies for adaptation and, if necessary, transformation, must be responsive, flexible and appropriate for a broad range of conditions.
7. Governing in the Arctic will require difficult choices that must grapple with different and sometimes conflicting priorities. The resilience approach helps capture the complex interrelated processes that need to be better understood for effective decision-making. Participatory processes can more effectively ensure that diverse voices are represented and that all relevant forms of knowledge are included in decisions.

Introduction

The ARR analyses the interdependence and resilience of human and environmental systems in the Arctic. The ARR is being developed in response to the Arctic Council's call to address the rapid changes taking place in the Arctic, as well as the increasing need to understand the cumulative impacts of these changes. The ARR is built around expert engagement to provide integrated analysis, workshops to enable engagement, and case studies to provide specific examples of resilience assessment "on the ground".

The ARR aims to:

1. Identify the potential for shocks and large shifts in ecosystem services that affect human well-being in the Arctic.
2. Analyse how different drivers of change interact in ways that affect the ability of ecosystems and human populations to withstand shocks, adapt or transform.
3. Evaluate strategies for adaptation and transformation in the face of rapid change.

The first phase of the project (November 2011 – May 2013) focused on developing a methodological framework and addressing the first two aims. Its results are presented in this Arctic Resilience Interim Report 2013. The second phase will be completed in May 2015.

This Summary for policy-makers presents seven key messages from the first phase of the ARR, and a discussion of priorities for the second phase.

What is resilience?

Social-ecological systems are interwoven systems of human societies and ecosystems. The concept of a social-ecological system emphasizes that humans are part of nature and that these systems function in interdependent ways.

Resilience is a property of social-ecological systems that relates to the capacity of the system to cope with disturbance and recover in such a way as to maintain its core function and identity, whilst also maintaining the ability to learn from and adapt to changing conditions, and when necessary to transform.

A resilient Arctic system is thus better able to absorb disruptions in the form of both abrupt disturbance events as well as more gradual forces of change. Furthermore, a resilient Arctic system is capable of persisting within a broad range of conditions, and adjusting in a relatively smooth manner to varying circumstances.

When a system is no longer able to adapt, it is likely to experience a transformation. Transformations are fundamental changes in social-ecological systems that involve crossing a threshold to a new "regime" characterized by a different set of critical interactions. While transformations can entail considerable disruption, they are not always undesirable. In some cases they may lead to greater future resilience for certain components of the system.

Village near Ilulissat, Greenland

© Annika E Nilsson

1. The Arctic is subject to major and rapid changes in social and economic systems, ecosystems and environmental processes. These interact in ways that have profound implications for the wellbeing of indigenous and non-indigenous peoples.

The Arctic is changing rapidly in ways that interact and fundamentally affect the region's ecosystems and societies. Climate change is important, but it is not the only driver of rapid change in the Arctic. In many contexts, social, political and economic drivers may be of greater importance than global warming. Social processes driving Arctic change include increasing demand for resources and need for transportation, migration, geopolitical changes, and globalization. As a result, many Arctic social-ecological systems are facing multiple social and environmental stressors at the same time.

Functioning ecosystems serve as a foundation for human wellbeing by providing basic necessities such as food and water and other ecosystem services. Moreover, for indigenous peoples and many rural communities, culture is constructed around livelihood activities such as reindeer husbandry, farming, fishing, and hunting and gathering. Changes in the environment can thus lead to the erosion or loss of core elements of culture.

Adaptive capacity is based on many factors, such as knowledge (including traditional knowledge and languages), a capacity to work collectively as a group to solve problems, skills and leadership, financial resources, and infrastructure. Adaptive capacity also depends on the availability of and access to diverse ecological resources. Social change can affect many of these sources of resilience. Moreover, economic development leads both to new opportunities and to increased competition for resources, including the risk of loss of ecosystem services that provide options for future adaptation.

A major task for the second phase of the ARR is to analyze how environmental and social changes affect adaptive capacity, and how adaptive capacity can be strengthened.

2. A resilience framework provides an integrative approach for assessing linked social and ecological changes across scales, identifying the risk of threshold effects, and building capacity to respond.

While some changes in the Arctic are already upon us, others will be avoidable, and yet others are necessary in order to ensure the long-term viability of Arctic social-ecological systems. For example, observations show that the Arctic climate is changing, but the ultimate amount of warming and the nature of society's response to anticipated changes are largely matters of societal choices and capacities. An understanding of resilience – the ability of human and natural systems to adapt or transform in the face of change – is essential for such choices. Society's options for action can be shaped by an understanding of resilience and the risks associated with crossing thresholds of change.

The resilience concept focuses on change, and how social and environmental processes interact across time and space in ways that can reinforce change, potentially causing abrupt and irreversible shifts or threshold effects. It also includes attention to how social and environmental changes shape the capacity to respond. The resilience approach recognizes that dynamics of change are shaped by feedbacks that can act at multiple scales of space and time. For example, global trends are playing out in the Arctic, while at the same time changes in the Arctic can have consequences on larger scales. Understanding the coupled social and environmental dynamics of Arctic change is an important step toward identifying and implementing strategies for adaptation and transformation.

Decisions about future development in the Arctic should be better informed about the risks of interacting ecological and social changes. An area of focus in Phase 2 of the ARR will be the further analysis of these interactions and how effects cascade across scales.

Sea ice patterns

3. Abrupt changes have been observed in the environment across the Arctic. Such changes risk crossing environmental thresholds, which can have long-term consequences that affect options for future development.

There is widespread evidence of major changes in Arctic landscapes and marine environments. Many of these changes are abrupt, large scale, and sometimes irreversible. Some thresholds have already been crossed, and others are at risk of being crossed.

Climatic changes are affecting the Arctic cryosphere, hydrology, habitats and species. Examples of climate-related thresholds include the formation of wetlands and new lakes in some areas, and – as permafrost degrades – the rapid draining of lakes and loss of freshwater resources in other areas. Changes in temperature, sea-ice cover, snow cover and water regimes are linked to the loss of important habitats for Arctic species, as well as shifts in the species composition of ecosystems and landscape transformations, which impact on ecosystem services and livelihoods.

Ecosystem shifts often arise from extreme events. Such shifts have been observed in connection with drainage of shallow lakes, insect outbreaks and wildfires. Many Arctic species are long-lived and well-adapted to a wide range of climate variability, but cannot recover from catastrophic events beyond that range.

Phase 2 of the ARR will further analyze the biophysical and social feedbacks that increase the risk for crossing environmental thresholds.

4. Arctic change has global effects, with potential impacts on societies, ecosystems and options for development across the world.

Ecological and social changes can cascade across scales. Strong evidence points to the importance of the Arctic in the physical functioning of the Earth's climatic regulatory systems. The current sea ice loss in the Arctic may represent a threshold change of global significance. Because the ice-capped poles play a vital role in cooling the global climate, the extensive loss of ice in the Arctic is causing a positive warming feedback. It has been linked to changes in persistent weather patterns and to extreme conditions in the Northern Hemisphere. It is also an indicator that climate change is entering a new phase. Other examples of impacts of environmental change that extend far beyond the Arctic region include the role of melting ice caps and glaciers in sea level rise, and the release of carbon dioxide and methane as a result of thawing permafrost. The changing global role of Arctic natural resources in the world's economy exemplifies the importance of the links between social and ecological systems.

5. Options for responding to change may be compromised by past decisions and interventions, particularly those that have eroded traditional safeguards of resilience.

Arctic indigenous cultures have evolved in a highly variable environment. Well-known cultural adaptations that enhance flexibility, such as nomadic lifestyles and ways of making decisions that include attention to diversity in food sources and subsistence practices, have been important sources of resilience when environmental conditions vary. Forced settlement, loss of land, and management strategies that do not allow for diversity have eroded some of this flexibility. Other policies have also eroded traditional institutions, practices, languages, and the diversity of "ways of knowing". The notion of the inherently highly adaptive northerner may no longer be valid, raising the need to better understand how policy decisions today can increase flexibility and capacity to respond to ecological and social changes in the immediate and long-term future.

Understanding traditional sources of resilience is an important part of a resilience assessment. Phase 2 of the ARR will continue to engage with and explore the role of traditional and indigenous knowledge.

6. Rapid Arctic change is likely to produce surprises, so strategies for adaptation and, if necessary, transformation, must be responsive, flexible and appropriate for a broad range of conditions.

Planning for the future in the Arctic needs to take into account rapid environmental and social change, including inevitable uncertainty about the details of future conditions. The decline in sea ice has been more drastic than anticipated and similar surprises are likely as ecosystems pass thresholds that affect their ability to provide ecosystem services. How successfully society and individuals respond is likely to depend on diverse perspectives and innovative problem solving. Some innovative adaptive solutions have already emerged in the Arctic, along with a stronger focus on co-management and social learning, the devolution of power to local decision makers, and the incorporation of local and traditional knowledge. However, more work is needed to understand and facilitate local responses to rapid environmental and social changes. New networks can build social relations and trust and enhance the ability to respond to surprises.

7. Governing in the Arctic will require difficult choices that must grapple with different and sometimes conflicting priorities. The resilience approach helps capture the complex interrelated processes that need to be better understood for effective decision-making. Participatory processes can more effectively ensure that diverse voices are represented and that all relevant forms of knowledge are included in decisions.

Governing for resilience raises questions about "resilience for whom" and "resilience of what". A useful adaptation for some people can be maladaptive when viewed from a different perspective. Socio-economic transformation can be desirable for some, but not for others. Governing for transformation can include political decisions that remove barriers to change, and inevitably include choices about a desirable future. Such choices benefit from broad engagement in decision making. Effective engagement across the Arctic requires investing in capacity-building, including skills and knowledge, and finding ways to stimulate creativity and motivation. Innovative participatory processes in the Arctic can provide examples for other parts of the world.

Next steps

The present rate and extent of social and environmental change in the Arctic places new demands on society to prepare for both anticipated developments and unexpected events. This interim report has laid out a framework for understanding the interaction of social and environmental change. It has documented several environmental threshold changes and identified other potential thresholds that could yet result in major changes. It has also pointed to the importance of adaptive governance and participatory processes for ensuring the capacity for adaptation and desired transformation.

By highlighting the dynamic relationships between changes in the biophysical environment and changes in society, resilience provides a method for dialogue and integration across several Arctic Council activities. Some activities already mention resilience, including the work of the Ecosystem-Based Management Experts Group, Arctic Biodiversity Assessment, Arctic Ocean Acidification Assessment, and Arctic Ocean Review. Others provide knowledge that is essential for understanding resilience, including on-going work with the Arctic Human Development Report-II. Resilience can also be a valuable guiding concept for further work within the Adaptation Actions for a Changing Arctic initiative. In its next phase, the ARR will link closely to these other Arctic Council processes in order to fill specific knowledge gaps in the resilience assessment and analyze how resilience thinking can bring further insights to issue-specific assessments and policy-related initiatives. One major priority is to analyze cascading social and ecological effects across scales. It is also particularly important to understand the role that policy decisions play in increasing capacity for adaptation and transformation, including the provision of institutional support for sharing knowledge and experiences.

The second phase of the ARR will continue to employ its comprehensive approach of expert engagement, workshops and detailed investigation of specific social-ecological systems. To ensure that resilience assessment can be used as a tool for understanding and responding to ecological and social change after the ARR project is finalized, the second phase of the project will also continue its commitment to capacity building and engage in dialogue with decision makers.

Part I

Summary

The Arctic is changing rapidly in ways that fundamentally affect the region's ecosystems and societies. The Arctic Resilience Report (ARR) uses resilience as an integrative concept and model to aid systemic understanding of the Arctic, including the cumulative impacts of a diverse suite of interconnected changes.

Chapter 1 describes the background and rationale for the ARR, including how it relates to other assessment processes. It explains the three aims of the ARR: to identify the potential for shocks and large shifts in ecosystems services that affect human well-being in the Arctic; to analyze how different drivers of change interact in ways that affect the ability of ecosystems and human populations to withstand shocks, adapt or transform; and to evaluate strategies for adaptation and transformation in the face of rapid change. Furthermore, the chapter provides a guide to the different project activities (integrative analysis, case studies, workshops, and capacity building), and sets this interim report into context of the project as a whole.

Chapter 2 elaborates on the definition of resilience as a property of social-ecological systems. Resilience relates to their capacity to cope with disturbances and recover in such a way that they maintain their core function and identity. It also relates to the capacity to learn from and adapt to changing conditions and, when necessary, transform. Social-ecological systems are interwoven systems of human societies and ecosystems. The concept emphasizes that humans are part of nature and that these systems function in interdependent ways. A resilience assessment is an attempt to generate systemic and anticipatory knowledge about linked social-ecological systems to better inform decision-making. It emphasizes dynamic changes, including feedbacks and the risk of crossing critical thresholds. The chapter presents some of the central concepts in resilience thinking and the basic steps of a resilience assessment, and discusses how they are applied in the ARR. Furthermore, it highlights the normative aspects of assessing resilience.

Chapter 3 provides an overview of resilience from the perspectives of indigenous societies in North American Arctic and the Eurasian North. Sources of indigenous resilience include traditional knowledge and connections with the land and with traditional livelihoods and practices. Our initial findings show a range of conditions, from societies in a state of crisis and shock, to healthy communities and well-functioning collaborative management of lands. Also apparent is a unifying view of indigenous societies as strong actors within the context of Arctic change, if indigenous people can act on their own, culturally appropriate terms. Oral history materials from both Eurasian and North American communities illustrate these findings. Traditional knowledge is seen here as a knowledge paradigm of its own, in parallel with "western" science discourse.

Chapter 1

The Arctic Resilience Report: Background, aims and scope

Chapter 2

A resilience approach to social-ecological systems: Central concepts and concerns

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Chapter 3

Indigenous perceptions of resilience

Chapter 1

The Arctic Resilience Report: Background, aims and scope

Lead authors: Annika E Nilsson[1], Martin Sommerkorn[2], Cathy Wilkinson[3], Martin Robards[4] and Tatiana Vlasova[5]

1.1 Rapid and pervasive change

The Arctic region is changing rapidly in ways that will dramatically affect ecosystems, people, and their interdependencies (ACIA 2005). More far-reaching change is forecast for the region over the years and decades to come (Anisimov et al. 2007; AMAP 2011c). The pervasiveness of Arctic change and the anticipation of even greater change are major concerns for people and decisions-makers, as they challenge established political practice to maintain or improve current conditions based on an understanding of the past. The situation requires new approaches that address and conceptualize Arctic change and inform policy on how to respond and prepare.

The direct impact of climate change on Arctic terrestrial and marine environments is now widespread; affects people, species, habitats, and ecosystems, and may induce state changes in the cryosphere (ACIA 2005; Anisimov et al. 2007; CAFF 2010; AMAP 2011c; Callaghan et al. 2011). Some of the implications of those changes are discussed in more detail in Chapter 4. For example, in marine systems, observations point to dramatic changes in both ice cover and the underlying water column (Carmack et al. 2012; Duarte et al. 2012). Ecosystem repercussions will be diverse (Post et al. 2009; Christie and Sommerkorn 2012). Some trophic groups will benefit, such as the expected dramatic increase in primary production (Arrigo et al. 2008). However, for other groups such as marine mammals, fortunes will be mixed, with pagophilic species such as polar bear, walrus, and ringed seal particularly vulnerable to reductions in sea ice (Moore and Huntington 2008). Nevertheless, the future structure and function of marine ecosystems in the Arctic is still very uncertain.

In terrestrial ecosystems, similar rapid changes have occurred in the cryosphere. Degradation of permafrost is leading to dramatic thermokarst features across the landscape (Jorgenson and Osterkamp 2005; Jorgenson et al. 2006). Biologically, rapid Arctic greening, with increasing shrub growth, indicates the potential for structurally novel ecosystems to emerge within the tundra zone (Macias-Fauria et al. 2012). Vanishing permafrost alters the hydrology, accelerating the observed changes in community composition and diversity (e.g., Molau 2010). Thanks to recent syntheses within the International Tundra Experiment (Elmendorf, Henry, Hollister, Björk, Boulanger-Lapointe, et al. 2012; Elmendorf, Henry, Hollister, Björk, Bjorkman, et al. 2012), evidence has accumulated of relatively rapid shifts (10-25 years) in keystone plant communities throughout the Arctic.

Rapid changes at the ecosystem and landscape levels in the Arctic tundra, such as increasing shrub coverage, are brought about by multiple drivers (temperature increase, permafrost release), with feedbacks on the radiation balance adding to the surface warming (Sturm et al. 2005; Tape et al. 2006; Blok et al. 2011). Ongoing landscape changes reduce the carrying capacity for summer grazing by caribou and reindeer. While some changes may be gradual, there will also be more rapid shifts in physical features (e.g., sea ice and permafrost) and ecosystems. Those shifts could have large impacts on ecosystem services important for local livelihoods, regional economic activities, and for the Earth system and humanity (Wassmann and Lenton 2012).

Rapid economic development is a significant new driver of change in the Arctic, particularly as new technologies, economic demand, and the need for rural development foster greater use of land and marine areas for non-renewable resource extraction, habitat modification, and transportation (AHDR 2004; Arctic Council 2009). Changes in the biophysical environment interact with the rapid social changes that are affecting all inhabitants in the Arctic (AHDR 2004). Humans have often successfully adapted to changes in the past and, especially in the Arctic, have developed elaborate ways to ensure resilience of livelihoods in a highly dynamic environment (Huntington and Fox 2005; Nuttall 2009). However, the rate and magnitude of exogenous and endogenous changes, partly as a result of increased connectivity with the outside world, has been unprecedented. One impact of the pace and scale of changes has been to challenge the adaptive capacities of communities (Amundsen 2012), including indigenous communities (Forbes et al. 2009; West 2011; Furberg et al. 2011; Graybill 2012). Nevertheless, indigenous peoples across the Arctic are also gaining new rights as they are increasingly recognized in national and international policies, offering new opportunities for self-determination and adaptation (AHDR 2004). Another impact has been the emergence of significant governance challenges (Young 2012) resulting from the need to better support resilience across the Arctic (Meek et al. 2008; Hausner et al. 2011) and from a changing geo-political situation (Parsons 2011; Huebert et al. 2012).

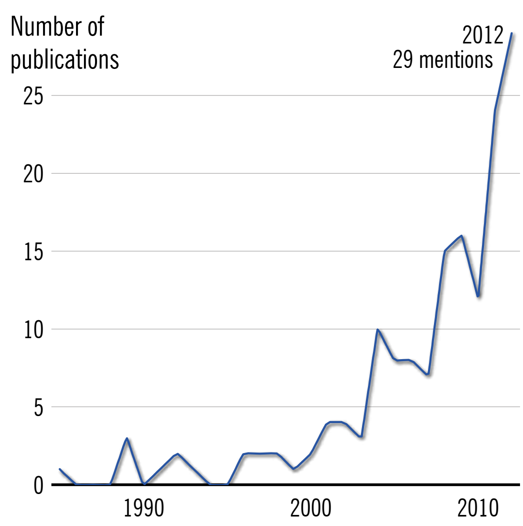
Some changes in the Arctic are now inevitable, others will be avoidable, and yet others are needed to ensure the long-term viability of Arctic social and ecological systems. Understanding the thresholds for those changes we wish to avoid, or how to facilitate crossing the thresholds towards change that we see as beneficial, is at the heart of why we need to understand and assess resilience in the Arctic. A central premise of the Arctic Resilience Report (ARR) is that resilience is a useful and necessary "lens" for Arctic research and decision-making.

1.2 A resilience lens to Arctic change

The need for "integrative concepts and models" that can aid systemic understanding of the Arctic, including the cumulative impacts of a diverse suite of interconnected changes, is critical in the current period of rapid ecological, social, and economic change. Resilience has been mentioned in previous assessments of Arctic change (Huntington and Fox 2005), but it has not been a major theme, and attempts to analyze the impacts of multiple stressors have focused on vulnerability (McCarthy and Martello 2005). The relevance of a resilience approach to the Arctic has gained greater attention recently over the past decade (see Figure 1.1) although there have only been limited attempts to assess general Arctic resilience (e.g., Chapin et al. 2006; Christie and Sommerkorn 2012).

Recently resilience has been proposed as an integrative concept for understanding current development in the Arctic (Wassmann and Lenton 2012, p.7). An important reason is that such a framework helps to prepare for change. An analysis based on resilience focuses on how linked social-ecological systems can be governed in the face of disturbances, whilst maintaining the capacity for adaptation, learning and transformation (Folke et al. 2010). Critically important in the Arctic is that a resilience lens can facilitate integration of relevant knowledge from different traditions. Chapter 3 further discusses the special role of indigenous perspectives and traditional knowledge for assessing resilience.

Figure 1.1 **Number of articles mentioning Arctic and resilience**



The resilience concept is especially suited to answer to the challenges of rapid Arctic change because it recognizes change as a central characteristic of linked social-ecological systems. Moreover, it considers the effects of drivers across nested scales and acknowledges that changes are interlinked and often produce non-linear effects and cumulative impacts that are difficult to predict. There is an emerging but still limited understanding of physical and ecological thresholds or tipping points in the Arctic (Wassmann and Lenton 2012). For example, a variety of physical Arctic climate tipping elements have been identified, including the Arctic sea ice, the Greenland ice sheet, Atlantic thermohaline circulation and boreal forest (Lenton 2012). Chapter 4 discusses thresholds in the Arctic in detail.

A resilience lens also focuses on understanding how to maintain functioning social-ecological systems by supporting adaptive and transformative capacity (Berkes et al. 2002). There is a close relationship here with the growing body of knowledge on vulnerability and adaptation to climate change (e.g., Hovelsrud and Smit 2010), and with efforts to identify the sources of resilience that are important for adaptive and transformative capacity (Folke et al. 2009; West and Hovelsrud 2010; Davidson 2010; Kofinas and Chapin 2009). Adaptive and transformative capacity are discussed further in Chapter 5.

1.2.1 Integrating science to analyze Arctic change

Scientific assessments carried out under the auspices of the Arctic Council have played a major role in advancing knowledge about environmental, economic and social changes in the region (see See section 1.4 for further detail). Several large-scale research initiatives (e.g., International Polar Year, see Krupnik et al. 2011) and efforts to coordinate Arctic research (e.g., International Study of Arctic Change, see Murray et al. 2010) have further added to the growing body of knowledge about Arctic change. While research results are likely to find their way into future assessments focusing on specific issues, one of the key challenges is to better understand how to integrate knowledge from different scientific disciplines, including natural, social and integrative sciences, and insights from both scientific and traditional knowledge. There has been limited integrated assessment to date of the implications of research findings across scales of space and time. The ARR seeks to integrate as far as possible the available disciplinary, transdisciplinary, and interdisciplinary science in its focus on social-ecological systems in the Arctic. The conceptual framework to provide that integration is further described in Chapter 2.

Figure 1.2 **An image of the Arctic as part of nested scales provides a foundation for analyzing the relationships between processes at different scales, from local to global**

1.2.2 Generating policy-relevant insights

Along with synthesizing knowledge, scientific assessments in the Arctic provide guidance for decision – and policy-making. The Arctic Council commissioned the ARR in the context of strengthening the ability to address rapid change in the region (see Box 1.1). By analyzing the dynamics of change in Arctic social-ecological systems, a resilience approach generates inter-disciplinary knowledge that can better inform decision-making about the opportunities for adaptation and transformation. A resilience approach is especially concerned about interactions across scales, recognizing that local changes are nested in large-scale processes. It can therefore help analyze the interplay between levels of governance and identify policy processes at the appropriate spatial and temporal scales (Figure 1.2).

1.3 Aims and project overview

1.3.1 Aims

The ARR analyzes the resilience of linked human and environmental systems in the Arctic to global and local changes. The aims set out in the approved Implementation Plans (in bold below) are put into context with the methodology developed for the ARR. The aims are to:

Identify the potential for shocks and large shifts in ecosystems services that affect human well-being in the Arctic. We seek to identify and understand thresholds of concern in the Arctic – an important aspect of the question "resilience to what?" Addressing the question requires special attention to interacting global and local changes that affect ecosystem services important for quality of life and human capital improvement in the Arctic.

Analyze how different drivers of change interact in ways that affect the ability of ecosystems and human populations to withstand shocks, adapt or transform. We are gauging the ability of Arctic social-ecological systems to respond to Arctic change through adaptation or transformation. This work includes analysis of how the capacity to adapt and transform is affected both by thresholds, and by more gradual drivers of Arctic change. The analysis emphasizes the significance of positive and negative feedbacks.

Evaluate strategies for adaptation and transformation in the face of rapid change. This aim is about using the insights from the analyses of potential thresholds (aim 1) and of adaptive and transformative capacities (aim 2) to evaluate strategies for adaptation and transformation of Arctic social-ecological systems in the face of rapid change. The analysis aims to inform decision-making processes that affect Arctic social-ecological systems, including those processes informed by work of the Arctic Council.

1.3.2 Project overview and reader's guide

The ARR project is being carried out in two phases. The initial phase concludes with this interim report; the second phase will culminate in a final report in May 2015.

Interim report

The interim report focuses on developing the methodological approach to the ARR (Chapter 2), including attention to indigenous perspectives and traditional knowledge (Chapter 3). It also provides an initial assessment of the risk for shocks and large shifts in ecosystem services that may affect human well-being in the Arctic (Chapter 4). Then it reviews the available literature on adaptive and transformative capacity as a basis for later analysis of how different drivers of change interact in ways that affect the ability of ecosystems and human populations to withstand shocks, adapt or transform (Chapter 5). Finally, four pilot case studies are presented to illustrate the resilience approach on the ground (Chapters 6-10).

Final report

The final report will include updates of the thresholds assessment, as needed, but will primarily focus on assessing how different drivers of change interact in ways that affect the ability of ecosystems and human populations to withstand shocks, adapt or transform. The second phase will also include more case studies and an overall synthesis of results. In addition, the final report will address the third major aim of the ARR, to "evaluate strategies for adaptation and transformation in the face of rapid change". This evaluation will form an important basis for identifying policy-relevant implications of the findings from the assessment. The second phase of the ARR will link more explicitly to other on-going Arctic Council activities.

Box 1.1 **Origins of the ARR project**

In the context of welcoming the assessment of the Arctic cryosphere entitled *Snow, Water, Ice and Permafrost in the Arctic* (SWIPA), the Nuuk Ministerial Declaration:

"… notes with concern the accelerated change in major components of the cryosphere and the profound local, regional and global effects of observed and expected changes, emphasize the need for forward looking Arctic cooperation with a view to increase Arctic resilience and to enhance Arctic Council leadership to minimize the human and environmental impact of climate change and instruct Senior Arctic Officials to consider how to best follow up on the SWIPA recommendation in the future work of the Arctic Council" *(Arctic Council 2011a)*.

The SAO report to the Nuuk Ministerial meeting in May 2011 states:

"… a scoping exercise will be undertaken to review the need of an integrated assessment of multiple drivers of Arctic change, *including an Arctic Resilience Report*. The projects will address questions on how the Arctic, in particular indigenous peoples, are affected by current and planned activities, how negative effects can be minimized and how resilience can be strengthened. Scoping activities will take place in the fall of 2011 … result in a proposal for the SAO meeting in November 2011" *(Arctic Council 2011c, emphasis added)*.

Based on the Ministerial declaration and the SAO report, a scoping workshop was held 26-28 September 2011, in Stockholm, Sweden, with participants from the Arctic Council working groups and invited experts (Nilsson and Olsson 2011). This workshop, along with a scoping workshop for the Arctic Change Assessment (ACA) that same week (AMAP 2011a), showed a need for new approaches in assessing Arctic change. The scoping phase included consultations with experts from all Arctic countries and several indigenous peoples' organizations. It also provided the base for collaboration with international organizations that represent relevant communities of experts.

Arctic Council Ministerial meeting in Nuuk 2011

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Based on the scoping activities, a proposal for the Arctic Resilience Report was prepared and presented to the SAO meeting in Luleå on 8-9 November, 2011. Following the presentation of the proposal, the ARR was discussed in the Arctic Council, as recorded in the minutes from the meeting:

"Several of the working groups noted that the ARR may be useful and interlinked with ongoing work in their groups. The project proposal as presented was broadly welcomed by both member states and PPs. The importance of involving the PPs from the beginning of the process, and the question of financing of PP participation was underlined. The management structure of the ARR, and the interconnections with ACA and EBM were debated." *(Arctic Council 2011b)*

Figure 1.3 **A resilience assessment can add value by linking assessments of specific issues in an integrative framework**

1.4 The ARR in relation to other Arctic Council processes

There are several assessment processes relevant to the ARR, either recently completed or currently underway. The following provides a brief description of processes with links to the Arctic Council and explains how the ARR will learn from and integrate with them.

1.4.1 Assessments of climate change and its impacts

The Arctic Climate Impact Assessment (ACIA 2005) provided the first circumpolar analysis of the impacts of climate change in the Arctic, showing clearly the sensitivity of the region to global climate change. The ACIA report mentioned resilience (defined as "adaptive capacity") and the need for analysis of human-environment systems in an analysis of vulnerability of climate change in the context of multiple stressors (McCarthy and Martello 2005) and indigenous observations of climate change (Huntington and Fox 2005). The ACIA was followed up by an assessment that focused more specifically on impacts of climate change related to the cryosphere: *Snow, Water, Ice and Permafrost in the Arctic* (SWIPA), with results presented in 2011 (AMAP 2011c). Also relevant is the Intergovernmental Panel on Climate Change (IPCC) *Fifth Assessment Report*, due for release in 2013-2014.

The ARR does not include analysis of Arctic climate processes, so the ACIA, SWIPA and IPCC reports provide an important knowledge base, especially in relation to understanding the Arctic climate system and its sensitivities. They also provide a baseline for understanding impacts of climate change. With the rapid rate of change in the Arctic, the IPCC *Fifth Assessment Report* will provide important updates on climate change processes towards the second phase of the ARR. The IPCC will also be relevant in analyzing the global climate system context of Arctic change. So far, assessments of climate change in the Arctic have mainly been based on analyses of biophysical processes, with discussion of social aspects focusing on impacts and vulnerability. With its explicit attempt at analyzing both social and biophysical processes and their linkages, the ARR, in contrast, will highlight the two-way interactions between social and ecological processes, including how social processes can contribute to adaptive and transformative capacity and thus to resilience.

1.4.2 Ocean acidification

The Arctic Ocean is rapidly accumulating carbon dioxide (CO_2), causing ocean acidification. Anthropogenic emissions are the major source of the additional CO_2 in the ocean, but changes in freshwater balance, heat budget and land-ocean exchange contribute as well. Ocean acidification will influence the Arctic Ocean in a number of ways that affect marine ecosystems and ecosystem services. AMAP is carrying out an assessment of Arctic Ocean acidification, with a report due to be delivered to the Arctic Council in May 2013. The results will form an important knowledge base for ARR's analysis of thresholds related to the marine environment and will be included in the second phase of the ARR.

1.4.3 Arctic Biodiversity Assessment and the Circumpolar Biodiversity Monitoring Programme

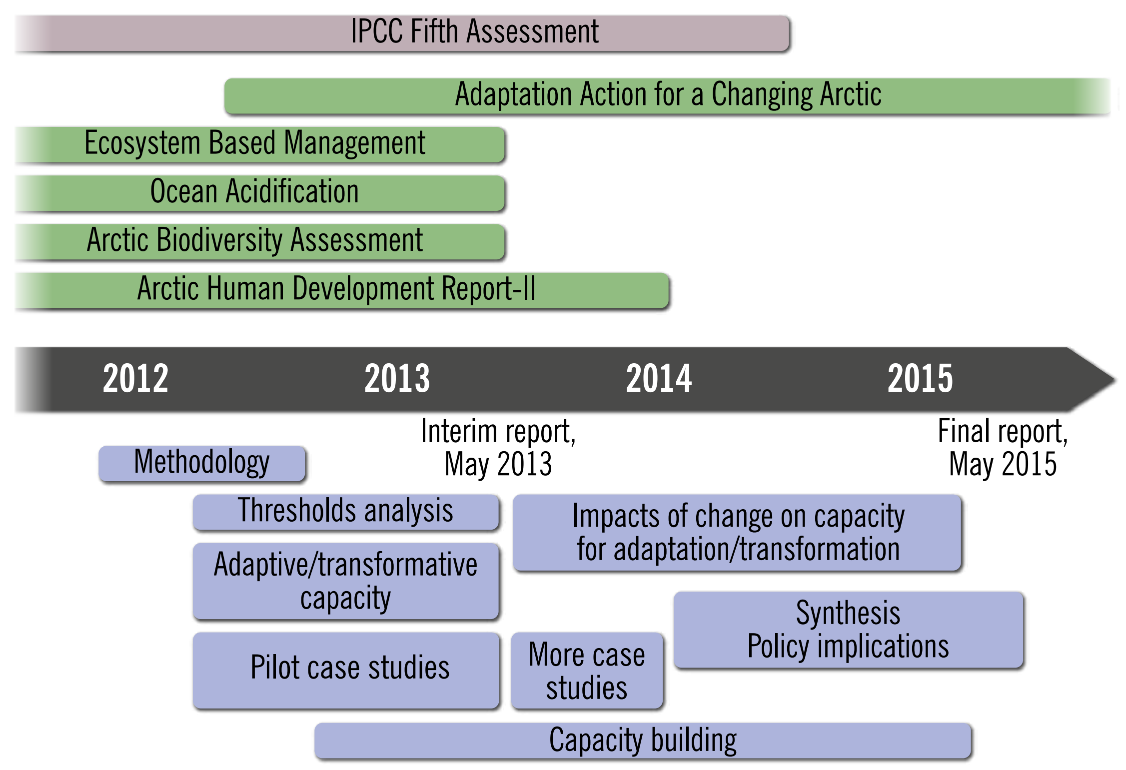
Biodiversity is an essential foundation for ecosystem services (TEEB 2010) and is thus critically relevant both for identifying the potential for shocks and large shifts in ecosystems services that affect human well-being in the Arctic (ARR aim 1), and for analyzing how different drivers of change interact in ways that affect the ability of ecosystems and human populations to withstand shocks, adapt or transform (ARR aim 2). The Arctic Biodiversity Assessment (ABA), carried out by the Working Group on Conservation of Arctic Flora and Fauna (CAFF), is due to deliver its report to the Arctic Council in May 2013. This will form an important knowledge base for the second phase of the ARR, both in its provision of a baseline description of biodiversity, and in its assessment of major drivers of change affecting Arctic biodiversity. The first ABA report, *Arctic Biodiversity Trends 2010: Selected Indicators of Change* (CAFF 2010), notes that climate change is emerging as the most far-reaching and significant stressor on Arctic biodiversity, but also that contaminants, habitat fragmentation, industrial development, and unsustainable harvest levels continue to have impacts. Complex interactions between climate change and other factors have the potential to magnify impacts on biodiversity (ibid.).

CAFF has also created a framework for tracking of status and trends in Arctic biodiversity, the Circumpolar Biodiversity Monitoring Programme (CBMP). The purpose is to allow for a more focused and rapid detection and assessment of emerging trends. The CBMP is organized to coordinate monitoring of marine, freshwater, terrestrial and coastal ecosystems and operates under an ecosystem-based approach that aims to provide a bridge between ecosystems, habitats, species, and the impacts of stressors on ecological functions. CAFF is developing the Arctic Biodiversity Data Service (ABDS), an online circumpolar data management system that will consolidate and display biodiversity information.

1.4.4 Assessments of pollution in the Arctic

Several assessments of pollution in the Arctic have been carried out by the Arctic Monitoring and Assessment Programme (AMAP 1997; 2002; 2009), focusing both on particular pollutants and on impacts on human health. In some cases, pollution has direct impact on ecosystem services, including the contamination of important local foods. Assessments of pollution have also pointed to the interactions between climate change and contaminants (AMAP 2011b). For the ARR, the published assessments and continued AMAP activity regarding contaminants and the impacts of short-lived climate forcers (SLCF) in the Arctic will form an important knowledge base in the context of understanding how interactions among different drivers of change can contribute to threshold behaviour and also affect the capacity for adaptation and transformation.

Figure 1.4 **Timeline for the ARR and other relevant projects**



1.4.5 Arctic Human Development Reports and Arctic Social Indicators

Although climate warming is an important driver of Arctic change, it is increasingly clear that knowledge about social changes and socio-economic trends is equally important for understanding Arctic change. The *Arctic Human Development Report* (AHDR 2004) was a first attempt at providing an overview of social systems and trends in the Arctic. One of its major findings was that human societies in the circumpolar North are highly resilient; they have faced severe challenges before and have adapted successfully to changing conditions. However, the authors also stated that it would be a mistake to assume that Arctic societies and cultures can remain resilient in the face of rapid biophysical and social changes (AHDR 2004, p.230).

The AHDR was followed up by the Arctic Social Indicators (ASI) project, which identified domains where it was particularly important to follow trends in social development in an Arctic context, including identifying indicators for which data would be available. Several of these domains relate directly to ecosystem services that are relevant for the analysis in the ARR, such as "cultural well-being and cultural vitality" and "contact with nature" (Larsen et al. 2010). Material well-being and health are other domains where ecosystem services are highly relevant because of their importance for local foods and the subsistence economy. The AHDR and ASI will contribute to ARR's aim of analyzing shifts in ecosystem services that affect human well-being. A follow-up to the AHDR is now under way, scheduled to be delivered in 2014. This report will provide important input to the second phase of the ARR on current social trends and to gain a better understanding of social capacities for adaptation and transformation and how are likely to change.

1.4.6 Ecosystem-based management

Ecosystem-based management (EBM) is the comprehensive integrated management of human activities based on the best available scientific knowledge about ecosystems and their dynamics, in order to identify and take action on critical influences and ensure the sustainable use of ecosystem goods and services and the maintenance of ecosystem integrity (e.g., OSPAR Commission). In the Arctic Council, an approach based on EBM, also referred to as the ecosystem approach to management, has informed a number of different processes, including work within the Expert Group on Ecosystem Based Management (EBM), CAFF and PAME (Protection of the Arctic Marine Environment). The Arctic Council EBM Expert Group has highlighted that ecosystem-based management can support resilience in order to maintain ecological functions and services. The EBM Expert Group is scheduled to deliver its report to the Arctic Council in May 2013 and will inform ARR's second phase, in particular the discussion about the role of governance and the policy implications of the resilience analysis. The ARR analysis will support further development of the EBM approach within the Arctic Council.

1.4.7 Adaptation Actions for a Changing Arctic (AACA)

A key challenge in the Arctic includes having appropriate adaptation strategies and actions to deal with multiple environmental stressors, such as climate variability and change, human demographic shifts, industrialization, and increasing demands for energy and natural resource extraction. The overarching goal of the AACA is to enable more informed, timely and responsive policy and decision-making related to adaptation action in a rapidly changing Arctic (Arctic Council 2012). In its first phase, which ends in May 2013, the project is tasked to 1) synthesize key finding from Arctic Council assessments and other relevant national and international reports to determine how these can contribute to and inform adaptation options for Arctic countries, and 2) identify existing national, regional and local adaptation efforts within or relevant to the Arctic region. In a longer time frame (to be completed in 2017), the project is to consider Arctic-focused climate and integrated environmental frameworks/models that can improve predictions of climate change and other relevant drivers of Arctic change. There are large potential synergies between the ARR and continued work in the AACA. Initial outcomes of the AACA inform the second phase of the ARR, in particular the analysis of capacities for adaptation and transformation. In addition, ARR's second phase will be able to contribute to developing models of integrated analysis of environmental and other changes in the Arctic. Figure 1.3 shows the timeline of the ARR and other relevant Arctic projects.

1.5 The ARR approach

1.5.1 Relevance to decision-makers

While research has addressed several aspects of Arctic resilience, there is a need for a policy-relevant synthesis of resilience in a pan-Arctic context. Moreover, it is important to develop aspects of the resilience assessment methodology in ways that take specific Arctic issues into consideration and address the interactions between Arctic social and biophysical processes. In its design, the ARR project has been guided by three general criteria for making assessments relevant to decision-makers: that the process and the results should be *salient, credible,* and *legitimate* (Mitchell et al. 2006). Salience means the assessment is seen as relevant by the intended users. Credibility means the knowledge provided is judged to be reliable by these users; legitimacy means the assessment process is deemed respectful to the relevant audiences.

Salience at a range of scales

The ARR is aimed at several different audiences, and needs to be salient, legitimate and credible to all of them. For example, intended users include people concerned with or participating in decision processes at different levels of governance, ranging from the global to the local. While many drivers of change are global in character, impacts and actions related to adaptation most often occur in local settings. Adaptation to Arctic change is a major concern, and the Arctic Council has made a commitment to strengthening its ability to addressing rapid change in the region (Arctic Council 2011c). At the same time, there is a strong demand for the ARR to be relevant to decision-makers at national

Life on the Yamal tundra, Russia

© Bruce Forbes

to international, regional and local levels, which is a major challenge given the diversity of environments, cultures and political structures across the Arctic and the limited resources for engaging with local and other sub-national actors. While the pan-Arctic perspective serves as a starting point for the ARR, it has therefore been important to also highlight links across scales and levels of governance. This is reflected in the applied methodology that explicitly recognizes scale interactions. It is also reflected in the choice to include project activities that focus on different scales, such as case studies that focus on specific local contexts. Over the course of the ARR, case studies will increasingly be able to refer to the emerging results of the integrated pan-Arctic analysis.

A capacity-building component has been included in the project to facilitate further analysis in a range of specific contexts. In order to be salient, the ARR also has to address the urgency of action in the Arctic. Current rapid rates of change require that the project deliver sooner rather than later. However, credible analysis takes time, especially in an interdisciplinary setting. One way in which the ARR has addressed this challenge is to create a two-step process that can deliver interim results already for the Arctic Council Ministerial meeting in May 2013. The final ARR report is to be delivered in May 2015. Moreover, the ARR has been designed as an open and transparent process, with outreach activities and possibilities to engage new experts along the way. At the rate Arctic change is happening, the ARR also has to be adaptive and able to include new insights as the process develops.

Credibility across knowledge traditions
The ARR should build on the best knowledge available, including insights from natural sciences, social sciences, and traditional knowledge. Yet it is not enough to gather information from each of these sources in isolation. Rather, as recognized in the scoping process for the ARR and related activities (Nilsson and Olsson 2011; AMAP 2011a), there is an urgent need for dialogue across knowledge traditions. This includes attention to the interaction between biophysical and social drivers (and repercussions) of change, as well as seeking to better understand the roles that local and traditional knowledge can play both for analyzing resilience and for building adaptive capacity. A previous example of the inclusion of traditional knowledge alongside natural science analysis is in the *Arctic Climate Impact Assessment* (Huntington and Fox 2005). The ARR process thus includes experts from a range of knowledge traditions, and a major focus for the first year of the project has been to develop ways of working that foster respectful integration of different types of credible knowledge. This is still work in progress and will continue to be an important part of method development for the ARR in the second phase of the project.

An important part of ensuring credibility is to create dialogues and links to scientific assessment and knowledge processes that go more in-depth regarding specific aspects of Arctic change, as discussed in section 1.3. This includes relying on results from the assessment of impacts of climate change as well as analysis focusing on social change.

Legitimacy with focus on the Arctic Council
Legitimacy refers to the process being seen as respectful by different audiences. Many of the issues relevant for credibility are linked to creating a legitimate process. As an Arctic Council project, legitimacy is especially important for the ARR in relation to Arctic Council Member States, Permanent Participants, and

Working Groups, which are all represented on the ARR Project Steering Committee. To ensure legitimacy to a broader scientific community, the Project Steering Committee also includes representatives from several scientific organizations working on issues related to Arctic change. A range of other actors are relevant, including decision-makers at the sub-national level and in global international processes. The project does not have capacity to engage directly with all relevant actors, but welcomes opportunities for dialogue within planned project activities, as is feasible with the available resources.

1.5.2 Scope of activities

The ARR is more than a report and includes a range of activities. These are summarized below and placed in the context of the relevant aims of the ARR project.

Integrated analysis

Integrated analyses are at the core of the ARR process and build on reviewing and synthesizing expert knowledge. In the initial phase, corresponding to this interim report, integrated analysis includes two major tasks. The first is to review the knowledge that is available about *thresholds* in Arctic social-ecological systems and the feedbacks that can affect ecosystem services (see Chapter 4). This addresses the first aim of the ARR. The second task for the interim report is to review available literature regarding *capacities for adaptation and transformation* in the Arctic (see Chapter 5). This review will set the stage for addressing the second aim of the ARR in the second phase of the project. For the final report, the focus will shift to addressing the second aim in more depth by analyzing how thresholds, along with other changes in the Arctic, can affect the capacity for adaptation and transformation. The final report will also include analysis of how policy decisions can help strengthen or risk eroding these capacities, addressing the third aim of the ARR.

Case studies

Pilot case studies illustrate some of the challenges facing particular social-ecological systems in a rapidly changing Arctic. These case studies are focused applications of a methodology developed by the Resilience Alliance, an organization established to advance resilience science and applications (Resilience Alliance 2010). The case studies, carried out in cooperation with relevant partners, serve several purposes. First, they provide an opportunity to investigate what a resilience lens can contribute to research that has been carried out from other starting points. Including case studies from a range of contexts also provides an opportunity to explore what resilience can look like in different contexts across the Arctic. Case studies provide opportunities to implement the resilience analysis methodology in contexts that are directly relevant to user communities and decision-makers in the Arctic. Finally, the use of case studies helps ensure that the ARR remains grounded in real policy-relevant Arctic situations, rather than become overly focused on the theoretical aspects of change, thresholds, and adaptation.

The four preliminary case studies focus on reindeer herding in Finnmark; commercial shipping through the Bering Strait; transformations in wildlife subsistence systems in the southwest Yukon, Canada; and food security. Additional case studies will be developed in the second phase of the ARR, seeking to add to the geographical coverage of the ARR; link to on-going research efforts and relevant partners; link to other Arctic Council projects; help balance success stories with studies of less-successful efforts; include contexts where resilience is under continued threat or where systems have been transformed; contribute to capacity-building activities of the ARR; and provide tangible examples of state changes in Arctic ecosystems.

The case studies, particularly those adopted in the early phases of the ARR, use a range of methods, but the ARR will aim to interpret their individual findings through a lens informed by the Resilience Alliance (2010) approach. Briefly, a common framework is used to present the case studies in ways that emphasize the integrated social-ecological systems and highlight features that are especially relevant for resilience. The case studies draw on integrated knowledge about the vulnerability and strengths of particular Arctic social-ecological systems, drivers of global change, and the intersection between ways of knowing and policies at multiple levels across the Arctic. This approach is described in more detailed in Chapter 6. The ARR will also include efforts to synthesize insights across case studies for the final integrative analysis.

Workshops

Workshops serve as a forum for developing a joint understanding of Arctic resilience among participants with the ARR and with other interested parties. Their purpose is threefold. First, they provide opportunities for sharing perspectives and for integrating knowledge across scientific disciplines and knowledge traditions. For example, a major workshop in the fall of 2012 focused on sharing traditional knowledge and scientific knowledge. Second, workshops provide opportunities to use participatory resilience assessment methodologies in ways that will inform both capacity-building activities and method development. Third, workshops will provide opportunities for dialogue between local and indigenous people, scientists, businesses, and decision-makers in the latter parts of the ARR process.

Sharing of knowledge at the ARR workshop in Guovdageaidnu/Kautokeino, Norway, October 2012

© ARR

Method development

A critical activity in the ARR is to explore different ways to analyze Arctic resilience in order to generate synthetic insights across Arctic regions, scientific disciplines and knowledge traditions. The methodology should also support decision-making, including increasing the capacity to respond to and shape change in the Arctic. The method development in the ARR has therefore initially focused on defining key concepts and creating a joint framework for analysis that emphasizes the linkages between social and biophysical processes. It also aims to provide decision support in a way that "fits" the Arctic policy context (Young 2002; Folke et al. 2007; Galaz et al. 2008; Robards and Lovecraft 2010). Parts of this methodology are presented in Chapter 2. More details and specific definitions in relation to thresholds are provided in Chapter 4, while Chapter 5 elaborates on ways to understand adaptive and transformative capacity. Method development will continue in the second phase of the ARR, including further exploring the linkages between society and ecosystems and how they affect capacities for adaptation and transformation.

Capacity-building

Ideally, a resilience analysis will continuously take new developments into account. A major task is therefore to build capacity within the Arctic to continue using resilience assessments as a tool for addressing and shaping rapid change for people's benefit after the project is finalized. Another objective of these activities is to develop materials that can be adopted for use at regional and local levels and by communities, as well as by government and non-government organizations. Initial capacity-building activities include the development of a course on Arctic resilience in collaboration with University of the Arctic, to be launched in the fall of 2013. This is particularly targeted towards students and professionals interested in learning about Arctic resilience and how to assess resilience in the context of real public policy challenges. At a later stage, and dependent on available funding, capacity-building could also include contributing Arctic specific insights and components for the resilience assessment handbook for practitioners, in liaison with the Resilience Alliance ■

References

ACIA (2005). *Arctic Climate Impact Assessment – Scientific Report*. J. Berner, C. Symon, L. Arris, and O. W. Heal (eds.). Cambridge University Press, Cambridge, UK, and New York. http://www.acia.uaf.edu/pages/scientific.html.

AHDR (2004). *Arctic Human Development Report*. N. Einarsson, J. N. Larsen, A. Nilsson, and O. R. Young (eds.). Prepared by the Stefansson Arctic Institute, under the auspices of the Icelandic Chairmanship of the Arctic Council 2002-2004, Akureyri, Iceland. http://www.svs.is/ahdr/.

AMAP (2011a). *ACA Scoping Workshop, Oslo, 28-30 September 2011. Workshop Report Final Version 7 November 2011*. AMAP Report 2011:2. Arctic Monitoring and Assessment Programme, Oslo, Norway. http://www.access-eu.org/modules/resources/download/access/fichiers_pdf/ACA_Scoping_Workshop_Minutes_7_Nov_2011.pdf.

AMAP (2011b). Combined Effects of Selected Pollutants and Climate Change in the Arctic Environment. Arctic Monitoring and Assessment Programme (AMAP, Oslo.

AMAP (2011c). *Snow, Water, Ice and Permafrost in the Arctic (SWIPA): Climate Change and the Cryosphere*. SWIPA Scientific Assessment Report. Arctic Monitoring and Assessment Programme, Oslo, Norway. http://www.amap.no/swipa/.

AMAP (2009). *Arctic Pollution 2009*. Arctic Monitoring and Assessment Programme, Oslo, Norway. http://amap.no/documents/index.cfm?action=getfile&dirsub=&filename=SOAER%5F2009.pdf.

AMAP (2002). *Arctic Pollution 2002: Persistent Organic Pollutants, Heavy Metals, Radioactivity, Human Health, Changing Pathways*. Arctic Monitoring and Assessment Programme, Oslo, Norway. http://amap.no/documents/index.cfm?dirsub=/Arctic%20Pollution%202002.

AMAP (1997). *Arctic Pollution Issues: A State of the Arctic Environment Report*. Arctic Monitoring and Assessment Programme, Oslo, Norway. http://amap.no/documents/index.cfm?dirsub=/Arctic%20Pollution%20Issues:%20A%20State%20of%20the%20Arctic%20Environment%20Report.

Amundsen, H. (2012). Illusions of Resilience? An Analysis of Community Responses to Change in Northern Norway. *Ecology and Society*, 17(4). Art. 46. DOI:10.5751/ES-05142-170446.

Anisimov, O. A., Vaughan, D. ., Callaghan, T. V., Furgal, C., Marchant, H., et al. (2007). Polar region (Arctic and Antarctic). *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson (eds.). Cambridge University Press, Cambridge, UK. 653–85. http://ipcc.ch/publications_and_data/ar4/wg2/en/ch15.html.

Arctic Council (2012). *Adaptation of Actions for a Changing Arctic*. DMM02, Item 4 – 15 May, 2012, Stockholm, Sweden. http://www.arctic-council.org/index.php/en/about/documents/category/118-deputy-ministers-meeting-stockholm-15-may-2012?download=493:adaptation-of-actions-for-a-changing-arctic-aaca.

Arctic Council (2011a). Nuuk Declaration. On the Occasion of the Seventh Ministerial Meeting of the Arctic Council. Arctic Council, Nuuk, Greenland. arctic-council.org.

Arctic Council (2011b). *Meeting of Senior Arctic Officials Luleå 8-9 November 2011 Final Report*. http://www.arctic-council.org/index.php/en/about/documents/category/65-sao-meeting-2011-1-in-lulea-sweden-november-2011?download=325:final-report-of-the-meeting-of-senior-arctic-officials-8-9-november-201-1-in-lulea.

Arctic Council (2011c). *Senior Arctic Officials (SAO) Report to the Ministers, Nuuk, Greenland, May 2012*. http://www.arctic-council.org/index.php/en/about/documents/category/20-main-documents-from-nuuk.

Arctic Council (2009). *Arctic Marine Shipping Assessment 2009 Report*. http://www.arctic.gov/publications/AMSA.html.

Arrigo, K. R., van Dijken, G. and Pabi, S. (2008). Impact of a shrinking Arctic ice cover on marine primary production. *Geophysical Research Letters*, 35(19). DOI:10.1029/2008GL035028.

Berkes, F., Colding, J. and Folke, C. eds. (2002). *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change*. Cambridge University Press, Cambridge, UK.

Blok, D., Sass-Klaassen, U., Schaepman-Strub, G., Heijmans, M., Sauren, P. and Berendse, F. (2011). What are the main climate drivers for shrub growth in Northeastern Siberian tundra? *Biogeosciences Discussions*, 8(5). 1169–79. DOI:10.5194/bgd-8-771-2011.

Callaghan, T. V., Johansson, M., Prowse, T. D., Olsen, M. S. and Reiersen, L.-O. (2011). Arctic Cryosphere: Changes and Impacts. *AMBIO*, 40(Suppl 1). 3–5. DOI:10.1007/s13280-011-0210-0.

Carmack, E., McLaughlin, F., Whiteman, G. and Homer-Dixon, T. (2012). Detecting and coping with disruptive shocks in Arctic marine systems: a resilience approach to place and people. *AMBIO*, 41(1). 56–65. DOI:10.1007/s13280-011-0225-6.

Chapin, F. S. I., Hoel, M., Carpenter, S. R., Lubchenco, J., Walker, B., et al. (2006). Building resilience and adaptation to manage Arctic change. *AMBIO*, 35(4). 198–202. DOI:10.1579/0044-7447(2006)35%5B198:BRAATM%5D2.0.CO;2.

Christie, P. and Sommerkorn, M. (2012). *RACER: Rapid Assesment of Circum-Arctic Ecosystem Resilience*. 2nd ed. WWG Global Arctic Programme, Ottawa, Canada. http://wwf.panda.org/what_we_do/where_we_work/arctic/publications/?204373/racer.

Conservation of Arctic Flora and Fauna (2010). *Arctic Biodiversity Trends 2010: Selected Indicators of Change*. CAFF International Secretariat, Akureyri, Iceland. http://www.arcticbiodiversity.is/.

Davidson, D. J. (2010). The Applicability of the Concept of Resilience to Social Systems: Some Sources of Optimism and Nagging Doubts. *Society & Natural Resources*, 23(12). 1135–49. DOI:10.1080/08941921003652940.

Duarte, C. M., Agustí, S., Wassmann, P., Arrieta, J. M., Alcaraz, M., et al. (2012). Tipping elements in the Arctic marine ecosystem. *AMBIO*, 41(1). 44–55. DOI:10.1007/s13280-011-0224-7.

Elmendorf, S. C., Henry, G. H. R., Hollister, R. D., Björk, R. G., Bjorkman, A. D., et al. (2012). Global assessment of experimental climate warming on tundra vegetation: heterogeneity over space and time. *Ecology letters*, 15(2). 164–75. DOI:10.1111/j.1461-0248.2011.01716.x.

Elmendorf, S. C., Henry, G. H. R., Hollister, R. D., Björk, R. G., Boulanger-Lapointe, N., et al. (2012). Plot-scale evidence of tundra vegetation change and links to recent summer warming. *Nature Climate Change*, 2(6). 453–57. DOI:10.1038/nclimate1465.

Folke, C., Carpenter, S. R., Walker, B., Scheffer, M., Chapin, T. and Rockström, J. (2010). Resilience thinking : integrating resilience, adaptability and transformability. *Ecology & society*, 15(4). Art. 20. http://su.diva-portal.org/smash/record.jsf?pid=diva2:377504.

Folke, C., Chapin, F. S. I. and Olsson, P. (2009). Transformations in Ecosystem Stewardship. *Principles of Ecosystem Stewardship*, C. Folke, G. P. Kofinas, and F. S. I. Chapin (eds.). Springer New York. 103–25. http://link.springer.com/chapter/10.1007/978-0-387-73033-2_5.

Folke, C., Pritchard, L., Berkes, F., Colding, J. and Svedin, U. (2007). The problem of fit between ecosystems and institutions: Ten years later. *Ecology and Society*, 12(1). Art. 30. http://www.ecologyandsociety.org/vol12/iss1/art30/.

Forbes, B. C., Stammler, F., Kumpula, T., Meschtyb, N., Pajunen, A. and Kaarlejärvi, E. (2009). High resilience in the Yamal-Nenets social–ecological system, West Siberian Arctic, Russia. *Proceedings of the National Academy of Sciences*, 106(52). 22041–48. DOI:10.1073/pnas.0908286106.

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

Galaz, V., Olsson, P., Folke, C., Hahn, T. and Svedin, U. (2008). The Problem of Fit among Biophysical Systems, Environmental Regimes, and Broader Governance Systems: Insights and Emerging Challenges. *Institutions and Environmental Change: Principal Findings, Applications, and Research Frontiers*, O. R. Young, H. Schroeder, and L. A. King (eds.). MIT Press, Cambridge, MA, US. 147–82.

Graybill, J. K. (2012). Imagining resilience: situating perceptions and emotions about climate change on Kamchatka, Russia. *GeoJournal*, published online November 2012. DOI:10.1007/s10708-012-9468-4.

Hausner, V. H., Fauchald, P., Tveraa, T., Pedersen, E., Jernsletten, J.-L., et al. (2011). The Ghost of Development Past: the Impact of Economic Security Policies on Saami Pastoral Ecosystems. *Ecology and Society*, 16(3). Art. 4. DOI:10.5751/ES-04193-160304.

Hovelsrud, G. K. and Smit, B. eds. (2010). *Community Adaptation and Vulnerability in Arctic Regions*. Springer, Dortrecht. http://www.springer.com/environment/global+change+-+climate+change/book/978-90-481-9173-4.

Huebert, R., Exner-Pirot, H., Lajeunesse, A. and Culledge, J. (2012). *Climate Change & International Security: The Arctic as a Bellwether*. http://www.c2es.org/publications/climate-change-international-arctic-security.

Huntington, H. and Fox, S. (2005). The Changing Arctic: Indigenous perspectives. *Arctic Climate Impact Assessment – Scientific Report*, J. Berner, C. Symon, L. Arris, and O. W. Heal (eds.). Cambridge University Press, Cambridge, UK, and New York. 61–98. http://www.acia.uaf.edu/PDFs/ACIA_Science_Chapters_Final/ACIA_Ch03_Final.pdf.

Jorgenson, M. T. and Osterkamp, T. E. (2005). Response of boreal ecosystems to varying modes of permafrost degradation. *Canadian Journal of Forest Research*, 35(9). 2100–2111. DOI:10.1139/x05-153.

Jorgenson, M. T., Shur, Y. L. and Pullman, E. R. (2006). Abrupt increase in permafrost degradation in Arctic Alaska. *Geophysical Research Letters*, 33(2). DOI:10.1029/2005GL024960.

Kofinas, G. P. and Chapin, F. S. I. (2009). Livelihoods and Human Well-Being during Social-Ecological Change. *Principles of Ecosystem Stewardship*, C. Folke, G. P. Kofinas, and F. S. Chapin (eds.). Springer, New York. 55–75. http://link.springer.com/chapter/10.1007/978-0-387-73033-2_3.

Krupnik, I., Allison, I., Bell, R., Cutler, P., Hik, D., et al. eds. (2011). *Understanding Earth's Polar Challenges: International Polar Year 2007-2008: Summary*. CCIP occasional publications series. CCI Press, Edmonton. http://www.icsu.org/publications/reports-and-reviews/ipy-summary.

Larsen, J. N., Schweitzer, P. P. and Fondahl, G. eds. (2010). *Arctic Social Indicators*. Nordic Council of Ministers, Copenhagen. http://www.norden.org/sv/publikationer/publikationer/2010-519.

Lenton, T. M. (2012). Arctic climate tipping points. *AMBIO*, 41(1). 10–22. DOI:10.1007/s13280-011-0221-x.

Macias-Fauria, M., Forbes, B. C., Zetterberg, P. and Kumpula, T. (2012). Eurasian Arctic greening reveals teleconnections and the potential for structurally novel ecosystems. *Nature Climate Change*, 2(8). 613–18. DOI:10.1038/nclimate1558.

McCarthy, J. J. and Martello, M. L. (2005). Climate change in the context of multiple stressors and resilience. *Arctic Climate Impact Assessment – Scientific Report*, J. Berner, C. Symon, L. Arris, and O. W. Heal (eds.). Cambridge University Press, Cambridge, UK, and New York. 945–88. http://www.acia.uaf.edu/PDFs/ACIA_Science_Chapters_Final/ACIA_Ch17_Final.pdf.

Meek, C. L., Lovecraft, A. L., Robards, M. D. and Kofinas, G. P. (2008). Building resilience through interlocal relations: Case studies of polar bear and walrus management in the Bering Strait. *Marine Policy*, 32(6). 1080–89. DOI:10.1016/j.marpol.2008.03.003.

Mitchell, R. B., Clark, W. C. and Cash, D. W. (2006). Information and Influence. *Global Environmental Assessments: Information and Influence* MIT Press, Cambridge, MA. 307–38.

Molau, U. (2010). Long-term impacts of observed and induced climate change on tussock tundra near its southern limit in northern Sweden. *Plant Ecology & Diversity*, 3(1). 29–34. DOI:10.1080/17550874.2010.487548.

Moore, S. E. and Huntington, H. P. (2008). Arctic marine mammals and climate change: Impacts and resilience. *Ecological Applications*, 18(sp2). S157–S165. DOI:10.1890/06-0571.1.

Murray, M. S., Andersson, L., Cherkashov, C., Forbes, B. C., Gascard, J. C., et al. (2010). *International Study of Arctic Change: Science Plan*. ISAC International Program Office, Stockholm, Sweden. http://www.arcticchange.org/storage/ISAC%20Science%20Plan%20Final%20Publication.pdf.

Nilsson, A. E. and Olsson, M. (2011). *Arctic Resilience Report Scoping Workshop*. Stockholm Environment Institute, Stockholm, Sweden. http://www.sei-international.org/publications?pid=2017.

Nuttall, M. (2009). Living in a World of Movement: Human Resilience to Environmental Instability in Greenland. *Anthropology and Climate Change: From Encounters to Actions*, S. A. Crate and M. Nuttall (eds.). Left Coast Press, Walnut Creek, CA. 292–310.

OSPAR Commission (n.d.). Ecosystem approach. *About OSPAR – Principles*. http://www.ospar.org/content/content.asp?menu=00430109150000_000000_000000. [Accessed 14 December, 2012].

Parsons, R. J. (2011). Strengthening Sovereignty: Security and Sustainability in an Era of Climate Change. *Sustainability*, 3(12). 1416–51. DOI:10.3390/su3091416.

Post, E., Forchhammer, M. C., Bret-Harte, M. S., Callaghan, T. V., Christensen, T. R., et al. (2009). Ecological Dynamics Across the Arctic Associated with Recent Climate Change. *Science*, 325(5946). 1355–58. DOI:10.1126/science.1173113.

Resilience Alliance (2010). *Resilience Assessment Workbook for Practitioners Version 2.0*. Resilience Alliance. http://www.resalliance.org/index.php/resilience_assessment.

Robards, M. D. and Lovecraft, A. L. (2010). Evaluating Comanagement for Social-Ecological Fit: Indigenous Priorities and Agency Mandates for Pacific Walrus. *Policy Studies Journal*, 38(2). 257–79. DOI:10.1111/j.1541-0072.2010.00361.x.

Sturm, M., Schimel, J., Michaelseon, G., Welker, J. M., OBERBAUER, S. F., et al. (2005). Winter Biological Processes Could Help Convert Arctic Tundra to Shrubland. *BioScience*, 55(1). 17–26. DOI:10.1641/0006-3568(2005)055[0017:WBPCH C]2.0.CO;2.

Tape, K., Sturm, M. and Racine, C. (2006). The evidence for shrub expansion in Northern Alaska and the Pan-Arctic. *Global Change Biology*, 12(4). 686–702. DOI:10.1111/j.1365-2486.2006.01128.x.
TEEB (2010). The Economics of Ecosystems & Biodiversity: Mainstreaming the Economics of Nature – a Synthesis of the Approach, Conclusions and Recommendations of TEEB. http://www.teebweb.org/publications/teebstudy-reports/synthesis/.
Wassmann, P. and Lenton, T. M. (2012). The Arctic in the Earth System perspective: the role of tipping points. *AMBIO*, 41(1). 1–9. DOI:10.1007/s13280-011-0230-9.
West, C. (2011). The survey of living conditions in the Arctic (SLiCA): A comparative sustainable livelihoods assessment. *Environment, Development and Sustainability*, 13(1). 217–35. DOI:10.1007/s10668-010-9257-5.
West, J. J. and Hovelsrud, G. K. (2010). Cross-scale Adaptation Challenges in the Coastal Fisheries: Findings from Lebesby, Northern Norway. *Arctic*, 63(3). 338–54. http://arctic.synergiesprairies.ca/arctic/index.php/arctic/article/view/1497.
Young, O. R. (2012). Arctic tipping points: governance in turbulent times. *AMBIO*, 41(1). 75–84. DOI:10.1007/s13280-011-0227-4.
Young, O. R. (2002). The Institutional Dimensions of Environmental Change: Fit, Interplay, and Scale. MIT Press, Cambridge, MA, US.

Sources for figures

Figure 1.1 Based on a SciVerse/Scopus search on Arctic and/or resilience in title, abstract or keyword.

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Chapter 2

A resilience approach to social-ecological systems: Central concepts and concerns

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2.1 Introduction

A resilience assessment is an attempt to generate systemic and anticipatory knowledge about linked social-ecological systems to better inform decision-making. While the Arctic Resilience Report (ARR) draws on the methodology for resilience assessments developed by the Resilience Alliance (Resilience Alliance 2010), there is no ready-made methodology for analyzing resilience at a pan-Arctic scale. Rather, there are several approaches that emphasize different aspects of resilience. The Resilience Alliance approach builds on participatory methods for developing conceptual models that include drivers, disturbances, feedbacks and potential threshold (Resilience Alliance 2010). Other approaches include scientific assessments of biophysical thresholds (Lenton et al. 2008; Wassmann and Lenton 2012); methods for mapping features of ecosystems that contribute to exceptional productivity and biodiversity (Christie and Sommerkorn 2012); and monitoring key issues and thresholds of concern in quality-of-life conditions, human capital and capacities through socially oriented observations (Vlasova 2009; Vlasova and Hofgaard 2011). Resilience has also been highlighted in efforts to improve risk assessment methodologies in connection with studying security in the Canadian Arctic (Fournier 2012). Furthermore, resilience is increasingly used as a phrase to capture, at a more general level, the need to pay attention to changes.

The ARR borrows from several approaches, and its methodology is evolving as part of the project. This chapter presents some of the central concepts in the ARR and how they are applied in the assessment process. They include the notions of resilience, social-ecological systems, and thresholds. The chapter also discusses the policy context and some normative aspects of assessing resilience in the Arctic.

2.2 What is resilience?

Resilience is a property of social-ecological systems. It relates to their capacity to cope with disturbances and recover in such a way that they maintain their core function and identity. It also relates to the capacity to learn from and adapt to changing conditions, and when necessary, transform.

Resilience is a concept with multiple meanings to different groups. The ARR uses resilience as it has evolved from ecology to apply to a system with distinct alternate sets of self-organized and self-stabilizing processes and structures recognized as "states" (Holling 1973). Such "states" or regimes are not necessarily stable – they are dynamic as the system evolves and responds to disturbances and changing conditions. A system can also cross thresholds to alternate states when internal or external conditions change too much (Figure 2.1 a, b). Resilience in the ecology-evolved sense refers to the capacity of a linked social-ecological system to both cope with disturbances and respond or reorganize in such a way as to maintain its essential structure, function, and identity, whilst also maintaining the capacity for adaptation, learning and transformation (Holling 1973; Gunderson and Holling 2002; Walker et al. 2004; Folke 2006; Folke et al. 2010). Resilience is both directly and indirectly influenced by the interactions among social and ecological components, and across scales. The essential functions at stake may be valued ecosystem services, that are important for human well-being. Resilience in this ecology-derived understanding is distinct from what is termed "engineering" resilience, which is a measure of the rate at which a system approaches a specific steady state (equilibrium) after a disturbance (Folke et al. 2004).

A resilience perspective emphasizes the possibility of thresholds and interactions across scales through system feedbacks (termed within the resilience literature as "panarchy"). For example, sporadic events such as insect outbreaks, wildfires, or the sudden release of meltwater from glaciers can all cause unexpected, abrupt changes to the system. Abrupt changes can also be induced by events in the social part of the system, such as a change in management regime or laws that affect ownership, as illustrated in Chapter 9. Feedbacks within the system can be perturbed by these kinds of largely unpredictable (or stochastic) events, and also by longer-term incremental change (press disturbances). When the feedbacks that keep the systems in their current state critically weaken or accelerate, the effects of the initial stressor are amplified. Thus a change in the system can have non-linear effects, often experienced as "surprises" because they are difficult to anticipate from past experience and extrapolations of trends. Sometimes a critical threshold has been crossed, and the system shifts into an alternate configuration that is controlled by different feedbacks, and may provide a different set of benefits – such as ecosystem services, economic or social benefits – to people. The concept of thresholds is further elaborated in Chapter 4. A system can be more or less resilient to these shocks and disturbances, depending on both the intensity and frequency of events – which may change over time – as well as the state of system properties that confer resilience (e.g., diversity and degree of connectedness).

2.2.1 Specified resilience and general resilience

Resilience can be viewed from the perspective of a particular system to a particular type of change in an assessment that starts by asking: Resilience of what? Resilience to what? This aspect of resilience is technically termed "specified resilience" (Carpenter et al. 2001). Specified resilience refers to the capacity of a system to withstand a shock which might push it across a threshold into an alternate state. Assessments of specified resilience pose questions such as: What is the resilience of the boreal forest to pine beetle outbreaks? What is the resilience of traditional food systems to warming temperatures in the Arctic? What is the resilience of ice-associated species to declining sea ice? What is the resilience of upriver fisheries to the changing escapement goals of coastal fisheries?

Figure 2.1a **Resilience and thresholds**

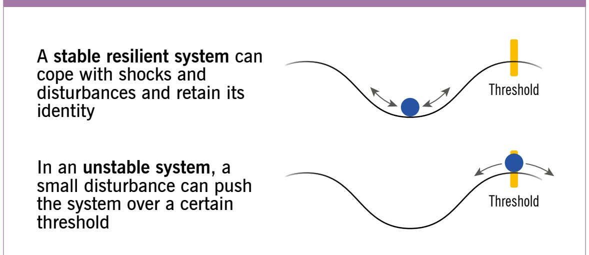
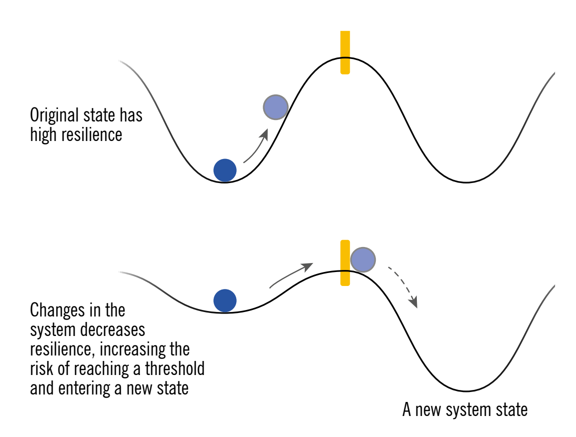


Figure 2.1b **Environmental and social changes can make a system less resilient**



However, efforts to increase the resilience of some aspect of a system regime to a specified set of disturbances can unwittingly reduce the resilience of other aspects of that system to other, non-specified (perhaps novel) disturbances. There is thus a need to pay attention to the general resilience of a system to changes that cannot be foreseen. Some aspects of general resilience are captured in the discussion on adaptive and transformative capacity in Chapter 5.

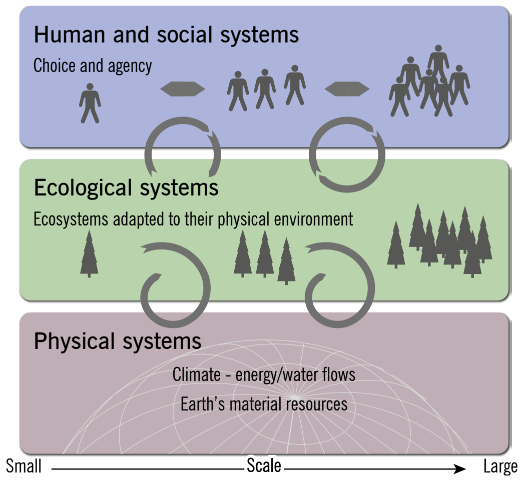
2.3 Social-ecological systems

Social-ecological systems are interwoven systems of human societies and ecosystems. The concept of a social-ecological system emphasizes that humans are part of nature and that these systems function in interdependent ways.

The ARR focuses on social-ecological systems in recognition that the important policy issues that the Arctic faces "are not just ecological or social issues, but have multiple integrated elements" (Resilience Alliance 2010). While there is broad acceptance of the basic premise of interaction between physical and social aspects of the environment, the language of "systems" is more accepted and useful in some research traditions than in others, so it requires particular care in its explanation and use. Social-ecological systems emphasize the "humans-in-nature" perspective in which ecosystems are integrated with human society. In social-ecological systems, cultural, political, social, economic, ecological, technological and other components interact. Examples of social-ecological systems in the Arctic include fisheries, reindeer herding, hunting and harvesting systems, tourism and recreation systems, nature conservation systems, agricultural systems, forestry systems, infrastructure systems (transport, pipelines, water, etc.), urban systems, and energy systems. Case studies in the ARR will shed light on the intricacies of concrete Arctic social-ecological systems.

Figure 2.2 is a simplified representation of the systems components that are addressed in the ARR: the physical environment (including climate, cryosphere, hydrology, etc.); ecological processes in different land and marine environments; the processes affecting material interactions of humans with their environment; and also the social institutions and decision-making processes that are capable of profoundly influencing all of the other components.

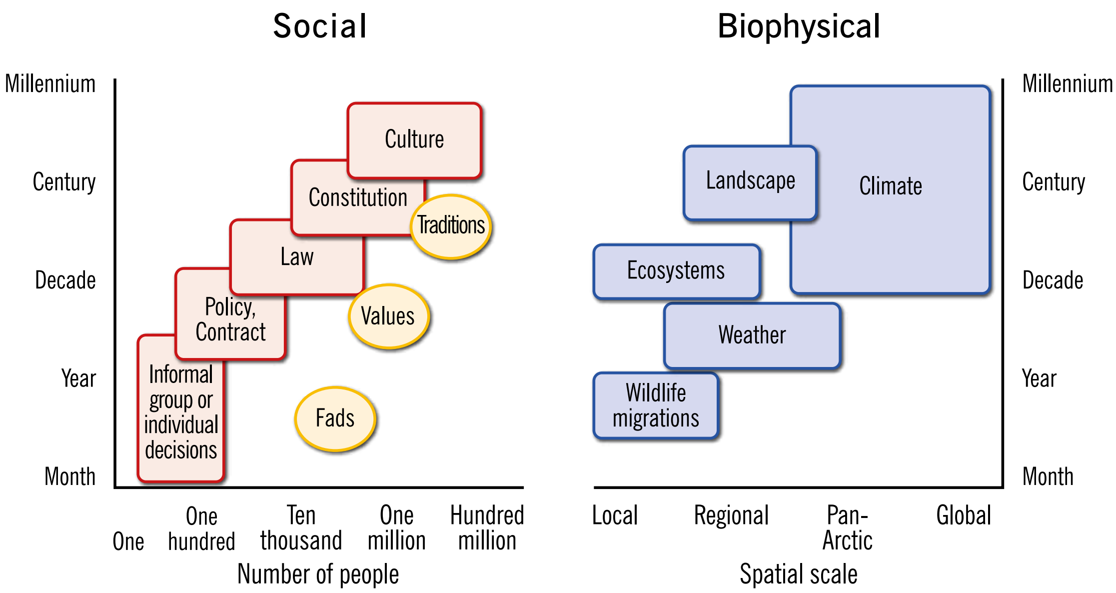
Figure 2.2 **Social-ecological systems include physical, ecological and social processes**



A challenge for defining and understanding social-ecological systems is that social-ecological changes are playing out over a range of temporal and spatial scales. The Arctic is not an isolated system. Global drivers affect regional and local processes, and vice versa. The global connectivity includes global financial flows and markets as well as multiple international governance structures that influence local activities (Keskitalo 2008; Heininen and Southcott 2010), globalized media (Christensen et al. 2011), and global environmental change (Zalasiewicz et al. 2010; Steffen et al. 2011). Figure 2.3 provides examples of processes at different spatial and temporal scales that are relevant for understanding Arctic change.

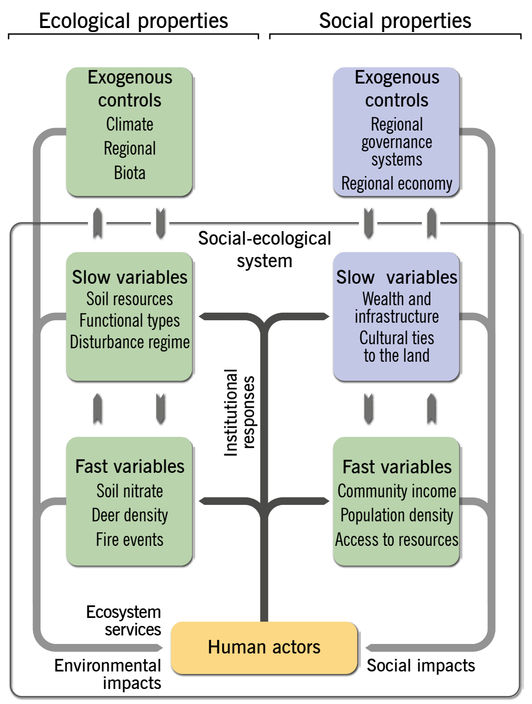
While the spatial scale of a particular assessment is a matter of choice, an analysis of resilience always has to address processes at larger scales as well. Moreover, processes at more detailed spatial scales can have repercussions in the larger context. An example is changes in the Arctic sea ice that can influence the global climate system, as discussed in Chapter 4. Understanding how social-economic and ecological systems interact across scales is central in a resilience approach to understanding, managing, and governing human-environment interactions (Berkes et al. 2002; Folke 2006; Gunderson and Holling 2002).

Figure 2.3 **Processes at a range of scales are relevant for understanding Arctic change**
Adapted from Westley et al (2002)



Speed of change is also important. Some processes of change are fast, while others are slower. In reality, slow and fast variables interact, and understanding their interaction is an important part of a resilience assessment. Figure 2.4 provides some examples of components of a generic social-ecological system, with a focus on interactions across scales.

Figure 2.4 **Interactions of different components in a social-ecological system**
Chapin et al (2009)



While cross-scale interactions are a core concept in the resilience approach, the focus of social-ecological resilience science to date has been on the assessment of fairly small-scale systems, allowing local communities to engage directly in defining the systems of which they are part. Conceptualizing resilience at larger regional and global scales is a new area of research. It requires improved integration with other treatments and understandings of complex systems. The ARR takes first steps towards enabling this integration by addressing scale issues as consistently as possible in its presentation of the evidence of changes and thresholds in the Arctic system, as described in detail in Chapter 4. It pays attention to both global drivers and global system changes, and to more local spatial scales and the meso-scales in between. In terms of time-scales, the priority for the analysis of thresholds in Chapter 4 is to identify rapid and abrupt changes, but the ARR is also concerned with issues where there are time lags or slower cumulative impacts.

2.3.1 Social-ecological systems as complex adaptive systems

The concept of social-ecological systems represents a "humans-in-nature" perspective that emerged largely in response to the widespread failure of governing human environmental use and impacts in a "command-and-control" type system. In contrast to a view based on change being predictable, progressively linear, and capable of only one stable equilibrium, the resilience approach is premised on the notion of complex adaptive systems (Holling and Meffe 1996; Levin 2000). Understanding social-ecological systems as complex adaptive systems focuses our attention on how component parts interact to bring about non-linear, unexpected change and on how the self-organizing (emergent) properties of social-ecological systems underlie the co-evolutionary development of environmental change and governance systems (Duit and Galaz 2008).

Two central notions in studying social-ecological systems are adaptation and transformation. As discussed further in Chapter 5, adaptation refers to a social, economic, or cultural adjustment to a change in the biophysical or social environment, allowing it to remain in the same system state (Walker et al. 2004; Chapin et al. 2009). When a system is no longer able to adapt, it is likely to experience a transformation. Transformations are fundamental changes in social-ecological systems that involve crossing a threshold to a new state or regime characterized by a different set of critical interactions. While transformations can entail considerable disruption, they are not always undesirable. In some cases they may lead to greater future resilience for certain components of the system (Walker and Salt 2006; Folke et al. 2009; Folke et al. 2010).

2.3.2 'Predictability' differs for physical, ecological and social systems

While recognizing that knowledge about the dynamic interactions between the social and biophysical components is critical for understanding the Arctic, our starting point in the ARR is that the assessment of resilience and the risks of thresholds has to be done with a different eye for the biophysical and social "components" of the system. In part, this conceptual structure is a pragmatic response to the fact that Arctic research tends to be produced in distinct biophysical and social fields of study. However, it is also a useful analytical approach because it can accommodate important differences in the behaviour of the sub-systems.

For Earth's physical systems, the dynamics of change, including the existence of alternate steady states, can be observed and explained in terms of causal mechanisms, and in many cases the capacity for scientific projection of future changes is now good (Goddard et al. 2012).

Local people on the ice in Ummennaq, Greenland. A resilience assessment emphasizes a people-in-nature perspective

In this context, evidence about likely future changes is an important input to policy processes. However, the predictive power of global physical models is arguably at its weakest for changes in the Arctic, where observations of sea ice and other aspects of the cryosphere lie outside of the projection envelope, and permafrost modelling has only very recently begun to include necessary parameters for simulation (Nicolsky and Shakhova 2010).

Adding to the challenge, the behaviours of ecosystems and human demographic change are not as simple to predict because they include processes of adaptive transformation (e.g., Holling 1973). They can potentially exhibit quasi-steady states, but causal chains are not straightforward. Even if we had good knowledge about the current state and all relevant drivers of change, the predictive power is much weaker than for physical processes. In the ARR, we aim to highlight the level of confidence in any projections of described changes, and explain the basis of the evidence.

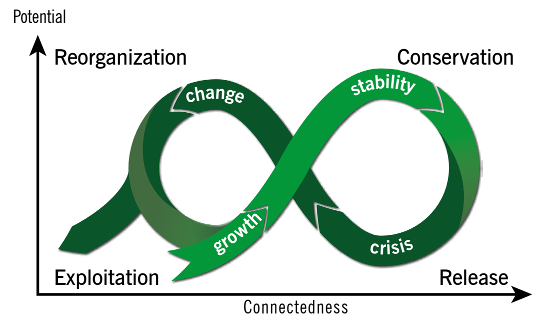
The ARR is also concerned with rapid transformations in social institutions, governance and societal values and norms. In Figure 2.2, these are shown as arising from community interactions, the capacity of individuals and groups to make choices (including irrational ones) and take action, and the interplay between individual and collective agency and social structures. Exact scientific prediction of these changes is neither effective nor appropriate, but by bringing together available knowledge on motivations and social dynamics, we can identify areas of concern and options for action.

Chapter 4 describes more fully how the different contributing disciplines address issues of social and biophysical change, situating the work of the ARR in its diverse theoretical contexts. Case studies provide an important way to explore the changes in coupled social-ecological systems, giving the depth and specificity of context and history that are needed to shed light on changes in institutions, values, rules and norms, as discussed in Chapters 6-10.

2.3.3 Embedding the cycles of change

A key challenge for the analysis of social-ecological systems is to find a structured way to address the two-way processes of change involving social and environmental interactions. The adaptive cycle (Figure 2.5) is a defining concept in the resilience approach (Holling et al. 2002), representing in general terms the processes of transition between different states of the social-ecological system – i.e., the process of transformation.

Figure 2.5 **The adaptive cycle in social-ecological system dynamics**
Holling and Gunderson (2001)



The ARR needs a conceptual framework that embeds the idea of cycles of change, but at the same time, the framework needs to be more transparent than this generalized picture of an adaptive cycle, accommodating both changes in society arising from environmental changes, and changes in the environment due to human activities. We have drawn on the Driver-Pressure-State-Impact-Response framework (see Box 2.1), a simple sequential cycle which explicitly links social and environmental processes (OECD 1993; EEA 1999).

2.4 Ecosystem services link ecosystems and society

The ARR explicitly frames the analysis in terms of ecosystem services, by which we mean the direct and indirect contributions that ecosystems make to human well-being. The ecosystem services concept has its origin in effort to conceptualize natural capital. It gained broad visibility with the Millennium Ecosystems Assessment, where it was used to capture the insight that human well-being is intrinsically linked to resources and processes that are supplied by ecosystems (Millennium Ecosystem Assessment 2005). The concept has since become a globally important discourse in national and transnational environmental policy (e.g., Scarlett and Boyd 2011; CBD 2010) and increasingly in economic policy (e.g., UNEP 2012). It has been further developed in *The Economics of Ecosystems and Biodiversity* (TEEB 2010), which defines it explicitly in economic terms where "flows of ecosystem services can be seen as the 'dividend' that society receives from natural capital". TEEB also highlights that maintaining stocks of natural capital allow the sustained provision of future flows of ecosystem services, and thereby help to ensure enduring human well-being. As discussed in Chapter 5, access to natural capital is an important source of adaptive capacity. Table 2.1 lists examples of ecosystem services in the four categories used by TEEB (2010).

Only a few ecosystems services have been explicitly priced in monetary terms, since this requires that either they be traded in a market, or we try to estimate the economic value of a particular ecosystem process. The latter includes efforts to estimate the indirect value of regulating services such as water purification, carbon sequestration, and pollination. However, the total economic value of ecosystems remains largely invisible in economic accounting. The monetary aspect of the concept has also been criticized because it only looks at the user value of nature and ignores its intrinsic value. Moreover, studies that recognize that assigning values is part of social practice and historical processes also point to the inherently political aspect of the concept (Ernstson and Sörlin 2013).

In the ARR, we are not interested in the direct economic value of ecosystems services, but use the concept as a way of clarifying how changes in the natural environment can have consequences for society, and that societies place different values on different aspects of nature, which is fundamentally important for understanding the relationship between social and ecological processes. In the ARR, we seek to clarify the links between changes in the Arctic system and changes in ecosystem services, because this provides a way of making risks and the consequences of society's management choices more transparent.

Box 2.1 **The driver-pressure-state-impact-response framework**

The DPSIR framework links concepts from environmental impact assessments, which seek to identify the impacts of human activities on the natural environment, with risk or hazard assessments, which identify the social consequences of a given environmental change. The DPSIR framework thus allows for the conceptual analysis of social-environmental interactions in both directions, on multiple scales, and over cyclical patterns of change. It also highlights that there are multiple options for effective responses. Remediation of a changed environment provides one set of options, but policy choices can also intervene in society to reduce the causes and impacts of environmental degradation.

The framework has been used extensively in fields such as coastal zone management, the delivery of aid programmes and, increasingly, in global-scale changes (e.g., the 2005 Millennium Ecosystem Assessment had a DPSIR structure, and the forthcoming Working Group 2 contribution to the *Fifth Assessment Report* of the Intergovernmental Panel on Climate Change (IPCC) also uses a state-impacts-response framework). The DPSIR framework can be adapted easily to various contexts, making it useful for both scientific synthesis and policy gap analysis.

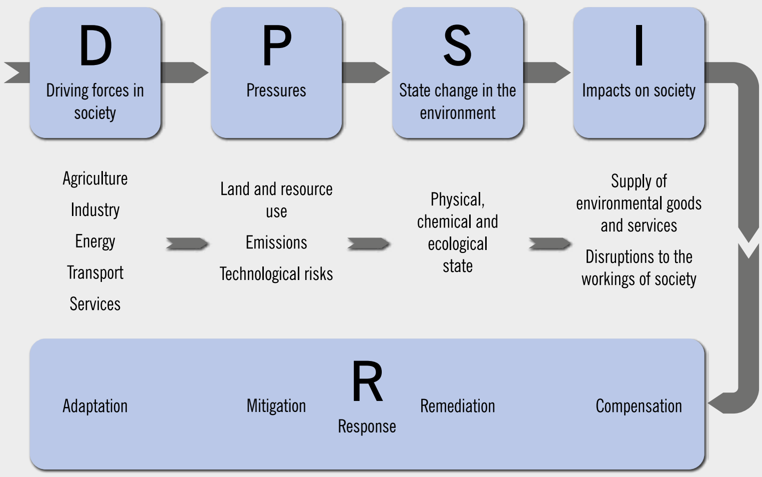


Figure 2.6 **Dynamic processes connect the biophysical and the social in the Arctic system**

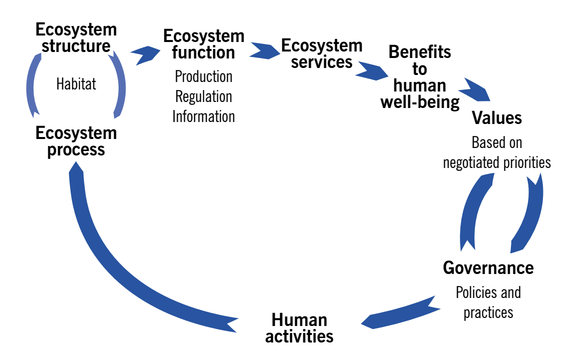


Figure 2.6 shows the conceptual cycle that informs the ARR analysis. It represents how human well-being and values are linked to the state and functioning of ecosystems. The starting point, shown in the upper part of the figure, is the TEEB (2010) conceptual framework of ecosystem services that integrates ecological and economic dimensions. The conceptual cycle also acknowledges that ecosystem services are determined not only by ecological processes, but also by social perceptions of the value of specific ecosystem functions, which in turn are affected by social negotiations and governance processes (Ernstson and Sörlin 2013). The lower arrows highlight the impact of human actions on ecosystems, which in turn are affected by individual and social practices, governance and policies. At the core of the social part of the figure are the values we place on specific benefits of ecosystem services, and how they are negotiated and transformed into action.

Figure 2.6 is an extremely simplified way of showing multiple changes and complex interactions. These social-ecological interactions assuredly will have important effects in the future, as they have in the past, on human communities, industrial enterprises, military operations, and ecosystems in the Arctic – and beyond. The aim of the ARR is not to predict these changes, but to help inform options for action that allow for adaptive management, and enable people in the region to plan for and anticipate "ongoing transformation".

2.5 Assessing resilience

A resilience assessment is an attempt to generate systemic and anticipatory knowledge about linked social-ecological systems to better inform decision-making. The ARR draws on the methodology for resilience assessments developed by the Resilience Alliance – in particular, the second edition of the *Workbook for Practitioners (Resilience Alliance 2010).* Resilience assessments informed by this sort of approach have been carried out to varying degrees in several different contexts, including with catchment management organizations in Australia (Walker and Salt 2006), natural resource managers in Afghanistan, and strategic planners in Sweden (Davoudi et al. 2012). These processes typically involve participatory workshop activities with stakeholders and experts relevant to a particular system. Since the ARR deals with a whole region that is difficult to define as a distinct social-ecological system, the ARR does not follow the guidelines of the Resilience Assessment workbook in detail. Nevertheless, the steps are illustrative of questions we ask, and the process has informed the stepwise approach of the ARR process.

2.5.1 Resilience of what and to what?

The critical first step in the Resilience Alliance approach is to answer the question: resilience *of* what/whom *to* what? A succinct description of the issue and relevant policy aspects should directly relate to the specific scale and component of the social-ecological system being assessed (resilience of what/whom?) and what the specific threats are (resilience to what?) in the form of drivers of change, disturbances, and potential thresholds. The loss of multi-year sea ice in the Arctic as a result of a warming climate would mark such a threshold change to a specific component of the Arctic social-ecological system to a specific driver.

In the ARR, defining the system (resilience of what) has been relevant for the case studies. For the pan-Arctic scale, it includes ongoing discussion of how to organize the final report and addressing the questions of what is the most useful lens for subdividing the material in relation to both issues and focal scale. The question of "resilience to what" is partly addressed in Chapter 4, in the identification of drivers and thresholds.

Ecosystem processes are part of the natural capital that is important for adaptive and transformative capacity

Table 2.1 **Four categories of ecosystem services**
de Groot et al. (2010)

PROVISIONING SERVICES
Food (e.g., fish, game, fruit)
Water (e.g., for drinking, irrigation, cooling)
Raw materials (e.g., fibre, timber, fuel wood, fodder, fertilizer)
Genetic resources (e.g., for crop-improvement and medicinal purposes)
Medicinal resources (e.g., biochemical products, models and test-organisms)
Ornamental resources (e.g,. artisan work, decorative plants, pet animals, fashion)
REGULATING SERVICES
Air quality regulation (e.g., capturing dust, chemicals, etc.)
Climate regulation (incl. carbon sequestration, influence of vegetation on rainfall, etc.)
Moderation of extreme events (e.g., storm protection and flood prevention)
Regulation of water flows (e.g., natural drainage, irrigation and drought prevention)
Waste treatment (especially water purification)
Erosion prevention
Maintenance of soil fertility (incl. soil formation)
Pollination
Biological control (e.g., seed dispersal, pest and disease control)
HABITAT SERVICES
Maintenance of life cycles of migratory species (incl. nursery service)
Maintenance of genetic diversity (especially in gene pool protection)
CULTURAL AND AMENITY SERVICES
Aesthetic information
Opportunities for recreation and tourism

2.5.2 Developing a conceptual model

A second step in the analysis involves developing a conceptual model of the system dynamics with a focus on the threshold dynamics, feedbacks and alternate states. The conceptual model may take a variety of forms and be explored using a number of tools – for example, representing the system as an adaptive cycle, developing a state and transition model, and/or creating a historical timeline of change. The emphasis with system dynamics is on characterizing thresholds of concern (i.e., indicating known values when possible, evidence, how close the system is to a threshold) and also exploring alternate states if the threshold were to be crossed. If the system shifted to an alternate state, what would be the main impacts? For example, how might a change in state affect bundles of ecosystem services supplied on the landscape/seascape, and what might be some of the trade-offs in terms of how the alternate states interact with the general resilience of the Arctic system at the pan-Arctic level?

For an analysis of change in social-ecological systems, the model would by necessity need to include both social and biophysical processes. The discussion earlier in this chapter is the ARR attempt to develop a generic conceptual model (see Figure 2.7). The model needs to be further refined with specific information for the social-ecological systems that will be placed in focus in the ARR final report, including identifying the most relevant drivers and feedbacks, and potential alternative regimes.

2.5.3 Adaptive and transformative capacity

The third step in the Resilience Alliance framework involves gauging the capacity of the social-ecological system to adapt or transform and identifying sources of resilience. Various analytical tools can be applied, depending on the case. This aspect of the assessment might involve analyses of institutions or governance systems, social network analysis, and consideration of opportunities for social learning and experimentation. In the ARR, the review of literature on adaptive and transformative capacity presented in Chapter 5 is a preparatory step toward an analysis of the adaptive and transformative capacities for particular social-ecological systems. In Chapter 5, ecosystems processes are discussed as natural capital and as one aspect of adaptive and transformative capacity. In ARR's further analysis, we will also review Arctic-relevant literature focused specifically on ecosystem processes that contribute to

Box 2.2 **Key words in the language of systems**

An assessment of resilience in the Arctic necessarily draws on multiple evidence sources. This presents an immediate practical challenge: although many different disciplinary traditions share much of a common language of systems and resilience, many terms are used in different ways, and for different kinds of phenomena, in different contexts. The following provides a brief summary of major concepts.

Social-ecological systems are systems that have both biophysical and social components. These components must interact in some coherent ways, so that their identity and structure can be determined, and the system's functioning and feedbacks described (e.g., Berkes et al. 2002).

Structure is the web of interactions that link the system's key actors or processes.

Function is the activities or services that are characteristic of the system.

Drivers are "any natural or human-induced factors that directly or indirectly cause a change in an ecosystem" (Nelson et al. 2005). Walker et al. (2012) propose narrowing the definition of drivers to just external agents or forces of change, arguing that there are no feedbacks between the system's functioning and external drivers. However, a change-forcing factor that is seen as external at one scale may well be an internal process at another.

Forcing is used in a similar way to drivers in climate science and in other fields of the physical sciences, to refer to the root causes of change in a system. In the ARR, we will avoid using this term, except in these specific scientific contexts.

Feedbacks are an important property of systems. Positive feedbacks cyclically reinforce the activities or functioning of a system, leading to phenomena such as "runaway effects" (rapid acceleration of change) and chain reactions (self-sustaining sequences). In contrast, negative feedbacks dampen the initial signal of change, tending to maintain the system in its initial state. Feedback processes play a very important role in determining system thresholds and also in maintaining system resilience.

Thresholds are points where the characteristic structure and function of the system change abruptly and qualitatively. The range of different types of thresholds is further discussed in Chapter 4. For simple systems, state changes are a switch between particular properties of the system, whereas for a complex system, passing a threshold level involves a **regime shift** (rather than a state change), in which the nature and extent of feedbacks in the system change (Christensen and Krogman 2012). **Tipping points** are a specific kind of threshold where the system shows a bifurcation, often recognized in systems that show oscillations between alternative states (Steffen et al. 2002; Christensen and Krogman 2012; Lenton et al. 2008; Schellnhuber 2009).

Resilience is "the capacity of a system to absorb disturbances and reorganize while undergoing change, so as to still retain essentially the same function, identity and structure, and feedbacks" (Walker et al. 2002; Gunderson and Holling 2002). A resilient system is thus a system that has not crossed a major threshold.

resilience. Examples of earlier relevant work in this area include the WWF RACER project (Christie and Sommerkorn 2012), along with chapters in the Arctic Climate Impact Assessment that focus on ecosystems processes (Callaghan 2005; Loeng 2005; Wrona et al. 2005) and parts of the *Snow, Water and Permafrost in the Arctic* report (AMAP 2011).

2.6 Resilience assessment as part of policy processes

While resilience assessment provides an integrative tool for understanding the linkages and dynamics within and across social-ecological systems, including the role of social decision-making and policy, it does not automatically inform political decision-making. To do so, the knowledge generated needs to link to society's collective ability to make decisions in relevant policy processes at the appropriate spatial and temporal scales. Some decisions require international agreements, while others are best negotiated in the particular local setting, and others will require national policies. Often policies must link across scales to be effective. Selecting the best policy forum for a particular issue has been addressed as a problem of "fit" (Young 2002; Folke et al. 2007; Galaz et al. 2008; Robards and Lovecraft 2010). The initial focus in the literature of fit was on selecting a proper scale for governance based on the environmental characteristics, but it increasingly recognizes the interplay between levels of governance and the challenge of connectivity across scales in both biophysical and social systems (Brondizio et al. 2009). Recognition of connectivity and the nested character of social-ecological systems highlight the need to also analyze the degree of nestedness and connectedness (often assessed as polycentricity) of policy contexts in which decisions that affect resilience are made.

At the international level, the ARR is nested in the specific policy context of international circumpolar cooperation in the Arctic Council. This includes an imperative to develop links to other Arctic Council assessment processes to gather relevant knowledge, as well as to relevant ongoing policy processes within the Arctic Council. The second phase of the ARR will include structured dialogues to further explore the policy implications of the assessment. Given the Arctic Council context, a natural focus for these policy dialogues will be issues where circumpolar cooperation provides added value and where the Arctic Council can influence other international policy processes, including negotiations in connection with global environmental conventions.

Many policy decisions relevant to resilience are situated at the national and sub-national levels. Here the ARR will aim to identify areas where there is added value in circumpolar coordination and collaboration. It will also seek to identify general insights that the Arctic countries can chose to include in their national and sub-national policy processes. A potential example might be in developing and implementing strategies for adaptation to climate change – a process that will likely differ in each country but require adherence to the same general principles.

2.6.1 The normative character of resilience assessments

Any assessment of Arctic change, including assessment of resilience, includes an element of social or political choice, in that resources allocated to one purpose are not readily available for something else. It is ultimately a normative decision to focus on some issues that are deemed more important. For the policy processes connected with resilience assessments, there are also normative dimensions that include value judgments: Which systems do we foster resilience for? Whose resilience is prioritized? When is it deemed suitable or desirable to keep a social-ecological system in its current state? When is transformative change deemed relevant or necessary?

The answers to these questions depend on who has the power to decide on policy and implement decisions. The system states we foster resilience for, and at what scale, are thus a function of policy decisions and management. From the governance perspective, resilience reflects the desires of those with the power to make and implement decisions (Robards et al. 2011).

The process of assessing resilience involves normative questions, such as whose resilience is being prioritized

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Recognizing the normative dimensions of resilience assessments is particularly important in the Arctic, where different interests and activities now intersect in ways that will inevitably affect the resilience of current social-ecological systems. For example, profound wildlife aggregations now intermingle with industrial development, and numerous indigenous communities are at the epicentre of climate change (which impacts traditional subsistence activities) while also grappling with new industrial activities and their own economic development needs. The power of self-determination through active and meaningful participation in decision-making processes is central to the environmental justice issues involved in any normative approach (such as a resilience analysis) to decision-making ■

References

AMAP (2011). *Snow, Water, Ice and Permafrost in the Arctic (SWIPA): Climate Change and the Cryosphere*. SWIPA Scientific Assessment Report. Arctic Monitoring and Assessment Programme, Oslo, Norway. http://www.amap.no/swipa/.

Berkes, F., Colding, J. and Folke, C. eds. (2002). *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change*. Cambridge University Press, Cambridge, UK.

Brondizio, E. S., Ostrom, E. and Young, O. (2009). Connectivity and the Governance of Multilevel Social-Ecological Systems: The Role of Social Capital. *Annual Review of Environmental Resources*, 34. 253–78.

Callaghan, T. V. (2005). Arctic tundra and polar desert ecosystems. *Arctic Climate Impact Assessment – Scientific Report*, J. Berner, C. Symon, L. Arris, and O. W. Heal (eds.). Cambridge University Press, Cambridge, UK, and New York. 243–352. http://www.acia.uaf.edu/PDFs/ACIA_Science_Chapters_Final/ACIA_Ch07_Final.pdf.

Carpenter, S., Walker, B., Anderies, J. M. and Abel, N. (2001). From Metaphor to Measurement: Resilience of What to What? *Ecosystems*, 4(8). 765–81. DOI:10.1007/s10021-001-0045-9.

CBD (2010). *Ecosystem Goods and Services in Development Planning: A Good Practice Guide*. Secretariat of the Convention on Biological Diversity, Montreal. http://www.cbd.int/development/doc/cbd-good-practice-guide-ecosystem-booklet-web-en.pdf.

Chapin, F. S. I., Kofinas, G. P. and Folke, C. eds. (2009). *Principles of Ecosystem Stewardship: Resilience-Based Natural Resource Management in a Changing*. Springer, New York. http://www.springer.com/environment/environmental+management/book/978-0-387-73032-5.

Christensen, L. and Krogman, N. (2012). Social thresholds and their translation into social-ecological management practices. *Ecology and Society*, 17(1). Art. 5. DOI:10.5751/ES-04499-170105.

Christensen, M., Jansson, A. and Christensen, C. eds. (2011). *Online Territories: Globalization, Mediated Practice, and Social Space*. Digital formations. Peter Lang, New York.

Christie, P. and Sommerkorn, M. (2012). *RACER: Rapid Asessment of Circum-Arctic Ecosystem Resilience*. 2nd ed. WWG Global Arctic Programme, Ottawa, Canada. http://wwf.panda.org/what_we_do/where_we_work/arctic/publications/?204373/racer.

Davoudi, S., Porter, L., Shaw, K., Haider, L. J., Quinlan, A. E., et al. (2012). Interface: Applying the Resilience Perspective to Planning: Critical Thoughts from Theory and Practice. *Planning Theory & Practice*, 13(2). 299–333. DOI:10.1080/14649357.2012.677124.

De Groot, R. S., Fisher, B. and Christie, M. (2010). Integrating the Ecological and Economic Dimensions in Biodiversity and Ecosystem Service Valuation. *The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations*, P. Kumar (ed.). Routledge, London and New York. 9–40. http://www.teebweb.org/publications/teeb-study-reports/foundations/.

Duit, A. and Galaz, V. (2008). Governance and Complexity—Emerging Issues for Governance Theory. *Governance*, 21(3). 311–35. DOI:10.1111/j.1468-0491.2008.00402.x.

Ernstson, H. and Sörlin, S. (2013). Ecosystem services as technology of globalization: On articulating values in urban nature. *Ecological Economics*, 86. 274–84. DOI:10.1016/j.ecolecon.2012.09.012.

European Environment Agency (1999). *Environmental Indicators: Typology and Overview.* Technical Paper 25/1999. Copenhagen. http://www.eea.europa.eu/publications/TEC25.

Folke, C. (2006). Resilience: The emergence of a perspective for social–ecological systems analyses. *Global Environmental Change*, 16(3). 253–67. DOI:10.1016/j.gloenvcha.2006.04.002.

Folke, C., Carpenter, S. R., Walker, B., Scheffer, M., Chapin, T. and Rockstrom, J. (2010). Resilience Thinking: Integrating Resilience, Adaptability and Transformability. *Ecology and Society*, 15(4). Art. 20. http://www.ecologyandsociety.org/vol15/iss4/art20/.

Folke, C., Carpenter, S., Walker, B., Scheffer, M., Elmqvist, T., Gunderson, L. and Holling, C. S. (2004). Regime Shifts, Resilience, and Biodiversity in Ecosystem Management. *Annual Review of Ecology, Evolution, and Systematics*, 35(1). 557–81. DOI:10.1146/annurev.ecolsys.35.021103.105711.

Folke, C., Chapin, F. S. I. and Olsson, P. (2009). Transformations in Ecosystem Stewardship. *Principles of Ecosystem Stewardship*, C. Folke, G. P. Kofinas, and F. S. I. Chapin (eds.). Springer New York. 103–25. http://link.springer.com/chapter/10.1007/978-0-387-73033-2_5.

Folke, C., Pritchard, L., Berkes, F., Colding, J. and Svedin, U. (2007). The problem of fit between ecosystems and institutions: Ten years later. *Ecology and Society*, 12(1). Art. 30. http://www.ecologyandsociety.org/vol12/iss1/art30/.

Fournier, S. (2012). *Getting It Right: Assessing and Building Resilience in Canada's North*. the Conference Boards of Canada, Ottawa, Canada. http://www.conferenceboard.ca/e-library/abstract.aspx?did=4842.

Galaz, V., Olsson, P., Folke, C., Hahn, T. and Svedin, U. (2008). The Problem of Fit among Biophysical Systems, Environmental Regimes, and Broader Governance Systems: Insights and Emerging Challenges. *Institutions and Environmental Change: Principal Findings, Applications, and Research Frontiers*, O. R. Young, H. Schroeder, and L. A. King (eds.). MIT Press, Cambridge, MA, US. 147–82.

Goddard, L., Hurrell, J. W., Kirtman, B. P., Murphy, J., Stockdale, T. and Vera, C. (2012). Two Time Scales for The Price Of One (Almost). *Bulletin of the American Meteorological Society*, 93(5). 621–29. DOI:10.1175/BAMS-D-11-00220.1.

Gunderson, L. H. and Holling, C. S. eds. (2002). *Panarchy*. Island Press, Washington, DC.

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

Holling, C. S. (1973). Resilience and Stability of Ecological Systems. *Annual Review of Ecology and Systematics*, 4(1). 1–23. DOI:10.1146/annurev.es.04.110173.000245.

Holling, C. S., Gunderson, L. H. and Ludwig, D. (2002). In quest of a theory of adaptive change. *Panarchy: Understanding Transformations in Human and Natural Systems*, C. S. Holling and L. H. Gunderson (eds.). Island Press, Washington, DC. 3–24.

Holling, C. S. and Meffe, G. K. (1996). Command and Control and the Pathology of Natural Resource Management. *Conservation Biology*, 10(2). 328–37. DOI:10.1046/j.1523-1739.1996.10020328.x.

Keskitalo, E. C. H. (2008). *Climate Change and Globalization in the Arctic. An Integrated Approach to Vulenrability Assessment*. Earthscan, London.

Lenton, T. M., Held, H., Kriegler, E., Hall, J. W., Lucht, W., Rahmstorf, S. and Schellnhuber, H. J. (2008). Tipping elements in the Earth's climate system. *Proceedings of the National Academy of Sciences*, 105(6). 1786–93. DOI:10.1073/pnas.0705414105.

Levin, S. A. (2000). *Fragile Dominion: Complexity and the Commons*. Perseus, Cambridge, Mass.; [Oxford].

Loeng, H. (2005). Marine systems. *Arctic Climate Impact Assessment – Scientific Report*, J. Berner, C. Symon, L. Arris, and O. W. Heal (eds.). Cambridge University Press, Cambridge, UK, and New York. 454–358. http://www.acia.uaf.edu/PDFs/ACIA_Science_Chapters_Final/ACIA_Ch09_Final.pdf.

Millennium Ecosystem Assessment (2005). *Ecosystems and Human Well-being: Synthesis*. Millennium Ecosystem Assessment Series. Island Press, Washington, DC.

Nelson, G. C., Janetos, A. and Bennet, E. (2005). Drivers of change in ecosystem conditions and services. *Scenarios assessment of the Millennium Ecosystem Assessment*, S. R. Carpenter, L. P. Pingali, M. E. Bennett, and M. B. Zurek (eds.). Island Press, London, UK. 174–222.

Nicolsky, D. and Shakhova, N. (2010). Modeling sub-sea permafrost in the East Siberian Arctic Shelf: the Dmitry Laptev Strait. *Environmental Research Letters*, 5(1). DOI:10.1088/1748-9326/5/1/015006.

Organization for Economic Cooperation and Development (1993). *OECD Core Set of Indicators for Environmental Performance Reviews*. 83. OECD, Paris. http://www.fao.org/ag/againfo/programmes/en/lead/toolbox/Refer/gd93179.pdf.

Resilience Alliance (2010). *Resilience Assessment Workbook for Practitioners Version 2.0*. Resilience Alliance. http://www.resalliance.org/index.php/resilience_assessment.

Robards, M. D. and Lovecraft, A. L. (2010). Evaluating Comanagement for Social-Ecological Fit: Indigenous Priorities and Agency Mandates for Pacific Walrus. *Policy Studies Journal*, 38(2). 257–79. DOI:10.1111/j.1541-0072.2010.00361.x.

Robards, M. D., Schoon, M. L., Meek, C. L. and Engle, N. L. (2011). The importance of social drivers in the resilient provision of ecosystem services. *Global Environmental Change*, 21(2). 522–29. DOI:10.1016/j.gloenvcha.2010.12.004.

Scarlett, L. and Boyd, J. (2011). *Ecosystem Services: Quantification, Policy Applications, and Current Federal Capabilities*. Discussion Paper No. 11-13. Resources for the Future, Washington, DC. http://www.rff.org/Publications/Pages/PublicationDetails.aspx?PublicationID=21513.

Schellnhuber, H. J. (2009). Tipping elements in the Earth System. *Proceedings of the National Academy of Sciences of the United States of America*, 106(49). 20561–63. DOI:10.1073/pnas.0911106106.

Steffen, W., Jaeger, J., Carson, D. J. and Bradshaw, C. eds. (2002). *Coping with Earth System Complexity and Irregularity*. Springer.

Steffen, W., Persson, Å., Deutsch, L., Zalasiewicz, J., Williams, M., et al. (2011). The Anthropocene: From Global Change to Planetary Stewardship. *AMBIO*, 40(7). 739–61. DOI:10.1007/s13280-011-0185-x.

TEEB (2010). *The Economics of Ecosystems & Biodiversity: Mainstreaming the Economics of Nature – a Synthesis of the Approach, Conclusions and Recommendations of TEEB*. http://www.teebweb.org/publications/teeb-study-reports/synthesis/.

UNEP (2012). *Valuing Nature*. Green Economy Briefing Paper. United Nations Environment Programme, Geneva, Switzerland. http://www.unep.org/greeneconomy/Portals/88/VALUING%20NATURE.pdf.

Vlasova, T. (2009). Experience in developing approaches and methods for socially-oriented observations of the North: the integration of interdisciplinary science and public opinion. *Russian Northern Innovation Strategy: Social Development of Northern Regions*, V. A. Chereshnev (ed.). 67–79. Proceedings of the V Northern Social and Environmental Congress, Moscow, April, 21-22, 2009.

Vlasova, T. and Hofgaard, A. (2011). Prospects for circumpolar system of socially-oriented observations construction based on the results of the International Polar Year 'PPS Arctic' and IASOS projects. *Problems of Health and Social Development in the Russian Arctic – Contribution of Russia to the International Polar Year* Paulsen, Moscow and St. Petersburg, Russia. 226–40.

Walker, B. H., Carpenter, S., Anderies, J., Abel, N., Cumming, G., et al. (2002). Resilience Management in Social-ecological Systems: a Working Hypothesis for a Participatory Approach. *Conservation Ecology*, 6(1).

Walker, B. H., Carpenter, S. R., Rockström, J., Crépin, A.-S. and Peterson, G. D. (2012). Drivers, 'Slow' Variables, 'Fast' Variables, Shocks, and Resilience. *Ecology and Society*, 17(3). Art. 30. DOI:10.5751/ES-05063-170330.

Walker, B. H., Holling, C., Carpenter, S. and Kinzig, A. (2004). Resilience, adaptability and transformability in social-ecological systems. *Ecology and Society*, 9(2). Art. 5. http://www.ecologyandsociety.org/vol9/iss2/art5/.

Walker, B. H. and Salt, D. (2006). *Resilience Thinking: Sustaining Ecosystems and People in a Changing World*. Island Press.

Wassmann, P. and Lenton, T. M. (2012). The Arctic in the Earth System perspective: the role of tipping points. *AMBIO*, 41(1). 1–9. DOI:10.1007/s13280-011-0230-9.

Westley, F., Carpenter, S.R., Brock, W.A., Holling, C.S. and Gunderson, L.H. (2002) Why systems of people and nature are not just social and ecological systems. *Panarchy: Understanding transformations in human and natural systems,* L.H. Gunderson and C.S. Holling (eds.). Island Press, Washington, DC. 103-19.

Wrona, F., Prowse, T. and Reist, J. D. (2005). Freshwater ecosystems and fisheries. *Arctic Climate Impact Assessment – Scientific Report*, J. Berner, C. Symon, L. Arris, and O. W. Heal (eds.). Cambridge University Press, Cambridge, UK, and New York. 353–452. http://www.acia.uaf.edu/PDFs/ACIA_Science_Chapters_Final/ACIA_Ch08_Final.pdf.

Young, O. R. (2002). *The Institutional Dimensions of Environmental Change: Fit, Interplay, and Scale*. MIT Press, Cambridge, MA, US.

Zalasiewicz, J., Williams, M., Steffen, W. and Crutzen, P. (2010). The New World of the Anthropocene. *Environmental Science & Technology*, 44(7). 2228–31. DOI:10.1021/es903118j.

Sources for figures

Figure 2.1a-b Based on original from Brian Walker.
Figure 2.3 Social processes adapted from Westely et al. (2002).
Figure 2.4 Based on Chapin, Folke, and Kofinas (2009).
Figure 2.5 Adapted from Holling and Gunderson (2001).
Table 2.1 Reproduced from de Groot et al. (2010), Annex 2, at pp.39-40.

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Chapter 3

Indigenous perceptions of resilience

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3.1 Introduction

An important aspect of a resilience assessment is to engage with available knowledge about how societies have responded to past changes in their environment. Indigenous peoples' traditional knowledge is increasingly recognized as important for such understanding (Berkes et al. 2000; Krupnik et al. 2011), and is also increasingly included into Arctic Council assessment processes (e.g., Huntington and Fox 2005; Arctic Biodiversity Assessment, forthcoming). In an oral history of Unalakleet, Alaska, Inupiaq Elder Charles O'Degnan refers to his people's traditions thus: "The thing in subsistence way of life, what I can say is, 'That if our ancestors were not the stewards of these resources, we wouldn't have any resources now'" (Mustonen et al. 2009, p.40).

Integrating traditional knowledge with western scientific traditions is not a straightforward process, however, as the two see the world very differently. In short, Arctic traditional ecological knowledge generally views all elements of matter as interconnected and not easily understood in isolation; it is gathered and studied over a long period of time in individual localities; it is rooted in a social context that sees the world in terms of social and spiritual relations between all life forms. Traditional-knowledge explanations of environmental phenomena are often spiritual and based on cumulative, collective experience (Johnson 1992). Such a view is evident in the words of the respected Inupiaq subsistence fisherman Jerry Ivanoff, also from Unalakleet:

> *Without the fish resources I worry about the tradition, I worry about my people. I saw that king salmon species go from twenty thousand to nothing in twenty years. The humpback [pink] salmon are in dire straits since 1992. We've had some crashes from north to south. Our ability to survive as native people depends a lot on that fish and it's staple in our diet… I didn't sign no piece of paper that gave away our rights to the land, to my subsistence lifestyle. When they signed the state product, I didn't as a native person. I didn't sign any proclamation saying that we give up any native rights to our subsistence lifestyle, the land that we've used for generations… I love king salmon fishing, because they are so big. When you're dealing with a big king salmon, it'll throw you around. And it just... it fills your inner being. You just have to do it, it is a part of your cycle of life. (Mustonen et al. 2009, pp.42–45)*

Traditional knowledge is transmitted orally, and it is often difficult to convey ideas and concepts to those who do not share the tradition and the experience. However, there is a growing body of epistemological material from indigenous scholars and published literature that places local experiences in a broader context. Thus, it is relevant to view traditional knowledge as a knowledge paradigm of its own, in parallel with western science discourses.

This chapter is an initial exploration of the concept of resilience from indigenous perspectives. The purpose is to set the stage for further discussion in the second phase of the ARR on the role of traditional knowledge in understanding resilience in the Arctic. By building on indigenous communities' involvement in previous Arctic Council assessments, such as the Arctic Climate Impact Assessment (ACIA 2005) and the Arctic Biodiversity Assessment (forthcoming), there is a potential of developing new, more innovative approaches for the ARR. While this chapter provides a few examples from different parts of the Arctic, future work will also aim towards a broader geographic representation of indigenous perspectives.

3.2 Traditional knowledge and resilience

The circumpolar Arctic is home to numerous indigenous peoples, including Inupiat, St. Lawrence Island Yupik, Central Yup'ik, Alutiiq, Aleuts and Athapaskans of Alaska; Inuit, Inuvialuit, Dene and Athabaskans of northern Canada; Kalaallit and Inughuit of Greenland;

Figure 3.1 **Map of Arctic indigenous peoples**

Sámi of Fennoscandinavia and Russia's Kola Peninsula; and peoples such as the Chukchi, Siberian Yupiaq, Even, Evenk, Nenets, Enets, Dolgan and Yukaghir of the Russian Far North and Siberia. Several other indigenous nations in Siberia can be considered "Arctic" in terms of their cultures and languages, but inclusion of their traditional territories into the Arctic and Sub-Arctic depends on the definition of the Arctic.

Berkes et al. (2000) define traditional knowledge as "a cumulative body of knowledge, practice and belief evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment". The common thread among Arctic indigenous peoples, with their diverse cultures, languages, histories, traditions and geographic regions, is that they each developed a highly specialized knowledge base with respect to weather, snow, ice, natural resources, hunting and travel, to name but a few things. This traditional knowledge ensured their survival in some of the harshest climates in the world.

Traditional knowledge preserves important experiences and indigenous history in the collective memory, and maintains a long-term communal understanding of the landscape, the flora and fauna, the human relationship to the environment, and cultural dynamics – all key determinants of indigenous resilience. Traditional knowledge clarifies how communities are organized and how they responded to past environmental states, thereby informing the present. An Inupiaq youth, Galen Doty from Alaska, described it thus in 2002: "We learn ever since we are young. Our parents and our elders, they teach us not to waste any food and to how to tell if it's good or not." (Mustonen et al. 2009, p.31)

3.2.1 Flexibility as a mechanism of resilience

For Arctic indigenous peoples themselves, understanding the ways in which they are resilient and the ways in which they are vulnerable is an essential starting point in determining how they will respond to the challenges posed by climate change. As noted in Chapters 1 and 2, physical, ecological, and social forces interact to shape these factors for each group of people. In times of rapid change, the dynamics of this interplay are particularly difficult for a society to track. An assessment of individual and collective perspectives of Arctic indigenous peoples on the challenges ahead can help determine strengths, weaknesses, and priorities. Practically, life in the Arctic requires great flexibility and resilience. We again cite the words of the Inupiaq fisherman Jerry Ivanoff, from Alaska:

> *The driving force in the ability of our people to survive has been subsistence, that's the most important thing. Basically that is how we have survived for generations, [following] the patterns of life that we depend on and the [seasonal] differences. Basically every season provides food as resource for us to harvest, and put away, to make it through the six months of cold. (Mustonen et al. 2009, p.30)*

Many of the well-known cultural adaptations in the Arctic, such as small-group and individual flexibility and the accumulation of specialist and generalist knowledge for hunting and fishing, may be interpreted as mechanisms providing resilience (Huntington and Fox 2005). Such adaptations enhance options and were (and still are) important for survival. If the caribou or snow geese do not show up at a particular time and place, the hunter has back-up options and knows where to go for fish or ringed seals instead. However, the adaptive capacity of indigenous peoples may be reduced by cultural changes; by the loss of some knowledge and sensitivity to environmental cues; or by developments such as the establishment of fixed villages with elaborate infrastructure that restrict mobility (Huntington and Fox 2005).

While the scale of the impacts of Arctic change over the long term is projected to be very significant, the predictability of this change in time and space is uncertain within the circumpolar Arctic. Inupiaq Elder Guerie Towarak is a respected knowledge-holder in Western Alaska. She described weather change as a significant issue for her people:

> *It's a lot warmer in the springtime. We didn't have big storms for a long, long time, like we used to have when we were growing up. We had a lot of snow then and we used to have lot of berries in the summer time, because the snow keeps them from freezing. I mean things that are growing in the springtime, they have a lot of water from the snow. This spring [2002], it was cold spring and not much snow on the ground, and people were wondering, I'm sure they, the older people, were thinking maybe the berries will freeze. (Mustonen et al. 2009, p.10)*

Even in the face of major changes, indigenous communities will attempt to adapt, within the constraints of the cultural, geographic, climatic, ecological, economic, political, social, national, regional, and local circumstances that shape their lives. As with all adaptations, the measures developed in the Arctic in response to change will protect some aspects of society at the expense of others. The overall success of the adaptations, however, will depend on the Arctic indigenous peoples themselves, probably based in large part on the degree to which they are able to conceive, design, develop, and carry out their own response measures.

This is crucial to effective adaptation: resilience increases if the response is led by the community itself, through its own institutions. Directives from administrative centres or solutions devised by outsiders are unlikely to lead to the specific adaptations necessary for each community. Therefore, local, community indigenous perspectives are needed to provide the details that Arctic-wide models cannot provide. Indigenous observations are increasingly included in published literature (e.g., Krupnik and Jolly 2002; Huntington and Fox 2005; Krupnik et al. 2011; see also Chapter 9 of this report). Indigenous peoples can also provide new evidence of unexpected changes, as is evident in the oral history of an Inupiaq Elder Leonard Brown from the shores of Norton Sound, Alaska:

> *I moved in to my grandfather's home back in 1939, and there's a lotta change since. It's noticeable. We used to have, you know, the break-up of the Unalakleet River used to occur late in May and in June. And now it's late April or first week of May – it's much earlier and much warmer, than it used to be. And when I was a kid, during the middle forties, it was a fun game for us to jump from ice cake to the water, and it'd be middle of*

June! It's warmer! Yeah it's warmer, and I'm told that the scientists are seeing a lot of different types of algae growing out there. And blue whale... blue whale is right in it. They're not supposed to be up here! But they're out here on the Bering Sea, in that green stuff. (Mustonen et al. 2009, pp.18–25).

Indigenous memory can also provide new frames of reference for the changes and their significance, as is evident in the words of the respected Inupiaq Elder Stanton Katchatag from Alaska:

I think the warming of the weather, is becoming noticeable about twenty-five to thirty years [ago], it's slow, you know. But when I think back, that's about the time when it seems like it changed. Because long ago, especially last part of December around Christmas and New Year, that used to be extremely cold and the temperature would drop down to sixty below [Fahrenheit] and so forth. My wife even said that one Christmas, that she saw the temperature was seventy-five [Fahrenheit] below. (Mustonen et al. 2009, p.20)

Indigenous knowledge perspectives can help identify local needs, concerns and actions. This is an iterative rather than a one-step solution because there is much uncertainty about what is to come. Thus, policies and actions must be based on incomplete information, to be modified as the understanding of change and its impacts evolves.

One significant aspect of Arctic indigenous perspectives to change is that they show the differences in the levels of vulnerability and resilience of each group or community, from place to place and over time. For policymakers, taking the nature and diversity of Arctic indigenous perspectives into account is essential in the effort to help those groups adapt. Indigenous peoples of the Arctic are struggling to maintain their identity and distinctive cultures in the face of rapid and unpredictable Arctic change. Responses to climate change can exacerbate or mitigate the impacts.

3.2.2 Learning at multiple scales

Indigenous perspectives are also important in that indigenous peoples are experts at learning by doing. Science can learn from Arctic indigenous knowledge to build on the adaptive management approach – which, after all, is a scientific version of learning by doing. Multi-scale learning is key – learning at the level of community institutions such as hunter-trapper committees, regional organizations, national organizations, and international organizations such as the Arctic Council. The use of adaptive management is a shift from the conventional scientific approach, and the creation of multi-level governance, or co-management systems, is a shift from the usual top-down approach to management (Caulfield 2004). A bottom-up approach relies on interactions and initiatives from within the local community and includes input from individuals, groups, businesses and public sector organizations. A traditional "top down" approach is inadequate for effectively building local resilience, because it does little to build capacity and often does not address locally defined priorities, cultural values, and resource constraints.

Despite the increasing trend worldwide of integrating indigenous and scientific knowledge into decision-making, there has been little stock-taking of lessons learned from bringing indigenous knowledge and science together and the implications for maintaining and building social-ecological system resilience. Decision-makers at all levels of governance need to utilize this great reservoir of traditional knowledge – human experience – because a) it is relevant to small-scale subsistence producers who are most vulnerable to Arctic change but are most often left out of (macro) policy decisions and their effects, and b) it supports cultural conservation, to the extent that indigenous social memory is a great repository of human experience. Traditional knowledge is a vital resource for resilience and adaptation in our rapidly changing contemporary global context, and can inform more legitimate, appropriate, and economically and culturally sustainable responses to Arctic change.

While some experiences are common among indigenous peoples across the Arctic, it is also important to recognize that there is a great deal of diversity in today's Arctic. The following sections feature different perspectives from North America and Eurasia.

3.3 North America

Northern communities in Canada have long considered the land and resources around them as crucial to their well-being. Many Inuit, Athabaskan, Métis and other northern peoples recognize the importance of respectful symbiotic relationships between themselves and the water, fish, wildlife and other beings of their natural world. What's more, these relationships are imbued with sacred or spiritual significance. Beliefs that people and animals "are related like families", and that the "land is alive" and cannot really be managed by people, are described in oral histories documented throughout the North, particularly in First Nations communities. In this context, the experience of environmental change is deeply personal and spiritual and can really only be understood through lived experience and the development of long-term respectful social and social-ecological relations (Parlee and Furgal 2010).

Maintaining traditional culture and ways of life is also seen as a source of strength and well-being, as a knowledge carrier of the Inupiaq people of Unalakleet, Alaska, Jolene Katchatak Nanouk, noted in her oral history:

I would suggest to keep on living your Inupiaq way of life. Following the values of respect, respect for nature and for yourself; humor, and hard work, and spirituality, and keep on believing. That this why you're here. Is because of what you learned from your parents and grandparents. And it makes it a lot easier if everyone just did live their Inupiaq way of life. Of being hard workers and respecting their nature, and having humor when things get too tough. It's just... it makes it a lot better, and you feel a lot better doing what you're doing. (Mustonen et al. 2009)

Building knowledge and skills is critical to reducing vulnerability and increasing the adaptive capacity of individuals and institutions (Hovelsrud and Smit 2010), and here again, northern indigenous peoples see tradition as an asset:

… in times of crisis or when we're low on resources, I think in the old days, they might have used those opportunities to educate youth, like active hunters can work with the younger folk to bring back some old values, old traditional laws. To learn to respect what we have when there's plenty of it and we can pass on those values for adaptation that we've probably used for the past thousands of years. (Parlee and Furgal 2010)

Dog sled team at rest on sea ice, Greenland

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Many communities already have extensive traditional knowledge about the past and present that can greatly contribute to scientific research about environmental change and to building adaptive capacity in the North. Research that is more inclusive of indigenous youth is also seen as critical, given the growing number of children and youth in northern communities (Parlee and Furgal 2010). The ultimate indicator that northern capacity-building has succeeded would be research projects that are developed, led, coordinated and implemented by indigenous communities themselves. Communities should have within them skilled, educated and experienced people who can develop research agendas to address their own concerns. Examples of such approaches in northern communities exist and require further research and analysis to identify successes.

3.4 Eurasian North

While indigenous peoples of the North have demonstrated remarkable capacity to adapt not only to a variable environment but also to externally driven development in their traditional lands, their resilience now appears to be very much under threat, especially in the Eurasian North. Indigenous societies in this region – the Sámi in Norway, Sweden, Finland and the Murmansk region of Russia, together with the various nations represented by RAIPON, such as the Chukchi, Nenets, Even, Evenk and, to some extent, the Aleut and the Siberian Yupiaq – are in a profound state of shock and crisis. This is evident in their own reflections on their capacity to influence change on their own terms, as in this statement by former Sámi Council President Pauliina Feodoroff, of the Skolt Sámi Nation, Finland, in January 2008:

The first genocide and destruction against the Sámi peoples and our society began in the 1500s and 1600s. Unless there are dramatic changes in the near future, the Sámi culture will die, disappear in my lifetime ... Sámi knowledge is knowledge about how to be with your environment, how to have your relationships with humans and with the world. Therefore the most effective ways to control a people are to destroy the things that reality consists of for that people. In the North this ancient knowledge has been beaten and destroyed for centuries in order that the indigenous peoples would forget this knowledge. If there is nothing else to do, at least we can try to prolong things. To play for more time to survive. We can try to gather indigenous knowledge from the old people who possess it. We can try to create safe havens of ecosystems, which contain our knowledge – the fjells, forests, and lakes which remain in pristine condition. (Mustonen and Mustonen 2011, p.14)

The absence or long-term delay of indigenous rights to the lands, waters and subsistence prevents these societies from being able to respond to on-going processes on their own terms – whether it is the loss of pasturelands or impacts of melting permafrost on their fisheries. This realization, with its various manifestations of social ills and local colonial context, is the root cause of indigenous peoples' shock. Naturally this contextualization has varying elements across Norway, Sweden, Finland and Russia. In Norway, for example, the Sámi have been able to secure resources, dialogues and some rights in relation to the state and multinational companies, but even there, the resilience of the indigenous communities is dependent on the state in various ways. The overall message is profound.

The capacity for self-reflection is a core constituent of the ability to grapple with a new phenomenon and respond – indigenous communities need to be able to contemplate the resources, options and choices they have when facing a given event or process. In traditional times, prior to their land being occupied by outsiders, most of these societies retained their own ways of making choices and governance on land use: e.g., free-ranging nomadic reindeer herding of the Sámi siida (Mustonen and Mustonen 2011), or Chukchi pastoralism (Mustonen 2009). Their own cosmologies and spiritual systems were, for the most part, *intact*. Knowledge was transferred through place names and oral histories, in local dialects that were intimately related with the land. In short, these communities possessed indigenous memory that allowed them to navigate through the various events – sometimes avoiding them, sometimes confronting the phenomena at hand.

Sámi reindeer herding in Finnmark, Norway

© Lawrence Hislop, UNEP/GRID-Arendal

Like all human societies, the indigenous peoples of Eurasia had their faults, but they lived in and through their own times, spaces and places. It is worth noting that change was the key component of their life-worlds, and the resilience portrayed by the people through their own survival is a living testimony of the strength of these societies and the autonomous capacities of their subsistence economies. Most of such community life has ended in the region due to the externally imposed, often violent changes of the past 100-200 years, depending on what part of Eurasia the focus might be. Examples of such resilience-destroying changes include the creation of hydroelectric stations in Finland and Sweden on Sámi communities (Mustonen et al. 2010); mining impacts on reindeer territories in Siberia (Mustonen 2009); oil and gas production in North-Central Siberia (Forbes et al. 2009), and in some cases, forestry operations, if we include the sub-Arctic boreal zone into our assessments. Even though these processes, with the exception of large-scale hydropower development and climate change impacts, do not destroy whole habitats or ecosystems, they have left a "broken whole". They have disrupted the landscape-wide engagement with the tundra and taiga that is the source of the resilience for these societies, and they have wrecked the sacred sites of many indigenous communities.

Contemporary discussions on resilience to the rapid changes throughout the Arctic, such on as climate (ACIA 2005), biodiversity (Arctic Council, forthcoming) or industrial land use and shipping (Arctic Council 2009; Mustonen 2009; Forbes et al. 2009) are taking place in a geospatial vacuum in that indigenous uses of the lands, waters and ice are not visible when the geopolitical plans are made and in that the geopolitics of indigenous peoples are nowhere to be seen. These changes have been identified as the most severe and significant ever in the Arctic; often it is said they are "unprecedented". Yet if we consult the collective memory of indigenous societies in the Eurasian North, a more complex picture emerges. Through their oral histories, many of these nations can still recall times of warming or other significant ecosystem changes from "pre-history" (reflecting the large variability in the Arctic climate), reflect on these communal memories and respond in terms of their land use and subsistence economies. This ability is one of the most important aspects of their resilience. Indigenous memory is also reflected in the local languages and in toponymic place-name knowledge, oral histories and different ways of being with the land. Yet for decades, indigenous memory in its various manifestations has been eroding due to multiple factors, including externally imposed schooling, degradation of community ecosystems and governance, and imposition of global market capitalism. This has left many communities in the Eurasian North on the verge of collapse.

What to do in the contemporary context if we take such messages seriously? We need to thoroughly review the possibilities for building resilience in the indigenous communities. First and foremost, the land uses of contemporary indigenous societies should be guaranteed as much as possible. Subsistence economies, whether they are fisheries, berry-picking, hunting or other systems, function well if they have their seasonal rounds and the necessary territory. By nature they are fragile systems, and therefore, indigenous peoples need the proper territory and reserved land use to cope with rapid ecological changes. In Eurasia one of the most significant remaining subsistence systems is the nomadic reindeer herding of Nenets, Chukchi and Even peoples. One of the herders in the Turvaurgin community from the Lower Kolyma region of Republic of Sakha-Yakutia, Siberia, Russia, described the relationship with the landscape thus:

The tundra is our life. We live there. We are so accustomed to the life in the tundra that we do not know any other kind of life. It is our homeland, place of birth. I cannot explain it; I do not have words for it. I know the tundra is our life. Especially in the summer time. Those who have lived all of their lives in the tundra cannot go to the taiga in the summer. In the summer together with our families we migrate [with the reindeer] to the coast of the Arctic Sea. Into the close proximity of the sea. That is our natural habitat. (Mustonen 2009 p. 221)

Local ice fishermen in a permafrost cave, Siberia, Russia

Other ways of allowing these societies to autonomously build their capacity and continue their specific ways of life should also be explored. This might include, in some areas, solar electrification of nomadic camps, language nests, establishment of nomadic schools, and exploring co-management or creation of territories of traditional land use. Practices will vary. If the communities agree to such a process, an oral history-driven documentation of community experiences would allow them to identify for themselves what factors increase or decrease their resilience in the current context. Such a process would bring forward the indigenous memory of what has happened locally, thus contextualizing the events of today with the larger frame of both people and ecosystems – key components of resilience. As the great Even scholar Vasilii Robbek has said, the unique indigenous societies of the Eurasian North have much to contribute to the cultural heritage and richness of the world. We must act urgently to work with them to ensure their existence is guaranteed even in these demanding times ■

References

ACIA (2005). *Arctic Climate Impact Assessment – Scientific Report*. J. Berner, C. Symon, L. Arris, and O. W. Heal (eds.). Cambridge University Press, Cambridge, UK, and New York. http://www.acia.uaf.edu/pages/scientific.html.

AHDR (2004). *Arctic Human Development Report.* N. Einarsson, J. N. Larsen, A. Nilsson, and O. R. Young (eds.). Prepared by the Stefansson Arctic Institute, under the auspices of the Icelandic Chairmanship of the Arctic Council 2002-2004, Akureyri, Iceland. http://www.svs.is/ahdr/.

Arctic Council (2009). *Arctic Marine Shipping Assessment 2009 Report*. http://www.arctic.gov/publications/AMSA.html.

Arctic Council (forthcoming). *Arctic Biodiversity Assessment*. Conservation of Arctic Flora and Fauna (CAFF) International Secretariat, Akureyri, Iceland. http://www.arcticbiodiversity.is/.

Berkes, F., Colding, J. and Folke, C. (2000). Rediscovery of traditional ecological knowledge as adaptive management. *Ecological Applications*, 10(5). 1251–62. DOI:10.1890/1051-0761(2000)010[1251:ROTEKA]2.0.CO;2.

Caulfield, R. A. (2004). Resource governance. *Arctic Human Development Report*. Stefansson Arctic Institute, Akureyri, Iceland. 121–38. http://www.svs.is/ahdr/.

Forbes, B. C., Stammler, F., Kumpula, T., Meschtyb, N., Pajunen, A. and Kaarlejärvi, E. (2009). High resilience in the Yamal-Nenets social–ecological system, West Siberian Arctic, Russia. *Proceedings of the National Academy of Sciences*, 106(52). 22041–48. DOI:10.1073/pnas.0908286106.

Hovelsrud, G. K. and Smit, B., eds. (2010). *Community Adaptation and Vulnerability in Arctic Regions*. Springer, Dortrecht. http://www.springer.com/environment/global+change+-+climate+change/book/978-90-481-9173-4.

Huntington, H. and Fox, S. (2005). The Changing Arctic: Indigenous perspectives. *Arctic Climate Impact Assessment – Scientific Report*. J. Berner, C. Symon, L. Arris, and O. W. Heal (eds.). Cambridge University Press, Cambridge, UK, and New York. 61–98. http://www.acia.uaf.edu/PDFs/ACIA_Science_Chapters_Final/ACIA_Ch03_Final.pdf.

Johnson, M. C. (1992). *Lore: Capturing Traditional Environmental Knowledge*. Dene Cultural Institute and International Development Research Centre, Ottawa, Canada.

Krupnik, I., Allison, I., Bell, R., Cutler, P., Hik, D., et al., eds. (2011). *Understanding Earth's Polar Challenges: International Polar Year 2007-2008: Summary*. CCIP occasional publications series. CCI Press, Edmonton. http://www.icsu.org/publications/reports-and-reviews/ipy-summary.

Krupnik, I. and Jolly, D., eds. (2002). *The Earth Is Faster Now: Indigenous Observations of Artic Environmental Change*. Arctic Research Consortium of the United States, Fairbanks, AK, US. http://www.arcus.org/publications/EIFN/.

Mustonen, K., Mustonen, T., Aikio, A. and Aikio, P. (2010). Drowning Reindeer, *Drowning Homes: Indigenous Sámi and Hydroelectricity Development in Sompio, Finland. Snowchange*.

Mustonen, T. (2009). *Karhun väen ajast-aikojen avartuva avara: tutkimus kolmen euraasialaisen luontaistalousyhteisön paikallisesta tiedosta pohjoisen ilmastonmuutoksen kehyksessä*. Joensuun yliopisto.

Mustonen, T. and Mustonen, K. (2011). *Eastern Sámi Atlas*. Snowchange, [Lehtoi].

Mustonen, T., Mustonen, K. and People of Unalakleet (2009). *It Has Been in Our Blood for Years and Years That We Are Salmon Fishermen – A Book of Oral History from Unalakleet, Alaska, USA*. Snowchange, Lehtoi.

Parlee, B. and Furgal, C. (2010). *Communities and Caribou Workshop – March 3-4, 2010: Summary Report from the Arctic Peoples, Culture Resilience and Caribou Project*. 1-1. Arctic Athabaskan Council and University of Alberta, Edmonton, Alberta, Canada.

Sources for figures

Figure 3.1 Based on AHDR (2004) and Map from Norwegian Polar Institute, provided by Winfried Dallmann (private communication, 2005).

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Part II

Summary

The Arctic plays a crucial role in global system dynamics. It is already displaying rapid physical changes in response to global warming that involve positive reinforcing feedbacks. There is evidence of temperature-induced threshold changes in northern hemisphere climate patterns, the planetary albedo, and marine ecosystems. The Arctic's seas and coastal zones are changing rapidly and projected to experience greater physical disturbance through sea-level rise, storminess, and permafrost degradation. There is also widespread evidence of local changes in terrestrial ecosystems across the Arctic region, triggered by both human and biophysical drivers of change. Many of these changes, especially in hydrological systems, are rapid and irreversible.

At the same time, social systems are undergoing major reconfigurations, linked in complex ways to events across and beyond Arctic territories. Pan-Arctic demand is escalating for shipping, oil and gas, renewable energy and other resources, leading to extensive infrastructure development and changing settlement patterns on the coasts and across the region. Rapid changes are also evident in social, economic, political and cultural trends. Some are deliberate transformations of the status quo, while others reflect the efforts of Arctic societies to cope with and adapt to the changing drivers and new combinations of pressures.

While many of these biophysical and social changes are well documented, it remains a major challenge to understand how they interact, escalate, and trigger changes across time and spatial scales. These interactions and cascades of effects are characteristic of disruptive change (shocks and collapses), but are also critical features of adaptation and desirable transformations. A better understanding of the dynamics of linked social and ecological systems can strengthen society's resilience to abrupt, extreme and sometimes irreversible threshold changes. Applying resilience approaches to the regional (and in some instances global) scale requires new integrative concepts and new approaches to transdisciplinary dialogue. This chapter describes how thresholds are identified and understood differently in different contexts, and sets out a typology of thresholds that can help bridge these multiple understandings. It identifies drivers of linked social-ecological change, informing the in-depth analyses of Phase 2 of the ARR. It emphasises the need to explicitly address issues of choice, agency and learning, again informing the ARR's mode of working in Phase 2.

Chapter 4

Thresholds in the Arctic

Chapter 4

Thresholds in the Arctic

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4.1 Introduction

The recent rapid changes in the Arctic's physical, climatic, ecological, social, economic, and geopolitical environments have been widely documented (see Box 4.1). Not only do certain changes have no precedent that can inform projections and planning, they are also acting in conjunction with each other, which has prompted experts in many fields to express concern (e.g., U.S. National Intelligence Council 2008; Emmerson and Lahn 2012). Such interactions increase the risk of shocks and surprises in social-ecological systems and create a very complex policy context. The multiple converging pressures on the Arctic region could exceed social and ecological capacities for adaptation, raising the prospect of system-wide collapses. The effects of the interacting social and environmental processes of change have a strong bearing on future living conditions in the Arctic, as well as the role of the region in a global context. Improved ways to identify, understand and respond to these complex interactions will be an important feature of effective adaptation.

Box 4.1 **Key recent assessments and reports on changes in the Arctic**

Physical environment, climate and ecosystems:

2004. Arctic Climate Impact Assessment (ACIA). *www.amap.no/acia/index.html*

2006, and annually since. Annual Arctic Report Cards. *www.arctic.noaa.gov/reportcard*

2006. AMAP Assessment on Acidifying Pollutants, Arctic Haze and Acidification. *http://amap.no/documents/index.cfm* (This is also the link for the AMAP assessments listed below.)

2007. Intergovernmental Panel on Climate Change (IPCC). The physical science of Arctic change is addressed in Working Group I by Lemke et al. (2007). *www.ipcc.ch/publications_and_data/ar4/wg1/en/ch4.html.* Impacts, adaptation and vulnerability are reviewed in Working Group II by Anisimov et al. (2007). *www.ipcc.ch/publications_and_data/ar4/wg2/en/ch15.html.* (The Fifth Assessment Report is due to be published in 2013.)

2010. CAFF Arctic Biodiversity Trends – Selected Indicators of Change.

2010. Conservation of Arctic Flora and Fauna Report on Arctic Biodiversity Trends. *www.arcticbiodiversity.is/index.php/en/the-report*

2011. AMAP Snow, Water, Ice and Permafrost in the Arctic (SWIPA). *http://amap.no/swipa*

2012. WWF Rapid Assessment of Circum-Arctic Ecosystem Resilience (RACER), by Christie and Sommerkorn (2012). *http://wwf.panda.org/what_we_do/where_we_work/arctic/what_we_do/climate/racer*

2012. IPCC Special Report on Managing the Risks of Extreme Events. *http://ipcc-wg2.gov/SREX/report*

Social, economic and geopolitical context:

2004. Arctic Human Development Report. (AHDR II is due for publication in 2014.) *http://hdr.undp.org/en/reports/regionalreports/other/name,3262,en.html*

2008. USA National Intelligence Council Global Trends 2025. *www.dni.gov/files/documents/Newsroom/Reports%20and%20Pubs/2025_Global_Trends_Final_Report.pdf*

2009. AMAP Assessment on Human Health in the Arctic. *www.amap.no/assessment/scientificbackground.htm*

2012. Chatham House-Lloyd's Risk Insight Report. Arctic Opening: Opportunity and Risk in the High North. *www.chathamhouse.org/publications/papers/view/182839*

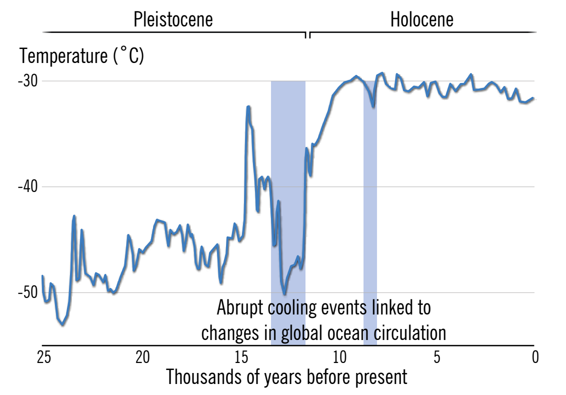
This chapter focuses on the emerging body of evidence about thresholds in the Arctic. The chapter is not intended as another comprehensive review of processes of Arctic change, but rather it aims to identify where current drivers of change have caused or could trigger abrupt, extreme or effectively irreversible transformations. It seeks to bring together several different strands of argument and evidence to better describe thresholds in Arctic social-ecological systems at various scales. Such an approach can help to build understanding of the current risks to the Arctic system, thus supporting decision-making for sustainable outcomes in the region. The analysis in this interim report provides a foundation for efforts to meet the first goal of the ARR ("Identify the potential for shocks and large shifts in ecosystems services that affect human well-being in the Arctic"). Therefore this chapter reviews the evidence base in the social and biophysical sciences, and addresses the conceptual challenges of integrating different understandings of systemic change, in order that the project will ultimately be equipped to:

- Provide a multidisciplinary synthesis of the scientific evidence relating to thresholds in or affecting the Arctic
- Map the key links and feedbacks between the social and the biophysical "sub-systems" in the Arctic, and
- Identify areas where Arctic ecosystem services are at risk from very rapid change.

4.2 Developing theoretical backgrounds for the ARR thresholds analysis

The ARR's analysis of thresholds needs to address many different kinds of process, affecting different kinds of systems, and operating over multiple scales. For example, the recent warming of the Arctic region is pushing temperatures to the upper limits of the range seen during the relative climatic stability of at least the past 5000 years of the Holocene period (Figure 4.1), inducing changes in Arctic ecosystems as well as the human societies that depend on them. Ongoing and accelerating change driven by temperature rise is expected in all Arctic terrestrial, freshwater and marine ecosystems, unless global society transforms rapidly to reduce its emissions of greenhouse gases. These ecosystems are also experiencing the direct effects of increasingly intensified human activity in the region. At the same time, societies in the Arctic and around the world are responding to shifts that are already under way, and also transforming long-standing behaviour in the light of anticipated future change. These social and ecological responses have a wide range of consequences: they can contribute to accelerated transformation (Olsson et al. 2006, Rosa and Scheuerman 2009), or result in "lock-in" situations where communities find themselves trapped in unsustainable situations and vulnerable to external shocks (Carpenter and Brock 2008). The term "threshold" is a shorthand term that is applicable to many different dynamic processes in the biophysical and social domains, including changes in state or regime, changes in rate, and changes in the interactions within a system. A thresholds analysis requires these different meanings to be unpacked. The approach of Moss and Schneider (2000) has informed how thresholds are identified in this report. They proposed that evaluating the state of knowledge involves agreement between theoretical foundations, models and observations, and expert consensus. The ARR is also informed by the IPCC's approach to describing anthropogenic changes in the context of natural variability (Hegerl et al. 2010).

Figure 4.1 The relative climatic stability of the Holocene



4.2.1 Characterizing biophysical thresholds

Whether the focus is on changes in the state of the whole planet (the normal domain of Earth system science) or of specific ecosystems (ecology and resilience science), attempts to characterize biophysical thresholds presuppose that dynamic processes that undergo abrupt or irreversible changes are observed and quantified, at least in relative terms. This has implications for the ARR: observational data are very sparse for many biophysical processes, so it is likely that even important thresholds will never be seen directly. However, at the same time, available observations may give indirect indications of regime shifts (see Box 4.2), raising the question of how these different strands of evidence can be combined into a robust and rigorous characterization of thresholds.

An understanding of Earth's physical dynamics has underpinned the identification of many past and potential thresholds at large regional scales, such as the Arctic (Wassmann and Lenton 2012; Duarte, Agustí, et al. 2012; Duarte, Lenton, et al. 2012). At the global scale, Rial et al. (2004) provide a number of illustrative examples of threshold changes in the physical climate system. These include the multi-millennial shifts from ice ages to warmer interglacial periods and back, episodes of abrupt warming, such as the Dansgaard-Oeschger events in the last glacial period, and the irregular patterns of the El Niño Southern Oscillation. These climatic thresholds highlight a range of biophysical mechanisms (often positively reinforcing) and biogeochemical mechanisms (often balancing) that give rise to nonlinear behaviour and system instabilities. Although the importance of feedback mechanisms in causing thresholds is known, Earth system modellers are still developing effective ways of describing and comparing the strength of such mechanisms. The engineering concept of "gain" has been adopted for physical feedbacks, such as the albedo effect and the water vapour effect (Hansen et al. 1984). These physical processes affect the sensitivity of Earth's climatic response to rising concentrations of greenhouse gases, and can be bundled under the common heading of radiative forcing. However, the many different kinds of feedback that involve biophysical and biogeochemical interactions (e.g., between vegetation and the atmosphere, or between the carbon cycle, nutrient cycles and climate) affect things other than radiative forcing and temperature. Representing these feedbacks mathematically and comparing different kinds of feedback with each other is still a problem for researchers who seek to describe and predict changes in the coupled physical, chemical and biological components of the Earth system (Gregory et al. 2009), especially when downscaling to regional impacts (Brands et al. forthcoming; Pielke and Wilby 2012).

The role of global biophysical thresholds has recently come under the spotlight (e.g., Rockström et al. 2009; Barnosky et al. 2012; Running 2012), but the exact qualities of thresholds in ecological functioning at the global level are not as well specified as for thresholds in the physical climate system. To date, ecological thresholds have been much more widely observed and documented at the local scale, as this chapter describes in Section 4.3.2. Rietkerk et al. (2011) discuss how changes to ecosystems at smaller scales can have larger-scale impacts on the climate system, and call for a stronger empirical and evidence base and better modelling to understand the feedbacks and amplifications that are involved. Box 4.2 briefly describes a collaborative initiative to build such an evidence base for social-ecological system changes.

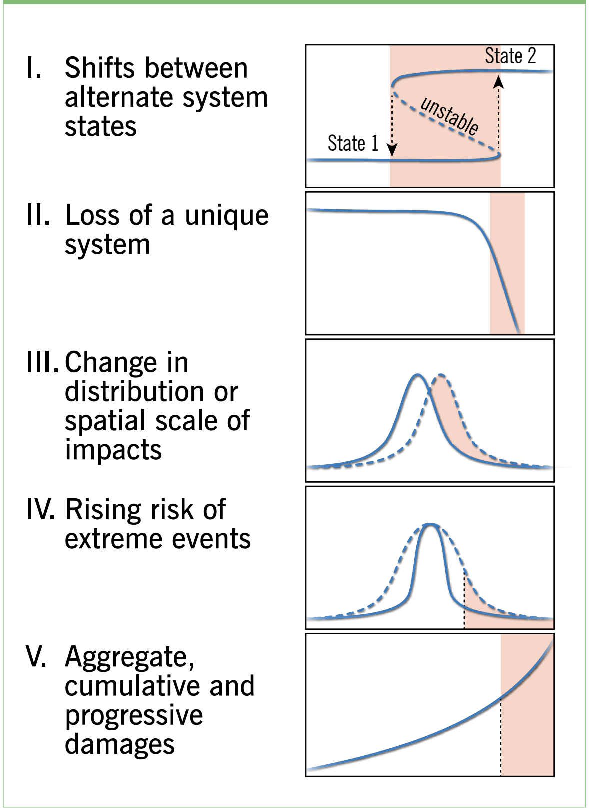
Box 4.2 **The Regime Shifts Database**

One important and promising approach to understanding thresholds across a wide range of scales is the Regime Shifts Database *(www regimeshifts.org)*, which is currently being constructed as an international collaborative initiative led by the Stockholm Resilience Centre (Rocha et al. 2012). The initiative aims to improve the evidence base for ecosystem thresholds and transformations, and increasingly also those of social-ecological systems. The initiative invites researchers who have documented different types of large-scale and persistent change in ecosystem services of social-ecological systems to review and synthesise their findings to collectively build a descriptive, open-source information resource on regime shifts. The resulting empirical data set will provide better temporal and spatial resolution that can both inform and be tested with integrative tools and quantitative models. This chapter will describe in more detail Arctic-relevant examples of regime shifts documented in the database.

Some work is under way to improve the classification and characterization of thresholds, drawing on models of system behaviour and empirical observations of system change (see Figure 4.2). Classic bifurcations and regime shifts are evident in physical, ecological, and some socio-economic systems, and they can be explored mathematically using nonlinear dynamical systems analysis (e.g., Scheffer and Carpenter 2003a). Sprinz and Churkina (1999) distinguish time-dependent and time-independent processes. In the case of time-independent processes (such as bifurcations, oscillations and instabilities) thresholds may be identified from the mathematical properties of the system's response to the driver (a "dose-response function" approach). However, Scheffer and Carpenter (2003b) point out two key difficulties associated with these kinds of analysis of environmental and social-ecological systems: first, real-world complex systems do not exist in stable steady states, but instead as dynamic regimes, so they are difficult to represent in simple models; and second, such systems are influenced by multiple causal processes, some of which are challenging to identify empirically as drivers at all. For time-dependent processes, identifying thresholds requires applying statistical methods to time-series data. Carstensen and Weydmann (2012) describe how such statistical properties can be used to define different kinds of threshold behaviour, using Arctic sea-ice changes as their proof-of-concept. In addition to thresholds characterised by regime shifts, or the changes in the behaviour, trends, rates and variability of a complex system over time, Dearing et al. (2012) characterize convergent trajectories as a different kind of threshold. Thresholds of this type are arguably particularly important in relation to social-ecological systems because they can be easier to characterize, even if individual trends are not quantified in high resolution. The analysis by Dearing et al., which relates to long-term changes in ecosystem services in China, can be interpreted as an assessment of a "risk spectrum" for threshold changes, in which a large number of environmental demands exceed the system's capacity for supply and regeneration, and where processes are interdependent and risks of abrupt (and undesirable) changes are higher.

At the same time, some question the rationale for mathematizing thresholds at all, highlighting the limitations of model-based quantitative prediction (or otherwise) for complex systems (e.g.,Ostrom 2007). Meanwhile, models allow for experimentation and exploration of complex systems in a way that is much more forgiving than full-scale experiments, and sometimes modelling is the only possible way to investigate a system's behaviour. Yet models are always a simplified representation of reality. As such, they may miss substantial features of the system (e.g., confounding factors and stochasticity). Therefore, particular care is required when using model outputs to inform real-world decisions, especially when attempting to predict change in social-ecological systems.

Figure 4.2 **A typology of threshold behaviours**



4.2.2 Characterizing thresholds in social systems

The idea of thresholds in social systems is more complex than it is in physical systems, with the result that social thresholds have not been given the same degree of scholarly attention as physical ones (Hatt 2012). Furthermore, different social sciences use the notion of thresholds in different ways. Thus, a challenge for the ARR is to investigate how far different aspects of social change can usefully be framed as thresholds, and as drivers of transformation in social-ecological systems.

One context in which thresholds are recognized is in efforts to find causal explanations for historical development, specifically in terms of the role of path dependence. Walker and Meyers (2004) argue that social-ecological system thresholds are not fixed points between steady states, and point out that the consequences of reaching and crossing a threshold are context dependent. The literature on path dependence highlights systemic phenomena such as increasing returns, self-reinforcement, positive feedbacks, and lock-in (Page 2006). A related concept is that of the "critical juncture"; a brief period in history where a direction is taken that is different from the previous regime (Collier and Collier 1991). For example, the creation of a new institution can thus be seen as a threshold in the social system, because its norms are likely to guide future behaviour. In the Arctic context, an example of this would be when the current political cooperation in the Arctic was first negotiated in the late 1980s to early 1990s (Young 1998). Another version of the same phenomenon would be the enactment of new laws or international agreements, especially if these introduced strong sanctions against certain behaviours that were common before the sanctions were put in place.

In sociology, concepts and theories of thresholds have been used to explain particular forms of social behaviour, social networks, social change, risk, and the success or failure of the diffusion of innovation (e.g., Granovetter 1978; Paterson 1950; Kadushin 2012; Valente 1996). For example, Granovetter's threshold model of collective behaviour postulates that the likelihood that an individual will engage in a given behaviour is based on the number of people in a social system already engaged in that behaviour, and that individuals have varying thresholds. According to this model, the adoption of collective behaviour is thus a function of the behaviour of others in the group or in the system. In the model, "adoption thresholds" arise where the collective behaviour accelerates and becomes irreversible (Nuttall 2012). However, one critique of notions of adoption thresholds is that it is not realistic: individuals are not always accurately monitoring the behaviour of everyone else in the system. The model also seems to privilege social structure over the capacity of people to make individual choices, whereas individual agency may override collective behaviour in driving change. Valente (1996) argues that individuals prefer to learn about an innovation from others before they adopt new kinds of behaviour, because innovations are fraught with uncertainty and risk. He emphasizes the importance of communication networks for understanding how people evaluate, assess and determine the effectiveness of innovation.

A reindeer in Svalbard grazes on icy ground

Thresholds may also be understood as the limits of socially acceptable change, and as triggers (either negative or positive) for social change and development. There have been some efforts to identify economic-political thresholds associated with the rising costs of adaptation, relative to the limited capacity or willingness of government to carry the costs (Huntington et al. 2012). However, there is also a well-articulated critique of the very concept of limits to adaptation (Adger et al. 2009) and the notion that society is reaching a "tipping point" (Nuttall 2012). Some identify thresholds in the cumulative social impacts of natural resource development (Christensen and Krogman 2012). In the economics literature, thresholds can be represented as a resource collapse (e.g., Reed and Heras 1992), a jump in one or several state variables (e.g., Nævdal 2001; 2003; 2006) or an internal change in system dynamics (e.g., Brock and Starrett 2003; Crépin 2003; 2007; Mäler et al. 2003). Ecosystem thresholds that result from cumulative impacts of resource use represent a relatively new focus for economics research. In these contexts, different kinds of thresholds, and the capacity of resource managers to pre-empt and respond to threats of resource collapse (whether driven by internal or external factors) motivate very different policy actions, involving different degrees of precaution and of resource use intensity (Reed and Heras 1992; Polasky et al. 2011). While an ecological threshold is the point at which an ecosystem tips from one regime to another, what may be more relevant for a social-ecological system is the point at which a society or an individual is indifferent to being in one regime or another. Such a point is often called a Skiba point, or, in a more general terminology, an indifference threshold (Skiba 1978; Grass et al. 2008). Ecological thresholds and indifference thresholds may occasionally coincide – but often they do not, because society may actively want to push the social-ecological system into an alternative regime, either to recover from a previous unwanted ecosystem regime shift or to actively transform society into a "better" regime (Crépin et al. 2012).

This leads to a core area of debate about social systems, which centres on the perspective that social systems involve human agency. Critiques of the notion that society is reaching a "tipping point" (e.g., Adger et al. 2009; Nuttall 2012; Hatt 2012) have two major dimensions. One concerns the fact that there is an ethical dimension to identifying thresholds. Adger et al. (2009) criticize the notion of limits to adaptation because it assumes that there are absolute limits; conversely, they argue that what society finds acceptable (i.e., a society's limits) involves a collective decision based on values. From this viewpoint, in order to identify social thresholds it would first be necessary to identify the important values that need protection, and to implement deliberative processes for doing so. However, values become increasingly diverse and sometimes contradictory when moving from small-scale single-agent systems to larger scales with multiple agents. This reality presents obvious challenges for the ARR analysis – a responsibility that the project participants are aware of and actively seek to address. The second major critique highlights the lack of attention to human agency itself, and argues that the focus on thresholds or "tipping points" involves a risk of returning to an environmental determinism that over-simplifies our understanding of social-ecological relations (Nuttall 2012; Hatt 2012). By understanding how anticipation is inherent in everyday life and implicit in social relations and cultural practices, and how aspects of those relations and practices can emerge from anticipation, we may better understand successful local strategies of adaptation and the nature of resilience (Nuttall 2010). Therefore the ARR's discussions of thresholds in social systems have to include attention to the human capacity to anticipate the future, or different futures, and to act on this anticipation in ways that favour preferred outcomes.

Thus, an understanding of social thresholds and transformations also requires an understanding of the social capacity for adaptation. This topic is discussed in detail in Chapter 5, but it is briefly introduced here, to provide context for the following discussions about thresholds in and affecting the Arctic.

Resilience and vulnerability – both social and ecological – are crucial to sustainable communities, livelihoods, and resource use. Furthermore, analysis of the social aspects of these concepts helps to explain why societal adaptation strategies meet with varying degrees of success when anticipating and responding to environmental change (i.e., being proactive and reactive). The notion of social resilience has been used as a way to understand the capacity of a household, community or larger society to "absorb" and adapt to processes such as global climate change (e.g., Adger and Kelly 1999; Berkes and Jolly 2001) and natural resource development (e.g., Adger 2000; Varghese et al. 2006) that influence human-environment relations and affect the wellbeing of societies. At the same time, especially for those for whom unequal property and power relations are at the heart of social (and ecological) problems, the use of the concept of resilience can be troublesome, in that it avoids issues of inequality by blaming social ills on abstract system properties (Watts 2011; Hatt 2012). Researchers have also focused on concepts of resilience, vulnerability and adaptation as ways to understand the social bases of disasters, arguing that it is important to include cultural, social, and physical dimensions in any analysis of disaster (Gaillard 2007; Oliver-Smith 1996). Human-environment mutuality, a term employed by Oliver-Smith (2002) to describe how a dynamic social system interacts with a dynamic natural system, resonates with how the ARR frames thresholds and feedbacks in social-ecological systems.

Vulnerability is basically an antonym of resilience. Füssel (2007) points out that vulnerability has been variously defined, but there appears to be a consensus in the social sciences that vulnerability is primarily a social characteristic rather than a physical one (Eakin and Luers 2006). Vulnerability relates to the present and future capability of a social group to withstand a socio-physical stress. This capability will be determined by a variety of influences and practices (social, cultural, political, and economic); the environmental, governance and institutional contexts; perceptions of risk; and also the severity, nature and duration of exposure to the stress or shock of system change. For example, Adger and Kelly (1999) discuss both the availability of resources and the extent to which individuals and groups are entitled to those resources as factors that can influence a society's vulnerability to climate change. The governance of vulnerability, and in particular how socio-cultural inequality, poverty and powerlessness increase vulnerability, have also been seen as critical issues for the resilience of social-ecological systems (e.g., Green 2009; Lazrus 2009). Smithers and Smit (1997) propose a framework for understanding the extent and intensity of the social impact of climatic disturbances. While the nature of the disturbance (i.e., its magnitude, spatial extent, frequency, duration, and suddenness) influences the impact, and thus needs to be taken into account, Smithers and Smit assert that the way a social system reacts and responds to climate change depends on its stability, resilience, vulnerability, flexibility, and scale. They argue that systems of human activity are vulnerable to failure or collapse when people are incapable of perceiving or are unable to cope with the negative impacts of climate change at the appropriate scale and pace. Hassan (2009) further emphasizes that the social, cultural and economic effects of climate change depend on the scale of societies, the extent to which they are able to deal with severe climatic events without significant or irreversible societal changes, and the capacity to take timely remedial action to sustain viable livelihoods and communities. In many cases, Hassan argues, a response to climate change in one location can affect adjacent populations; furthermore, responses to climate change within one part of a society can lead to social changes that may bring about significant shifts in other parts of a society, and even result in a social and cultural transition.

A vulnerability perspective is not necessarily concerned with understanding the outcomes of past responses to change, disruption and disturbance, but instead focuses attention on the potential for future preparedness and responses to change. Discussion of social thresholds thus needs to be oriented to the future; to a consideration of whether and how societies – and social systems inherent in those societies – conceptualize, approach and think about life beyond thresholds, how they enact socio-ecological futures, how people anticipate change, and how they imagine themselves in the future (Nuttall 2010; 2012). Although research on social-ecological systems still requires empirical data on typologies of thresholds (Christensen and Krogman 2012; Walker and Meyers 2004), it may yet be possible to predict future regime shifts that indicate opportunities for and limits to adaptability (Parlee et al. 2012). However, as Walker and Meyers (2004) point out, it remains more difficult to identify thresholds that might occur in the future than to identify those that have already been crossed.

4.2.3 Addressing drivers and mechanisms of Arctic change

A key aim of the ARR is to identify thresholds and the potential for shocks where changes in ecosystem services affect human wellbeing in the Arctic. It therefore prioritizes analysis of how different drivers of change interact in both the social and ecological domains. And, at the day-to-day level, these interactions are easy to understand intuitively. However, going beyond anecdotal or even speculative description of thresholds towards a use-oriented analysis requires new approaches for systematically describing cascades of events, as well as the "to-and-fro" exchanges between social and environmental drivers of change.

To understand thresholds, it is important to understand the driving processes that generate threshold events. In complex social-ecological systems, both social and biophysical drivers can bring about change. And in the Arctic, both these kinds of drivers actually take in multiple social, spatial and temporal scales (see Figures 4.3 and 4.4). Of course, these drivers may also interact with each other and across all these scales. In the process of scoping the ARR, Nilsson and Olsson (2011) identified various systems or processes that incorporate both social and biophysical drivers, some of which are explored more comprehensively as the case studies in Part 4 of the ARR. These processes and systems include:

- adaptation to climate change, including responding to new opportunities created by climate change
- the opening of Arctic shipping routes as sea-ice retreats
- changes in economies and distribution of wealth due to ecosystem change (e.g., shifts in marine food webs affecting commercial fisheries)
- increasing external financial investment in and control of the Arctic region
- migration towards the north driven by demand for land elsewhere
- increased tourism
- surprises linked to the opening up of the region to increased trade and mobility, such as epidemics of infectious disease or invasion of nuisance species, and
- infrastructure development (e.g., dams), and oil and mineral exploration.

As well as identifying drivers of change, we have sought to address the *mechanisms* of change in ways that enable more tractable descriptions of the complexity of Arctic change. Senge 1999; Petschel-Held et al. 1999; Lüdeke et al. 2004 describe how complex social-environmental systems often display fairly coherent patterns of behaviour, resulting in a typical and widely recognizable set of problems. They suggest that "archetypes" or "syndromes" can be identified from recurrent patterns of drivers and mechanisms of change. These patterns may determine the nature of potential thresholds, and also point towards effective interventions or leverage points for society's responses. For the ARR, this approach is promising, but the analysis is still preliminary. Despite the growing body of evidence of social and environmental changes in the Arctic (see Table 4.1), there is comparatively little information about how these changes interact. Nevertheless, a few kinds of mechanism are evident in Arctic social-ecological systems. These mechanisms include *positive feedbacks* (or runaway processes); "*lock-in*" *situations*, where the force of change builds up over time against a fixed capacity or resistance, resulting in an increasing vulnerability to crisis; the challenges of *multiple converging trends*, which in combination change the spectrum of risks to which social-ecological systems are adapted; and also the possibility that information flows between the external driver and a given system involve *too-weak feedbacks*, resulting in potential disconnections or mismatches in systems of governance or control, which can also result in critical vulnerabilities.

Figure 4.3 **Some social drivers of Arctic environmental change**

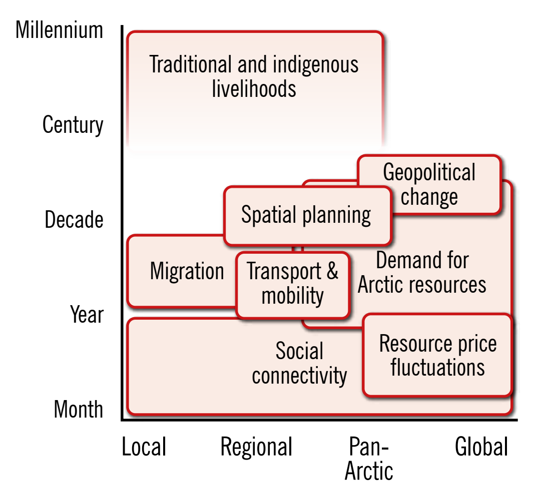


Figure 4.4 **Some biophysical drivers of social change**

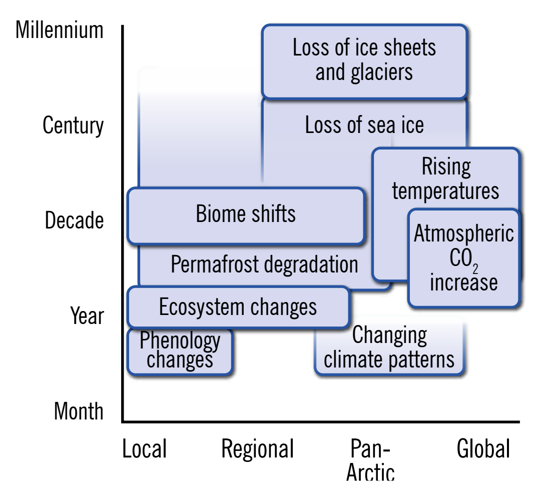


Table 4.1 summarizes the main drivers of Arctic change. It provides information on the nature and the scale of trends, and, where possible, it also includes information on the mechanism of change.

Table 4.1 Summary of the drivers of Arctic change

Driver	Observed change in the Arctic	Why it matters – prospective thresholds	Literature examples
Warming climate	Loss of sea-ice	Reduced albedo – strong physical feedback on Earth's climate Open seas allow increased Arctic sea-transport, perhaps also increased fossil-fuel extraction – strong social-ecological feedbacks	Meier et al., chapter 9 in AMAP (2011)
	Reduced snow cover, loss of lake and river ice	Reduced albedo (strong physical feedback) Impacts on regional water availability: e.g.,for drinking water; water available for vegetation; water for power plants – potential for loss of resilience through governance scale disconnects	Callaghan et al. (2011a) Callaghan et al. (2011b) Callaghan et al., chapter 4 in AMAP (2011) Vincent et al. (2012) Prowse et al. (2011)
	Permafrost degradation	Changing water cycling (lake formation in some areas, drainage elsewhere) and water quality – local ecosystem regime shifts Topographic changes, with effects on ecosystems, affecting species distributions and interactions – local ecosystem regime shifts Disruption of human infrastructure (roads, utilities, etc.) increasing social vulnerability	Callaghan et al., chapter 5 in AMAP (2011) U.S. Arctic Research Commission (2003) Vincent et al. (2012)
	Altered strengths of biogenic greenhouse gases (e.g., methane)	Moderate feedback on Earth's climate	Isaksen (2011) Anthony et al. (2012)
	Warmer seas, increased melt of glaciers and ice sheets	Sea-level rise and coastal erosion – changed local risk spectrum; some global climate feedback	Sharp et al., Chapter 7 in AMAP (2011) Dahl Jensen et al., Chapter 8 in AMAP (2011)
	Change in carbon sinks and sources	Climate/carbon cycle feedback	Le Quéré (2009; 2012)
	Biome shifts – shrubbification, tree-line advance	Some albedo impacts Ecosystem regime shift Potential "lock-in", ecosystem crisis – e.g., regions too warm for conifer reproduction (temperature constraint) but growing season too short for deciduous vegetation (light constraint)	Myers-Smith et al. (2011) Sexton et al. (2009)
	Species shifts	Range contraction, extinction, arrival of invasive species from the south, shifts from specialist to generalist taxa, loss of global biodiversity	Grebmeier et al. (2006)
	Phenology changes – potential effects on ecosystem assemblages and inter-species synchronies	Ecosystem regime shifts	E.g., Høye et al. (2007) Post et al. (2009)
Rising anthropogenic CO_2 (greenhouse gas) concentration	Ocean acidification Changes in carbon sinks and sources	Possible ecosystem regime shift	Yamamoto-Kawai et al. (2009) Brown and Arrigo (2012)
Climate disturbance (e.g., NAO/AO)	Changes in hydrological regime and local climate Altered wave action and storminess	Regional climate/water cycle feedback Potential ecosystem shifts Changed regional risk spectrum for coastal communities	Corell and Cleveland (2010) Kattsov et al., Section 4.4 in ACIA (2005) Kolstad and Bracegirdle (2008) IPCC SREX (2012)

Table 4.1 **Summary of the drivers of Arctic change**

Driver	Observed change in the Arctic	Why it matters – prospective thresholds	Literature examples
Demands on land/ shelf resources (e.g., oil, minerals)	Direct land use (e.g., mining impacts); indirect effects of industrial infrastructure (e.g., impacts on landscape, species mobility) Global trade raises resource prices	Regional social-ecological transformation and regime shifts Increased fossil-fuel extraction leads to a human system/climate feedback	Lange (2003) (BASIS) ArcticNet (2010) (Canada coastal IRIS studies)
Demand for marine/aquatic resources (e.g., fisheries)	Change in marine/aquatic biomass spectrum Change in distribution of economic wealth and activity Global trade raises resource price	"Lock in" effect with potential resource collapse High increases in resource prices; profitability of resource extraction in the Arctic – positive feedback	Lange (2003) (BASIS) ArcticNet (2010) (Canada coastal IRIS studies)
Transport and mobility	New opportunities – tourism, trade Opening of trans-polar and regional shipping routes – new impacts (e.g., from pollution, infrastructure) New land routes (e.g., roads from the south to Nunavik) Losses of traditional routes for hunting and fishing, loss of river ice roads	"Lock in" situations in both social and ecological contexts Positive climate feedback Positive feedback in rapid cultural and socio-economic change Multiple converging trends in biophysical change New risks: e.g., greatly increased probability of species invasions	Lemelin et al. (2010) Corbett et al. (2010) Stephenson et al. (2011) Kumpula et al. (2011) Campbell and Bergeron (2012)
Migration (in and out of the Arctic)	Urbanization and connectivity	New local-global connections for communities Risks of social fragmentation and loss of social capital and collective knowledge	Rasmussen (2011)
Geopolitical change	Militarization; changes in cooperation and investment opportunities; financial investment and shifting control of region's resources	Positive feedback to environmental transformations Social regime shifts	Young (2012) Johnson (2010)
New and projected economic opportunities	Meeting increased demand for natural resources in other regions Changes in region's sectoral and spatial planning Institutional change, including changed property rights and connections to outside world	Feedbacks to region's geopolitical processes Risks of loss of collective knowledge and of traditional governance approaches tailored to context	Parente et al. (2012) Hovelsrud et al. (2011)
Globalization and social connectivity	Altered markets for Arctic goods and services	"Adoption thresholds", spreading of different environmental ideologies	Lemelin et al. (2010)
	Communication technologies transforming information flows and increasing educational flexibility	Boosts to wellbeing (e.g., economy, education, telemedicine) but also potential societal shifts; "winners and losers" in access to new technology	Beck et al. (2005) Warf (2011)

4.3 Biophysical thresholds in the Arctic

The comparative sparseness of observational data from the Arctic, as well as the lack of long time-series evidence, mean that it is challenging to identify many thresholds that are likely to be present in the biophysical system. However, even with these observational constraints, it is already very clear that the Arctic region is currently undergoing rapid transitions, both local and large-scale, as a result of global social and environmental change. Box 4.3 outlines some issues relating to the detection and attribution of change and threshold behaviour in the Arctic.

Box 4.3 **Observation and detection of Arctic system biophysical change**

Climate change is occurring more rapidly in the Arctic than anywhere else on the globe (ACIA 2005, IPCC 2007; AMAP 2011), causing a cascade of physical and ecological changes (Figure 4.5a), many of which are closely coupled processes. These drivers of change include:

Physical change (i.e., the climate system): warming; sea-ice loss; ocean acidification; sea-level rise; wave action/storminess; permafrost degradation; large changes in the hydrological regime and local microclimate; coastal erosion; topographic changes.

Ecosystem change: feedbacks due to warming and increasing CO_2 levels (coupled climate/carbon cycle); changing sinks and sources of greenhouse gases (CO_2, CH_4); changing water cycling (wetlands formation in places, drainage elsewhere) with effects on phenology and ecosystem structure; shifts in the biomass spectrum in land and aquatic/marine systems; biome shifts, including shrubbification and tree-line advance; physical changes affecting species mobility and ecosystem synchronies.

Thresholds may be difficult to discern by direct observation; instead, they are seen more clearly through their consequences. Remote sensing (e.g., satellite images and air photos) is now a very valuable tool in observing current changes, especially in regional studies, but it requires massive ground-truthing efforts to interpret the data (e.g., Lindblad et al. 2006). This highlights the need for robust, long-term monitoring. Detailed protocols and very large-scale replication in time and space are normally required to detect change in Arctic ecosystems. The best example to date is provided by the International Tundra Experiment (ITEX). Long-term warming studies, which involved more than twenty Arctic field stations and more than twenty years of field work, have shed light on the sequence of change in the Arctic (Arft et al. 1999; Walker et al. 1999; Elmendorf et al. 2012a, 2012b). With our present knowledge, it is possible to construct scenarios for the future, and the combination of field experiments, observational data, and model-based analysis can support more accurate predictions of future biophysical regime shifts.

Detection of ecosystem change is often particularly difficult in the Arctic because processes tend to be slow, that is, ecosystems react relatively slowly to change, and the basal "ecosystem engineers" (vascular plants) are extremely long-lived. Many live close to the physiological margin in terms of temperature (best expressed as cumulative degree days above 0°C during the growing season, see Molau et al. 2007). This adaptation to harsh conditions makes many Arctic plants and animals rather resilient to change over short timeframes. Nevertheless, drastic changes have been recorded in past decades. An important feature that often distinguishes a threshold from other kinds of change is that thresholds are characterised by hysteresis (Figure 4.5b), or the dependence of the state of the system on its past environment. Ecosystems often show strong hysteresis effects. Recent sharp changes to Arctic ecosystems may be irreversible.

Fig. 4.5a **Cascade of physical and ecological changes**

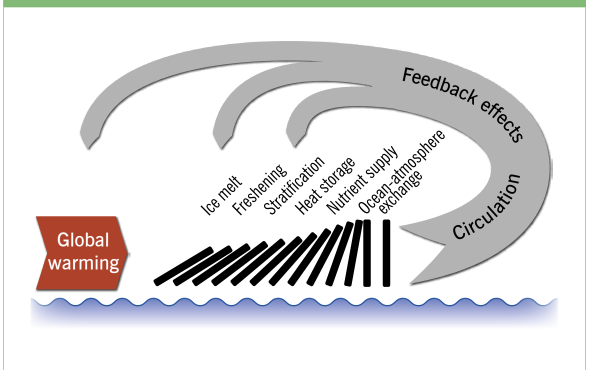
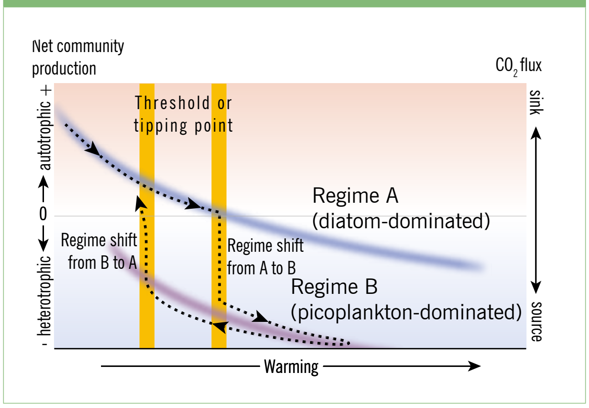


Figure 4.5b **Hysteresis in a marine ecosystem**
Duarte (2012), Agustí et al. (2012)

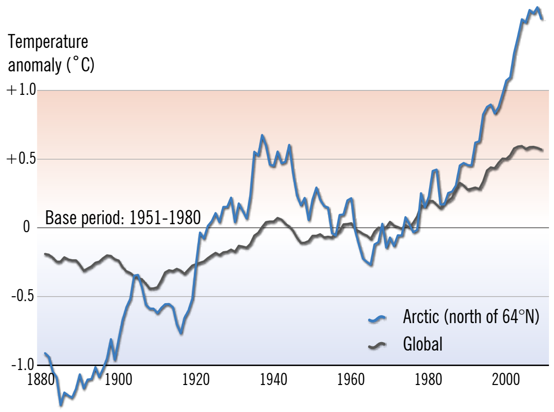


4.3.1 Thresholds linked to global warming: the current situation

Earth's altered climate dynamics – a planetary regime shift?

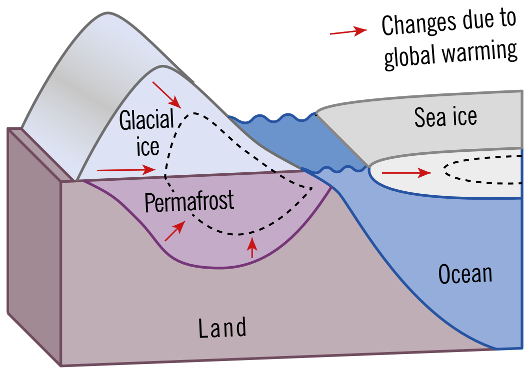
As Figure 4.6 shows, Arctic temperatures have increased sharply over the past 50 years (Jeffries et al. 2012). The temperature increase in the Arctic region is typically ~1°C greater than the global average (Walsh et al. 2011), with many localities already experiencing much higher warming (e.g., Bhiry et al. 2011). Warming in the Arctic is also projected to continue to increase more rapidly than the rest of the world. A 2°C global warming means a 4–6°C Arctic warming, and at 4°C globally, parts of the Arctic are projected to reach up to 12°C or more over pre-industrial temperatures (e.g., AMAP 2011).

Figure 4.6 **Arctic temperature rise in the last century (relative to the 1951–1980 average)**



It is known that several linked physical processes can amplify initial temperature increases and accelerate Arctic warming. Initiatives such as the Joint Ocean Ice Study and the Canada Three Oceans programme (Carmack et al. 2010) have contributed evidence about the linked changes and feedbacks in the oceans, cryosphere, land surface and atmosphere. As ice cover reduces, there is a positive albedo feedback as well as many perturbations in the geographical patterns of heat exchange affecting winds, sea currents, and the physical properties of the remaining ice. Recent anthropogenic warming has influenced the albedo feedback and north-south heat exchanges. This has steadily reduced the thickness, density, strength, and extent of ice in the Arctic, pulling it back from the coastline and islands for longer periods of time and progressively reducing the amount of multi-year ice, and generally yielding ice cover that is more mobile and responsive to the winds (see Figure 4.7).

Figure 4.7 **Arctic cryosphere warming**



The exceptional climatic conditions of 2007 prompted an intense focus on these mechanisms and feedbacks (e.g., McLaughlin et al. 2009; Overland and Wang 2010; Perovich 2011; Holland 2010; Stroeve et al. 2011; Barber, Asplin, Raddatz, et al. 2012; Hutchings and Rigor 2012). Since then, the Arctic has had larger expanses of open water, reflecting less sunlight and absorbing more heat in summer, and allowing for a more stored heat to return from the sea to the atmosphere in winter. Key underlying mechanisms have been documented that link ice, ocean physics and atmospheric processes, and which explain how recent shifts in Arctic weather patterns and weather extremes can be linked to the albedo effect. In one pattern of change, the circumpolar winds are weakened as ice cover decreases. This slows and amplifies the high-altitude atmospheric Rossby waves that spread along the polar jet stream. This increased turbulence leads to "blocking" (see Figure 4.8), resulting in persistent weather patterns (Overland et al. 2012) and extreme weather conditions (e.g., Francis and Vavrus 2012).

The striking recent acceleration of Arctic ice loss, together with these changes in the physical dynamics of northern latitudes, have set the stage for a regime shift in the climate system of the Northern Hemisphere. High temperatures and anomalous wind-fields may combine to destroy old ice and prevent its annual replacement – potentially taking the system over the threshold to a new state. Current models suggest that the Arctic Ocean will be largely ice-free in late summer in two decades from now or even earlier. While there may not be a single threshold for Arctic sea-ice cover, positive feedbacks do contribute to rapid changes that have consequences for the region's ecosystems and social systems (Barber, Asplin, Papakyriakou, et al. 2012; Perovich 2011). Furthermore, the effects of these changes are not just hemispheric; some are global.

Figure 4.8a **A regime shift in the climate patterns of the Northern Hemisphere?**

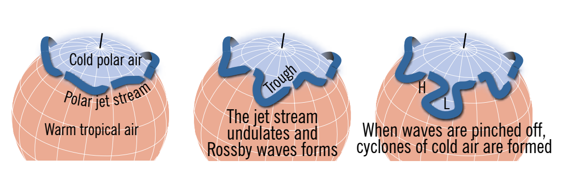
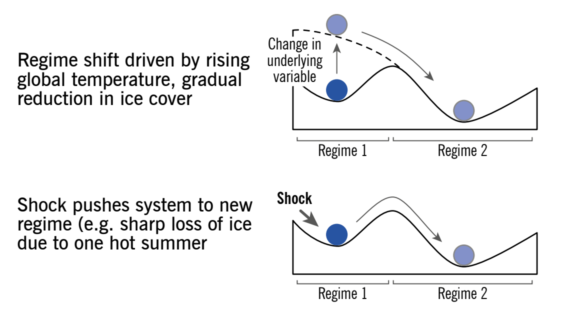


Figure 4.8b **A regime shift in the climate patterns of the Northern Hemisphere?**



Lenton et al. (2008) identify the Arctic ice pack as one of the key "tipping elements" in the world climate system. If current patterns persist, this would suggest that climate change is entering a new phase. The ice-capped poles play a vital part in Earth's energy balance; indeed, arguably the main ecosystem service that the Arctic provides is an annual cooling of the global climate system, largely through the high-albedo sea ice cover (Serreze 2010). Figure 4.9 shows the energy balance of planet Earth. The most intense solar warming occurs at the equator, and the atmosphere and oceans redistribute that heat polewards. At present, the switch point between heat energy gained from the sun and energy returned to space lies at about 38º latitude (both north and south). As the Earth warms and planetary albedo decreases, this higher-latitude zone of heat loss will decrease in area (Serreze 2010; Trenberth and Fasullo 2010), resulting in a positive warming feedback. Rial et al. (2004) point out that thresholds arise when a positive feedback is no longer balanced by a negative feedback.

In addition to the recent dramatic changes in sea ice, the extent of snow cover across the Arctic has decreased considerably in recent decades. The rate of snow cover loss over land in the Northern Hemisphere in June is – 17.6% per decade (compared to the 1979–2000 mean). This decrease is greater than the rate of September sea ice loss over the same time period (Derksen and Brown 2012). In 2012, surface melt affected almost the entire Greenland ice sheet. This almost 100% melt extent is nearly four times greater than the ~25% average melt extent recorded 1981–2010 (Box et al. 2012; Jeffries et al. 2012). Box et al. (2012) have documented the recent trend of Greenland's declining ice reflectivity, and argue that the 2012 summer decrease in albedo (Figure 4.10) was greater than would be expected under normal recent variability, potentially indicating a shift to a new physical regime. The thermodynamic impacts of a widespread decline in reflectivity include more absorption of solar energy, and that in the future the snowpack will be preconditioned for early melting.

In the past, melting of the polar icecap has been associated with threshold changes observed in Earth's thermohaline circulation, affecting climate and ecosystems in both hemispheres. These changes are inextricably linked from the global to the most local scales (see Figure 4.5a in Box 4.3). There is both palaeo-observational and model evidence showing that future changes to marine systems could occur (Broecker 1997; Delworth et al. 2008). However, the early Holocene shifts in global ocean circulation (driven by North Atlantic cold water sinking) have involved mechanisms that are not effective now, notably the presence of the Laurentide ice sheets.[1]

These extensive changes in the cryosphere are having – and will continue to have – unprecedented effects on Arctic ecosystems and the human systems that depend on them (Barber, Asplin, Papakyriakou, et al. 2012; Perovich 2011). Thus, it is urgent to establish where these changes involve potential "tipping points", and where rapid changes may exceed society's capacity to adapt. In this context, one area of focus is whether it is possible to quantitatively identify potential early warning indicators of impending threshold changes in the physical system (Livina and Lenton 2013). Another area, and a priority for the ARR, is to develop improved ways to display thresholds and the links between them, in closer dialogue with the communities and interests that will be most affected in the event that thresholds are crossed.

Anticipating multiple ecosystem regime shifts

Arctic ecosystems are also characterized by changing patterns of feedback, resulting in nested and interlinked thresholds. Because the rate of warming in the Arctic is twice the global rate (Walsh et al. 2011), Arctic ecosystems are particularly likely to encounter climate-driven thresholds. For example, the current melting of the Greenland ice cap is altering the impact of feedbacks in the functioning of the biophysical system. One positive feedback mechanism is the growth of pigmented microbial communities on the ice cap, which decrease albedo and increase local warming, which promotes further biological growth, which in turn may accelerate melting (Yallop et al. 2012). The first

1 Additional discussion is available on http://regimeshifts.org/component/k2/item/68-thermohaline-circulation#more

presence of meltwater on the ice surface signals that the local threshold has been crossed. Cascade effects link such local ecological changes to the large-scale climatic shifts described above. This kind of interaction can lead to abrupt ecological change in the Arctic much sooner than in other regions.

Figure 4.9 **The Arctic ice cap plays an important role in the energy balance of the Earth**

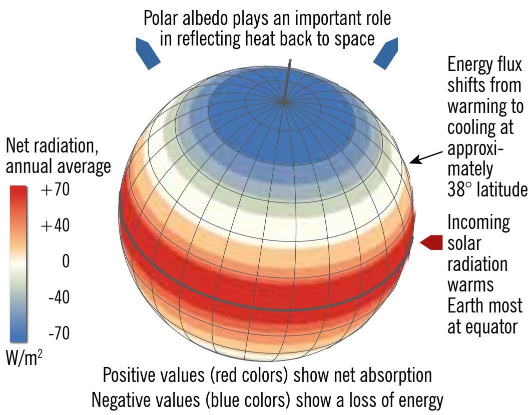
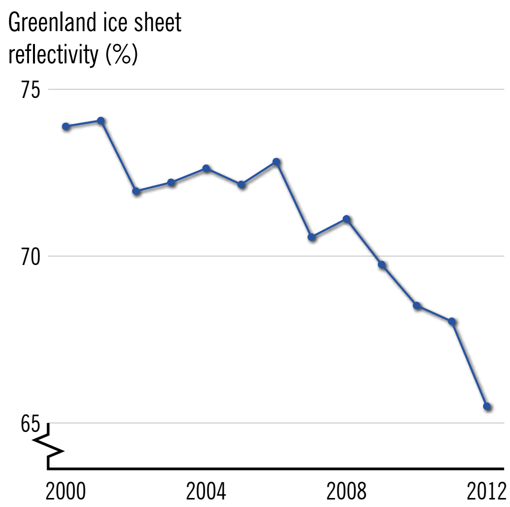


Figure 4.10 **Recent Greenland albedo changes**



There is evidence that Arctic region has already passed a temperature-mediated ecological threshold (Bhatt et al. 2010). For at least the past 5000 years (Figure 1), Arctic ecosystems – including the human societies that depend on them – have been in a state of relative ecological stability. Evidence has grown over the last 15–20 years that Arctic ecosystems are now "out of equilibrium" due to the recent temperature increases (e.g., Vors and Boyce 2009; Hu et al. 2010; Macias-Fauria et al. 2012). Arctic ecosystems are also experiencing the direct effects of intensifying human activity.

From an ecological perspective, both the living (biotic) and non-living (abiotic) components of Arctic ecosystems are in the process of rapid change, in an attempt to re-establish a new state of dynamic equilibrium with regional and local expressions of climate. Given the present anthropogenic input of climate-forcing greenhouse gases into the atmosphere, a new ecological equilibrium will not occur for some time, perhaps even centuries. Ongoing and – unless society transforms rapidly to reduce its emissions of greenhouse gases – accelerating temperature-driven and CO_2-driven changes are expected in all Arctic terrestrial, freshwater and marine ecosystems. At the same time, society is already responding to present change and also transforming long-standing behaviours in the light of anticipated future changes. These societal responses have a wide range of consequences: they can contribute to accelerated transformation (Olsson et al. 2006; Rosa and Scheuerman 2009), or result in "lock-in" situations where communities find themselves trapped in unsustainable practices and vulnerable to external shocks (Carpenter and Brock 2008).

4.3.2 Pan-Arctic thresholds

Marine ecosystems

Although marine systems are very dynamic and show many strong trends of change, there is still no agreement on clear evidence for crossing ecological thresholds that trigger abrupt marine changes and regime shifts (Overland et al. 2008). Grebmeier et al. (2006) reported that the biological communities of the shallow shelf of the northern Bering Sea have changed from typically Arctic to subarctic ecological structures. They argued that because these observed ecological changes have been contemporaneous with changing climatic drivers, they should be expected to affect a much greater area of the Arctic Ocean as global warming continues. Brown and Arrigo (2012; 2013) note that changes in sea ice are associated with large scale trophic changes in marine ecosystems, with major shifts seen in parts of the shallow Bering Sea. However, the spatial patterns of these trends are highly variable across the Arctic. In the Bering and Beaufort seas and neighbouring regions of the North Pacific, physical regime shifts have been observed, yet they have not been accompanied by expected ecological regime shifts, as seen in populations of beluga whales (e.g., Luque and Ferguson 2009).

Warming of the European sector of the Arctic Ocean may induce ecological tipping points. The Arctic Tipping Points (ATP) project of the EU Seventh Framework Programme (FP7) has been the most comprehensive study to date of abrupt ecosystem responses to climate change in the Arctic. Its findings confirm that warm, high-salinity Atlantic waters are spreading further north into the Arctic Ocean, and key

Arctic species are on the decline. Abrupt changes signal the presence of nonlinear processes that are remarkably elusive to predict. The ATP experiments have enabled models to be improved and validated with a wider set of observations. Model studies indicate that the most abrupt changes may occur following a warming of 4–6°C, levels that are expected for major parts of the Arctic Ocean during the 21st century, if current anthropogenic greenhouse gas emissions are not halted rapidly. These analyses also suggest that observation can reveal recent "tipping points" (Carstensen and Weydmann 2012; Wadhams 2012), which indicates that extended observation and monitoring may enable early detection of the approach of thresholds.

Ice reductions, the northward displacement of warmer waters and the response of marine ecosystems to climate change are all pushing key Arctic biota further north into the Arctic basin, driving significant changes in the composition and function of ecosystems. The ATP model predicts that annual primary production will decrease in areas dominated by Atlantic Water. The observed decline in primary production in the sub-Arctic regions, and the decline of the key, lipid-rich, Arctic zooplankton species *Calanus glacialis* in the mid latitudes of the Barents Sea are potential early warnings of approaching regime shifts (Carstensen et al. 2012; Krause-Jensen et al. 2012). In general, the Arctic zooplankton community does not react abruptly to temperature, except in the case of *Calanus glacialis,* the abundance of which is significantly reduced with temperatures above 6°C. This small crustacean is a key node in the Arctic food web, but the ATP surveys found that it was largely absent from regions where it was previously abundant. Its absence is consistent with model predictions and may already signal a major change in the Arctic food web. Today's rich fishing grounds may move towards today's ice-covered northern shelves, with implications for fisheries and the communities that depend on them.

And what about the sea bottom? Kortsch et al. (2012) found positive responses of marine vegetation to warming and increased duration of the ice-free period, along with changes in the structure of invertebrate communities. These changes may be useful as indicators of ecosystem responses to climate change and warning signals of thresholds. A threshold in response to ocean acidification was found for calcification in an Arctic mollusc (Comeau et al. 2009; Comeau et al. 2012), implying potential community-wide effects when a certain acidification level is reached.

The ecological "tipping points" that occur as a response to increasing water temperature and acidity will have major consequences for organisms higher in the trophic web, affecting populations and distributions of fish and marine mammals. Projections suggest that harvestable marine production will decrease in what are currently the most productive waters, but increases are projected in the Arctic shelves (hitherto areas of low productivity), raising the prospect of further societal thresholds driven by these ecosystem changes.

The present-day management of marine resources is and will continue to be characterized by uncertainty arising from both ecosystem and market dynamics. Managers have to cope with vague and often conflicting objectives, limited knowledge about system dynamics, and the uncertain consequences of different actions. The ATP project examined how institutions and policies for managing living marine resources, ecosystems, tourism, and petroleum development would cope with very rapid change in ecosystems driven by climate change (Hoel and Olsen 2012). A key recommendation was that management should be precautionary in cases where it influences the risk of crossing a threshold that impacts on ecosystem dynamics. The behaviour of resource users depends on their ability to cooperate as well as on the state of the system they use; and, when collectively exploiting an ecosystem, their behaviour tends to be more careful if they are aware that crossing a threshold could trigger a less productive regime (Crépin et al. 2012). However, societal objectives and associated uncertainties do change – and they also change due to climate change. Thus, developing a capacity for learning is an important part of resilient and adaptive responses to change (Chapin et al. 2006).

Coastal systems

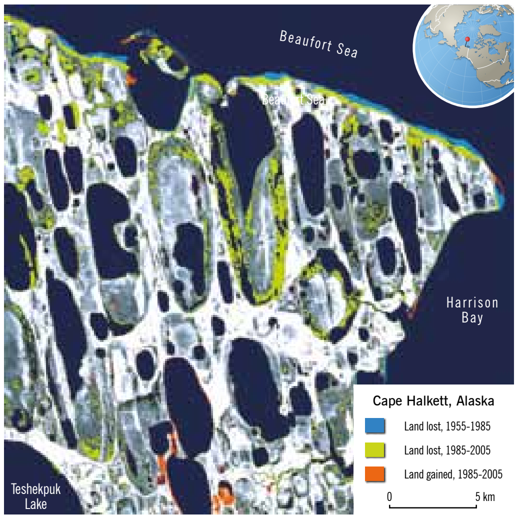
The Arctic coastal zone is the interface between the seas of the Arctic shelf and the Arctic terrestrial regions; the realm where the terrestrial ecosystem is affected by proximity to the marine, and vice versa, and which as a result is sensitive to changes or shifts in either. As a result of this interaction, the coastal zone supports high structural and ecological diversity, which includes its human component (Forbes et al. 2011). Both climatic and societal shifts are causing changes to the Arctic coastal zone. Here we focus on the climate, and return to social change in section 4.4. This review considers the drivers of change in the coastal zone and describes whether the changes – observed or predicted – exhibit threshold behaviour.

The 101,447 km coastline surrounding the Arctic Ocean is vulnerable to climate change because of the unconsolidated Quaternary sediments, high ice contents in the permafrost-affected bluffs, and accelerating disappearance of summer sea ice (Lantuit et al. 2010). Coastal erosion averages 0.5 m/yr over the entire coastline, but along 3% of the coast the erosion rates exceed 3 m/yr. Furthermore, erosion rates and ecological changes are increasing as a result of the rapid loss of summer sea ice, and the consequent increase in storm energy and the fetch length in open water (Jones et al. 2009; Polyak et al. 2010; Overeem et al. 2011). This erosion threatens coastal villages, leads to loss of wildlife habitats, mobilizes organic carbon that has long been sequestered in permafrost, and contributes sediment and carbon to near-shore ecosystems (Rachold et al. 2005; O'Brien et al. 2006; Rowland et al. 2010; Ping et al. 2011). The release of formerly trapped carbon dioxide and methane to the atmosphere represents a positive feedback from the terrestrial environment to the warming climate system (Schuur et al. 2008; Vonk et al. 2012). However, at present the timescale of change and the level of risk remain uncertain.

The Cape Halkett area of the Alaska Beaufort Sea coast provides an example of the high vulnerability of some of these coastal regions. The eroding land is comprised of extremely ice-rich glacio-marine sediments that are exposed to the open ocean (Jorgenson et al. 2006; Kanevskiy et al. 2013). Consequently, it has one of the highest erosion rates in the Arctic, as well as globally (Jorgenson et al. 2006; Mars and Houseknecht 2007; Jones et al. 2009; Lantuit et al. 2010; Lantuit et al. 2012), with average long-term erosion rates of 7.6 m/yr (Jones et al. 2009). The area also has a high abundance of thermokarst lakes and drained-lake basins that are susceptible to abrupt episodic flooding, which large storm surges can extend up to 15 km inland (see Figure 4.11) (Mars and Houseknecht 2007; Arp et al. 2010). The area is a critical habitat for ~90,000 geese that congregate there in summer for moulting, and ~46,000 caribou that use the area for both calving and migration. Coastline erosion of the Beaufort Sea has altered these tundra habitats by allowing saltwater intrusion, which causes shifts in the composition of plant forage. The ecological change may be altering optimal foraging habitats for moulting birds, or affecting competition between black brant and greater white-fronted geese, a situation that may be excluding brant geese from their preferred habitats (Flint et al. 2008).

The Arctic coastal zone is placed between potential "tipping elements" on both the terrestrial side (i.e. permafrost loss, accelerated carbon release) and the marine side (i.e., sea ice loss, sea level rise, ecosystem response). The major observed changes in physical drivers at the circumpolar spatial scale include sea level rise (Proshutinsky et al. 2007), the recent rapid decrease in sea ice extent (Jeffries et al. 2012) and warming of the lower atmosphere (Hansen et al. 2010). In the past, these drivers have varied at larger temporal scales. For example, sea levels in the Arctic have been rising slowly (i.e. millimetres per year) for thousands of years (e.g., Mason and Jordan 2001), but rates of sea level rise following the last glacial period were, at intervals, ten times higher and affected large regions of permafrost deposits on the Arctic shelves. And, during the Holocene climatic optimum, warming had an impact on permafrost and the landscape, with a cascade of effects on the ecology of the coastal lowlands of the Arctic.

Figure 4.11 **Coastline and lake shoreline changes in Cape Halkett, Alaska**
Mars and Houseknecht (2007)



Observed sea ice extent and thickness is currently changing at a higher rate than any reconstructed rate (Jeffries et al. 2012). A resulting intensification of land-to-sea fluxes has been observed, and includes increases and shifts in the seasonality of water flows (Peterson et al. 2002), and fluxes of sediment (Gordeev 2006), carbon (Frey and McClelland 2008; Guo et al. 2004), and contaminants (AMAP 2003). Nutrient distributions are also likely to be shifting (Arrigo and van Dijken 2011) but fluxes to surface Arctic waters remain very poorly understood. As a result, sea-shelf ecosystems and the life cycle of many species are changing (Sigler et al. 2011; Dunton et al. 2006).

Most drivers of sea level rise and sea ice change are processes that occur at larger scales than those that arise in or affect only the coastal zone. Understanding these external drivers is critical for managing responses to change in the zone. Both sea level rise and ice changes are serious physical, economic, and ecological threats to coastal communities (Forbes et al. 2011). Since Arctic peoples are mainly a coastal population who rely on access to the sea for transport, resources and culture, socio-ecological thresholds are likely to emerge as the coastal zone changes biophysically (see section 4.4.2, in particular).

The erosion of ice-rich coasts may be a threshold process involving abrupt and irreversible changes. Ice-rich coasts exist mostly where continental landmasses were not glaciated, and include the western North American Arctic region and all of the coasts of central and eastern Siberia. Warming of ice-rich permafrost results in subsidence of the land surface and the seabed by up to tens of meters. Subsidence of the land surface results in an effective relative sea level rise, and subsidence of the seabed can increase wave energy impinging on the shore, as well as create room ("accommodation space") for the deposit of eroded sediments.

The roles of permafrost relevant to climate at the circumpolar scale are the prevention of water infiltration into the subsurface for large regions; its related control of landscape and land-cover dynamics; and its function as a globally important reservoir for sequestered carbon in various forms (organic matter, methane, gas hydrates).

The cooling and warming of the subsurface, particularly where it contains groundwater or ice, is a physical threshold process. At a constant rate of import or export of heat energy, the subsurface warms or cools, respectively. However, when the subsurface reaches the phase-change temperature, the warming or cooling stops, and further energy flux results in melting or freezing. This is referred to as the zero-curtain effect when it occurs on a small scale (i.e. metres or less), and affects the upper layer that freezes and thaws every year with the seasons. On the stadial/interstadial timescale, there is a lag between heat transfer at the ground surface and permafrost distribution. This thermal inertia is reflected in the fact that most Arctic permafrost today is warming and/or thawing, a relic of past glacial periods. While cold permafrost sites are currently warming rapidly, the warming rates are very low for permafrost that has already warmed to close to the phase-change temperature, because it is already thawing (Romanovsky et al. 2010). Permafrost responds to warming in a nonlinear way, owing to the latent heat of fusion. However, for this nonlinear behaviour to qualify as a "tipping element", a positive (reinforcing) feedback must result (Lenton 2012). There are three key feedbacks:

Greenhouse gas release, whether through aerobic or anaerobic respiration, or through the release of gas or gas hydrate, is an indirect feedback that operates via the global climate system to increase thaw rates (e.g., Walter et al. 2006; Isaksen et al. 2011).

Thermokarst formation is an immediate effect (from annual to centennial) of permafrost thaw which, by changing the surface characteristics of permafrost landscapes, changes their heat transfer properties in a highly spatially heterogeneous manner (Schuur et al. 2008; Sannel and Kuhry 2011).

A shift from surface-flow hydrological regimes to base-flow regimes, at the continental spatial scale, is a long-term effect (centennial to millennial). This latter feedback has wide-reaching implications for the coastal zone, the Arctic shelf sea ecosystems and for land-to-sea fluxes (Frey and McClelland 2008).

How permafrost thaw affects ecosystems in the coastal zone will vary regionally based on the current coupling of land to sea through river flows, marine currents and species life cycles. Most strongly affected will be those regions with cold permafrost underlying broad coastal plains, such as northern Alaska, the Yukon and the Northwest Territory coastlines, as well as the whole Siberian coastline east of the Urals. Most of the Arctic shelf sea territory (>80%) is located in eastern Siberia, and this region is expected to react most sensitively to shifts in land-to-ocean transfer of water and sediment.

Many societal impacts are associated with intensified coastal dynamics. Coastal erosion currently directly threatens industrial and community infrastructure in many places in the Arctic, especially where ice-rich permafrost is present at the modern coastline. Given the changes in social and environmental driving forces, coastal dynamics will intensify and increase pressure on communities living on the coast. Indeed, the anticipation of future change and disruption is already transforming coastal communities. Differing narratives of change in the Arctic are generated by various actors, in particular governments, NGOs (e.g., Sommerkorn and Hamilton 2008), the region's residents, and the scientific communit (e.g., Mars and Houseknecht 2007). Media attention feeds off all four sources to produce a popular narrative of change that may not be fully representative of the local realities, but still tends to swamp the others in terms of its reach, longevity and influence. For example, coastal erosion threatens infrastructure for many of the Chukchi Alaskan settlements, a number of which have relocated in response, enabled in part by media-driven awareness and concern. Many Siberian settlements face the same threat of rapid erosion, such as Bykovsky (Lantuit et al. 2011), and receive minimal media attention. Mason et al. (2012) examine and compare media and science accounts of coastal change for the coastal village of Shishmaref in Alaska, and conclude that, regardless of current and future changes in forcing factors, residents and governments must choose between the high costs of adaptation and the high costs of relocating settlements.

4.3.3 Thresholds in terrestrial ecosystems

Ecosystem responses to cryosphere changes and loss of permafrost

Rapid ecological changes, with obvious thresholds being passed, have been detected in many locations in the Arctic in relation to permafrost degradation and final thaw. While many of these changes occur at a local scale, they are increasingly widespread in the pan-Arctic context. These processes are of course more evident in the southern outskirts of the Arctic where the permafrost is discontinuous (AMAP 2011) than in the main area of the terrestrial Arctic. These observed changes are in part attributed to sequential drivers, the most significant among these being climatic warming of the tundra soils. Then, permafrost thaw initiates rather different pathways of ecosystem change depending on the soil type.

Permafrost degradation in the organic soils (formerly frozen deep layers of peat) that are dominant across the low level coastal tundra across the entire Low Arctic, leads to the formation of swamps and new lakes (Christensen et al. 2004; AMAP 2011). Final thaw of permafrost in mineral soils, on the other hand, leads to rapid draining and shifts in species balance that can be rather rapid (in Arctic terms). Thus, Molau (2010) showed that a former tussock tundra in a sub-Arctic alpine area in northern Swedish Lapland shifted to a community dominated by boreal rather than tundra plant species within 10 years. In 1992, the area was underlain by permafrost with an active layer of up to 60 cm. By 2002, no permafrost was left (Molau 2010; Beylich et al. 2006). Because the observed shift in species balance was from the Arctic cottongrass (*Eriophorum vaginatum*), an important grazing species for reindeer and caribou (particularly calf grazing), to lingonberry (*Vaccinium vitis-idaea*; of no importance as to grazing), this hydrological shift has an immediate negative bearing on the potential to use the land for reindeer husbandry (Molau 2010).

During the past few years, even more drastic changes involving final permafrost thaw in mineral soils have been observed in northern Swedish Lapland, and this phenomenon may be widely distributed in the Low Arctic (though observational data is lacking). Former shallow smaller lakes in the tundra have rapidly and totally drained, and are now stony and gravelly impediments to the movement of reindeer, caribou and other organisms. These former lakebeds are slowly being invaded by terrestrial plants. The rate of change in these cases is only 3–5 years, and the profound hydrological changes must inevitably affect grazing potential in late summer. Smol and Douglas (2007) also report the total loss of several High Arctic ponds in Ellesmere Island. In this case, the water losses are not due to drainage, but instead to higher evaporation linked to warmer temperatures and a shorter period of ice cover.

The existence of alternative biophysical states has long been noted in shallow lakes. As essentially closed systems, these ecosystems are particularly vulnerable to perturbations. Changes (deliberate or inadvertent) in ecosystem assemblages can tip lakes from a turbid to a clear state (Moss et al. 1996; Jeppesen et al. 1998; Scheffer 2004; Ibelings et al. 2007). There are anecdotal descriptions of regime shifts in response to exceptionally heavy storms (Hamilton and Mitchell 1988) and changing water levels (Wallsten and Forsgren 1989). Some work has also sought to unravel the internal drivers and mechanisms behind natural regime shifts in shallow lakes, including work on cyclic oscillations from clear to turbid water and back (Nes et al. 2007; Hargeby et al. 2007). External events such as extreme weather conditions may play a role in triggering the shifts, suggesting that future climate change may have consequences for shallow lakes in the Arctic.

Arctic snowbeds are another critical set of ecosystems. These snowbeds form in topographic depressions or at leeward abrupt slopes (for a review of snowbed ecology, see Björk and Molau 2007). They are formed year after year in exactly the same position, and melt out in mid to late summer (or some years, not at all). Snowbeds that melt out most years have a maximum late winter snow depth of 3–15 m; they may vary in size from a hectare to many square kilometres, but even the smaller snowbeds play an important role at the landscape level and for certain ecosystem services. They are the habitat for many highly specialized plants and animals and therefore of utmost importance for regional biodiversity. Several species of birds, such as snow bunting and rock ptarmigan, do much of their foraging during the breeding season on snowbeds due to the abundance of insects and seeds on the snow surface. Lemmings preferentially over-winter under snowbeds since ground temperatures rarely do not decrease more than a few degrees below 0°C because of the insulation of the deep winter snowpack. In summer, reindeer herds frequently use the beds for temperature relief when resting and to escape the worst mosquito densities. Finally, snowbeds provide watering of nearby heaths and pastures throughout the summer, improving grazing quality for reindeer and caribou.

Many snowbeds are currently close to a threshold when they melt out earlier than usual, and specialized snowbed species are replaced by more competitive ones. Boreal willows are now invading snowbeds in northernmost Sweden. Furthermore, as the snowbeds retreat, so do the birds that depend on them. The north Scandinavian population of snow bunting has decreased drastically during the last decades (by up to 50% since 1995 in some areas; see Björk and Molau 2007). This trend is also observed at more southerly birding stations during migration. In mountain regions just south of the Arctic, true snowbeds are completely lost and with them entire ecosystems over large areas (e.g., Kullman 2010).

Callaghan et al. (2011) have concluded that it is not just the presence or absence of snow that is crucial to ecosystems; it is also the snow quality. Warm spells have become more common in the middle of the winter. In Russia, rain-on-snow events have increased by at least three days in the period 1989–2006 as compared to 1951–1980 (Shmakin 2010). These events have been shown to have strong cascading effects on the landscape level food web in the High Arctic (Hansen et al. 2013). In Fennoscandia, in the second half of the 20th century, the number of days with winter thaw increased by six days over 50 years, or by 35% (Groisman et al. 2009). These events result in the sudden loss of snow protection to vegetation. Where temperatures rise rapidly to well above freezing, snowmelt occurs at landscape scales (Phoenix and Lee 2004; Bokhorst et al. 2008; Bokhorst et al. 2009), which warms plants and soils. Then, following a few days of warming, the ecosystem is exposed to thermal shock as extreme cold rapidly returns. Manipulation experiments have been set up in sub-Arctic Sweden to simulate the effects of these cold spells. The outcomes of the experiment, together with observations of a natural event in the winter of 2007/8, have shown that shrub species may suffer, with increased mortality of buds and shoots, delayed bud burst in spring and reduced flowering and berry production (Bokhorst et al. 2008; 2009). The large scale of the natural event (reduced NDVI – an index related to vegetation productivity – was observed over an area of more than 1400 km^2) suggests that extreme warming events may reduce productivity of Arctic vegetation (Bokhorst et al. 2009) and counterbalance the long term trend of shrub expansion into the tundra (Sturm et al. 2001; Tape et al. 2006).

Changes to ecosystem structure and assemblage tundra ecosystems rely on the productivity of long-lived perennial plants. Annual plants are unusual and make up less than 1% of the total species stock. Clonal life spans of about 5000 years have been reported for Arctic sedges in the Siberian Low Arctic (*Carex bigelowii* and allied taxa; Stenström et al. 2002), implying that today's plants are just the first or second generation since the last glaciation (except in Beringia, which was not glaciated and where ecosystems are much older). Very high ages of individual plants have also been determined for tree-line mountain birch in northern Fennoscandia and white spruce in the Canadian Arctic.

The ITEX study (www.geog.ubc.ca/itex/about.php, or see Molau and Mølgaard 1996) focuses on the effects of rising temperature on tundra species. It combines monitoring of untreated control plots with warming experiments that use open-top chamber greenhouses that increase surface temperature by 2°C on average (Marion and Pidgeon 1992). At many sites, this pairwise analysis has been under way since the early 1990s. The meta-analyses from ITEX data on Arctic vascular plants have shown that phenological changes (e.g., timing of leaf bud burst, onset of flowering, fruit ripening) already occur during the first four years of experimentally raised temperature (Arft et al. 1999). Productivity and biomass changes lag behind, but are evident after 5–10 years (Walker et al. 2006). Effects on species structures of the communities are first realized after 15–20 years (Elmendorf, Henry, Hollister, Björk, Boulanger-Lapointe, et al. 2012; Elmendorf, Henry, Hollister, Björk, Bjorkman, et al. 2012). Typically, the High Arctic with its discontinuous vegetation cover is more reactive than the Low Arctic, where there is continuous vegetation cover, and, perhaps more important, a continuous rhizosphere – the below-ground root zone – which effectively blocks incoming plant seeds or seedlings from getting established.

There is evidence from Antarctica (Fowbert and Smith 1994; Parnikoza et al. 2009) that climate change has led to the rapid increase in individuals and cover of the only two species of vascular plant (the cushion plant *Colobanthus quitensis* of the Caryophyllaceae family, and the grass *Deschampsia Antarctica*) into areas that were previously climatically unsuitable. The increasing summer temperature and subsequent longer growing season have driven the ecosystem past a threshold, where in most years the plants are now able to reach a similar level of stable reproductive success (including seed maturation and dispersal) as populations of the species at lower latitudes. Increasing plant populations means higher productivity and biomass, which enables insects and other arthropods to follow in their turn. This Antarctic example of an ecosystem regime shift was relatively easy to monitor. However, the same kinds of processes have to be looked for in the Arctic, from high alpine fellfields at its southern limits to the High Arctic, where Arctic deserts, still poorly inhabited by plants, dominate the landscape.

Shrub encroachment, or the increasing dominance of a shrub layer, is a trend that is currently being projected to change relatively rapidly across the Low Arctic (Tape et al. 2012; Blok et al. 2011). The main driver behind shrub expansion is warmer summers with longer growing seasons. In particular, the extension of spring warming in May is crucial because of high solar radiation, while the later extension in September/October is marginal for biomass productivity (Molau 1997). The higher shrub canopy emerging above the winter snow cover triggers earlier snowmelt in spring due to the albedo reduction, thus initiating a positive feedback to the regional climate system (Sturm et al. 2005). When such a feedback is established, a threshold is passed. The regional studies from Alaska and Siberia cited above show that this shift has taken about two decades to become established, and the threshold is already passed over vast areas.

Conifer to deciduous forest: A recent study (Mann et al. 2012) of the "muskeg" boreal forest in the Alaska Interior (a large part of which lies north of the Arctic Circle) brings valuable insights for detecting and attributing change. The study was based on observations and modelling, and shows that increased frequency of wildfires in the conifer forest (for which increasing summer temperature is the main driver) will turn the landscape into a deciduous broad-leaf forest. The dominant slow-growing conifer black spruce (*Picea mariana*) is replaced by more open ecosystems dominated by aspen and birch, with a much higher nutrient turnover. A high reduction in the age of stands has already been observed, starting around 1990. The modelling efforts by Mann et al. (2012) show that a major threshold will likely be passed within two decades, shifting the entire system from a carbon sink to a source, again imposing feedback effects to the climate. This is an example of a relatively abrupt threshold that includes sequential drivers (climate warming plus fire frequency).

All of the thresholds described above may be sharpened by the increasing dominance of invasive species, mainly of boreal origin. These new life forms may feedback on the albedo and increase the warming effect, or drive other ecosystem regime shifts, or alter the flows of ecosystem services in a particular locality. For example, there is concern that warming brings about a loss of reproductive capacity in boreal forest species, but despite the suitability of the new temperature at given latitudes, deciduous plants cannot adapt fast enough to the short growing season at high latitudes to expand into the newly available areas. A biogeographic ecosystem "gap" at those latitudes can thus potentially grow over time. It remains a complicated challenge to identify and attribute the primary drivers of changes such as these.

Table 4.2 summarizes examples of detected ecosystem changes for which anthropogenic climate change drivers have been attributed.

Table 4.2 **Detected changes in Arctic ecosystems that have been attributed to anthropogenic climate change**

Threshold	Detected /Forecast	Description	Location	Time period, years	Gradual/ abrupt	Confidence in detection	Attribution	Confidence in attribution	Confounding factors	Implications	Examples
Lake drainage	D	Rapid drainage of shallow lakes on periglacial moraines	Northern Scandes	3–5	A	Very high	Final permafrost thaw	High	Precipitation	Hydrology change; reindeer grazing quality and quantity	Callaghan et al. (in press)
Marine kelp loss	D	"Deforestation" of marine kelp community	Aleutians	10–15	G	High	Sea otter depletion due to hunting (sea otters feed from sea urchins that graze on kelp)	High	Bald eagle predation; hunting pressure	Reduced coastal fish stocks; loss of biodiversity	Anthony et al. (2008)
Tussock tundra drainage	D	Tussock tundra dominated by cottongrass turning into dwarf-shrub tundra with boreal species	Northern Scandes	10	A	Very high	Final permafrost thaw	Very high	Precipitation, summer temperature	Hydrology change; reindeer grazing quality and quantity	Molau (2010)
Shrub encroachment	D	Increasing shrub canopy in the tundra	Entire Low Arctic + Subarctic alpine	20–30	G	Very high	Longer growing season	High	Snow distribution, grazing pressure	Reduced reindeer grazing quality; loss of biodiversity	Sturm et al. (2001); Bokhorst et al. (2008); Tape et al. (2006); Blok et al. (2011)
Auk reproduction	D	Reduced auk reproduction due to phenological mismatch	Low and High Arctic bird cliffs	10–20	G	Very high	Longer flying distances for fish foraging at ice margin	High	Conditions at wintering areas	Loss of biodiversity; loss of traditional food	(Moe et al. 2009; Karnovsky et al. 2011)
Snowbed reduction	D	Snowbeds melt out earlier; they are habitats of particular communities of organisms that are being replaced	Low Arctic, alpine Subarctic	20–50	G	Medium	Growing season length	Very high	Winter snow accumulation	Ecosystem change; biodiversity loss; reindeer health	Björk and Molau (2007); Molau (2010)
Coastal erosion	D/F	Erosion of Arctic coastline comprised of frozen peat	Low Arctic shorelines	10–100	G	High	Increasing sea wave erosion due to increased ice-free season	High	Permafrost degradation	Livelihood of coastal communities	Barber, Asplin, Papakyriakou, et al. (2012); Rowland et al. (2010)
Arctic tourism	F	Increasing vessel-based tourism	High Arctic	Next 10–20	G	Very high	Ecosystem disturbance	Low	World economy	Loss of biodiversity due to disturbance	Hall et al.(2010)
Plant population expansion	F	Populations of Arctic plants increasing in numbers due to more successful reproduction	High Arctic	10–30	A	Medium	Growing season length	Medium	Precipitation, disturbance grazing	Change in ecosystem structure	Parnikoza et (2009)

4.4 Social thresholds in the Arctic

The main task of the ARR is to consider resilience "of whom and to what". Shifting our focus from the biophysical domain to the social raises two issues that need to be unpacked and collectively deliberated in order to address this task. First, we should avoid the temptation to focus primarily on climate change as the main driver of vulnerability, surprises and other non-linearities in Arctic social-ecological systems. This temptation arises in part because of the intense and long-standing global focus on climate change as a scientific and policy priority, which has provided a large and coherent information resource to draw upon. In addition, much of the science of climate change has focused on quantitative prediction of relatively few specific aspects of change and their impacts. Studies of the functioning of social systems generally take more diverse perspectives, recognize the contingency of social change, and seek to respect and reflect the specificity of local concerns. For the Arctic, social, political and economic drivers of change may be of equal or greater importance, bringing about thresholds whether or not there are changes in the climate. However, it remains a challenge to obtain strong evidence about social thresholds from the research literature. Christensen and Krogman (2012) propose valuable ways in which social thresholds can be conceptualized, through collective recognition of change and new experiences.

Second, human agency is a potential source of resilience that should be given due and explicit consideration. While it features in many small scale or community-level studies, it is often bypassed in the larger-scale studies of environmental change. According to one recently published definition: "Agency encompasses both individual-level action, premised on confidence among autonomous and able members of society that change is possible, and collective agency, expressed in the cultural, infrastructural, and communicative resources that enable collective action" (Davidson 2010). One example makes this clear: Arctic social-ecological systems are sparsely populated in comparison to more temperate regions. However, by virtue of extensive resource management regimes (e.g., forestry, hydropower, mining, reindeer herding) relatively small numbers of people can affect large areas quickly, potentially triggering feedbacks and accelerating or delaying thresholds. Human agency can thus have both positive and negative implications for long-term resilience within social-ecological systems. Ford and Pearce (2012) propose new approaches to research that not only deliver usable knowledge about social-ecological change but also empower people to act on that knowledge in adapting to change. Jones et al. (2013) describe similar engaged approaches in support of improved marine governance, in the potential planning of protected areas.

The ARR methodology has therefore necessarily evolved through the interim phase to address these two challenges. The planned continuation of case studies and deliberative workshops provides opportunities to focus on Arctic priority concerns in ways that engage better with the stakeholders involved in social-ecological change.

4.4.1 Demographic change in the Arctic

Thresholds and societal dynamics

The basic parameters of demography include the statistics on a population's birth rates, death rates, life expectancy, mobility, and so on. These are important measures, as they both influence and characterize societal change and stability. Individually, the demographic parameters relate to factors intimately connected to the environment, the economy, and social, historic and cultural dynamics. In this regard, it is necessary to understand human populations as dynamic, adaptive, evolving systems, and to explore how populations respond in different ways to changing environmental, cultural and economic conditions and how effectively they manage these change processes.

The concept of demographic transition has long been a central ingredient in the analysis of natural population development (see, e.g., Leibenstein and Notestein 1954; Leibenstein 1957; 1974; Becker et al. 1960; Becker 1965; 1993; Schultz 1974). The concept emphasises how relations between crude birth and death rates have a great deal of power to explain the development and transformation of populations in different countries and regions. In situations where rates of birth and death are both high (typical of all pre-industrial societies), population increase or decrease has depended on variations in the death rate. In the classic model of demographic transition, fertility decline (a change in birth rate) is an essential factor for explaining the transition to stable populations where birth and death rates are both low. As societies develop, a "population explosion" has been identified during the second phase of the demographic transition, in which death rates have started to decrease while birth rates have remained at a high level. In a following phase, birth rates have begun to drop and population increase has slowed, while in the fourth phase of the model, both birth and death rates have stabilised at a lower level. These phases have some characteristics of threshold changes. However, a major criticism of this model is that in its original form it focuses only on natural population change (i.e., fertility and mortality) and ignores processes such as migration. The broadened concept of epidemiological transition relates additional social and political variables to economic change. However, it may be relevant to critique how these kinds of demographic thresholds are equivalent to processes that are identified in natural systems. It is especially important to emphasize the marked differences between natural processes and processes that are under human control (Rauhut et al. 2008; Carson et al. 2011).

Demographic modelling can help us to understand social change and policy issues, including: competition for skilled workers; urbanization and ruralization; population ageing; the life outcomes of indigenous peoples; the impacts of climate change; and globalization and international migration. However, for each of these examples it is often unclear whether demographic change is a driver or an indicator. It is hard to establish the cause-and-effect chains that influence demographic dynamics. To understand changes in social structures, it is important to examine how demographics and general drivers of societal change interrelate. Using other kinds of models of human interaction can shed light on demographic changes and their impact on individual lifestyles, family and community living conditions and settlement structures.

The AHDR (2004) documents many of the socially disruptive changes that Arctic inhabitants are experiencing, including health issues, community fragmentation with its associated cultural impacts, and economic and political disparities. Rasmussen (2011) outlines how some of these trends in the Arctic region relate to social trends at larger scales (see Box 4.4). These regional and global trends are closely linked to demographic dynamics, both in terms of the natural reproduction of the population, and also the migration and mobility characteristics of settlements at any point in time. These basic demographic parameters are important empirical evidence of changes to social structures and stability. However, obtaining overarching views of social thresholds in the Arctic is hampered by the challenge of comparing population statistics among different countries.

Settlement, migration, and urbanization
A key issue for deeper analysis in the ARR is the way that demographic changes and other drivers impact on settlement structures, which will probably be a focal area for a case study in Phase 2. It can be easy to assume that the number, size and location of settlements, towns and cities is "as it always has been", but history tells a different story. Obvious examples of abrupt change include the destruction of settlements through natural catastrophes, or the decay and abandonment of settlements due to epidemics that "wipe out" populations. However, other major events such as booms and busts in fish stock (Hamilton et al. 2000) and the exploitation of mineral and energy resources have also resulted in the set up and disappearance of settlements. Communities established for such reasons have existed for varying periods, from just a few to many years – in some cases enduring for centuries. And while they were still viable, it is likely that no one imagined that "their" place would eventually become a part of the surrounding nature again some hundred years later. A demographic perspective seeks to identify factors that determine the structural characteristics of existing settlement patterns, and that shape potential settlement types and environmental or territorial relations.

Box 4.4 **Ten social "megatrends" that affect the Arctic**
Rasmussen (2011)

Urbanization is increasing worldwide, both in the Arctic and affecting it.

Demographic change presents challenges for the functioning of societies – older people are tending to remain in rural regions, while younger people are leaving in increasing numbers (even if the migration is sometimes temporary). Also, relatively more women than men are leaving rural regions.

Strong economic contrasts are evident in the Arctic, with growth in capital-intensive natural resource extraction, and pressures on labour-intensive, family-based traditional economies.

Anthropogenic forces (e.g., pollution, climate change) have cumulative effects, and the Arctic's complex cross-boundary interests present challenges to co-management and regulatory control.

Investment is needed in the Arctic's "knowledge economy".

New interactions between the public and private spheres have strong impacts on the region's development (e.g., shifts from community quotas to private ownership in resource rights).

Renewable energy presents new opportunities (e.g., hydropower, sparsely populated land).

Increased accessibility of the region (see the shipping case study in Chapter 7) presents both opportunities and new risks.

The Arctic is emerging as a player in "the global game" – it is increasingly the centre of global attention for both environment and development.

Urbanization refers to the process through which society is transformed from one with predominantly rural characteristics in terms of economy, culture and lifestyle, to one which can be characterised as urban (Dybbroe et al. 2010). It usually also includes a process of territorial reorganization, leading to a shift in the location of inhabited areas, while affecting both population size and the processes of economic production. Urbanization is a global trend that will significantly shape human life in the future – and the Arctic region is no exception.

Reindeer herding on the Yamal Peninsula, Russia, in the midst of an oil and gas boom in the region

© Anna Degteva

Since the 1960s, most of the population growth in the Arctic has occurred in urban centres tied to industrial activities, social services and public administration. However, since the early 1990s there has also been a marked change in this pattern of human concentration. Growth in total population has slowed in North America and Greenland, and population has declined across Arctic Fennoscandia, and particularly in Russia. However, the concentration of population in urban settings has continued stepwise, with people gravitating towards ever more populated places (Rasmussen, 2011). People move for many reasons, often attracted by the promise of work, higher salaries and a better social life, and urban areas usually offer better opportunities, more diverse economic activity, and more options for education and social networks.

In the current context, notions of urban and rural seem to be changing rapidly. Rural societies are often stereotyped in terms of their strong adherence to farming, fishing and hunting, and a high regard for tradition. This may be contrasted with urban areas, which are often seen as being characterized by impersonal bureaucracy, rationalised specialization and mechanization. At the same time, however, individuals in urban areas are often part of different social networks, and have the option to choose between different jobs and a wider variety of cultural activities. And this contrasts with the perception that the rural life may be bleak and without significant options for choice and individual behaviour. These perceptions – along with other issues – are important for understanding the observed demographic shifts involved in urbanization in the Arctic. A critical issue for identifying demographic thresholds is to determine which factors lead some places to grow and some to be abandoned. There is also widespread concern about whether incoming industry is exploiting Arctic people, as well as about widening gaps between communities, in terms of access to new technologies and socio-infrastructure investments. In this context, there has also been growing attention to the way in which men's and women's different exposure and preferences shape social, cultural and demographic change.

The diaspora process in the Arctic is one of migration away from often sparsely populated areas and other isolated regions. Individuals tend to maintain their identity, social networks and social ties to the place they have left, while at the same time creating parallel networks in the place to which they have moved. A crucial question is whether or not the relations and networks in one place or another are robust enough to be sustained. Here, too, there is scope for conceptualizing these social changes in terms of thresholds, and the reconfiguring of social networks.

4.4.2 Social resilience, adaptation and livelihoods

Adger (2000) distinguishes between ecological and social resilience, but nonetheless points to their mutuality: a resilient ecosystem may reinforce the resilience of the social system, and vice versa. The pilot case studies described in Chapters 7–10 of this report highlight that social and ecological resilience are clearly linked, and provide an important basis for further assessment of these links across the Arctic region.

However, merely appropriating the concept and the principles of ecological resilience and applying them to social systems "assumes that there are no essential differences in behaviour and structure between socialized institutions and ecological systems" (Adger 2000). A fundamental challenge for a social-ecological systems approach is that it reduces the complexity of society to an observable equivalent of nature, rather than viewing it as ontologically unique and distinct. In attempts to define and identify thresholds, resilience, vulnerability and tipping points, it can fall short because it fails to provide an adequate definition of society. Adger (2000) argues that explicit attention to social resilience is important for understanding how individuals and social groups respond and adapt to social change. Society and nature need to be considered within the theoretical frameworks of resilience and vulnerability, but they also need to be recognized as ontologically different. The essence of resilience as the basis for adaptive strategy is to retain, and to act upon, information about the possible relationships between people and the environment, because these relationships are at the core of understanding environmental problems and ecological change. Yet these complex relationships may be difficult to understand if society and environment are conflated as a coupled social-ecological system (Davidson 2010).

One important aspect of the resilience concept is that it recognizes human agency (Finan 2009; Nuttall 2009). From an anthropological perspective, Finan argues that adaptation, vulnerability, and resilience are social phenomena that convey significant information about local decision-making processes. These processes are often affected and inhibited by such factors as powerlessness and inequity, but also indicate often-remarkable coping and survival strategies. In viewing adaptation as a strategy to reduce vulnerability and enhance resilience, we cannot consider human-environment dynamics without taking into account issues such as power, culture, race, class, gender and ethnicity. Finan argues for a "quintessentially holistic" livelihoods approach that addresses these issues, and "that formally incorporates natural system change (abrupt or cumulative) into a dynamic human system defined by its multiple asset packages (human, social, political, economic, and physical capitals), the sets of decisions that mobilize and allocate these resources, and the outcomes of these decisions" (Finan 2009, p.177).

Coastal communities face new risks and opportunities as ice sheets melt

Social resilience not only depends on ecosystem functions and diversity, but also on the institutional rules that govern social and economic systems. Can governance institutions create additional opportunities to increase resilience, flexibility and the ability to deal with change? How can, for example, new governance mechanisms help people negotiate and manage the impacts of rapid environmental change? The answer to these questions depends on a range of factors, including an improved understanding of the nature of relationships between people, communities, their environments and institutions as a basis for developing effective policy responses. Institutions or governance systems are often regarded (and relied upon) as a positive source of resilience. However, dysfunctional institutions can hinder resilience. The history of Arctic social-ecological systems is crowded with cases of failed governance regimes that pre-date the current focus on climate change, and show the power of existing laws and customs to thwart resilience.

Institutions can be regarded as either external drivers or internal components of the system. Given the structures and dynamics of institutional change, institutions are generally slow controls on the system, although this is not always the case. For example, as discussed below, new laws can have sudden impacts – and sweeping unintended consequences. Adger (2009) defines social resilience as the ability of groups or communities to cope with external stresses and disturbances as a result of social, political, and environmental change. He goes on to argue that it is institutionally determined and, as such, can be examined through a number of proxy indicators, such as economic structure, institutional change, and demographic change. However, resilience also depends on how people perceive and conceptualize change—in short, people's world view goes some way to determine the kinds of adaptive strategies they utilize (Nuttall 2009).

The challenge that Arctic communities face is to maintain their long-term viability – socially, economically, and culturally, and despite the unpredictability of future conditions – by promoting resilience and sustainable use of local resources. Societies across the Arctic are culturally and economically diverse and are affected by environmental change in different ways. Such diversity also means that local impacts and responses to climate variability and change may not be universal. As Scheraga and Grambsch (1998, p.87) put it, there "is a regional texture to changes in climate, and therefore to the effects of climate change," as well as a regional texture to the risks and opportunities that climate change presents. Communities differ in the ways they perceive risk and resilience, in the strategies they use for mitigating negative change or taking hold of positive opportunities, and in the effectiveness of local adaptive capacity. The resilience of many Arctic communities has been challenged by governance systems and institutions that often constrain the availability of locally specific resources around communities over the long term, and the entitlement of individuals and rights of communities to access those resources (e.g., Heikkinen et al. 2011). This points to the continuing importance of research on localized, regional and circumpolar studies of the socio-economic impacts of recent societal and environmental change, to improve understanding of how potential impacts are distributed across different regions and populations.

4.4.3 The role of law in resilience

Law is such a pervasive sub-system of society and the human world that it is difficult to imagine any area of modern western society that is not covered by the legal system. A key function of law (and legal systems) is that it not only regulates human behaviour on the basis of shared values but also, in effect, creates and maintains the basic values of that society. For instance, the definition of who is a legal person or subject is created in law, and this influences how people perceive themselves, and as what type of "unit", in a given social system. The definition of which entities can enact laws in which specific ways – a definition that is made in constitutional law – conditions us to accept certain institutions as authoritative. Law defines who can own land and under what conditions, and sets clear limits to government policy.

The difficulty in identifying general traits of law as a social system or as a component of a social system is that there are various different legal cultures (civil law, common law, indigenous customary laws, European Union law, international law), all of which have their own view on what the place of law is in human communities. Even without addressing these specific features of the legal system, it is difficult to describe what role law would have in contributing to a state change, because law is everywhere, and it can play the role of both a driver of change and an impediment to it (Bankes 2005; Berkes et al. 2005). For example, in the case of mining, law tends to impede change. It sets out and maintains the basic fundamental rights on who can own space and in what manner. This means that generally, law is long lasting and difficult to alter. Law empowers certain institutions to enact generally applicable rules, even if no such general consensus exists at a given time. It transmits institutions, such as the rules that determine how mining should be done, from the past to the future, with the effect that whenever social agents want to revise a law, they need to confront the basics of how mining has been conducted in the country for a very long time (which makes it hard to effect a major change via new legal rules). At the same time, it includes possibilities for various individuals and groups to invoke their fundamental or human rights in order to change the rules of the game.

If we are to say something general about the role of law in influencing the resilience of the Arctic, we must identify some commonalities in its legal systems. But we have to also admit that there are differing and at times conflicting conceptions of how law functions in different parts of the Arctic, making law a complex social system in itself.

Predominant scales of law

Most legal systems or sub-systems operate on the basis of geographical regions, such as the planet, European Union countries, nation-states, and federal states. The predominant and most influential legal system in the Arctic still functions at the level of the nation-state. This is not only because each nation-state produces and enacts laws that apply across their own territory, but also because all the international obligations (which are nowadays plentiful) are implemented via nation-states. Although law is always in a state of change as new policies are developed and new precedents set, the current nation-state system (which international law upholds) has been particularly resilient to any clear changes. Even where there may be new polities emerging, these new human societies (almost without exception) opt to become new nation-states, since this guarantees them the full membership in an international society.

The predominance in law of the nation-state means that law differs from many other disciplines and practices in terms of understandings of the various "layers" and connections across scales. (For example, for economy, the nesting of scales might be family-village-regional economy-global.) This is worth noting simply because it raises the question of how well a legal system can take into account the nation-state's peripheries. There is a general view that Arctic considerations do not routinely play a significant role in the enactment of national legislation (e.g., acts of parliament). This has been evident in the past for most Arctic states, except arguably for Iceland, where the geographical scale of the "periphery" is much smaller.

Institutions need to respond to the prospects of increased access to the Arctic as sea ice melts

A characteristic of western legal systems is that law tends to be perceived as associated with the more long-lasting social institutions (ownership, family law, inheritance, and so on), rather than with dramatic change. Even though rapid transformations are also possible, as in the case of important court cases that change the course of society, legal scholarship tends more to analyze how legislative change can be fitted into the vast amount of already existing legislation. Legal scholars and practitioners are generally more focused on looking into the past, rather than the future.

The influence of law in contributing to social change (and vice versa)
Law is a powerful factor in shaping how society evolves, since it is linked both to notions of legitimacy (what is accepted by most members of society) and punishment (those who breach the law will have to suffer the consequences). Legal developments often play a key role in determining in which direction societies will change. Supreme Court decisions or new legislation have a direct impact on society. International treaties or EU legislation also have a strong influence, especially if these are incorporated and implemented properly via the national legislation. New international treaties have now been negotiated under the auspices of the Arctic Council. In the context of increasing international focus on exploration of the Arctic's national resources, in all likelihood these treaties will have an influence on matters like how search and rescue operations or oil spills are managed in the region.

Still, law is only one of the factors in the continuous evolution of societies, sometimes playing a bigger, sometimes a smaller, role. Nowadays, when legal systems interact with each other (in similar ways as economies do, or human communities), it is difficult to predict what type of changes will be caused by, say, one single court decision. For instance, the 1992 Mabo decision on native title in Australia (Australia Bureau of Statistics 1995) had a significant impact nationally (even if modified by Australia's later legislative enactments), and these judgements about traditional land rights have also inspired and influenced many other jurisdictions and international law.

Climate change offers a prominent example of how law can play a negative role. International law enables each and every nation-state to decide whether or not to participate in an international treaty and under what conditions. It also has weak enforcement institutions in general. As a result, the climate regime under the UN Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol has been at the mercy of each state. This shows that international law upholds and maintains the nation-state system, which makes it difficult to come up with strong measures against undesirable outcomes for society, such as the impacts of climate change.

Thus legal developments can have either a positive or negative influence on whether the state of society – or the state of an ecosystem service – will change from one regime to another. A very broad generalization is that law acts mostly as a conservative force in society, for better or for worse. The concept of law is mostly associated with institutions that have a very long history, and which are resilient to change (especially as to their fundaments). In the context of a rapidly changing environment, law can perhaps be said to be amplifying the worsening state of ecosystem services, since to maintain or restore the health of these services would require effective response policies, which have to meet the institutions maintained by law. Yet, as argued above, sometimes reform policies take place via legal institutions, and this can happen also in respect of countering the problems observed in the state of ecosystem services. Because of this complexity, legal issues will be an important lens through which changes, including thresholds, should be viewed in the case studies and further analysis of the ARR.

Global demand for resources is focusing attention on the Arctic region

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4.4.4 Economic perspectives on thresholds
Economic systems can easily be pictured as complex systems with multiple actors pursuing different goals, thereby creating a self-organizing entity driven by individual heterogeneous objectives forming demand and supply for goods and services. The resulting market prices and other outcomes then feedback on individual actors and affect their behaviour. These forces sometimes increase social welfare and sometimes decrease it, depending on how sources of potential market failures are addressed, such as externalities, public goods, incomplete markets, imperfect information, non-convexities and thresholds (see, e.g., Smith 1776; Arrow 1951; Debreu 1959; Krugman 1996).

With regard to any economic activity, an important threshold occurs when individuals or other entities with decision power (firms, municipalities, or governments) decide to undertake an activity or not. For example a firm will typically decide to produce some good or service, or extract some resource, if it is profitable to do so. This depends on multiple factors such as the demand for the output, existing supply by other firms, production costs and whether or not a positive profit might be made. For a municipality, the decision criteria can be quite similar, but instead of maximizing profit the municipality may want to increase the aggregated wellbeing of the community's citizens.

It has proven very difficult to evaluate the socio-economic impact of ecological factors, especially of regime shifts, in ecosystems (Crépin et al. 2012). One of the few well-documented examples is the 1992 fisheries collapse of the North-West Atlantic cod (*Gadus morhua*). The cod stock went from being the largest in the world (millions of tons in the late 1960s, generating annual catches of up to 800,000 tons) to just 1% of earlier levels (Fudge and Rose 2008). The collapse was due to overfishing combined with climatic factors (Myers et al. 1997; Rose 2004). Its societal consequences were well documented in Newfoundland, where it affected the livelihoods of about 40,000 fishermen and associated jobs, and caused a fall in revenue from landings of over USD 200 million per year (Steele et al. 1992; Brubaker 2000; Gien 2000; Hamilton and Butler 2001). Eventually society adapted to the change and invested in invertebrate fisheries and other high value species (e.g., the Northern shrimp (*Pandalus borealis*), snow crabs (*Chionocetes opilio*) and American lobster (*Homarus americanus*) (Worm and Myers 2003). In West Greenland fishermen started catching shrimp and Greenland halibut (*Reinhardtius hippoglossoides*) when the cod vanished (Hvingel 2003; Hamilton et al. 2000). Meanwhile local adaptation was uneven. Some communities, such as Paamiut, lost their economic vitality with a following decline in population due to out-migration. In contrast others grew rapidly, like Sisimiut, 500 km farther north, which had already targeted other species than the cod (Hamilton et al. 2000; Rasmussen and Hamilton 2001). While some insights about resilience and sustainability can be drawn from this experience, the gaps in scientific and socio-economic evidence mean that the risks and opportunities being presented through current trends in the Arctic (especially in the High Arctic) are largely unseen.

In the Arctic, sectors like fisheries and oil, gas and mineral extractions are strongly influenced by world market outcomes for these goods, again highlighting the need for the ARR to advance methodologies for characterizing cross-scale interactions in social-ecological system resilience. For example, global demand and supply for oil influence its market price. Up to now, the market price has been low compared to the costs of oil exploitation in the Arctic, implying negative profit – and explaining why Arctic oil production has not taken off on a large scale yet. This is changing fast, as increased world demand, decreased production costs in the Arctic and decreased production in other parts of the world raise the prospects of the oil market price exceeding costs, making it profitable to start exploiting these resources on a larger scale in the Arctic (Harsem et al. 2011).

Arguably, a threshold has already been passed in this context: as of 2012, every shelf sea[2] in the Arctic now has oil exploration, after drilling began in the Chukchi Sea. Whereas up to this point, the Arctic has been a vital part of the Earth system's self-balancing climate mechanism through its albedo effect, it is now undeniably seen as a resource – and the source of accelerating anthropogenic climate change. In economic terms, this could be envisaged as some kind of profitability threshold: depending on the costs and benefits of different activities, some will be profitable and will then probably take place while others will not. If the global market price of oil keeps increasing and Arctic infrastructure keeps improving, at some point it will become lucrative to start oil exploitation in new places in the region where it is not yet profitable. Crépin et al. (2012) discuss how global economic dynamics may result in social-ecological transitions and shocks at other scales.

4.5 Outlook for feedbacks and thresholds in social-ecological systems

It is clear that we, as a global community, are about to cross several thresholds in the Arctic (Wassmann and Lenton 2012). This first phase of the ARR has demonstrated the widespread concern across many areas of academic inquiry about the current rates of change and the complex patterns of transformation in both social and biophysical systems in the region. Many kinds of change in the Arctic can already be characterized in terms of crossing thresholds, and the combined picture from these multiple perspectives is clear: the outlook for the future is for even more dynamic change and transformation. Expert contributors have made comparisons with the Arab Spring, the opening of the Amazonian frontiers and even the U.S. gold rush in the 1840s. The prospects for people's livelihoods in Arctic communities are entwined with the concerns and ambitions of people far away from Arctic landscapes and seascapes. For some people, the condition of the natural environment and its capacity to sustain ecosystem functioning and the benefits this provides to society are pressing concerns, while for others the biophysical dynamics of the Arctic may seem an irrelevance.

Exemplifying the challenge, the climatic changes in the Arctic represent an entirely new situation: the causes of the changes are almost entirely external to the Arctic region, and even if they were to cease immediately, the dynamics and lags of the Earth system have already committed the Arctic to major changes and impacts over the coming decades. The current trends and the

2 See: http://blogs.nature.com/news/2012/09/arctic-oil-drilling-begins-in-chukchi-sea.html

prospects of future change severely test the ability of existing institutions to deliver policies that are sustainable over time. The marginal ice zones are no longer the last frontier of the unknown polar regions; they are simultaneously becoming the trenches of the fight against climate change and the horizons for the world's future development opportunities. Climate driven changes have resulted in a significant reduction of Arctic ice mass, and this is reducing the cost of oil and gas exploration, thus making increased resource exploitation activity more likely. At the same time, as a result of new technological improvements, the oil and gas industry is able to tackle the previously prohibitive challenges of increasing ice movement and changes in ice structure.

This is a challenging time because of the large uncertainties about the consequences of crossing social and biophysical thresholds and the extent to which we can or should avoid doing so. Meanwhile, knowing this in advance also offers substantial opportunities to document the ongoing changes in a way never experienced before. In principle we also have the opportunity to experiment to some extent with adaptation strategies and thus learn more about what works well and what is less successful. For example, ecosystem-based ocean management is a useful strategy for confronting the challenges posed by rapid climate change (Hoel 2009); existing management regimes are flexible and have a proven capacity to adapt to change.

The Arctic can be an important bellwether for global change

However, in the face of such complex objectives and changes, how can the ecosystem services concept be applied? In the typologies of ecosystems services used for the 2005 Millennium Ecosystem Assessment and other assessments and studies, different kinds of services are often framed in terms of trade-offs. In the context of a rapidly changing natural environment, it is worth highlighting the expert consensus set out in The Economics of Ecosystems and Biodiversity (TEEB 2010), in which provisioning, regulating and cultural services may be traded off against each other, but the supporting functions provided by habitat structures and processes underpin the flows of these services. Eroding these underpinnings puts the other ecosystem benefits to society at risk. Dearing et al. (2012) have shown how tracking the flows in a region's ecosystem services over time can highlight where trends are converging and reducing the capacity of the underpinning habitat to maintain those flows, and can potentially be a useful way of identifying social-ecological system thresholds.

Using the different categories of ecosystem services (i.e. provisioning, regulating, cultural, plus habitat as an underpinning condition) might also help to systematically identify and explain links between scales (i.e., local, regional, pan-Arctic and global) where thresholds may be important. For example, the role of Arctic ice cover in regulating the planet's climate is a link between a regional environmental variable and a global ecosystem service. In broad terms, the regulating services provided by the Arctic (e.g., the role of albedo and thermohaline circulation in maintaining Earth's heat balance, or of permafrost in Earth's carbon cycling) have important global benefits, but these are not well understood nor adequately captured in decision-making processes. Provisioning services bridge geographic scales (e.g., reindeer husbandry is primarily local, fisheries are regional, and extractive resources range from regional to global) – but there is growing evidence of shifts in scale and of transnational "teleconnections". The benefits of cultural ecosystem services are mostly regarded as locally realised, but examples of a much wider range include the increasingly iconic role of polar bears in environmentalism, Lapland as the home of Santa Claus, the longstanding appeal of polar explorers, and the tourism draw of the northern lights and midnight sun. As the world's attention turns increasingly to the Arctic, it is likely that new constituencies will develop many more Arctic cultural reference points.

Transgressing ecosystem thresholds entails large and persistent changes in ecosystem services, with more or less substantial welfare implications. These could also lead to a regime shift in the social system (e.g., Hvingel 2003; Hamilton et al. 2000), but the links between flows of ecosystem services and the resilience of social-ecological systems are still not well understood beyond the general conceptual level. Ecosystem services are influenced both by ecological processes and how we (as society) value the ecosystems. Valuation is a social (multi-actor) process, so there is a need to consider how best to achieve a collective recognition of the values embedded in the Arctic, to demonstrate these values in decision-making processes, and capture these values in processes that set priorities for action in the region and beyond.

4.6 Conclusions, key findings, and the process ahead

The "joining up" of knowledge about Arctic thresholds across scientific disciplines is still in its exploratory stage. In order to deepen the understanding of current and potential thresholds in coupled social-ecological systems in the Arctic context, the ARR plans to continue to engage in various modes of expert and stakeholder debate. The October 2012 project workshop at Guovdageaidnu/Kautokeino was an important milestone in this process. A planned activity for the second phase of the ARR is to devise a template-based approach for a structured process to elicit expert opinion (Arkes et al. 1997; Stirling 2005; Aspinall 2010). Given the novelty and uncertainty in this area of research, "mapping" expert judgment about Arctic system change can be a valuable way to inform a transparent and comprehensive integrative synthesis.

Female polar bear on melting sea ice, Franz Josef Land, Russian Arctic National Park

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Bringing together knowledge about social-ecological changes from multiple perspectives and contexts is a challenge that must not be underestimated. Integrating knowledge across disciplines and across the science-policy-practice boundaries is recognized as a major contemporary challenge (Cornell et al. 2013) and an area of expertise in its own right (Bammer 2005). For the next stages of the ARR, several integrative approaches are available that have demonstrated their value for representing and understanding thresholds in social-ecological systems. These include the participatory development of representations of system change (such as causal loop diagrams; e.g., Mendoza and Prabhu 2005; Cockerill et al. 2007; Fazey 2010); the Resilience Alliance's scale/disturbance templates to support analysis of change (Resilience Alliance 2010); and narrative descriptions (examples of which can be found in the Regime Shifts Database, at: *www.regimeshifts.org*). A common feature of all of these approaches is that they engage directly with people who live or operate within the systems of interest, reflecting the fact that communities often know a great deal about the value of "their" ecosystem services. However, applying these approaches presents two challenges for the next steps of the ARR. First, the stakeholders of interest now include not just the local inhabitants of the Arctic but also a much broader swathe of the global community. Secondly, these interconnections and interdependencies highlight more than ever the need for a clear focus on scientific responsibility and the role of research, and on the building of processes that are socially trustworthy and which support the development of the necessary insights into prospective Arctic social-ecological change.

Rapid, widespread, and in some cases irreversible biophysical changes are happening across the whole Arctic region. At the same time, social transformations are taking place, often in complex inter-relation with environmental change. The world's attention is focusing on the Arctic not least because many of these linked changes have pivotal implications for future global climate (whether by the inadvertent release of methane as permafrost thaws, or through the deliberate extraction of the region's fossil fuels). These changes link Arctic communities to diverse interests around the globe, bringing new risks and opportunities. The potential impacts of Arctic "tipping points" on ecosystems and on human wellbeing require a robust framework for policy and management to be put in place that addresses the risk of thresholds and associated regime shifts. Such a framework would benefit from more systematic information gathering on both social and biophysical trends, supporting modelling and prediction programmes to analyse potential thresholds and their impacts. The ARR analysis also shows the limits of prediction of such complex linked systems. The framework must also be flexible in the face of a wide range of possible futures. Despite their shortcomings, existing management regimes in the Arctic have shown their responsiveness and capacity to change. Adaptation has been the prime strategy in the Arctic throughout the times ■

References

ACIA (2005). *Arctic Climate Impact Assessment – Scientific Report*. J. Berner, C. Symon, L. Arris, and O. W. Heal (eds.). Cambridge University Press, Cambridge, UK, and New York. http://www.acia.uaf.edu/pages/scientific.html.

Adger, W. N. (2000). Social and ecological resilience: Are they related? *Progress in Human Geography*, 23(3). 347–64. DOI:10.1191/030913200701540465.

Adger, W. N., Dessai, S., Goulden, M., Hulme, M., Lorenzoni, I., et al. (2009). Are there social limits to adaptation to climate change? *Climatic Change*, 93(3-4). 335–54. DOI:10.1007/s10584-008-9520-z.

Adger, W. N. and Kelly, P. M. (1999). Social vulnerability to climate change and the architecture of entitlements. *Mitigation and Adaptation Strategies for Global Change*, 4(3-4). 253–66. DOI:10.1023/A:1009601904210.

AHDR (2004). *Arctic Human Development Report*. N. Einarsson, J. N. Larsen, A. Nilsson, and O. R. Young (eds.). Prepared by the Stefansson Arctic Institute, under the auspices of the Icelandic Chairmanship of the Arctic Council 2002-2004, Akureyri, Iceland. http://www.svs.is/ahdr/.

AMAP (2011). *Snow, Water, Ice and Permafrost in the Arctic (SWIPA).* Arctic Monitoring and Assessment Programme, Oslo, Norway. http://amap.no/documents/index.cfm?dirsub=%2FSnow%2C%20Water%2C%20Ice%20and%20Permafrost%20in%20the%20Arctic%20%28SWIPA%29.

AMAP (2003). *AMAP Assessment 2002: Influence of Global Climate on Contaminant Pathways to, Within, and from the Arctic*. Arctic Monitoring and Assessment Programme, Oslo, Norway. http://amap.no/documents/index.cfm?dirsub=/AMAP%20Assessment%202002%20-%20The%20Influence%20of%20Global%20Change%20on%20Contaminant%20Pathways.

Anisimov, O. A., Vaughan, D. G., Callaghan, T. V., Furgal, C., Marchant, H., et al. (2007). Polar regions (Arctic and Antarctic). Chapter 15 in *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds.) Cambridge University Press, Cambridge, 653-685. http://ipcc.ch/publications_and_data/ar4/wg2/en/ch15.html

Anthony, K. M. W., Anthony, P., Grosse, G. and Chanton, J. (2012). Geologic methane seeps along boundaries of Arctic permafrost thaw and melting glaciers. *Nature Geoscience*, 5(6). 419–26. DOI:10.1038/ngeo1480.

Anthony, R. G., Estes, J. A., Ricca, M. A., Miles, A. K. and Forsman, E. D. (2008). Bald eagles and sea otters in the Aleutian archipelago: indirect effects of trophic cascades. *Ecology*, 89(10). 2725–35. DOI:10.1890/07-1818.1.

ArcticNet (2010). *Impacts of Environmental Change in the Canadian Coastal Arctic: a Compendium of Research Conducted During ArcticNet Phase I (2004-2008)*. ArcticNet Inc., Québec City, Canada. http://www.arcticnet.ulaval.ca/pdf/research/compendium.pdf.

Arft, A., Walker, M., Gurevitch, J. et al, Alatalo, J., Bret-Harte, M. (1999). Responses of tundra plants to experimental warming: meta-analysis of the international tundra experiment. *Ecological Monographs*, 69(4). 491–511. DOI:10.1890/0012-9615(1999)069[0491:ROTPTE]2.0.CO;2.

Arkes, H. R., Manpower, J. and Stewart, T. R. (1997). Combining expert opinions. *Science*, 275(5299). 463. DOI:10.1126/science.275.5299.461e.

Arp, C. D., Jones, B. M., Schmutz, J. A., Urban, F. E. and Jorgenson, M. T. (2010). Two mechanisms of aquatic and terrestrial habitat change along an Alaskan Arctic coastline. *Polar Biology*, 33(12). 1629–40. DOI:10.1007/s00300-010-0800-5.

Arrigo, K. R. and van Dijken, G. L. (2011). Secular trends in Arctic Ocean net primary production. *Journal of Geophysical Research: Oceans*, 116(C9). C09011. DOI:10.1029/2011JC007151.

Arrow, K. J. (1951). *Social Choice and Individual Values.* (2nd edition 1963). Yale University Press, New Haven, Connecticut.

Aspinall, W. (2010). A route to more tractable expert advice. *Nature*, 463(7279). 294–95. DOI:10.1038/463294a.

Australia Bureau of Statistics (1995). The Mabo Case and the Native Title Act. *Year Book Australia, 1995*. ABS Catalogue No. 1301.0, Canberra, Australia. http://www.abs.gov.au/Ausstats/abs@.nsf/Previousproducts/1301.0Feature%20Article21995.

Bammer, G. (2005). Integration and Implementation Sciences: Building a New Specialization. *Ecology and Society*, 10(2). Art. 6.

Bankes, N. (2005). Exploring the roles of law and hierarchy in ideas of resilience: regulating resource harvesting in Nunavut. *Breaking Ice: renewable resource and ocean management in the Canadian North.* F. Berkes, R. Huebert, H. Fast, M. Manseau, and A. Diduck (eds.). University of Calgary Press, Calgary.

Barber, D. G., Asplin, M. G., Papakyriakou, T. N., Miller, L., Else, B. G. T., et al. (2012). Consequences of change and variability in sea ice on marine ecosystem and biogeochemical processes during the 2007–2008 Canadian International Polar Year program. *Climatic Change*, 115(1). 135–59. DOI:10.1007/s10584-012-0482-9.

Barber, D. G., Asplin, M. G., Raddatz, R. L., Candlish, L. M., Nickels, S., et al. (2012). Change and variability in sea ice during the 2007–2008 Canadian International Polar Year program. *Climatic Change*, 115(1). 115–33. DOI:10.1007/s10584-012-0477-6.

Barnosky, A. D., Hadly, E. A., Bascompte, J., Berlow, E. L., Brown, J. H., et al. (2012). Approaching a state shift in Earth's biosphere. *Nature*, 486(7401). 52–58. DOI:10.1038/nature11018.

Beck, R. A., Eisner, W., Hinkel, K., Pesanti, H., Ellis, B., et al. (2005). Nutarniq: Uniting the Arctic Community with a Wireless Arctic Network for Circumpolar Communications. *Polar Geography*, 29(1). 43–78. DOI:10.1080/789610165.

Becker, G. S. (1993). Nobel lecture: The economic way of looking at behavior. *Journal of Political Economy*, 101(3). 385–409.

Becker, G. S. (1965). A Theory of the Allocation of Time. *The Economic Journal*, 75(299). 493–517.

Becker, G. S., Duesenberry, J. S. and Okun, B. (1960). An economic analysis of fertility. *Demographic and economic change in developed countries*. Columbia University Press, New York and London. 225–56. http://www.nber.org/chapters/c2387.pdf.

Berkes, F., Huebert, R., Fast, H., Manseau, M. and Diduck, A., eds. (2005). *Breaking Ice: Renewable Resource and Ocean Management in the Canadian North.* University of Calgary Press, Calgary.

Berkes, F. and Jolly, D. (2001). Adapting to Climate Change: Social-ecological Resilience in a Canadian Western Arctic Community. *Conservation Ecology*, 5(2). Art. 18.

Beylich, A. A., Sandberg, O., Molau, U. and Wache, S. (2006). Intensity and spatio-temporal variability of fluvial sediment transfers in an arctic-oceanic periglacial environment in northernmost Swedish Lapland. *Geomorphology*, 80(1-2). 114–30. DOI:10.1016/j.geomorph.2005.09.014.

Bhatt, U. S., Walker, D. A., Raynolds, M. K., Comiso, J. C., Epstein, H. E., et al. (2010). Circumpolar Arctic tundra vegetation change is linked to sea ice decline. *Earth Interactions*, 14(8). 1–20.

Bhiry, N., Delwaide, A., Allard, M., Bégin, Y., Filion, L., et al. (2011). Environmental Change in the Great Whale River Region, Hudson Bay: Five Decades of Multidisciplinary Research by Centre d'études Nordiques (CEN). *Ecoscience*, 18(3). 182–203. DOI:10.2980/18-3-3469.

Björk, R. G. and Molau, U. (2007). Ecology of Alpine Snowbeds and the Impact of Global Change. *Arctic, Antarctic, and Alpine Research*, 39(1). 34–43. DOI:10.1657/1523-0430(2007)39[34:EOASAT]2.0.CO;2.

Blok, D., Sass-Klaassen, U., Schaepman-Strub, G., Heijmans, M., Sauren, P. and Berendse, F. (2011). What are the main climate drivers for shrub growth in Northeastern Siberian tundra? *Biogeosciences Discussions*, 8(5). 1169–79. DOI:10.5194/bgd-8-771-2011.

Bokhorst, S., Bjerke, J., Bowles, F., Melillo, J., Callaghan, T. and Phoenix, G. (2008). Impacts of extreme winter warming in the sub-Arctic: growing season responses of dwarf shrub heathland. *Global Change Biology*, 14(11). 2603–12. DOI:10.1111/j.1365-2486.2008.01689.x.

Bokhorst, S. F., Bjerke, J. W., Tømmervik, H., Callaghan, T. V. and Phoenix, G. K. (2009). Winter warming events damage sub-Arctic vegetation: consistent evidence from an experimental manipulation and a natural event. *Journal of Ecology*, 97(6). 1408–15. DOI:10.1111/j.1365-2745.2009.01554.x.

Box, J. E., Fettweis, X., Stroeve, J. C., Tedesco, M., Hall, D. K. and Steffen, K. (2012). Greenland ice sheet albedo feedback: thermodynamics and atmospheric drivers. *The Cryosphere*, 6(821-839). 6–821. DOI:10.5194/tc-6-821-2012.

Brands, S., Herrera, S., Fernandez, J. and Gutierrez, J. M. (forthcoming). How well do CMIP5 Earth System Models simulate present climate conditions? A performance comparison for the downscaling community. *Climate Dynamics* (in press).

Brock, W. A. and Starrett, D. (2003). Managing systems with non-convex positive feedback. *Environmental and Resource Economics*, 26(4). 575–602. DOI:10.1023/B:EARE.0000007350.11040.e3.

Broecker, W. (1997). Thermohaline Circulation, the Achilles Heel of Our Climate System: Will Man-Made CO2 Upset the Current Balance? *Science*, 278(5343). 1582–88. DOI:10.1126/science.278.5343.1582.

Brown, Z. W. and Arrigo, K. R. (2013). Sea ice impacts on spring bloom dynamics and net primary production in the Eastern Bering Sea. *Journal of Geophysical Research: Oceans*, 118(1). 43–62. DOI:10.1029/2012JC008034.

Brown, Z. W. and Arrigo, K. R. (2012). Contrasting trends in sea ice and primary production in the Bering Sea and Arctic Ocean. *ICES Journal of Marine Science: Journal du Conseil*, 69(7). 1180–93. DOI:10.1093/icesjms/fss113.

Brubaker, E. (2000). Unnatural disaster: How politics destroyed Canada's Atlantic ground fisheries. *Political Environmentalism: Going Behind the Green Curtain*. T. I. Andersson (ed.). Hoover Institution Press. 161–210.

CAFF (2010). *Arctic Biodiversity Trends 2010: Selected Indicators of Change.* CAFF International Secretariat, Akureyri, Iceland. www.arcticbiodiversity.is.

Callaghan, T. V., Johansson, M., Brown, R. D., Groisman, P. Y., Labba, N., Radionov, V., Bradley, R. S., et al. (2011a). Multiple effects of changes in Arctic snow cover. *AMBIO*, 40(1). 32–45. DOI:10.1007/s13280-011-0213-x.

Callaghan, T. V., Johansson, M., Brown, R. D., Groisman, P. Y., Labba, N., Radionov, V., Barry, R. G., et al. (2011b). The changing face of Arctic snow cover: A synthesis of observed and projected changes. *AMBIO*, 40(1 Supplement). 17–31. DOI:10.1007/s13280-011-0212-y.

Callaghan, T. V., Jonasson, C., Thierfelder, T., Zhenlin, Y., Hedenås, H., et al. (in press). Ecosystem change and stability over multiple decades in the Swedish sub-Arctic: complex processes and multiple drivers. *Philosophical Transactions of the Royal Society B: Biological Sciences*, .

Campbell, D. and Bergeron, J. (2012). Natural Revegetation of Winter Roads on Peatlands in the Hudson Bay Lowland, Canada. *Arctic, Antarctic, and Alpine Research*, 44(2). 155–63. DOI:10.1657/1938-4246-44.2.155.

Carmack, C. E., McLaughlin, A. F., Vagle, S., Mellinga, H. and Williams, W. J. (2010). Structures and property distributions in the three oceans surrounding Canada in 2007: A basis for a long-term ocean climate monitoring strategy. *Atmosphere-Ocean*, 48(4). 211–24. DOI:10.3137/OC324.2010.

Carpenter, S. R. and Brock, W. A. (2008). Adaptive Capacity and Traps. *Ecology and Society*, 13(2). Art. 40.

Carson, D., Rasmussen, R. O., Ensign, P., Huskey, L. and Taylor, A., eds. (2011). *Demography at the Edge: Remote Human Populations in Developed Nations*. Ashgate Publishing, Ltd., Farnham, UK.

Carstensen, J. and Weydmann, A. (2012). Tipping Points in the Arctic: Eyeballing or Statistical Significance? *AMBIO*, 41(1). 34–43. DOI:10.1007/s13280-011-0223-8.

Carstensen, J., Weydmann, A., Olszewska, A. and Kwaśniewski, S. (2012). Effects of environmental conditions on the biomass of Calanus spp. in the Nordic Seas. *Journal of Plankton Research*, 34(11). 951–66. DOI:10.1093/plankt/fbs059.

Chapin, F. S. I., Hoel, M., Carpenter, S. R., Lubchenco, J., Walker, B., et al. (2006). Building resilience and adaptation to manage Arctic change. *AMBIO*, 35(4). 198–202. DOI:10.1579/0044-7447(2006)35%5B198:BRAATM%5D2.0.CO;2.

Christensen, L. and Krogman, N. (2012). Social thresholds and their translation into social-ecological management practices. *Ecology and Society*, 17(1). Art. 5. DOI:10.5751/ES-04499-170105.

Christensen, T. R., Johansson, T., Akerman, H. J., Mastepanov, M., Malmer, N., et al. (2004). Thawing sub-arctic permafrost: Effects on vegetation and methane emissions. *Geophysical Research Letters*, 31(4). L04501.

Christie, P. and Sommerkorn, M. (2012). *RACER: Rapid Assessment of Circum-Arctic Ecosystem Resilience.* 2nd edition. WWF Global Arctic Programme, Ottawa, Canada. http://wwf.panda.org/what_we_do/where_we_work/arctic/publications/?204373/racer.

Cockerill, K., Tidwell, V., Passell, H. and Malczynski, L. (2007). Cooperative modeling lessons for environmental management. *Environmental Practice*, 9(1). 28–41. DOI:10.1017/S1466046607070032.

Collier, R. B. and Collier, D. (1991). *Shaping the Political Arena*. Princeton University Press, Princeton.

Comeau, S., Gattuso, J.-P., Nisumaa, A.-M. and Orr, J. (2012). Impact of aragonite saturation state changes on migratory pteropods. *Proceedings of the Royal Society B: Biological Sciences*, 279(1729). 732–38. DOI:10.1098/rspb.2011.0910.

Comeau, S., Gorsky, G., Jeffree, R., Teyssié, J. L. and Gattuso, J. P. (2009). Key Arctic pelagic mollusc (Limacina helicina) threatened by ocean acidification. *Biogeosciences Discussions*, 6(1). 2523.

Corbett, J. J., Lack, D. A., Winebrake, J. J., Harder, S., Silberman, J. A. and Gold, M. (2010). Arctic shipping emissions inventories and future scenarios. *Atmos. Chem. Phys*, 10(19). 9689–9704.

Corell, R. and Cleveland, C. (2010). Arctic Climate Impact Assessment (ACIA). *Encyclopedia of Earth*. C. J. Cleveland (ed.). Environmental Information Coalition, National Council for Science and the Environment, Washington, D.C.

Cornell, S., Berkhout, F., Tuinstra, W., Tàbara, J. D., Jäger, J., et al. (2013). Opening up knowledge systems for better responses to global environmental change. *Environmental Science & Policy*, (0). DOI:10.1016/j.envsci.2012.11.008.

Crépin, A.-S. (2007). Using fast and slow processes to manage resources with thresholds. *Environmental and Resource Economics*, 36(2). 191–213. DOI:10.1007/s10640-006-9029-8.

Crépin, A.-S. (2003). Multiple Species Boreal Forests – What Faustmann Missed. *Environmental and Resource Economics*, 26(4). 625–46. DOI:10.1023/B:EARE.0000007352.02799.0e.

Crépin, A.-S., Biggs, R., Polasky, S., Troell, M. and de Zeeuw, A. (2012). Regime shifts and management. *Ecological Economics*, 84. 15–22. DOI:10.1016/j.ecolecon.2012.09.003.

Dahl-Jensen, D., Bamber, J., Bøggild, C., Buch, E., Christensen, J. H. H., et al. (2011). The Greenland Ice Sheet in a changing climate. Chapter 8 in *Snow, Water, Ice and Permafrost in the Arctic (SWIPA)*. Arctic Monitoring and Assessment Programme (AMAP), Oslo.

Davidson, D. J. (2010). The applicability of the concept of resilience to social systems: Some sources of optimism and nagging doubts. *Society & Natural Resources*, 23(12). 1135–49. DOI:10.1080/08941921003652940.

Dearing, J. A., Yang, X., Dong, X., Zhang, E., Chen, X., et al. (2012). Extending the timescale and range of ecosystem services through paleoenvironmental analyses, exemplified in the lower Yangtze basin. *Proceedings of the National Academy of Sciences*, 109(18). E1111–E1120. DOI:10.1073/pnas.1118263109.

Debreu, G. (1959). *Theory of Value: An Axiomatic Analysis of Economic Equilibrium.* Yale University Press, New Haven and London. http://cowles.econ.yale.edu/P/cm/m17/m17-all.pdf.

Delworth, T., Clark, P., Holland, M., Johns, W., Kuhlbrodt, T., et al. (2008). The potential for abrupt change in the Atlantic Meridional Overturning Circulation. *Abrupt Climate Change. A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research*. U.S. Geological Survey, Reston, VA. 117–62. http://downloads.climatescience.gov/sap/sap3-4/sap3-4-final-report-ch4.pdf.

Derksen, C. and Brown, R. (2012). Spring snow cover extent reductions in the 2008-2012 period exceeding climate model projections. *Geophysical Research Letters*, 39.

Duarte, C. M., Agustí, S., Wassmann, P., Arrieta, J. M., Alcaraz, M., et al. (2012). Tipping elements in the Arctic marine ecosystem. *AMBIO*, 41(1). 44–55. DOI:10.1007/s13280-011-0224-7.

Duarte, C. M., Lenton, T. M., Wadhams, P. and Wassmann, P. (2012). Abrupt climate change in the Arctic. *Nature Climate Change*, 2(2). 60–62. DOI:10.1038/nclimate1386.

Dunton, K. H., Weingartner, T. and Carmack, E. C. (2006). The nearshore western Beaufort Sea ecosystem: Circulation and importance of terrestrial carbon in arctic coastal food webs. *Progress in Oceanography*, 71(2–4). 362–78. DOI:10.1016/j.pocean.2006.09.011.

Dybbroe, S., Dahl, J. and Mueller-Wille, L. (2010). Dynamics of Arctic Urbanization: Introduction. *Acta Borealia*, 27(2). 120–24. DOI:10.1080/08003831.2010.527526.

Eakin, H. and Luers, A. L. (2006). Assessing the vulnerability of social-environmental systems. *Annual Review of Environment and Resources*, 31. 365–94. DOI:10.1146/annurev.energy.30.050504.144352.

Elmendorf, S. C., Henry, G. H. R., Hollister, R. D., Björk, R. G., Bjorkman, A. D., et al. (2012). Global assessment of experimental climate warming on tundra vegetation: heterogeneity over space and time. *Ecology letters*, 15(2). 164–75. DOI:10.1111/j.1461-0248.2011.01716.x.

Elmendorf, S. C., Henry, G. H. R., Hollister, R. D., Björk, R. G., Boulanger-Lapointe, N., et al. (2012). Plot-scale evidence of tundra vegetation change and links to recent summer warming. *Nature Climate Change*, 2(6). 453–57. DOI:10.1038/nclimate1465.

Emmerson, C. and Lahn, G. (2012). *Arctic Opening: Opportunity and Risk in the High North*. Lloyd's and Chatham House, London. http://www.lloyds.com/the-market/tools-and-resources/research/exposure-management/emerging-risks/emerging-risk-reports/climate/arctic-report-2012.

Fazey, I. (2010). Resilience and higher order thinking. *Ecology and Society*, 15(3). Art. 9.

Finan, T. (2009). Storm Warnings: The Role of Anthropology in Adapting to Sea Level Rise in Southwestern Bangladesh. *Anthropology and Climate Change: From Encounters to Actions*. S. A. Crate and M. Nuttall (eds.). Left Coast Press, Walnut Creek, CA, US.

Flint, P. L., Mallek, E. J., King, R. J., Schmutz, J. A., Bollinger, K. S. and Derksen, D. V. (2008). Changes in abundance and spatial distribution of geese molting near Teshekpuk Lake, Alaska: interspecific competition or ecological change? *Polar Biology*, 31(5). 549–56. DOI:10.1007/s00300-007-0386-8.

Forbes, D. L., Kremer, H., Lantuit, H., Rachold, V. and Reiersen, L.-O. (2011). *State of the Arctic Coast 2010: Scientific Review and Outlook*. Land-Ocean Interactions in the Coastal Zone, Institute of Coastal Research. http://www.ferrybox.eu/imperia/md/content/loicz/osc/a2_don-forbes.pdf.

Ford, J. D. and Pearce, T. (2012). Climate change vulnerability and adaptation research focusing on the Inuit subsistence sector in Canada: Directions for future research. *The Canadian Geographer / Le Géographe canadien*, 56(2). 275–87. DOI:10.1111/j.1541-0064.2012.00418.x.

Fowbert, J. A. and Smith, R. I. L. (1994). Rapid population increases in native vascular plants in the Argentine Islands, Antarctic Peninsula. *Arctic and Alpine Research*, 26(3). 290–96.

Francis, J. A. and Vavrus, S. J. (2012). Evidence linking Arctic amplification to extreme weather in mid-latitudes. *Geophysical Research Letters*, 39(6). L06801.

Frey, K. E. and McClelland, J. W. (2008). Impacts of permafrost degradation on arctic river biogeochemistry. *Hydrological Processes*, 23(1). 169–82. DOI:10.1002/hyp.7196.

Fudge, S. B. and Rose, G. A. (2008). Life history co-variation in a fishery depleted Atlantic cod stock. *Fisheries Research*, 92(1). 107–13. DOI:10.1016/j.fishres.2008.02.005.

Füssel, H.-M. (2007). Vulnerability: A generally applicable conceptual framework for climate change research. *Global Environmental Change*, 17(2). 155–67. DOI:10.1016/j.gloenvcha.2006.05.002.

Gaillard, J. C. (2007). Resilience of traditional societies in facing natural hazards. *Disaster Prevention and Management*, 16(4). 522–44. DOI:10.1108/09653560710817011.

Gien, L. (2000). Land and sea connection: The East Coast fishery closure, unemployment and health. *Canadian Journal of Public Health*, 91(2). 121–24.

Gordeev, V. V. (2006). Fluvial sediment flux to the Arctic Ocean. *Geomorphology*, 80(1-2). 94–104. DOI:10.1016/j.geomorph.2005.09.008.

Granovetter, M. (1978). Threshold models of collective behaviour. *The American Journal of Sociology*, 83(6). 1420–43.

Grass, D., Caulkins, J. P., Feichtinger, G., Tragler, G. and Behrens, D. A. (2008). *Optimal Control of Nonlinear Processes With Applications in Drugs, Corruption, and Terror*. Springer.

Grebmeier, J. M., Overland, J. E., Moore, S. E., Farley, E. V., Carmack, E. C., et al. (2006). A Major Ecosystem Shift in the Northern Bering Sea. *Science*, 311(5766). 1461–64. DOI:10.1126/science.1121365.

Green, D. (2009). Opal waters, rising seas: how sociocultural inequality reduces resilience to climate change among indigenous Australians. *Anthropology and Climate Change: From Encounters to Actions*. S. A. Crate and M. Nuttall (eds.). Left Coast Press, Walnut Creek, CA. 218–27.

Gregory, J. M., Jones, C. D., Cadule, P. and Friedlingstein, P. (2009). Quantifying carbon cycle feedbacks. *Journal of Climate*, 22(19). 5232–50. DOI:10.1175/2009JCLI2949.1.

Groisman, P. Y., Clark, E. A., Lettenmaier, D. P., Kattsov, V. M., Sokolik, I. N., et al. (2009). The Northern Eurasia Earth Science Partnership: An Example of Science Applied to Societal Needs. *Bulletin of the American Meteorological Society*, 90(5). 671–88. DOI:10.1175/2008BAMS2556.1.

Guo, L., Semiletov, I., Gustafsson, Ö., Ingri, J., Andersson, P., Dudarev, O. and White, D. (2004). Characterization of Siberian Arctic coastal sediments: Implications for terrestrial organic carbon export. *Global Biogeochemical Cycles*, 18(1). DOI:10.1029/2003GB002087.

Hall, C. M., James, M. and Wilson, S. (2010). Biodiversity, biosecurity, and cruising in the Arctic and sub-Arctic. *Journal of Heritage Tourism*, 5(4). 351–64. DOI:10.1080/1743873X.2010.517845.

Hamilton, D. P. and Mitchell, S. F. (1988). Effects of wind on nitrogen, phosphorus and chlorophyll in a shallow New Zealand lake. *Internationale Vereinigung für Theoretische und Angewandte Limnologie*, 23. 624–28.

Hamilton, L. C. and Butler, M. J. (2001). Outport adaptations: Social indicators through Newfoundland's cod crisis. *Human Ecology Review*, 8(2). 1–11.

Hamilton, L., Lyster, P. and Otterstad, O. (2000). Social Change, Ecology and Climate in 20th-Century Greenland. *Climatic Change*, 47(1-2). 193–211. DOI:10.1023/A:1005607426021.

Hansen, B. B., Grotan, V., Aanes, R., Saether, B.-E., Stien, A., et al. (2013). Climate Events Synchronize the Dynamics of a Resident Vertebrate Community in the High Arctic. *Science*, 339(6117). 313–15. DOI:10.1126/science.1226766.

Hansen, J., Lacis, A., Rind, D., Russell, G., Stone, P., et al. (1984). Climate sensitivity: Analysis of feedback mechanisms. *Geophysical Monograph Series*, 29. 130–63.

Hansen, J., Ruedy, R., Sato, M. and Lo, K. (2010). Global surface temperature change. *Reviews of Geophysics*, 48(4). RG4004. DOI:10.1029/2010RG000345.

Hargeby, A., Blindow, I. and Andersson, G. (2007). Long-term Patterns of Shifts between Clear and Turbid States in Lake Krankesjön and Lake Tåkern. *Ecosystems*, 10(1). 29–36.

Harsem, Ø., Eide, A. and Heen, K. (2011). Factors influencing future oil and gas prospects in the Arctic. *Energy Policy*, 39(12). 8037–45. DOI:10.1016/j.enpol.2011.09.058.

Hassan, F. A. (2009). Human agency, climate change, and culture: an archaeological perspective. *Anthropology and Climate Change: From Encounters to Actions*. S. A. Crate and M. Nuttall (eds.). Left Coast Press, Walnut Creek, CA. 87–115.

Hatt, K. (2012). Social Attractors: A Proposal to Enhance 'Resilience Thinking' about the Social. *Society & Natural Resources*, 26(1). 30–43. DOI:10.1080/08941920.2012.695859.

Hegerl, G. C., Hoegh-Guldberg, O., Casassa, G., Hoerling, M., Kovats, S., et al. (2010). *Good Practice Guidance Paper on Detection and Attribution Related to Anthropogenic Climate Change.* IPCC Expert Meeting on Detection and A ttribution Related to Anthropogenic Climate Change. IPCC WGI Technical Support Unit, Bern. https://www.ipcc-wg1.unibe.ch/guidancepaper/IPCC_D&A_GoodPracticeGuidancePaper.pdf.

Heikkinen, H. I., Moilanen, O., Nuttall, M. and Sarkki, S. (2011). Managing predators, managing reindeer: contested conceptions of predator policies in Finland's southeast reindeer herding area. *Polar Record*, 47(03). 218–30.

Hoel, A. H. (2009). Do we need a new legal regime for the Arctic Ocean? *The International Journal of Marine and Coastal Law*, 24(2). 443–56. DOI:10.1163/157180809X421770.

Hoel, A. and Olsen, E. (2012). Integrated Ocean Management as a Strategy to Meet Rapid Climate Change: The Norwegian Case. *AMBIO*, 41(1). 85–95. DOI:10.1007/s13280-011-0229-2.

Holland, P. (2010). Climate change: Warm bath for an ice sheet. *Nature Geoscience*, 3(3). 147–48. DOI:10.1038/ngeo801.

Hovelsrud, G. K., Poppel, B., van Oort, B. and Reist, J. D. (2011). Arctic societies, cultures, and peoples in a changing cryosphere. *AMBIO*, 40(1). 100–110. DOI:10.1007/s13280-011-0219-4.

Høye, T. T., Post, E., Meltofte, H., Schmidt, N. M. and Forchhammer, M. C. (2007). Rapid advancement of spring in the High Arctic. *Current Biology*, 17(12). R449–R451.

Hu, F. S., Higuera, P. E., Walsh, J. E., Chapman, W. L., Duffy, P. A., Brubaker, L. B. and Chipman, M. L. (2010). Tundra burning in Alaska: Linkages to climatic change and sea ice retreat. *Journal of Geophysical Research: Biogeosciences*, 115(G4). DOI:10.1029/2009JG001270.

Huntington, H. P., Goodstein, E. and Euskirchen, E. (2012). Towards a Tipping Point in Responding to Change: Rising Costs, Fewer Options for Arctic and Global Societies. *AMBIO*, 41(1). 66–74. DOI:10.1007/s13280-011-0226-5.

Hutchings, J. K. and Rigor, I. G. (2012). Role of ice dynamics in anomalous ice conditions in the Beaufort Sea during 2006 and 2007. *Journal of Geophysical Research: Oceans*, 117(C5). C00E04. DOI:10.1029/2011JC007182.

Hvingel, C. (2003). The fishery for northern shrimp (Pandalus borealis) off West Greenland, 1970-2003. *NAFO SCR Doc*, 3(75). 26.

Ibelings, B. W., Portielje, R., Lammens, E. H. R. R., Noordhuis, R., Berg, M. S. van den, Joosse, W. and Meijer, M. L. (2007). Resilience of Alternative Stable States during the Recovery of Shallow Lakes from Eutrophication: Lake Veluwe as a Case Study. *Ecosystems*, 10(1). 4–16. DOI:10.1007/s10021-006-9009-4.

IPCC (2012). *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change* [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. IPCC. http://ipcc-wg2.gov/SREX/.

Isaksen, I. S., Gauss, M., Myhre, G., Anthony, K. M. W. and Ruppel, C. (2011). Strong atmospheric chemistry feedback to climate warming from Arctic methane emissions. *Global Biogeochemical Cycles*, 25(2). GB2002. DOI:10.1029/2010GB003845.

Jeffries, M. O., Richter-Menge, J. A. and Overland, J. E., eds. (2012). *Arctic Report Card 2012*.

Jeppesen, E., Søndergaard, M., Jensen, J. P., Mortensen, E., Hansen, A.-M. and Jørgensen, T. (1998). Cascading Trophic Interactions from Fish to Bacteria and Nutrients after Reduced Sewage Loading: An 18-Year Study of a Shallow Hypertrophic Lake. *Ecosystems*, 1(3). 250–67. DOI:10.1007/s100219900020.

Johnson, L. (2010). The fearful symmetry of Arctic climate change: accumulation by degradation. *Environment and Planning D: Society and Space*, 28. 828–47. DOI:10.1068/d9308.

Jones, B. M., Arp, C. D., Jorgenson, M. T., Hinkel, K. M., Schmutz, J. A. and Flint, P. L. (2009). Increase in the rate and uniformity of coastline erosion in Arctic Alaska. *Geophysical Research Letters*, 36(3). L03503.

Jones, P. J. S., De Santo, E. M., Qiu, W. and Vestergaard, O. (2013). Introduction: An empirical framework for deconstructing the realities of governing marine protected areas. *Marine Policy*, in press. DOI:10.1016/j.marpol.2012.12.025.

Jorgenson, M. T., Shur, Y. L. and Pullman, E. R. (2006). Abrupt increase in permafrost degradation in Arctic Alaska. *Geophysical Research Letters*, 33(2). DOI:10.1029/2005GL024960.

Kadushin, C. (2012). *Understanding Social Networks: Theories Concepts, and Findings*. Oxford University Press, Oxford.

Kanevskiy, M., Shur, Y., Jorgenson, M. T., Ping, C.-L., Michaelson, G. J., et al. (2013). Ground ice in the upper permafrost of the Beaufort Sea coast of Alaska. *Cold Regions Science and Technology*, 85. 56–70. DOI:10.1016/j.coldregions.2012.08.002.

Karnovsky, N. J., Brown, Z. W., Welcker, J., Harding, A. M. A., Walkusz, W., et al. (2011). Inter-colony comparison of diving behavior of an Arctic top predator: implications for warming in the Greenland Sea. *Marine Ecology Progress Series*, 440. 229–40. DOI:10.3354/meps09351.

Kattsov, V., Källén, E., Cattle, H., Christensen, J., Drange, H. et al. (2005) Future climate change: modeling and scenarios for the Arctic. Chapter 4 in *Arctic Climate Impact Assessment – Scientific Report*. J. Berner, C. Symon, L. Arris, and O. W. Heal (eds.). Cambridge University Press, Cambridge, UK, and New York. *www.acia.uaf.edu/pages/scientific.html.*

Kolstad, E. W. and Bracegirdle, T. J. (2008). Marine cold-air outbreaks in the future: an assessment of IPCC AR4 model results for the Northern Hemisphere. *Climate Dynamics*, 30(7). 871–85.

Kortsch, S., Primicerio, R., Beuchel, F., Renaud, P. E., Rodrigues, J., Lønne, O. J. and Gulliksen, B. (2012). Climate-driven regime shifts in Arctic marine benthos. *Proceedings of the National Academy of Sciences*, 109(35). 14052–57. DOI:10.1073/pnas.1207509109.

Krause-Jensen, D., Marbà, N., Olesen, B., Sejr, M. K., Christensen, P. B., et al. (2012). Seasonal sea ice cover as principal driver of spatial and temporal variation in depth extension and annual production of kelp in Greenland. *Global Change Biology*, 18(10). 2981–94. DOI:10.1111/j.1365-2486.2012.02765.x.

Krugman, P. (1996). *The Self-organizing Economy, Mitsui Lectures in Economics*. Wiley-Blackwell, Cambridge, MA, US.

Kullman, L. (2010). A Richer, greener and smaller alpine world: Review and projection of warming-induced plant cover change in the Swedish Scandes. *AMBIO*, 39(2). 159–69. DOI:10.1007/s13280-010-0021-8.

Kumpula, T., Pajunen, A., Kaarlejärvi, E., Forbes, B. C. and Stammler, F. (2011). Land use and land cover change in Arctic Russia: Ecological and social implications of industrial development. *Global Environmental Change*, 21(2). 550–62. DOI:10.1016/j.gloenvcha.2010.12.010.

Lange, M. (2003). The Barents Sea impact study (BASIS): methodology and first results. *European Land-Ocean Interaction*, 23(17–19). 1673–94. DOI:10.1016/j.csr.2002.12.002.

Lantuit, H., Atkinson, D., Paul Overduin, P., Grigoriev, M., Rachold, V., Grosse, G. and Hubberten, H.-W. (2011). Coastal erosion dynamics on the permafrost-dominated Bykovsky Peninsula, north Siberia, 1951–2006. *Polar Research*, 30(0). DOI:10.3402/polar.v30i0.7341.

Lantuit, H., Overduin, P. and Couture, N. (2010). *A pan-Arctic View of Arctic Coasts: A New High Resolution Coastline Database from the Arctic Coastal Dynamics Project*. IPY Oslo Science Conference, Oslo, Norway.

Lantuit, H., Overduin, P. P., Couture, N., Wetterich, S., Aré, F., et al. (2012). The Arctic coastal dynamics database: A new classification scheme and statistics on Arctic permafrost coastlines. *Estuaries and Coasts*, 35(2). 383–400. DOI:10.1007/s12237-010-9362-6.

Lazrus, H. (2009). The governance of vulnerabillity: Climate change and agency in Tuvalu, South Pacific. *Anthropology and Climate Change: From Encounters to Actions*. S. A. Crate and M. Nuttall (eds.). Left Coast Press, Walnut Creek, CA. 240–49.

Le Quéré, C., Andres, R. J., Boden, T., Conway, T., Houghton, R. A., et al. (2012). The global carbon budget 1959–2011. *Earth System Science Data Discussions*, 5(2). 1107–57. DOI:10.5194/essdd-5-1107-2012.

Le Quéré, C., C., R., R, M., Canadell, J. G. and Marland, G. (2009). Trends in the sources and sinks of carbon dioxide. *Nature Geoscience*, 2(12). 831–36.

Leibenstein, H. (1974). An interpretation of the economic theory of fertility: Promising path or blind alley? *Journal of Economic Literature*, 12(2). 457–79.

Leibenstein, H. (1957). *Economic Backwardness and Economic Growth: Studies in the Theory of Economic Development*. Wiley, New York.

Leibenstein, H. and Notestein, F. (1954). *A theory of economic-demographic development*. Princeton University Press Princeton, NJ. http://library.wur.nl/WebQuery/clc/1625616.

Lemelin, H., Dawson, J., Stewart, E. J., Maher, P. and Lueck, M. (2010). Last-chance tourism: the boom, doom, and gloom of visiting vanishing destinations. *Current Issues in Tourism*, 13(5). 477–93. DOI:10.1080/13683500903406367.

Lemke, P., Ren, J., Alley, R.B., Allison, I., Carrasco, J., et al. (2007). Observations: Changes in snow, ice and frozen ground. Chapter 4 in *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, et al. (eds.) Cambridge University Press, Cambridge, 338-384. www.ipcc.ch/publications_and_data/ar4/wg1/en/ch4.html

Lenton, T. M. (2012). Arctic climate tipping points. *AMBIO*, 41(1). 10–22. DOI:10.1007/s13280-011-0221-x.

Lenton, T. M., Held, H., Kriegler, E., Hall, J. W., Lucht, W., Rahmstorf, S. and Schellnhuber, H. J. (2008). Tipping elements in the Earth's climate system. *Proceedings of the National Academy of Sciences*, 105(6). 1786–93. DOI:10.1073/pnas.0705414105.

Lindblad, K. E. M., Nyberg, R. and Molau, U. (2006). Generalization of heterogeneous alpine vegetation in air photo-based image classification, Latnjajaure Catchment, Northern Sweden. *Pirineos* 161. 3–32.

Livina, V. N. and Lenton, T. M. (2013). A recent tipping point in the Arctic sea-ice cover: abrupt and persistent increase in the seasonal cycle since 2007. *The Cryosphere*, 7(1). 275–86. DOI:10.5194/tc-7-275-2013.

Lüdeke, M. K. B., Petschel-Held, G. and Schellnhuber, H.-J. (2004). Syndromes of global change: The first panoramic view. *GAIA – Ecological Perspectives for Science and Society*, 13(1). 42–49.

Luque, S. and Ferguson, S. (2009). Ecosystem regime shifts have not affected growth and survivorship of eastern Beaufort Sea belugas. *Oecologia*, 160(2). 367–78.

Macias-Fauria, M., Forbes, B. C., Zetterberg, P. and Kumpula, T. (2012). Eurasian Arctic greening reveals teleconnections and the potential for structurally novel ecosystems. *Nature Climate Change*, 2(8). 613–18. DOI:10.1038/nclimate1558.

Mäler, K.-G., Xepapadeas, A. and Zeeuw, A. de (2003). The economics of shallow lakes. *Environmental and Resource Economics*, 26(4). 603–24.

Mann, D. H., Rupp, T. S., Olson, M. A. and Duffy, P. A. (2012). Is Alaska's boreal forest now crossing a major ecological threshold? *Arctic, Antarctic, and Alpine Research*, 44(3). 319–31.

Marion, G. M. and Pidgeon, D. E. (1992). *Passive Techniques for Manipulating Field Soil Temperatures*. DTIC Document. http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA254303.

Mars, J. C. and Houseknecht, D. W. (2007). Quantitative remote sensing study indicates doubling of coastal erosion rate in past 50 yr along a segment of the Arctic coast of Alaska. *Geology*, 35(7). 583–86. DOI:10.1130/G23672A.1.

Mason, O. K. and Jordan, J. W. (2001). Minimal late Holocene sea level rise in the Chukchi Sea: Arctic insensitivity to global change? *Global and Planetary Change*, 32(1). 13–23. DOI:10.1016/S0921-8181(01)00146-1.

Mason, O. K., Jordan, J. W., Lestak, L. and Manley, W. F. (2012). Narratives of shoreline erosion and protection at Shishmaref, Alaska: The anecdotal and the analytical. *Pitfalls of Shoreline Stabilization*. J. A. G. Cooper and O. H. Pilkey (eds.). Coastal Research Library. Springer Netherlands. 73–92. http://link.springer.com/chapter/10.1007/978-94-007-4123-2_5.

McLaughlin, F. A., Carmack, E. C., Williams, W. J., Zimmermann, S., Shimada, K. and Itoh, M. (2009). Joint effects of boundary currents and thermohaline intrusions on the warming of Atlantic water in the Canada Basin, 1993–2007. *Journal of Geophysical Research*, 114(C1). C00A12.

Mendoza, G. A. and Prabhu, R. (2005). Combining participatory modeling and multi-criteria analysis for community-based forest management. *Forest Ecology and Management*, 207(1–2). 145–56. DOI:10.1016/j.foreco.2004.10.024.

Moe, B., Stempniewicz, L., Jakubas, D., Angelier, F., Chastel, O., et al. (2009). Climate change and phenological responses of two seabird species breeding in the high-Arctic. *Marine Ecology Progress Series*, 393. 235–46. DOI:10.3354/meps08222.

Molau, U. (2010). Long-term impacts of observed and induced climate change on tussock tundra near its southern limit in northern Sweden. *Plant Ecology & Diversity*, 3(1). 29–34. DOI:10.1080/17550874.2010.487548.

Molau, U. (1997). Phenology and reproductive success in arctic plants: susceptibility to climate change. *Global Change and Arctic Terrestrial Ecosystems*. W. C. Oechel, T. V. Callaghan, T. Gilmanov, J. I. Holten, B. I. Maxwell, U. Molau, and B. Sveinbjörnsson (eds.). Ecological Studies. Springer Verlag, New York. 153–70.

Molau, U. and Mølgaard, P. (1996). ITEX Manual. www.geog.ubc.ca/itex/PDFs/ITEXmanual.pdf.

Moss, B., Stansfield, J., Irvine, K., Perrow, M. and Phillips, G. (1996). Progressive restoration of a shallow lake: a 12-year experiment in isolation, sediment removal and biomanipulation. *Journal of Applied Ecology*, 3(1). 71–86.

Moss, R. H. and Schneider, S. H. (2000). *Towards Consistent Assessment and Reporting of Uncertainties in the IPCC TAR: Initial Recommendations for Discussion by Authors*. The Energy and Resources Institute (TERI), New Delhi.

Myers, R. A., Hutchings, J. A. and Barrowman, N. J. (1997). Why do fish stocks collapse? The example of cod in Atlantic Canada. *Ecological Applications*, 7(1). 91–106. DOI:10.1890/1051-0761(1997)007[0091:WDFSCT]2.0.CO;2.

Myers-Smith, I. H., Forbes, B. C., Wilmking, M., Hallinger, M., Lantz, T., et al. (2011). Shrub expansion in tundra ecosystems: dynamics, impacts and research priorities. *Environmental Research Letters*, 6(4). 045509.

Nævdal, E. (2006). Dynamic optimisation in the presence of threshold effects when the location of the threshold is uncertain – with an application to a possible disintegration of the Western Antarctic Ice Sheet. *Journal of Economic Dynamics and Control*, 30(7). 1131–58. DOI:10.1016/j.jedc.2005.04.004.

Nævdal, E. (2003). Optimal regulation of natural resources in the presence of irreversible threshold effects. *Natural Resource Modeling*, 16(3). 305–33.

Nævdal, E. (2001). Optimal regulation of eutrophying lakes, fjords, and rivers in the presence of threshold effects. *American Journal of Agricultural Economics*, 83(4). 972–84.

Nes, E. H. van, Rip, W. J. and Scheffer, M. (2007). A theory for cyclic shifts between alternative states in shallow lakes. *Ecosystems*, 10(1). 17–28. DOI:10.1007/s10021-006-0176-0.

Nilsson, A. E. and Olsson, M. (2011). *Arctic Resilience Report Scoping Workshop*. Stockholm Environment Institute, Stockholm, Sweden. http://www.sei-international.org/publications?pid=2017.

Nuttall, M. (2009). Living in a World of Movement: Human Resilience to Environmental Instability in Greenland. *Anthropology and Climate Change: From Encounters to Actions*. S. A. Crate and M. Nuttall (eds.). Left Coast Press, Walnut Creek, CA. 292–310.

Nuttall, M. (2010). Anticipation, climate change, and movement in Greenland. *Etudes/Inuit/Studies*, 34(1). 21–37. DOI:10.7202/045402ar.

Nuttall, M. (2012). Tipping points and the human world: living with change and thinking about the future. *AMBIO*, 41(1). 96–105. DOI:10.1007/s13280-011-0228-3.

O'Brien, M. C., Macdonald, R. W., Melling, H. and Iseki, K. (2006). Particle fluxes and geochemistry on the Canadian Beaufort Shelf: implications for sediment transport and deposition. *Continental Shelf Research*, 26(1). 41–81. DOI:10.1016/j.csr.2005.09.007.

Oliver-Smith, A. (2002). Theorizing disasters: Nature, power and culture. *Catastrophe & Culture: The Anthropology of Disaster*. A. Oliver-Smith and S. M. Hoffman (eds.). School for Advanced Research Press, Santa Fe, NM, US. 23–47.

Oliver-Smith, A. (1996). Anthropological research on hazards and disasters. *Annual Review of Anthropology*, 25. 303–28.

Olsson, P., Gunderson, L. H., Carpenter, S. R., Ryan, P., Lebel, L., Folke, C. and Holling, C. S. (2006). Shooting the rapids: navigating transitions to adaptive governance of social-ecological systems. *Ecology and Society*, 11(1). Art. 18.

Ostrom, E. (2007). A diagnostic approach for going beyond panaceas. *Proceedings of the National Academy of Sciences*, 104(39). 15181–87. DOI:10.1073/pnas.0702288104.

Overeem, I., Anderson, R. S., Wobus, C. W., Clow, G. D., Urban, F. E. and Matell, N. (2011). Sea ice loss enhances wave action at the Arctic coast. *Geophysical Research Letters*, 38(17). n/a–n/a. DOI:10.1029/2011GL048681.

Overland, J. E., Francis, J. A., Hanna, E. and Wang, M. (2012). The recent shift in early summer Arctic atmospheric circulation. *Geophysical Research Letters*, 39(19). L19804. DOI:10.1029/2012GL053268.

Overland, J. E. and Wang, M. (2010). Large-scale atmospheric circulation changes are associated with the recent loss of Arctic sea ice. *Tellus A*, 62(1). 1–9. DOI:10.1111/j.1600-0870.2009.00421.x.

Overland, J., Rodionov, S., Minobe, S. and Bond, N. (2008). North Pacific regime shifts: Definitions, issues and recent transitions. *Progress in Oceanography*, 77(2-3). 92–102. DOI:10.1016/j.pocean.2008.03.016.

Page, S. E. (2006). Path Dependence. *Quarterly Journal of Political Science*, 1(1). 87–115. DOI:10.1561/100.00000006.

Parente, G., Shiklomanov, N. and Streletskiy, D. (2012). Living in the new North: migration to and from Russian Arctic cities. *Focus on Geography*, 55(3). 77–89. DOI:10.1111/j.1949-8535.2012.00048.x.

Parlee, B. L., Geertsema, K. and Willier, A. (2012). Social-ecological thresholds in a changing boreal landscape: insights from Cree knowledge of the Lesser Slave Lake region of Alberta, Canada. *Ecology and Society*, 17(2). Art. 20. DOI:10.5751/ES-04410-170220.

Parnikoza, I., Convey, P., Dykyy, I., Trokhymets, V., Milinevsky, G., et al. (2009). Current status of the Antarctic herb tundra formation in the Central Argentine Islands. *Global Change Biology*, 15(7). 1685–93. DOI:10.1111/j.1365-2486.2009.01906.x.

Paterson, T. T. (1950). The theory of the social threshold: the social aspect of accidents. *The Sociological Review*, 2(1). 53–68.

Perovich, D. (2011). The Changing Arctic Sea Ice Cover. *Oceanography*, 24(3). 162–73. DOI:10.5670/oceanog.2011.68.

Peterson, B. J., Holmes, R. M., McClelland, J. W., Vörösmarty, C. J., Lammers, R. B., et al. (2002). Increasing River Discharge to the Arctic Ocean. *Science*, 298(5601). 2171–73. DOI:10.1126/science.1077445.

Petschel-Held, G., Block, A., Cassel-Gintz, M., Kropp, J., Lüdeke, M. K. B., et al. (1999). Syndromes of Global Change: a qualitative modelling approach to assist global environmental management. *Environmental Modeling & Assessment*, 4(4). 295–314. DOI:10.1023/A:1019080704864.

Phoenix, G. K. and Lee, J. A. (2004). Predicting impacts of Arctic climate change: Past lessons and future challenges. *Ecological Research*, 19(1). 65–74. DOI:10.1111/j.1440-1703.2003.00609.x.

Pielke, R. A. and Wilby, R. L. (2012). Regional climate downscaling: What's the point? *Eos, Transactions American Geophysical Union*, 93(5). 52–53. DOI:10.1029/2012EO050008.

Ping, C.-L., Michaelson, G. J., Guo, L., Jorgenson, M. T., Kanevskiy, M., et al. (2011). Soil carbon and material fluxes across the eroding Alaska Beaufort Sea coastline. *Journal of Geophysical Research: Biogeosciences*, 116(G2). n/a–n/a. DOI:10.1029/2010JG001588.

Polasky, S., de Zeeuw, A. and Wagener, F. (2011). Optimal management with potential regime shifts. *Journal of Environmental Economics and Management*, 62(2). 229–40. DOI:10.1016/j.jeem.2010.09.004.

Polyak, L., Alley, R. B., Andrews, J. T., Brigham-Grette, J., Cronin, T. M., et al. (2010). History of sea ice in the Arctic. *Quaternary Science Reviews*, 29(15–16). 1757–78. DOI:10.1016/j.quascirev.2010.02.010.

Post, E., Forchhammer, M. C., Bret-Harte, M. S., Callaghan, T. V., Christensen, T. R., et al. (2009). Ecological synamics across the Arctic associated with recent climate change. *Science*, 325(5946). 1355–58. DOI:10.1126/science.1173113.

Proshutinsky, A., Ashik, I., Häkkinen, S., Hunke, E., Krishfield, R., et al. (2007). Sea level variability in the Arctic Ocean from AOMIP models. *Journal of Geophysical Research: Oceans*, 112(C4). DOI:10.1029/2006JC003916.

Prowse, T., Alfredsen, K., Beltaos, S., Bonsal, B. R., Bowden, W. B., et al. (2011). Effects of changes in Arctic lake and river ice. *Ambio*, 40. 63–74. DOI:10.1007/s13280-011-0217-6.

Rachold, V., Are, F. E., Atkinson, D. E., Cherkashov, G. and Solomon, S. M. (2005). Arctic Coastal Dynamics (ACD): an introduction. *Geo-Marine Letters*, 25(2-3). 63–68. DOI:10.1007/s00367-004-0187-9.

Rasmussen, R. O., ed. (2011). *Megatrends*. Nordic Council of Ministers, Copenhagen.

Rasmussen, R. O. and Hamilton, L. C. (2001). *The Development of Fisheries in Greenland, with Focus on Paamiut/Frederikshåb and Sisimiut/Holsteinsborg*. North Atlantic Regional Studies, Roskilde, Denmark.

Rauhut, D., Rasmussen, R. O., Roto, J., Francke, P. and Österberg, S. (2008). *The Demographic Challenges to the Nordic Countries*. Nordregio Working Paper 2008:1. Nordregio, Stockholm. http://www.nordregio.se/en/Publications/Publications-2008/The-Demographic-Challenge-to-the-Nordic-Countries/.

Reed, W. J. and Heras, H. E. (1992). The conservation and exploitation of vulnerable resources. *Bulletin of Mathematical Biology*, 54(2–3). 185–207. DOI:10.1016/S0092-8240(05)80022-9.

Resilience Alliance (2010). *Resilience Assessment Workbook for Practitioners Version 2.0*. Resilience Alliance. http://www.resalliance.org/index.php/resilience_assessment.

Rial, J. A., Sr, R. A. P., Beniston, M., Claussen, M., Canadell, J., et al. (2004). Nonlinearities, feedbacks and critical thresholds within the earth's climate system. *Climatic Change*, 65(1-2). 11–38. DOI:10.1023/B:CLIM.0000037493.89489.3f.

Rietkerk, M., Brovkin, V., van Bodegom, P. M., Claussen, M., Dekker, S. C., et al. (2011). Local ecosystem feedbacks and critical transitions in the climate. *Ecological Complexity*, 8(3). 223–28. DOI:10.1016/j.ecocom.2011.03.001.

Rocha, J. C., Biggs, R. and Peterson, G. D. (2012). Regime shifts. *The Berkshire Encyclopedia of Sustainability: Ecosystem Management and Sustainability*. Berkshire Publishing Group, Great Barrington, MA, US. 330–34.

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F. S. I., et al. (2009). Planetary boundaries: exploring the safe operating space for humanity. *Ecology and Society*, 14(2). Art. 32.

Romanovsky, V. E., Smith, S. L. and Christiansen, H. H. (2010). Permafrost thermal state in the polar Northern Hemisphere during the international polar year 2007–2009: a synthesis. *Permafrost and Periglacial Processes*, 21(2). 106–16. DOI:10.1002/ppp.689.

Rosa, H. and Scheuerman, W. E. (2009). *High-speed Society: Social Acceleration, Power, and Modernity*. Penn State University Press, University Park, PA, US. http://www.psupress.org/books/titles/978-0-271-03416-4.html.

Rose, G. A. (2004). Reconciling overfishing and climate change with stock dynamics of Atlantic cod (Gadus morhua) over 500 years. *Canadian Journal of Fisheries and Aquatic Sciences*, 61. 1553–57.

Rowland, J. C., Jones, C. E., Altmann, G., Bryan, R., Crosby, B. T., et al. (2010). Arctic landscapes in transition: Responses to thawing permafrost. *Eos, Transactions American Geophysical Union*, 91(26). 229–30. DOI:10.1029/2010EO260001.

Running, S. W. (2012). A Measurable Planetary Boundary for the Biosphere. *Science*, 337(6101). 1458–59. DOI:10.1126/science.1227620.

Sannel, A. B. K. and Kuhry, P. (2011). Warming-induced destabilization of peat plateau/thermokarst lake complexes. *Journal of Geophysical Research: Biogeosciences*, 116(G3). G03035. DOI:10.1029/2010JG001635.

Scheffer, M. (2004). *Ecology of Shallow Lakes*. Springer. http://www.springer.com/life+sciences/ecology/book/978-1-4020-2306-4.

Scheffer, M. and Carpenter, S. R. (2003a). Catastrophic regime shifts in ecosystems: linking theory to observation. *Trends in Ecology & Evolution*, 18(12). 648–56. DOI:10.1016/j.tree.2003.09.002.

Scheffer, M. and Carpenter, S. R. (2003b). Catastrophic regime shifts in ecosystems: linking theory to observation. *Trends in Ecology & Evolution*, 18(12). 648–56.

Scheraga, J. D. and Grambsch, A. E. (1998). Risks, opportunities and adaptation to climate change. *Climate Research*, 11. 85–95.

Schultz, T. W. (1974). Fertility and economic values. *Economics of the Family: Marriage, Children, and Human Capital*. T. W. Schultz (ed.). UMI. 3–22. http://www.nber.org/chapters/c2961.

Schuur, E. A., Bockheim, J., Canadell, J. G., Euskirchen, E., Field, C. B., et al. (2008). Vulnerability of permafrost carbon to climate change: Implications for the global carbon cycle. *BioScience*, 58(8). 701–14. DOI:10.1641/B580807.

Senge, P. M. (1999). *The Fifth Discipline: The Art and Practice of the Learning Organization.* Doubleday Business, New York.

Serreze, M. C. (2010). Understanding recent climate change. *Conservation Biology*, 24(1). 10–17. DOI:10.1111/j.1523-1739.2009.01408.x.

Sexton, J. P., McIntyre, P. J., Angert, A. L. and Rice, K. J. (2009). Evolution and ecology of species range limits. *Annual Review of Ecology, Evolution, and Systematics*, 40. 415–36.

Shmakin, A. (2010). Climatic characteristics of snow cover over North Eurasia and their change during the last decades. *Ice and Snow*, 1(1). 43–57.

Sigler, M., Renner, M., Danielson, S., Eisner, L., Lauth, R., et al. (2011). Fluxes, fins, and feathers: Relationships among the Bering, Chukchi, and Beaufort Seas in a time of climate change. *Oceanography*, 24(3). 250–65. DOI:10.5670/oceanog.2011.77.

Skiba, A. K. (1978). Optimal growth with a convex-concave production function. *Econometrica: Journal of the Econometric Society*, 46(3). 527–39.

Smith, A. (1776). *An Inquiry into the Nature and Causes of the Wealth of Nations.* W. Strahan and T. Cadell, London.

Smithers, J. and Smit, B. (1997). Human adaptation to climatic variability and change. *Global Environmental Change*, 7(2). 129–46. DOI:10.1016/S0959-3780(97)00003-4.

Smol, J. P. and Douglas, M. S. V. (2007). Crossing the final ecological threshold in high Arctic ponds. *Proceedings of the National Academy of Sciences*, 104(30). 12395–97. DOI:10.1073/pnas.0702777104.

Sommerkorn, M. and Hamilton, N., eds. (2008). *Arctic Climate Impact Science: An Update Since ACIA*. WWF International Arctic Programme, Oslo, Norway. http://assets.panda.org/downloads/arctic_climate_impact_science_1.pdf.

Sprinz, D. F. and Churkina, G. E. (1999). The Analysis of Environmental Thresholds. Presented at the Advanced Research Workshop 'Caspian Sea: A Quest for Environmental Security', Venice International University, Venice, Italy, 15-19 March 1999. http://www.uni-potsdam.de/u/sprinz/doc/nato_thresh.pdf.

Steele, D. H., Andersen, R. and Green, J. M. (1992). The managed commercial annihilation of Northern cod. *Newfoundland and Labrador Studies*, 8(1). 34–68.

Stenström, A., Jónsdóttir, I. S. and Augner, M. (2002). Genetic and environmental effects on morphology in clonal sedges in the Eurasian Arctic. *American Journal of Botany*, 89(9). 1410–21. DOI:10.3732/ajb.89.9.1410.

Stephenson, S. R., Smith, L. C. and Agnew, J. A. (2011). Divergent long-term trajectories of human access to the Arctic. *Nature Clim. Change*, 1(3). 156–60. DOI:10.1038/nclimate1120.

Stirling, A. (2005). Opening up or closing down? Analysis, participation and power in the social appraisal of technology. M. Leach, I. Scoones, and B. Wynne (eds.). Zed Books, London and New York. 218–31.

Stroeve, J. C., Serreze, M. C., Holland, M. M., Kay, J. E., Malanik, J. and Barrett, A. P. (2011). The Arctic's rapidly shrinking sea ice cover: a research synthesis. *Climatic Change*, 110(3-4). 1005–27. DOI:10.1007/s10584-011-0101-1.

Sturm, M., Douglas, T., Racine, C. and Liston, G. E. (2005). Changing snow and shrub conditions affect albedo with global implications. *Journal of Geophysical Research*, 110(G1). G01004.

Sturm, M., Racine, C. and Tape, K. (2001). Climate change: Increasing shrub abundance in the Arctic. *Nature*, 411(6837). 546–47. DOI:10.1038/35079180.

Tape, K. D., Hallinger, M., Welker, J. M. and Ruess, R. W. (2012). Landscape heterogeneity of shrub expansion in Arctic Alaska. *Ecosystems*, 15(5). 711–24. DOI:10.1007/s10021-012-9540-4.

Tape, K., Sturm, M. and Racine, C. (2006). The evidence for shrub expansion in Northern Alaska and the Pan-Arctic. *Global Change Biology*, 12(4). 686–702. DOI:10.1111/j.1365-2486.2006.01128.x.

TEEB (2010). *The Economics of Ecosystems & Biodiversity: Mainstreaming the Economics of Nature – a Synthesis of the Approach, Conclusions and Recommendations of TEEB*. http://www.teebweb.org/publications/teeb-study-reports/synthesis/.

Trenberth, K. E. and Fasullo, J. T. (2010). Tracking Earth's energy. *Science*, 328. 316–17.

U.S. National Intelligence Council (2008). *Global Trends 2025: A Transformed World*. NIC 2008-003. Washington, DC. http://www.dni.gov/index.php/about/organization/national-intelligence-council-global-trends.

Valente, T. W. (1996). Social network thresholds in the diffusion of innovations. *Social Networks*, 18(1). 69–89. DOI:10.1016/0378-8733(95)00256-1.

Varghese, J., Krogman, N. T., Beckley, T. M. and Nadeau, S. (2006). Critical Analysis of the Relationship between Local Ownership and Community Resiliency*. *Rural Sociology*, 71(3). 505–27. DOI:10.1526/003601106778070653.

Vincent, W. F., Laurion, I., Pienitz, R. and Walter Anthony, K. M. (2012). Climate impacts on Arctic lake ecosystems. *Climatic Change and Global Warming of Inland Waters: Impacts and Mitigation for Ecosystems and Societies*. C. R. Goldman, M. Kumagai, and R. D. Robarts (eds.).27–42. http://onlinelibrary.wiley.com/book/10.1002/9781118470596.

Vonk, J. E., Sanchez-Garcia, L., van Dongen, B. E., Alling, V., Kosmach, D., et al. (2012). Activation of old carbon by erosion of coastal and subsea permafrost in Arctic Siberia. *Nature*, 489(7414). 137–40. DOI:10.1038/nature11392.

Vors, L. S. and Boyce, M. S. (2009). Global declines of caribou and reindeer. *Global Change Biology*, 15(11). 2626–33. DOI:10.1111/j.1365-2486.2009.01974.x.

Wadhams, P. (2012). Arctic ice cover, ice thickness and tipping points. *AMBIO*, 41(1). 23–33. DOI:10.1007/s13280-011-0222-9.

Walker, B. and Meyers, J. A. (2004). Thresholds in ecological and social-ecological systems: a developing database. *Ecology and Society*, 9(2). Art. 3.

Walker, M. D., Wahren, C. H., Hollister, R. D., Henry, G. H. R., Ahlquist, L. E., et al. (2006). Plant community responses to experimental warming across the tundra biome. *Proceedings of the National Academy of Sciences of the United States of America*, 103(5). 1342–46. DOI:10.1073/pnas.0503198103.

Wallsten, M. and Forsgren, P. (1989). The effects of increased water level on aquatic macrophytes. *Journal of Aquatic Plant Management*, 27. 32–37.

Walsh, J. E., Overland, J. E., Groisman, P. Y. and Rudolf, B. (2011). Ongoing climate change in the Arctic. *AMBIO*, 40(1). 6–16. DOI:10.1007/s13280-011-0211-z.

Walter, K. M., Zimov, S. A., Chanton, J. P., Verbyla, D. and Chapin, F. S. (2006). Methane bubbling from Siberian thaw lakes as a positive feedback to climate warming. *Nature*, 443(7107). 71–75. DOI:10.1038/nature05040.

Warf, B. (2011). Contours, contrasts, and contradictions of the Arctic internet. *Polar Geography*, 34(3). 193–208. DOI:10.1080/1088937X.2011.589012.

Wassmann, P. and Lenton, T. M. (2012). The Arctic in the Earth System perspective: the role of tipping points. *AMBIO*, 41(1). 1–9. DOI:10.1007/s13280-011-0230-9.

Watts, M. (2011). On confluences and divergences. *Dialogues in Human Geography*, 1(1). 84–89. DOI:10.1177/2043820610386340.

Worm, B. and Myers, R. A. (2003). Meta-analysis of cod-shrimp interactions reveals top-down control in oceanic food webs. *Ecology*, 84(1). 162–73. DOI:10.1890/0012-9658(2003)084[0162:MAOCSI]2.0.CO;2.

Yallop, M. L., Anesio, A. M., Perkins, R. G., Cook, J., Telling, J., et al. (2012). Photophysiology and albedo-changing potential of the ice algal community on the surface of the Greenland ice sheet. *The ISME Journal*, 6(12). 2302–13. DOI:10.1038/ismej.2012.107.

Yamamoto-Kawai, M., McLaughlin, F. A., Carmack, E. C., Nishino, S. and Shumada, K. (2009). Aragonite undersaturation in the Arctic ocean: effects of ocean acidification and sea ice melt. *Science*, 326(5956). 1098–1100.

Young, O. R. (2012). Arctic tipping points: governance in turbulent times. *AMBIO*, 41(1). 75–84. DOI:10.1007/s13280-011-0227-4.

Young, O. R. (1998). *Creating Regimes: Arctic Accords and International Governance*. Cornell University Press, Ithaca, NY, US.

Sources for figures and boxes

Figure 4.1 Data sourced from Alley, R.B. (2004). GISP2 Ice Core Temperature and Accumulation Data. IGBP PAGES/World Data Center for Paleoclimatology Data Contribution Series #2004-013. NOAA/NGDC Paleoclimatology Program, Boulder CO, USA. ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/greenland/summit/gisp2/isotopes/gisp2_temp_accum_alley2000.txt Accessed March 20 2012

Figure 4.5b Adapted from Duarte, C. M., Agustí, S., et al. (2012).

Figure 4.6 Data sourced from NASA Goddard Institute for Space Studies. Global and hemispheric monthly means, http://data.giss.nasa.gov/gistemp.

Figure 4.9 Data sourced from Loeb, N.G., Wielicki, B.A., Doelling, D.R., Smith, G.L., Keyes, D.F., Kato, S., Manalo-Smith, N. and Wong T. (2008). Toward optimal closure of the Earth's Top-of-Atmosphere radiation budget. Journal of Climate, 22(3). 748-766. http://ceres-tool.larc.nasa.gov/ord-tool/jsp/EBAFSelection.jsp Accessed March 22, 2013

Figure 4.10 Data sourced from Box, J. and Decker D. Greenland ice sheet reflectivity July 2000-2011, 2012 days 1-23. Byrd Polar Research Centre. http://bprc.osu.edu/wiki/File:Timeseries_Reflectivity_07_All.png Accessed March 22, 2012

Figure 4.11 Image sourced from Mars, J. and Houseknecht, D. (2007) Landsat imagery courtesy of NASA Goddard Space Flight Center and U.S. Geological Survey. http://landsat.gsfc.nasa.gov/pdf_archive/cape_halkett_4web.pdf Accessed March 24, 2012

Box 4.4 Adapted from Rasmussen (2011)

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Part III

Summary

This chapter focuses on the capacity of societies to adapt to social, political, economic, and ecological changes in the Arctic and, where needed, navigate transformations in social and social-ecological interactions. Novel conditions, challenges, and opportunities currently abound in the Arctic, suggesting the need to question former notions of the "inherently and highly adaptive northerner", reframe the Arctic as a dynamic and highly complex adaptive system, and embrace responses that reflect new ways of framing human response to change. We present key concepts and frameworks related to assessing adaptive capacity and transformative capacity, drawing from a broad range of theories including on resilience, adaptation and transformation. We examine sources of adaptive and transformative capacity in the Arctic context, focusing specifically on seven types of assets: natural capital, social capital, human capital, infrastructure, financial capital, knowledge assets, and cultural capital. We also examine mechanisms of adaptive and transformative change as well as their underlying dynamics, and consider them in the context of a changing North. We note differences in how adaptive capacity is shaped and talked about in North America, the Nordic countries and Russia. We explore the role of governance, including collective action, social learning and adaptive co-governance. Finally, we identify strategies for maintaining and enhancing adaptive and transformative capacity in the future. We stress the need to recognize that preventing Arctic change – or shifts to new system states and regimes – is not an option. Instead, what is needed is active transformation in the social, economic, and institutional arenas to respond to continuous change.

Chapter 5

Adaptive and transformative capacity

Chapter 5

Adaptive and transformative capacity

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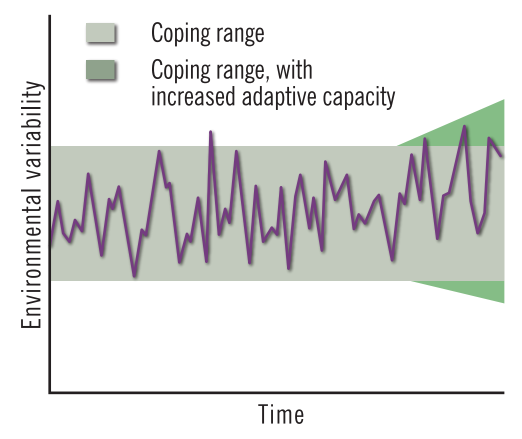
5.1 Introduction

The analysis in this chapter follows the social-ecological systems definition of adaptation as adjustment to a change in environment, and uses it to examine how cultures, institutions and human agency respond to, drive and shape interactions between humans and the environment (Armitage and Plummer 2010). Smit and Wandel (2006) elaborated that adaptation refers to "a process, action or outcome in a system (household, community, group, sector, region, country) in order for the system to better cope with, manage or adjust to some changing condition, stress, hazard, risk or opportunity" (p.282). Adaptation has also been applied by evolutionary biologists as a genetic change in a population and, by anthropologists, to the processes by which society adapts to environmental changes (Steward 1968). In the context of social-ecological resilience, adaptation refers to a social, economic, or cultural adjustments to changes in the bio-physical or social environment, allowing it to remain in the same system state (Walker et al. 2004; Chapin et al. 2009). Assumed in this definition are hypothesized thresholds or tipping points that would potentially result in social-ecological state changes or regime shifts (Gunderson and Holling 2002; see also Chapter 4).

Adaptation differs from coping, which is a short-term adjustment to minimize the impacts of hazards or stresses. As defined here, coping mechanisms enable society to deal with fluctuations that fall within the normal range of experience (see Figure 5.1), whereas adaptation requires more significant and long-term behavioural modifications when conditions fall outside the normal range of variability (Smit and Pilifosova 2003; Smit and Wandel 2006; Chapin et al. 2009).

Adaptive capacity is a set of properties that allow a system or individual to adjust or recover from impacts and/or changing conditions, while retaining the same social-ecological system state. This capacity is related to the particular factors and processes that enable or constrain choices, such as actors' management of current and past stresses and their ability to anticipate and plan for future change, and is critical in shaping community vulnerability (Adger 2003; Adger et al. 2005; Adger et al. 2009; Smit et al. 2010; Keskitalo et al. 2011). Adaptive capacity, therefore, is a way of describing preconditions and processes or drivers necessary for human actors to respond to, create, and shape variability and change within the existing state of the system (Ford and Smit 2004; Ford et al. 2006; Smit and Wandel 2006; Nelson et al. 2007).

Figure 5.1 **Coping range and extreme events**
Smit and Wandel (2006)



Transformation connotes a more fundamental change to the coupled social-ecological system. It can be unintended or actively navigated through the alteration of a system when current ecological, social, or economic conditions become untenable or are undesirable (Walker and Salt 2006; Folke et al. 2009; Ford and Furgal 2009; Folke et al. 2010; O'Brien 2012; Kates et al. 2012). Transformation typically involves a paradigm shift that re-conceptualizes the nature of the system in terms of a different set of critical slow variables and feedbacks in the system, and in social goals. It therefore involves changes in both social construction (e.g., the way meaning is constructed in language) and human behaviour. Transformation can be rapid or incremental, occurring over generations – and in such cases may be imperceptible to actors. Here we focus on the capacity of societies to navigate transformations and actively transform their system to meet human needs (Folke et al. 2010). Like adaptive capacity, transformative capacity is determined by a set of factors, such as situational conditions, availability of and access to resources, livelihood flexibility, and enabling institutions (Hovelsrud et al. 2010).

Given the rapid changes facing northern social-ecological systems, both adaptive and transformative capacity are crucial to Arctic resilience. As noted in Chapter 4, directional and incremental changes, such as a changing climate and/or economies affecting local livelihoods, are likely to be punctuated with the crossing of thresholds, resulting in non-linear and abrupt state changes that modify the structure, function and identity of the system (Walker et al. 2004; McCarthy and Martello 2005; Folke et al. 2010). The ways in which changes in climate, ecosystems, and societal conditions combine and interact will have consequences for adaptation, adaptive capacity and social-ecological resilience, especially because the region depends so much on natural resources for local livelihoods as well as industrial activities.

For example, changes in snow, ice, hydrology, permafrost and sea-ice are increasingly affecting bio-physical systems in the Arctic, with cascading effects on society (AMAP 2011). At the same time, non-climatic drivers such as increased industrial activity, socio-economic development, changes in demographic patterns and governance, and globalization are affecting the health and well-being of Arctic people. The combination of these factors may result in multifaceted and cascading effects (AMAP 2011). Combined and cascading effects between societal and environmental change create unprecedented challenges to current adaptive capacity (e.g., West and Hovelsrud 2010).

The possibility of state changes in the Arctic, such as a shift to a seasonally ice-free Arctic Ocean, raises several questions about the capacity of humans to respond effectively. What are the critical thresholds of interacting drivers of Arctic change, and how might human responses affect such thresholds? Will cross-scale interactions cascade throughout the system, affecting different levels in different regions in different ways? What resources are needed to adapt to changes, and by what means can society build resilience in preparation for projected future changes and surprises? To what extent can past experience inform future conditions? At what point are the potential benefits of adaptation strategies outweighed by the benefits of transforming the system? With what tools and through what processes can their respective trade-offs be assessed to make choices?

The well-being of northern peoples rests on human capacity to monitor and assess the possible trajectories of change, understand the mechanics of change, and identify and implement strategies for adaptation and transformation. These tasks are difficult because of the complexity of social-ecological system dynamics, the interactions of multiple drivers of change, and the limited capacity of people to predict the future with certainty.

Uncertainty is an inherent component of most future conditions, in terms of type, magnitude, rate and direction of change. It is caused by a number of factors: questions of attribution (linking specific changes to specific causes); questions of context (understanding how conditions change from case to case and how those differences affect the effectiveness of possible responses); questions of knowledge (having and using sufficient knowledge from multiple sources to understand the system's behaviour) (Board on Atmospheric Sciences and Climate 2010). In projecting future climate change, there are uncertainties about the global and regional climate circulation models used, about natural variations in climate, and about future CO_2 emissions (AMAP 2011). There is also uncertainty about drivers of change, such as climate, politics, economy or social conditions, and the linkages between these drivers are not entirely clear.

These uncertainties have implications for adaptation. For example, rising ocean temperatures are directly affecting northern fisheries in terms of abundance and distribution of fish stocks and a northward expansion of fish species. Fisheries management also has a direct impact on the fish stocks, but it is not clear to what extent such management and regulations consider the impacts of climate change on commercial fish stocks and marine ecosystems. The combined effects of changes in policy and climate may reveal surprising consequences for northern fisheries (Hovelsrud et al. 2010). In other words, if adaptation is tailored to an incorrectly perceived or evaluated set of impacts, the measures may prove to be maladaptive in the long term, unless learning and adjustments occur as the trajectory unfolds.

Ultimately, adaptation in the Arctic to changing social-ecological change entails adapting to, and accepting some degree of, uncertainty (O'Brien and Wolf 2010). Still, humans are accustomed to living and acting under uncertainty, so the importance of this variable may be overestimated. For example, studies from municipalities in northern Norway show that uncertainty about future climatic conditions was not local officials' main concern when making decisions about the future, while more immediate economic concerns were (Dannevig et al., in press). Nevertheless, communicating such uncertainties is necessary, because they are likely to contain risks that must be dealt with in decades to come. A recent report by Lloyd's and Chatham House (Emmerson and Lahn 2012) described a range of social, political, and economic risks and uncertainties, and their inherent complexities; Table 5.1 summarizes the analysis.

Table 5.1 **Summary of risks and opportunities – Lloyd's Arctic Risk Assessment**
Emmerson and Lahn (2013)

Rapid and disruptive change in the Arctic environment presents uneven prospects for investment and economic development
Environmental changes, especially those linked to global climate change, are giving rise to a broad set of economic and political developments. Sustainable realisation of the economic opportunities that result from these developments depends on strong regulatory frameworks and corporate environmental stewardship. All across the Arctic, changes in climate will create new vulnerabilities for infrastructure and present new design challenges.
The Arctic is likely to attract substantial investment over the coming decade, potentially reaching US$100billion or more
There is a wide range of potential scenarios for the Arctic's economic future, depending principally on local investment conditions and global commodity prices. Oil and gas, mining and the shipping industries will be the biggest drivers and beneficiaries of Arctic economic development. Industries supporting these activities, such as fisheries, aquaculture, tourism and scientific research, could also contribute to the longer-term economic sustainability of Arctic communities. Based on current trends, expected investment in the Arctic could reach $100bn or more over the next decade. However, given the high risk/potentially high reward nature of Arctic investment, this figure could be significantly higher or lower.
Significant knowledge gaps across the Arctic need to be closed urgently
Uncertainties and knowledge gaps exist around the nature of environmental change, the geological potential of the Arctic and environmental baselines, as well as seabed mapping, and how to deal with the risks of significant Arctic industrial activity. Governments, research institutes, non-governmental organizations and businesses can help close these gaps, as a way of reducing risk and ensuring that development takes place within sensible, defined, ecological limits.
Arctic conditions will remain challenging and often unpredictable
The Arctic will remain a complex risk environment. Many of the operational risks to Arctic economic development – particularly oil and gas developments, and shipping – amplify one another. At the same time, the resilience of the Arctic's ecosystems to withstand risk events is weak, and political and corporate sensitivity to a disaster is high.
The environmental consequences of disasters in the Arctic are likely to be worse than in other regions
While particular risk events – such as an oil-spill – are not necessarily more likely in the Arctic than in other extreme environments, the potential environmental consequences, difficulty and cost of clean-up may be significantly greater, with implications for governments, businesses and the insurance industry. Transborder risks, covering several jurisdictions, add further complications.
The politics of Arctic economic development are controversial and fluid
Given the Arctic's iconic status and sensitive environment, Arctic development is often politically contentious, with sometimes opposing interests and perspectives between local, national and international levels. Political support for development will continue to represent an uncertainty for businesses seeking to invest in Arctic projects.
Governance frameworks in the Arctic should continue to develop in their current direction and be reinforced where possible:
There are major differences between regulatory regimes, standards and governance capacity across the Arctic states. The challenges of Arctic development demand coordinated responses where viable, common standards where possible, transparency and best practice across the North. These frameworks need to be in place to enable sustainable development and uphold the public interest.
Risk management is fundamental for companies to work safely, sustainably and successfully in the Arctic
Companies operating in the Arctic require robust risk management frameworks and processes that adopt best practice and contain worst case scenarios, crisis response plans and full-scale exercises. There are many practical steps businesses can take to manage risks effectively, including investing in Arctic-specific technologies and implementing best-in-class operational and safety standards, as well as transferring some of the risks to specialist insurers.

While there is uncertainty about the future, there is also an immediate need to prepare, to consider possible futures and assess the capacity to respond. Thus, adaptation in a changing Arctic is not simply an ecological or scientific problem to be understood and resolved by technicians – it is directly related to the collective action of people and their social systems (Nelson et al. 2007), including their social institutions (Boyd and Folke 2011). Collective action in the North is limited, first and foremost, by the level of empowerment of communities, and the distribution of power and access to it. Collective action is also related to the ways in which people perceive change, their vulnerability, and their need for action. This tension between uncertainty and action points to the importance of human agency and reflexivity in contributing to the resilience of the Arctic and in sustaining human well-being and development (O'Brien and Wolf 2010). While human agency is limited by several factors, such as access to resources and skill, creativity, and motivation, all underappreciated in theory, it is a critically important driver of social-ecological change and among the most important sources of resilience. As Davidson (2010) frames it:

> *The application of the resilience framework to social systems will require improved articulation of the relationship – or more precisely the multiple relationships – between complexity and disturbance in a less deterministic manner than is afforded by ecological systems, in order to specify the conditions favoring the likelihood for resilience, adaptation, or transformation. While the structural complexity of both ecological and social systems can be conceived of in similar terms, the feedback processes associated with each are incomparable: Social systems are unique in that the tendencies toward complexity, and the responses of individual organisms to those levels of complexity, are defined not solely by structural variables, but by agency. (p.1142)*

The study of human adaptation has long been a focus of discussion among scholars of the Arctic, with local and indigenous peoples of the North celebrated for their tremendous capacity to adapt to the environmental extremes and periodic changes in ecosystem services (e.g., Vanstone 1974; Krupnik 1993; Burch 1998). However, few studies have addressed the extent to which Arctic peoples' adaptive capacity will be challenged if the conditions change beyond the known variability. It is therefore timely to discuss whether perceptions of resilience in some contexts may lead to complacency with respect to the need to prepare for and respond to interlinked social, economic, and ecological changes, including climate change (Amundsen 2012), and whether perceived resilience may hinder necessary transformation in the same way that it may hinder adaptation (West and Hovelsrud 2010).

Resilience describes the ability to maintain a system state, not necessarily a preferred condition. In fact, staying within the same system state may not be desirable. Lock-in "traps" that represent entrenched system dynamics may perpetuate dysfunction and stand as significant barriers to needed transformation (Carpenter and Brock 2008). For example, inequality between indigenous peoples and southern peoples persisted through long periods of colonialism in the North. Social conditions, such as widespread substance abuse in a community or limited opportunities for cash revenues, may create significant barriers to transformation and perpetuate existing social traps (Berardi 1998). Research in Australia, meanwhile, found attachment to place and occupational identity were barriers to adaptation and transformation (Marshall et al. 2012).

Drying racks of cod on the Lofoten Islands, Norway

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The research on navigated transformations and transformative capacity is more limited than the study of adaptive capacity, and is just now gaining traction among some resilience scholars (Fisher-Kowalski and Rotmans 2009; Leach et al. 2012). It has received some attention from political scientists and others, in studies grounded in social theory that framed social transitions and focused on devolution in governance, the fall of the former Soviet Union, and the establishment of new institutional arrangements, such as the specification of indigenous rights through land claims and co-management systems.

The Arctic as a social-ecological system may already be experiencing a regime shift (see Chapter 4), with significant social implications. Arctic communities in many regions are relocating due to flooding, the thawing of permafrost, and coastal erosion, and government agencies have a limited capacity to support and facilitate their moves (Huntington et al. 2012), raising a host of economic and human rights issues (Bronen 2011). Subsistence harvesters are facing problems because of climate-induced changes in seasonality (Berkes and Armitage 2010) and fire regimes, while resource management is not providing adequate flexibility in policy-making to make necessary adjustments to meet local needs (McNeeley and Shulski 2011; Ray et al.

2012). And in other areas, policy analysts are seeking to ascertain the potential effects of Arctic shipping in anticipation of an ice-free North, and are doing so with limited understanding of impacts on local communities, market demands, technology, and rates of change (O'Brien and Leichenko 2000; Emmerson and Lahn 2012).

As noted in the Lloyd's/Chatham House report (Emmerson and Lahn 2012), there are also emergent opportunities, such as the rediscovery of agricultural practices by rural peoples who have historically self-identified as hunters and gatherers (Loring and Gerlach 2010). Opportunities in climate change are also found in Greenland among Tunumiut or East Greenlanders, where subsistence harvesters are increasingly becoming fishermen, due to significantly reduced sea ice conditions that were formerly a platform for hunting and travel (Hovelsrud et al. 2011; Ray et al. 2012). Novel conditions, challenges, and opportunities currently abound in the Arctic, suggesting the need to question former notions of the "inherently and highly adaptive northerner", reframe the Arctic as a dynamic and highly complex adaptive system, and embrace responses that reflect this way of framing change.

The recent efforts of climate science, the study of human societies in global environmental change, and advancement of resilience theory and vulnerability science have captured the attention of social scientists and transdisciplinary and interdisciplinary scholars. Theories about adaptive capacity and transformation has been derived from a diversity of interrelated concepts (Smit and Wandel 2006), with roots in multiple academic traditions (Janssen et al. 2006). The study of vulnerability has roots in geography; adaptation studies are rooted in anthropological traditions; and resilience theory has developed to a great extent through an ecological lens (Chapin et al. 2009). While interdisciplinary efforts have led to some conceptual confusion and misunderstandings, an integration of ideas and rich transdisciplinary problem formulation opened doors to new ways to frame adaptation and transformation (e.g., Folke et al. 2010).

5.2 Dimensions of adaptation

Addressing climate adaptation and resilience, Adger (2003) noted that adaptive responses have two dimensions, one of *scale* (who and where is the response occurring?) and one of *purpose* (what motivated the action, and to what end was it taken?). The initiation and implementation of reactive or proactive responses, by governments or through grassroots initiatives, may in turn have a bearing on the acceptance, compliance and long-term success of adaptive strategies. The dimensions of scale, purpose and local context also remind us of the normative character of the adaptation (similar to that of resilience, as noted in Chapter 1). What may be highly adaptive for a group, or even individuals, in one locale may be untenable or even maladaptive for other individuals in the same group or for another group at another location. Similarly, groups and individuals within groups may elect to respond to changes in similar ways, yet may differ in their motivations for doing so. While some actions may be autonomous (e.g., self-organized by disaggregated individuals or citizen groups), some may be planned and centrally directed (e.g., government-led) (Adger 2003), or coordinated as multi-scale or polycentric efforts (Ostrom 2007), while others are driven by engaged municipal officials despite the lack of national guidelines or efforts (Dannevig et al., in press).

From an economic perspective, some have argued that adaptation is initiated when the rewards of action are perceived to outweigh the costs of inaction (Adger et al. 2009), yet the costs-benefit rubric of adaptation decision-making, while helpful, can miss important social and cultural aspects that shape human choice (Adger et al. 2013), such as social values, group identity, and world view. Therefore, motivation and reward systems related to adaptive responses need to be considered with an appreciation for bounded rationality (Simon 1957; Williamson 1975) and local context.

Useful frameworks

Much of the recent empirical and theoretical work on adaptation has been centred on how adaptation may shape vulnerability to climate change. In their seminal framework on vulnerability (see Figure 5.2), Turner et al. (2003) considered adaptive capacity as synonymous with resilience, pointing to *exposure* (the nature and degree to which the system experiences environmental or socio-political stress), *sensitivity* to change (depending on the nature of social-ecological coupling, the intensity, frequency and duration of perturbations), and *resilience* or adaptive capacity (best assessed through an understanding of entitlements, the ability of social system to learn from disturbance, and mostly through social, economic, institutional, and political structures).

In an early application of resilience thinking to the Arctic, McCarthy and Martello (2005) used the Turner et al. (2003) framework in the Arctic Climate Impact Assessment as a way of assessing community vulnerability. Since then, others have applied similar frameworks to assess the vulnerability and resilience of social-ecological systems of the North (e.g., Berkes and Jolly 2001; Ford et al. 2007; Trainor et al. 2009; Hovelsrud and Smit 2010; Lovecraft and Eicken 2011). One such framework was applied in the CAVIAR Project (Community Adaptation and Vulnerability to change in the Arctic Regions) of the International Polar Year programme (2007-2009) in which adaptive capacity was seen as closely related to resilience and reflecting the ability of an individual or community to respond to an exposure-sensitivity. In CAVIAR, adaptive capacity was reflected in the capacity to deal and manage stresses and to anticipate and plan for future changes, and in how resilient a community is to perturbations (Smit et al. 2010, p.6).

Exploring the opportunities for integrating vulnerability analysis with resilience theory, Nelson et al. (2008) noted that the former provides a more actor-centred understanding of adaptation with attention to normative elements, while the latter provides important considerations for system dynamics such as multiple states, trade-offs, and governance, not typically captured with the vulnerability lens. Capturing the characteristics of the process and outcomes of adaptation actions, Nelson et al. (2007) highlighted the relationship between system disturbances, incremental system adjustments (adaptation), deliberate and inadvertent transformation, and "adaptedness", the state in which a system is effective in relating with the environment and meets normative goals of stakeholders. Figure 5.3 illustrates their findings.

Kofinas and Chapin (2009) pointed to the links between sources and processes important in achieving of adaptive capacity. As represented in Figure 5.4, adaptive capacity depends on a suite of interrelated conditions and processes, including, but not limited to, sense of place, knowledge systems, social learning, experimentation, innovation, and social learning, and shared decision making. Analogous to Ostrom et al.'s (2007) argument that there is no institutional panacea, no one process or collection of elements is necessary and sufficient to achieve adaptive capacity. Context is critical to understanding the mix of conditions necessary for a successful response.

Figure 5.2 **Vulnerability framework**
Turner et al. (2003)

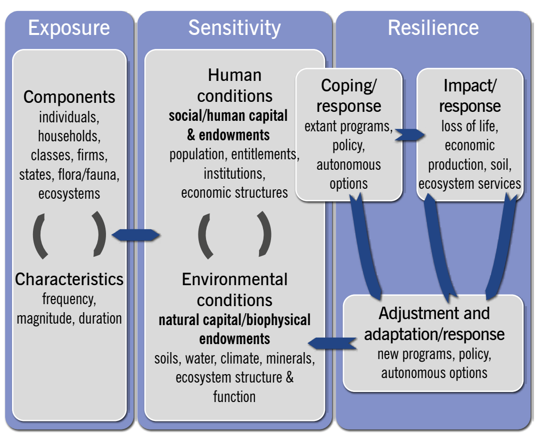
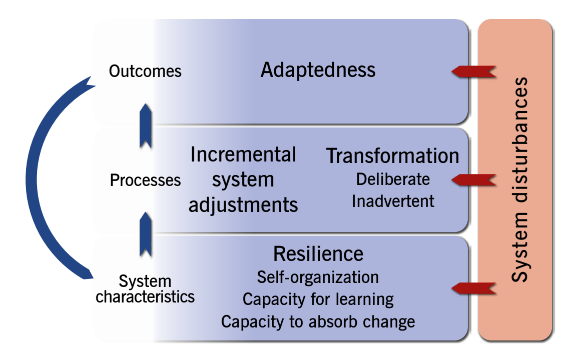


Figure 5.3 **Integrating vulnerability analysis with resilience theory**
Nelson et al. (2008)



From a more theoretical perspective, several scholars have explored a "weakest link" hypothesis for adaptive capacity in a wide range of situations of the globe. The idea, developed by Tol and Yohe (2007), is that adaptive capacity is limited by the weakest among eight underlying determinants:

1. The range of available technological options for adaptation;

2. The availability of resources and their distribution across the population;

3. The structure of critical institutions, the derivative allocation of decision-making authority, and the decision criteria that would be employed;

4. The stock of human capital, including education and personal security;

5. The stock of social capital including the definition of property rights;

6. The system's access to risk-spreading processes;

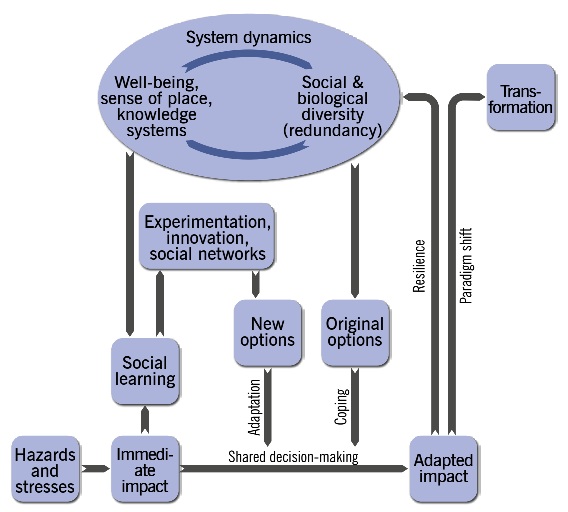
7. The ability of decision-makers to manage information, the processes by which these decision-makers determine which information is credible, and the credibility of the decision-makers themselves; and

8. The public's perceived attribution of the source of stress and the significance of exposure to its local manifestations.

Subsequent empirical research and modelling has confirmed the theory and explored the extent to which certain determinants can compensate for one another (Tol and Yohe 2007). This line of inquiry builds on Intergovernmental Panel on Climate Change (IPCC) treatments of adaptation in which a system's capacity to cope with exposure and/or sensitivity depends on the degree to which people can exploit innate adaptive capacity (Parry et al. 2007). Following the IPCC approach to adaptation, all these factors work together to define social-economic thresholds of tolerance to external stress in ways that are path-dependent and site-specific. Drawing on case studies and comparisons of 26 communities throughout the polar region, the CAVIAR project found similar results: adaptive capacity to changes in coupled social-ecological systems was related to resource accessibility, allocation and extraction policy, economic opportunities, market access constraints, infrastructure, demographics, attitudes and perceptions of change, threats to cultural identity and well-being, transfer of local and traditional knowledge, economic and livelihood flexibility, and enabling institutions (Hovelsrud et al. 2010).

Others who have focused on the resilience of social-ecological systems have offered similar but more general pre-conditions, such as the value of redundancy, diversity, and flexibility (Folke et al. 2002; Folke et al. 2003). Corroborating findings from a recent study from northern Norway (Amundsen 2012) identified six dimensions of community resilience that are activated in processes and activities in the village to respond to current challenges: community resources, community networks, institutions and services, people–place connections, active agents, and learning. These resources, including human, social, cultural, political, economic, and natural (Flora et al. 2004), were identified as the foundation for community resilience, and the ways in which these are engaged in a community affect its resilience (Magis 2010).

Figure 5.4 **Components of adaptive capacity and resilience**
Kofinas and Chapin (2009)



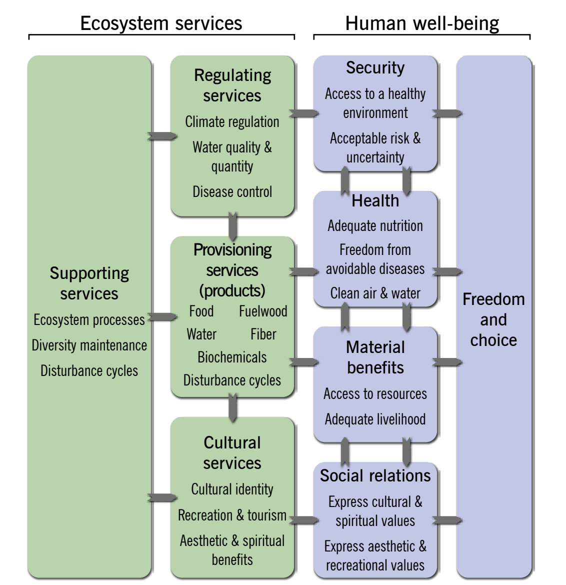
5.3 Sources of adaptive capacity in the Arctic context

We have assessed existing literature and empirical case studies to identify sources or determinants of adaptive capacity in the Arctic context that can be identified *a priori* as important for responding to Arctic change. In many respects, sources or determinants can be described as a set of assets or entitlements available to actors, as well as their ability to draw on them when needed. Here we emphasize seven assets: natural capital, social capital, human capital, infrastructure, financial capital, knowledge assets, and cultural capital.

5.3.1 Natural capital

Natural capital is the stock of resources that indirectly or directly produce the flow of ecosystem services that are important to human well-being, as illustrated in Figure 5.5 (Millennium Ecosystem Assessment 2005).

Figure 5.5 **Ecosystem services and human well-being**
Millennium Ecosystem Assessment (2005)



Provisioning services, the materials harvested from ecosystems, include potable water, fish, game, berries, and other plant products that are critical food resources throughout the Arctic. Regulating ecosystem services, sometimes overlooked in resource management, are especially important in maintaining ecosystem structure and function. These include the effects of sea ice on the erosional potential of coastal storms and the role of wetlands in filtering water and constraining the spread of wildfires. In addition, fundamental ecosystem processes, sometimes known as supporting services, such as diversity maintenance, disturbance regime maintenance, rates of biological productivity, ecological richness, landscape connectivity, and species and ecosystem health are important to ecological resilience. Finally, cultural services such as the cultural connection to landscapes and seascapes and to culturally important foods are critical to culture and sense of place in the North.

Maintenance of natural capital broadens human choice in conditions of change. Given the rates and magnitude of change in Arctic ecosystems due to climate change impacts, human actions to maintain existing system states may need to be balanced with inevitable changes in natural systems. For example, mitigation may prove ineffective, such as some efforts to abate the encroachment of invasive species, preserve seriously endangered species, or suppress wildfires. In those cases, it may be necessary to plan adaptation that assumes trajectories of ecological change.

5.3.2 Social capital

The capacity of individuals to adapt to change is, in part, related to their capacity to act collectively (Adger 2003). Social capital is defined with the sociological lens as the capacity of a group to work collectively to address and solve problems (Coleman 1990; Putnam 2000). Trust relations and reciprocal action among individuals and organizations are crucial to a group's development and maintenance and are generally achieved through shared experiences and ongoing social relations that function to build social cohesion (Duhaime et al. 2004).

Measures of social capital are reflected, in part, through social networks, the links that establish relations among individuals, communities, and organizations across time and space (Hahn et al. 2008). Typically governed by formal and informal institutions, social networks distribute and give access to resources, including information. Economists have argued that there are problems with conflating private access to resources as social capital with societal-level conceptualization of the term, but the two are not mutually exclusive (Adger 2003). In the Arctic, cultural norms that require some indigenous hunters to share their harvest illustrate a kind of social capital with relevance to resilience, functioning to distribute resources to the less fortunate and to build community (e.g., Wenzel 2000; Collings et al. 1998; Magdanz et al. 2002; Wolfe et al. 2009). In the political arena, networks achieved through cross-scale forms of governance, such as co-management, can provide important access to influential non-local decision-makers, enabling adaptation strategies that would otherwise be unavailable (Armitage and Plummer 2010; Berkes and Armitage 2010; Meek 2013).

Social relations and their underlying social networks are therefore endowments that define the sensitivity of a household, community, and society to risk and vulnerability. One such example is a post-Soviet social survival mode of household food production, termed cow-and-kin, which focuses on keeping cows through interdependent relations of labour and produce exchange with kin households (Crate 2006). Typically slow to build and potentially quick to deteriorate, social capital can be essential in times of rapid social or environmental change (Kofinas and Chapin 2009). Social relations, however, are never static and develop and disappear as social linkages shift with changing social networks, as would be expected in any complex adaptive system.

The principle of "six degrees of separation" – that each person is separated from any other person by a maximum of six linkages (Watts 2003) – and the theory of weak ties (Granovetter 1973), which states that critical information is most commonly received outside one's stronger social network, suggest that resilience is maintained both through bonding networks of long-standing familiar relations (e.g., among a kinship group) and bridging networks that connect with more distant actors, for more generalized forms of reciprocity. Weak ties developed through bridging networks can therefore generate novelty and resilience and shape adaptation. For example, the internal relationships among members of a remotely situated indigenous group may provide a sense of common identity and cohesion when confronting external agents, whereas interactions with outside individuals and groups through bridging networks, such as co-management bodies, can provide vital understanding and planning for changes not recognized within the group.

Social capital as a source of adaptive capacity in a world of media-based connectivity raises a number of questions for residents of the Arctic. Increasingly, communities with access to internet services are using the web, Facebook and other social media, and text messaging to communicate about their situations amongst themselves and with the world. These media blur the distinction between local, regional, and global, and serve as emergent and potentially important resources to the Arctic actor. Mass media and globalization, however, may challenge the intergenerational knowledge exchange that grounds and informs subsistence and livelihood practices. Because of the pervasiveness of mass media messages and their emphasis on Western consumer culture and modernity, a perceived gap between the generations can be accentuated.

5.3.3 Human capital

Human capital refers to human resources and competencies, such as skills derived through education and other means, interpersonal skills, historical insights, and leadership. These assets are important in mobilizing for collective action, facilitating planning processes, interpreting information from non-local sources, communicating with other actors, and engaging with decision-makers to navigate political systems and capturing funding sources and employment. Resilience scholars have pointed to the value of effective leadership in adaptation, innovation, and transformation (Olsson et al. 2004; Olsson et al. 2006). Particularly helpful in the highly diverse setting of the North are leadership skills with a bi-cultural orientation, allowing key leaders to move between social worlds, communicate concerns and needs, and effect change.

In a more traditional sense, human capital complements cultural capital by providing knowledgeable people who can harvest traditional resources, negotiate travel on the land and sea in high risk conditions, understand ecological dynamics, and offer wisdom about culturally appropriate ways of interacting with the environment. Some continue to subscribe to variants of modernization theory, suggesting that engagement in the cash economy increases human capital for in the market economy while depleting knowledge of more traditional ways. Empirical evidence, however, shows otherwise: that economic development and cultural continuity may be concurrent, without actual contradictions (Kruse 1992; BurnSilver et al. 2012). The resilience challenge is to maintain cultural values and practices that foster cultural strength in a globalized world.

Sheila Watt-Cloutier is an Inuit and indigenous peoples leader and activist, on both the national and international levels

Human capital in Arctic regions affects population mobility, and migration can have significance impacts on human and social capital. Young people often leave rural Arctic communities to obtain post-secondary education. Although many return with enhanced human capital, individuals with more education are more mobile and likely to leave small Arctic communities for larger settlements (Huskey et al. 2004; Rasmussen 2011). Many moves involve step-by-step migration from villages to small towns to larger settlements (Howe 2009). Gender differences in education, with young women more likely to aspire to higher education (Hamilton and Seyfrit 1994), lead to gender differences in migration and potential sex-ratio imbalances in the population (Hamilton and Rasmussen 2010; Hamilton 2010). Out-migration can therefore drain rural communities of precious human skills when families relocate to urban areas to seek economic or educational opportunities. Fewer women in a community means fewer children; declining school-age populations potentially lead to school closures and community abandonment (Martin 2009).

Conversely, in-migration of individuals (e.g., extractive industry workers) can alter the cultural fabric of communities and potentially create either social and environmental problems, or transfer knowledge that broadens a community perspective (Forbes and Stammler 2009; Forbes et al. 2009). Migration is commonly a direct result of social and economic policies of the state (see the BOREAS "Move" Project under the International Polar Year). Migration may also provide opportunities through education and interactions that enable people to function effectively in both the indigenous and non-indigenous worlds and extend the reach of local sharing networks. It is not uncommon for people from a community to leave for a period of time and return to assume leadership roles that bridge community values with western realities. Findings from recent research also show that migration patterns vary widely across the Arctic. For example, the 2002 Russian Census shows the country's northern periphery underwent a massive out-migration, averaging more than 14% of the Soviet-era population, with half of all northern regions experiencing a 20% or greater decrease. Most residents who left were relatively younger, educated people who had the resources and initiative to leave (Hill and Gaddy 2003; Crate and Nuttall 2009). Some have argued, however, that the massive depopulation of the Russian North during the economic transition is a positive trend that will move the area to a more sustainable population resembling its circumpolar counterparts (Lewis 1999).

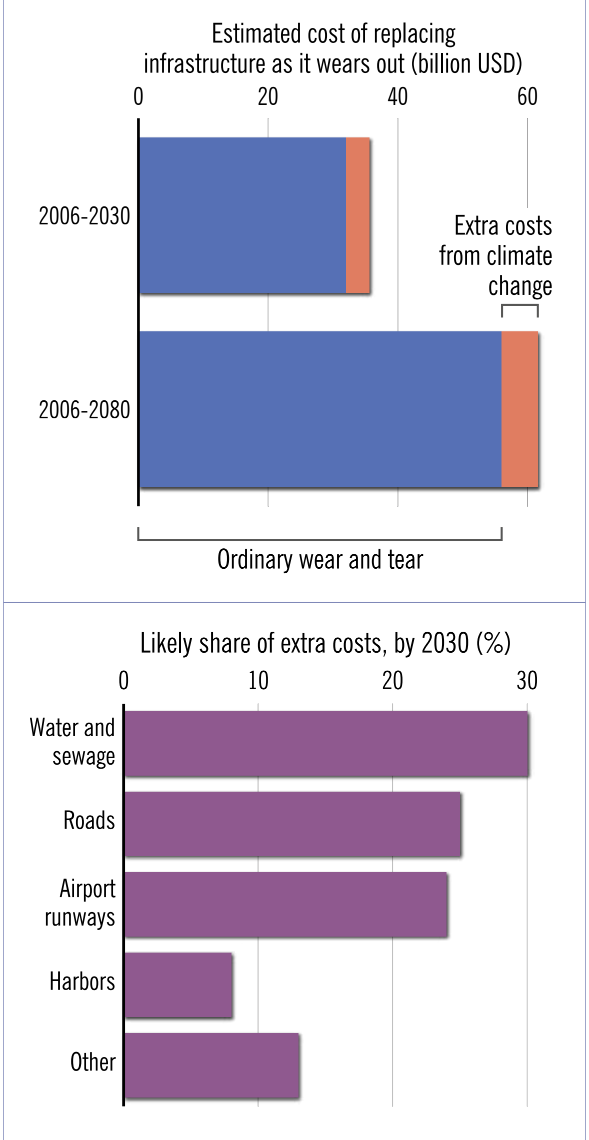
5.3.4 Infrastructure

Infrastructure can serve as an important asset in adaptive capacity. Good-quality housing, modern educational facilities, links to the digital highway, and road access provide an expanded set of adaptation options. Infrastructure may also contribute to the standard-of-living conditions that influence health. The quality of housing and other infrastructure in Arctic communities, as well as transportation infrastructure linking communities to one another and to regions outside the Arctic, can have a significant effect on migration rates and population change (Berman and Howe 2012). Conversely, once in place, infrastructure can demand human and financial resources for maintenance, which can be difficult if funding is limited.

In Russia, damage to infrastructure due to floods and permafrost thawing is attributed to climate change

(Tsalikov 2009). In Alaska, such costs are playing out where coastal erosion is accelerated due to climate change. Once seasonally nomadic without human settlements and extensive infrastructure, Alaskan communities and their governments are currently facing high costs associated with settlement relocation and/or infrastructure maintenance related to climate change mitigation (Bronen 2011). Recent studies at the Institute of Social and Economic Research at the University of Alaska projected future costs of public infrastructure damage due to climate change, as illustrated in Figure 5.6 (Larsen et al. 2008). Costs to industry and private individuals are mostly uncalculated, but are likely to be considerable (Forbes et al. 2009).

Figure 5.6 **Added cost of infrastructure repair and replacement due to climate change**
Larsen et al. (2008)



5.3.5 Financial capital

The role of financial capital is not highly emphasized in studies of adaptive capacity. Individuals, households, organizations and government with access to financial resources have options not available to others. Defined by Smit and Pilifosova (2001) in the context of adaptation, financial capital is economic assets, capital resources, financial means, wealth or poverty that facilitate human responses to change. For example, well-financed government programmes, such as those in Scandinavia, offer important safety nets for local residents. The Alaska Permanent Fund, currently valued at 44 billion USD, serves as a resource for the state's population of 734,000 people.

At the household level, cash reserves can provide a buffer during times of subsistence harvesting shortfalls by making it possible to buy additional food stocks at local stores. During the 2008 spike in global oil prices, the North Slope Borough of Alaska, which generates considerable financial resources by taxing oil facility infrastructure, was able to subsidize North Slope village residents' costs of fuel; in interior Alaska villages, meanwhile, where no subsidies were offered, fuel costs increased twice as much. Conversely, the need to maintain these assets may also prove to be a barrier in some situations.

Given the boom-bust economies typical of the North, access to financial capital and means of generating streams of cash income may be important to resilience (Chapin et al. 2006). In these and other ways, economic resources can ultimately have a bearing on livelihood diversification and flexibility, both with consequences for adaptive capacity.

5.3.6 Knowledge assets

Knowledge is included as a source of adaptive capacity because of the importance of information for assessing current conditions, and strategically planning for the future. The uncertainty associated with a rapidly changing North is largely a consequence of 1) the inherent natural variability in the Arctic physical environment, and 2) poor or insufficient data with limited time depth and spatial representation, which in turn limits people's capacity to analyze and understand patterns of change in order to make meaningful projections about future conditions. There is also a significant cognitive dimension to knowledge as a source of adaptive capacity, related to the ability to perceive changes, assimilate their meaning, and translate that meaning into action (Alessa et al. 2008; Kliskey et al. 2009).

It has been demonstrated that there is a need for knowledge co-production in the Arctic that draws from multiple scales and different cultural perspectives

(Huntington et al. 2002; Krupnik and Jolly 2002; Parlee et al. 2005; Armitage et al. 2008; Dale and Armitage 2011). As in many parts of the world, knowledge in the Arctic comes from many different cultural traditions, the acknowledgement of which is necessary for more accurate data integration and more holistic learning (Armitage et al. 2011; also see discussion of adaptive governance below). Although many have argued for the benefits of integrating different knowledge types, others have stressed the underlying power relations in these processes and the problems that arise when seeking to combine differing cultural traditions into "one knowledge" (Nadasdy 1999; Cruikshank 2000; Natcher et al. 2005; Dowsley and Wenzel 2008). Moreover, traditional indigenous knowledge has spiritual dimensions, lacking in western science (Berkes 2012), that can be useful in providing an ethical framework for adapting to change (Cochran et al., in press).

Each knowledge system has its own logic and its own kind of "peer review". One way to respect the integrity of each knowledge system is to seek ways of "bridging" different kinds of knowledge (Millennium Ecosystem Assessment 2006). Such an approach may be preferable to "synthesizing" or "combining" or "integrating" knowledge systems because, due to unequal power relations, integration often works to the disadvantage of indigenous peoples and many local communities. As many examples show, power imbalances make local and indigenous communities and their knowledge vulnerable to outside influences (Berkes 2012). Hence, bridging knowledge systems is preferable to integration, because it helps mutual exchange and mutual learning, leading to knowledge co-production while respecting the integrity of each kind of knowledge. While there are many examples where multiple ways of knowing have contributed to resilience, such as bowhead whale population estimates (Huntington 2000), processes of "integration" are still in need of further development.

5.3.7 Cultural capital

The rich cultural diversity found across the Arctic is potentially an important resource for maintaining human well-being and enhancing viability in an unknown future. Here we define culture as encompassing virtually all aspects of human life including language, knowledge, world views, beliefs, norms, values, social relationships, perceptions of risk, power relations, and understanding of and responses to the world (Crate 2008, Heyd 2008, Roncoli et al. 2009, Strauss 2009, O'Brien and Wolf 2010, Tingley et al. 2010). This bundle of cultural elements can shape adaptive responses to both socio-economic and environmental changes (Siurua and Swift 2002; Buikstra et al. 2010; Petheram et al. 2010; Paul and Routray 2011; Forbes, accepted).

Differing ways of valuing and approaching problems yield multiple avenues to respond and, in some cases, can provide lessons from past experiments, experiences, and cultural traditions. Understanding how culture relates to community resilience, however, requires that we recognize that cultures and sub-cultures are dynamic and change over generations, resulting in potential for both adaptation and degradation – for example, through the adoption of new technologies, changing norms and, in the latter case, the deterioration of oral traditions (Alessa et al. 2010).

For many indigenous and rural communities in the Arctic, culture is constructed around livelihood activities such as reindeer husbandry, farming, fishing, and hunting and gathering (Nuttall 2005). Changing and new seasonal weather patterns and extreme events, changing sea ice conditions, sea-level rise, coastal erosion, species abundance and composition, community relocation and increasingly dangerous travel conditions and the profound infiltration of media technologies (e.g., television, internet, smartphones) are rapidly modifying culture in ways that are poorly understood. As environmental changes lead to modifications in ecosystem services upon which the cultures depend, core cultural elements such as world view and mythological symbols will change and may even be lost or eroded (Crate 2008). On the other hand, many cultures have adapted to significant societal and environmental changes throughout history and colonial encounters (Nuttall and Callaghan 2000; Strauss 2009; Cameron 2012). The challenges to maintaining cultures and livelihoods are now being exacerbated by climate change, which poses a greater risk than before to adaptive capacities (Crate and Nuttall 2009; Rybråten and Hovelsrud 2010). Such risks may be exacerbated when policy creates barriers for adaptation (Wenzel 2009), and these risks may be reduced if policy-makers intervene to remove them (Ford et al. 2006), or if governance institutions remain flexible. Diverse factors can contribute to cultural resilience, including an accommodating world view, a firm sense of stewardship, individual and collective agency, recruitment of youth, and the maintenance of nuclear families to fulfil respective gender roles (Forbes, accepted).

Adaptive capacity is increasingly found to have a gender dimension. The importance of examining gender within the global interdisciplinary research on climate change is well established (Fleischman and Huttunen 1990; Denton 2000; Nelson et al. 2002; Lambrou and Piana 2006; UNDP 2009; Preet et al. 2010). In the Arctic, education and out-migration of women can be problematic for communities because of loss of critical resources and demographics (e.g., Forbes, accepted). Moreover, women tend to be the initiators of successful responses to change in communities, particularly in making traditional knowledge while incorporating other forms of best available science to perceive and mobilize others to respond to undesired changes or capitalize on new opportunities (Alessa and Kliskey 2012).

5.4 Noting regional differences

In compiling a list of sources or determinants of adaptive capacity, it is important to note differences in how adaptive capacity is shaped and talked about in North America, the Nordic countries and Russia. Studies from Alaska and Arctic Canada often emphasize how the adaptive capacity of small-scale indigenous communities is closely linked with harvesting activities, food security and access to hunting grounds and traditional foods (e.g., Berkes and Jolly 2001; Kofinas et al. 2010). Studies from the Nordic and Russian context have focused on adaptive capacity with a greater focus on globalization, economic resources, technology, information and skills, infrastructure, institutions and equity (Keskitalo et al. 2011). Findings suggest that in the Nordic and Russian context, current capacity to respond to climate change is low compared with the capacity to respond to changing societal conditions.

When there is an absence of a clear national policy and guidelines, adaptation is often driven by reactive measures and engaged individuals (Amundsen et al. 2010; Dannevig et al., in press), rather than rational and proactive strategic planning. In addition, a lack of policies on adaptation raises critical questions about the consequences for adaptive capacity in natural resource management and industry. These issues are particularly relevant in Russia, where indigenous peoples experienced collectivization (Crate 2002), northern industrial expansion in the Soviet time (Fondahl 1998; Crate 2002; Forbes and Stammler 2009; Vinokurova 2011), and more recently, economic, environmental and socio-cultural impacts since the fall of the Soviet Union in 1991 (Crate 2006; Vinokurova 2011). Although indigenous minorities of the Russian North have held certain rights and privileges, these rights have not always been recognized (Golovnev and Osherenko 1999; Crate and Nuttall 2009; see also governance section below).

Taking into consideration the multi-faceted drivers of change in the Arctic, their trajectories and rates of change, and the complexities of their impacts, planning strategies for responding to climate change are needed, with a specific focus on assessing and building adaptive capacity of communities, agencies, NGOs, and industries. Whereas the adaptive capacity of communities depends on regional and political governance, national and regional historical development is shaped by path-dependent institutions that restrain resource use in particular ways (Keskitalo et al. 2011). Infrastructure development may also contribute to the adaptive capacity profile of the location in question, but as noted above, infrastructure comes with the costs of maintenance, which can strain available resources (Larsen et al. 2008). The strength of cultural identity and well-being, the ability to transfer local/traditional knowledge, and the possibilities for livelihood flexibility and diversification also emerge as salient determinants of adaptive capacity (Hovelsrud et al. 2010; Keskitalo et al. 2011). The extent to which these objectives can be achieved through adaptive governance is discussed in the following section.

5.5 Adaptation and governance

Governance is defined as collective efforts of society to define and achieve societal goals (Young et al. 2008; Ostrom 2009) and serves as a kind of navigation device for addressing societal challenges (Young 2013). It is the process by which citizen groups, government agencies, NGOs, businesses, communities, and individuals and organizations interact as part of a decision-making process, which may or may not involve government. As noted in Chapter 2, governance and its institutions (formal and informal rules that shape human behaviour and define roles) are determinants of social process and social-ecological interactions. In a world where human activities are a major force for change at the global scale (i.e., "the Anthropocene"), the extent to which the governance at multiple scales is sensitive and responsive to change will have a major bearing on the resilience of people, ecosystems and their interactions.

Successful adaptive governance is responsive to change, focused holistically on social–ecological interactions, well informed by a diversity of perspectives, reflexive in decision making, and innovative in problem solving (Folke et al. 2005; Kofinas 2009; Brunner and Lynch 2010). In theory, adaptive governance is achieved through networks of decision-making arrangements that are guided by good leadership to effectively link communities of resource users with regional-, national-, and global-scale institutions (Armitage et al. 2007; Armitage and Plummer 2010). Adaptive governance is also informed by systematic social and ecological monitoring and data collection, ongoing and in some cases long-term research, model development and reflection, and data analysis. It is implemented through a range of science and management activities, such as habitat protection and impacts assessment, enforcement; resource allocation, education, and policy-making. In these ways, adaptive governance is particularly suited to addressing conditions of dynamic change.

However, realizing the ideals of adaptive governance for the North is a significant challenge. In spite of many changes in Arctic institutional arrangements addressing social-ecological interactions, "scientific management" remains the dominant approach to governance of social-ecological systems and their Arctic constituents. In this context, scientific management refers to a paradigm in which science is taken as an objective source of information that forms the authoritative basis of policies that are implemented in a top-down manner by a centralized, bureaucratic state institution (Brunner et al. 2005). The scientific management approach has an established record of failure at solving complex problems that have social and ecological components (ibid.). In the Arctic, scientific management has in many cases been experienced locally as top-down enforcement of legislation and policies that differ from indigenous and local norms or practices.

The *Arctic Human Development Report* (AHDR) identified four recent trends in resource policy in the Circumpolar North (Caulfield 2004). First is the growing importance of land and resource rights: the focal elements of comprehensive indigenous land claims, which have led to fundamental changes in the political landscape of the Circumpolar North. Second is the incorporation of local or traditional ecological knowledge ("TEK") in decision-making, which is perhaps the most high-profile and contentious feature of current environment and resource policy processes in the region. Third is devolution of powers to local decision-makers and co-management. Devolution of authority has taken place within Arctic nation-states (e.g., the creation of the Territory of Nunavut in Canada from a portion of the former Northwest Territories, the transition to home rule and the more recent self-government in Greenland, and development of the Finnmark Act of 2005 in northern Norway). In some cases devolution has come with funding and resources that are critical for policy implementation, and in other cases it has not. The fourth trend identified is the widening involvement of Arctic peoples in ownership and development of lands and resources. The active involvement by Arctic peoples in resource ownership and development has its roots in the indigenous self-determination movement that began in the 1960s, but is now being expressed in a proliferation of forms, ranging from municipal-style governments to private-sector partnerships. The AHDR concluded that these trends are likely to continue, generally leading to greater legitimacy in management. Further, Caulfield et al. (2004) argued that the most appropriate resource governance institutions are typically those that take into account the social and cultural values of Arctic peoples, are flexible and responsive to change, and are scaled appropriately – characteristics considered by resilience scholars under the rubric of "adaptive governance" (Folke et al. 2005).

Significant and constructive institutional adaptation is indeed taking place throughout the region, but the pace of such innovation is painfully slow (typically decadal), and appears not to be keeping pace with the accelerating speed of observed biophysical and socio-economic changes. In other words, the problems faced in the Arctic are getting worse faster than we are growing our capabilities for solving them. This "ingenuity gap" (Homer-Dixon 2001) poses a considerable challenge for maintaining social-ecological system resilience in the region and globally. One prominent example is the failure of national and international institutions for polar bear conservation to adapt to changing societal conditions or make meaningful progress towards mitigating the threat of sea ice habitat loss due to climatic warming (Clark et al. 2009; Meek 2011; Peacock et al. 2011).

Members of the Western Arctic Herd Working Group review maps to consider the implications of land use change to subsistence hunting

Similarly, policies based on static and obsolete conceptions of ecology (i.e. ecosystems in equilibrium) have kept officials in Kluane National Park in the Yukon, Canada, from being able to decide whether an immigrating population of reintroduced wood bison should be welcomed or eliminated (Markel and Clark 2012). Projecting all these trends forward from present conditions and assuming no radical change from a "business as usual" approach to institutional development, maintaining societal and institutional capacity for adaptation will be difficult, and is likely to become increasingly so. Ironically, prospects for transformation may improve as crises proliferate, but options and resources for constructive transformations will likely also become more constrained.

We anticipate that surprises will occur that existing institutions will be incapable of meeting. Inuit author Rachel A. Qitsualik (2006) cautions that from her cultural perspective, *Nalunaqtuq* – translated as "the Arctic environment's inherent unpredictability and indeterminacy" – will continue to confound colonial efforts, as it has in the past. Acceptance of *Nalunaqtuq* is one key to the resilience of Inuit culture, and this philosophical principle is of immediate and obvious salience for others in or concerned with the Arctic as changes there continue to accelerate.

Surprises will not originate solely in the biophysical realm. Society will produce emergent and unexpected responses, such as the 2012 ocean fertilization/ geoengineering experiment conducted in international waters off Haida Gwaii by a Canadian First Nation community's development corporation and an American entrepreneur (Tollefson 2012). There is no authoritative body capable of controlling such activities, which other indigenous communities may decide to undertake, either in the Arctic or elsewhere, since cost is not prohibitive for non-state actors (Dyer 2008). We are likely to see declarations of crises as biophysical and social thresholds are passed (Chapter 4). Many such transitions will have concrete and observable social, physical and biological effects, yet how different groups in the Arctic are affected by those changes will differ, and the extent of many such apparent crises will depend on differences in context. Societal actions will generate responses, too, some of which will also be declared crises and, notwithstanding any such labels, may or may not promote resilience. In the absence of successful policies to curb greenhouse gas emissions, sub-national actions will proliferate at and across multiple institutional scales, societies, and regions. Social media now enable unprecedented rapid communication and self-organization of activities among individuals and organizations in the Arctic and globally, which will likely hasten the proliferation of smaller-scale adaptation efforts.

5.6 Governance for adaptation

Counterproductive potential responses for adaptive governance abound. One could simply give up and do nothing, adopt a free-for-all "gold rush" mentality, or double down on scientific management and specific governance approaches developed for static conditions. This third tactic is judged by Brunner and Lynch (2010) as "the epitome of hubris" (p.309). Fortunately, more productive approaches exist, though it will be necessary to rethink some conventional assumptions about them. Below we provide a list of essential elements for achieving adaptive governance in the context of the Arctic.

5.6.1 Collective action

The Arctic faces major problems of environmental change, and is at the front line for climate change impacts (Chapin et al. 2004; Chapin et al. 2006; Hansen et al. 2006). One dilemma is that by the time climate change effects are sufficiently evident and harmful to compel action, it will be too late to mitigate greenhouse gases enough to maintain the current state and functioning of Arctic social-ecological systems (see Chapter 1). A second dilemma is that problems such as climate change challenge the ability of nation-states to guarantee security to their citizens and thus require a new kind of social contract (O'Brien et al. 2009). No two Arctic countries face exactly the same costs and benefits in terms of action, and no country can take effective action alone. Collective action to tackle the problem is necessary to reduce the costs of both mitigation and adaption.

International collaboration to address the climate change problem requires multi-level action from the local to the national (Galaz et al. 2008, Young et al. 2008). Removal of cross-scale constraints on adaptation and transformation may be feasible to expand opportunity for local and regional innovations. In this context, some of the barriers are state-imposed constraints on indigenous peoples, cultural practices, and political-economic activities. In many arenas, Arctic peoples over the past decades have lost the possibility of making their own decisions, but successful adaptation will no doubt require regaining greater levels of control in local and regional decision-making (Huntington et al. 2005). Some such "decolonization" has taken place, especially through native land and resource claims agreements and decentralization, but this dependency on central governments continues in many arenas.

Local and regional-scale initiatives are more likely to pay off and move farther and faster towards adaptation. For example, the "bottom-up" development of an international carbon market between California and Quebec is a contrast to the relative lack of progress of North American governments to advance greenhouse gas mitigation activities under the "top-down" United Nations Framework Convention on Climate Change (UNFCCC) and its constituent agreements. Similarly, note the efforts of the Alaska Climate Change Sub-Cabinet, established in 2007 by then-Gov. Sarah Palin. The Sub-Cabinet was charged with building the state's knowledge of the actual and foreseeable effects of climate warming in Alaska; developing appropriate measures and policies to prepare communities in Alaska for the anticipated impacts from climate change; and providing guidance regarding Alaska's participation in regional and national efforts addressing causes and effects of climate change. It led to wide participation across many sectors and initiated an ongoing discussion about mitigation and adaptation planning options available to the state. The Sub-Cabinet was most successful in initiating actions to assist a few communities threatened by climate-change-induced coastal erosion, but otherwise, the group's recommendations were largely ignored by the Alaska government. This is an example where the information, analysis and policy consequences were gathered, but the political will for implementation was lacking.

The need to expand the scale of such local and regional innovations remains. "Scaling-up" is the most commonly promoted approach, yet it is difficult to do, and whether it is even possible at large spatial scales remains an open question (Berkes 2006). Diffusion of innovations is much more feasible under present conditions, and is likely to be more effective than simply scaling-up (Brunner and Lynch 2010). Such diffusion can happen horizontally (i.e., peer-to-peer or group to group), or can be facilitated by deliberately created networks. An Arctic Resilience Network that facilitates the sharing experiences across lateral and horizontal scales may become useful to foster social learning, collaboration across cultures and among multiple ways of knowing, exploration of new problem definitions, and support actions for adaptation and transformation. Clearly, developing successful adaptation strategies will require a multi-pronged approach which builds on multiple cases (e.g., Ford and Frugal 2009).

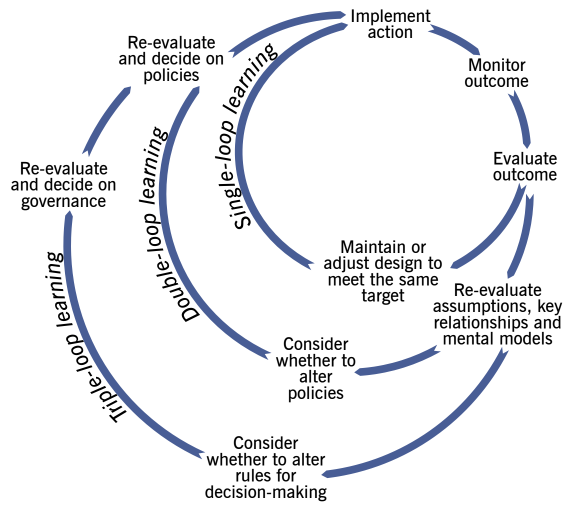
5.6.2 Social learning

The transition to adaptive governance will require fundamental changes in decision-making processes that better enable social learning (Armitage et al. 2007; Armitage and Plummer 2010). It has been suggested that such changes will require a "culture change" among agency professionals and others, moving from trial-and-error decision-making dominated by interests, to reflexive processes that systematically view past experiences as natural experiments. By regularly questioning assumptions, and building appropriate innovative and actively tested novel approaches, such a culture change can help to validate and build knowledge (i.e. "double-loop learning" of adaptive management), as illustrated in Figure 5.7.

While these principles are laudable, they are extremely difficult to realize when there is no clear public consensus on objectives for the future, and when causality attributable to a change in policy (e.g., a change in fish and wildlife harvesting regulations) is confounded by climate-induced changes with major biophysical effects (Nicol et al., in review).

In spite of these problems, there is an urgent need for social learning to generate new problem definitions. Conserving the Arctic in its current state is no longer feasible (see Chapter 4), yet to date there has been an almost total absence of imagining any other objective. Among the first casualties of the unfolding processes in the Arctic may be the notion of "sustainability" as an achievable steady-state, and most conventional approaches to environmental conservation (Ludwig 2001). While such considerations will no doubt keep chroniclers and scholars busy, individuals, groups, and institutions that identify with those ideas will be deeply threatened, and ideological conflicts will likely confound many Arctic adaptation efforts. Such conflicts are not new in the Arctic (e.g., Wenzel 1991), but their resurgence could be especially problematic as changes accelerate.

Figure 5.7 **Single, double, and triple loop learning**
Chapin et al. (2009)



5.6.3 Fragile aspirations: adaptive co-management and adaptive governance

Adaptive management, as originally envisioned by Holling (1978) and Walters (1986), is a structured, iterative process of decision-making under conditions of uncertainty, with the aim of reducing uncertainty over time by monitoring the outcomes of previous decisions; it is simply a refinement of scientific management in which science compels policy. Under conditions of rapid change as currently observed in the Arctic, this approach would be insufficient. Originally implemented as a technocratic approach (Lee 1999), adaptive management requires a participatory emphasis to come to grips with Arctic adaptation issues.

The concept of "adaptive co-management" includes more participatory and knowledge co-production elements (Armitage et al. 2007), but neither of these approaches is a prescription for policy processes. Instead, both reflect self-organizing responses of social-ecological systems in which participants are able to move towards clarifying and securing their common interests only when they are sufficiently motivated to do so. Conditions for emergence are limiting (Armitage and Plummer 2010), and imposed forms of these approaches are vulnerable to failure. That said, the case study literature is replete with nascent efforts in the Arctic to move beyond co-management (i.e., power-sharing arrangements) and towards adaptive co-management approaches that incorporate iterative learning (Berkes 2006; Kofinas et al. 2007; Berkes 2009; Dowsley and Wenzel 2008; Armitage et al. 2011; Dale and Armitage 2011). Still, the complexity of both problems and institutions may increasingly narrow the future scope of possibilities for the emergence of adaptive co-management and adaptive governance (Folke et al. 2005). Since such complexity may increase vulnerability, such limitation may only be temporary and may in fact provide the stimulus for transformation. However, the implications of complexity may depend on its nature and structure. For example, complexity that results from diversity and modularity may reduce vulnerability (e.g., more options, some of which have desirable levels of functional complexity).

Reindeer herding in the taiga is under intense pressure, yet survives due to the strong and ancient bond between herding communities and their reindeer

5.7 Transformative capacity – determinants and prospects for the Arctic

Most scholarship on governance and policy relevant to Arctic resilience implicitly or explicitly aims to prevent crises and system breakdown – a predominant assumption in the sustainability and social justice literature. Thomas Homer-Dixon, however, has advanced the idea – rooted in resilience theory – that simply trying to forestall breakdown in complex systems is self-defeating and futile (Homer-Dixon, T.A.D. 2005. The upside of down: catastrophe, creativity, and the renewal of civilization. Random House, Toronto, ON). He put forward an alternative strategy termed "catagenesis": essentially expecting surprise and collapse in such systems, and planning to use such crises to rebuild and transform. He suggested that some breakdown, or "release", in resilience theory's adaptive cycle terminology (Gunderson and Holling 2002), can be deliberately employed, with one overall goal being to avoid cascading collapse across scales or even entire systems. Given the current situation and even short-term trends in Arctic systems, the notion of catagenesis warrants further attention.

In the language of resilience theory, catagenesis suggests the need for navigated or active transformation on the social, economic, and institutional arenas (Walker et al. 2004; Folke et al. 2009; Olsson et al. 2010). Alternatively, stewardship (the active shaping of social-ecological change) to enhance ecosystem resilience and human well-being may allow for transforming subsystems without a full system collapse (Chapin et al. 2011). This approach begs the question: what is the system you want to transform? Resilience scholars have increasingly focused on transformational process and, to a lesser extent, the pre-conditions that determine its likelihood, with some recent discussions in the Arctic context of deliberate societal transformation to meet the challenges presented by climate change (O'Brien 2012).

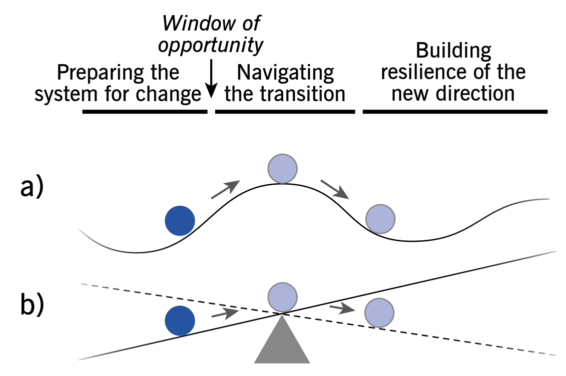
Given the regime shift for the Arctic described in Chapter 4, an obvious question is how to avoid a degradation of coupled social-ecological conditions. Folke et al. (2009) point out that unintended transformations can follow from several conditions, including introduction or loss of keystone functional types (top-down effects), pollution or soil resource loss due to erosion (bottom-up effects), an altered disturbance regime, degradation of human well-being, the erosion of social capital, dysfunctional social institutions such as institutional misfits (Galaz et al. 2008), and limited cross-scale interactions. The Arctic is well endowed with social and ecological richness, while at the same time subject to powerful forces for change. How then can society actively navigate changes to transform or adapt to the changing conditions?

Constructive transformation requires avoiding unfavourable state changes and navigating to potentially favourable new state (Folke et al. 2009). Figure 5.7 illustrates triple-loop learning – a step beyond the questioning of operating assumptions, as described in the double loop, and a process by which rule-making is significantly modified or paradigms are shifted, changing how the system is conceptualized.

Figure 5.8 illustrates active transformation, which suggests monitoring the system for windows of opportunity for change, selectively creating institutional change (i.e. political processes) that modifies thresholds and reduces barriers to state changes, and once achieved, building resilience of the transformed state (i.e. resilience planning).

The prospects of navigating transformative change successfully at a grand scale are made especially difficult when governing nation-states have interests that are not aligned with the Arctic residents. Institutional innovations, such as self-government in Greenland, the Arctic Council, and co-management arrangements through land claims represent some modest transformations. Climate change impacts may provide the needed challenges for motivating collective action.

Figure 5.8 **Three phases of transformation**
Folke et al. (2009) and Olson et al. (2010)



The dramatic changes in governance achieved in the creation of Nunavut and Greenland home rule are two examples of how these processes unfolded. Folke et al. (2009) provided a list of 14 conditions, shown in Table 5.2, that foster successful navigated transformation.

The creation of bridging organizations (i.e., groups that link actors across scales or sectors) and shadow networks (i.e., informal networks without affiliation with formal organizations) may be especially helpful in moving towards change. Scenario planning, multi-scale observation systems, integrated computer model situations, visualization tools, and decision support systems are some of the emerging methods have been employed and are being developed that can support these processes. If these approaches are to be used successfully in the Arctic, it requires that they be administered with sensitivity to cultural differences, power inequities, and their high financial costs. As noted by Olsson et al. (2010), navigated transformation of a social-ecological system from a lock-in trap with high dysfunction to a more desirable state is a multi-level and interacting process, one that is panarchical in nature (Gunderson and Holling 2002) and may be slow to realize.

Table 5.2 **Conditions that foster successful transformation**
Folke et al. (2009)

Change attitudes among groups to a new, shared vision; differences are good, polarization is bad.
Check for and develop persistent, embedded leadership across scales; one person can do it for a time, but several are better locally, regionally, and politically.
Design resilient processes, e.g., discourse and collaborations, not fixed structures.
Evaluate and monitor outcomes of past interventions and encourage reflection followed by changes in practices.
Change is both bottom-up and top-down. Otherwise, scale conflicts ultimately compromise the outcome; globalization is good but can destroy adaptive capacity both regionally and locally.
Develop and maintain a portfolio of projects, waiting for opportunities to open.
Always check larger scales in different sectors for opportunities; this is not science, but politics.
Know which phase of an adaptive cycle the system has reached and identify thresholds; talk about it with others.
Plan actions for surprise and renewal differently than growth and conservation; efficiency is on the last part and resilience on the first.
The time horizon for effect and assessment is at least 30–50 years; restructuring resilience requires attention to slow dynamics.
Create cooperation and transform conflict, but some level of conflict ensures that channels for expressing dissent and disagreement remain open.
Create novel communication face-to-face, individual-to-individual, group-to-group,and sector-to-sector.
Encourage small-scale revolts, renewals and reorganizations, not large-scale collapses.
Try to facilitate adaptive governance by allowing just enough flexibility in institutions and politics.

5.8 Conclusion, key findings, and the process ahead

In this chapter we have presented the concepts of adaptive and transformative capacity as discussed in the scientific literature, and to a limited extent, applied those ideas to the Arctic context. We have highlighted the role of uncertainty in decision-making about the Arctic's future, noted sources or determinants for adaptive capacity, and evaluated the extent to which emerging ideas for governance, such as adaptive co-management, can meet the challenges faced by an Arctic of inevitable dramatic change. While active transformation of the system may in some cases be the only logical way forward, the combination of institutional inertia and political control by non-Arctic entities set up barriers to significant change. There are, however, emerging tools and methods for resilience strategic planning that may help lower barriers and lead to a greater realization of possible futures. Many of these tools and methods are "cutting edge" and require more effort for their refinement and successful application. The concepts of resilience, adaptive capacity, and transformation, even with their limitations, nevertheless have much to offer in helping redefine the problems of a changing Arctic. Clearly, more work is needed both in understanding how best to conceptualize these issues and in securing the future ■

References

Adger, W. N. (2003). Social Capital, Collective Action, and Adaptation to Climate Change. *Economic Geography*, 79(4). 387–404. DOI:10.1111/j.1944-8287.2003.tb00220.x.

Adger, W. N., Arnell, N. W. and Tompkins, E. L. (2005). Successful adaptation to climate change across scales. *Global Environmental Change*, 15(2). 77–86. DOI:10.1016/j.gloenvcha.2004.12.005.

Adger, W. N., Barnett, J., Brown, K., Marshall, N. and O'Brien, K. (2013). Cultural dimensions of climate change impacts and adaptation. *Nature Climate Change*, 3(2). 112–17. DOI:10.1038/nclimate1666.

Adger, W. N., Lorenzoni, I. and O'Brien, K. L., eds. (2009). *Adapting to Climate Change: Thresholds, Values, Governance*. Cambridge University Press, Cambridge, UK.

Alessa, L. (Na'ia), Kliskey, A. (Anaru) and Williams, P. (2010). Forgetting Freshwater: Technology, Values, and Distancing in Remote Arctic Communities. *Society & Natural Resources*, 23(3). 254–68. DOI:10.1080/08941920802454813.

Alessa, L. (Na'ia), Kliskey, A. (Anaru), Williams, P. and Barton, M. (2008). Perception of change in freshwater in remote resource-dependent Arctic communities. *Global Environmental Change*, 18(1). 153–64. DOI:10.1016/j.gloenvcha.2007.05.007.

Alessa, L. and Kliskey, A. (2012). The Role of Agent Types in Detecting and Responding to Environmental Change. *Human Organization*, 71(1). 1–10.

AMAP (2011). *Snow, Water, Ice and Permafrost in the Arctic (SWIPA): Climate Change and the Cryosphere*. SWIPA Scientific Assessment Report. Arctic Monitoring and Assessment Programme, Oslo, Norway. http://www.amap.no/swipa/.

Amundsen, H. (2012). Illusions of Resilience? An Analysis of Community Responses to Change in Northern Norway. *Ecology and Society*, 17(4). Art. 46. DOI:10.5751/ES-05142-170446.

Amundsen, H., Berglund, F. and Westskog, H. (2010). Overcoming barriers to climate change adaptation—a question of multilevel governance? *Environment and Planning C: Government and Policy*, 28(2). 276–89. DOI:10.1068/c0941.

Armitage, D., Berkes, F., Dale, A., Kocho-Schellenberg, E. and Patton, E. (2011). Co-management and the co-production of knowledge: Learning to adapt in Canada's Arctic. *Global Environmental Change*, 21(3). 995–1004. DOI:10.1016/j.gloenvcha.2011.04.006.

Armitage, D. and Plummer, R., eds. (2010). *Adaptive Capacity and Environmental Governance*. Springer, New York. http://www.springer.com/environment/environmental+management/book/978-3-642-12193-7.

Armitage, D. R., Berkes, F. and Doubleday, N., eds. (2007). *Adaptive Co-management: Collaboration, Learning, and Multi-level Governance*. Sustainability and the environment. University of British Columbia Press, Vancouver, Canada.

Armitage, D. R., Plummer, R., Berkes, F., Arthur, R. I., Charles, A. T., et al. (2008). Adaptive co-management for social–ecological complexity. *Frontiers in Ecology and the Environment*, 7(2). 95–102. DOI:10.1890/070089.

Berardi, G. (1998). Natural Resource Policy, Unforgiving Geographies, and Persistent Poverty in Alaska Native Villages. *Natural Resources Journal*, 38(1). 85–108.

Berkes, F. (2012). *Sacred Ecology*. 3rd ed. Routledge, New York. http://www.routledge.com/books/details/9780415517324/.

Berkes, F. (2009). Evolution of co-management: Role of knowledge generation, bridging organizations and social learning. *Journal of Environmental Management*, 90(5). 1692–1702. DOI:10.1016/j.jenvman.2008.12.001.

Berkes, F. (2006). From Community-Based Resource Management to Complex Systems: The Scale Issue and Marine Commons. *Ecology and Society*, 11(1). Art. 45.

Berkes, F. and Armitage, D. (2010). Co-management institutions, knowledge, and learning: Adapting to change in the Arctic. *Études/Inuit/Studies*, 34(1). 109–31. DOI:10.7202/045407ar.

Berkes, F. and Jolly, D. (2001). Adapting to Climate Change: Social-ecological Resilience in a Canadian Western Arctic Community. *Conservation Ecology*, 5(2). Art. 18.

Berman, M. and Howe, E. L. (2012). Remoteness, transportation infrastructure, and urban-rural population movements in the Arctic. Presented at the International Conference on Urbanisation of the Arctic, Nuuk, Greenland, 28-30 August.

Board on Atmospheric Sciences and Climate (2010). *Adapting to the Impacts of Climate Change*. America's Climate Choices: Panel on Adapting to the Impacts of Climate Change. National Academies Press, Washington, DC. http://www.nap.edu/openbook.php?record_id=12783.

Boyd, E. and Folke, C., eds. (2011). *Adapting Institutions: Governance, Complexity and Social-Ecological Resilience*. Cambridge University Press, Cambridge, UK.

Bronen, R. (2011). Climate-Induced Community Relocations: Creating an Adaptive Governance Framework Based in Human Rights Doctrine. *New York University Review of Law & Social Change*, 35. 357.

Brunner, R. D. and Lynch, A. H. (2010). *Adaptive Governance and Climate Change*. American Meteorological Society, Chicago, IL, US. http://www.press.uchicago.edu/ucp/books/book/distributed/A/bo8917780.html.

Brunner, R., Steelman, T. A., Coe-Juell, L., Cromley, C., Edwards, C. and Tucker, D. (2005). *Adaptive Governance: Integrating Science, Policy, and Decision Making*. Columbia University Press, New York.

Buikstra, E., Ross, H., King, C. A., Baker, P. G., Hegney, D., McLachlan, K. and Rogers-Clark, C. (2010). The components of resilience—Perceptions of an Australian rural community. *Journal of Community Psychology*, 38(8). 975–91. DOI:10.1002/jcop.20409.

Burch, E. (1998). *Inupiaq Eskimo Nations of Northwest Alaska*. 1st ed. University of Alaska Press, Fairbanks, AK, US.

BurnSilver, S., Kofinas, G. P. and Magdanz, J. S. (2012). *Sharing and Cooperation in the Far North: Old Social Mechanisms Under Evolving Economic and Climatic Conditions in Village Alaska*. Society for Applied Anthropology, Denver, CO, US.

Cameron, E. S. (2012). Securing Indigenous politics: A critique of the vulnerability and adaptation approach to the human dimensions of climate change in the Canadian Arctic. *Global Environmental Change*, 22(1). 103–14. DOI:10.1016/j.gloenvcha.2011.11.004.

Carpenter, S. R. and Brock, W. A. (2008). Adaptive Capacity and Traps. *Ecology and Society*, 13(2). Art. 40.

Caulfield, R. A. (2004). Resource governance. In *Arctic Human Development Report*. N. Einarsson, J. N. Larsen, A. Nilsson, and O. R. Young (eds.). Prepared by the Stefansson Arctic Institute, under the auspices of the Icelandic Chairmanship of the Arctic Council 2002-2004, Akureyri, Iceland. 121–38. http://www.svs.is/ahdr/.

Chapin, F. S. I., Hoel, M., Carpenter, S. R., Lubchenco, J., Walker, B., et al. (2006). Building resilience and adaptation to manage Arctic change. *AMBIO*, 35(4). 198–202. DOI:10.1579/0044-7447(2006)35%5B198:BRAATM%5D2.0.CO;2.

Chapin, F. S. I., Kofinas, G. P. and Folke, C., eds. (2009). *Principles of Ecosystem Stewardship: Resilience-Based Natural Resource Management in a Changing*. Springer, New York. http://www.springer.com/environment/environmental+management/book/978-0-387-73032-5.

Chapin, F. S., Peterson, G., Berkes, F., Callaghan, T. V., Angelstam, P., et al. (2004). Resilience and Vulnerability of Northern Regions to Social and Environmental Change. *AMBIO*, 33(6). 344–49. DOI:10.1579/0044-7447-33.6.344.

Chapin, F. S., Power, M. E., Pickett, S. T. A., Freitag, A., Reynolds, J. A., et al. (2011). Earth Stewardship: science for action to sustain the human-earth system. *Ecosphere*, 2(8). art89. DOI:10.1890/ES11-00166.1.

Clark, D., Tyrrell, M., Dowsley, M., Foote, L., Freeman, M. and Clark, S. G. (2009). Polar bears, climate change, and human dignity: seeking integrative conservation policies. In *Inuit, Polar Bears, and Sustainable Use: Local, National and International Perspectives*. M. M. R. Freeman and L. Foote (eds.). Canadian Circumpolar Institute Press, Edmonton, Alberta, Canada. 233–42.

Cochran, P. O., Huntington, H., Pungowiyi, C., Tom, S., Chapin, F. S. I., et al. (in press). Indigenous frameworks for observing and responding to climate change in Alaska. *Climatic Change*, .

Coleman, J. S. (1990). *Foundations of Social Theory*. 1st ed. Harvard University Press, Cambridge, MA, US.

Collings, P., Wenzel, G. and Condon, R. G. (1998). Modern Food Sharing Networks and Community Integration in the Central Canadian Arctic. *Arctic*, 51(4). 301–14.

Crate, S. A. (2008). Gone the bull of winter? Grappling with the cultural implications of and anthropology's role(s) in global climate change. *Current Anthropology*, 49(4). 569–95.

Crate, S. A. (2006). *Cows, Kin, and Globalization: An Ethnography of Sustainability*. AltaMira Press, Landham, MD, US.

Crate, S. A. (2002). Co-option in Siberia: The Case of Diamonds and the Vilyuy Sakha. *Polar Geography*, 26(4). 289–307. DOI:10.1080/789610151.

Crate, S. A. and Nuttall, M., eds. (2009). *Anthropology and Climate Change: From Encounters to Actions*. Left Coast Press, Walnut Creek, CA, US.

Cruikshank, J. (2000). *The Social Life of Stories: Narrative and Knowledge in the Yukon Territory*. Paperback. University of British Columbia Press, Vancouver, Canada.

Dale, A. and Armitage, D. (2011). Marine mammal co-management in Canada's Arctic: Knowledge co-production for learning and adaptive capacity. *Marine Policy*, 35(4). 440–49. DOI:10.1016/j.marpol.2010.10.019.

Dannevig, H., Hovelsrud, G. K. and Husabø, I. A. (in press). Driving the agenda for climate change adaptation in Norwegian Municipalities. *Environment & Planning C: Government & Policy*, .

Davidson, D. J. (2010). The Applicability of the Concept of Resilience to Social Systems: Some Sources of Optimism and Nagging Doubts. *Society & Natural Resources*, 23(12). 1135–49. DOI:10.1080/08941921003652940.

Denton, F. (2000). Gendered Impacts of Climate Change – A human security dimension. *Energia News*, 3(3). 13–14.

Dowsley, M. and Wenzel, G. (2008). 'The Time of the Most Polar Bears': A Co-Management Conflict in Nunavut. *Arctic*, 61(2). 177–89.

Duhaime, G., Searles, E., Usher, P. J., Myers, H. and Fréchette, P. (2004). Social Cohesion and Living Conditions in the Canadian Arctic: From Theory to Measurement. *Social Indicators Research*, 66(3). 295–318. DOI:10.1023/B:SOCI.0000003726.35478.fc.

Dyer, G. (2008). *Climate Wars: How Peak Oil and the Climate Crisis Will Change Canada*. Random House Canada, Toronto.

Emmerson, C. and Lahn, G. (2012). *Arctic Opening: Opportunity and Risk in the High North*. Lloyd's and Chatham House, London. http://www.lloyds.com/the-market/tools-and-resources/research/exposure-management/emerging-risks/emerging-risk-reports/climate/arctic-report-2012.

Fisher-Kowalski, M. and Rotmans, J. (2009). Conceptualizing, Observing, and Influencing Social–Ecological Transitions. *Ecology and Society*, 14(2). Art. 3.

Fleischman, S. and Huttunen, D. (1990). *Noatak River Sonar Progress Report*. 3A90-01. Alaska Department of Fish and Game, Anchorage, AL, US.

Flora, C. B., Flora, J. L. and Fey, S. (2004). *Rural Communities: Legacy and Change*. 2nd ed. Westview Press, Boulder, CO, US.

Folke, C., Carpenter, S., Elmqvist, T., Gunderson, L., Holling, C. S., et al. (2002). *Resilience and Sustainable Development: Building Adaptive Capacity in a World of Transformations*. Scientific Background Paper on Resilience for the process of The World Summit on Sustainable Development on behalf of The Environmental Advisory Council to the Swedish Government. Stockholm. http://www.sou.gov.se/mvb/pdf/resiliens.pdf.

Folke, C., Carpenter, S. R., Walker, B., Scheffer, M., Chapin, T. and Rockstrom, J. (2010). Resilience Thinking: Integrating Resilience, Adaptability and Transformability. *Ecology and Society*, 15(4). Art. 20.

Folke, C., Chapin, F. S. I. and Olsson, P. (2009). Transformations in Ecosystem Stewardship. In *Principles of Ecosystem Stewardship*. C. Folke, G. P. Kofinas, and F. S. I. Chapin (eds.). Springer New York. 103–25. http://link.springer.com/chapter/10.1007/978-0-387-73033-2_5.

Folke, C., Colding, J. and Berkes, F. (2003). Synthesis: Building Resilience and Adaptive Capacity. In *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change*. F. Berkes, J. Colding, and C. Folke (eds.). Cambridge University Press, Cambridge, UK. 352–87.

Folke, C., Hahn, T., Olsson, P. and Norberg, J. (2005). Adaptive Governance of Social-Ecological Systems. *Annual Review of Environment and Resources*, 30(1). 441–73. DOI:10.1146/annurev.energy.30.050504.144511.

Fondahl, G. (1998). *Gaining Ground?: Evenkis, Land and Reform in Southeastern Siberia*. Allyn and Bacon, Wilton, CT, US.

Forbes, B. C. (accepted). Cultural resilience of social-ecological systems in the Nenets and Yamal-Nenets Autonomous Okrugs, Russia: A focus on reindeer nomads of the tundra. *Ecology and Society*,

Forbes, B. C. and Stammler, F. (2009). Arctic climate change discourse: the contrasting politics of research agendas in the West and Russia. *Polar Research*, 28(1). 28–42. DOI:10.1111/j.1751-8369.2009.00100.x.

Forbes, B. C., Stammler, F., Kumpula, T., Meschtyb, N., Pajunen, A. and Kaarlejärvi, E. (2009). High resilience in the Yamal-Nenets social–ecological system, West Siberian Arctic, Russia. *Proceedings of the National Academy of Sciences*, 106(52). 22041–48. DOI:10.1073/pnas.0908286106.

Ford, J. D. and Furgal, C. (2009). Foreword to the special issue: climate change impacts, adaptation and vulnerability in the Arctic. *Polar Research*, 28(1). 1–9. DOI:10.1111/j.1751-8369.2009.00103.x.

Ford, J. D., Pearce, T., Duerden, F., Furgal, C. and Smit, B. (2010). Climate change policy responses for Canada's Inuit population: The importance of and opportunities for adaptation. *Global Environmental Change*, 20(1). 177–91. DOI:10.1016/j.gloenvcha.2009.10.008.

Ford, J. D. and Smit, B. (2004). A framework for assessing the vulnerability of communities in the Canadian Arctic to risks associated with climate change. *Arctic*, 57(4). 389–400.

Ford, J. D., Smit, B. and Wandel, J. (2006). Vulnerability to climate change in the Arctic: A case study from Arctic Bay, Canada. *Global Environmental Change*, 16(2). 145–60. DOI:10.1016/j.gloenvcha.2005.11.007.

Ford, J., Pearce, T., Smit, B., Wandel, J., Allurut, M., et al. (2007). Reducing Vulnerability to Climate Change in the Arctic: The Case of Nunavut, Canada. *Arctic*, 60(2). 150–66.

Galaz, V., Olsson, P., Folke, C., Hahn, T. and Svedin, U. (2008). The Problem of Fit among Biophysical Systems, Environmental Regimes, and Broader Governance Systems: Insights and Emerging Challenges. In *Institutions and Environmental Change: Principal Findings, Applications, and Research Frontiers*. O. R. Young, H. Schroeder, and L. A. King (eds.). MIT Press, Cambridge, MA, US. 147–82.

Golovnev, A. V. and Osherenko, G. (1999). *Siberian Survival: The Nenets and Their Story*. Cornell University Press, Ithaca, NY, US.

Granovetter, M. S. (1973). The strength of weak ties. *American Journal of Sociology*, 78(6). 1360–80.

Gunderson, L. H. and Holling, C. S., eds. (2002). *Panarchy*. Island Press, Washington, DC.

Hahn, T., Schultz, L., Folke, C. and Olsson, P. (2008). Social Networks as Sources of Resilience in Social-Ecological System. In *Complexity Theory for a Sustainable Future*. J. Norberg and G. Cumming (eds.). Columbia University Press, New York. 119–43.

Hamilton, L. C. (2010). Footprints: Demographic effects of outmigration. In *Migration in the Circumpolar North: Issues and Contexts*. L. Huskey and C. Southcott (eds.). Canadian Circumpolar Institute Press, Edmonton, Alberta, Canada. 1–14.

Hamilton, L. C. and Rasmussen, R. O. (2010). Population, sex ratios and development in Greenland. *Arctic*, 63(1). 43–52.

Hamilton, L. C. and Seyfrit, C. L. (1994). Coming out of the country: Community size and gender balance among Alaskan Natives. *Arctic Anthropology*, 31(1). 16–25.

Hansen, J., Sato, M., Ruedy, R., Lo, K., Lea, D. W. and Medina-Elizade, M. (2006). Global temperature change. *Proceedings of the National Academy of Sciences*, 103(39). 14288–93. DOI:10.1073/pnas.0606291103.

Heyd, T. (2008) Cultural responses to natural changes such as climate change. *Espace Populations Sociétés / Space Populations Societies* (2008/1). 83–88.

Hill, F. and Gaddy, C. G. (2003). *The Siberian Curse*. Brookings Institution Press, Washington, DC. http://www.brookings.edu/research/books/2003/siberiancurse.

Holling, C. S. (1978). *Adaptive Environmental Assessment and Management*. John Wiley & Sons, Chichester, UK.

Homer-Dixon, T. (2001). *The Ingenuity Gap: Can We Solve the Problems of the Future?* Knopf Canada, Toronto.

Hovelsrud, G. K., Dannevig, H., West, J. and Amundsen, H. (2010). Adaptation in Fisheries and Municipalities: Three Communities in Northern Norway. In *Community Adaptation and Vulnerability in Arctic Regions*. G. K. Hovelsrud and B. Smit (eds.). Springer, Dortrecht. 23–62. http://www.springer.com/environment/global+change+-+climate+change/book/978-90-481-9173-4.

Hovelsrud, G. K., Poppel, B., van Oort, B. and Reist, J. D. (2011). Arctic societies, cultures, and peoples in a changing cryosphere. *AMBIO*, 40(1). 100–110. DOI:10.1007/s13280-011-0219-4.

Hovelsrud, G. K. and Smit, B., eds. (2010). *Community Adaptation and Vulnerability in Arctic Regions*. Springer, Dortrecht. http://www.springer.com/environment/global+change+-+climate+change/book/978-90-481-9173-4.

Howe, E. L. (2009). Patterns of migration in Arctic Alaska. *Polar Geography*, 32(1-2). 69–89. DOI:10.1080/10889370903000422.

Huntington, H. P. (2000). Using Traditional Ecological Knowledge in Science: Methods and Applications. *Ecological Applications*, 10(5). 1270–74. DOI:10.1890/1051-0761(2000)010[1270:UTEKIS]2.0.CO;2.

Huntington, H. P., Brown-Schwalenberg, P. K., Frost, K. J., Fernandez-Gimenez, M. E., Norton, D. W. and Rosenberg, D. H. (2002). Observations on the Workshop as a Means of Improving Communication Between Holders of Traditional and Scientific Knowledge. *Environmental Management*, 30(6). 0778–92. DOI:10.1007/s00267-002-2749-9.

Huntington, H. P., Goodstein, E. and Euskirchen, E. (2012). Towards a Tipping Point in Responding to Change: Rising Costs, Fewer Options for Arctic and Global Societies. *AMBIO*, 41(1). 66–74. DOI:10.1007/s13280-011-0226-5.

Huskey, L., Berman, M. and Hill, A. (2004). Leaving home, returning home: Migration as a labor market choice for Alaska Natives. *The Annals of Regional Science*, 38(1). 75–92. DOI:10.1007/s00168-003-0141-1.

Janssen, M. A., Schoon, M. L., Ke, W. and Börner, K. (2006). Scholarly networks on resilience, vulnerability and adaptation within the human dimensions of global environmental change. *Global Environmental Change*, 16(3). 240–52. DOI:10.1016/j.gloenvcha.2006.04.001.

Kates, R. W., Travis, W. R. and Wilbanks, T. J. (2012). Transformational adaptation when incremental adaptations to climate change are insufficient. *Proceedings of the National Academy of Sciences*, 109(19). 7156–61. DOI:10.1073/pnas.1115521109.

Keskitalo, E. C. H., Dannevig, H., Hovelsrud, G. K., West, J. J. and Swartling, Å. G. (2011). Adaptive capacity determinants in developed states: examples from the Nordic countries and Russia. *Regional Environmental Change*, 11(3). 579–92. DOI:10.1007/s10113-010-0182-9.

Kliskey, A. (Anaru), Alessa, L. (Na'ia) and Barr, B. (2009). Integrating Local and Traditional Ecological Knowledge. In *Ecosystem-Based Management for the Oceans*. K. McLeod and H. Leslie (eds.). Island Press, Washington, DC. 145–61. http://islandpress.org/ip/books/book/islandpress/E/bo7019313.html.

Kofinas, G. P. (2009). Adaptive Co-management in Social-Ecological Governance. In *Principles of Ecosystem Stewardship: Resilience-Based Natural Resource Management in a Changing*. F. S. I. Chapin, G. P. Kofinas, and C. Folke (eds.). Springer, New York. 77–102. http://www.springer.com/environment/environmental+management/book/978-0-387-73032-5.

Kofinas, G. P., Chapin, F. S., BurnSilver, S., Schmidt, J. I., Fresco, N. L., et al. (2010). Resilience of Athabascan subsistence systems to interior Alaska's changing climate. *Canadian Journal of Forest Research*, 40(7). 1347–59. DOI:10.1139/X10-108.

Kofinas, G. P. and Chapin, F. S. I. (2009). Livelihoods and Human Well-Being during Social-Ecological Change. In *Principles of Ecosystem Stewardship*. C. Folke, G. P. Kofinas, and F. S. Chapin (eds.). Springer, New York. 55–75. http://link.springer.com/chapter/10.1007/978-0-387-73033-2_3.

Kofinas, G. P., Herman, J. S. and Meek, C. (2007). Novel Problems Require Novel Solutions: Innovation as an outcome of adaptive co-management. In *Adaptive co-management: collaboration, learning, and multi-level governance*. D. R. Armitage, F. Berkes, and N. Doubleday (eds.). Sustainability and the environment. University of British Columbia Press, Vancouver, Canada. 249–467.

Krupnik, I. (1993). *Arctic Adaptations: Native Whalers and Reindeer Herders of Northern Eurasia*. University Press of New England, Hanover, NH, US.

Krupnik, I. and Jolly, D., eds. (2002). *The Earth Is Faster Now: Indigenous Observations of Artic Environmental Change*. Arctic Research Consortium of the United States, Fairbanks, AK, US. http://www.arcus.org/publications/EIFN/.

Kruse, J. A. (1992). Alaska North Slope Inupiat Eskimo and resource development: Why the apparent success. Presented at the American Association for the Advancement of Science 1992 Annual Meeting, Chicago.

Lambrou, Y. and Piana, G. (2006). *Gender: The Missing Component of the Response to Climate Change*. Food and Agriculture Organization of the United Nations, Rome. http://www.fao.org/docrep/010/i0170e/i0170e00.htm.

Larsen, P. H., Goldsmith, S., Smith, O., Wilson, M. L., Strzepek, K., Chinowsky, P. and Saylor, B. (2008). Estimating future costs for Alaska public infrastructure at risk from climate change. *Global Environmental Change*, 18(3). 442–57. DOI:10.1016/j.gloenvcha.2008.03.005.

Leach, M., Rockström, J., Raskin, P., Scoones, I., Stirling, A. C., et al. (2012). Transforming Innovation for Sustainability. *Ecology and Society*, 17(2). Art. 11. DOI:10.5751/ES-04933-170211.

Lee, K. N. (1999). Appraising Adaptive Management. *Conservation Ecology*, 3(2). Art. 3.

Lewis, M. (1999). Foreword. Social Protection Discussion Paper No. 9925, The World Bank, Washington, DC. http://siteresources.worldbank.org/SOCIALPROTECTION/Resources/SP-Discussion-papers/Social-Protection-General-DP/9925.pdf.

Loring, P. A. and Gerlach, S. C. (2010). Outpost Gardening in Interior Alaska: Food System Innovation and the Alaska Native Gardens of the 1930s through the 1970s. *Ethnohistory*, 57(2). 183–99. DOI:10.1215/00141801-2009-060.

Lovecraft, A. L. and Eicken, H., eds. (2011). *North by 2020: Perspectives on Alaska's Changing Social-Ecological Systems*. University of Alaska Press, Fairbanks, AK, US. http://www.alaska.edu/uapress/browse/detail/index.xml?id=444.

Ludwig, D. (2001). The Era of Management Is Over. *Ecosystems*, 4(8). 758–64. DOI:10.1007/s10021-001-0044-x.

Magdanz, J. S., Utermohle, C. J. and Wolfe, R. J. (2002). *The Production and Distribution of Wild Food in Wales and Deering, Alaska*. Technical Paper 259. Division of Subsistence, Alaska Department of Fish and Game, Kotzebue, AK, US. http://www.subsistence.adfg.state.ak.us/techpap/tp259.pdf.

Magis, K. (2010). Community Resilience: An Indicator of Social Sustainability. *Society & Natural Resources*, 23(5). 401–16. DOI:10.1080/08941920903305674.

Markel, C. and Clark, D. (2012). Developing Policy Alternatives for the Management of Wood Bison (Bison bison athabascae) in Kluane National Park and Reserve of Canada. *Northern Review*, 0(36). 53–75.

Marshall, N. A., Park, S. E., Adger, W. N., Brown, K. and Howden, S. M. (2012). Transformational capacity and the influence of place and identity. *Environmental Research Letters*, 7(3). 034022. DOI:10.1088/1748-9326/7/3/034022.

Martin, S. (2009). The effects of female out-migration on Alaska villages. *Polar Geography*, 32(1-2). 61–67. DOI:10.1080/10889370903000455.

McCarthy, J. J. and Martello, M. L. (2005). Climate change in the context of multiple stressors and resilience. In *Arctic Climate Impact Assessment – Scientific Report*. J. Berner, C. Symon, L. Arris, and O. W. Heal (eds.). Cambridge University Press, Cambridge, UK, and New York. 945–88. http://www.acia.uaf.edu/PDFs/ACIA_Science_Chapters_Final/ACIA_Ch17_Final.pdf.

McNeeley, S. M. and Shulski, M. D. (2011). Anatomy of a closing window: Vulnerability to changing seasonality in Interior Alaska. *Global Environmental Change*, 21(2). 464–73. DOI:10.1016/j.gloenvcha.2011.02.003.

Meek, C. L. (2013). Forms of collaboration and social fit in wildlife management: A comparison of policy networks in Alaska. *Global Environmental Change*, 23(1). 217–28. DOI:10.1016/j.gloenvcha.2012.10.003.

Meek, C. L. (2011). Putting the US polar bear debate into context: The disconnect between old policy and new problems. *Marine Policy*, 35(4). 430–39. DOI:10.1016/j.marpol.2010.11.005.

Millennium Ecosystem Assessment (2006). *Bridging Scales and Knowledge Systems: Concepts and Applications in Ecosystem Assessment*. W. V. Reid, F. Berkes, T. J. Wilbanks, and D. Capistrano (eds.). Millennium Ecosystem Assessment Series. Island Press, Washington, DC. http://islandpress.org/ip/books/book/islandpress/B/bo3767347.html.

Millennium Ecosystem Assessment (2005). *Ecosystems and Human Well-being: Synthesis*. Millennium Ecosystem Assessment Series. Island Press, Washington, DC.

Nadasdy, P. (1999). The politics of TEK: Power and the' integration' of knowledge. *Arctic Anthropology*, 36(1/2). 1–18.

Natcher, D. C., Davis, S. and Hickey, C. G. (2005). Co-Management: Managing Relationships, Not Resources. *Human Organization*, 64(3). 240–50.

Nelson, D. R., Adger, W. N. and Brown, K. (2007). Adaptation to Environmental Change: Contributions of a Resilience Framework. *Annual Review of Environment and Resources*, 32(1). 395–419. DOI:10.1146/annurev.energy.32.051807.090348.

Nelson, R., Howden, M. and Smith, M. S. (2008). Using adaptive governance to rethink the way science supports Australian drought policy. *Environmental Science & Policy*, 11(7). 588–601. DOI:10.1016/j.envsci.2008.06.005.

Nelson, V., Meadows, K., Cannon, T., Morton, J. and Martin, A. (2002). Uncertain predictions, invisible impacts, and the need to mainstream gender in climate change adaptations. *Gender & Development*, 10(2). 51–59. DOI:10.1080/13552070215911.

Nicol, S., Griffith, B., Austin, J. and Hunter, C. M. (in review). Optimal water depth management on river-fed national wildlife refuges in a changing climate. *Climatic Change*, .

Nuttall, M. (2005). Hunting, herding, fishing and gathering: indigenous peoples and renewable resource use in the Arctic. In *Arctic Climate Impact Assessment – Scientific Report*. J. Berner, C. Symon, L. Arris, and O. W. Heal (eds.). Cambridge University Press, Cambridge, UK, and New York. 649–90. http://www.acia.uaf.edu/pages/scientific.html.

Nuttall, M. and Callaghan, T., eds. (2000). *Arctic: Environment, People, Policy*. 1st ed. Harwood Academic Publishers, Amsterdam.

O'Brien, K. (2012). Global environmental change II: From adaptation to deliberate transformation. *Progress in Human Geography*, 36(5). 667–76. DOI:10.1177/0309132511425767.

O'Brien, K., Hayward, B. and Berkes, F. (2009). Rethinking social contracts: building resilience in a changing climate. *Ecology and Society*, 14(2). Art. 12.

O'Brien, K. L. and Leichenko, R. M. (2000). Double exposure: assessing the impacts of climate change within the context of economic globalization. *Global Environmental Change*, 10(3). 221–32. DOI:10.1016/S0959-3780(00)00021-2.

O'Brien, K. L. and Wolf, J. (2010). A values-based approach to vulnerability and adaptation to climate change. *Wiley Interdisciplinary Reviews: Climate Change*, 1(April). n/a–n/a. DOI:10.1002/wcc.30.

Olsson, P., Bodin, Ö. and Folke, C. (2010). Building Transformative Capacity in Ecosystem Stewardship in Social-Ecological Systems. In *Adaptive Capacity and Environmental Governance*. D. Armitage and R. Plummer (eds.). Springer, New York. 263–85. http://www.springer.com/environment/environmental+management/book/978-3-642-12193-7.

Olsson, P., Folke, C. and Berkes, F. (2004). Adaptive Comanagement for Building Resilience in Social–Ecological Systems. *Environmental Management*, 34(1). 75–90. DOI:10.1007/s00267-003-0101-7.

Olsson, P., Gunderson, L. H., Carpenter, S. R., Ryan, P., Lebel, L., Folke, C. and Holling, C. S. (2006). Shooting the rapids: navigating transitions to adaptive governance of social-ecological systems. *Ecology and Society*, 11(1). Art. 18.

Ostrom, E. (2009). A General Framework for Analyzing Sustainability of Social-Ecological Systems. *Science*, 325(5939). 419–22. DOI:10.1126/science.1172133.

Ostrom, E. (2007). A diagnostic approach for going beyond panaceas. *Proceedings of the National Academy of Sciences*, 104(39). 15181–87. DOI:10.1073/pnas.0702288104.

Ostrom, E., Janssen, M. A. and Anderies, J. M. (2007). Going beyond panaceas. *Proceedings of the National Academy of Sciences*, 104(39). 15176–78. DOI:10.1073/pnas.0701886104.

Parlee, B., Manseau, M. and Łutsël K'é Dene First Nation (2005). Using Traditional Knowledge to Adapt to Ecological Change: Denésǫ̨lıné Monitoring of Caribou Movements. *Arctic*, 58(1). 26–37.

Parry, M. L., Canziani, O. F., Palutikof, J. P., van der Linden, P. J. and Hanson, C. E., eds. (2007). *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007*. Cambridge University Press, Cambridge, UK, and New York. http://www.ipcc.ch/publications_and_data/ar4/wg2/en/contents.html.

Paul, S. K. and Routray, J. K. (2011). Household response to cyclone and induced surge in coastal Bangladesh: coping strategies and explanatory variables. *Natural Hazards*, 57(2). 477–99. DOI:10.1007/s11069-010-9631-5.

Peacock, E., Derocher, A. E., Thiemann, G. W. and Stirling, I. (2011). Conservation and management of Canada's polar bears (Ursus maritimus) in a changing Arctic 1 1 This review is part of the virtual symposium 'Flagship Species – Flagship Problems' that deals with ecology, biodiversity and management issues, and climate impacts on species at risk and of Canadian importance, including the polar bear (Ursus maritimus), Atlantic cod (Gadus morhua), Piping Plover (Charadrius melodus), and caribou (Rangifer tarandus). *Canadian Journal of Zoology*, 89(5). 371–85. DOI:10.1139/z11-021.

Petheram, L., Zander, K. K., Campbell, B. M., High, C. and Stacey, N. (2010). 'Strange changes': Indigenous perspectives of climate change and adaptation in NE Arnhem Land (Australia). *Global Environmental Change*, 20(4). 681–92. DOI:10.1016/j.gloenvcha.2010.05.002.

Preet, R., Nilsson, M., Schumann, B. and Evengård, B. (2010). The gender perspective in climate change and global health. *Global Health Action*, 3(0). DOI:10.3402/gha.v3i0.5720.

Putnam, R. D. (2000). *Bowling Alone: The Collapse and Revival of American Community*. Simon & Schuster, New York.

Qitsualik, R. A. (2006). Nalunaktuq: The Arctic as force, instead of resource. *CBC News*, 31 August. In Depth: Canada 2020. http://www.cbc.ca/news/background/canada2020/essay-qitsualik.html.

Rasmussen, R. O. (2011). Why the other half leave: Gender aspects of remote sparsely populated areas. In *Demography at the Edge: Remote Human Populations in Developed Nations*. D. Carson, R. O. Rasmussen, P. Ensign, L. Huskey, and A. Taylor (eds.). Ashgate Publishing, Ltd., Farnham, UK. 237–54.

Ray, L. A., Kolden, C. A. and Chapin III, F. S. (2012). A Case for Developing Place-Based Fire Management Strategies from Traditional Ecological Knowledge. *Ecology and Society*, 17(3). Art. 37. DOI:10.5751/ES-05070-170337.

Roncoli, C., Jost, C. Kirshen, P., Sanon, M., Ingram, K.T. Woodin, M., Somé, L. et al. 2009. From Accessing to assessing forecasts: An end-to-end study of participatory climate forecast dissemination in Burkina Faso (West Africa)." *Climatic Change* 92 (3-4). 433–460. doi:10.1007/s10584-008-9445-6.

Rybråten, S. and Hovelsrud, G. K. (2010). Local Effects of Global Climate Change: Differential Experiences of Sheep Farmers and Reindeer Herders in Unjárga/Nesseby, a Coastal Sámi Community in Northern Norway. In *Community Adaptation and Vulnerability in Arctic Regions*. G. K. Hovelsrud and B. Smit (eds.). Springer, Dortrecht. 313–33. http://www.springer.com/environment/global+change+-+climate+change/book/978-90-481-9173-4.

Simon, H. A. (1957). *Administrative Behavior: A Study of Decision-making Processes in Administrative Organization*. 2nd ed. Macmillan, New York.

Siurua, H. and Swift, J. (2002). Drought and Zud but No Famine (Yet) in the Mongolian Herding Economy. *IDS Bulletin*, 33(4). 88–97. DOI:10.1111/j.1759-5436.2002.tb00048.x.

Smit, B., Hovelsrud, G. K., Wandel, J. and Andrachuk, M. (2010). Introduction to the CAVIAR Project and Framework. In *Community Adaptation and Vulnerability in Arctic Regions*. G. K. Hovelsrud and B. Smit (eds.). Springer, Dortrecht. 1–22. http://www.springer.com/environment/global+change+-+climate+change/book/978-90-481-9173-4.

Smit, B. and Pilifosova, O. (2003). From adaptation to adaptive capacity and vulnerability reduction. In *Climate Change: Adaptive Capacity and Development*. J. B. Smith, R. J. T. Klein, and S. Huq (eds.). Imperial College Press, London. 9–28.

Smit, B. and Pilifosova, O. (2001). Adaptation to Climate Change in the Context of Sustainable Development and Equity. In *Climate Change 2001: Working Group II: Impacts, Adaptation and Vulnerability*. J. J. McCarthy, O. F. Canziani, N. A. Leary, D. J. Dokken, and K. S. White (eds.). Cambridge University Press for the Intergovernmental Panel on Climate Change, Cambridge, UK. http://www.grida.no/climate/ipcc_tar/wg2/641.htm.

Smit, B. and Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. *Global Environmental Change*, 16(3). 282–92. DOI:10.1016/j.gloenvcha.2006.03.008.

Steward, J. (1968). Cultural ecology. In *International Encyclopedia of the Social Sciences*. Macmillan, New York. 337–44.

Strauss, S. (2009). Global Models, Local Risks: Responding to Climate Change in the Swiss Alps. In *Anthropology and Climate Change: From Encounters to Actions*. S. A. Crate and M. Nuttall (eds.). Left Coast Press, Walnut Creek, CA, US. 166–74.

Tingley, D., Ásmundsson, J., Borodzicz, E., Conides, A., Drakeford, B., Eðvarðsson, I.R., Holm, D., Kapiris, k., Kuikka, S. and Mortensen, B. (2010). Risk identification and perception in the fisheries sector: Comparisons between the Faroes, Greece, Iceland and UK. *Marine Policy* 34 (6). 1249–1260. doi:10.1016/j.marpol.2010.05.002.

Tol, R. S. J. and Yohe, G. W. (2007). The weakest link hypothesis for adaptive capacity: An empirical test. *Global Environmental Change*, 17(2). 218–27. DOI:10.1016/j.gloenvcha.2006.08.001.

Tollefson, J. (2012). Ocean-fertilization project off Canada sparks furore. *Nature*, 490(7421). 458–59. DOI:10.1038/490458a.

Trainor, S. F., Calef, M., Natcher, D., Chapin, F. S., McGuire, A. D., et al. (2009). Vulnerability and adaptation to climate-related fire impacts in rural and urban interior Alaska. *Polar Research*, 28(1). 100–118. DOI:10.1111/j.1751-8369.2009.00101.x.

Tsalikov, R. K. (2009). Climate changes in the North of Russia: risks and threats. *Region: Economics and Sociology*, 1. 158–66.

Turner, B. L., Kasperson, R. E., Matson, P. A., McCarthy, J. J., Corell, R. W., et al. (2003). A framework for vulnerability analysis in sustainability science. *Proceedings of the National Academy of Sciences*, 100(14). 8074–79. DOI:10.1073/pnas.1231335100.

UNDP (2009). *Resource Guide on Gender and Climate Change*. United Nations Development Programme. http://www.undp.org/content/undp/en/home/librarypage/womens-empowerment/resource-guide-on-gender-and-climate-change/.

Vanstone, J. (1974). *Athabaskan Adaptations: Hunters and Fishers of the Subarctic Forests*. Aldine Publishing Co., Chicago.

Vinokurova, L. I. (2011). Rural Yakutia: perception indigenous population ǫhanges in enviroment. *Arctic and North*, (4). 154–61.

Walker, B. H., Holling, C., Carpenter, S. and Kinzig, A. (2004). Resilience, adaptability and transformability in social-ecological systems. *Ecology and Society*, 9(2). Art. 5.

Walker, B. H. and Salt, D. (2006). *Resilience Thinking: Sustaining Ecosystems and People in a Changing World*. Island Press.

Walters, C. (1986). *Adaptive Management of Renewable Resources*. McGraw-Hill, New York.

Watts, D. J. (2003). *Six Degrees: The Science of a Connected Age*. 1st ed. W. W. Norton & Company, New York.

Wenzel, G. W. (2009). Canadian Inuit subsistence and ecological instability— if the climate changes, must the Inuit? *Polar Research*, 28(1). 89–99. DOI:10.1111/j.1751-8369.2009.00098.x.

Wenzel, G. W. (2000). Sharing, money, and modern Inuit subsistence: obligation and reciprocity at Clyde River, Nunavut. *Senri Ethnological Studies*, (53). 61–85.

Wenzel, G. W. (1991). *Animal Rights, Human Rights: Ecology, Economy and Ideology in the Canadian Arctic*. University of Toronto Press, Toronto.

West, J. J. and Hovelsrud, G. K. (2010). Cross-scale Adaptation Challenges in the Coastal Fisheries: Findings from Lebesby, Northern Norway. *Arctic*, 63(3). 338–54.

Williamson, O. E. (1975). *Markets and Hierarchies: Analysis and Antitrust Implications, A Study in the Economics of Internal Organization*. 1st ed. The Free Press, New York.

Wolfe, R. J., Scott, C. L. and Simeone, W. E. (2009). *The 'Super-Household' in Alaska Native Subsistence Economies*. National Science Foundation.

Young, O. R. (2013). *On Environmental Governance: Sustainability, Efficiency, and Equity*. Paradigm Publishers, Boulder, CO, US. http://www.paradigmpublishers.com/books/BookDetail.aspx?productID=298804.

Young, O. R., King, L. A. and Schroeder, H., eds. (2008). *Institutions and Environmental Change: Principal Findings, Applications, and Research Frontiers*. The MIT Press, Cambridge, MA, US.

Sources for figures and tables

Figure 5.1 Based on Smit and Wandel (2006).
Figure 5.2 Based on Turner et al. (2003).
Figure 5.3. Based on Nelson et al. (2008).
Figure 5.4 Based on Kofinas and Chapin (2009).
Figure 5.5 Based on Millennium Ecosystem Assessment (2005).
Figure 5.6 Based on Larsen et al. (2008).
Figure 5.7 Based on Chapin et al. (2009).
Figure 5.8 Based on Folke et al. (2009) and Olson et al. (2010).
Table 5.1 Based on Emmerson and Lahn (2013).
Table 5.2 Based on Folke et al. (2009).

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Part IV

Summary

This part presents four pilot case studies that illustrate some of the challenges and opportunities relating to resilience in particular places and for particular issues in the Arctic.

Chapter 6 presents a common framework for the case studies. The framework treats the cases as integrated social-ecological systems, with feedbacks and other interactions within the systems and across scales. The framework also highlights the need to consider potential shocks, disturbances and ongoing change, and to pay attention to key variables, important ecosystem services, drivers and feedbacks.

Chapter 7 looks at the capacity for adaptation and learning in the governance of Arctic shipping. Vessel traffic is increasing rapidly in the Arctic and is likely to increase even more as the ice recedes and routes open up. In some regions, such as the Bering Strait, ships will be passing through areas with large congregations of wildlife. The fact that marine mammals and indigenous livelihoods are likely to be directly affected by policies that constrain or promote outside commercial interest, raises questions about how the international governance system can take into account local interests.

Chapter 8 focuses on the southwest Yukon Territory, which has undergone repeated transformations over the 8000 years it has been inhabited. These include shifts in populations of large grazing animals, as well as major social changes following European colonization and the building of the Alaska Highway. More recent social change includes implementation of co-management, which has the potential to provide balancing feedbacks in the context of human-wildlife interactions. The case study identifies a range of strategies to build resilience, including learning to live with change and uncertainty, nurturing diversity, combining different types of knowledge and ways of learning, and creating opportunities for self organization.

Chapter 9 focuses on nomadic Sámi reindeer herding in Finnmark, Norway. The case study describes how reindeer herding – a clear example of an integrated social-ecological system – is embodied in the Sámi language and traditional governance models. Major historic shocks to the system include the closure of national borders and the introduction of new laws on reindeer management. Major future challenges include climate change, industrial development and subsequent loss of grazing land. Strategies for enhancing resilience include integrating traditional knowledge in formal governance systems and engaging young people.

Chapter 10 discusses food security, which is emerging as a major cross-cutting issue in a changing Arctic. The preliminary reflections presented in the chapter highlight that food security brings together concerns over a range of interacting environmental, social, economic, political and cultural changes. These include: food and water-borne diseases; increasing incidence of lifestyle diseases; high costs of healthy foods; contamination; changing ecosystems that impede access to food; high fuel costs; and loss of traditional knowledge. The chapter concludes that food security is intimately interlinked with social relations and cultural well-being.

Chapter 6

Purpose and scope of pilot case studies

Chapter 7

Resilience of international policies to changing social-ecological systems: Arctic shipping in the Bering Strait

Chapter 8

Transformations in subsistence systems in the southwest Yukon Territory, Canada

Chapter 9

Strategies to enhance the resilience of Sámi reindeer husbandry to rapid changes in the Arctic

Chapter 10

Food security in the Arctic: Preliminary reflections from a resilience perspective

Chapter 6

Purpose and scope of pilot case studies

Lead author: Allyson Quinlan[1]

6.1 Introduction

The chapters in this part of the report present pilot case studies in distinct social-ecological systems that illustrate some of the challenges as well as opportunities for building resilience in particular places and sub-systems of a rapidly changing Arctic. The four case studies focus on various aspects of social-ecological resilience, while building on existing research projects. Chapter 7 focuses on Arctic shipping in the Bering Strait, Chapter 8 on wildlife and subsistence systems in the southwest Yukon, Chapter 9 on reindeer herding in Finnmark, and Chapter 10 on resilience perspectives on food security.

These case studies provide an opportunity to investigate what a resilience lens can contribute to research that has been carried out from other starting points. They also provide examples of how external system drivers such as climate change or global economic forces interact with the internal dynamics of different systems in ways that influence their capacity to cope with shocks, adapt to change, or transform. Taken together, the case studies also inform our understanding of resilience at the pan-Arctic level.

Framed as integrated social-ecological systems, the case studies ground resilience concepts such as thresholds, adaptation, and transformation in particular times and places, and address pragmatic issues such as food security, human wildlife interactions, resource development, and governance challenges that affect the well-being of people across the Arctic. By applying a resilience lens to each case, the aim is to improve our understanding of the current capacity of Arctic systems to cope with both on-going and potentially abrupt change in ways that can inform strategies for building resilience. They also help to demonstrate the value of a resilience approach in the Arctic where rapid changes are under way and there is a high degree of uncertainty about the future. Strategies for securing resilience are needed to prepare for a wide array of possible futures and for coping with a broad range of potential future shocks.

A common framework is used to conceptualize each of the case studies as an integrated social-ecological system with feedbacks and other interactions occurring within the system and also across scales. Specifically, each case study evaluates the resilience of particular components of the system to potential shocks, disturbances, or on-going change, by considering key variables, important ecosystem services, external drivers, and feedbacks that maintain the system state. Each assessment begins by asking the question, “resilience of what, to what?” The case studies proceed to identify valued ecosystem services, consider scales of time and space relevant to the central issue(s), and characterize the main external forces of change, including social, technological, environmental, economic, and political drivers.

Keeping the focus on the central issue, each case study also aims to identify variables internal to the system that control its overall structure and function, and explores how system variables interact to influence communities and the benefits they derive from ecosystems. These assessments draw on integrated knowledge about the vulnerability and strengths of Arctic communities (e.g., social networks, economic opportunities, education, employment), Arctic ecosystems (e.g., response diversity, feedbacks), drivers of global change (e.g., climate trends, resource development), and governance (e.g., at local, national, and pan-Arctic levels). The case studies reveal some of what we know about the resilience of specific Arctic sub-systems. They also provide tangible examples in which to explore the opportunities and constraints of using a resilience lens. Combined with the other parts of this report, the case studies contribute analytical insights that help build understanding of Arctic resilience.

6.2 Further case studies

Additional case studies will be developed to complement the initial set of four by expanding the geographical scope of examples and highlighting a more diverse range of Arctic social-ecological systems. The inclusion of additional case studies will take into consideration the following criteria: a) the case study adds diversity to geographical coverage; b) it links to on-going research efforts and relevant partners; c) it links to other Arctic Council projects, d) it contributes to a balance of success stories with those presenting negative outcomes – i.e., contexts where resilience is under continued threat, or the system has transformed for better or worse; e) it contributes to capacity-building activities of the ARR, and f) it offers tangible examples of state changes in Arctic ecosystems (e.g., loss of summer sea ice in the Chukchi Sea). All case studies aim to be directly relevant to user communities and decision-makers in the Arctic and to inform the pan-Arctic assessment.

6.3 Conclusion, key findings, and the process ahead

Each of the four preliminary case studies offers insight into how a resilience approach can inform our understanding of issues currently confronting Arctic communities and sub-systems. With a strong focus on system feedbacks and interactions with external drivers, the cases highlight ways in which a whole-system approach can help to identify key variables for monitoring and how these variables work to reinforce and maintain the system in a particular regime or operating space. For example, in the case of changing wildlife and subsistence systems in southwest Yukon, while various external forces have contributed to changing species composition on the landscape, cultural values and the sharing of traditional knowledge are important controlling variables that contribute to the longer-term sustainability of the system. These underlying variables enhance the effectiveness of "faster" variables such as local-scale co-management initiatives and harvest practices.

Together the case studies provide examples of social-ecological systems in which the potential thresholds discussed in Chapter 4 of this report pose significant challenges. They also serve to demonstrate sources of resilience and adaptive capacity, providing insights into policy options, including a basis for transformation, as discussed in Chapter 5. The recent regime shift in the northern hemispheric climate system, discussed in Chapter 4, has set into motion new system feedbacks that are changing weather patterns and creating extreme weather conditions. These observations resonate with the increased frequency over the past three decades of *Goavvi* events in Finnmark, in which reindeer are unable to graze through snow or ice layers. Previous adaptation strategies, such as keeping castrated males in the herd to dig through the ice, thus allowing a herd to persist through the season, may be stressed by modern herd management that is coupled with a greater frequency of *Goavvi* events.

In each of the summary points for policy-makers, the case studies help to situate these key messages by providing context and making a connection to particular places, issues, and communities. Each summary point emphasizes the opportunity to respond to rapid Arctic change in ways that build or maintain system resilience, whilst also recognizing potential traps and pitfalls. In the case studies, examples such as the rapid increase in marine shipping through the Bering Strait highlight that there are difficult choices to be made and suggest how a resilience approach might inform these decisions, including by enabling innovative participatory processes and conceptualizing issues in the context of linked social-ecological systems.

Looking ahead, further analyses of these and other case studies will aim to focus on system dynamics, interactions across scales, and policy-relevant impacts and opportunities. Shared themes to emerge across the case studies, such as the rapid growth of industrial development in the Arctic, focus attention on important Arctic system drivers that affect a variety of sub-systems in different ways. In the southwest Yukon, increased mineral resource exploration and development activity will hinder subsistence hunting activities. In Finnmark, meanwhile, reindeer herders' migratory routes are being fragmented by industrial activity. As resource exploration and development expand across the Arctic, vessel traffic through the Bering and Anadyr straits is expected to increase significantly. All of this will affect food security in the northern communities – which, in itself, may serve to provide a composite indicator of pan-Arctic system resilience ■

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Chapter 7

Resilience of international policies to changing social-ecological systems: Arctic shipping in the Bering Strait

Lead author: Martin Robards[1]

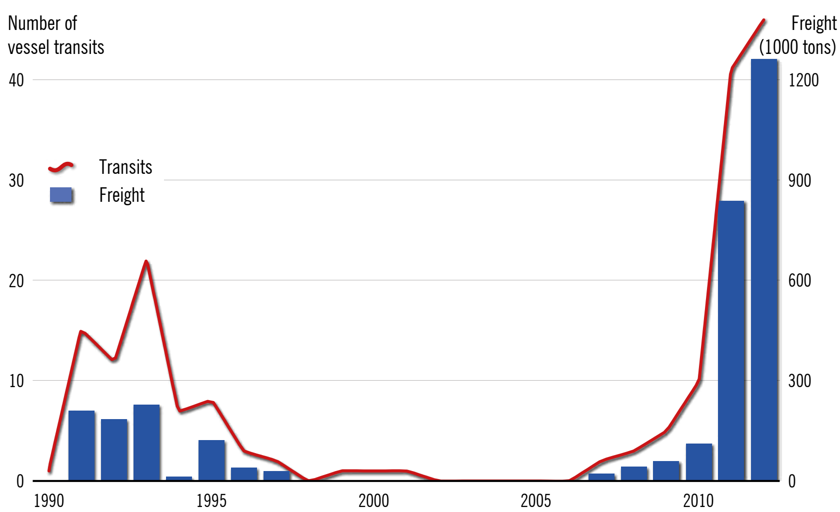
7.1 Arctic shipping in sensitive areas

The Bering Strait, an 85 kilometre-wide passage that connects the North Pacific Ocean and Bering Sea to the Chukchi Sea and Arctic Ocean, and the Anadyr Strait, a 70 km-wide passage separating St. Lawrence Island in Alaska (United States) from Chukotka (Russian Federation), are globally significant for their marine, avian and coastal biological diversity (see Figure 7.2). They are also home to a wide array of indigenous subsistence communities dependent on marine life for their nutritional and cultural survival. The International Union for the Conservation of Nature (IUCN) has designated 13 ecological or biological sensitive areas in the Arctic, including three in the area that encompasses the Bering and Anadyr straits. The entire populations of some species, such as the Pacific bowhead whale and walrus (about 13,000 and more than 150,000 animals, respectively) pass through the Bering Strait twice each year.

Profound reductions and changing patterns of sea-ice cover in recent years as a result of climate change are affecting wildlife distributions and subsistence hunters' ability to hunt. The combination of changing sea ice, strong currents, and the large number of subsistence communities on the Alaskan and Chukotkan coasts make the Bering Strait a challenging area for mitigating the cumulative risks of new industrial developments, including shipping and offshore oil and gas drilling.

Vessel traffic through the Bering and Anadyr straits is expected to significantly increase over the next decade and beyond as the Arctic warms, industrial activities expand, and the Northern Sea Route and Northwest Passage become active transcontinental shipping routes. Already cargo has increased by an order of magnitude since 2010, with 1.3 million tonnes of cargo transported across the Northern Sea Route in 2012 by 47 vessels, up from only two vessels in 2007 (see Figure 7.1). We have transitioned from what was previously called "experimental" shipping activities (Brigham 2010) to a more routine use of the Northern Sea Route.

Figure 7.1 **Transit traffic on the Northern Sea Route 1990-2012**



Aggregations of whales in shipping lanes elsewhere (including Alaska) have resulted in persistent ship strikes and the death of whales (e.g., Neilson et al. 2012; Silber et al. 2012). In the Bering Strait region, whale strikes by ships could impact conservation, food security, and political systems (at the International Whaling Commission through subsistence quotas or nationally via the Marine Mammal Protection Act). Without policies that proactively address the risks associated with large vessels transiting hotspot areas for marine mammals, or areas that support indigenous subsistence practices, negative impacts on marine mammal populations and indigenous food security can be expected.

Figure 7.2 **Bering Strait**

Changes in maritime policy tend to come in response to crises. International laws such as the International Convention for the Safety of Life at Sea (SOLAS) and the International Convention for the Prevention of Pollution from Ships (MARPOL) came about through catastrophic events – the Titanic and Torrey Canyon disasters, respectively. Currently, the International Maritime Organization (IMO), which balances the principle of "freedom of the seas" with the need to regulate for the safety of people, ships, and the environment, needs to approve any regulation of vessels that pass through international straits. However, the IMO requires the coastal states of international straits (in this case, the Russian Federation and United States) to first agree on protective measures before the IMO will consider regulation of all international traffic. The questions that this case study addresses are: What circumstances would allow global shipping policies to change in response to new risks in the Bering Strait region as a result of climate change, industrial development, and growing transportation activities? Can national, bilateral, regional, and international institutions work cooperatively to develop policies that proactively respond to changing localized threats, based on experience from analogous situations elsewhere, or must a crisis happen to force such a response?

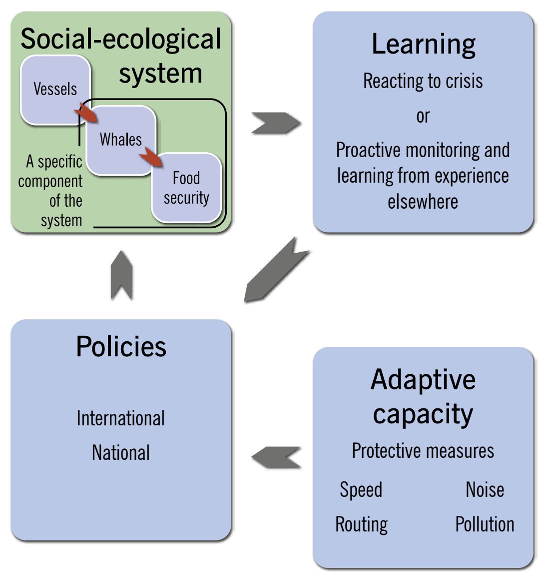
The Arctic Marine Shipping Assessment (Arctic Council 2009) proactively provided a baseline snapshot of Arctic marine activity, a strategic guide for stakeholders and actors, and a policy framework (Brigham 2013). The assessment provides 17 recommendations along three themes: enhancing Arctic marine safety; protecting Arctic people and the environment; and building the Arctic marine infrastructure. In addition, proactive regulations are now being developed at the IMO to address safe navigation in the polar regions through a mandatory Polar Code. Arctic-specific amendments will be developed for SOLAS, MARPOL and other maritime conventions in conjunction with the global maritime industry, ship classification societies, and the marine insurance industry. However, our primary assumption in this case study is that conditions and risks in the Bering Strait region are unique within the Arctic, particularly as they relate to wildlife aggregations and indigenous food security, and thus are not conducive to being governed by the top-down generic regulations that apply to shipping elsewhere in the world or across the Arctic as a whole.

7.2 A resilience lens in the Bering Strait

An increasing number of scholars recognize that in multi-scale dynamic systems, top-down single policy prescriptions, what have been termed "panaceas", rarely work (Ostrom et al. 2007). Policy tools must "fit" both the temporal and spatial scale of the problem being addressed (Young 2002). Consequently, there has been interest in using proactive, multi-scale, and adaptive (often termed ecosystem-based) approaches to management (Chapin et al. 2009; Adger et al. 2011; Ruhl 2011). Prescriptions out of the resilience literature usually rely on such integrative approaches that work across disciplines and are premised on iterative and adaptive learning. However, such approaches are a marked departure from most existing policy approaches, and their implementation is a relatively new arena of study for resilience scholars, most of whom have regarded policy as a "black box" – or else as something that automatically responds to enough science.

Figure 7.3 illustrates a conceptual framework for applying a resilience lens to shipping in the Bering Strait region. Resilience is frequently conceptualized as the ability of specific components (whales and food security) within a social-ecological system (green box) to adapt to impacts (in this case shipping). However, this case study focuses on the (engineering) resilience of the existing legal structures governing global shipping (regulated by the IMO), and the ability of this legal structure to adapt to new environmental conditions at the local scale of the Bering Strait – with a specific focus on the unique ecological needs of marine mammals and food security needs of indigenous peoples. This approach reflects an increasing interest in the tensions between the resistance of global policies to change and the need for them to address emerging conditions and policy problems.

Figure 7.3 **Conceptual framework for applying a resilience lens to shipping in the Bering Strait**



A shipping policy explicitly protecting whales or food security in the Bering Strait region would require the incremental development of new national agreements in the United States and Russian Federation, bilateral agreement between these two nations, and international agreements under the IMO about specific protective measures – either for vessel operations (such as routing) or for the area as a whole (such as under a Particularly Sensitive Sea Area designation). Policies would need to minimize loss of marine mammals as a result of shipping and thus not impact conservation needs or subsistence activities. While significant impacts have not been documented yet, hindering a proactive response based on current decision rules, we can look at the range of feedbacks in the system to provide inferences about future trajectories and the developing policy problem. Table 7.1 lists those feedbacks; collectively, feedbacks limiting the further development of Arctic shipping are rapidly declining or becoming less significant, while positive feedbacks encouraging continued expansion of shipping are increasing.

The resilience of the Bering Strait's marine mammals and indigenous communities is directly related to the policies that support or constrain activities of outside commercial interests. How well these policies adapt or transform is contingent on whether they proactively respond to the trend of increasing shipping activity and expected impacts, or only react after threshold impacts are experienced.

Like ecologists, social scientists, and complex-systems researchers, legal scholars understand that a resilient legal system is one that enjoys consistency in overall behavioural structure (e.g., constitutional divisions of power) and processes (e.g., administrative decision processes), notwithstanding continuous change of external and internal conditions (Ruhl 2011). From a resilience perspective, the negotiation of international policy may be regarded as a "slow variable". While resilience of international shipping policy maintains some (but not all) important safeguards for shipping, finding thresholds within a policy arena for proactively protecting novel local conditions (aggregated marine mammals or indigenous food security) in the Arctic presents a significant challenge. Local actors are constrained in their ability to foster their own resilience without active and meaningful engagement in global governance of activities affecting their local resources. Currently, the greatest opportunity for engagement is nationally, via public comments to U.S. Coast Guard or internationally as Permanent Participants in the Arctic Council, including active engagement in working groups such as the Protection of the Arctic Marine Environment (PAME). There is currently no direct representation of wildlife or indigenous interests at the IMO, although observers note the influence of the Arctic Council on the IMO (e.g., Stokke 2013).

Table 7.1 **Positive feedbacks driving increases in Arctic shipping and negative feedbacks that limit expansion**
Humpert and Raspotnik (2012)

Feedbacks	Justification
Positive feedbacks	
Sea Ice	Loss of multi-year sea ice provides for easier and safer transit.
Shipping Technology	New ice-class vessels dedicated to the Arctic increase capacity and season.
Distance	Northern Sea Route is up to 40% shorter than the southern equivalent
Congestion	Less congestion on Northern Sea Route
Fuel Economy	Slower transit on the shorter Northern Sea Route benefits fuel efficiency
Globalization	Desire for resources in Asia will drive demand for shipping
Experience	Shipping has advanced from experimental to routine transit
Negative feedbacks	
Vessel speed	Slower speeds result in more time at sea (but note fuel economy above)
Insurance	Higher costs due to higher risks on Northern Sea Route
Fees	Russian Federation requires Ice Pilots and fees on Northern Sea Route
Emergency Response	Limited
Environmental Conditions	Cold, icing, and sea-ice conditions will continue to challenge the safety, ease, and speed of passage
Economies of Scale	The long-term economic viability of individual voyages is low
Experience/Scheduling	No regular/routine shipping to rely on
Draft/Beam Restrictions	Narrow shallow straits in and around the Kara and Laptev Seas, particularly through the New Siberian Islands
Ice Classification Needs	Only ice-class vessels will use the Northern Sea Route. These are uneconomic on more southerly routes

7.3 Identifying opportunities for policy change

Despite the challenges of changing international or even national policies, the policy sciences literature has a long history of exploring mechanisms leading to policy change. When policy change is necessary – in other words, when people recognize a problem and identify a solution – transitions can occur over short periods within a window of opportunity, such as following a crisis (Kingdon 1995), or sometimes in conjunction with coalitions of like-minded entities advocating for a new direction (Sabatier 1988). The nexus between indigenous rights (advocating for food security) and conservation (ensuring the long-term health of marine mammal populations) that is formalized in both national (e.g., under the Marine Mammal Protection Act or in the National Security Presidential Directive-66) and international forums (e.g., the International Whaling Commission or the U.N. Declaration on the Rights of Indigenous Peoples) offers avenues for collective engagement. In this context, it is important that there be enough coordination and cohesion among diverse partners to establish that there is a policy problem that needs resolving and a set of protective measures that can mitigate that problem (Henshaw 2012; Stokke 2013).

Walrus resting on sea ice

Although transformational change in policy so often occurs at times of crisis, there are opportunities for changes that are more in line with the recommendations in the resilience literature, to learn from crises occurring at other times and places (Olsson et al. 2008; Stone 1999). Silber et al. (2012) identify 10 actions that have been implemented to protect whales from the impacts of shipping elsewhere – on the eastern seaboard of the United States, the Scotia-Fundy region of Canada, and the western Mediterranean Sea. While all these actions were reacting to observed problems (i.e., they are not precautionary), they provide opportunities for learning and application in new environments.

Supporting transitions in policy to reflect the dynamic needs of marine mammals and indigenous food security is a normative consideration for policy. Such goals require tradeoffs with other normative goals specified in law, such as freedom of navigation. Trade-offs among normative policy goals are increasingly well described in a variety of policies (e.g., Doremus 2001; Robards and Lovecraft 2010). Because more powerful interest groups' efforts to protect their own goals may limit local adaptation (Nadasdy 2007), it is critical to consider social factors, not just the resources and infrastructure in a system. As Brown and Westaway (2011) note: "Issues of resilience are intimately intertwined with issues of power, knowledge, justice, and self-determination." ■

References

Adger, W. N., Brown, K., Nelson, D. R., Berkes, F., Eakin, H., et al. (2011). Resilience implications of policy responses to climate change. *Wiley Interdisciplinary Reviews: Climate Change*, 2(5). 757–66. DOI:10.1002/wcc.133.

Arctic Council (2009). *Arctic Marine Shipping Assessment 2009 Report*. http://www.arctic.gov/publications/AMSA.html.

Brigham, L. W. (2013). Environmental Security Challenges and the Arctic Council's Arctic Marine Shipping Assessment. *Environmental Security in the Arctic Ocean*, P. A. Berkman and A. N. Vylegzhanin (eds.). NATO Science for Peace and Security Series C: Environmental Security. Springer Netherlands. 157–73. http://link.springer.com/chapter/10.1007/978-94-007-4713-5_16.

Brigham, L. W. (2010). The Fast-Changing Maritime Arctic. *Proceedings of the U.S. Naval Institute*, 136(5), May., 54–59. http://www.usni.org/magazines/proceedings/2010-05/fast-changing-maritime-arctic.

Brown, K. and Westaway, E. (2011). Agency, Capacity, and Resilience to Environmental Change: Lessons from Human Development, Well-Being, and Disasters. *Annual Review of Environment and Resources*, 36(1). 321–42. DOI:10.1146/annurev-environ-052610-092905.

Chapin, F. S. I., Kofinas, G. P. and Folke, C. eds. (2009). *Principles of Ecosystem Stewardship: Resilience-Based Natural Resource Management in a Changing*. Springer, New York. http://www.springer.com/environment/environmental+management/book/978-0-387-73032-5.

Doremus, H. (2001). Adaptive Management, the Endangered Species Act, and the Institutional Challenges of New Age Environmental Protection. *Washburn Law Journal*, 41. 50. http://heinonline.org/HOL/Page?handle=hein.journals/wasbur41&id=68&div=&collection=journals.

Henshaw, A. S. (2012). Fostering resilience in a changing sea ice context: a grant maker's perspective. *Polar Geography*, online first. DOI:10.1080/1088937X.2012.724460.

Humpert, M. and Raspotnik, A. (2012). The future of Arctic shipping. *Port Technology International*(55), October., 10–11. http://www.porttechnology.org/technical_papers/the_future_of_arctic_shipping.

Kingdon, J. W. (1995). *Agendas, Alternatives, and Public Policies*. HarperCollinsCollege.

Nadasdy, P. (2007). Adaptive co-management and the gospel of resilience. *Adaptive co-management: collaboration, learning, and multi-level governance*, D. R. Armitage, F. Berkes, and N. Doubleday (eds.). Sustainability and the environment. University of British Columbia Press, Vancouver, Canada. 208–27.

Neilson, J. L., Gabriele, C. M., Jensen, A. S., Jackson, K. and Straley, J. M. (2012). Summary of Reported Whale-Vessel Collisions in Alaskan Waters. *Journal of Marine Biology*, 2012. 1–18. DOI:10.1155/2012/106282.

Olsson, P., Folke, C. and Hughes, T. P. (2008). Navigating the transition to ecosystem-based management of the Great Barrier Reef, Australia. *Proceedings of the National Academy of Sciences*, 105(28). 9489–94. DOI:10.1073/pnas.0706905105.

Ostrom, E., Janssen, M. A. and Anderies, J. M. (2007). Going beyond panaceas. *Proceedings of the National Academy of Sciences*, 104(39). 15176–78. DOI:10.1073/pnas.0701886104.

Robards, M. D. and Lovecraft, A. L. (2010). Evaluating Comanagement for Social-Ecological Fit: Indigenous Priorities and Agency Mandates for Pacific Walrus. *Policy Studies Journal*, 38(2). 257–79. DOI:10.1111/j.1541-0072.2010.00361.x.

Ruhl, J. B. (2011). General Design Principles for Resilience and Adaptive Capacity in Legal Systems – With Applications to Climate Change Adaptation. *North Carolina Law Review*, 89(5). 1373–1403. http://www.nclawreview.org/documents/89/5/ruhl.pdf.

Sabatier, P. (1988). An Advocacy Coalition Framework of Policy Change and the Role of Policy-Oriented Learning Therein. *Policy Sciences*, 21. 129–68.

Silber, G. K., Vanderlaan, A. S. M., Tejedor Arceredillo, A., Johnson, L., Taggart, C. T., et al. (2012). The role of the International Maritime Organization in reducing vessel threat to whales: Process, options, action and effectiveness. *Marine Policy*, 36(6). 1221–33. DOI:10.1016/j.marpol.2012.03.008.

Stokke, O. S. (2013). Regime interplay in Arctic shipping governance: explaining regional niche selection. *International Environmental Agreements: Politics, Law and Economics*, 13(1). 65–85. DOI:10.1007/s10784-012-9202-1.

Stone, D. (1999). Learning Lessons and Transferring Policy across Time, Space and Disciplines. *Politics*, 19(1). 51–59. DOI:10.1111/1467-9256.00086.

Young, O. R. (2002). *The Institutional Dimensions of Environmental Change: Fit, Interplay, and Scale*. MIT Press, Cambridge, MA, US.

Sources for figures and tables

Figure 7.1 Based on data from Centre for High North Logistics. "Transits" are those vessels passing between the Barents and Bering Seas via the set of waterways between Kara Gate (southern tip of Novaya Zemlya) and Bering Strait.

Table 7.1 Adapted from Humpert and Raspotnik (2012).

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Chapter 8

Transformations in subsistence systems in the southwest Yukon Territory, Canada

Lead authors: Douglas Clark[1] and Linaya Workman[2]

8.1 Summary of the case study

The southwest Yukon Territory, Canada, has been inhabited for at least 8000 years. During that time it has undergone repeated, episodic biophysical transformations, including glacial advances and retreats, changing drainage patterns, climatic change, and shifting ecological communities. Most recently, the large caribou herds present until the 1930s were replaced as subsistence species by immigrant moose. Since the 1980s moose populations have decreased and they have been increasingly supplanted as a food source by reintroduced wood bison. During the past century and a half, European colonization and settlement has brought about a series of abrupt social changes, such as the enforced relocation of Aboriginal children into residential schools and the establishment of protected areas that ended traditional livelihoods within them. Construction of the Alaska Highway in 1942 also led to rapid social change (see below and Section 8.3). More positively, settlement of comprehensive Aboriginal land claims in 1993 led to the implementation of First Nation self-government agreements and co-management institutions for natural resources.

Throughout this time, First Nations people in the territory have adapted effectively to these changes and the regional social-ecological system remains remarkably diverse and resilient. This case study surveys existing literature to identify a range of resilience-building strategies documented in the southwest Yukon, with particular emphasis on the traditional territory of the Champagne and Aishihik First Nations, from the 1930s to the present (see Table 8.1).

8.2 Resilience of what, to what?

In this case study we consider the resilience of culture, livelihoods, and specific ecosystem services to specific shocks, disturbances, and trends. Ecosystem services in focus are:

- *Provisioning services*: shifts in species, but with a continued supply of food and materials (e.g., wood, medicines, hides and other animal parts).
- *Cultural services*: reciprocal relationships with wildlife and the land, traditional knowledge and teachings, plus shared norms of interdependence, generosity, and reciprocity (O'Leary 1992).
- *Regulating services*: rivers, marine-to-terrestrial nutrient transfer from salmon runs.

Figure 8.1 **Southwest Yukon Territory**

Shocks and disturbances of interest include abrupt regional climatic changes, with cascading effects on plant communities and wildlife; for example, large-scale spruce beetle infestation from the 1990s to the present, plus the Alaska Highway and its related impacts.
Over the time period of interest, subsistence resource availability has varied both inter-annually (e.g., salmon runs) and directionally over the longer term. Directional changes include: the disappearance of the large herds of caribou in the late 1930s; the "arrival" of moose; the consequent adoption of the *sha-kat* (annual round of

resource harvesting; see McClellan et al. 1987) by the Champagne and Aishihik First Nations (CAFN); decline in moose population and apparent maintenance at a low-population equilibrium; and reintroduction of wood bison (including subsequent herd growth and harvest).

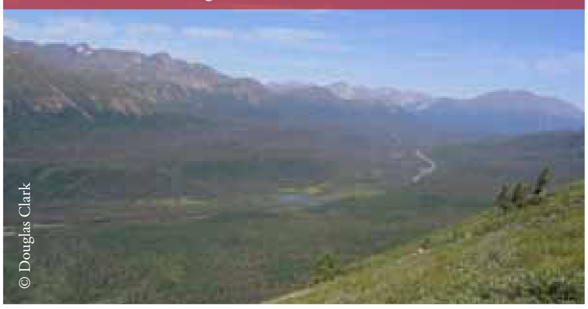
8.3 System dynamics and cross-scale interactions

External drivers of change in the region are numerous, spanning multiple institutional levels and geographic and temporal scales. The key drivers are listed below.

Social drivers. Perhaps most important among these is the Alaska Highway, completed in 1942. The highway brought a large U.S. military presence, and led to the creation of Kluane Game reserve (later Kluane National Park) by the federal government, prohibition of Aboriginal subsistence activities, and settlement by non-aboriginals.

Technological drivers. The Alaska Highway was the first all-season road in the region. Road access changed hunting patterns, as did the introduction of all-terrain vehicles and snowmobiles, with their improving capabilities.

Looking down from Klukshu Mountain onto spruce-beetle affected forest along the Haines Road, Southwest Yukon. Red-tinged trees are recent beetle kill



Environmental drivers. These include regional climate patterns (e.g., the Pacific Decadal Oscillation, directional warming), immigration of moose in the 1940s, introduction of elk in the 1950s and 1980s, rapid growth in the Aishihik wood bison herd since the animal was reintroduced in the period 1988–1992, and the apparent and ongoing immigration of mule deer.

Economic drivers. Chief among these are the introduction of a wage economy, global demand for natural resources (characterized by boom and bust cycles in mineral exploration and production), and increasing pressure on subsistence harvest from competing land uses (which persist alongside the wage economy).

Political drivers. This set of drivers includes World War II, the organization of the Yukon Fish and Game Association and the territorial "game branch", devolution of political authority from federal government to territorial governments (1970s–2000s), the 1993 settlement of comprehensive Aboriginal land claims and self-government for CAFN, the national wood bison recovery strategy, and the Pacific Salmon Treaty (United States and Canada).

Internal system variables include "slow" variables, such as cultural values and teachings; plant community succession; wildlife population dynamics (predation is an issue of longstanding local importance and controversy); and (with some exceptions) territorial and federal legislation. "Fast" variables include: local-scale co-management institutions, practices on the land (e.g., decisions about distribution of harvest effort spatially, temporally, and of which species).

Provisionally, we speculate that there are two important positive feedbacks (i.e., self-reinforcing feedbacks, that reinforce the change happening in the system), and two negative (balancing) feedbacks. However, we have not assessed the relative strengths, durations, or efficacy of these feedbacks. The first positive feedback is cascading climate-driven ecosystem change, which includes spruce beetle infestation, deforestation, and potential subsequent ecological regime shifts (e.g., coniferous forest shifting to deciduous forest or grassland). The second is mineral resource exploration and development activity, driven by global natural resource markets and demand.

The first negative, or balancing, feedback is the effect of post-land claim institutions, especially co-management bodies and development assessment and review processes. The second is the impact of traditional knowledge and teachings, which foster a close and respectful relationship with the land.

Recent research with CAFN members suggests that they have a quite different perspective on the concept of thresholds in social-ecological systems from that of mainstream resilience scholars. Christensen and Krogman (2012) write:

"Our findings suggest that rather than view social thresholds as breakpoints between two regimes, as thresholds are typically conceived in the resilience literature, that they be viewed in terms of collectively recognized points that signify new experiences. Some examples of thresholds identified in our case study include power in decision making, level of healing from historical events, and a preference for small-scale development over large capital intensive projects."

A recent synthesis project (Ogden 2006) identified a series of strategies applied by CAFN people as well as non-Aboriginal Yukoners. These strategies are described and updated in table 8.1 ■

Table 8.1 **Strategies for coping with change in social-ecological systems in the southwest Yukon**
Ogden (2006)

Strategies		Documented examples from the southwest Yukon	Source
Learning to live with change and uncertainty	Evoking disturbance	Ecological: radiational burns, fuel abatement projects, Aishihik wolf control Social: recruiting, "new blood" into institutions	Ogden (2006), Clark and Slocombe (2009)
	Learning from crises	Adopting the seasonal *Sha-kat* lifestyle and moose hunting after the disappearance of caribou in the 1930s, stories and institutional memory	McClellan et al. 1987, Cruikshank (1998; 2005), Clark and Slocombe (2009); Clark et al. (in press)
	Expecting the unexpected	Inter-annual shifts in resource use (salmon vs other foods) and group size, stories, participatory climate change adaptation research	O'Leary 1992, Cruikshank (1998; 2005); Ogden and Innes (2008; 2009)
Nurturing diversity for change and renewal	Maintain a diversity of subsistence species and habitats	Aishihik wolf control and caribou recovery, wood bison management planning, maintaining diversity of salmon species and distinct salmon runs	Ogden (2006); Clark (2010); Fillatre et al. (2003), Miller et al. (2011)
	Nurturing ecological memory (biological legacies, mobile links, support areas)	Techniques for coexistence with grizzly bears on salmon streams, salmon rescues/ beaver dam removal at Hutshi and Klukshu Lake, hatchery-raising Kokanee from upper Alsek River system	Clark and Slocombe (2009); Ogden (2006)
	Sustaining social memory	Southern Tutchone language training, oral histories, culture camps, traditional trail mapping, newly-constructed CAFN Heritage Centre	Ogden (2006)
	Enhancing social-ecological memory (societal and institutional)	Culture camps, youth and community hunts, involving elders, creating new stories	Cruikshank (2005); Ogden (2006); Clark (2010)
Combining different types of knowledge for learning	Combining experiential and experimental knowledge	Ice patch and Kwäday Dän Ts'ínchi collaborative research projects	Beattie et al. (2000); Greer and Strand (2012)
	Expanding from knowledge of structure to knowledge of function	Integrative research programmes: e.g., "Multiscale Ecology and Dynamics of the Forest-Tundra Ecotone"	Danby and Hik (2007a; 2007b; 2007c)
	Building process knowledge into institutions	Social learning in the Yukon Wood Bison Technical Team	Clark (2010)
	Fostering complementarity of different knowledge systems	Community-based research initiatives arising in the wake of grizzly bear management controversies	Clark (2010), Clark et al. (in press)
Creating opportunity for self-organization	Recognizing the interplay between diversity and disturbance	Ecosystem-based management efforts among and within adjoining protected areas, regional-scale ecological assessments	Danby et al. (2003); Danby and Slocombe (2005)
	Dealing with cross-scale dynamics	Independent Yukoner lifestyles may maintain social-ecological feedback loops and incentives for sustainable resource use	Ogden (2006); Christensen and Krogman (2012)
	Matching scales of ecosystems and governance	Traditional territories and other institutions matching ecological boundaries	Ogden (2006); Christensen and Krogman (2012)
	Accounting for external drivers (social and ecological)	Establishing cross-scale institutions, e.g., Kluane Park Management Board	Ogden (2006); Christensen and Krogman (2012)

References

Beattie, O., Apland, B., Blake, E. W., Cosgrove, J. A., Gaunt, S., et al. (2000). The Kwädǫāy Dän Ts' ínchǫi Discovery From a Glacier in British Columbia. *Canadian Journal of Archaeology/Journal Canadien d'Archéologie*, 24(1). 129–47.

Christensen, L. and Krogman, N. (2012). Social thresholds and their translation into social-ecological management practices. *Ecology and Society*, 17(1). Art. 5. DOI:10.5751/ES-04499-170105.

Clark, D. A. (2010). *Socio-Economic Impact Assessment of the Aishihik Wood Bison Transplant*. Report under contract #K2F50-09-4987 to Environment Canada. University of Saskatchewan, Saskatoon, SK, Canada.

Clark, D. A. and Slocombe, D. S. (2009). Respect for grizzly bears: an aboriginal approach for co-existence and resilience. *Ecology and Society*, 14(1). Art. 42.

Clark, D. A., Workman, L. and Slocombe, D. S. (in press). Science-based grizzly bear conservation in a co-management environment: The Kluane region case, Yukon. *Large Carnivores, People, and Governance: Reforming Conservation in the North American West*. S. G. Clark and M. B. Rutherford (eds.). University of Chicago Press, Chicago, IL, US.

Cruikshank, J. (2005). *Do Glaciers Listen? Local Knowledge, Colonial Encounters, and Social Imagination*. University of British Columbia Press, Vancouver, BC, Canada.

Cruikshank, J. (1998). *The Social Life of Stories: Narrative and Knowledge in the Yukon Territory*. University of British Columbia Press, Vancouver, BC, Canada.

Danby, R. K. and Hik, D. S. (2007a). Evidence of recent treeline dynamics in southwest Yukon from aerial photographs. *Arctic*, 60(4). 411–20.

Danby, R. K. and Hik, D. S. (2007b). Responses of white spruce (*Picea glauca*) to experimental warming at a subarctic alpine treeline. *Global Change Biology*, 13(2). 437–51. DOI:10.1111/j.1365-2486.2006.01302.x.

Danby, R. K. and Hik, D. S. (2007c). Variability, contingency and rapid change in recent subarctic alpine tree line dynamics. *Journal of Ecology*, 95(2). 352–63. DOI:10.1111/j.1365-2745.2006.01200.x.

Danby, R. K., Hik, D. S., Slocombe, D. S. and Williams, A. (2003). Science and the St Elias: An evolving framework for sustainability in North America's highest mountains. *Geographical Journal*, 169(3). 191–204. DOI:10.1111/1475-4959.00084.

Danby, R. K. and Slocombe, D. S. (2005). Regional ecology, ecosystem geography, and transboundary protected areas in the St. Elias Mountains. *Ecological Applications*, 15(2). 405–22. DOI:10.1890/04-0043.

Fillatre, E. K., Etherton, P. and Heath, D. D. (2003). Bimodal run distribution in a northern population of sockeye salmon (*Oncorhynchus nerka*): life history and genetic analysis on a temporal scale. *Molecular Ecology*, 12(7). 1793–1805. DOI:10.1046/j.1365-294X.2003.01869.x.

Greer, S. and Strand, D. (2012). Cultural landscapes, past and present, and the south Yukon ice patches. *Arctic*, 65(5). 136–52.

McClellan, C., Birckel, L., Bringhurst, R., Fall, J. A., McCarthy, C. and Sheppard, J. R. (1987). *Part of the Land, Part of the Water: A History of the Yukon Indians*. Douglas & McIntyre, Vancouver, BC, Canada.

Miller, E. K. F., Bradbury, I. r. and Heath, D. d. (2011). Juvenile habitat partitioning and relative productivity in allochronically isolated sockeye salmon (*Oncorhynchus nerka*). *Ecology and Evolution*, 1(4). 601–9. DOI:10.1002/ece3.55.

O'Leary, B. L. (1992). *Salmon and Storage: Southern Tutchone Use of an 'Abundant' Resource*. Occasional Papers in Archaeology No. 3. Yukon Tourism, Heritage Branch, Whitehorse, YT, Canada.

Ogden, A. E. (2006). *Forest Management in a Changing Climate: Building the Environmental Information Base for Southwest Yukon*. Northern Climate ExChange, Whitehorse, YT, Canada. http://pubs.cif-ifc.org/doi/pdf/10.5558/tfc83806-6.

Ogden, A. E. and Innes, J. L. (2009). Application of structured decision making to an assessment of climate change vulnerabilities and adaptation options for sustainable forest management. *Ecology and Society*, 14(1). Art. 11.

Ogden, A. E. and Innes, J. L. (2008). Climate change adaptation and regional forest planning in southern Yukon, Canada. *Mitigation and Adaptation Strategies for Global Change*, 13(8). 833–61. DOI:10.1007/s11027-008-9144-7.

Sources for table

Table 8.1. Updated from Ogden (2006).

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Chapter 9

Strategies to enhance the resilience of Sámi reindeer husbandry to rapid changes in the Arctic

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9.1 Introduction

Reindeer herding peoples of northern Eurasia have accumulated a unique knowledge about the social-ecological system of the environment in which they live. This case study focuses on the nomadic Sámi reindeer herding community of Guovdageaidnu (Kautokeino), Finnmark, Norway and is based on the work of the International Polar Year project EALÁT, Reindeer Herding and Climate Change, and on an ARR workshop in Guovdageaidnu in October 2012. It addresses the challenges of integrating multiple sources of knowledge in reindeer herding governance and suggests how resilience can be enhanced in Sámi communities.

The Sámi Siida is an ancient community system that involves a group of reindeer owners who practice reindeer husbandry jointly within a designated area (Sara 2011; Sara 2010). The Siida is an informal governance structure that has enabled reindeer herders to apply resilience-enhancing strategies such as promoting diversity and flexibility and is based on traditional knowledge of pasture areas, reindeer herds, and climate conditions (Turi 2008). Specialized language has also evolved to help herders cope with ecological variability and to minimize risks (Magga 2006; Eira 2012a). Since the 1600s, however, governments have increasingly influenced indigenous reindeer herding communities and economies through assimilation with host states, border management, and legislation. In 1852 the closing of the national border between Finland and Norway blocked migratory routes of nomadic reindeer herders in Guovdageaidnu. More recently, the 1978 Reindeer Husbandry Act in Norway has restricted the use of traditional knowledge in Sámi herding and social organization by not emphasizing reindeer herders' knowledge in the Act, contributing to an erosion of resilience locally in the Siidas (Eira 2012b).

Today, climate change and globally driven socio-economic changes are profoundly affecting reindeer herding cultures (Magga et al. 2011; Oskal et al. 2009). Regional scenarios predict dramatic changes in land use, temperature, precipitation, and snow conditions for key reindeer herding areas (Magga et al. 2011; Vistnes et al. 2009; Oskal et al. 2009). Traditional knowledge, including social organization and languages of the Sámi people, are considered critical to ensuring effective governance of reindeer herding systems. Greater autonomy and strengthening of Sámi institutions will help build adaptive capacity to deal with rapid change. Resilience thinking provides a framework for strengthening adaptive capacity locally in herding communities, by combining traditional knowledge with other ways of learning and understanding.

Figure 9.1 **Finnmark**

9.2 Time and space scales of Sámi reindeer herding

Reindeer herding is the primary livelihood for over 20 indigenous groups in the Arctic and sub-Arctic, involving close to 100,000 herders and 2.5 million semi-domesticated reindeer (Turi 2002; McCarthy and Martello 2005). Figure 9.2 shows the distribution of reindeer-herding peoples and reindeer. Norway's 2010 reindeer count (by the Reindeer Husbandry Administration, Reindriftsforvaltningen, *www.reindrift.no*), estimated that there were roughly 200,000 reindeer and 3,000 active reindeer herders in the country. Reindeer are herded over an area of approximately 146,000 km^2, which is equivalent to 40% of the mainland area of Norway. The Sámi reindeer herders in Finnmark may migrate up to 350 km from inland winter pastures to coastal summer pastures. In Guovdageaindu there are roughly 90,000 reindeer and 1,500 people involved in reindeer husbandry. Reindeer husbandry in Norway is estimated to be more than a thousand years old (Storli 1994), while the modern regime of Norwegian governance of reindeer husbandry is around 150 years old.

Figure 9.2 **Reindeer herding**

9.3 Reindeer herding – an integrated social-ecological system

Sámi reindeer nomadism represents a strongly coupled social-ecological system (Tyler et al. 2007). Humans describe the natural environment on the basis of their local experience, their interactions with nature, and in terms of its relevance to their daily lives. These descriptions are incorporated into local languages and form a specialized terminology that is specifically applicable to local needs and practices (Magga 2006). Through Sámi language, the humans and ecosystems in Guovdageaidnu are interconnected (Eira et al. 2013; Eira 2012a). The reindeer are semi-domesticated and ideally, herders simply allow them to graze, protect them against threats, and otherwise disturb the animals as little as possible. *Guođohit* (to herd reindeer) means basically that you get the deer to graze (*guohtut*), by predicting the animals' movements through knowledge of their behaviour in different seasons, pasture and terrain, and intervening only in very rare occasions, when the conditions are difficult (Eira 2012a).

The Sámi concept of a "beautiful" herd (*čáppa eallu*) incorporates diversity and rejects the homogeneity of a purebred herd of livestock (Oskal 2000). The traditional diversity of reindeer herds reflects a strategy to reduce risks associated with variability in weather conditions. Reindeer herders have traditionally maintained high levels of phenotypic diversity in their herds with respect to the age, sex, size, colour and temperament of their animals (Magga 2006; Oskal 2000). Even "non-productive" animals have other roles that contribute to the productivity of the herd as a whole (Tyler et al. 2007). For example, in the 1960s, reindeer herds in Guovdageaidnu typically comprised between 25% and 50% adult males, many of which were castrated (Paine 1994). Castrates do not go into rut, and they are calmer, heavier and better snow-diggers. These qualities improve the use of the landscape for the whole herd.

9.4 Resilience to shocks and disturbances

The closing of the national border between Norway and Finland in 1852 meant the Siidas could no longer maintain their traditional migration routes, creating a crisis for the Guovdageaidnu Sámi nomadic herders, who lost their traditional pastures. Sámi nomadic reindeer husbandry continued separately on each side of the border, with small changes to its identity and local governance structure. Similarly, the Norwegian Reindeer Husbandry Act of 1978 is considered a shock because the new law did not draw on traditional knowledge, and it forced changes that the herders were not prepared for, such as changes in the internal governance model which could have affected the number of reindeer (Eira 2012b).

Weather and climate events are other types of shocks in Guovdageaidnu to which Sámi herders have developed adaptive responses over time. For reindeer herders, understanding snow, precipitation, and ice conditions has been critical for them and their herds' survival (Maynard and Oskal 2011; Roturier and Roué 2009). Snow defines most of the conditions necessary to support Sámi reindeer pastoralism and is a prerequisite for mobility, tracking, visibility and availability of pasture plants (Eira 2012a). The Sámi snow concept *goavvi* relates to extreme poor grazing conditions, either when there is too much snow and reindeer can't get through it, or there an ice layer has developed on the ground underneath the snow; either scenario can lead to starvation, loss of reindeer, and strong negative effects on the herders' economy (Eira 2012a). During the last 100 years, there have been 12 *goavvi* events in Guovdageaidnu, with a trend of increased frequency over the last 30 years (Eira 2012a). In 1967–68, several winter Siidas and migration routes had ice so thick that reindeer were not able to break through (Eira 2012a). Individual reindeer herders and Siidas able to recover from such extreme years may have greater resilience to future climate variability and change (Eira 2012a).

9.5 Change and trends

Climatic change is now evident across the Arctic, particularly in reindeer herding areas. Climate scenarios developed indicate that winter temperatures in Guovdageaidnu may increase by 7°C to 8°C over the next 100 years (Benestad 2008), creating conditions that would resemble the coastal area of Finnmark (Nordreisa) today (Magga et al. 2011). Industrial extraction of hydrocarbons and minerals in the region is also expected to continue to increase (Magga et al. 2011; Vistnes et al. 2009). Habitat fragmentation and degradation of pasturelands, combined with a changing climate, presents substantial challenges to the future of reindeer husbandry. For herders, the principal issue is securing the landscapes used during migrations over eight distinct grazing seasons per year. The loss of grazing areas due to industrial development and other types of encroachment is probably the single greatest threat to reindeer husbandry in the circumpolar North today (Magga et al. 2011; Vistnes et al. 2009).

9.5.1 Valued ecosystem services

Nomadic reindeer herding systems provide cultural and economic benefits to indigenous peoples in Guovdageaidnu. Habitat provision is a key ecosystem service that directly supports reindeer husbandry. Other important ecosystem services valued by local indigenous peoples and others in this system include food production, tourism opportunities, and cultural benefits.

9.5.2 External drivers of change

In addition to climate change and increased connectivity with global economic systems, the Norwegian state involvement in Sámi reindeer husbandry is considered to also represent a significant driver of change. Sámi reindeer herders in Norway have in theory been given considerable autonomy through international conventions, as well as within the Norwegian constitution (O'Brien et al. 2009). However, reindeer herding in Norway is highly regulated by national legislation that imposes a production-oriented agricultural model on traditional herding systems (Tyler et al. 2007). Traditional elements of Sámi governance, such as diversity, flexibility and mobility, are not reflected in Norway's reindeer husbandry regulations (Turi 2008). Instead, Norway's approach to governing Sámi reindeer herding systems uses equilibrium-based management tools such as carrying capacity and other tools designed for agricultural contexts that can undermine the system's resilience (O'Brien et al. 2009; Tyler et al. 2007).

9.6 Strategies for building resilience

Reindeer herding involves an awareness and understanding of rapid changes in the condition of pasture and the knowledge to respond accordingly, based on nomadic traditions and cooperation between Siidas. The sustainable management of Sámi reindeer husbandry is likely to face major challenges related to on-going changes and potential future thresholds in the Arctic. Reindeer herders' traditional knowledge, culture, and language provide the foundation for strengthening resilience locally. Reindeer herding communities in Guovdageaidnu are also affected by institutional regulations, governance systems and surrounding economic conditions (Turi 2008; Eira 2012a; Eira 2012b). Integrating traditional knowledge into formal governance systems and supporting the transfer of knowledge to reindeer-herding youth is an important strategy for enhancing resilience in this system. Engaging youth in herding practices and providing relevant education opportunities are key factors; the perspectives of youth are also important in the development of educational programs. Accordingly, reindeer herding youth have provided input to this case study and are included in several related projects, such as an assessment of resilience in reindeer husbandry to be presented to the UN Permanent Forum on Indigenous Issues (UNPFII), the Arctic Council SDWG project EALLIN, Reindeer Herding Youth; the project Enhancing the Resilience of Reindeer Herders' Ecosystems and Livelihoods, and the research project Dávggas, Economics and Land-Use Conflicts in Sami Reindeer Herding in Finnmark: Exploring the Alternatives ■

References

Eira, I. M. G. (2012a). *Muohttaga Jávohis Giella: Sámi Árbevirolaš Máhttu Muohttaga Birra Dálkkádatrievdanáiggis* (The Silent Language of Snow: Sámi Traditional Knowledge of Snow in Times of Climate Change). Ph.D. thesis. University of Tromsø.

Eira, I. M. G., Jaedicke, C., Magga, O. H., Maynard, N. G., Vikhamar-Schuler, D. and Mathiesen, S. D. (2013). Traditional Sámi snow terminology and physical snow classification – Two ways of knowing. *Cold Regions Science and Technology,* 85. 117–30. DOI:10.1016/j.coldregions.2012.09.004.

Eira, R.B. M (2012b). *Using Traditional Knowledge In Unpredictable Critical Events In Reindeers Husbandry: The Case of Sámi Reindeer Husbandry in Western Finnmark, Norway and Nenets Reindeer Husbandry on Yamal Peninsula, Yamal-Nenets AO, Russia.* Master of Philosophy in Indigenous Studies thesis. University of Tromsø.

Benestad, R.E (2008): *Empirical-Statistical Downscaling of Russian and Norwegian Temperature Series.* Working paper no. 13:2008, Norwegian Meteorological Institute, Oslo, Norway.

Magga, O. H. (2006). Diversity in Saami terminology for reindeer, snow, and ice. *International Social Science Journal*, 58(187). 25–34. DOI:10.1111/j.1468-2451.2006.00594.x.

Magga, O. H., Mathiesen, S. D., Corell, R. W. and Oskal, A. eds. (2011). *Reindeer Herding, Traditional Knowledge, Adaptation to Climate Change and Loss of Grazing Land.* Report from EALAT project, led by Norway and the Association of World Reindeer Herders. Arctic Council, Sustainable Development Working Group, Alta, Norway. http://www.sdwg.org/content.php?doc=103.

Maynard, N. G. and Oskal, A. (2011). Impact of Arctic Climate and Land Use Change on Reindeer Pastoralism: Indigenous Knowledge and Remote Sensing. *Eurasian Arctic Land Cover and Land Use in a Changing Climate*, G. Gutman and A. Reissell (eds.). Springer. 177–205.

McCarthy, J. J. and Martello, M. L. (2005). Climate change in the context of multiple stressors and resilience. *Arctic Climate Impact Assessment – Scientific Report*, J. Berner, C. Symon, L. Arris, and O. W. Heal (eds.). Cambridge University Press, Cambridge, UK, and New York. 945–88. http://www.acia.uaf.edu/PDFs/ACIA_Science_Chapters_Final/ACIA_Ch17_Final.pdf.

O'Brien, K., Hayward, B. and Berkes, F. (2009). Rethinking social contracts: building resilience in a changing climate. *Ecology and Society*, 14(2). Art. 12. http://www.ecologyandsociety.org/vol14/iss2/art12/.

Oskal, N. (2000). On nature and reindeer luck. *Rangifer: Research, Management and Husbandry of Reindeer and other Northern Ungulates*, 20(2-3). 175–80. http://septentrio.uit.no/index.php/rangifer/article/view/1511.

Oskal, A, Turi, J.M., Mathiesen, S.D. and Burgess, P. eds. (2009): EALÁT Reindeer Herders' Voice: *Reindeer Herding, Traditional Knowledge and Adaptation to Climate Change and Changed Use of the Arctic.* Arctic Council SDWG EALÁT-Information Ministerial Report. International Centre for Reindeer Husbandry and Association of World Reindeer Herders. International Centre for Reindeer Husbandry Report 2:2009, Guovdageaidnu/ Kautokeino, Norway.

Paine, R. (1994). Herds of the Tundra: a Portrait of Saami Reindeer Pastoralism. Smithsonian Institution Press, Washington, DC.

Roturier, S. and Roué, M. (2009). Of forest, snow and lichen: Sámi reindeer herders' knowledge of winter pastures in northern Sweden. *Forest Ecology and Management*, 258(9). 1960–67. DOI:10.1016/j.foreco.2009.07.045.

Sara, M. N. (2011). Land usage and Siida autonomy. *Arctic Review of Law and Politics,* 3(2). 138–58. http://site.uit.no/arcticreview/files/2012/11/AR2011-2_Sara.pdf.

Sara, M. N. (2010). Mainna lágiin galget siiddat joatkahuvvat? Siida sulladallama gažaldagat (How is the Siida going to continue?). *Sámi diedalaš áigečála*, (2). 25–55.

Storli, I. (1994). *'Stallo'-boplassene: Spor Etter de Første Fjellsamer?* (Settlements: First Sign of the Mountain Sami?). Instituttet for Sammenlignende Kulturforskning.

Turi, E. I. (2008). *Living with Climate Variation and Change: A Comparative Study of Resilience Embedded in the Social Organisation of Reindeer Pastoralism in Western Finnmark and Yamal Peninsula*. Master Thesis, Masteroppgave ved Institutt for Statsvitenskap, Universitet i Oslo. https://www.duo.uio.no/handle/123456789/14839.

Turi, J. M. (2002). The World Reindeer Livelihood – Current Situation, Threats and Possibilities. *Northern Timberline Forests: Environmental and Socio-economic Issues and Concerns*, S. Kankaanpää, L. Müller-Wille, P. Susiluoto, and M.-L. Sutinen (eds.). Finnish Forest Research Institute, Kolari Research Station, Jyväskylä, Finland. 70–75.

Tyler, N. J. C., Turi, J. M., Sundset, M. A., Strøm Bull, K., Sara, M. N., et al. (2007). Saami reindeer pastoralism under climate change: Applying a generalized framework for vulnerability studies to a sub-Arctic social–ecological system. *Global Environmental Change*, 17(2). 191–206. DOI:10.1016/j.gloenvcha.2006.06.001.

Vistnes, I. I., Burgess, P., Mathiesen, S. D., Nellemann, C., Oskal, A. and Turi, J. M. (2009). *Reindeer Husbandry and Barents 2030: Impacts of Future Petroleum Development on Reindeer Husbandry in the Barents Region*. Report prepared for StatoilHydro by the International Centre for Reindeer Husbandry. Alta, Norway. http://www.grida.no/publications/list/4324.aspx.

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Chapter 10

Food security in the Arctic: Preliminary reflections from a resilience perspective

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10.1 Introduction

Food security exists "when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO 2001). It is an essential aspect of human security and closely connected to the functioning of both the ecological and social systems. Food security is also closely associated with issues of water security, defined as access for each individual to sufficient, safe and affordable water to satisfy the need for drinking, washing and livelihood (Rijsberman 2006). The broader context of food security is further spelled out in the evolving definition of food and nutrion security, which emphasizes how it is supported by "an environment of adequate sanitation, health services and care, allowing for a healthy and active life" (Committee on World Food Security 2012). A definition of food security for the Arctic context would also emphasize the important cultural and social aspects of food for indigenous peoples, such as opportunities to use and teach traditional harvesting techniques and food sharing practices that promote community resilience (White et al. 2007). Food security in the Arctic, as elsewhere, also includes political aspects captured in concepts such as "food sovereignty", which highlight peoples' right to define their own policies and strategies for the sustainable production, distribution and consumption of food that guarantee the right to food for the entire population.

The provision of food and fresh drinking water are important ecosystem services upon which human well-being depends (Millennium Ecosystem Assessment 2005), and there is increasing international recognition of the need to understand how ecosystem change can affect food security, including the links between food and water (UNEP 2011). Food security also relates to the role that food plays in fostering social and cultural ties. Thus, when considering food security in the Arctic, there is a need to understand both how pressures on ecosystems can affect their functioning *and* changes in the social, cultural, economic and political contexts in which people live.

For many people in the Arctic, food and water security are pressing concerns that are connected to a variety of interacting components (e.g., Guyot et al. 2006; Wesche and Chan 2010; Evengard et al. 2011; Ford and Beaumier 2011; Schuster et al. 2011). These include exposure to water- and food borne diseases (caused by pathogens); increasing incidence of life-style diseases (metabolic syndrome); very high costs for a "healthy food basket" of store-bought foods combined with low cash incomes; dependence on global markets with increasingly volatile prices; contaminants in traditional/country foods; rapidly changing ecosystems that impede access to food resources; high fuel costs; economic transformation; and loss of traditional knowledge on food provision. Food security and closely related issues have also been discussed in assessments of climate change in the Arctic (Anisimov et al. 2007; Berner and Furgal 2005), in relation to pollution (AMAP 2009), in the Survey of Living Conditions (SLiCA) in the Arctic (Poppel et al. 2007), and the Arctic Human Development Report (Hild and Stordahl 2004). However, to date there exists no pan-Arctic assessment that focuses specifically on food security and provides an overall picture of its complex nature.

Food and water security have received increasing attention and have been priority issues during the Swedish chairmanship of the Arctic Council 2011–2013. This has included a study aimed at defining indicators of food and water security in a circumpolar context, carried out by the human health expert groups of the Arctic Monitoring and Assessment Programme (AMAP) and the Sustainable Development Working Group (SDWG) of the Arctic Council (Nilsson and Evengård 2013). Moreover, various Arctic States and communities have national food security assessment or projects under way. Canada, for example, has initiated work on a "State of Knowledge of Food Security in

Northern Canada" through the Council of Canadian Academies (due 2014). Additionally, the Inuit Circumpolar Council Alaska (ICC-Alaska) has started to develop a framework for how to assess food security from an Inuit perspective, which includes inter-linkages between cultural and environmental systems. The study builds on literature reviews, community meetings, interviews and traditional knowledge, and attempts to identify baselines needed to assess vulnerabilities associated with food security. The aim is to complete the project by 2015, and the final product will be a tool for assessing food security in ways that match Arctic ecosystems and the cultures that exist within them. In addition to efforts to understand Arctic food security from an Inuit perspective, the project will suggest ways to monitor and measure identified indicators (Behe 2012; ICC Alaska 2012).

These examples of food security projects give only an incomplete picture of all current activities, and it is not possible to fully map them all in the context of this short case study. However, the next phase of assessing resilience and food security should identify food security projects across the Arctic that represent different livelihoods and social contexts.

Bearded seals are hunted for subsistence by the Inuit and thus linked to food security

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Because food security encompasses so many issues, it could, in the context of the ARR, be seen as a composite indicator of change in Arctic social-ecological systems. From a resilience perspective there is a need to understand how multiple variables and ongoing changes interact to affect food security, and a need to address them together as a complex system, as opposed to dealing with them in isolation. Therefore, one overarching purpose of this case study is to initiate a discussion about what a resilience lens can bring to studies of food security, and vice versa: how insights from studies of food security can inform the methodology of resilience assessments. Ecosystems are a foundation of food production, therefore this chapter first identifies ecosystem services that are relevant for further analysis. Second, it identifies some of the key drivers and feedbacks that can affect these ecosystem services, as well as how these drivers and feedbacks link to social processes that should receive further attention.

10.2 Ecosystem services

All food ultimately comes from the flow of nutrients and energy through ecosystems. In the Arctic, a significant proportion of people's food is harvested directly from local ecosystems, and ecosystem changes can have a direct impact on the availability of traditional or country foods, for example through changes in species composition (e.g., health, population density, migration routes, invasive species), changes to fire regimes, and ice cover (White et al. 2007; Kofinas et al. 2010). In the Arctic, store-bought food is more likely to come (by air, truck and ship) from ecosystems far away, where availability and prices can be affected by ecosystem and market changes elsewhere in the world. The availability of freshwater is a critical aspect of food production (both in agriculture, and when food is harvested from ecosystems that are less actively managed). In the Arctic, food and freshwater systems are also linked spatially, because communities tend to aggregate along coasts and major rivers, in part to access traditional foods such as moose, caribou, waterfowl, whale, seal and walrus (White et al. 2007). Communities also need water to drink, to prepare food, and to uphold basic hygiene.

Available clean water is a crucial regulating service in the Arctic, and it depends on the ability of the landscape to circulate freshwater in such a way that contaminants and disease-causing organisms are removed. Water purification technologies (ranging from very simple to advanced) are usually necessary to obtain sufficient standards for drinking water. The capacity of the landscape to purify water is especially important in remote and rural areas, which often lack more advanced infrastructure. Other services such as temperature and climate regulation are also important in relation to food security, through their role in traditional methods of preserving food (e.g., drying and storage in ice cellars).

Food is also intimately linked to culture and thus embodies more than simply nutrition and energy to sustain our bodies. It is an integral part of societies, cultures and identities, which in the Arctic is especially relevant in relation indigenous peoples. Changes in the provision of food can therefore have wide-ranging effects on social relationships and cultural well-being. Knowledge about local cultural and social contexts, and how they vary across the Arctic, can support a better understanding of these effects.

10.3 Scales

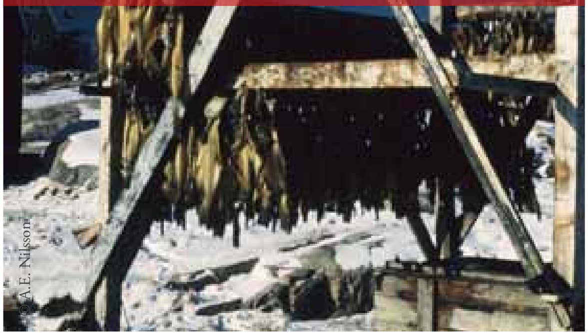
The geographical scales relevant for studies of food security range from the local to the global. Increasingly more people are integrated with global food systems, but local food provision remains important in the Arctic, including traditional hunting, herding and harvesting practices as well as, to a lesser degree, local agriculture/horticulture. The Arctic also contributes to global food provision, in particular through marine fisheries.

The timescales relevant to acute effects of food and water security range from days (access to safe drinking water and basic foods) to the seasonal cycle over the year, to which food production systems are generally adapted. Other food security concerns include serious disruption of food supplies, for example due to failure of infrastructure or challenges in distributing food. With the current rapid climate and social changes in the Arctic, it is increasingly important to analyze how long-term shifts in ecosystems and social structures will affect access to and production and distribution of safe and nutritious food. Social changes that affect people's ability to afford healthy foods can be gradual or abrupt, since they include a combination of factors related to transitions from a subsistence to market based food supply, income (poverty, wage earning vs subsistence economy), social networks, and food prices.

10.4 External drivers of change and their potential impacts

An array of drivers affects food and water security in the Arctic. Important environmental drivers include climate change, with impacts on ecosystems such as shifts in the kinds of macrofauna that are available for hunting (e.g., see Chapter 8); declining sea ice that can make it more difficult to access hunting grounds for marine mammals; and pressure from grazing and insects that affect reindeer herding. Another major concern is contaminants that bioaccummulate in food. In the Arctic, higher levels of contaminants in Arctic biota have raised concerns about how safe it is to consume some nutritionally important food species, for example marine mammals (AMAP 2009). Economic drivers include changes in food prices (locally and on global food markets) as well as changes in people's ability to pay (including cash income). Technological drivers include changes to infrastructure and technologies connected with both traditional and new ways of producing, hunting, harvesting, processing and storing food. Social drivers include changes in dietary preference, as well as shifts in the social context in which food is produced and shared, as well as the traditional knowledge used in hunting and gathering practices. Political drivers of change can include decisions that affect harvesting rights, incomes, or access to local country foods, but also decisions that influence technological, social, and economic development in more general ways. It is often relevant to analyze how various drivers of change interact.

Changing climate can affect traditional ways of preserving food



10.5 Feedbacks and thresholds

Disruptions of food supply are not new phenomena and societies have developed a number of mechanisms to respond. Within a resilience framework these can be viewed as balancing feedbacks. Examples include knowledge of alternative sources of food and water, and ways of sharing available food. For example, seasonal family fish camps that bring people together provide nutritional benefits while also supporting healthy communities through shared harvesting activities (White et al. 2007). There are also social structures that help address causes of food insecurity, such as poverty, for example financial support from the state for families with low incomes.

In the longer term, it will be increasingly important for society to understand ongoing changes in the Arctic and their associated risks, as well as to act on early warning signals for potential thresholds and other types of change. This could include recognizing the likely impacts of climate change on food supply and distribution, locally as well as globally. The capacity to understand and respond effectively relates directly to the discussion of adaptive and transformative capacity in Chapter 5 of this report. Slower feedbacks that may contribute to food security include the development of new practices and technologies to enhance the availability of and access to local food in the Arctic, in spite of long-term environmental changes that are difficult to influence.

In Arctic social-ecological systems, some feedbacks, if activated, can potentially make the situation worse by increasing the risk of threshold changes that would negatively impact on food and water security. For example, White and colleagues (2007) report that an increasing reliance on market foods that requires more time to be spent earning money, combined with high numbers of young people leaving their villages, could create a feedback that results in the erosion of traditional subsistence activities. In addition to the ecological feedbacks mentioned in Chapter 4 of this report, it is important to understand how social feedbacks, such as decisions on natural resource management, can affect social behaviour and market prices. A major task that phase two of the ARR could pursue is to thoroughly map the links and potential feedbacks in Arctic social-ecological systems that impact on food security.

Access to store-bought food is one aspect of food security. Ilulissat, Greeland 1996.

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10.6 Continued focus on food security needed

The issue of food security brings together concerns over a range of environmental, social, economic, political and cultural changes. For the ARR, a further focus on food security could place the issue in the larger context of social-ecological change that is affecting the resilience of the Arctic at local and pan-Arctic scales. In addition, a mapping effort would make the results of the resilience analysis immediately relevant for many people for whom the issue is a high political priority. A further focus on food security should involve close collaboration with current work on indicators of food and water security in the Arctic, as well as other relevant initiatives ■

References

AMAP (2009). *AMAP Assessment 2009: Human Health in the Arctic*. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

Anisimov, O. A., Vaughan, D. ., Callaghan, T. V., Furgal, C., Marchant, H., et al. (2007). Polar region (Arctic and Antarctic). *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. M. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson (eds.). Cambridge University Press, Cambridge, UK. 653–85. http://ipcc.ch/publications_and_data/ar4/wg2/en/ch15.html.

Behe, C. (2012). Building a Framework on How to Assess Food Security in the Alaskan Arctic. Abstract to the IPY Conference in Montreal, Canada 2012. http://132.246.11.198/2012-ipy/Abstracts_On_the_Web/pdf/IPY2012ARAbstract00938.pdf.

Berner, J. and Furgal, C. (2005). Human health. *Arctic Climate Impact Assessment – Scientific Report*. J. Berner, C. Symon, L. Arris, and O. W. Heal (eds.). Cambridge University Press, Cambridge, UK, and New York. 863–906. http://www.acia.uaf.edu/PDFs/ACIA_Science_Chapters_Final/ACIA_Ch15_Final.pdf.

Committee on World Food Security (2012). *Committee on World Food Security. Thirty-ninth Session. Rome, Italy, 15-20 October 2012*. Committee on World Food Security, Rome, Italy. http://www.fao.org/docrep/meeting/026/MD776E.pdf.

Evengard, B., Berner, J., Brubaker, M., Mulvad, G. and Revich, B. (2011). Climate change and water security with a focus on the Arctic. *Global Health Action*, 4(8449). DOI:10.3402/gha.v4i0.8449.

FAO (2001). *The State of Food Insecurity in the World 2001 Food Insecurity: When People Live with Hunger and Fear Starvation.food Insecurity.* Food and Agriculture Organization of the United Nations, Rome; [Great Britain]. http://site.ebrary.com/id/10018711.

Ford, J. D. and Beaumier, M. (2011). Feeding the family during times of stress: experience and determinants of food insecurity in an Inuit community. *The Geographical Journal*, 177(1). 44–61. DOI:10.1111/j.1475-4959.2010.00374.x.

Guyot, M., Dickson, C., Paci, C., Furgal, C. and Chan, H. M. (2006). Local observations of climate change and impacts on traditional food security in two northern Aboriginal communities. *International Journal of Circumpolar Health*, 65(5). 403–15.

Hild, C. M. and Stordahl, V. (2004). Human health and well-being. *Arctic Human Development Report*. N. Einarsson, J. N. Larsen, A. Nilsson, and O. R. Young (eds.). Prepared by the Stefansson Arctic Institute, under the auspices of the Icelandic Chairmanship of the Arctic Council 2002-2004, Akureyri, Iceland. 155–68. http://www.svs.is/ahdr/.

ICC Alaska (2012). Fact sheet on the study 'An Inuit perspective on food security in the Alaska Arctic: Building a framework on how to assess change in the Arctic'. http://www.iccalaska.org/servlet/content/icc_alaska_projects.html.

Kofinas, G. P., Chapin, F. S., BurnSilver, S., Schmidt, J. I., Fresco, N. L., et al. (2010). Resilience of Athabascan subsistence systems to interior Alaska's changing climate. *Canadian Journal of Forest Research*, 40(7). 1347–59. DOI:10.1139/X10-108.

Kofinas, G. P., Herman, J. S. and Meek, C. (2007). Novel Problems Require Novel Solutions: Innovation as an outcome of adaptive co-management. *Adaptive co-management: collaboration, learning, and multi-level governance*. D. R. Armitage, F. Berkes, and N. Doubleday (eds.). Sustainability and the environment. University of British Columbia Press, Vancouver, Canada. 249–467.

Millennium Ecosystem Assessment (2005). *Ecosystems and Human Well-being: Synthesis*. Island Press, Washington, DC.

Nilsson, L. M. and Evengård, B. (2013). *Food and Water Security Indicators in an Arctic Health Context*. Report by the AHHEG/SDWG and the AMAP/HHAG during the Swedish chairmanship of the Arctic Council 2011-2013. Umeå, Sweden. http://umu.diva-portal.org/smash/record.jsf?searchId=1&pid=diva2:585006.

Poppel, B., Kruse, J., Duhaime, G. and Abryutina, L. (2007). *SliCa Results*. University of Alaska Anchorage, Anchorage, AL. http://www.arcticlivingconditions.org/.

Rijsberman, F. R. (2006). Water scarcity: Fact or fiction? *Agricultural Water Management*, 80(1–3). 5–22. DOI:10.1016/j.agwat.2005.07.001.

Schuster, R. C., Wein, E. E., Dickson, C. and Chan, H. M. (2011). Importance of traditional foods for the food security of two First Nations communities in the Yukon, Canada. *International Journal of Circumpolar Health*, 70(3). DOI:10.3402/ijch.v70i3.17833.

UNEP (2011). *Ecosystems for Water and Food Security*. United Nations Environment Programme, Nairobi, Kenya. http://www.unep.org/pdf/DEPI-ECOSYSTEMS-FOOD-SECUR.pdf.

Wesche, S. D. and Chan, H. M. (2010). Adapting to the impacts of climate change on food security among Inuit in the Western Canadian Arctic. *EcoHealth*, 7(3). 361–73. DOI:10.1007/s10393-010-0344-8.

White, D. M., Craig Gerlach, S., Loring, P., Tidwell, A. C. and Chambers, M. C. (2007). Food and water security in a changing Arctic climate. *Environmental Research Letters*, 2(4). 045018. DOI:10.1088/1748-9326/2/4/045018.

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