Chapter 17

Climate Change in the Context of Multiple Stressors and Resilience

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Contents

Summary

Climate change occurs amid myriad social and natural transformations. Understanding and anticipating the consequences of climate change, therefore, requires knowledge about the interactions of climate change and other stresses and about the resilience and vulnerability of human–environment systems that experience them. Vulnerability analysis offers a way of conceptualizing interacting stresses and their implications for particular human–environment systems. This chapter presents a framework for vulnerability analysis and uses this framework to illuminate examples in Sachs Harbour, Northwest Territories, Canada; coastal Greenland; and Finnmark, Norway. These examples focus on indigenous peoples and their experiences or potential experiences with climate change, organic and metallic pollution, and changing human and societal conditions. Indigenous peoples are the focus of these studies because of their (generally) close connections to the environments in which they live and because of the coping and adaptive strategies that have, for generations, sustained indigenous peoples in the highly variable arctic environment. The Sachs Harbour and Greenland examples are cursory since vulnerability field studies in these areas have yet to be undertaken. The Finnmark example provides a more in-depth analysis of Sámi reindeer herding developed through a collaborative effort involving scientists and herders, a subset of whom are authors of this chapter. These examples reveal a number of factors (e.g., changes in snow quality, changes in ice cover, contaminant concentrations in marine mammals, regulations, resource management practices, community dynamics, and economic development) likely to be important in determining the vulnerability of arctic peoples experiencing environmental and social change. The examples also illustrate the importance of understanding (and developing place-based methods to refine this understanding) stress interactions and the characteristics of particular human–environment systems, including their adaptive capacities. Moreover, meaningful analyses of human–environment dynamics require the full participation of local people, their knowledge, perspectives, and values.

Full vulnerability assessments for communities in Sachs Harbour and coastal Greenland, require in-depth investigations into what the people living in these areas view as key concerns and how these residents perceive the interrelations among, for example, natural resources and resource use, climate change, pollution, regulations, markets, and transnational political campaigns. This information will contribute to the identification of relevant stresses and to analysis of adaptation and coping, historically, presently, and in the future. For the Finnmark case study next steps should include attaining a more complete understanding of interrelations among reindeer herding, climate change, and governance and how reindeer herders might respond to consequences arising from changes in these factors. This case study highlights a number of other areas for future and/or continued investigation. These include analysis of the possibility that governmental management authorities or herders might respond to environmental and social changes in ways that enhance or degrade the reindeer herding habitat, and a more in-depth inquiry into extreme events and their implications for sustainable reindeer herding.

A comprehensive picture of the vulnerability of arctic human–environment systems to climate change and other changes will benefit from further development of case studies, longer periods of longitudinal analysis, and more comprehensive research with interdisciplinary teams that include local peoples as full participants. Case studies should be selected to provide information across a wide array of human–environment systems and conditions so as to enable comparative work across sites. This will lead to refinements in the vulnerability framework and improved understanding of resilience and vulnerability in this rapidly changing region.

17.1. Introduction

The impact assessments in the preceding chapters demonstrate significant effects that climate change and increases in ultraviolet (UV) radiation are now having and are expected to have on arctic peoples and ecosystems. These chapters also illustrate that (1) climate change and increases in UV radiation occur amidst a number of other interacting social and environmental changes, (2) the consequences of social and environmental changes depend on the interconnectedness of human and environmental systems and the ability of these coupled systems to cope with and otherwise respond to these changes, and (3) these changes and their consequences occur within and across scales from local to regional and even global dimensions (NRC, 1999). Assessments of potential impacts of social and environmental change in the Arctic will benefit from formalized frameworks for conceptualizing and analyzing these three characteristics and their implications for the dynamics of arctic social and biophysical systems.
The fund of knowledge and learning that underpins these frameworks is based in risk–hazard and vulnerability studies, but only in recent years have these frameworks been applied in studies of arctic human and environment systems. Thus, unlike earlier chapters, this chapter does not have the benefit of a large body of published literature from which conclusions can be drawn regarding the resilience of arctic peoples and ecosystems in relation to future climate change and its interactions with other social and environmental changes.

This chapter develops the case for using a vulnerability framework to explore these interactions and ultimately to generate understanding as to where resilience, made possible through coping and adaptive strategies, could be effective in diminishing future climate change impacts in arctic coupled human–environment systems. “Coupled human–environment system” refers to the ensemble of inextricable relationships linking people and the environment within which they live. Use of the word “system” should not complicate this term, but rather it should communicate that various elements, from politics and history to the behavior of individuals and the ecology of plants and animals, form a complex whole. A vulnerability analysis that builds upon the assessment of climate impacts will consider a climate event in the context of other stresses and perturbations that together produce impacts of a compound character (Kasperson J. and Kasperson, 2001). Elements of a vulnerability approach are evident throughout preceding chapters of this assessment. The concept of vulnerability itself is noted in Chapters 1, 3, and 12, and adaptation and resilience are important themes in the overall assessment, particularly in Chapters 1, 3, 7, 11, 12, and 13.

This chapter uses the definitions of vulnerability and its elements that were adopted in the Third Assessment Report of the Intergovernmental Panel on Climate Change with vulnerability defined as the degree to which a system is susceptible to, or unable to cope with, adverse effects of stresses. Vulnerability is a function of the character, magnitude, and rate of change in stresses to which a system is exposed, its sensitivity, and its adaptive capacity. Exposure is the degree to which a system is in contact with particular stresses. Sensitivity is the degree to which a system is adversely or beneficially affected by stimuli. And adaptive capacity (or resilience) refers to a system's ability to adjust, to moderate possible harm, to realize opportunities, or to cope with consequences (IPCC, 2001b).

The presentation of vulnerability analysis in this chapter rests on three primary assumptions: (1) arctic human–environment systems are experiencing multiple and interacting stresses in addition to changes in climate and UV radiation; (2) consequences of social and environmental change depend upon how human–environment systems respond to such changes; and (3) the dynamics of changes, adaptations, and consequences span varied scales. Climate change and UV radiation increases trigger changes in ecosystems upon which arctic residents depend. For example, global warming is expected to increase net primary productivity in terrestrial and freshwater ecosystems (IPCC, 2001b; see also Chapters 7 and 8), but increased UV radiation penetration is likely to adversely affect productivity in aquatic ecosystems (AMAP, 1998). Although the Arctic is still a relatively pristine environment compared with many other areas, this region is experiencing significant problems associated with contaminants such as persistent organic pollutants (POPs) and heavy metals (AMAP, 1998, 2002). Climate change and exposure to pollutants interact, since changes in ice cover and runoff can cause lakes to become greater sinks for river-borne contaminants, and increased catchment rates and melting ice can lead to wider dispersion of pollutants. Moreover, sea-ice reductions can speed the entry of POPs trapped in Arctic Ocean ice into the food chain, posing risks to humans (AMAP, 2003; IPCC, 2001b). Linked human health effects of UV radiation, arctic diets, and pollutants have received little attention, but are plausible (De Fabo and Björn, 2000). Clearly, an assessment of arctic vulnerabilities and the adaptive capacities that can modify vulnerabilities requires a holistic understanding of multiple drivers of change and their interactions.

Examples of resilience are also illustrated in the preceding chapters of this assessment. Consequences arising from climate change and increased UV radiation depend in large part both on the interconnectedness of human–environment systems and the capacities of these systems to respond to changes (see especially Chapters 1, 3, 7, 11, 12, 13; Freeman, 2000; Stenbaek, 1987). As noted by the authors of the Mackenzie Basin Impact Study:

> *Traditional lifestyles could be at risk from climate change, but this new challenge will not occur in a vacuum. Population growth and economic and institutional changes will influence the North's sensitivities and vulnerabilities to climate variability and climate change. They will also influence how regions and countries respond to the prospects of a global scale phenomenon that could affect their climate no matter what they do on their own.* Cohen, 1997

Studies of some regional arctic seas have also considered changes in factors that will interact with climate change. One such example is the Barents Sea Impact Study, which examines the possible mobilization of contaminants on the Kola Peninsula. The success of the Barents Sea Impact Study rests on a number of factors including place-based research that addresses socio-economic factors, the inclusion of indigenous knowledge, and attention to cross-scale interactions (Lange et al., 2003).

How arctic peoples experience, respond to, and cope with environmental phenomena will be shaped to some degree by the social changes they have experienced in the past (Freeman, 2000; Stenbaek, 1987; Chapters 1, 3, 11, 12, 13). Increasingly these changes concern relationships between local and central governments (Chapter 3), ties to a global economy and external markets and ways of life (Chapters 11 and 12), campaigns relating to animal rights and environmental issues (Chapter 12), resource management systems grounded in transnational as well as domestic policy fora (Chapters 11, 12, 13), habitat loss due to urbanization, industrial development, and agriculture (Chapter 11), and extraction of nonrenewable resources (Chapters 11, 12, 16). Additional contemporary concerns of high priority for arctic peoples include poverty, domestic violence, substance abuse, inadequate housing, and substandard infrastructure (Chapters 3, 15, and 16).

Analysis of these and other changes and their implications for arctic human–environment systems must take account of dynamics at different scales. Some changes, such as those associated with climate change, for example, originate outside the Arctic, and arctic peoples contribute little to their sources. At the same time, the lives of many arctic peoples are closely interconnected with their environments through fishing, hunting, herding, and gathering (see Chapters 3 and 12). These relationships are also evolving, through, for example, technological changes, which can influence the future sustainability of arctic livelihoods. These close ties to transnational processes and intimate relationships between many arctic people and their environments underscore the importance of examining the vulnerability of particular arctic human–environment systems within the context of dynamics operating within and across local, regional, and global levels.

Social and environmental changes often yield benefits, as well as adverse effects for human–environment systems (Chapter 12). It is, therefore, appropriate to ask: in addition to the obvious desire to minimize future adverse effects of climate and other changes, in what ways might new opportunities be realized? Climate change could lead to increased vegetation growth/cover (Chapter 7), increased production of reindeer meat, new trade routes (Chapter 12), and new or intensified forms of commercial activity. Innovations in hunting equipment and practices might enable some hunters to hunt even more effectively and sustainably under snow and ice cover alterations brought about by climate change. Hunters may adapt to climate change by changing the type of species that they hunt and by altering the location, timing, and intensity of hunting. They may also take actions to minimize risk and uncertainty under unpredictable climate and ice conditions (e.g., by taking greater safety precautions or by electing not to hunt or fish) (Chapter 12).

The integrated vulnerability analysis described in this chapter begins with a general framework from Turner et al. (2003a). This framework provides a means of conceptualizing the vulnerability of coupled human–environment systems, under alterations in social and biophysical conditions arising from and interacting across global, regional, and local levels (e.g., NRC, 1999). Two examples are given where the extension of a climate impact analysis to a vulnerability analysis would be a logical next step. An example of a fully participatory exercise with a Sámi reindeer herding community in the Finnmark area of northern Norway is then used to explore aspects of vulnerability in their reindeer-herding livelihood. A full understanding of vulnerability in any of the systems examined is beyond the scope of this chapter. Such an analysis would require in-depth fieldwork and extensive participation of arctic residents (e.g., in planning and carrying out the assessment, in determining the stresses of greatest concern to them, in generating and disseminating results, etc.). The initial phase of work presented here illustrates, however, preliminary results of a conceptual and methodological approach to vulnerability analysis. These results offer insights into: the vulnerability of particular arctic human–environment systems to multiple human and environmental changes, how human and environmental conditions and behavior might attenuate or amplify these changes and their consequences, and what options exist to reduce vulnerability (see Turner et al., 2003a). Examples used in this chapter focus on the experiences and likely future prospects for indigenous communities and the environments upon which they depend. Although non-indigenous populations far outnumber indigenous peoples in the Arctic, there are a number of reasons why a focus on indigenous livelihoods is particularly suited for initial analyses of interactions between climate and other factors that can contribute to the vulnerability of arctic residents. First, analyses of vulnerability require an understanding of human–environment interactions and their historical evolution. Such connections can be complex and difficult to discern. Indigenous ways of life, however, often offer ready insights into the ways in which people depend upon and adapt to their surroundings. Many indigenous peoples, for example, have livelihoods based partly or wholly on subsistence activities that entail strong human–environment relationships that have persisted through many generations. These activities include hunting, fishing, herding, and/or gathering, and their execution requires knowledge about the highly variable arctic environment, how to interact and cope with it, and how earlier generations adapted to past changes (Krupnik and Jolly, 2002). Second, analyses of vulnerability have the greatest potential for informing decisions regarding adaptation and mitigation when there is a distinct possibility of social and environmental loss. Arguably, the potential for such loss is particularly acute in indigenous arctic communities as they encounter varied forms of environmental and social change.

Rates of climate changes projected for some regions of the Arctic exceed, however, those likely to have been experienced during multiple past human generations. Thus, the resiliencies sufficient during the past may or may not suffice in the future. Moreover, while not all forms of likely future change portend likely negative consequences, climate change, UV radiation exposure, transboundary air pollution, and economic globalization, singly and in combination have the potential to adversely affect long-standing indigenous cultural practices, livelihoods, economies, and more. It is also noteworthy that among arctic residents a much larger body of literature is available on the resilience of indigenous peoples' livelihoods in response to climate change and in the context of multiple stressors.

The prospect of climate change in the Arctic has now begun to seriously influence planning in this region. Over an even shorter period researchers have begun to explore the degree to which likely future climate change will interact with other factors in the broader realm of human–environment interactions. At this early stage in the development of methodologies to quantitatively assess the vulnerability of different aspects of the human–environment system, studies of indigenous arctic communities are timely. Studies of indigenous peoples in other areas can now provide a common context within which to test characterizations of human–environment systems and their interactions, and to advance integrative data collection and analytical methodologies. Notable among these approaches is the absolute necessity of co-generating knowledge of exposures, sensitivities, and resiliencies inherent in these systems by involving indigenous peoples at the earliest stages of research planning and analysis.

Analyses of indigenous communities can also yield insights into the lives and livelihoods of non-indigenous arctic residents. However, without the same degree of historical and cultural ties to localities and ways of life, and with greater freedom to relocate, perhaps to an area outside the Arctic, non-indigenous residents will be vulnerable to likely future change in the Arctic in different ways. Eventually, suites of case studies focused on indigenous peoples and non-indigenous peoples and their environments will form useful comparative analyses from which questions regarding comparative resiliencies and ultimately their relative vulnerabilities can be assessed.

17.2. Conceptual approaches to vulnerability assessments

Large-scale studies of climate impacts have begun to examine the vulnerability of social and ecological systems to climate change. The seminal work of Timmerman (1981) provided intellectual underpinning for linking the concepts of vulnerability, resilience, and climate change. Examples of recent projects that incorporate these perspectives include the IPCC (particularly the contribution of Working Group II to the Third Scientific Assessment; IPCC 2001b), the Assessments of Impacts of and Adaptation to Climate Change in Multiple Regions and Sectors (AIACC) implemented by the United Nations Environment Programme, the Finnish global change research projects FIGARE and SILMU, the European Commission project on Tundra Degradation in the Russian Arctic (TUNDRA), the Norwegian project NORKLIMA, the US National Assessment of Climate Change Impacts on the United States (NAST, 2000), and the Regional Vulnerability Assessment (ReVA) Program under the United States Environmental Protection Agency (Smith, 2000). Some of these assessments were based on published research, and as such are limited in their completeness with respect to their spatial coverage, and especially to their inclusiveness of other stressors that can interact with climate to influence the vulnerability of human–environment systems. Other assessments are underway, and the surge in vulnerability research over the last few years will ensure that future climate impact assessments are more complete with respect to interactions with other stressors.

Vulnerability analysis is rooted in a long history (e.g., Cutter, 1996; Dow, 1992; Downing, 1992; Kates, 1971; Liverman, 1990; Turner et al., 2003a; White, 1974), and in research traditions (for recent reviews see Cutter, 1996; Golding, 2001; Kasperson J. et al., 2003; Polsky et al., 2003; Turner et al., 2003a) that encompass work on risk–hazards–disasters (Blaikie et al., 1994; Cutter, 1996), climate impacts (Cutter, 2001; IPCC, 1997; Kates et al., 1985; Parry 1978; Parry et al., 1998), food security (Böhle et al., 1994; Downing, 1991; Easterling, 1996), national security (Bachler, 1998; Dabelko and Simmons, 1997; Gilmartin et al., 1996; Homer-Dixon and Blitt, 1998; Winnefield and Morris, 1994), and resilience (Berkes and Folke, 1998; Berkes et al., 2003; Turner et al., 2003a). Much of the applied hazards, climate impact, and food security research to date has focused on the source of and potential exposure to a hazard, and has sought to understand the magnitude, duration, and frequency of this hazard and the sensitivity of the exposed system (Burton et al., 1978; Cutter, 1996).

It is common to distinguish between impacts and vulnerability perspectives by saying that the former focuses more on system sensitivities and stops short of specifying whether or not a given combination of stress and sensitivity will result in an effective adaptation. The latter emphasizes the factors that constrain or enable a coupled human–environment system to adapt to a stress. Another distinction that has been drawn between climate impact and vulnerability assessments is that the former proceeds by examining a climate event and the stresses that are exerted upon an exposure unit to produce critical downstream outcomes. The latter, by contrast, considers the climate event in the context of other stresses and perturbations that together produce impacts from compound events (Vogel as quoted in Kasperson J. and Kasperson 2001).

These distinctions are, however, to some degree oversimplifications, since a lack of emphasis on adaptation applies more to past empirical studies of climate change impacts than to the conceptual underpinnings of such studies. Adaptation has long been at the heart of the debate on reducing vulnerability to environmental stresses (Turner et al., 2003a). Even the early models on climate change impacts (e.g., Kates et al., 1985) consider the importance of adaptation, and the same applies to the broader, related literature on risk/hazards (e.g., Burton et al., 1978; Cutter, 1996; Kasperson R. et al., 1988) and food security (e.g., Böhle et al., 1994; Downing, 1991). Parry and Carter (1998) also acknowledge the seminal ideas of Kates (1985) on this topic and go on to discuss the evolution from a climate impact approach to a climate interaction approach. They describe how the severe economic hardship experienced by Canadian prairie farmers in the 1930s arose as a result of interaction among multiple factors. "Economics, weather and farming technology interacted to create a severe economic and social impact that was perhaps preconditioned by the Depression but triggered by drought."

Thus, increasing interest in "global change vulnerability" is not so much the result of a revolution in ideas – although the theoretical bases are maturing (e.g., Adger and Kelly, 1999) – but more a response to a general dissatisfaction with the ways in which adaptive capacity has been captured in empirical research and the associated need to reconnect with this concept if climate impact and global change models are to improve.

Increasingly, studies of vulnerability go beyond understanding the behavior of a stress and the degree to which an exposed system reacts adversely or beneficially (Holling, 1996, 2001). These studies also investigate (1) ways in which the exposed system might respond to, intensify, and/or ameliorate the effects of multiple stresses; and (2) why the same hazard might affect different systems in different ways and what system characteristics (including political economy, social structures and institutions) help to explain this variation. The concept of resilience in ecological studies has also informed treatment of adaptive capacity in vulnerability assessment (Resilience Alliance, no date; Walker et al., 2002). Resilience generally refers to the ability of a system to return to a reference state or remain within a range of desirable states following a perturbation. Berkes and Jolly (2001) have pointed out that the concept of resilience has three defining characteristics. It is a measure of: the amount of change the system can experience and still retain the same controls on function and structure; the degree to which the system is capable of self-organization; and the systems' ability to sustain and increase its capacity for adaptation.

Similarly, adaptive capacity refers to ecosystem flexibility and social system responsiveness in the face of disturbances (Turner et al., 2003a). According to one line of thought in political ecology, for example, adaptive capacity derives from human ecology of production, entitlements pertaining to market exchanges, and political economy (Böhle et al., 1994). These factors depend, for example, on resources available to a social group, the ability to sell these resources, the selling price, and access to markets (Sen, 1981). In addition, social, institutional, and political conditions might affect the ability of a social system to utilize resources or make other adjustments in overcoming the effects of a disaster such as drought (Turner et al., 2003a). Initiatives such as the Management of Social Transformations Programme's Circumpolar Coping Processes Project (MOST CCPP) advances understanding of human responses to environmental and other forms of change. MOST CCPP is a cross-disciplinary network comprising participants from Norway, Finland, northwest Russia, Denmark, Faroe Islands, Greenland, Iceland, Canada, and Sweden. This project is a comparative research endeavor that examines ways in which local authorities, civil society actors, and enterprise networks cope locally and regionally with global technological, economic, and environmental changes.

Researchers are also increasingly attentive to the socio-ecological, multi-scalar, and dynamic nature of vulnerability. Studies aimed at understanding the vulnerability of particular places are forgoing the tendency to treat social and biophysical vulnerability as separate conditions (e.g., see Adger and Kelly, 1999; Kelly and Adger, 2000). They are instead examining the vulnerability of the coupled human–environment system with place-based approaches (Cutter, 1996; Turner et al., 2003a) (also see Berkes and Folke, 1998; Berkes et al., 2003). In addition, conditions and phenomena spanning global, national, and local levels can have important implications for the vulnerability of specific people and areas. For example, the globalization of markets, technological innovations originating abroad, changes in national policy, and the condition of local infrastructure could all potentially increase or decrease the vulnerability of a particular household or community to drought or flood (Leichenko and O'Brien, 2002). The ever-changing character of biogeophysical, environmental, institutional, economic, and political processes that influence human–environment systems requires that vulnerability be treated as a process (Handmer et al., 1999; Leichenko and O'Brien, 2002; Reilly and Schimmelpfenning, 1999). In its simplest static state vulnerability can be seen as the residual of change after considering the resilience and adaptive capacity of a system. However, the dynamic nature of these processes requires that vulnerability also be considered as an integral part of the change rather than external to it.

17.2.1. A framework for analyzing vulnerability

Building on this history, the combined effects of climate and other stressors can be examined via the following questions:

1. How do social and biophysical conditions of human–environment systems in the Arctic influence the resilience of these systems when they are impacted by climate and other stressors?
2. How can the coupled condition of these systems be suitably characterized for analysis within a vulnerability framework?
3. To what stresses and combinations of stresses are coupled human–environment systems in the Arctic most vulnerable?
4. To what degree can mitigation and enhanced adaptation at local, regional, national, and global scales reduce vulnerabilities in these systems?

Answers to these questions require a holistic research approach that addresses the interconnected and multi-scale character of natural and social systems. A framework for this approach (Fig. 17.1) depicts a cross-scale, coupled human–environment system. The multiple and linked scales in each diagram are reflected in the nesting of different colors with blue (place), pink (region), and green (world). The place (whatever its spatial dimensions) contains the coupled human–environment system whose vulnerability is being investigated. Figure 17.2 presents a more detailed schematic of the place. The influences (including stresses) acting on the place arise from outside and inside its borders. However, given the complexity and possible non-linearity of these influences, their precise character (e.g., kind, magnitude, and sequence) is commonly specific to the place-based system. This system has certain attributes denoted as human and environmental conditions. These conditions can interact with one another and can enable or inhibit certain responses in, for example, the form of coping, adaptation, and impacts. Negative impacts at various scales result when stresses or perturbations exceed the ability of the place-based human–environment system to cope or respond. There are a number of feedbacks and interactions within and around the place-based system and these dynamics can extend across place-based, regional, and global levels. Impacts and mitigating and adaptive responses, for example, can modify societal conditions of the place and/or alter societal and environmental influences within the place and at regional and global scales.

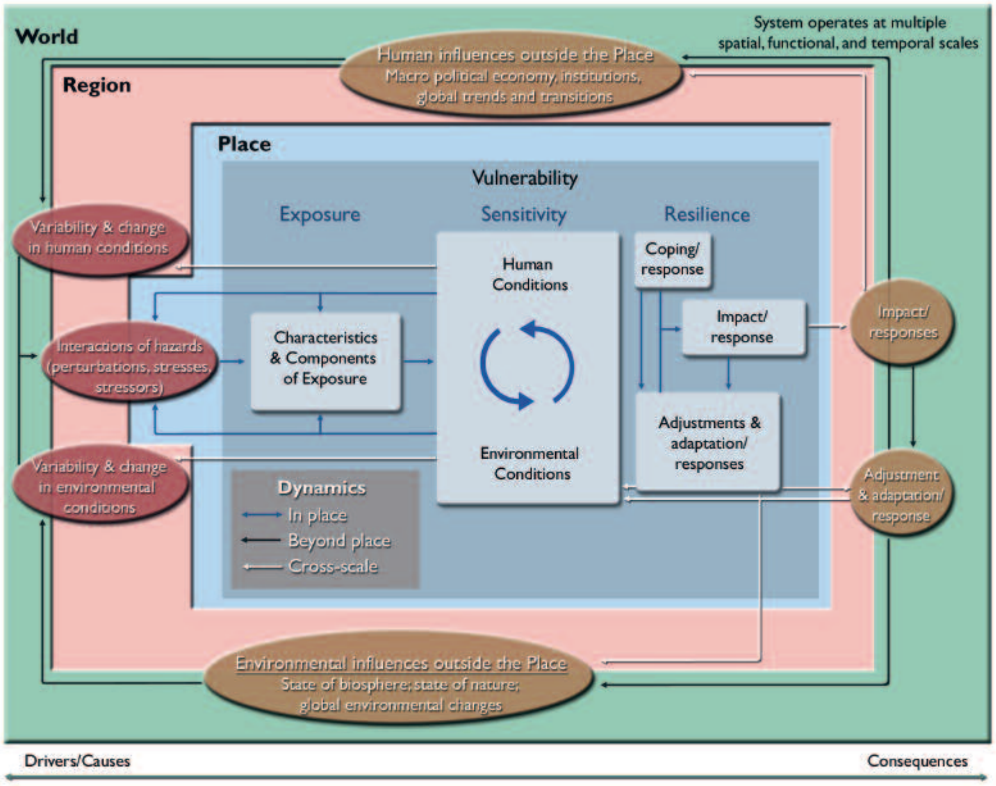

Fig. 17.1. Vulnerability framework (Turner et al., 2003a).

The vulnerability of the coupled human–environment system can be thought of as the potential for this system to experience adverse impacts, taking into consideration the system's resilience. Adverse impacts might arise from phenomena such as climate change, pollution, and social change. The system's resilience depends on its ability to counter sources of adverse change and to adapt to and otherwise cope with their consequences. It is important to note differences between mitigation and adaptation. Mitigation involves the amelioration of a stress at its source (e.g., changes in fossil fuel consumption resulting in reduced greenhouse gas (GHG) emissions). While the Arctic is experiencing the effects of climate change, actions to mitigate climate change through GHG reductions are largely dependent on the actions of people living at more southern latitudes. Adaptation (e.g., through mobility, new hunting or fishing practices, and/or the development or adoption of new technologies) requires that resources and other forms of capacity be accessible to the human–environment system in question. Such resources and capacity can take years, even generations to develop.

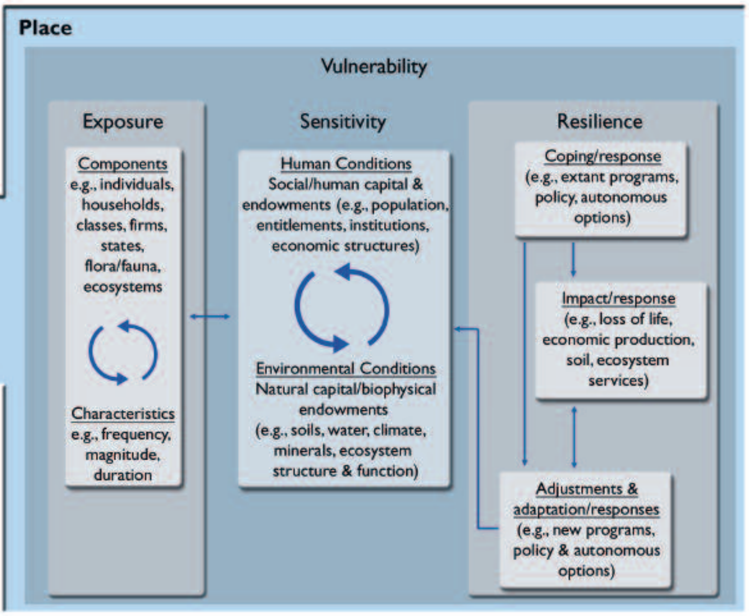

Fig. 17.2. Details of the exposure, sensitivity, and resilience components of the vulnerability framework (Turner et al., 2003a).

17.2.2. Focusing on interactive changes and stresses in the Arctic

The Arctic is experiencing a number of striking social and environmental changes and influences. While some are welcome, others (considered stresses) have adverse consequences. Given that vulnerability is highly complex and can vary significantly with location, it is essential to conduct "place-based" analyses, where "place-based" suggests a spatially continuous set of human–environment conditions or systems (Turner et al., 2003a). Since the vulnerability of a system is closely connected to the particular social and environmental conditions at a given location, the priorities and perspectives of people living in the location and those of other stakeholders are essential for identifying the key stresses, and understanding the exposure, sensitivity, and resilience of their coupled human–environment system (see section 17.3.4). Thus, knowledge, values, and understanding held by local residents are integral in determining which factors are most likely to test resilience of a system. Recent research on coupled human–environment systems (Turner et al., 2003a,b) demonstrates the efficacy of a participatory approach. The Sachs Harbour and Finnmark examples discussed in this chapter similarly evidence the importance of collaborating with local people and other stakeholders.

Preliminary consultations with arctic researchers and residents led the authors of this chapter to consider environmental pollution (POPs and heavy metals) and trends in human and societal conditions in addition to climate change and variability and UV radiation as potential stressors in arctic human–environment systems. The case for climate change is central to the Arctic Climate Impact Assessment, and so needs only a brief review in this section. Changes in UV radiation also receive considerable attention in the ACIA, but rather less is known about how possible harmful effects will be distributed in the Arctic. So little can be done at this time to assess vulnerability to this potential stress either in isolation or in combination with other factors. The comprehensive nature of the Arctic Monitoring and Assessment Programme (AMAP) studies allow much more to be said about organic and metal pollution as a potential stress in arctic systems, so more attention is given to pollution in this section.

It is important to note that, although they are often referred to here as stresses, climate change and trends in human and societal conditions can have positive as well as negative effects. Changes in climate and climate variability refer to changes in temperature, precipitation, snow cover, permafrost, sea ice, and extreme weather events. Major POPs include DDT (Dichlorodiphenyltrichloroethane), PCBs (polychlorinated biphenyls), HCH (hexachlorocyclohexane), and major heavy metals include lead (Pb), cadmium (Cd), and mercury (Hg) (AMAP, 1998, 2002). Human and societal trends of interest are consumption (especially pertaining to foodstuffs and technology), settlement patterns and demography, governance and regulation (particularly regarding natural renewable resources), connectivity (e.g., telephones, email, Internet), and markets and trade (Turner et al., 2003b) (see also Beach, 2000; Bjerregaard, 1995; Caulfield, 1997, 2000; Kuhnlein and Chan, 2000; Macdonald et al., 2003; Stenbaek, 1987; Svensson, 1987a,b; Wheelersburg, 1987). More in-depth fieldwork and analysis might reveal additional high priority stresses important for these sites.

17.2.2.1. Trends in human and societal conditions

Arctic peoples have experienced significant social changes over the past few human generations (Freeman, 2000; Stenbaek, 1987) as the Arctic's borders have become more permeable to southerners, material goods, and ways of thinking; as indigenous peoples have asserted their identity, rights, and culture in legal and policy forums; and as new relationships have formed between local and national governments. The Arctic Council's Arctic Human Development Report (AHDR, 2004), especially its chapters on sustainable human development and economies is a logical and welcome next step in a synthesis of understanding in this area. Technology has been an important part of many such transformations. Satellites, television, the Internet, and telephones, for example, have revolutionized communication. Snowmobiles, all terrain vehicles, and more powerful small boats have brought new modes of transportation and recreation while accompanying changes in some hunting, herding, and fishing practices. The modernization of hunting equipment has also contributed to changes in approaches to whaling and marine mammal hunting. Individuals often have differing views about what types of social changes are beneficial and what types are unwanted. Some arctic residents, for example, might support the use of snowmobile technology in reindeer herding, while others might oppose it. Similarly, some people might view certain forms of human and societal change as adversely stressing a human–environment system, while others might view these changes as enhancing the resilience of that system. In seeking to understand how such changes bear on the vulnerability of arctic communities, this chapter examines a variety of human and societal factors including governance, population dynamics, migration, consumption, economies, markets and trade, and connectivity. These represent only a small subset of topics that constitute human and societal conditions. In some instances these factors are considered influences or stresses on the system (e.g., regulations limiting flexibility in reindeer herding). In other instances these factors can serve as both influences and part of the system's adaptive and coping responses (e.g., migration and changes in consumption).

17.2.2.2. Climate change

Projections of future climate change in the Arctic are documented in Chapter 4. Temperatures are projected to increase throughout the Arctic, even in sub-regions that have shown slight cooling trends in the latter half of the 20th century. Summer sea ice in the Arctic Ocean is projected to continue to decrease in area and thickness. The active layer of permafrost is projected to continue to deepen. Seasonal weather and precipitation patterns are likely to change, altering forms of precipitation between rain, freezing rain, and snow, and affecting snow quality. Recent evidence indicates that many of these changes are already affecting the distribution and abundances of terrestrial and marine species (see Chapters 7, 8, 9). Changes in temperature, precipitation, and storm patterns can affect the type, abundance, and location of animals and plants available to humans and may lessen the productivity of certain traditional forms of hunting and gathering. Decreases in the extent and thickness of sea ice can alter the distribution, age structure, and size of marine mammal populations, expose the arctic coast to more severe weather events, exacerbate coastal erosion, and affect modes of transportation and the ability of people to reach hunting locations and other villages. Changes in surface water budgets and wetlands can change coastal microclimates, alter the size and structure of peatlands, and result in pond drainage. In addition, damp, wet air during the traditional "drying season" makes it difficult to dry and preserve foods for winter months. These changes would, in turn, result in effects felt not only in human communities in the Arctic, but in other areas of the world as well (IPCC, 2001b).

17.2.2.3. UV radiation

Continued ozone depletion and the related problems of UV radiation exposure are likely to result in serious human and ecosystem impacts (Cahill and Weatherhead, 2001). UV radiation can harm humans directly via sunburn and skin cancer, immune system suppression, and eye damage, such as cataract photokeratitis (AMAP, 1998; De Fabo and Björn, 2000). The synergistic effects of UV radiation, climate change, and pollution could be more intense than the effects of any one of these stresses acting alone. For example, aquatic organisms that have assimilated UV-B absorbing polyaromatic hydrocarbons have shown phototoxic effects when exposed to UV-B radiation. Exposure to UV radiation has also been found to increase the toxicity of some chemicals, especially those associated with oil spills (Cahill and Weatherhead, 2001).

Adverse effects of UV radiation on arctic plants and animals can also indirectly affect humans. The vulnerability of arctic ecosystems to UV radiation is greatest in spring when ozone depletion is at its maximum and when new organisms are beginning life. Arctic plants have fewer protective pigments and are more sensitive to UV radiation than similar plants in other regions of the world, partly because at low temperatures plants are less able to repair UV radiation damage (AMAP, 1998; De Fabo and Björn, 2000).

Wildlife can experience UV radiation effects similar to those found in humans, although fur and plumage mean skin effects are less likely than eye damage (De Fabo and Björn, 2000). Increased UV radiation may affect fisheries through changes in planktonic food webs, but these changes are difficult to predict because they involve long-term alterations in species adaptation and community structure. If UV radiation were to change arctic aquatic ecosystems, this could in turn affect seabirds and land predators (e.g., seals, foxes, and bears) that feed on aquatic organisms (AMAP, 1998).

17.2.2.4. Pollution

AMAP concluded in both of its two recent assessments that pollution can pose problems in the Arctic (AMAP, 1998, 2002). Heavy metals and POPs are of particular concern, although there are important regional and local variations within the Arctic. Both heavy metals and POPs are transported to the Arctic via long-range air and water pathways and both bioaccumulate in food webs (see Fig. 17.3) (AMAP, 2002; Wania and Mackay, 1996). In addition to long-range transport, some pollutants originate from local sources such as the geology, industrial activities, pesticide use, and private use.

Heavy metals and POPs are associated with several environmental risks. These include estrogenic effects, disruption of endocrine functions, impairments of immune system functions, functional and physiological effects on reproduction capabilities, and reduced survival and growth of offspring (AMAP, 1998, 2002; UNECE, 1994). Data on human health effects suggest that human exposure to levels of POPs and heavy metals found in some traditional foods may cause adverse health effects, particularly during early development (AMAP, 2003; Ayotte et al., 1995; Colborn et al., 1996; Hild, 1995; Kuhnlein and Chan, 2000).

Traditional foods also provide health benefits, however, which need to be weighed against risks (see section 17.2.3.3). Many traditional foods are rich in vitamins and nutrients and low in saturated fats. Whale skin and blubber, for example, are a good source of vitamins A and C, thiamin, riboflavin, and niacin. They are also low in saturated fats and high in omega-3 polyunsaturated fatty acids that guard against cardiovascular diseases. Additional health benefits arise from the physical activity required to obtain traditional foods. Moreover, traditional harvesting, processing, and sharing of traditional foods serve important roles in the social, cultural, and economic life of many arctic inhabitants (AMAP, 2003; Freeman et al., 1998). In communities where contaminant levels are sufficiently high to prompt health concerns, balanced dietary advice is needed, especially for pregnant women and small children. Risk–benefit discussions have been most productive when they involve local communities, local public health authorities, and experts from a wide array of disciplines (AMAP, 2002, 2003).

Persistent organic pollutants that require special attention in arctic vulnerability studies include the industrial chemicals PCBs; the pesticide DDT; and the pesticide HCH, the most common form of which, γ-HCH, is the insecticide Lindane. These are well-known arctic pollutants of concern (AMAP, 1998, 2002) that are currently being addressed by national legislation and international agreements (Downie et al. 2004; Eckley, 2001; Selin, 2003; Selin and Eckley, 2003).

Many other POPs are known to be hazardous, as well as possibly other, lesser known organic substances that may have negative impacts. For example, levels of the flame-retardants polybrominated diphenyl ethers (PBDEs), polychlorinated naphthalenes (PCNs), and the pesticide endosulfan are increasingly found in the Arctic. Levels of PBDEs are increasing in the Canadian Arctic (AMAP, 2002; Ikonomou et al., 2002). Ikonomou et al. (2002) suggested that at current rates of bioaccumulation, PBDEs will surpass PCBs to become the most prevalent contaminant in ringed seals (*Phoca hispida*) in the Canadian Arctic by 2050.

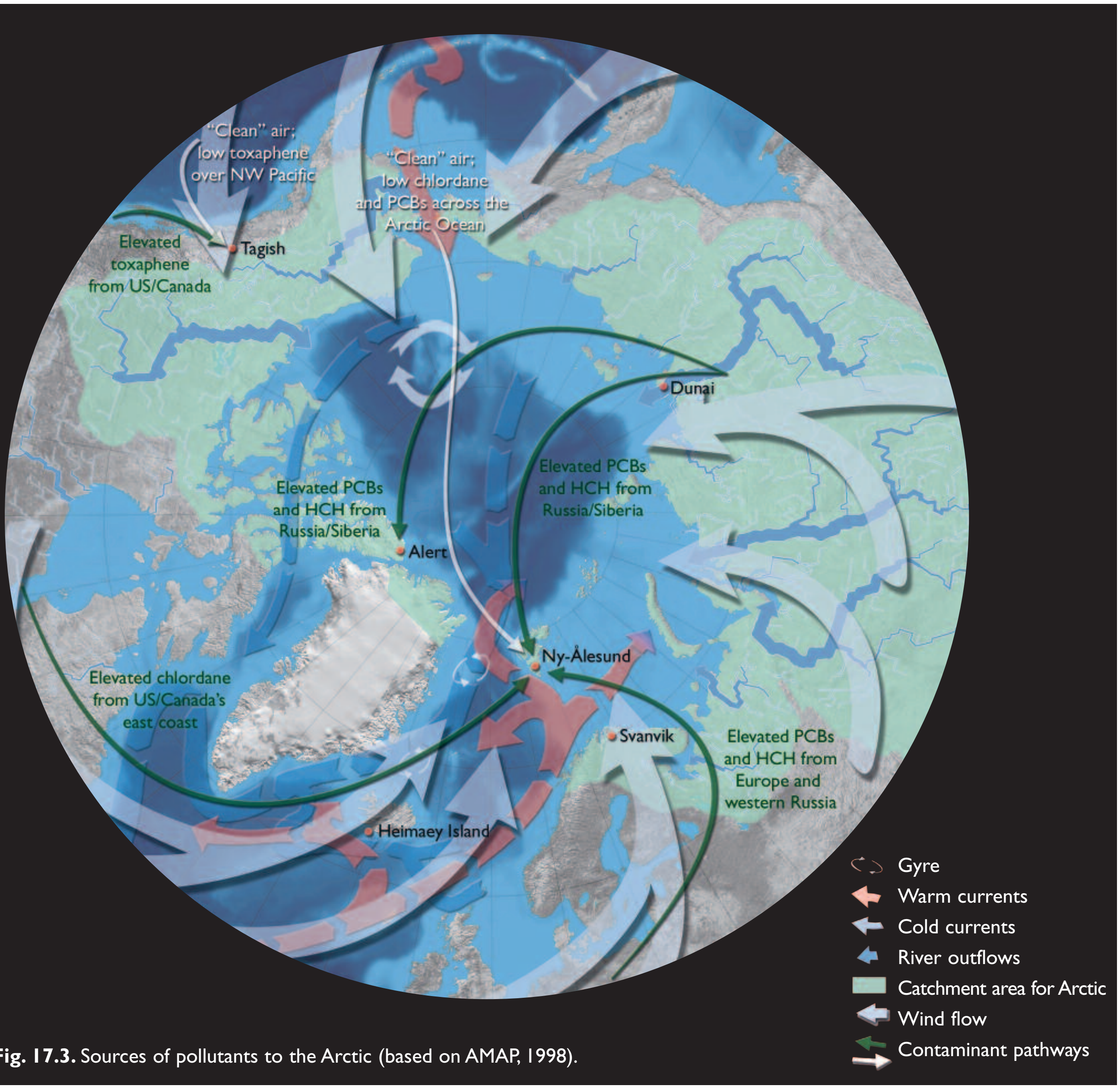

Fig. 17.3. Sources of pollutants to the Arctic (based on AMAP, 1998).

For heavy metals, special attention should be given to Cd, Pb, and Hg. The rationale for selecting these heavy metals is similar to the rationale for selecting the POPs; they are well known arctic pollutants that have been subject to much previous study (AMAP, 1998, 2002). They are also being addressed by national legislation and regional international agreements. Heavy metals are naturally-occurring environmental trace elements, and many are essential elements for living organisms. However, some have no known metabolic roles, and some are toxic even at low exposures. In the last 150 years there have been changes in the form in which these metals are released and dramatic increases in the quantity of these metals emitted to the environment. Anthropogenic emissions have altered the natural biogeochemical cycles of these elements (Nriagu, 1996). Anthropogenic sources of heavy metal pollution include industrial production, combustion processes, and waste incineration. These anthropogenic inputs add to the natural background levels and can pose a toxic risk to environmental and human health (AMAP, 2002).

17.2.2.5. Pollutant interactions

Climate change, pollution, and human and societal conditions are interrelated and the consequences of these phenomena will depend largely on their interactions. It is becoming increasingly clear, for example, that climate change and pollution interact closely and that climate changes can affect the pollution transport chain (Alcamo et al., 2002). Air current changes affect pollutant transport patterns. Temperature changes affect which pollutants are deposited where, how they migrate, and which animals accumulate which pollutants. More extensive melting of multi-year sea ice and glacial ice can result in pulse releases of pollutants that were captured in the ice over multiple years or decades (AMAP, 2002; Macdonald et al., 2003).

Recently discovered mercury depletion events (MDEs) in the high Arctic (Schroeder et al., 1998) reflect additional ways in which pollution interacts with other factors. Levels of gaseous elemental mercury drop sharply each spring following polar sunrise, in a series of events that begin shortly after the first sunrise and continue until the snow melts. These MDEs are highly correlated with depletions in surface ozone, and appear to be caused by a reaction involving sunlight and bromine. The gaseous elemental mercury is transformed into reactive gaseous mercury, which is quickly deposited and can potentially enter food webs in a bioavailable form. Because MDEs occur at a time when biological productivity is increasing, the interactions between pollutant transport pathways, solar radiation, and climate can be extremely important (Lindberg et al., 2002; Lu et al., 2001). It is still unclear to what extent changes in climate and pollutant pathways may affect these events (AMAP, 2002).

Anthropogenic climate change and pollution are the products of societal activity and their consequences depend heavily on human and societal conditions. The effects of pollutants on human health are determined, in part, by regulations governing the use and disposal of hazardous chemicals, policies and public health guidance regarding human intake of potentially contaminated foods, public perceptions of and responses to such guidance, how much pollutant-contaminated food people ingest, cultural attitudes toward various types of food, and what access people have to these various foods.

17.2.3. Identifying coping and adaptation strategies

The Arctic has been inhabited by many diverse groups of people for several thousand years. Each group has its own distinct history, culture, language, and economic system. Despite the cultural and economic diversity found among arctic indigenous peoples, they have, through time, adapted to a number of similar conditions, such as a challenging and highly variable environment generally unsuited for most agriculture, severe climatic conditions, extended winter darkness, changes in wildlife populations, great expanses between settlements, and sparse populations (Chapter 3). The varied livelihoods of arctic indigenous peoples are examples of such adaptation. Reindeer herding in Finnmark and Russia, and fishing, sealing, and whaling in Greenland, Canada, Russia, and Alaska reflect the ability of arctic peoples to utilize and innovate with available resources, and to anticipate environmental and social changes in ways that enable people to take advantage of opportunities and guard against adverse effects.

Colonization has been another important source of change for arctic peoples. Prior to European contact, arctic indigenous peoples lived primarily in small settlements, and those dependent on terrestrial versus marine resources led nomadic lifestyles in order to follow the animals they relied upon for their livelihoods. Historically, their cultures, identities, social organizations, and economies centered on these livelihoods, which represent successful adaptations to local environments. More recently, however, all arctic indigenous peoples, have, to greater or lesser extent, been colonized by outsiders interested in extracting and profiting from the Arctic's resources. In addition to centuries of European and Asian settlement, arctic indigenous peoples have also encountered missionaries and traders and, more recently social, economic, environmental, and political impacts and changes brought about by globalization (Freeman, 2000). In response, many indigenous peoples have developed mixed cash–subsistence economies. Yet, despite a number of challenges, these people continue to keep alive their traditional ways of life and in recent decades have acquired considerable authority in matters of governance. Arctic peoples have shown a remarkable resilience to extreme environmental conditions and profound societal change. At the same time, cultural change could reduce the adaptive capacity of arctic peoples (Chapter 3).

Adaptive responses to environmental changes are multidimensional. They include adjustments in hunting, herding, fishing, and gathering practices as well as alterations in emotional, cultural, and spiritual life. Arctic peoples change their hunting and herding grounds, become more selective about the quality of the fish they ingest, and build new partnerships between federal governments and indigenous peoples' governments and organizations. Adaptation can involve changing personal relationships between people and the weather and new forms of language and communication developed in response to novel environmental phenomena. Changes in knowledge and uses of knowledge can also constitute forms of adaptation. Altered weather prediction techniques are an example (Chapter 3).

In this chapter the term "adaptation" is used broadly, but in some instances it requires refinement. In their discussion on the term "adaptive" Berkes and Jolly (2001) apply terminology long used in anthropology (McCay, 1997) and the development literature (Davies, 1993), to distinguish between coping mechanisms and adaptive strategies. Coping responses are the ensemble of short-term responses to potential impacts that can be successfully applied season-to-season or year-to-year as needed to protect a resource, livelihood, etc. Some forms of coping are explicitly anticipatory and take the form of, for example, insurance schemes and emergency preparedness. Adaptive responses refer to the ways individuals, households, and communities change their productive activities and modify their rules and institutions to minimize risk to their resources and livelihoods. Depending on the frequency, duration, and suddenness in the onset of a stress, and on the resilience of a system, either coping or adaptive responses or both will come into play. With a progression of change in climatic conditions, coping mechanisms may at some point be overwhelmed, and by necessity supplanted by adaptive responses.

17.2.3.1. Governance, regulations, and subsistence

A number of changes in governance and regulation are transforming arctic governments and their relationships with the rest of the world. Since the early 1970s, authority has devolved from central governments to local and regional governing bodies in places like Greenland, Alaska's North Slope Borough, and northern Quebec's Nunavik region (Young, 2000). But while indigenous peoples in these communities have gained control over local affairs, external regulations have had considerable bearing on local ways of life. Seal harvest protests in Europe and the United States have affected seal hunting livelihoods in Greenland (e.g., Hovelsrud-Broda, 1997, 1999). Recently, proposals have been made to the International Whaling Commission (IWC) to deny the aboriginal subsistence hunters in Alaska and Chukotka in Russia a quota for bowhead whales (*Balaena mysticetus*). And Sámi reindeer herders must defend their practices against claims by others that they are allowing overgrazing (Beach, 2000).

For a long time, east–west tensions and core–periphery relationships (e.g., between Greenland and Copenhagen) kept arctic relations with the rest of the world connecting, for the most part, along north–south lines. Since the 1980s, however, arctic countries have become more open to pan-arctic cooperation with, for example, the thawing of the Cold War and the growing recognition of indigenous peoples' rights (Young, 1998a). Cooperative alliances include the Arctic Council, the Inuit Circumpolar Conference, and the North Atlantic Marine Mammal Commission. The Arctic Environmental Protection Strategy (AEPS), which provided a basis for the Arctic Council, was a pan-arctic initiative begun in 1991 when the eight arctic states signed the Declaration on the Protection of the Arctic Environment. A primary purpose of AEPS was a better understanding of environmental threats through a cooperative approach to these threats (Young, 1998a). There is also an increasing effort to link arctic initiatives with global regimes such as the Convention on Biological Diversity, the UN Framework Convention on Climate Change, ozone agreements, pollution-related agreements and initiatives, and the International Labour Organisation Convention 169 concerning Indigenous and Tribal Peoples in Independent Countries (Young, 2000).

Several factors are likely to characterize arctic international relations of the future. These include a greater role for non-state actors (especially indigenous peoples and environmental groups) in arctic affairs and a focus on sustainable development as a policy goal that means different things to different people. However, the future shape of environmental institutional arrangements (e.g., geographically broad with a narrow focus on an environmental program, or geographically limited, but encompassing a wide range of environmental issues) remains to be seen (Young, 1998a).

17.2.3.2. Settlements, population, and migration

Over the past decades indigenous populations in Greenland, Finnmark, and elsewhere have tended to migrate to towns and larger settlements. These movements have generally resulted in mixed economies where individuals are more likely to engage in wage labor and supplement their cash incomes with the sale of subsistence products. While these mixed economies can perpetuate traditional systems of land use and allow the use of cash to support household hunting and fishing (Caulfield, 1997), the diets of people who migrate from smaller settlements to larger towns tend to contain significantly less marine mammal and fish (Pars, 1997).

Indigenous peoples throughout the Arctic have often coped with and adapted to change via migration. Certain types of migration, however, can pose problems. People in general have responded to changes in animal populations and movements by altering their own locations and movement patterns and by varying the types of species hunted. Migration to towns might also serve as an adaptive strategy if, for example, economic trends, regulations and/or the effects of climate change and pollution make hunting or fishing in settlements impractical or unproductive. The movement of Greenlanders to permanent towns and settlements over recent decades restricted the ability of hunters to follow animals on their seasonal migrations, introduced more Greenlanders to wage labor, and helped to catalyze the indigenous political movement that culminated in Home Rule. Alternatively, certain economic conditions, regulatory policies, and/or the stresses of urban life could conceivably prompt people to move from towns to settlements. This type of coping through mobility is evident in Greenland over the past thirty years as the size, composition, and distribution of Greenland's population during this period has varied with changes in policies, economics, and educational and occupational opportunities.

Migration and settlement practices have also had implications for governance. Danish government policy encouraging a growth in town populations led many Greenlanders to concentrate in towns and major settlements in the 1960s. Migration from rural to more urban areas was part of Danish modernization programs of the 1950s and 1960s. These programs, for example, shut down a number of small settlements so that their inhabitants could work in fish-processing plants located in larger towns. Many Greenlanders were not in favor of these activities, believing that they were detrimental to Greenlandic culture and practices. Greenlandic resistance to forced migrations and other modernization initiatives eventually contributed to the establishment of Home Rule (Caulfield, 2000).

17.2.3.3. Consumption

Access to new foods and technologies have accompanied changes in diet and livelihood practices, respectively, and mark important ways in which consumption patterns are part of changing arctic lifestyles. The diets of indigenous peoples are changing as they use smaller amounts of traditional foods, and rely more on commercially available products and imports. These changes have implications for culture and health as traditional foods are closely tied to indigenous identity and offer significant nutritional benefits (Kuhnlein and Chan, 2000). A decrease in traditional foods combined with an increase in western foods in the diet of indigenous peoples increases the rate of western diseases such as heart disease. Examples of technological change include snowmobile use which has accompanied changes in transportation, hunting, trapping and fishing, and recreation and tourism among the Sámi in Norway (Muga, 1987). In addition, imported modern hunting equipment has made whaling and marine mammal hunting activities, in general, safer and more efficient in Alaska, Greenland, and Canada.

17.2.3.4. Economies, markets, and trade

Mixed economies based on wage labor and on subsistence activities are increasingly prevalent in arctic indigenous communities (Chapter 3) and broader trade and growing access to markets have innumerable implications for arctic indigenous peoples. Easier access to world markets continues to provide arctic inhabitants with increasingly better access to new material goods and new sources of income. At the same time, growing arctic-based businesses (e.g., tourism, see Chapter 12) can be sensitive to fluctuations in the distant economies to which they connect. An important question is whether, and if so how, this type of economic diversification affects resilience of local household and community economies.

17.2.3.5. Connectivity

A particular way in which technology is part of transformations in the Arctic is via the provision of new means of communication such as television, Internet, and telephones. The Anik satellites in Canada, for example, have been instrumental in exposing Inuit to outside cultures and in providing these peoples with a tool for asserting their own identity and culture (Stenbaek, 1987).

17.3. Methods and models for vulnerability analysis

A successful vulnerability assessment is one that prepares specific communities for the effects of likely future change. A vulnerability assessment should: draw upon a varied and flexible knowledge base; focus on a "place-based" study area; address multiple and interacting stresses; allow for differential adaptive capacity; and be both prospective and historical (Polsky et al., 2003). Data and methodologies to support such an assessment vary widely and any given vulnerability study is likely to involve a variety of quantitative and qualitative forms of data and methodological techniques. Interviews with "key informants" and surveys (Kelly and Adger, 2000) have been employed to obtain data on transience, immigration and education levels, income, education, age, family structure (Clark et al., 1998), literacy, infant mortality, and life expectancy (Downing et al., 2001). Floodplain maps are important in analyzing the vulnerability of communities to extreme storm events (Clark et al., 1998). Agricultural vulnerability analyses often require information about extent of land degradation, crop type, soil moisture, runoff, and groundwater (Downing et al., 2001). As described by Cutter (1996) analytical techniques can include historical narratives, contextual analyses, case studies, statistical analyses and GIS approaches, mapping, factor analysis and data envelopment analysis, and vulnerability index development (see also Downing et al., 2001). Thus, what is novel about vulnerability assessments is not the individual techniques used to explore specific parts of a coupled human–environment system, but the integration of these techniques across varied intellectual domains.

A framework, such as that proposed by Turner et al. (2003a) enables at least two approaches for investigating vulnerability (see Fig. 17.1). One approach is to begin with knowledge about stresses and trace them through to consequences, while another is to begin with consequences and trace these back to stresses. It is also possible to work in both directions in an iterative fashion to yield a more comprehensive analysis. Figure 17.4 presents a research approach that allows for iterative analysis, in which (reading from left to right) information about stresses and their interactions are used both to develop scenarios and to project impacts. Impact projections can be used in conjunction with interviews, focus groups, workshops, and other means for engaging residents of the place of interest to explore coping strategies and adaptive capacities of a human–environment system. Knowledge of impacts and adaptive capacity can then be used to characterize site-specific vulnerabilities. Proceeding from consequences to stresses (right to left), researchers can work with residents of a particular locale to identify consequences experienced within a coupled human–environment system and then trace them back to identify the specific nature of the stresses.

Application of a framework to understand vulnerabilities within a coupled human–environment system requires different types of knowledge, as well as tools from a wide range of disciplines and from local and indigenous sources. For example, vulnerability analysis in the form presented here requires integration of natural science, social science, indigenous and local knowledge, cooperation among researchers and people who are part of the coupled human–environment system under study, and reliance on diverse techniques such as interviews, participant observation, focus groups, climate modeling, and climate downscaling. A proper vulnerability analysis will engage (1) a number of scientific disciplines (ecology, biology, climate and global change research, meteorology, social anthropology, sociology, political and policy science, economics, geography, ocean sciences, physiology and veterinary science, and environmental chemistry) and (2) local people with significant knowledge of their environment, of relevant

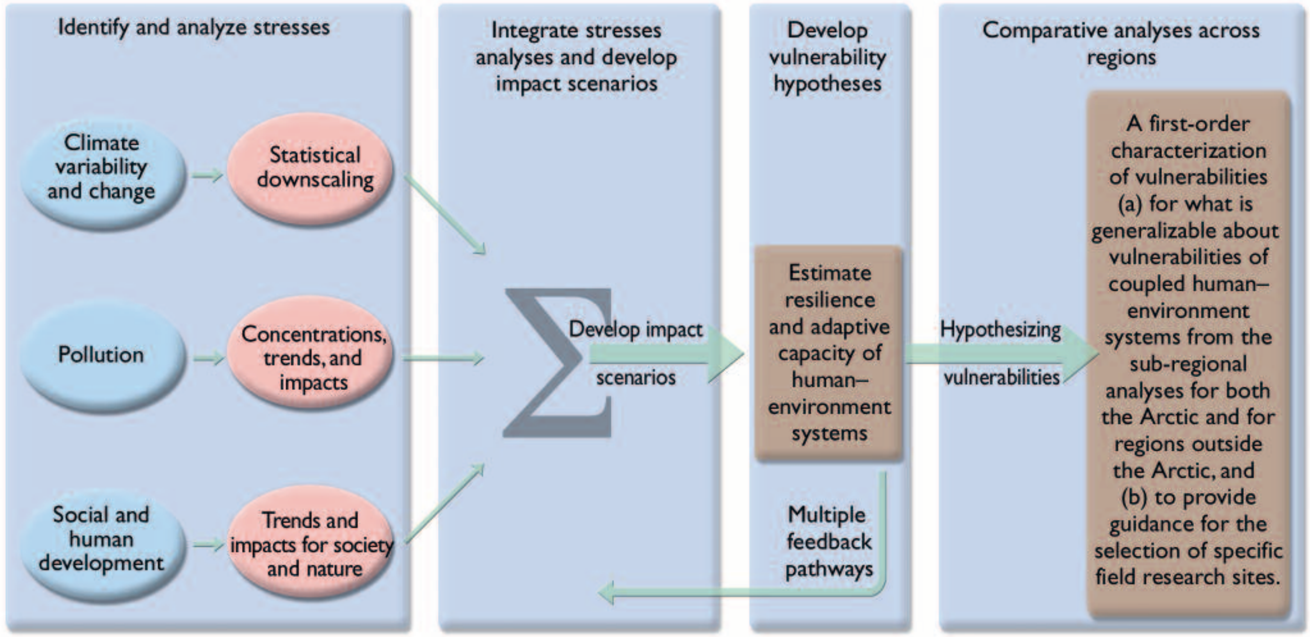

Fig. 17.4. Methodological framework.

social, political, and economic factors, and of human–environment interactions concerning, for example, hunting, herding, gathering, processing, and production. The success of a vulnerability assessment depends on the success of partnerships among various groups of stakeholders (Polsky et al., 2003).

17.3.1. Climate scenarios and downscaling to specific sites

An active area of climate change research is the translation of atmosphere–ocean general circulation model (AOGCM) projections calculated at large spatial scales to smaller spatial scales, a process termed "downscaling". In this way, selected study sites can be provided with customized climate projections.
There are two principal approaches for downscaling: dynamical downscaling (also known as regional climate models) and statistical downscaling (also known as empirical downscaling). As described in Chapter 4, there are advantages and disadvantages to each approach. While both generate similar results for current climate, they have been known to generate different projections for future climates.

Greenhouse gas emissions scenarios used to drive the AOGCMs are based on projections of economic activity. In turn, the projected economic activity is a function of anticipated changes in global population, technology, and trends in international trade. As a result, each of the 40 scenarios used by the IPCC can be characterized by its anticipated trajectories of population, economy, environment, equity, technology, and globalization (IPCC, 2001a). It is impossible to assign likelihoods to these or any other GHG emissions scenario. Thus the IPCC emissions scenarios are individually equally plausible, but collectively represent only a subset of the possible futures.

Current arctic climate projections are limited in their utility for vulnerability analyses for two main reasons. First, the AOGCMs that produce these projections do not capture all important features of regional climate. For example, local ocean and atmospheric circulation patterns, and topographic relief are not well represented in AOGCMs. These factors often play a decisive role in determining local climate in the Arctic. As a result, additional analytical techniques are needed to produce local-scale climate projections. Chapter 4 reviews the various methods available for this task.

Second, for downscaling results to contribute to successful vulnerability assessments, local people must be involved in the planning and analysis of downscaling studies (Polsky et al., 2003). Otherwise, the downscaled climate projections may not reflect the climate factors relevant for decision-making to enable arctic residents to adapt or employ mitigation strategies.
For example, one of the climate variables of concern for reindeer herders in northern Norway is snow quality. Too much snow hinders reindeer mobility and restricts their access to food on the ground, especially when the snow contains enough ice to mask the smell of the food. Too little snow, by contrast, makes it difficult for the herders to contain the reindeer (no restrictions on mobility) and to track the animals when they stray (no snow tracks). For these and other reasons, the Sámi employ many words to describe snow quality, as it relates to timing, amount, consistency, bearing, surface, trees, thawing, patches, accessibility, and other aspects (Ruong, 1967). The point here is that the way climate matters for any particular activity is specific to that activity. Thus a downscaled projection of, for example, mean monthly surface temperature may not be sufficient (or even necessary) information for contributing to the process of social adaptation to the effects of climate change for any group of arctic people.

Likelihoods of extreme conditions are difficult attributes to derive with confidence from climate scenarios, especially at the local scale, and this is the scale of most interest in assessing vulnerabilities in human–environment systems. As Smithers and Smit (1997) pointed out, "frequency, duration, and suddenness" of climatic events influence the character of successful adaptation strategies. Higher frequency of a potentially harmful event will heighten decision-makers' awareness of risk associated with a class of climate events. Greater duration of a climate event could inflict a correspondingly greater impact, or alternatively allow for more adaptation than would be possible with a shorter duration but otherwise similar event. Rapid onset of a particular climate event or condition, whether a specific flood or myriad aspects of the broader syndrome of climate change, will be much more limiting with respect to adaptation options than slowly rising water or very gradual climate change. Scales of social and political organization are important, since they reflect inertia in the response or adaptive capabilities of a human–environment system (Berkes and Jolly, 2001). Future projections of arctic climate change models (see Chapter 4) do not yet systematically resolve details in climate extremes that will be useful for assessing changes in frequency, duration, and suddenness of most climate events. Within the last few years, however, some progress has been made with ensemble simulations, especially for precipitation (Palmer and Räisänen, 2002).

17.3.2. Measurement and methodology for pollutant analyses

Data on POPs and heavy metal pollution and impacts for many arctic locations are now available. Although analytical methodology has advanced significantly for both since the late 1970s, some older and more recent data can be difficult to compare. For example, early PCB studies reported concentrations relative to industrial mixtures (e.g., Aroclor). Current studies report PCBs as a sum of individual congeners. In addition, levels of POPs and metals in biota may differ dramatically depending on the species sampled, the part of the individual animal from which the sample was taken, and the age and sex of the sampled individual. Shifts in diet can also affect exposure. Few studies have monitored the same species at the same site over a long timescale, a procedure necessary for making reliable comments on trends. Heavy metals pose an additional challenge for measurement and assessment because they are derived from both anthropogenic and natural sources. It is not always possible to determine whether a given concentration measured in biota originated from a natural or an anthropogenic source (Muir et al., 1999). In the last few years, the assessment and standardization efforts implemented by AMAP have dramatically improved knowledge of the pollutant situation in the Arctic. The data used here for analyzing interactions with multiple stresses and for identifying vulnerabilities draw heavily on the latest AMAP assessment (AMAP, 2002).

17.3.3. Analysis of human and societal trends

Data on trends in human and societal conditions can be obtained from published and unpublished institutional and governmental databases (e.g., Statistics Greenland) and from research in fields such as anthropology, sociology, political science, economics, and native studies. An in-depth analysis of human and societal trends requires a wide array of data sources, extensive statistical analysis, and knowledge shared and generated through interactions between researchers and arctic residents. Such an analysis might draw upon economic data pertaining to markets operating at various scales, employment, retail transactions, trade, imports, exports, and the processing and sale of natural and other resources. Public health information can also form an important part of human and societal trends analyses with information about contaminant levels in food and humans, diseases, and health care. Census data can provide information about general demographics, education, family structure, employment, and migration patterns. Election data can be useful in revealing trends in governance and the implementation and enforcement of regulations and policies emanating from transnational, national, and subnational decision-making bodies. Archives and other documentation that track negotiations and participation within such bodies are also useful. Surveys and interviews with local people are essential in ascertaining the views of individuals with, for example, respect to dietary practices, consumption patterns, values, and priorities.

17.3.4. Sources of local knowledge and stakeholders as participants

The vulnerability of a coupled human–environment system will be perceived differently across cultures, age groups, economic sectors, etc. A reindeer herder will most likely define the vulnerability of his/her human–environment system differently than would an outsider assessing the same system. There may also be diverging opinions within a community. There may well be a range of different perspectives on what constitutes a vulnerable condition and it is essential to recognize and address these perspectives in carrying out a vulnerability analysis. Evaluation of the exposure, sensitivity, and adaptive capacity of a coupled human–environment system will require the knowledge, observation, and participation of people who are part of the system. These people can, for example, identify important stresses, human–environment interactions, and outcomes that they seek to avoid. They can also identify changes in the human–environment system, describe coping and adaptive capacities, monitor environmental and social phenomena, and communicate research findings. The involvement of local people in research design, implementation, and the dissemination of research results should, therefore, be a central aspect of any comprehensive vulnerability study.

Participatory research has become increasingly common in arctic research on socio-ecological changes, as evident throughout this assessment and a number of other projects e.g., SnowChange (Mustonen, 2002), Scannet (Scannet, no date), the Mackenzie Basin Impact Study (Cohen, 1997), Voices from the Bay (McDonald et al., 1997), and Inuit Observations on Climate Change (IISD, 2001). Participatory research follows from a long tradition. From the time people in the "South" began to take an interest in the high latitudes, indigenous peoples of northern regions have often had a role to play in arctic research and exploration. Early anthropologists and archaeologists frequently used indigenous peoples as guides, laborers, informants, and/or interpreters (e.g., Boas, 1888; Rasmussen, 1908; Stefansson, 1941), as did arctic seamen and explorers (Peary, 1907). Since those days, indigenous peoples have continued to work with visiting researchers and explorers. Throughout, there have been a variety of reports on the positive and negative outcomes of these interactions and relationships (e.g., Harbsmeier, 2002). However, despite the many ways in which arctic indigenous peoples have contributed to arctic research, often there has been little mention of their role or acknowledgement of their efforts (Brewster, 1997).

The way outside researchers worked with indigenous peoples changed considerably in the mid-1980s. Coinciding with the settlement of land claims, the emergence of co-management regimes, and the ascendancy of indigenous peoples' power and influence in formal decision-making processes (Kuhn and Duerden, 1996), indigenous knowledge became a topic of interest for many researchers who worked in the Arctic. It was centered around a few key themes: documentation of indigenous knowledge about various aspects of the environment (Ferguson and Messier, 1997; Fox, 2004; Huntington and the communities of Buckland, 1999; Jolly et al., 2003; Kilabuck, 1998; McDonald et al., 1997; Mymrin and the communities of Novoe Chaplino, 1999; Reidlinger and Berkes, 2001); the increasing use of cooperative approaches to wildlife and environmental management (Berkes, 1998, 1999; Freeman and Carbyn, 1988; Huntington, 1992; Pinkerton, 1989; Usher, 2000); environmental impact assessment (Stevenson, 1996a); and collaborative research between scientists and indigenous peoples (Huntington, 2000; Krupnik and Jolly, 2002). This last theme has particular relevance for vulnerability studies. A brief literature review on the development of collaborative and participatory research in the Arctic follows.

Early efforts to involve arctic indigenous peoples in research and land management began with much discussion on the validity and utility of indigenous knowledge. Researchers who had worked with indigenous peoples for some time recognized that indigenous knowledge could reveal valuable information that could augment scientific understanding about many aspects of environment and ecology. Further, some researchers were beginning to recognize that indigenous knowledge holders needed to participate in the research process themselves (e.g., Wenzel, 1984). Seminal edited volumes on northern indigenous knowledge, e.g., Johnson M. (1992) and Inglis (1993) use case studies from the Arctic to present a number of perspectives on the validity and utility of this knowledge. The case studies illustrate that indigenous knowledge can make a key contribution to resource management and sustainability. Arguing for the inclusion of indigenous peoples in research and decision making, several case studies present examples of how these initiatives were needed, or underway, in a variety of settings. For example Eythorsson (1993) explained why the knowledge of Sámi fishermen in northern Norway is integral to successful resource management there and Usher (1993) discussed some of the successes of the Beverly-Kaminuriak Caribou Management Board, one of the earliest examples of wildlife co-management in North America.

As interest in indigenous knowledge in the Arctic picked up through the 1990s, many people continued to focus on promoting the validity and utility of indigenous knowledge and the need to integrate it into research and management. However, critiques began to surface that questioned the methods behind the "integration", as well as the intentions. Bielawski (1996) examined interactions between scientists and indigenous land users involved in co-management systems and noted that, although co-management is supposed to combine scientific and indigenous expertise, the model and process for co-management is not integrative at all, but scientific and bureaucratic. Usher (2000) echoed this when stating that although indigenous knowledge (also called TEK, "traditional ecological knowledge") is required to be incorporated into Canadian resource management and environmental assessments there is little understanding of what TEK is and how to implement it in policy. This confusion was especially visible during 1996 when a senior policy advisor with the Northwest Territories (NWT) government wrote an article claiming that the inclusion of indigenous knowledge in environmental assessments not only hinders the scientific process, but is against the constitutional rights of Canadian citizens since indigenous knowledge is based on spiritual beliefs, not facts (Howard and Widdowson, 1996). The article created a heated debate (see Berkes and Henley, 1997; Stevenson, 1996b) and caused both researchers and managers to look more closely at the reasons and methods for incorporating indigenous knowledge into research and policy. As shown by Usher (2000), these reasons and methods remained unclear until the end of the 1990s. In 1999, others such as Nadasdy (1999) still believed that indigenous knowledge and the engagement of indigenous peoples in research were not taken seriously and were merely paid lip-service for political reasons. Nadasdy (2003) called for a more critical look at "successful" co-management efforts and the political, as well as methodological obstacles, to the integration of indigenous knowledge.

By 2000, a number of indigenous knowledge projects in the Canadian Arctic and Alaska had made advances in participatory methods for working with arctic communities (Krupnik and Jolly, 2002). For example the Tuktu (caribou) and Nogak (calves) Project (Thorpe et al., 2001, 2002), which documented Inuit knowledge of Bathurst caribou and calving grounds in the Kitikmeot region of Nunavut from 1996 to 2001, established a local advisory board for the project and relied on trained local researchers to help with interviews and data analysis. Fox (1998, 2004), who has a long-term project with Nunavut communities regarding Inuit knowledge of climate and environmental change, has used an iterative approach to community work, incorporating community input and feedback in research methods. Jolly et al. (2002) also used an iterative approach over a one-year project in Sachs Harbour, NWT to collect Inuvialuit observations of climate change. In the Sachs Harbour project, scientific experts worked one-on-one with local experts to understand a variety of phenomena and community workshops were held to establish common goals for the research and to clarify information. A number of other projects and management systems have incorporated participatory approaches with much success in recent years (Huntington, 1998, 2000; Kofinas and the communities of Aklavik, 2002; Krupnik and Jolly, 2002). Common to many of these projects are some aspects of participatory research in the Arctic that have emerged as key including time, trust, communication, and meaningful goals and results. Many of these projects span multiple years, where researchers and community members form friendships and fruitful working relationships. In several projects, results were produced in forms that the community could use and found interesting. For example, the Tuktu and Nogak Project produced a community-directed book (Thorpe et al., 2001). Fox (2003) developed an interactive multi-media CD ROM and an Inuktitut book for participants, and the Sachs Harbour project created a documentary film (IISD, 2000).

Indigenous peoples themselves are also making an impact on participatory research in the Arctic. Many arctic communities and organizations are reaching out to scientists and decision-makers to set research priorities and form partnerships for investigations (Fenge, 2001).

17.4. Understanding and assessing vulnerabilities through case studies

Comparative vulnerability assessments at continental scales (IPCC, 2001b) can reveal regional differences in the vulnerability of human–environment systems. The differences reflect, for example, geographically uneven rates of climate change projected in regional climate scenarios and broad regional distinctions in the capacity of individuals and institutions to cope with and adapt to change.

The Third Scientific Assessment of the IPCC ascertained the following as likely projections for the Arctic using the IPCC scenarios for climate change (Anisimov and Fitzharris, 2001):

> *The Arctic is extremely vulnerable to climate change, and major ecological, sociological, and economic impacts are expected.*
>
> *Habitat loss [will occur] for some species, and apex consumers – with their low-reproductive outputs – are vulnerable to changes in the long polar marine food chains.*
>
> *Adaptation to climate change in natural polar ecosystems is likely to occur through migration and changing species assemblages but the details of these effects are unknown.*
>
> *Loss of sea-ice in the Arctic will provide increased opportunities for new sea routes, fishing and new settlements, but also for wider dispersal of pollutants.*
>
> *Although most indigenous peoples are highly resilient, the combined impacts of climate change and globalization create new and unexpected challenges. Because their livelihood and economy increasingly are tied to distant markets, they will be affected not only by climate change in the Arctic but also by other changes elsewhere. Local adjustments in harvest strategies and in allocation of labor and capital will be necessary. Perhaps the greatest threat of all is to maintenance of self-esteem, social cohesion, and cultural identity of communities.*

This chapter builds upon more general climate change vulnerability analyses by placing climate in the context of other factors that can enhance or diminish vulnerability of arctic systems to future climate change.
In order to ensure that such an analysis realistically characterizes the perspectives of the people who will be making decisions to apply coping and adaptive strategies to increase resilience, and hence minimize vulnerability, a vulnerability analysis must focus on a particular place. The dynamic character of vulnerability requires that the human–environment system be represented on a scale that is meaningful to individual decision-makers.

Sections 17.4.1.1 and 17.4.1.2 provide examples for which a vulnerability assessment would be tractable, revealing, and ultimately useful to residents of the Arctic who will be making decisions in relation to future change. The first example (see section 17.4.1.1) is drawn from a case study on the Sachs Harbour community, NWT, Canada. This case study is one of several such cases presented in Chapters 3, 11, and 12 for which a vulnerability analysis would be illuminating. The study of Sachs Harbour, however, is particularly well suited because its design and development fully engaged the residents of this community, while detailing the ways in which local people and other stakeholders view, experience, and respond to climate change. The community has a mixed economy, with strong historical dependence on fish and wildlife, and lies in a region of the Arctic that experiences high rates of climate change. However, at this time it is not possible to go beyond the work that has already been conducted with respect to recent and likely future climate change. Without a new phase of research that fully involves the Inuvialuit people of Sachs Harbour, their resilience in accommodating interactive future impacts of changes in climate and other stressors cannot be assessed. A primary purpose of the description in section 17.4.1.1 is to signal the importance of the next phase in such an assessment in this community.

The second example (see section 17.4.1.2) focuses on the coastal communities of Greenland. These communities are attractive potential sites for vulnerability analysis because of their historical documentation of their strong dependence on marine living resource use, including fishing, sealing, and whaling for subsistence and income, and in particular their growing knowledge of the amounts of pollutants in the local marine food webs. In addition the governance of Greenland is evolving, and its institutions will continue to play important roles in shaping coping and adaptive capacities for Greenlanders. Research on this human–environment system is at a very early stage. In order to proceed, residents knowledgeable about the roles of past and likely future climate in local livelihood activities must be engaged.

Furthermore, assessing climate change in the context of multiple stresses and resilience in both Sachs Harbour and coastal Greenland will require scenarios, i.e., a range of plausible futures. These scenarios should reflect the combined effects of likely future changes in climate, in other environmental factors that could affect livelihoods (e.g., natural resources), and in human and societal conditions that influence resilience and coping strategies.

A third example (see section 17.4.2) focuses on reindeer populations and reindeer herding in Finnmark, Norway. Reindeer herding by Sámi takes place well inland in winter and on the coast and nearby islands in summer. This practice involves management of grazing grounds in both locations and migration of the herds between them in spring and autumn. The long history of these practices during periods of past climate change and the increasing role of governmental regulation raises interesting questions about the vulnerability of this system. Sámi reindeer herding represents a tightly coupled human–environment system in which indigenous peoples interact closely with an ecosystem upon which they depend for their way of life.

Two additional factors support the inclusion of the Finnmark case study. A vulnerability assessment has recently been conducted for Norway (O'Brien et al., 2004). It aptly demonstrates that the arctic region of Norway will be more vulnerable to climate change than more southern regions, and the importance of selecting the appropriate scale of analysis in vulnerability assessments. Secondly, work to date with the Sámi reindeer herding community in Finnmark offers an excellent example of the co-generation of knowledge involving academic scientists and indigenous peoples. A research effort is now underway to ascertain the resilience of this system to future change in climate and other factors, and the preliminary findings from this study are discussed below.

These three communities and livelihoods are not intended to be representative of the Arctic as a whole. They have been selected because they present examples of tightly coupled human–environment systems in which indigenous peoples interact closely with local ecosystems and rely upon these ecosystems to support their ways of life. Yet, they also span different geographic settings, environmental conditions, governance systems, and socio-ecological dynamics. For example, neither Sámi reindeer herders nor reindeer herding itself are "typical" of anything beyond themselves. The system of which they form a part possesses unique ecological, sociological, and ethnological features. Therefore, the system represents a useful site in which to examine the plasticity and adaptability of a generalized methodological framework for vulnerability studies.

In each of these cases there lies potential to test concepts and methodologies described in this chapter and to present information about stresses, sensitivity, and resilience within the coupled human–environment system. Other examples could have been developed by building upon material presented in Chapters 3 and 12. For example, the Dene Nation, NWT, Canada, and the Yamal Nenets of Northwest Siberia. The Dene case study (Chapter 3) is of interest because of the success of the Dene in forming the Denendeh Environmental Working Group. The Dene culture emphasizes interconnectedness among all aspects of the environment, and this working group is observing, documenting, and communicating information related to climate change. However, there is not much information available to judge what factors in addition to climate change are contributing to the vulnerability and resilience of the Dene at this time, and the detailed content of their working group reports are not yet publicly available. The Yamal Nenets case study (Chapter 12) is of interest because it focuses, like the Finnmark study, on a reindeer herding livelihood with a history of adaptive management during times of change. The Yamal Nenet situation differs from that of the Finnmark herders in that the Yamal Nenets are experiencing stresses relating to oil and gas extraction, and might in the future experience stresses related to Northern Sea Route coastal development made possible by climate change. Krupnik (2000) and Krupnik and Jolly (2002) suggest that these other stresses may be straining the resilience of a livelihood that has sustained Nenet people for centuries. Although a comparative analysis of the Yamal and the Finnmark cases would certainly be instructive it is premature given the preliminary character of research on each of these at this time.

17.4.1. Candidate vulnerability case studies

The following are preliminary findings from the two sites for which assessments of climate change in the context of multiple stresses and resilience would be particularly timely. Knowledge about what makes a system either vulnerable to or resilient to change can be used to minimize risks and damage and to capitalize on opportunities. Regional scenarios for climate and other changes and field research conducted with the full participation of inhabitants of Sachs Harbour and coastal Greenland will be needed to develop an assessment of climate impacts and other changes beyond these initial findings.

17.4.1.1. Sachs Harbour

Berkes and Jolly (2001) have identified three reasons why the Arctic is a highly appropriate region in which to address questions relating to human adaptations to climate change. First, people living in the Arctic, particularly indigenous peoples with subsistence livelihoods, have historically experienced a high degree of climate variability, and their ability to adapt to varying climate, from seasonal to interannual, is part of their culture. Second, as is well documented in earlier chapters, the rate of climate change recently experienced in the Arctic, and likely to continue over the next several decades, may be exceeding the range of experience and hence capacity of arctic peoples to adapt. Third, there is a growing body of participatory research, with topics ranging from wildlife co-management to the use of traditional knowledge in environmental assessments (Berkes et al., 2001). The focus of the analysis by Berkes and Jolly (2001) is a Canadian Arctic community, Sachs Harbour, on Banks Island, NWT.

Sachs Harbour, a community of 150 Inuvialuit hunters and trappers was the subject of a two-year study (1999–2001) by the Canadian International Institute for Sustainable Development (Ashford and Castledown, 2001). This area is known to have been inhabited episodically, beginning with Pre-Dorset peoples over 3500 years ago. Traditional livelihoods (hunting, trapping, fishing) continue to thrive, and increasingly tourism, including guiding and the sale of arts and crafts, contributes to the local economy. The study became widely known through the distribution of an educational video, and several research papers (Ford, 2000; Fox et al., 2001; Riedlinger, 2000).

The report on this study describes a community at a crossroads. Climate has changed in recent decades and traditional ways of predicting weather are no longer reliable. Within the last few decades the later dates for autumn freeze-up, earlier dates for spring thaw, thinner winter ice, diminished extent of multi-year sea ice, thawing permafrost, and increased coastal erosion have altered abundances of and accessibility to fish and wildlife. The people of Sachs Harbour wonder whether they can maintain their traditional ways of life if these trends continue.

Berkes and Jolly (2001) analyzed the adaptive capacity of this community, considering a continuum of near-term coping responses to longer term cultural and ecological adaptations. Given the high degree of natural climate variability in the Arctic, coping strategies have always been essential for the success of indigenous peoples' livelihoods. These strategies include adjusting the timing of activities and switching between fished and hunted species to minimize risk and uncertainty in harvest. Waiting is also a coping strategy. "People wait for the geese to arrive, for the land to dry, for the weather to improve, or for the rain to end". But as annual climate cycles become more and more unfamiliar, new strategies are necessary. With changes in snow and ice cover, permafrost conditions, and coastal erosion, modes of transportation need to change. Greater unpredictability in weather also requires a greater caution for those who travel on ice. Coping with changes in harvest has in some regards become easier as alternatives to traditional diets have become more available with the growing reach of market economies.

Longer term adaptive responses that are considered central to the long-term success of indigenous peoples in the Arctic are categorized as follows: (1) mobility and flexibility in terms of group size; (2) flexibility with regard to seasonal cycles of harvest and resource use, backed up by oral traditions to provide group memory; (3) detailed local environmental knowledge and related skill sets; (4) sharing mechanisms and social networks to provide mutual support and minimize risks; and (5) intercommunity trade (Berkes and Jolly, 2001). The authors go on to suggest that the first response, mobility and group size, became much less relevant following the settlement of Inuit in permanent villages several decades ago. However, the remaining four responses have continuing potential to offer some adaptive capacity to deal with future climate change.

But will these time-proven strategies be sufficient for a future where factors in addition to climate change become increasingly important in this human–environment system? Are there other adaptive responses that need to be examined? Increasing dependence on cash economies and industries such as tourism raise new questions about the sustainability and overall vulnerability of this system.

The co-generation of knowledge in the IISD study, which fully involved the Inuvialuit people of Sachs Harbour, sets the stage for discussions about vulnerabilities in this location. However, in addition to participatory research methods to support the collaboration of researchers and local peoples, there are also institutional arrangements in this region that can facilitate the assessment of vulnerability in the context of multiple stresses, including climate change, pollution, and economic change. Over the last two decades co-management bodies have arisen that provide individual Inuit communities with formal mechanisms to interact with regional, territorial, and federal government institutions. These bodies provide greater local flexibility and response capacity in dealing with local uncertainties such as climate change (Berkes and Jolly, 2001). Moreover, they facilitate self-organization and learning across levels of organization, thus enhancing feedbacks across the levels. A community like Sachs Harbour can improve its understanding of risks and vulnerabilities and therefore better prepare itself for the future by examining possible effects of and responses to climate change in a historical perspective and within the context of other forms of social and environmental transformation.

17.4.1.2. Greenland

Communities in Greenland (and other similar communities elsewhere in the Arctic) that rely heavily on living natural resources, such as marine resources, might utilize vulnerability analysis in anticipating and planning for future social and environmental changes. Many such communities have a mixed subsistence/cash economy that involves a combination of commercial fishing, wage employment, and small-scale hunting and fishing activities. Commercial fishing (for shrimp, Greenland halibut (*Reinhardtius hippoglossoides*) and other species) is dominant in terms of monetary return. The residents of these communities and the environments with which they interact are affected by many factors including governance and market dynamics spanning local to global contexts, as well as climate and pollution. Recent decades have witnessed significant changes in these variables and the future may hold even more pronounced alterations. A vulnerability analysis could be useful for residents, other stakeholders, and decision-makers in identifying which social and environmental influences warrant their concern, the potentially advantageous or adverse consequences of these factors, and how human–environment systems could respond.

Climate change could have important consequences for Greenland's human–environment systems. Recent statistically downscaled temperature scenario results based on the Max Planck Institute climate model ECHAM4/OPYC3 for Greenland project a warming trend for the period 1990 to 2050 of 1.3 to 1.6 °C for West Greenland and around 0.4 °C for East Greenland (Førland et al., 2004). In West Greenland such a trend is likely to have significant implications for sea-ice cover, for ice-dependent marine mammal species such as the ringed seal, and for hunting and fishing activities that require secure ice cover.

Pollution is another factor that could bear on the vulnerability and resilience of Greenland's human–environment systems. Although no clear effects on human health are presently observed in Greenland, the occurrence of POPs and heavy metals in traditional foods is identified by some researchers as an important environmental threat to human health (AMAP, 2003; Bjerregaard, 1995). Health concerns have been expressed in particular for pregnant women and small children (AMAP, 2003). Greenlandic residents have in general a high consumption of marine mammals and fish and are exposed to POPs mainly through their marine diet. Data indicate that levels of some POPs in biota in Greenland have decreased over the past 20 years, although it is difficult to compare earlier and more recent data for methodological reasons (Frombert et al., 1999). Given international and national policies regarding these compounds, it is reasonable to expect that environmental levels of DDT, PCBs, and HCH in Greenland will decline toward 2020 (Macdonald et al., 2003). In contrast, PBDE levels are increasing in some parts of the Arctic (AMAP, 2002). Data since the mid-1990s reveal that the estimated average human intake of both Hg and Cd from local marine food continues to greatly exceed the FAO/WHO limits (Johansen et al., 2000). The study that produced these data involved surveys in two towns and two settlements in the Disko Bay region where the main dietary source of Hg and Cd was seal liver. This study shows that Hg and Cd are still posing problems in arctic ecosystems and could affect humans whose diet results in high levels of exposure to these metals. Most Hg contamination arises from long-range transport and there are indications of increased Hg levels in seabirds and marine mammals in West Greenland (AMAP, 2002). Smoking is often the major source of human Cd contamination. Lead contamination, another heavy metal of concern in the Arctic, is linked to the use of lead shot for bird hunting (Johansen et al., 2001) and to continued use of leaded gasoline in parts of Russia and in some non-arctic countries.

Governance could shape the vulnerability and resilience of human–environment systems in marine resource use communities. The distribution of power among supranational, national, and sub-national decision-making bodies, for example, could help to create or ameliorate particular problems for a given human–environment system and could influence the ability of such a system to anticipate and react to stresses or potential stresses. Self-determination and self-government via Home Rule (established in 1979) allow Greenlanders a greater say in charting the country's economic and social development. However, some observers argue that the Greenlandic government, though supported by Greenland's inhabitants, has allowed for less autonomy at local levels than did its predecessor. According to this view, local people had more control over access to territory and other aspects of natural resource use and management under the more distant central government (Dahl, 2000). Currently, hunting methods and catches of a number of target species are influenced to a large extent by scientific data and by the management institutions that draft hunting and fishing regulations. Prior to the early 1990s, local communities granted territorial access for hunting and fishing to all members of a local community. This access (e.g., available for full-time hunters and fishers and fishing vessel owners) is now decided by the centralized Home Rule Government that manages hunting and fishing through regulations.

Natural resource management decisions are further influenced by international laws and policies and global markets. Greenland is heavily involved with transnational policymaking that has implications for domestic governance decisions regarding natural resource use and the environment. Consequently, Greenlandic hunters and fishers have to cope with and adapt to international politics and policymaking concerning species conservation and other matters. Greenland is represented in several multilateral fishery organizations and Greenland and the EU renegotiate a fishing agreement every five years (Nuttall, 2000; Statistics Greenland, 1997). The Home

Rule Government sets fishery quotas based on recommendations of biologists and international organizations (Statistics Greenland, 1997). In addition, global competition among commercial fisheries forces Royal Greenland (an independent limited company owned by the Home Rule Government that engages in the catching, processing, manufacture, and distribution of seafood products) to fish more efficiently (so affecting the nature of the fishery) and to cut costs (which can include shutting long-operating processing plants in some communities). This situation has important implications for households that engage in the fishing industry and rely to varying degrees on subsistence hunting and fishing.

Whaling of minke (*Balaenoptera acutorostrata*) and fin whales (*B. physalus*) in Greenland is subject to a variety of political pressures and regulations. Whales caught for subsistence purposes are to be used only for local consumption and may not be exported. The Greenland parliament regulates minke and fin whaling by, in part, requiring that whalers have a full-time hunting license, reside in Greenland, and have a "close affiliation" with Greenlandic society, a special whaling permit issued for each whale taken, and, at minimum, a 50 mm harpoon canon with a penthrite grenade (if a fishing vessel is used, the harpoon canon offers the best method for killing the animal). The Home Rule Government, in conjunction with the national hunters and fishers association (KNAPK) and the nationwide municipal government organization (KANUKOKA), allocates IWC quotas for minke and fin whales. After a municipality receives its annual quota consultations take place with the local hunter and fisher associations and quotas are assigned to vessels and collective hunters (Caulfield, 1994).

Marine mammal hunters have been subject to international protests and bans on marine mammal products since the early 1980s. The EU has maintained its 1983 trade ban on sealskins for certain species of seal pups, the 1972 Marine Mammal Protection Act remains in place, and the International Convention for the Regulation of Whaling (and its Commission – the IWC), sets quotas for aboriginal subsistence whaling. In addition, environmental and animal welfare organizations (e.g., Greenpeace, the International Fund for Animal Welfare, and the World Wildlife Fund) continue to criticize and protest against marine mammal utilization. Indigenous arctic peoples argue against restrictions on marine mammal hunting on the basis that the targeted animals are not endangered and that protests are not based on science, but on ethics particular to industrialized country politics (Caulfield, 2000).

Commercial and non-commercial fishing and hunting practices are inextricably linked and are integral to the social, economic, and cultural lives of Greenlanders. Marine resource use in general, entails cultural and social organization on many levels, through shared language, transmission of appropriate behavior, validation of identity, and reinforcement of social ties and kinship networks. Sealing and whaling, in particular, reflect the traditional social order of the communities and reinforce ties within and among families and households. The consumption, distribution, and exchange of marine resource products integrate the households and the community through a complex exchange network that reinforces cultural identity and social networks and provides important foodstuffs to households that are not able to hunt themselves.

Climate change, pollution, and governance are likely to be major factors in a vulnerability study of marine resource use communities in Greenland. Climate change and pollution could alter the availability, conditions, and health of animals such as seals and halibut, while changes in climate could affect the distribution and migration patterns of these animals, as well as ice and snow cover. Diminishing ice and snow cover could also have serious impacts on the mobility, hunting, and fishing activities of the residents of these communities. Climate alterations could further affect the ability of hunters and fishers to interpret and predict weather in planning safe and successful harvesting activities. Changes in politics, policies, and markets at local, national, and transnational levels could have negative or positive effects on the communities. Trade bans on marine mammal products, the increasing role that Home Rule and municipal governments play at the local level in towns and settlements, the growing importance of transnational policymaking forums, the financial support that individuals receive through transfer payments and subsidies, and consumption patterns of people near and far all have a bearing on the state of human–environment systems and their economies, social lives, and cultures. A vulnerability study would be useful in exploring how factors such as climate, pollution, and governance interact, their implications for human–environment systems, the resources Greenlanders might draw upon in reacting to social and environmental change, and the strategies that could be effective in guarding against negative consequences while capitalizing on opportunities.

17.4.2. A more advanced vulnerability case study

17.4.2.1. Reindeer nomadism in Finnmark, Norway

World reindeer herding

Reindeer herding is today the most extensive form of animal husbandry in the Eurasian Arctic and subarctic (also see Chapter 12). Some 2 million semi-domesticated reindeer (*Rangifer tarandus*) graze natural, contiguous mountain and tundra pastures covering an area of around 5 million km^2, which stretches from the North Sea to the Pacific Ocean (Fig. 17.5, Box 17.1). These reindeer provide the basis of the livelihood of herders belonging to some 28 different indigenous and other local peoples, from the Sámi of northern Fennoscandia (northern Norway, Sweden, and Finland) and the Kola Peninsula in northwest Russia, who herd approximately 500000

Box 17.1. Biological adaptations by reindeer to life in the north (parts of this text have been published previously by Tyler and Blix, 1990)

Reindeer is one of only 13 out of 180 different species of ruminants that has been domesticated. The grazing areas of reindeer, however, cover almost 25% of land surface of the world (Turi, 1994). Reindeer inhabit a wide range of different biotopes. Like other species resident in the Arctic, reindeer are exposed to large seasonal variations in ambient light and temperature conditions and in the quality and availability of food.

The Arctic is a hostile place in winter, yet the cold, dark "polar wastes" sustain life. The environment is truly marginal and for this reason it might be thought that warm-blooded animals that spend the winter there must endure a truly marginal existence. However, most arctic animals usually neither freeze nor starve and it is therefore self-evident that they are well adapted to the several challenges of the natural environment in which they live.

Several species of monogastric mammals (i.e., those having a stomach with only one compartment) circumvent the problem of cold and the scarcity of food in winter by hibernating. Reindeer, however, are ruminants. Unlike monogastric species they have to remain active to feed continuously throughout winter. Moreover, they are truly homeothermic, requiring maintenance of a constant internal body temperature that is considerably above environmental temperature. For these, like other true homeotherms, the problem of survival becomes one of keeping warm. To do this they need both to reduce heat dissipation and to ensure an adequate supply of fuel, in the form of metabolites from food, for heat production. Therefore, adaptations for survival can be divided between those which help the animals to reduce their energy expenditure and those which help them to make best use of what little food they can find.

Reduction in energy losses

Reindeer and caribou have two principal defenses against cold. First, they are very well insulated by fur (e.g., Nilssen et al., 1984); second, they restrict loss of heat and water from the respiratory tract. In humans exposed to low ambient temperature but warmly dressed, the heat lost in exhaled air may account for more that 20% of metabolic heat production. In resting reindeer exposed to cold, by contrast, expired air is cooled and the animals are capable of conserving about 70% of the heat and 80% of the water added to the inspired air in the lungs (Folkow and Mercer, 1986).

Reduction in energy expenditure

Appetite and growth

Reindeer, like several other species of deer, show a pronounced seasonal cycle in appetite and growth which appears to follow an intrinsic rhythm entrained by photoperiod and associated with changes in levels of circulating hormones. In winter their appetite falls by as much as 70% of autumn values (Larsen et al., 1985; Mesteig et al., 2000; Tyler et al., 1999a). Growth slows or even stops (McEwan, 1968; Ryg and Jacobsen, 1982) and the animals begin to mobilize their fat reserves even when good quality food is freely available (e.g., Larsen et al., 1985). Intrinsic cycles of growth and fattening appear to be adaptations for survival in seasonal environments in which animals are confronted with long, predictable periods of potential under-nutrition. Slowed rate of growth and, to an even greater extent, actual loss of weight have the effect of reducing an animal's daily energy requirements (e.g., Tyler, 1987). This may be literally vitally important in winter when food is not only scarce and of poor quality but is also energetically expensive to acquire.

Activity

Besides minimizing heat loss in winter by means of increased insulation, reindeer and caribou can reduce energy expenditure by adopting appropriate behavior; in particular, by reducing the total daily locomotor activity.
The nature of the surface over which animals travel is also very important. The relative net cost of locomotion in a caribou sinking to 60% of brisket height at each step is almost six times greater than the cost of walking on a hard surface (Fancy and White, 1985). The capacity of snow to support an animal depends on the hardness of the snow and the pressure (foot load) that the animal exerts on it. Thus, if snow hardness consistently exceeds foot loads, animals can walk on top of the snow or will sink to only a fraction of its total depth. The broad, spreading feet of reindeer and caribou, a well-known characteristic of this species, is clearly an adaptation to walking on snow, through minimizing the extent to which they break through the crust and sink in. Reindeer and caribou, with the exception of musk deer (*Moschus moschiferus*), have the lowest foot load measured in any ungulate

(Fancy and White, 1985). The potential significance of reducing locomotion as a means of saving energy is made clear from Fancy and White's (1985) calculation that the costs of locomotion for a 90 kg caribou breaking the trail at the head of the spring migration will represent an increment to its minimal metabolism of 82%. For the animals following the packed trail in its wake the incremental cost would be equivalent to about 33% of their minimal metabolism, a saving of more than half (Fancy and White, 1985).

Gathering and storing energy

Diet and digestion

Reindeer have an exceptional ability to cope with seasonal changes in the availability and quality of the different species of forage plants that they eat. This, together with the diversity of habitats in which the animals live, provides the basis for the capacity of reindeer to adapt toward climatic variability and change. Reindeer are highly adaptable intermediate mixed feeding types. They fall between true grazers that eat fibrous plants (25% of all species of ruminants) and concentrate selectors (40% of all species) that eat plants with low fiber content (Hofmann, 2000). By feeding selectively, they avoid highly fibrous plants and take, instead, the nutritious and easily digestible parts of a variety of different forage types including lichens, grasses, and some woody plants (Mathiesen et al., 1999, 2000; Storeheier et al., 2002a).

In some areas, the proportion of lichens in their diet increases in winter (Boertje, 1984; Mathiesen et al., 1999, 2000). Lichens are unusual as food for ruminants. They are rich in carbohydrate that is easily digestible in reindeer and are therefore also a good source of energy for the animals. However, they are deficient in nitrogen and minerals (Aagnes and Mathiesen, 1994; McEwan and Whitehead, 1970; Nieminen and Heiskari, 1989; Scotter, 1965; Storeheier et al., 2002a). Reindeer cannot, therefore, survive on lichens as their sole food supply. Ruminal fermentation of lichens has an important effect on ruminal absorption of energy rich volatile fatty acids in winter (Storeheier et al., 2003) and reindeer that eat lichens are better able to extract nitrogen from dietary vascular plants in winter (Storeheier et al., 2002b).

The consequences of increased temperatures over arctic ranges include an increase in the abundance of shrubs (Silapaswan et al., 2001; Strum et al., 2001) and a decrease in the abundance of lichens (Cornelissen et al., 2001). Reindeer herders report that the abundance and distribution of mountain birch (*Betula pubescens*) have increased and the abundance and distribution of mat-forming lichens have decreased in Finnmark over the last three to four decades. There are undoubtedly multiple causes underlying these changes. Thus, it is important to understand how reindeer can regulate their forage consumption to meet energy requirements under changing conditions. Though reindeer are able to survive without lichens in winter (Leader-Williams, 1988; Mathiesen et al., 1999; Sørmo et al., 1999) little is known about the level of production and the economy – and therefore, also, the vulnerability – of herding in lichen-free areas.

Fat

Many animals that live in highly seasonal environments store large amounts of energy as fat during summer and autumn in anticipation of food shortage during winter. In hibernating species, fat deposits may constitute up to 35% of the animals' total body weight. Ungulates, by contrast, usually store relatively little fat. The fat deposits of temperate and subarctic deer, for example, represent usually only between 4 and 10% of their total body weight in autumn (Tyler, 1987). Such low values cast doubt over the widely held view that fat is likely to be a major source of energy for deer and other ungulates in winter. Even using the most conservative models of energy expenditure it seems that the fat reserves of female Svalbard reindeer, the fattest of all reindeer, could contribute only between 10 and 25% of the animals' energy demands during winter (Mathiesen et al., 1984; Tyler, 1987).
In practice, the contribution from fat is likely to be lower than these models predict because reindeer which survive winter do not normally use up all their fat (Tyler, 1987). Moreover, there is increasing evidence that the principal role of fat reserves in ungulates is to enhance reproductive success, rather than to provide a substitute for poor quality winter forage (although the very presence of fat will necessarily also provide insurance against death during periods of acute starvation). Substantial pre-rut fat reserves, for example, enable male deer to gather, defend, and serve their harems without being distracted by the need to feed and, in several species, males hardly eat at all for two or three weeks during the rut. It is more difficult to distinguish between alternative roles (reproduction and food supplement) for fat reserves in female ungulates because, in many species, these are pregnant throughout winter. Kay (1985) suggested that the principal role of fat reserves in females may be to supplement (but not to substitute for) their food intake during late pregnancy.

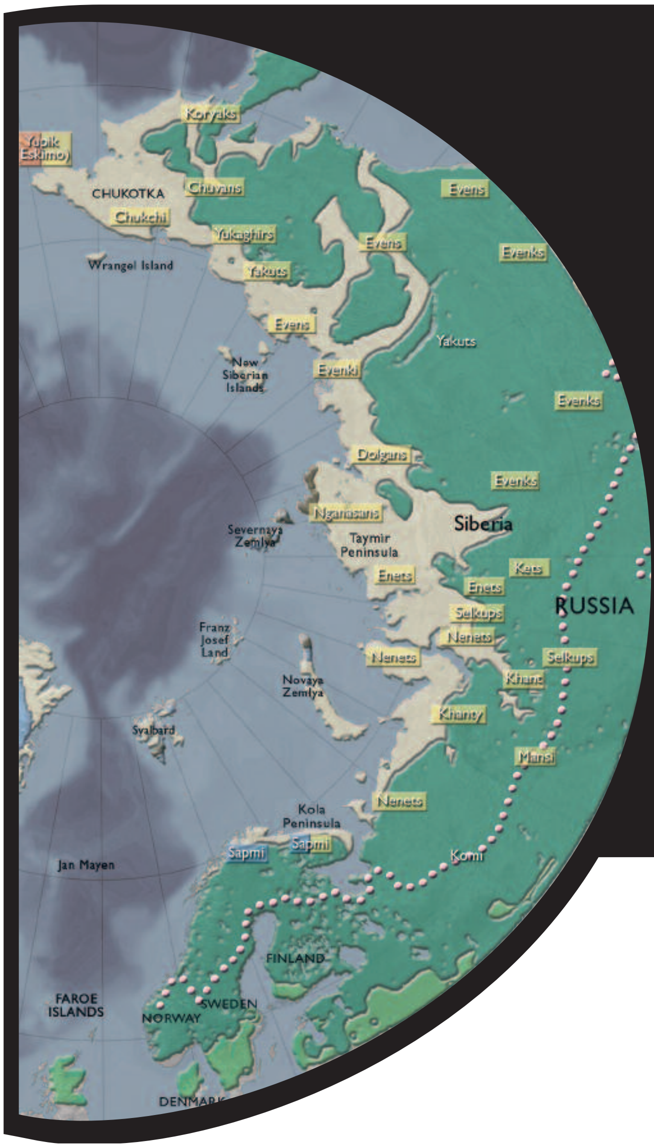

Fig. 17.5. Distribution of semi-domesticated reindeer in Eurasia and some of the indigenous and other peoples of the Eurasian north for which reindeer hunting and herding has major cultural and economic significance.

reindeer, to the Chukchi of the Chukotka Peninsula in the far east (Slezkine, 1994). The herding and hunting of reindeer has major cultural and economic significance for these people. Moreover, their herding practices, ancient in origin, represent models in the sustainable exploitation and management of northern terrestrial ecosystems that have developed and adapted *in situ* over hundreds of years to the climatic and administrative vagaries of these remote regions (Turi, 2002).

A Norwegian context

O'Brien, et al. (2004) asked whether Norway is vulnerable or resilient to future anthropogenic climate change (using projections from the ACACIA project, Parry, 2000). At a national level Norway can be considered relatively resilient and hence unlikely to be seriously affected by conditions forecast by climate scenarios over the next few decades. Its relative protection from hazards associated with sea-level rise, its weather-hardened architecture and infrastructure, its strong and equitable economy, its state of technological development, etc., all signal a good measure of resilience at the national scale. Certain economic sectors (oil and gas, hydropower, fishing, agriculture, tourism etc.) will experience gains and losses, but on average the scenarios for responses to anticipated warmer and wetter conditions point to likely sufficiency of adaptive capacity to minimize costly climate-related disruptions.

Through the application of multi-scale analyses, using dynamic and empirical downscaling techniques for regional and local climate scenarios, respectively, O'Brien, et al. (2004) were able to refine their assessments of vulnerability accordingly. Although climate extremes are not well captured in this analysis, it is clear that projections for differences in mean climate conditions vary greatly across Norway: northern, southwestern, and southeastern Norway fare quite differently. Only the first of these regions falls within the Arctic as defined in this chapter. Not surprisingly, it is this arctic portion of Norway that shows the greatest potential vulnerability to projected climate change; in large part due to the anticipated changes in natural ecosystems. The high dependence of human livelihoods on these resources, for economic and cultural reasons, contributes to a strong linkage between ecosystem changes and socio-economic consequences.

The primacy of fishing in many Norwegian coastal economies provides one example of such human–environment relationships. There is no historical analogue to allow confident predictions of fish stocks under a warmer coastal regime, and circulation changes in the North Atlantic may in fact be even more influential in determining the recruitment in key stock such as cod and herring. It is, however, likely that there will be changes in

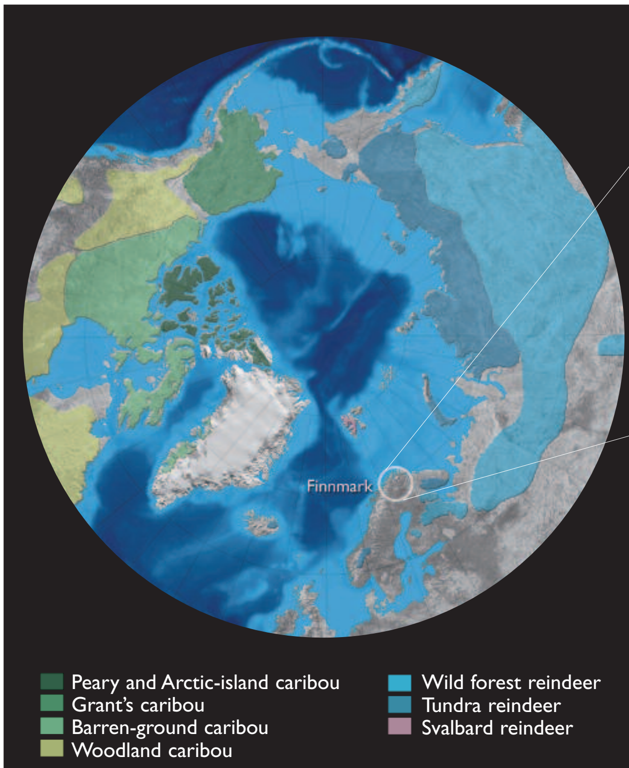

Fig. 17.6. World distribution of reindeer, showing Finnmark – the northernmost, largest, and least populated county in Norway (CAFF, 2001).

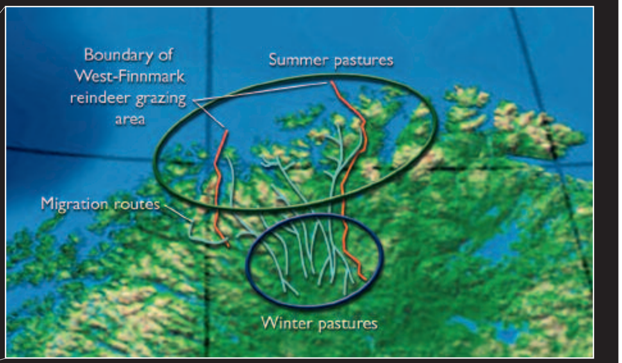

Fig. 17.7. The present pattern of semi-domesticated reindeer migration in western Finnmark.

these marine ecosystems under projected climate regimes. Studies elsewhere reveal the difficulty that communities highly dependent on fishing have in adapting to alternative livelihoods when faced with permanently unfavorable changes in catch (Mariussen and Heen, 1998). Coastal areas in more temperate regions of North America and Europe contain many such examples.

Reindeer herding in northern Norway provides a similar example. Changes in temperature can affect vegetation and changes in the timing and form of precipitation can affect the animals' access to food. Either of these changes can influence the health and productivity of the herd, and hence the livelihoods and cultural practices of indigenous peoples who are highly dependent on this ecosystem.

O'Brien et al. (2004) also gave good examples of how the overall perspective on Norway's vulnerability could change with diminished importance of revenues from oil and gas over the next five decades (considered likely), and how climate impacts experienced in other nations can affect Norway via commerce, political relations, and movements of people. But an important underlying message is that for the foreseeable future the people most likely to be negatively affected by climate change are those whose lives are most intimately linked with terrestrial and marine ecosystems.

Finnmark Sámi reindeer herding

This analysis represents an interdisciplinary and intercultural approach to understanding the vulnerabilities (*hearkivuohta*) of specific human–environment systems in the Arctic. As a work in progress it explores only some features of the human–environment system represented in reindeer nomadism. These features include climate and non-climate factors that impinge on, and may influence, the sensitivity and adaptive capacity of the system to environmental change. The perspective adopted here is that of members of local communities: the focus is on their interpretation of the concept of vulnerability analysis and on how it might usefully be applied to their situation. Thus, the information provided here is the result of a partnership between researchers and reindeer herders. The case study demonstrates how through active participation the reindeer herders modified and applied a general conceptual framework and interpreted research findings in a co-production of knowledge.

Finnmark is the northernmost, largest, and least populated county in Norway (Fig. 17.6). Within its 49 000 km^2 there live approximately 76 000 people, including a large proportion of Sámi. Populations of 114 000 reindeer and 2059 registered reindeer owners in Finnmark in 2000 represented 74 and 71% of semi-domesticated reindeer and Sámi reindeer owners in Norway, respectively (Reindriftsforvaltningen, 2002).

Reindeer in Finnmark are managed collectively in a nomadic manner rich in tradition. Herds of mixed age and sex, varying in size from 100 to 10 000 animals, are free-living and range in natural mountain pasture all year round. The herders typically make two migrations with their animals each year, moving between geographically separate summer and winter pastures. In spring (April and May), they and their animals generally move out to the mountainous coastal region where the reindeer are left on peninsulas or are swum or ferried across to islands where they feed throughout the summer, eating nutritious parts of bushes and shrubs, sedges, and grasses. In September the animals are gathered and taken inland to winter pastures in landscape typically consisting of open, upland plains of tundra and taiga birch scrub (Fig. 17.7, Paine, 1996; Tyler and Jonasson, 1993). The pattern of migration observed today is probably as much a legacy from earlier times, when Sámi moved to the coast to fish in the summer and retired inland to hunt game in winter, as a reflection of the natural behavior of their reindeer. The autumn migration inland is clearly an adaptation to climatic conditions. Winters are mild and wet near the coast but colder and drier inland (Fig. 17.8). Consequently, the climate is more continental inland and cycles of thawing and re-freezing (which increase both the density and the hardness of the snow making it increasingly difficult for the animals to dig to the plants beneath) occur less frequently than at the coast. Grazing (snow) conditions are generally better inland as a result.

Reindeer herding in northern Norway has many advantages over herding throughout much of the rest of the Eurasian Arctic and subarctic. First, although the absolute number of animals is small (the population in Finnmark, for example, represents approximately 4% of semi-domesticated reindeer in Eurasia), the density of reindeer is very high. This reflects, in part, the relatively high productivity of this region, which, in turn, is a consequence of the warming effect of a branch of the North Atlantic Current. The overall density of approximately 2 reindeer per km^2 in Finnmark is roughly four times greater than the density of reindeer in Russia. Second, reindeer meat is regarded as a delicacy in Norway and in many years production fails to meet demand. This, in combination with the richness of the Sámis' traditional gastronomic culture, provides opportunities for development of the economic basis of their industry through small-scale family-based productions focusing on the concept of adding value. Third, northern Fennoscandia possesses well developed infrastructure and transport and an electronic communication network superior to that in any other region of the circumpolar Arctic at similar latitude. These three factors form the basis of a potentially robust and vibrant form of cerviculture. They also represent features of both the natural and the social environments that potentially influence the vulnerability of reindeer herding to the effects of climate variability and change.

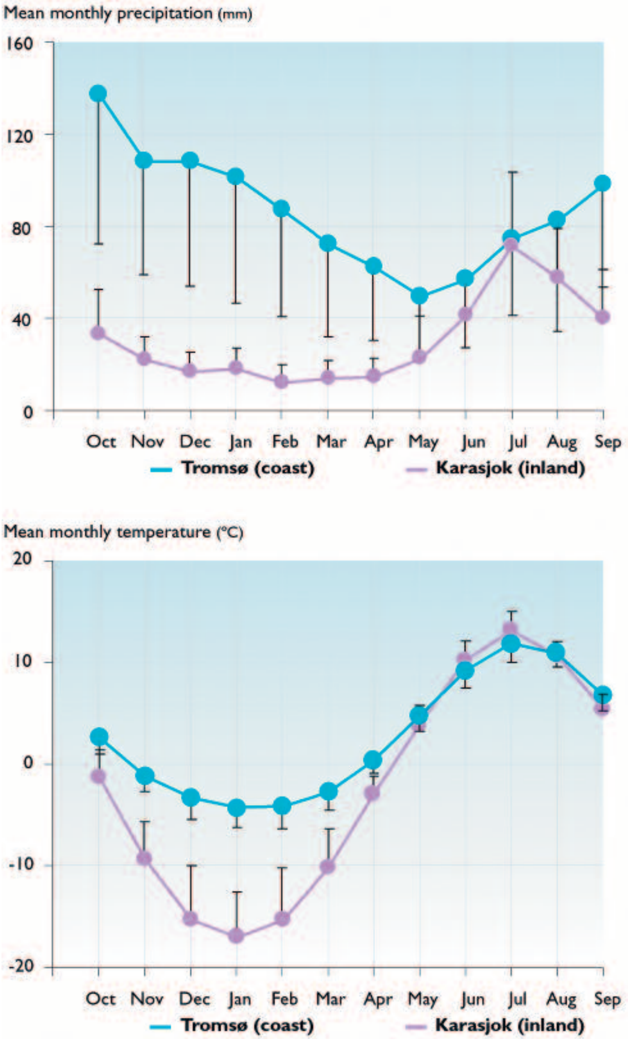

Fig. 17.8. Monthly mean precipitation and temperature at Tromsø and at Karasjok in Finnmark (26° E, 69° N). Data are for 1961 to 1990 and the bars indicate 1 standard deviation (data supplied by the Norwegian Meteorological Institute).

17.4.2.2. Modifying the general vulnerability framework

The first step in a vulnerability study is to evaluate the general methodological framework (Fig. 17.1) and modify it, where necessary, to suit the characteristics of the system of interest, in this case reindeer herding in Finnmark. A conceptual framework must be developed that focuses on the specific and, perhaps, even unique attributes of each particular case. Reindeer, reindeer herders, and the natural and social environments to which they belong represent a coupled human–environment system. Many of the components of this system, though only distantly related, are closely and functionally linked. Herders' livelihoods, for example, depend on the level of production of their herds. Production, in turn, depends on the size of herds and on the productivity of individual reindeer in them, which depend, again in turn, on the quantity and quality of forage available. The level of feeding the animals enjoy is determined in the short term by prevailing weather conditions including temperature in summer, which affects the growth and nutritional quality of forage plants, and by weather conditions in winter, in particular a combination of precipitation, temperature, and wind, which affect the quality of the snow pack and, hence, the availability of the forage beneath. In the medium and long term, however, feeding levels are also determined by a suite of non-climate factors all of which have a major influence on the level of production and, completing the circle, on the profitability of reindeer herding. These include the quality of pasture (in terms of the species composition and biomass of forage and the availability of other important natural resources), the area of pasture available, herders' rights of access to pasture, the level of competition between reindeer and other grazers, the level of predation to which herds are subjected, the monetary value of reindeer products and so on. Common to all these non-climate factors is that they are influenced by the decisions and policies of institutions far removed from Finnmark. Hence, it was clear at the outset that reindeer herding is a production system

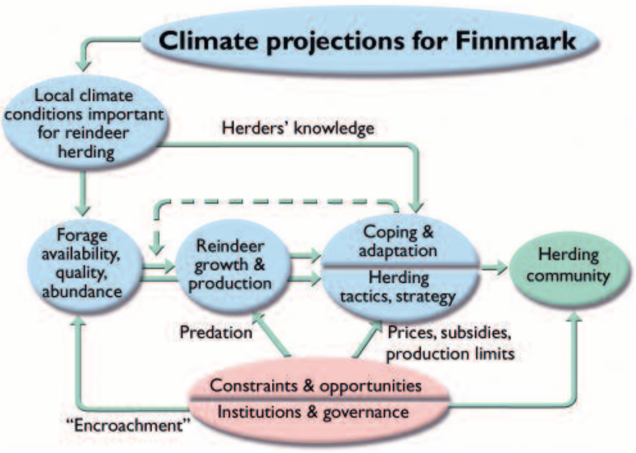

Fig. 17.9. Conceptual framework for the Finnmark case study.

affected not just by climate variability, and potentially also by climate change, but also potentially very strongly by the socio-economic environment in which it exists.

A conceptual model relevant for reindeer herding in Finnmark was developed at a five-day meeting held in Tromsø in August 2002. The president of the Association of World Reindeer Herders drew together a team of natural scientists, social scientists, administrators, and reindeer herders. All the participants were encouraged to emphasize their own particular perspectives and, working together in this way, the group then revised the generalized conceptual framework to suit the conditions prevailing in Finnmark. The herders, for example, were largely responsible for selecting the principal components included in the final model and upon which the study was based. The customized framework (Fig. 17.9) describes the perceived relationships through which (1) climate change influences the growth and productivity of herds of reindeer, (2) herders cope with climate-induced changes in the supply of forage and in the level of production of their herds, and (3) herders' ability to cope with climate-induced changes is constrained by extrinsic anthropogenic factors collectively called "institutions and governance". (These include "predation", the level of which is influenced by legislation that protects populations of predators.) Each part was tempered with herders' understanding of the dynamics of herding, of their society, and of the natural and social environments in which they live. Superficially the final model (Fig. 17.9) bore little resemblance to the general framework (Fig. 17.1) from which it evolved, yet key elements, including human and environmental driving forces, human and societal conditions, impacts, responses, and adaptation, all remain.

17.4.2.3. Climate change and climate variability in Finnmark: projections and potential effects

Climate change is one of a suite of factors that influence the physical environment, the biota and, ultimately, the cultures of indigenous and other arctic communities. Large-scale climate changes in the Arctic will influence local climate (e.g., Bamzai, 2003), which, in turn, can possibly affect foraging conditions for reindeer, the productivity of herds and, ultimately, herders' income and livelihood.

Projections for Fennoscandia

The climate of northern Fennoscandia is milder than at similar latitudes in Russia or North America owing to the warming effect of a northeastern branch of the North Atlantic Current, which flows north along the coast of Norway. The mean July temperature at the coastal town of Vadsø (70° 05' N) in northern Norway, for example, is approximately 11 °C, while that at Point Barrow (71° 30' N) in Alaska is approximately 4 °C. Likewise, the mean January temperature inland at Kautokeino (68° 58' N) is approximately -16 °C compared to approximately -35 °C at Old Crow (67° 34' N) in Canada (both located at similar elevations).

These differences notwithstanding, recent modeling indicates that during the next 20 to 30 years the mean annual temperature over northern Fennoscandia is likely to increase by as much as 0.3 to 0.5 °C per decade (Christensen et al., 2001; Hanssen-Bauer et al., 2000; Hellström et al., 2001; see also Chapter 4). The projected rise in temperature is greater in the north than in the south of the region, greater inland than at the coast, and greater in winter than in summer.

Confidence in these projections is based on the trend in mean annual temperature for the period 1970 to 2000, generated retrospectively by the same models, corresponding reasonably well with empirical observations. Figure 17.10, for example, illustrates the observed mean annual temperature measured at Karasjok, a representative inland grazing region used in winter, between 1900 and 2000 and a modeled projection for mean annual temperature for the period 1950 to 2050 (Hanssen-Bauer et al., 2000). The trend in the projection from 1970 to 2000 compares well with, and is not significantly different from, the observed temperature trends (Hanssen-Bauer et al., 2003). The models do not, however, capture the changes in variability which

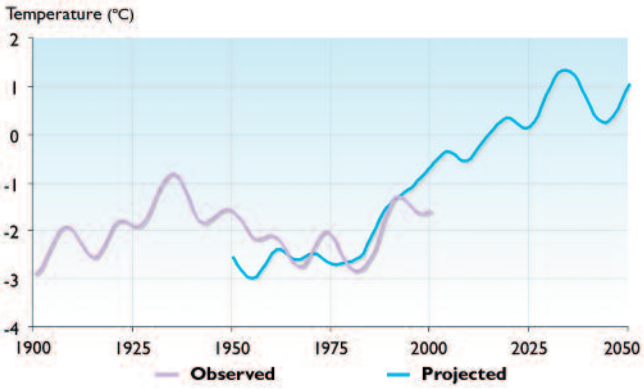

Fig. 17.10. Low-pass filtered series of observed and projected mean annual temperature in Karasjok, eastern Finnmark. The projected temperature is downscaled from the ECHAM4/OPYC3 global climate model, run with the IS92a emissions scenario (Hanssen-Bauer et al., 2000).

have been observed. At this stage, therefore, it is not possible to project with any degree of confidence to what extent the variability in mean annual temperature in northern Fennoscandia is likely to change over the next 50 to 100 years.

Global projections for the next 70 years or so indicate increased precipitation at high latitudes. These projections seem robust (e.g., Räisänen, 2001) and are qualitatively consistent with the expected intensification of the hydrological cycle caused by increased temperatures. Regional models for Fennoscandia project an increase in annual precipitation of between 1 and 4% per decade (Fig. 17.11). The regional precipitation scenarios are, however, generally less consistent than the regional temperature scenarios and their ability to reproduce the trends observed in recent decades remains limited.

Increases in temperature and precipitation can potentially affect snow conditions in a variety of ways that can influence foraging conditions for reindeer. Increased temperature in autumn might lead to a later start of the period with snow cover and increased temperature combined with more frequent precipitation may increase the frequency of snow falling on unfrozen ground. Furthermore, increased precipitation in winter would be expected to contribute to increased snow depth at the winter pastures of reindeer. With increased temperatures, the melting period in spring might start earlier but the last date of melting might be significantly delayed where the initial snow cover is deeper. The physical structure of the snow pack could also be affected by the projected changes in temperature and precipitation. No local projections for snow conditions in Finnmark have, however, yet been made. Their development would require an integration of the projections for temperature and precipitation, both of which are currently available only at a coarse scale of resolution. To be meaningful, models would have to be downscaled and would need to incorporate data on the physical structure of the landscape, especially altitude which influences local temperature profiles and, hence, the transition of precipitation from rain to snow (e.g., Mysterud et al., 2000; see also Chapter 7).

Downscaling global projections

The spatial resolution of the projections for temperature and precipitation over northern Fennoscandia is very coarse and, consequently, of limited use for projecting local trends in any but the most general terms. Downscaled scenarios, designed to improve the spatial resolution of the projections, have been developed for temperature and precipitation at selected stations in Finnmark. Projections for Karasjok in eastern Finnmark are shown in Figs. 17.10 and 17.11. The downscaled temperature scenarios show some of the same characteristics as the regional scenarios for Fennoscandia, including greater warming in winter than in summer and inland compared to the coast. However, the inland–coast gradient was in most cases greater in the downscaled projections than in the global scenarios. Downscaled projections for precipitation did not match the global projections for Fennoscandia well. This result was not unexpected and reflects the fact that downscaling, unlike global modeling, is sensitive to the effects of local topography on patterns of precipitation.

Local climate conditions important for reindeer herding

To be manageable, the models developed by downscaling analysis were necessarily made very simple. The weather patterns over reindeer pastures, by contrast, are highly complex and display a large degree of regional, local, and temporal variation. Some of the temporal variation is apparent from data for particular parameters. The observed winter precipitation in Karasjok, for example, has varied during the last five decades from less than half the 1961–1990 average to almost twice this value (Fig. 17.12). Likewise, at Tromsø at the coast, the date on which the last snow disappeared (between 1960 and 2000) has varied by as much as 60 days from year to year. There is also considerable spatial variability: the mean annual precipitation for Finnmark (1961–1990), for example, ranges from 325 mm at Kautokeino (inland) to 914 mm at Loppa (coast). The situation is, however, more complicated than these simple comparisons indicate owing to the many ways in which weather

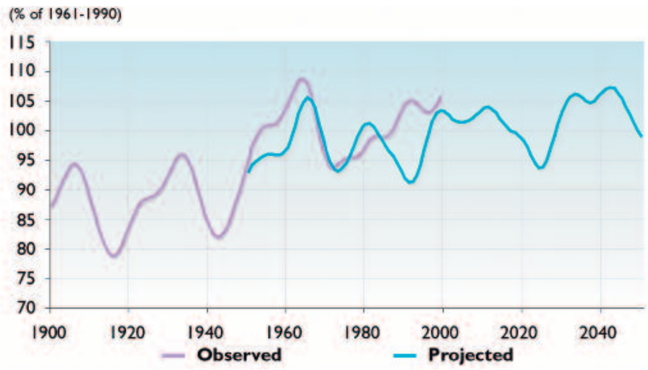

Fig. 17.11. Low-pass filtered series of observed and projected annual precipitation in Karasjok, eastern Finnmark. The projected precipitation is downscaled from the ECHAM4/OPYC3 global climate model, run with the IS92a emissions scenario (Hanssen-Bauer et al., 2000).

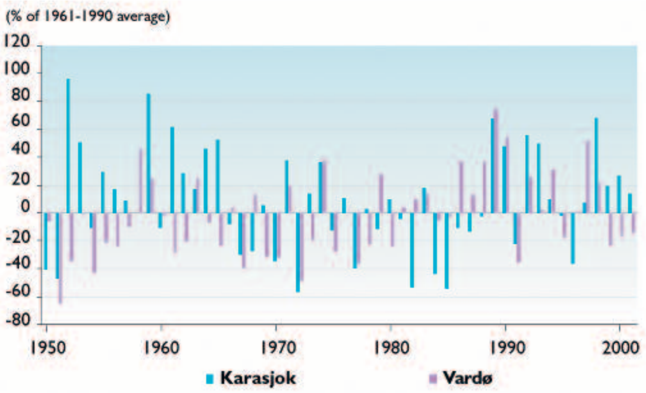

Fig. 17.12. Winter precipitation anomalies for Karasjok (eastern Finmark) and Vardø (northeastern Norway), 1950 to 2001. The anomalies are given in percent relative to the 1961–1990 average.

can vary. Data collected over 35 years from two weather stations in central eastern Finnmark reveal, for example, that almost every year is a record year. Every year one parameter or another is colder, or warmer, or earlier, or deeper, and so on than ever before. There are, in effect, no "normal" years in Finnmark; instead, every year is exceptional. In herders' parlance: *Jahki ii leat jagi viellja* ("One year is not another's brother").

The challenge, therefore, is to extract data from global, regional, or local meteorological records in the form of selected parameters that, singly or in combination, represent useful proxies for those aspects of the weather in this complex system that significantly influence the growth and survival of reindeer and the work of the herders who look after them. Ecologists select proxies that are either as highly generalized or as highly specific as possible, including major atmospheric phenomena such as the North Atlantic Oscillation or monthly mean records of precipitation from a particular local weather station, respectively. The application of either highly generalized or highly specific data can be useful and can yield robust results. The selection of proxies, however, is largely arbitrary and the results lack the sophistication that characterizes herders' understanding of the ways in which short-term variation in weather and longer term variation in climatic conditions affect their lives. Reindeer herders, like other people whose livelihood depends on close reading of the natural environment, have a deep understanding of the significance of the changing patterns of weather (Box 17.2). An important step in a vulnerability analysis of this kind, therefore, is to describe the effects of temporal and regional variation in weather on grazing conditions in terms of herders' experience and, hence, to identify climate phenomena and thresholds that are potentially important for reindeer production.

17.4.2.4. Ecological impacts

The ecological impact of large-scale climate variability and recent climate change on temperate species of

Box 17.2. The significance of snow

Reindeer herders, like other people whose livelihood depends on close reading of the natural environment, have a deep understanding of the significance of changing weather patterns. This knowledge is based on generations of experience accumulated and conserved in herding practice. Herders' understanding of snow (*muohta*) is one example.

In winter, each herding group grazes their animals in a defined area to which it has usufructory rights. In Finnmark, herds are typically tended continuously in winter, with herders taking watches that last seven to ten days. Their daily duties include maintaining the integrity of their herds – by preventing animals from straying and by keeping other reindeer away – and, most importantly, by finding fresh places for the animals to graze. "Good grazing" is a place where the snow is dry, friable, and not too deep to prevent the animals easily digging through it to reach the plants beneath. "Bad grazing" is a place where the snow is icy, hard, and heavy, or where a layer of ice lies over the vegetation on the ground beneath. "Exhausted grazing" is a place where reindeer have already dug and trampled the snow, consequently rendering it hard and effectively impenetrable.

Snow lies in the mountain pastures of northern Norway for up to 240 days per year and it is therefore not surprising that herders have learned to cope with varying snow conditions. The significance of snow for the lives of the people probably increased when they turned from hunting reindeer to herding them (Ruong, 1964). Winter grazing conditions must have become an important determinant of trade and, hence, an important topic of discussion. The distribution of snow and its physical characteristics such as its depth, hardness, density, structure, and variability all had to be expressed in a linguistic form. The Sámi recognize about 300 different qualities of snow and winter pasture – each defined by a separate word in their language (Eira, 1984, 1994; Jernsletten, 1997; Pruitt, 1979; Ryd, 2001).

A selection of Sámi words for snow

Čearga	Hard-packed drift snow "which one can't sink one's staff into"– impossible for reindeer to dig through.
Čiegar	Snow that has been dug up and trampled by reindeer, then frozen hard.
Fieski	Snow in an area where only a few reindeer have been, evidenced by few tracks.
Oppas	Thickly-packed snow through which reindeer can dig if the snow is of the *luotkku* (loose) or *seanas* type.
Sarti	A layer of frozen snow on the ground at the bottom of the snow pack that represents poor grazing conditions for reindeer.
Seanas	Dry, coarse-grained snow at the bottom of the snow pack. Easy for reindeer to dig through. Occurs in late winter and spring.
Skárta	A thin layer of frozen, hard snow on the ground that forms after rain. Also poor grazing conditions.

plants and animals is well documented (Ottersen et al., 2001; Post and Stenseth, 1999; Post et al., 2001; Stenseth et al., 2002; Walther et al., 2002). Among northern ungulates, variation in growth, body size, survival, fecundity, and population rates of increase correlate with large-scale atmospheric phenomena including the North Atlantic Oscillation (Forchhammer et al., 1998, 2001, 2002; Post and Stenseth, 1999) and Arctic Oscillation (Aanes et al., 2002). Putative causal mechanisms underlying these correlations involve the climatic modulation of grazing conditions for the animals. The effects may be either direct, through the influence of climate on the animals' thermal environment or the availability of their forage beneath the snow in winter (e.g., Forchhammer et al., 2001; Mysterud et al., 2000), or indirect, through modulation, by late lying snow, of the phenological development and nutritional quality of forage plants in summer (e.g., Mysterud et al., 2001). The consequences for the animals may, in turn, be either direct, involving the survival of the current year's young, or indirect, whereby climate-induced variation in early growth influences the survival and breeding performance of the animals in adulthood (e.g., Forchhammer et al., 2001).

Some well-established reindeer populations characteristically display high-frequency, persistent instability (e.g., Solberg et al., 2001; Tyler et al., 1999b) indicating that their dynamics, and the dynamics of the grazing systems of which they are a part, may be strongly influenced by variation in climate (Behnke, 2000; Caughley and Gunn, 1993). However, despite a substantial volume of research related to the effects of snow on foraging conditions in tundra and taiga pastures (Adamczewski et al., 1988; Collins and Smith, 1991; Johnson C. et al., 2001; Miller et al., 1982; Priutt, 1959; Skogland, 1978) and, more recently, research related to the effects of variation in summer weather on forage (e.g., Lenart et al., 2002; Pentha et al., 2001; Van der Wal et al., 2000), only little evidence of a strong and pervasive influence of large-scale climate variation on the rate of growth of populations (Aanes et al., 2000, 2002, 2003; Post and Stenseth, 1999; Solberg et al., 2001; Tyler et al., 1999b) or the performance of individual reindeer (Post and Stenseth, 1999; Weladji et al., 2002) has yet emerged.

17.4.2.5. Coping with climate variability and change

The potential impact of climate variation and change on the productivity of herds can be ameliorated by tactical and strategic changes in herding practice. Herders' responses (feedback) represent coping (*birgehallat*), indicated by the dotted line in Fig. 17.9. The conceptual framework proposes that responses may be triggered at two levels. Ultimately, the herders respond to climate-induced changes in the performance of their animals. They also respond directly to the kinds of weather conditions that are important for successful herding. This proximal response is indicated by the line marked "Herders' knowledge" in Fig. 17.9. The model makes no assumption about the extent or effectiveness of herders' ability to cope or the magnitude of the influence of climate change on the system.

A major point emphasized in this study is that climate change is not a new phenomenon in eastern Finnmark, even over the timescale of human memory. Systematic records of meteorological data have been made at Karasjok, close to the winter pastures, since 1870. These data provide clear evidence of climate change during the last 100 years. The dominant features of the temperature and precipitation records displayed in Figs. 17.10 and 17.11 are not the overall trends but, rather, the substantial decadal variation. Hence, although temperature displayed no statistically significant trend during the course of the last century, it is readily apparent that between 1900 and 2000 inner Finnmark experienced two periods with generally increasing temperatures. Between 1900 and 1935 and again between 1980 and 2000 the mean annual temperature at Karasjok increased by about 0.5 °C per decade. The observed rate of increase closely matches the projections for warming over Fennoscandia over the next 20 to 30 years that lie in the range of 0.3 to 0.5 °C per decade (see Chapter 4). Similarly, the modest net increase in precipitation during the last century, which occurred at a rate of 1.6% per decade, belies the observation that there were, in fact, three separate and substantial periods of increasing precipitation in those years. Between 1945 and 1965, for example, the mean annual precipitation at Karasjok increased by 20%. The rate of increase during this event greatly exceeds the current projections for precipitation increase over Fennoscandia of 1 to 4% per decade (see Chapter 4). Projections for future temperature and precipitation fail to capture these rapid changes and, instead, reflect only the modest trends observed across the 20th century as a whole.

Sámi reindeer herders have therefore, in the course of the last century, been exposed to climate change events of a magnitude at least as great as – and in some cases much greater than – those currently projected for northern Fennoscandia over the next 20 to 30 years. It needs to be noted, however, that a reoccurrence in the future of the large variations in climate experienced historically is certainly not excluded in the projections of climate change. Moreover, what is likely to be unprecedented historically is the level of mean climate around which these fluctuations will occur. One potentially useful approach to predicting the likely impact of, and herders' responses to, climate change, therefore, is to explore how they were affected in the past and what responses they displayed then. This kind of exploration requires the codification and analysis of herders' responses to weather-related changes in foraging conditions and of their perception and assessment of the risks associated with different coping options.

Strategic responses

Diversity in the structure of herds

Aboriginal production systems in extreme, highly variable, and unpredictable climates are based on the sequential utilization of, often, a large number of ecological or climatic niches (Murra, 1975). The essence of such systems is flexibility and the distribution of risk through diversity. Reindeer herders maintain high levels of phenotypic diversity in their herds with respect, for example, to the age, sex, size, color, and temperament of their animals (Oskal, 2000). A *čappa eallu* ("beautiful" herd of reindeer) is, therefore, highly diverse and, in this respect, is the antithesis of a purebred herd of livestock of the kind developed by careful selection to suit the requirements of a modern, high yielding agricultural ruminant production system.

The traditional diversity in the structure of reindeer herds is an example of a coping strategy aimed at reducing the vulnerability of the herd to the consequences of unfavorable – and unpredictable – conditions. Thus, in traditional reindeer herding, even apparently "non-productive" animals of either sex have particular roles which, when fulfilled, contribute significantly to the productivity of the herd as a whole. Traditionally, for example, reindeer herds in Finnmark typically consisted of as many as 40% adult males. Large numbers of large males were required for traction; they acted as focal points, helped keep the herd gathered, and reduced the general level of activity of the females: in modern jargon, the males contributed to energy conservation within the herd. Many were carefully castrated to this end (Linné, 1732). Their strength, moreover, enabled them to break crusted snow and to smash ice with their hooves, opening the snow pack to gain access to the plants beneath to the benefit of themselves and – incidentally – also for the females and calves in the herd. The modern agronomist, however, considers adult males unproductive and today few herds in Finnmark have more than 5% males. Males' role as draft animals and in gathering and steadying the herd has been largely superceded by snowmobiles – albeit at greatly increased economic cost. The reliance on snowmobiles, moreover, renders herding early in winter difficult in years when little or no snow arrives before the New Year. But old ways sometimes die out only slowly and there are ingenious solutions. When asked recently (in 2002) why he kept several heavy, barren females in his herd, Mattis Aslaksen Sara, a herder from Karasjok, replied "I have so few big males now – so who else will break the ice?" The decline in the diversity of the herd structure and, specifically, the increased proportion of females in today's herds is largely a result of government intervention. It reflects the influence of practices copied from sheep production systems that have been translated to reindeer herding by agronomists. The reduced heterogeneity of herds represents a reversal of the traditional approach; its consequences, in terms of the performance of the animals, remain largely unknown. The pattern of dispersion of female-dominated herds over the landscape is said to be different. The consequences of reduced heterogeneity in terms of changes in the vulnerability of the herding system to environmental change remain completely unknown.

Pastoral nomadism

The characteristic seasonal pattern of movement reflects herders' responses to the spatial and temporal heterogeneity and unpredictability of key resources, usually forage or water, whether these be for goats or cattle on a tropical savannah (Behnke et al., 1993) or for reindeer on northern taiga (Behnke, 2000). Nomadism is adaptive in the sense that, by moving his herd, the herder gains or averts what he anticipates will be the advantages or undesirable consequences of his doing so or not doing so, respectively.

Tactical responses

Movement

For Sámi nomads, one principal feature of the natural environment that influences the pattern of movement of herds into, within, and out of winter pastures is the condition of the snow pack. Snow determines the availability of forage (crusted snow is bad) and, in late winter, the mobility of herds (crusted snow is good). Skilled herders observe how the snow drifts, how it settles, and where conditions remain suitable for grazing and then make decisions about how and when to move after assessing the physical quality of the snow pack in relation to topography, vegetation, time of year, and condition of the animals. In the warm winters of the 1930s (see Fig. 17.10), for example, conditions were sometimes so difficult owing to heavy precipitation that herds spread out and moved to the coast earlier than normal in spring. Today, neighboring herding groups (*siida*) may even "trade" snow in the sense that one group may allow its neighbors to move their herd to an area of undisturbed snow (good grazing) on the former's land. In every case, success is contingent on the freedom to move.

Feeding

Reindeer husbandry in Norway is based on the sustainable exploitation of natural pasture. In winter, access to forage can be restricted by deep snow or ice and the animals have to cope with reduced food intake as a result. So extreme were snow conditions in the winter of 1917/18, with ensuing loss of animals, that Sámi herders in Norway employed Finnish settlers to dig snow to improve access to forage. Herders often provided small amounts of lichen both to reward animals they were in the process of taming and also as a supplement for draft animals or for hungry ones. Gathering lichens, however, is laborious and, instead, in addition to locally produced grass converted into hay or silage, several commercially available pelleted feeds have been developed (Aagnes et al., 1996; Bøe and Jacobsen, 1981; Jacobsen and

Skjenneberg, 1975; Mathiesen et al., 1984; Moen et al., 1998; Sletten and Hove, 1990). The provision of small amounts of supplementary feed can help to improve survival in winter (especially for calves), to increase the degree of tameness of the herd, and to improve the animal welfare image of reindeer herding in the eyes of the public. Negative effects include increased frequency of disease (Oksanen, 1999; Tryland et al., 2001) and increased cost. The use of pellets and locally harvested grass increased throughout Fennoscandia in the 1990s; reflecting this, many petrol stations in the reindeer herding areas of northern Finland now stock sacks of feed during winter. The use of pellets is less widespread in Norway owing in part to its high cost: the grain products in pelleted ruminant feeds are heavily taxed in Norway and the cost of providing artificial feed for reindeer is between four and six times higher than in Finland. In Norway, therefore, use of feed is generally restricted to periods of acute difficulty. This pattern might alter, however, in future should snowfall increase substantially.

17.4.2.6. Constraints on coping

The strategic and tactical decisions herders make in response to changes in pasture conditions represent aspects of coping. The success of the kinds of responses outlined in the previous section, however, depends to a large extent on herders' freedom of action. This section outlines five constraints or potential constraints on this freedom of action. The first four concern government policy (state, regional, and municipal) and present institutional arrangements that reduce the herders' ability to respond creatively to changing conditions, including climate variability and change. The fifth is pollution.

In Norway, Sámi reindeer herding takes place in a complex institutional setting heavily influenced by various forms of governance (see Fig. 17.1) that constrain herders' options. Constraints include the loss of habitat, predation (where the abundance of predators and, hence, the rates of mortality due to predation, is influenced by legislation protecting predators), and the governmental regulation of herding (including the regulation of rights of pasture, of the ownership of animals, and of the size and structure of herds) and of market- and price-controls. The effects of non-climate factors like these on the development of reindeer herding potentially dwarf the putative effects of climate change described previously. Institutions and governance have since the early 1980s demonstrably reduced the degree of freedom and the flexibility of operation under which reindeer herders traditionally acted. Their ability to cope with vagaries of climate may be reduced as a result. For these reasons, institutions and governance were included as a major element in the conceptual model (Fig. 17.9). The challenge remains to identify and quantify their impact on reindeer herding and to identify and understand the effects of this on herders' ability to cope with and adapt to changing environmental conditions. Of course, not all forms of governance and institutions are negative for reindeer herding: central administration also provides important protection and opportunities for the industry and has supported both research and education. Interestingly, a major development in government support for reindeer herding was precipitated by an extreme climatic event. Severe icing over the pasture during the winter of 1967/68 resulted in substantial starvation and loss of reindeer in Finnmark. The government responded in an unprecedented manner and provided compensation equivalent, in today's monetary terms, to US$ 6.5 million. Out of this action arose a debate among the Sámi regarding the division and distribution of government funds within the reindeer industry, which continues, in one form or another, to this day. Loss of habitat, predation, the economic and socio-political environment, and law, however, were factors highlighted at the co-operative meeting in Tromsø (see section 17.4.2.2): their legitimacy and relevance lie in the fact that they are based on herders' subjective evaluation of their own situation.

Loss of habitat

Reindeer herding is a highly extensive form of land use. Roughly 40% (136 000 km^2) of Norway's mainland is designated reindeer pasture and within this area Sámi herders have – at least in principle – the right to graze their animals on uncultivated ground irrespective of land ownership. Herders' rights of usufruct, however, afford them neither exclusive access to the land nor protection from the interests of other land users. Conflicts of interest are common. For herders the principal issue is generally the securing of habitat in which to graze their reindeer. Indeed, the progressive and effectively irreversible loss of the uncultivated lands which reindeer use as pasture is probably the single greatest threat to reindeer husbandry in Norway today. Preservation of pastureland is, likewise, perhaps the single greatest priority for sustaining the resilience of reindeer herding confronted by changes in both the natural and the socio-economic environment.

Habitat loss occurs in two main ways: (1) through physical destruction and (2) through the effective, though non-destructive, removal of habitat or through a reduc-

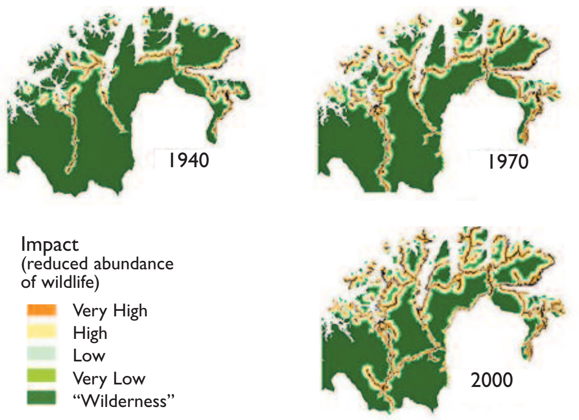

Fig. 17.13. Encroachment of roads in Finnmark 1940 to 2000, and the associated loss of reindeer pasture (UNEP, 2001).

Fig. 17.14. Projected development of infrastructure (including roads, houses, military training areas) in the Barents Euro-Arctic region 2000–2050. This scenario is based on the historical development of infrastructure, the distribution and density of the human population, the existing infrastructure, the known location of natural resources, distance from the coast, and vegetation type (GloBio, 2002).

tion in its value as a resource. Physical destruction of habitat is chiefly a result of the development of infrastructure, including the construction of artillery ranges, buildings, hydro-electricity facilities, pipelines, roads, etc. The effective removal of habitat may result from disturbance (for example, by hunters, fishers, and walkers), local pollution, increased grazing pressure by potentially competing species (e.g., sheep, Coleman, 2000) or through loss of rights of access either locally (Strøm Bull, 2001) or as a result of the closure of regional or international borders (Hætta et al., 1994). Taking Norway as a whole, piecemeal development of infrastructure has resulted in an estimated loss of 70% of previously undisturbed reindeer habitat during the last 100 years (Nellemann et al., 2003); in Finnmark, the figure is close to 35% for the last 60 years alone (Figs. 17.13 and 17.14).

Predation

Fennoscandia is home to the last remaining sizeable populations of large mammalian predators in Western Europe, including bear (*Ursus arctos*), lynx (*Lynx lynx*), wolf (*Canis lupus*), and wolverine (*Gulo gulo*). These species are all capable of killing medium-sized ungulates like reindeer (although bears probably rarely do this). Wolverine, a major predator for reindeer, were completely protected in 1981 though limited hunting is now permitted. In Norway, very large numbers of domesticated animals range freely in the mountain areas in summer, including approximately 2 million sheep and 140 000 reindeer (which remain at pasture both in summer and winter) and these, not surprisingly, are potential prey. Reindeer herders in Finnmark, the county with the highest losses, estimate that between 30 and 60% of their calves are taken as prey each year (Anon., 2003); in some herds losses exceed 90% (Mathis Oskal, reindeer herder, pers. comm., 2003). Losses on this scale dwarf all other causes of mortality including climate-related deaths (Reindriftsforvaltningen, 2002) and are therefore a major determinant of levels of production in herds.

Norway's mountain pastures are an important renewable natural resource: their management as pasture, however, is clearly complicated by the presence of predators and the resulting predation on grazing animals. Intervention designed to ensure the sustained usefulness of mountain pastures as a resource for grazing animals by reducing the density of predator populations to levels at which they no longer represent a threat to the livelihood of the sheep farmers and reindeer herders, must select from among several unsatisfactory alternatives. Consequently, any solution is likely to be an unsatisfactory compromise. Alternative strategies range from implementing a general reduction in the density of predator populations, to establishing "predator-free zones" where grazing can continue uninterrupted while leaving the predators elsewhere undisturbed. Any course adopted must be commensurate both with Norway's commitment to the conservation of viable populations of mammalian predators under the terms of the Convention on the Conservation of European Wildlife and Natural Habitats (the "Bern Convention") and other international agreements and, at least as far as reindeer are concerned, by the country's commitment to safeguarding the special interests of the Sámi people. This commitment is enshrined in the terms of the International Labour Organisation (ILO) Convention No. 169 on Indigenous and Tribal Peoples. Moreover, it seems apparent, as reindeer herders argue, that obligations with respect to the intentions of ILO Convention No. 169 may take precedence over those of the Bern Convention (Schei, no date; Uggerud, 2001) and they press for the establishment of predator-free zones accordingly.

In practice, the situation remains unclear. No predator-free zones have been created. The culling of predators takes place only on a limited scale and herders – who have the best local knowledge about the predators – are not normally permitted to take part. Compensation for loss of animals is generally paid only in cases where claims are substantiated with unequivocal evidence such as post-mortem examination of carcasses. Herders, however, normally determine losses by observing the absence of particular animals and are only rarely able to support their claims by producing a carcass; the gathering up, transport, and delivery of carcasses is generally impracticable. Consequently, their claims are mostly unsubstantiated and usually rejected: in 2001–2002 herders in Finnmark were compensated for only one in four reindeer claimed lost (Lund, 2002). Loss of reindeer through predation, possibly exacerbated by increased snow, therefore, remains a major constraint on herd production levels and the herders, furthermore, remain largely powerless to tackle the situation owing to legislation that runs counter to their immediate interests.

Economic and socio-political environment

Reindeer herding in Norway is the most regulated reindeer husbandry in the world today. In 2000, the annual cost of its administration was US$ 21 million, which was more than twice the amount paid to reindeer herders for their meat. (This refers to the raw product; the market value of the reindeer meat sold is substantially greater.) The current high level of regulation of herding dates from 1978 when Sámi reindeer husbandry was brought more closely under the management of the Royal Norwegian Ministry of Agriculture where economic planning remained the policy-makers paradigm. This development reflected an earnest desire to improve the economic basis of Sámi reindeer husbandry and, hence, help herders to achieve the stable income indispensable in modern society. Its consequence was that central government became one of the most potent forces shaping the development of reindeer herding. The reigning paradigm of government policy was that of a modern, agricultural food-production system and an immediate consequence of its implementation was an increase in the number of reindeer and reindeer herders (Anon., 1992). Today, policies established by the central administration influence virtually every aspect of reindeer husbandry, from the granting of licenses to own reindeer and the allocation of grazing rights, to the monitoring and regulation of the size-, age-, sex-, and weight-structure of herds, the setting of production quotas, the influencing of both the age and sex composition of animals selected for slaughter, the timing of slaughtering, and determining to which slaughterhouses herders must sell their animals.

Some aspects of government intervention have been necessary and valuable. Once the aboriginal system of pasturing rights (the *siida* system) ceased to be recognized by Norwegian law (Strøm Bull, 2001), an alternative governance structure was needed. Other government interventions, such as a centralized regulation of the price of reindeer meat, have resulted in stagnation in herders' economy. Political and market power was lifted from the hands of the herders in 1978 and consolidated in early 2000 when an alliance took place between *Norsk Kjøtt* (a meat farmers' co-operative which controls 75% of slaughtering in Norway) and two large, private, reindeer slaughterhouses neither of which are Sámi owned. Sámi ownership and control is minimal: in Norway only a small proportion of reindeer are slaughtered by Sámi-owned enterprises compared to a large proportion in both Sweden and Finland (Reinert and Reinert, in press). Import tariffs and pricing policies have been used to protect and promote the interests of agricultural meat production at the expense of reindeer herding interests. The market mechanism has been eliminated as a price setting mechanism for reindeer meat and, instead, its price is negotiated annually by the herders' organization (the Sámi Reindeer Herders Association of Norway) and the government. In reality, the negotiating power of the herders is minimal because *Norsk Kjøtt* is responsible both for the marketing and the regulation of the reindeer meat market. For example, from 1976 to 1991 the net price paid to herders for their meat, corrected for inflation, fell by 45% largely in response to an increase in the level of production (Reinert and Reinert, in press). In the following decade the trend was reversed and the level of production was halved; yet, contrary to all normal practice, the real price paid to herders for their meat remained at the 1991 level. The absence of normal market mechanisms for price setting has been economically most disadvantageous for the herders. The fall in the price of reindeer meat over the last 25 years exemplifies the influence wielded over the economic development of reindeer husbandry by agricultural meat producers with vested interests. Lacking direct control over the slaughtering and marketing of reindeer meat, the Sámi of Norway became, *de facto*, an internal colony (Reinert and Reinert, in press). This recalls the term "Welfare Colonialism" coined by Paine (1977) to characterize culturally destructive colonialism in the Arctic.

Central administration, therefore, remains responsible for key aspects of the economic and socio-political environment in which herding exists and to which herders are obliged to adapt. The traditional fluidity and flexibility of practice that reindeer herding had developed to meet the vagaries of the natural environment of the north has been eroded. The exploration of the consequences of these developments for the adaptability, resilience, and vulnerability of Sámi reindeer herding under potential climate change remains, therefore, an important area of research.

Law

The elaborate legal structure upon which the regulation of reindeer husbandry is based is another aspect of the complex institutional setting in which Sámi reindeer herding is practiced in Norway. The law is comprehensive, complex and, occasionally, liberal to the point of ambiguity (Strøm Bull et al., 2001). It represents, therefore, a fourth non-climate factor that has a major influence on herding and which, by constraining herders' options, influences their ability to cope with changes in the natural environment.

Legislation governing reindeer husbandry is of considerable antiquity. A treaty agreed in 1751 between the respective joint kingdoms of Denmark/Norway and Sweden/Finland included the division along a common national border of hitherto undefined northern lands. This same border divides Norway and Finland today. The 18th century legislators realized that the creation of a border would potentially disrupt the lives of the nomads whose freedom of movement across the area had hitherto been unrestricted. An addendum was, therefore, included in the treaty confirming agreement between the two states that Sámi reindeer herders' customary utilization of the land should remain undisturbed notwithstanding the creation of a common border and the nomads' obligation to adopt one or other nationality.

This document, the Lapp Codicil, is the first formal legislation of reindeer husbandry. Crucially, it was built upon the principle of local self-government regarding the division of resources (Hætta et al., 1994).

The legislation of reindeer husbandry has evolved and increased in complexity since 1751. Successive statutes have been revised and new ones created to meet the challenges of changes in the economic and political climate, culminating in the Reindeer Husbandry Act of 1978 and its revision in 1996. Today's law includes provisions for the regulation of a wide range of issues. Section 2 alone includes rules for the designation of herding areas, the duration of grazing seasons within them, the size of herds, and the body mass of the animals in them. The level of detail of the legislation contrasts sharply with the lack of detail in the guidelines for its implementation. The Act is built on the premise that the organization of reindeer herding is best left in the hands of public administration. No groups have protected rights of usage. Instead, successive levels of the legislature – including the Ministry of Agriculture, the Reindeer Husbandry Board, Regional Boards, and Area Boards – determine, virtually unimpeded by legal barriers, the division of grazing districts, the allocation of herding franchises, and reindeer numbers. Regulation is achieved through rules, not statutes, as a consequence of which there remains considerable uncertainty among administrators and herders alike about the scope of the Act and a severe limitation of individual herder's opportunity to challenge administrative decisions.

The prevailing uncertainty is compounded by the fact that reindeer herding is regulated *de facto* by a Convention on Herding rather than through the provisions of the 1978 Act. The Convention is negotiated annually between the Government represented by the Ministry of Agriculture and the herders represented by the Sámi Reindeer Herders Association of Norway (NRL).
The two parties are by no means equal. The Ministry is responsible both for drafting the regulations contained in each Convention, albeit in consultation with the NRL, and, ultimately, also for the interpretation and implementation of the final agreement. The regulations contained in the Convention are far more flexible than the Act but lack the legal checks and balances that the Act contains. The regulations agreed at each Convention, moreover, are frequently changed which only increases the level of uncertainty. Clearly, the complexities and ambiguities of the law contribute to the unpredictability of the administrative environment within which reindeer herding is practiced and, consequently, represent an important potential constraint on herders' ability to cope with changes in the natural environment.

Pollution

Pollution from sources outside the Arctic (AMAP, 2002) is another non-climate factor that can potentially influence the development of reindeer herding. Just as clean, local water is a fundamental human right, so also is the availability of uncontaminated food that can be gathered from traditional local sources. Imported agricultural food products are no substitute. Fortunately, chemical pollution is substantially less important for reindeer herding in Finnmark (generalizing from data for nearby regions in Russia) and, indeed, for all reindeer herding in Fennoscandia, than it is for marine resources (Bernhoft et al., 2002).

Most radioactive contamination on land in northern Fennocscandia is derived from fallout from atmospheric nuclear tests conducted up to 1980. Observed levels of contamination have not been considered hazardous for human health in Finnmark (Åhman, 1994; AMAP, 2004).

Radioactive contamination from the explosion at the Chernobyl nuclear power plant in 1986 is a major source of contamination in parts of southern Fennoscandia. This is a serious problem locally but is not directly a problem for reindeer herding as a whole because the majority of reindeer and reindeer herders live in the north of the region (Åhman, 1994). The radioactive pollution from Chernobyl has, however, been an indirect problem for the entire reindeer herding industry owing to negative focus in mass media, which failed to distinguish between those regions that received some fallout and those that were not affected at all. Misinformation of this kind can potentially turn consumers away and can encourage international food producers to step in and provide "clean", although non-traditional, substitute foods. The influence of effects of this kind on the vulnerability of small arctic enterprises like Sámi reindeer herding remains an important area of study.

Heavy metals accumulate in lichens (AMAP, 2002). Concentrations of heavy metals in reindeer meat, however, are no higher than in the meat of pigs, cattle, and poultry (Bernhoft et al., 2002). No data are available on concentrations of heavy metals in reindeer in Finnmark. Data on trends in heavy metals are available only for reindeer from Sweden where samples have been collected annually in three reindeer districts since the early 1980s (Swedish Museum of Natural History Contaminant Research Group, 2000). These data indicate that there have been no significant changes in the concentration of Pb, Cd, or Hg in reindeer meat for the period 1983 to 1998. In liver, the concentration of Pb decreased by 6.8% per year over this period, while the concentration of Cd showed a slight increase. Concentrations of Pb and Cd are very low (0.06 µmol/L) in blood among women in arctic Norway (Odland et al., 1999).

Cadmium is a potential problem owing to its tendency to accumulate in reindeer kidneys: people who consume these organs are exposed to this metal. AMAP (2002) reported that concentrations of Cd in reindeer kidneys in arctic Norway and Sweden are approximately three times higher than those in southern Norway and Sweden. Bernhoft et al. (2002) reported very low levels of Cd in the kidneys of reindeer from Kola in northwest Russia.

No data are available on concentrations of POPs in reindeer in Finnmark. In general, concentrations of POPs are lower in terrestrial mammals than in marine mammals (AMAP, 2002). Concentrations have been measured on an annual basis since 1983 in reindeer at Abisko, Sweden (AMAP, 1998). Current levels are not thought to represent a significant threat for reindeer (AMAP, 2002). Levels of two POPs in other species in the Swedish Arctic are declining, e.g., ΣDDT and ΣPCBs in otters in northern Sweden (Roos et al., 2001), and this trend is expected to continue.

17.4.2.7. Insights from the reindeer nomadism vulnerability case study

The reindeer nomadism vulnerability case study demonstrated the versatility of the general conceptual framework for vulnerability studies proposed in section 17.2. The development of a framework that was tailored specifically for reindeer herding in Finnmark also showed the diversity of the kinds of information that need to be included in an assessment of the vulnerability of a human–environment system in the Arctic. It illustrated the usefulness of reducing potential complexity to manageable proportions by developing a conceptual model containing just a few selected elements. It also showed the importance of collaborating with reindeer herders in a co-production of knowledge.

The validity and legitimacy of reducing an immensely complex system to something simple and, therefore, amenable to a vulnerability assessment depended wholly on the participation of herders themselves. Outsiders should not decide what factors, or suites of factors, influence reindeer herding: nobody, except for herders themselves, can legitimately make the required selection. The conceptual model, developed as a result of the interdisciplinary and intercultural effort, necessitated the integration of empirical data and herders' knowledge. The integration of different ways of knowing, called the "co-production of knowledge" (e.g., Kofinas and the communities of Aklavik, 2002), is not widely exploited in ecological research probably because aboriginal knowledge often does not lend itself to reductionist analysis and hypothesis testing. However, herders' knowledge of the impact of something as specific as climate variation on their way of life is based on an understanding resulting from generations of experience accumulated and conserved in herding practice and herders' specialized vocabulary. Consequently, in some instances herders can contribute knowledge gathered over a time span longer than the periods over which climate change has been documented by other means. The success of the approach outlined here was evident from the logical design and usefulness of the resulting conceptual model.

The joint effort in developing a conceptual model appropriate for a study of the vulnerability of reindeer herding in Finnmark to climate change quickly revealed that herding is affected by much more than just change in climate. Moreover, it is extremely likely that the effects on reindeer herding of the non-climate factors introduced into the model potentially dwarf the putative effects of climate change on the system. Hence, the potential consequences of the projected increase in the average annual temperature at Karasjok over the next 20 to 30 years (Fig. 17.10) cannot meaningfully be considered independent of concurrent changes in the socio-economic environment for which, in some cases, clear predictions are already available (e.g., Figs. 17.13, 17.14).

Clearly, reindeer herding has been very resilient. The continued existence of nomadic reindeer herding by Sámi and other northern peoples in Eurasia today is evidence that these have, through the centuries, coped with and adapted to the vagaries and transitions of the socio-economic environment of the north. On one hand, it has not been overlooked that, if the marginalization of reindeer nomadism continues and if constraints on the freedom of action of the herders increase, new climatic conditions might threaten the resilience and increase the vulnerability of herding societies in ways that are without precedent. On the other hand, action provokes reaction: changes in climate and in the socio-economic environment might also create new opportunities for sustainable development in reindeer peoples' societies. Herders can be expected to grasp new opportunities, wherever they arise, and to take the initiative in improving the economy of their industry thereby reducing the vulnerability of their society.

17.5. Insights gained and implications for future vulnerability assessments

Arctic human–environment systems are subject to high rates of change in climate and/or other environmental and societal factors. Some changes emanate from outside the Arctic, while other changes arise from within the region. The vulnerability of human–environment systems in the face of such changes can vary widely with differences in the character and relative importance of environmental and societal changes across local settings. Vulnerability analysis offers an approach for exploring implications of environmental and social changes in a way that recognizes the interconnectedness of human and environment systems and the exposure, sensitivity, and adaptive capacity of these systems as they experience stresses or anticipate potential stresses arising from and interacting across local, regional, and global scales.

The Sachs Harbour and Greenland examples, plus the more developed case study on reindeer herding in Finnmark (section 17.4.2), reveal the importance of characterizing the place-based aspects of coupled human–environment systems, analyzing multiple and interacting stresses across multiple scales, accounting for adaptive capacity in assessing vulnerability, and incorporating varied forms of knowledge, analytical tools, and methodologies in vulnerability analysis. These case studies demonstrate that in their decision-making *arctic residents integrate their experiences and expectations of change in environmental and societal factors in addition to changes in climate and varia-*

tion in climate. They also illustrate that *vulnerability analysis can be applied in situations where the social and environmental changes important for a particular human–environment system operate at different scales.*

Given the close linkages between arctic peoples and the natural settings in which they live and on which they depend, a meaningful and useful analysis of arctic vulnerabilities requires the definition, characterization, and analysis of coupled human–environment systems. The human–environment systems at the heart of the case studies presented in this chapter are centered around human livelihoods (e.g., marine resource use). Seen from a human perspective, livelihoods are arguably the most salient aspect of a coupled human–environment system because the practices they entail involve close, fairly well-circumscribed, and critical interactions between social and natural systems in a particular locale, yet with discernible linkages to dynamics operating not only within, but also across local, regional, and global levels. Livelihoods are also the focal point of social organization, culture, and identity. The focus on reindeer herding in Finnmark, for example, enables the identification of specific climate-related changes (e.g., regarding snow pack and forage) and regulations (e.g., regarding land rights and predators) that affect this system. The identification of stresses, vulnerabilities, and response strategies for a more broadly defined system (e.g., for all indigenous peoples in Fennoscandia) would be more difficult and arguably less useful. The complex dynamics important for understanding vulnerability are apparent in all case studies. In Greenland and Sachs Harbour the size, health, and harvest of fish and marine mammals depend on climate, pollution, market factors, regulations, and technology. In Finnmark, climate changes and regulations have profound effects on reindeer, reindeer habitats, and herder practices and livelihoods. In Greenland with its market ties to distant localities via fish and fur products *it is evident that coupled human–environment systems in the Arctic are influenced by socio-political, socio-economic, and cultural factors originating outside as well as inside the region. Arctic residents accommodate this range of influences in their coping decisions.*

As these studies also show, primary stresses like climate change can have cascading and interacting impacts on many different aspects of the arctic physical and biological environment. Some factors, for example local climate shifts, can impact on many different components of the arctic system with differing magnitudes, timing, effects, and interactions. Thus, an increase in air and water temperature will probably affect the distribution of coastal winter sea ice and alter the access of local people to fishing and hunting areas; it may affect local oceanography and alter the habitats of marine mammals and their prey; it may increase the abundance of forage that reindeer eat; it may accelerate physical processes of pollutant transport and reactivity; and it may affect the health and well-being of arctic residents through decreased access to traditional foods and increased incidence of disease, etc. Each of these effects can interact with others leading to more complex, higher-order effects. For example, the seasonal distribution and migratory routes of marine mammals may shift, forcing the hunters and their families either to follow the animals and relocate or to adopt new economies and lifestyles.

The case studies also illustrate *the importance of examining multiple, interacting stresses, operating within and across local, regional, and global scales, as well as the adaptive capacity of systems weathering these stresses.* Stresses (as well as potential opportunities) facing marine resource systems arise from interactions among, for example, climate, global markets, environmental and animal welfare campaigns, and changes in governance. Stresses (as well as potential opportunities) facing reindeer herding systems arise from interactions among changes in, for example, climate, forage, technology, and regulation. These factors do not, by definition, always lead to negative consequences. Changes in governance might be just as likely to reduce vulnerability as they are to contribute to vulnerability. A holistic understanding of vulnerability requires analysis of these many factors and their interactions, along with an understanding of how the coupled human–environment system in question might cope with or adapt to the changes brought about by these factors. *Coping and adaptation can diminish the vulnerability of certain components of the system and thereby offset adverse impacts. Vulnerability analyses reveal where actions can best be taken to enhance adaptive capacity, for example, via changes in public policy and new strategies in resource management, and anticipatory measures to prepare for adverse circumstances and mitigate their effects.* Arctic human and environment systems have a long history of coping with and adapting to social and natural changes. The resilience exhibited by arctic peoples provides insight into how these coupled human–environment systems might adapt in the future. Mobility, flexibility in livelihood (e.g., hunting, fishing, herding) practices, and a capacity for innovation all contribute to adaptive capacity, including a capacity to plan and prepare for contingencies. For example, the varied strategies that reindeer herders have developed for dealing with environmental and social changes are also strategies through which herders anticipate and prepare for future events. Nomadism itself is a way of anticipating future opportunities or adverse conditions. Because they are mobile, Sámi reindeer herders can respond quickly to unfavorable weather and/or snow conditions in one location by moving to another. "Trading" in snow is another practice that helps herders to successfully handle contingencies. An accounting of past and present adaptive measures is an important component of vulnerability assessment.

Vulnerability assessment also requires varied forms of knowledge and the development of new analytical tools and methodologies. Understanding the stresses facing place-based coupled human–environment systems and the adaptive measures they might take in response to these stresses necessitates novel modes of inquiry. *Involving indigenous peoples and other arctic residents in the research process is extremely important in developing such understandings.* Methods to integrate indigenous knowledge and scientific knowledge such as biology, climate science, political science, and anthropology are similarly important. Climate downscaling, pollutant modeling, scenario development for societal trends, environmental monitoring, interviews, focus groups, workshops, and ethnography comprise additional approaches that could be integral to vulnerability analysis.

The following sections contain general conclusions pertaining to the assessment of trends in climate, pollution, and human and societal conditions, and some comments on next steps.

17.5.1. Climate

The results of downscaling analyses reported for Finnmark provide preliminary insights into how temperature and precipitation may change in this region. The projections presented in the Finnmark case study were calculated using a single domain (20º W–40º E and 50º N–70º N for Karasjok, Norway). A more comprehensive downscaling program would provide projections using multiple downscaling domains. The models presented here also use a single predictor variable: large-scale temperature for projecting local temperature, and large-scale precipitation for projecting local precipitation. It remains to be seen how sensitive the results are to the selection of downscaling domain or predictor variables. Also important to include would be downscaling results for a number of additional variables such as snow and ice cover, permafrost conditions, and extreme events, as well as sensitivity analyses to examine the robustness of the various projections. A more comprehensive program would also involve residents more directly in research design, analysis, and dissemination.

Effective downscaling must engage local people. Snow quality, for example, is an extremely important factor for reindeer herding and reindeer herders have many words to describe snow quality. In contrast, climate downscaling provides information about a relatively limited number of variables. It is therefore not obvious how typical climate forecasting products and terminology might be made relevant for reindeer herders. Thus, in principle, analysts conducting downscaling for a vulnerability study should first assimilate the views and information needs of local people for the products of these analyses. In practice this will require creative ways for presenting results to non-climate specialists in order to address their needs and concerns and make most advantage of their local knowledge. As with any climate analysis, the models used in this study produce an enormous quantity of information – all of which is important for the analysis but most of which may not be useful for decision-makers. The risk of information overload is high. For example, at a minimum, for each downscaled climate variable, month, and general circulation model analyzed, vulnerability researchers should examine estimates of trend, variability, historical goodness-of-fit, and spatial distribution. Thus, climate analysts need to be willing to tailor their model products to the specific needs of local decision-makers.

17.5.2. Pollution

Information on POPs and heavy metals in the Arctic is widely available for the past two decades. Data on environmental concentrations for a number of chemicals exist for both western Greenland and Fennoscandia. These data, however, tend to be temporally and spatially dispersed. Data on local, long-term trends in environmental levels of POPs and heavy metals are much less abundant for both loci. There are, however, reliable time trends for certain species (e.g., reindeer and arctic char) in Fennoscandia. Data from the early 1980s to 2000 indicate generally declining environmental levels of POPs in both Disko Bay on the west coast of Greenland and in Fennoscandia. Trends in environmental heavy metal levels in western Greenland and Fennoscandia are less clear than for POPs. Some heavy metal levels have increased, while others show no change, or even a decrease.

Long-term local human trend data are even less available for western Greenland and Fennoscandia than environmental trend data. Available data suggest that observed human health problems relating to POPs and heavy metals are greater in western Greenland than in Fennoscandia. At the regional level, the greatest heavy metal threat to human health is due to Hg. Exposure to Hg in Greenland is at levels where subtle health effects can occur on fetal and neonatal development (AMAP, 2003). As in Fennoscandia, environmental heavy metal levels in the Disko Bay region show diverse trends. Daily human intake of Cd and Hg in the Disko Bay region is comparatively high.

Levels of POPs in both regions can be expected to decline toward 2020 due to increasing international regulation, although other POPs such as brominated flame retardants could become a growing problem (AMAP, 2002). Trends in environmental heavy metal levels to 2020 in both regions are more difficult to project than for POPs.

Future place-based pollutant research for vulnerability analysis would ideally consist of exposure and trend monitoring, human health and epidemiological analyses, and collection of other relevant data such as information about dietary intake, smoking, and other influences on pollutant burden. All these types of study are feasible and have been done at various sites; however, a vulnerability study necessitates that this information be available for a specific location. There is also a need to better understand local means of adaptation to problems with pollution, both in terms of what has been done and what could be done.

17.5.3. Trends in human and societal conditions

Several general trends (i.e., those concerning governance; population and migration; consumption; economy, markets and trade; and connectivity) are apparent in human and societal conditions throughout much of the Arctic. In recent decades, governing authority in Greenland and places within Canada and Alaska has rested increasingly with indigenous peoples. At the same time, regulations (particularly those pertaining to natural resource use) emanating from local, national, and international bodies are playing important roles in the lives of arctic peoples and the ways in which they are permitted to use land and to harvest fish and marine and terrestrial mammals. In addition, pan-arctic cooperation is increasing and transnational networks of indigenous peoples are growing. More people live in arctic urban areas than was the case thirty years ago, less traditional food is being consumed, a larger number and greater variety of imported technologies are employed, and people are more "wired" via the Internet, television, telephones, and satellites. Mixed economies have become more prevalent throughout the Arctic and the connections linking arctic economies with global markets are becoming stronger.

But while human and societal trends identified in this project are noteworthy for the Arctic as a whole, they by no means represent a complete inventory of such trends. Nor are they necessarily the most important trends for understanding the vulnerability of the case study sites. A more comprehensive and complete analysis of human and societal trends within the context of a fully-fledged vulnerability analysis would require the broad and systematic engagement of people living in the case study locations, and the use of tools such as surveys, participant observation, workshops, interviews, focus groups, and ethnography to ascertain what human and societal conditions are most relevant to a particular coupled human–environment system, how these conditions have changed over recent decades, and how they are expected to change in the future. The development of several alternative future societal scenarios would be useful in carrying out the difficult task of projecting future human and societal conditions and assessing their implications for coupled human–environment system vulnerabilities. The production and comparison of multiple scenarios could facilitate sensitivity analysis.

Oran Young (1998b) defined sustainable development as "…an analytic framework intended to provide structure and coherence to thinking about human/environment relations". Young calls for a sustainable development discourse that will facilitate efforts to identify and address arctic concerns. He adds that "To be useful in an arctic context, sustainable development must take into account the distinctive ecological, social, and cultural features of the region and offer an integrated approach to the endogenous and exogenous threats to sustainability peculiar to the circumpolar world". According to this view, vulnerability (and resilience) analysis as outlined in this chapter, can serve as a vehicle for conceptualizing and implementing sustainable development. Vulnerability analysis offers a holistic vision of human–environment systems and their dynamics at local to global scales. It recognizes that environmental changes are interactive, that ecology, culture, economics, history, and politics are interconnected, and that decisions about what to sustain and how must be made in particular social and ecological contexts. However, vulnerability analysis is more than a research strategy. It has the potential to provide processes in which people with varied backgrounds and interests can engage in dialogue, produce knowledge, and articulate values. Such processes can ultimately inform the ways in which communities and governments balance aspirations for human and societal development with those of environmental and social sustainability.

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