Chapter 15

Human Health

Lead Authors
Jim Berner, Christopher Furgal

Contributing Authors
Peter Bjerregaard, Mike Bradley, Tine Curtis, Edward De Fabo, Juhani Hassi, William Keatinge, Siv Kvernmo, Simo Nayha, Hannu Rintamaki, John Warren

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Summary

The nature of projected climate-related changes and variability, and the characteristics of arctic populations, means that impacts of climate change on the health of arctic residents will vary considerably depending on such factors as age, gender, socio-economic status, lifestyle, culture, location, and the capacity of local health infrastructure and systems to adapt. It is more likely that populations living in close association with the land, in remote communities, and those that already face a variety of health-related challenges will be most vulnerable to future climate changes. Health status in many arctic regions has changed significantly over the past decades and the climate, weather, and environment have played, and will continue to play a significant role in the health of residents in these regions.

Direct health impacts may result from changes in the incidence of extreme events (avalanches, storms, floods, rockslides) which have the potential to increase the numbers of deaths and injuries each year. Direct impacts of winter warming in some regions may include a reduction in cold-induced injuries such as frostbite and hypothermia and a reduction in cold stress. As death rates are higher in winter than summer, milder winters in some regions could reduce the number of deaths. Direct negative impacts of warming could include increased heat stress in summer and accidents associated with unpredictable ice and weather conditions. Indirect impacts may include increased mental and social stress related to changes in the environment and lifestyle, potential changes in bacterial and viral proliferation, vector-borne disease outbreaks, and changes in access to good quality drinking water sources. Also, some regions may experience a change in the rates of illnesses resulting from impacts on sanitation infrastructure. Impacts on food security through changes in animal distribution and accessibility have the potential for significant impacts on health as shifts from a traditional diet to a more "western" diet are known to be associated with increased risk of cancers, diabetes, and cardiovascular disease.

Increased exposure to ultraviolet (UV) radiation among arctic residents has the potential to affect the response of the immune system to disease, and to influence the development of skin cancer and non-Hodgkin's lymphoma, as well as the development of cataracts. However, as the current incidence rates for many of these ailments are low in small arctic communities it is difficult to detect, let alone predict, any trends in their future incidence. The presence of environmental contaminants threatens the safety of traditional food systems, which are often the central fabric of communities. The projected warming scenarios will affect the transport, distribution, and behavior of environmental contaminants and thus human exposure to these substances in northern regions.

These changes are all taking place within the context of cultural and socio-economic change and evolution. They therefore represent another of many sources of stress on societies and cultures as they affect the relationship between people and their environment, which is a defining element of many northern cultures. Through potential increases in factors influencing acculturative stress and mental health, climate-related changes may further stress communities and individual psychosocial health. Communities must be prepared to identify, document, and monitor changes in their area in order to adapt to shifts in their local environment. The basis of this understanding is the ability to collect, organize, and understand information indicative of the changes taking place and their potential impacts. A series of community indicators are proposed to support this development of monitoring and decision-making ability within northern regions and communities.

15.1. Introduction

15.1.1. Background and rationale

The arctic regions share common characteristics such as sparse population, harsh climate, similar geographic features, high latitude, and characteristic seasonal extremes of daylight hours and temperatures. The modern climate record shows that regions of the same high latitude often have very different mean annual temperatures, precipitation regimes, and ecosystems. It is important to incorporate this diversity in any assessment of the current and future impacts of climate change on the health of northern peoples.

In general, arctic regions of the United States, Canada, and Nordic Europe have more economic support than those of the former Soviet Union. As a result, the availability and quality of data on human health status vary widely and are not available for some regions. The evaluation, both current and future, of the impact of climate change on human health is entirely data dependent.

As a result, this chapter (unlike those addressing specific climate issues) cannot address the potential health impact of climate change using a regional or time-specific approach.

The ACIA-designated models project climate change relative to baseline conditions (1981–2000) for three 20-year "time slices" (2011–2030, 2041–2060, and 2071–2090) for four arctic regions. The time-slice regional scenario is a useful construct for those ecological components which are not able to quickly relocate or utilize technology to mitigate climate-related impacts, but is not as useful for human populations, where non-climate factors can cause mass relocations over periods of days to weeks. The reactor accident at Chernobyl in 1986 is one such example. Also, economic decisions such as those to develop natural resources (e.g., petroleum, minerals, timber) can bring food, education, and health resources to a region, and may accelerate or mitigate a decrease in numbers of a traditional food species. These changes might result in population growth and an improvement in health status, or the erosion of a community's cultural base, bringing cultural stress and a deterioration in health status.

This chapter does not attempt to predict health impacts for any specific region, or any specific time frame, for the following reasons.

- Climate models, over prolonged intervals (decades), are uncertain, and thus impacts on people and their communities are also uncertain.
- Humans can adopt strategies to mitigate almost any possible health impact, given sufficient support.
- Levels of governmental, public health, social, and cultural support vary dramatically among circumpolar communities and will continue to fluctuate in the future.
- Over the past four decades, many regions of the circumpolar arctic have shown a warming trend, however significant areas have also shown a cooling trend, such that uniform temperature assumptions can not yet be justified.

This chapter presents a discussion of mechanisms by which climate can influence human health in arctic communities such that these communities might plan appropriate monitoring strategies to support the development of adaptive or mitigation actions. In this way, potential negative impacts might be recognized and mitigated, and potential opportunities might be recognized and exploited.

15.1.2. Health in the circumpolar Arctic

According to the World Health Organization (WHO, 1967), health includes aspects of physical, mental, and social well-being and is not simply the absence of disease. In this holistic vision of health, which is very similar to that supported by the many indigenous groups throughout the world, the well-being of individuals and communities is tied to that of their environment. Human health status is a result of the complex interaction of genetic, nutritional, and environmental factors. "Environment" in this context includes the socio-economic, cultural, and physical infrastructure and ecosystem factors. Many of these groups of factors can improve or degrade health status, by enhancing the resilience of a population, or by causing stress. In these instances, the stress can be a direct physical change such as temperature, can take the form of increased prevalence of a disease-causing organism, or be represented by a perceived threat or sense of loss, engendering psychological stress.

Previous reports have concluded that, for the residents of the contiguous United States, climate change will have a small overall health impact, due to the ability of the existing public health system to respond to new threats (Patz et al., 2000). This conclusion is unlikely to be true for the North American Arctic, or for arctic residents in many other countries, for the following reasons.

- Many arctic residents live in very small, isolated communities, with a fragile system of economic support, dependence on subsistence hunting and fishing, and little or no economic infrastructure.
- Rural arctic public health and acute care systems are often marginal, sometimes poorly supported, and in some cases, non-existent.
- Culture is often critical to community and individual health, and may be affected by climate change via mechanisms such as the loss of a traditional subsistence food source, which can result in a grief response and severe stress. Climate changes can become a source of illness, injury, and mortality for arctic communities.

The combined result of these factors is that rural arctic residents are often uniquely vulnerable to health impacts from climate change, mediated by a variety of mechanisms. Also, owing to their close relationship and dependence on the land, sea, and natural resources for cultural, traditional, social, economic, and physical well-being, indigenous peoples are also uniquely vulnerable to these environmental changes. It is for these reasons that this chapter emphasizes potential climate impacts on health in small arctic communities, among whose residents many are indigenous.

This chapter presents a brief overview of available data on the current health status of arctic residents, followed by a series of sections describing the potential impact mechanisms of climate change on socio-cultural and socio-economic environments and physical infrastructures as they relate to human health. Sets of indicators are then proposed to prospectively monitor potential climate change impacts on human health. The chapter concludes with recommendations for research and action.

15.2. Socio-cultural conditions, health status, and demography

Social conditions and lifestyles among indigenous populations vary widely throughout the Arctic. Many indigenous peoples rely on the food that they hunt and harvest from the land and sea, as it provides for much of their nutritional intake as well as being a critical component of their cultural identity, and in many cases, their local informal economy (Duhaime, 2002). Members of the urban population, of whom many are of European descent, have lives that are to some extent indistinguishable from those of their kinfolk in Europe or North America, although the arctic climate still determines much of their daily life and is an underlying condition for infrastructure and transport.

15.2.1. Socio-cultural conditions and health status

Living conditions are changing throughout the Arctic for indigenous as well as non-indigenous residents as a consequence of the change from an economy based on hunting to modern wage earning (AMAP, 2003). The following description of social change in Greenland (Bjerregaard and Curtis, 2002) is similar to that in many other circumpolar regions. The shift from a traditional Inuit community to a modern society started at the beginning of the 20th century when fishing began to replace the hunting of marine mammals as the main source of livelihood. This was accompanied by population movement from a large number of small villages to larger – although still small by many standards – population centers, and by the gradual supplement of the traditional subsistence economy by a cash economy. By the end of the Second World War, however, Greenland still had a relatively isolated and traditional society where most people lived in small villages and subsisted on small-scale hunting and fishing activities. During the latter half of the 20th century unprecedented changes occurred in Greenland resulting in a very modern society thoroughly integrated in global political and economic systems. Fishing and the associated processing industry are the basis of the present economy but at a very advanced level with ocean-going fishing vessels existing alongside smaller crafts and some fishing from the ice. Subsistence hunting and fishing are still widespread but are increasingly becoming a leisure activity. Daily connections by air to Denmark now exist, and even small villages have telephone service and internet access. Supermarkets contain products such as fresh mangos and papayas, as well as a range of European meats, dairy, and vegetable products, and frozen Greenlandic fish and seal meat.

The influence of such changes on physical health and everyday life are obvious; positive changes include vastly improved housing conditions, a stable supply of food and increased access to western goods, and decreased mortality and morbidity from infectious diseases including tuberculosis. However, societal change and modernization have also brought a number of social and mental health problems as well as increasing prevalence of chronic diseases such as cardiovascular diseases and diabetes (Bjerregaard and Young, 1998). Children have been brought up with values that were useful for hunters and hunters' wives living in small communities: independence, self-reliance, non-interference with other people's lives, and physical strength. As adolescents and adults they have had to cope with life in much larger and more densely populated communities, in a world that rewards formal education, language skills, and discussion instead of action. The majority of individuals have adjusted to the new situation but for some the burden has been a significant challenge. In some cases, these changes have been associated with historical changes in climatic conditions. The relationship between climate and settlement in Greenland illustrates the complexity of these changes in arctic communities (see Box 15.1).

Over the last 50 years, the population of most arctic regions has dramatically increased. Much of this increase is due to a reduction in infant mortality and mortality from infectious diseases, particularly tuberculosis and the vaccine preventable diseases of childhood. Also, safe water supplies, sewage disposal, development of rural hospitals, and in some regions, community-based medical providers, have contributed to improved care and access to care for injuries and illness. All regions have greatly improved transportation infrastructure, resulting in the availability of western food items, tobacco, and alcohol on a scale not previously possible. Plus, in many arctic regions communications technology has made western culture visible in even the most remote settlements. Arctic indigenous residents are, in most regions, encouraged to become permanent residents in fixed locations, to facilitate the provision of services and economic opportunities. This has eliminated the historic practice of families and groups of families to move, intact, when climate or other environmental change made a region

Box 15.1. Climate change impacts on settlement in Greenland

In the early 20th century, climate warming resulted in Atlantic cod (*Gadus morhua*) appearing in great shoals off the west coast of Greenland. Cod fishing became a source of cash income for the Greenlanders and the traditional society based on hunting of seals and whales began to make way for a modern fishing society and cash economy. The population of Greenland concentrated in fewer and larger towns and the number of villages decreased. This development was intensified after the Second World War due to deliberate concentration of the population in towns with schools, health care, and shops. Fishing was planned to be the major source of revenue for the Greenland society. In the 1960s, however, climate cooling together with overfishing resulted in the disappearance of cod from the west coast of Greenland (Hamilton et al., 2003) (see also section 15.5.5.3).

In the 1960s, large numbers of shrimp were detected in Disko Bay. Over the course of a few years, the village of Qasigiannguit with a population of only 343 in 1955 developed into a lively town centered on the shrimp factory. During the 1990s, the shrimp disappeared from the coastal waters. Large sea-going vessels now fish and process the shrimp far from the coast and the factory has closed. People have started moving from the town. In 1982 when the population was at its maximum there were 1800 inhabitants; in 2000 the population of Qasigiannguit was only 1400. The unemployment rate is among the highest in Greenland: 14.4% compared to 7.1% in the towns in general.

The examples show how climate change can influence the occurrence of commercially important species and how the disappearance of a species can have negative impacts on socio-economic conditions within a local community. Many Inuit communities are particularly vulnerable to changes in species availability because they often rely on the availability of only one or a few species.

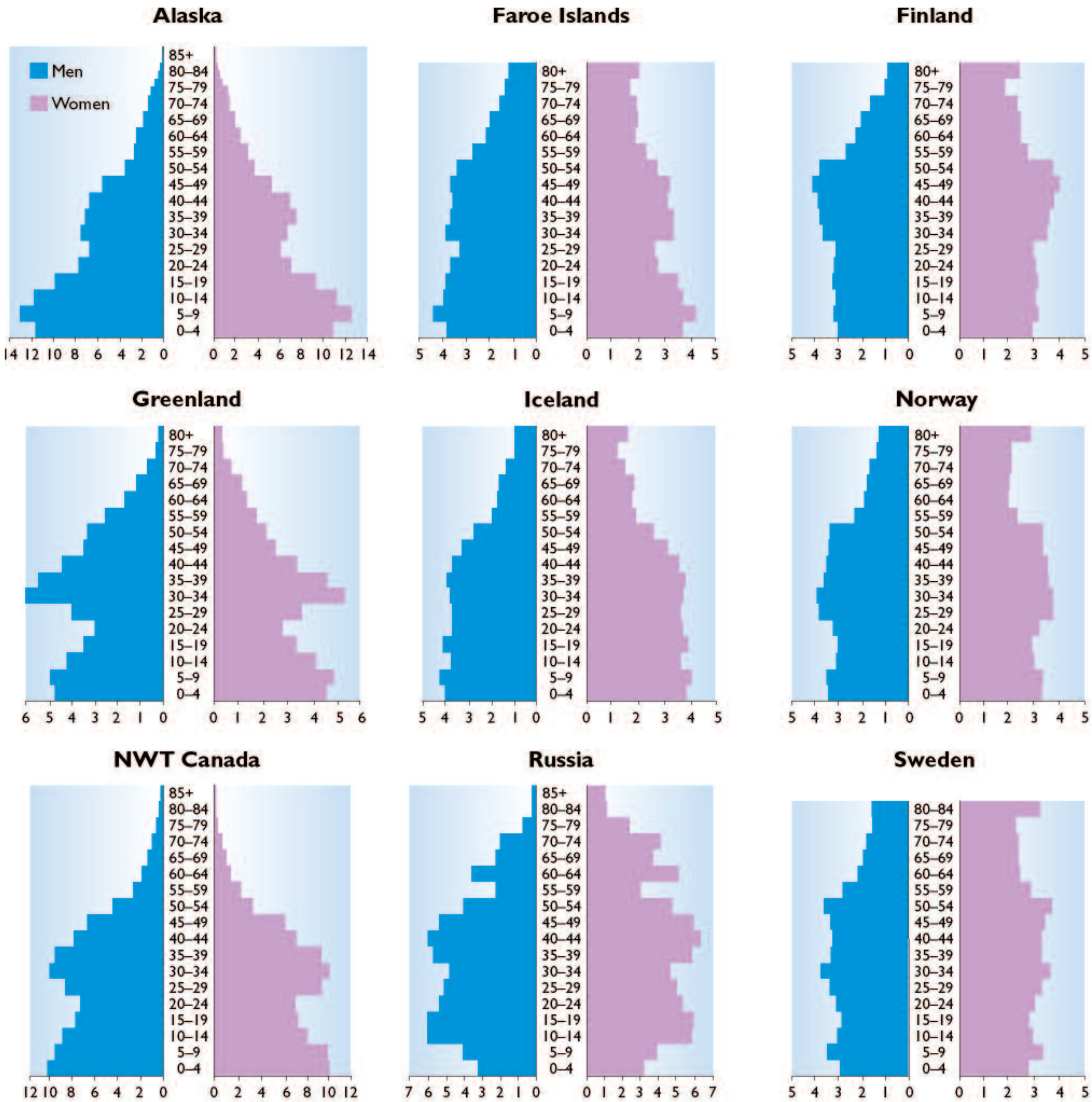

Fig. 15.1. Age structure of arctic populations (WHO, 2000).

unable to sustain them. Also, there are often few products or services that many small communities can contribute to the overall economy, such that survival often depends on a complex web of government-funded economic support, combined with primarily service-based employment in schools, sanitation facilities, and transportation infrastructure. The establishment of fixed village locations has also affected subsistence activities.

Indigenous culture is under stress from competing western culture, and subsistence activities are affected by climate change and concerns about the contamination of traditional food resources by contaminants, both from local sources and from long-range sources transported to the Arctic via ocean and atmospheric currents. Zoonotic diseases (animal diseases that can be passed to humans) and parasitic diseases are also associated with some traditional food species and traditional food preparation methods (e.g., trichinosis or botulism). Assessments of food safety have resulted in the collection of information on micronutrients and anthropogenic chemicals and have often resulted in the release of confusing or conflicting messages to rural residents (AMAP, 2003; CACAR II, 2003). As a result, erosion of cultural support, a decrease in traditional activities, and substitution of western foods for traditional foods are becoming more important as the causes of morbidity and mortality among arctic populations such that, in some respects, they now more closely resemble western populations.

Historically, there was little heart disease, cancer, obesity, or diabetes in circumpolar populations. Major causes of mortality were infectious diseases, especially tuberculosis, pneumonia, and injury. Life expectancy was short,

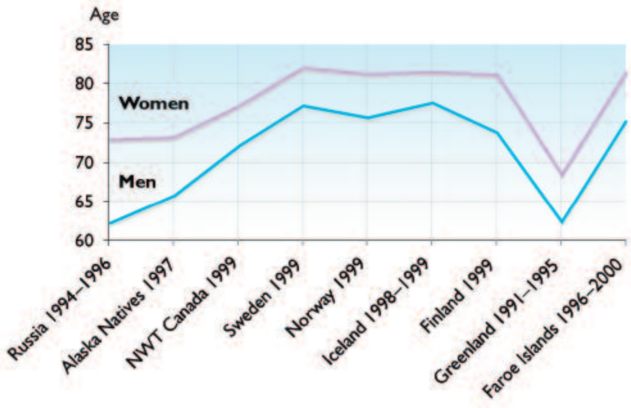

Fig. 15.2. Life expectancy in arctic populations (IHS, 1999b; WHO, 2000).

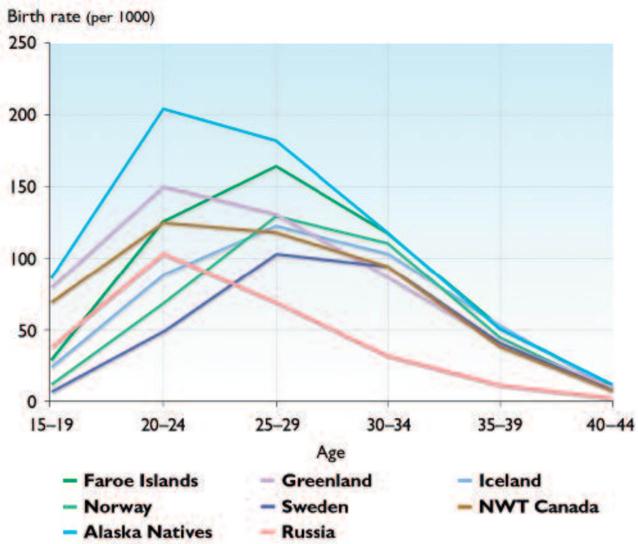

Fig. 15.3. Birth rates by age group in arctic populations (IHS, 1999b; WHO, 2000).

and infant mortality was high (Bjerregaard and Young, 1998). However, for the reasons discussed in this section much has now changed. Section 15.2.2 presents the current population structure, birth rates, infant mortality, and causes of adult mortality for the countries with arctic residents. Arctic regions of the Russian Federation have few comparable data but there is no reason to believe that this region does not also have similar serious health problems as seen elsewhere.

Many technological advances have made subsistence hunting safer, such as modern protective clothing, Global Positioning System (GPS) devices, radio, cellular telephones, and weather forecasts. Hunting efficiency has also improved dramatically through the use of modern firearms and improved transportation, such as boats, snowmobiles, all terrain vehicles, and aircraft. These advances have the potential to erode traditional knowledge and skills, which could increase risk. For instance, loss of traditional knowledge of short-term weather changes and ice thickness could result in injury or death.

15.2.2. Population structure and health statistics

Some regions of the Arctic have a different population structure compared to that of more temperate regions of the same country. This is true for the indigenous rural arctic populations; including Alaska Natives, Canadian Arctic indigenous groups, Inuit, and Greenland Inuit.

The populations of the Northwest Territories (NWT, including Nunavut) and the Yukon (which are predominantly indigenous), as well as Alaska Natives and Greenland residents (who are 90% Inuit), have a greater percentage of children and a smaller percentage of older people than in the Nordic countries (Fig. 15.1; AMAP, 2002). These three groups represent the majority of rural arctic residents for whom comparable health data exists. All these groups typically reside in very small communities (of around 50 to 5000 inhabitants), in remote regions, and with traditional foods comprising a significant part of the diet.

The health of arctic populations can be determined from a range of health status indicators, including life expectancy at birth, birth rate, infant mortality, population mortality, and age-adjusted causes of death.

15.2.2.1. Life expectancy

Life expectancy in arctic populations has improved owing to a wide variety of changes in social conditions and lifestyles. A significant contributor to improved life expectancy is decreased infant mortality. Alaska Natives, NWT residents, and Greenland residents generally have lower life expectancies than residents in the Nordic countries and on average, life expectancy is lower for indigenous populations (Fig. 15.2; Statistics Canada, 2003).

15.2.2.2. Birth rate

Alaska Natives, NWT residents, and Greenland residents have higher birth rates than residents in the Nordic countries (Fig. 15.3). This reflects the greater proportion of children in these populations.

15.2.2.3. Infant mortality

Infant mortality has decreased considerably since around 1950 for Alaska Natives (Fig. 15.4). Despite the improvement the overall infant mortality rates for indigenous arctic residents in Alaska and Greenland remain higher than for all races infant mortality rates in the United States and Canada. Infant mortality rates are lowest in the Nordic countries.

15.2.2.4. Common causes of death

Differences also exist in the most common causes of death based on death certificate data. To account for differences in population age structure (see Fig. 15.1) the mortality rates were adjusted to those for a standardized population structure; although the standard population structure used for the Nordic countries is slightly different to that for Canada and the United States. Figure 15.5 compares death

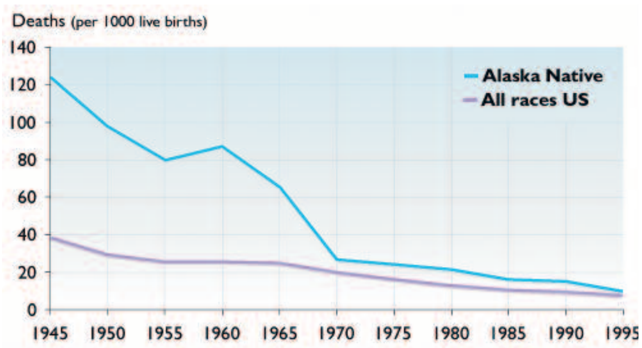

Fig. 15.4. Rates of infant mortality in Alaskan Natives and all races U.S. infants (IHS, 1999b; WHO, 2000).

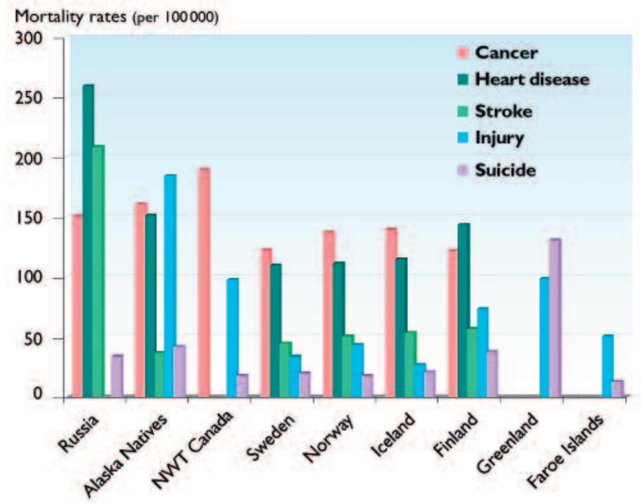

Fig. 15.5. Common causes of death in arctic populations (IHS, 1999b; WHO, 2000).

rates for a range of conditions in indigenous populations (or largely indigenous in the case of the NWT) and the American and European populations. It is evident that Alaska Natives and Greenland residents have much higher mortality rates for injury and suicide. Mortality rates for heart disease and cancer are now similar in arctic indigenous populations and in relation to overall rates for the United States, Canada, and Northern European countries.

15.3. Potential impacts of direct mechanisms of climate change on human health

Human health in northern communities is affected via a number of direct and indirect impacts of climate-related changes. "Direct impacts" refers to those health consequences resulting from direct interactions with aspects of the environment that have changed or are changing with local climate (i.e., resulting from direct interactions with physical characteristics of the environment: air, water, ice, land; and for example exposure to thermal extremes). They include such things as difficulties in dealing with heat and cold stress; alleviation of cold stress due to warmer winters; dangers associated with travel and activities on the land resulting from unpredictable weather patterns and ice conditions; and increased incidences of sunburn and rashes as a result of increased sun intensity and exposure to UV-B radiation.

The direct impacts of climate and UV radiation on human health are primarily related to extreme events, temperature, and changes induced by exposure to UV-B radiation. Much of the discussion in this section on the mechanisms involved in these potential impacts involves associations of health events with observed climate change, without assigning causality. Where the effects are understood, the mechanisms are described. However, in many instances, the exact mechanisms are not known, or the relationships between human health and climate variables are multifaceted.

15.3.1. Extreme events

Some reports indicate that extreme weather events such as droughts, floods, and storms may become more frequent and intense in the future (Haines and McMichael, 1997) and there is some evidence that this is already occurring (see Krupnik and Jolly, 2002). Injury and death are the direct health impacts most often associated with natural disasters. Precipitation regimes are expected to affect the frequency and magnitude of natural processes which can potentially lead to death and injury, such as debris flow, avalanches, and rock falls (Koshida and Avis, 1998).

Thunderstorms and high humidity have been associated with short-term increases in hospital admissions for respiratory and cardiovascular diseases (Kovats et al., 2000). According to Mayer and Avis (1997), there is controversy concerning the incidence and continuation of significant mental health problems, such as post traumatic stress disorders following natural disasters. An increase in the number of mental health disorders has been observed in the United States after natural disasters. Longer periods of extreme weather and storm events could have social impacts on communities that are isolated from regional centers and if major modes of transport are no longer available. The impacts of extreme events on everyday subsistence activities could also affect community and individual well-being.

Indigenous people throughout the Arctic have reported that the weather has become more "unpredictable" and in some cases that extreme or storm events progress more quickly today than in the past (Fox S., 2002; Furgal et al., 2002; Krupnik and Jolly, 2002). Some northern residents report that this unpredictability limits subsistence activities and travel and increases the risks of people being trapped by weather while outside the community (Fox S., 2002; Furgal et al., 2002; Krupnik and Jolly, 2002; see Chapter 3).

> *Yeah, it changes so quick now you find. Much faster than it used to… Last winter when the teacher was caught out it was perfect in the morning, then it went down flat and they couldn't see a thing. It was like you were traveling and floating in the air, you couldn't see*

the ground. Eighteen people were caught out then, and they almost froze, it was bitterly cold. Labrador hunter, as quoted in Furgal et al., 2002

15.3.2. Temperature-related stress

Warming is projected for some regions of the Arctic (see Chapter 4), and this may result in an increase in the number and magnitude of extreme warm days. Exposure to extreme and prolonged heat is associated with heat cramps, heat exhaustion, and heatstroke. However, because of the low mean temperature in many arctic regions, the likelihood of such events having large impacts on public health for the general population is low. Death rates are higher in winter than in summer and milder winters in some regions could actually reduce the number of deaths during winter months. However, the relationship between increased mortality and winter weather is difficult to interpret and more complex than the association between mortality and morbidity and exposure to high temperatures (Haines and McMichael, 1997; Patz et al., 2000). For example, many winter deaths are due to respiratory infections such as influenza and it is unclear how influenza transmission would be affected by warmer winter temperatures. Some studies indicate an association between extreme temperature-related events and mortality. For these associated impacts, groups such as the elderly and people affected by cardio-respiratory problems are more vulnerable (Patz et al., 2000).

In North America, summer heat waves affect more urban populations than northern people, especially because of the urban heat-island effect (Kovats et al., 2000). The impact is greater when the high temperatures (>25 ºC) are irregular and occur at the beginning of summer (Thouez et al., 1998). Indigenous people in some regions of the Arctic are reporting incidences of stress related to temperature extremes not previously experienced. For example, shortness of breath and reduced physical activity (e.g., fishing), and an increase in respiratory discomfort (Furgal et al., 2002).

Fewer cold days, associated with a general warming trend in some regions during winter, are reported to have the positive effect of allowing people to get out more in winter and so alleviate stress related to extreme cold (Furgal et al., 2002). However, in Nunavik for example, approximately one to two heat waves occur every 30 years while extreme cold is much more common. In regions where heat waves do not represent a real risk for northern populations, an increase in extreme cold events could have more serious implications. According to Dufour (1991), respiratory problems were responsible for one in seven deaths among the Inuit population of Nunavik. Muir (1991) reported that respiratory problems were the primary reason for visits to the nurse or doctor. Chronic respiratory illnesses are highly prevalent in some northern regions. For example, in Labrador, breathing problems are among the most common long-term medical conditions in adults and children (LIA, 1997). In these two northern Canadian regions, chronic respiratory illnesses could be amplified by prolonged cold events. Indirect effects of prolonged cold events could also occur as other public health problems are further aggravated. For example, spending a longer period of time in crowded and overheated houses during prolonged cold periods could affect the transmission of viral infections, especially among the elderly, the young, and the physiologically vulnerable (e.g., individuals who are immunosuppressed due to the presence of other diseases or medication). Other factors such as smoking can also modify the incidence of respiratory illnesses.

In the 1970s, scientific research focused for the first time on dramatic rises in mortality every winter, and on smaller rises in unusually hot weather. Heat-related deaths often result from severe dehydration (causing hemoconcentration) resulting from the loss of electrolytes and water in sweat and the inability to regulate body temperature. In northern Sweden, a clear association between atmospheric pressure, changing temperature, and increasing rates of cardiac events was documented (Messner et al., 2003). Exposure to low ambient temperatures for long periods brings specific physiological stresses. Cold exposure is part of daily working life in the Arctic. It affects human outdoor activity significantly because the arctic winter is long and cold conditions are severe. Winter, with mean temperatures of less than 0 ºC, lasts for more than seven months in some regions. The interactions between temperature (in this case cold) and health, and the various health consequences are summarized in Fig. 15.6. Responses to cold may be normal, exaggerated (hyperreactions), or damped (hyporeactions). These result in eventual body cooling and associated impacts. In some instances, hyperreactions may occur which themselves result in disease. Climate models project that cool winter temperatures will persist in many circumpolar regions (see Chapter 4). Cold is likely to remain an environmental cause of illness and death.

15.3.2.1. Limits of human survival in the thermal environment

Human body heat balance depends on: the thermal environment (air temperature, air velocity, air moisture, and radiative heat gain from sun or artificial sources); the thermal insulation of clothing; and the rate of physical work producing heat via metabolic pathways (e.g., Parsons K., 1993). For a naked human at rest, the thermoneutral air temperature is 27 ºC. In temperatures above the thermoneutral zone, heat loss is increased by sweating, and in lower temperatures, heat production is increased by muscular work (up to about 1200 W) or by shivering (up to about 500 W). By doing heavy physical work, a naked human can survive at an air temperature of about -5 ºC for several hours. The extreme limits of behavioral temperature regulation depend on available technology, but working at extreme low or high temperatures is possible with special clothing. The removal of body heat by air movement, and its practical application in designing appropriate clothing, is known as the "windchill" effect (Quayle and Steadman, 1998).

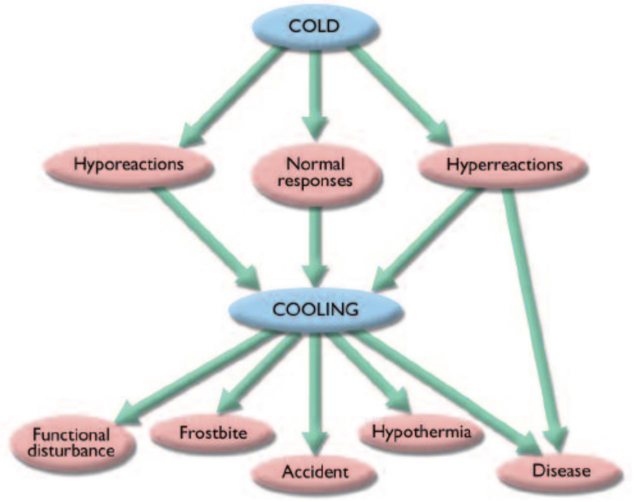

Fig. 15.6. Interactions between temperature and health.

The effects of heat balance are usually classified in terms of five levels: comfort, discomfort, performance degradation, health effects, and tolerance (Lotens, 1988). For an adequately clothed person initial cold problems start to appear at an ambient temperature of 10 ºC when fingers start to cool during light manual work. Even with heavy work, cold problems appear at between -20 and -25 ºC. For optimal manual performance, skin temperature is 32 to 36 ºC. Below a skin temperature of 13 ºC manual performance rapidly deteriorates. Marked changes in ambient temperature can increase or decrease cognitive performance or remain without effect. When effects are seen, cold particularly appears to affect the performance of complex cognitive tasks involving short-term or working memory (Palinkas, 2001).

Psychological, whole body, and local physiological acclimatization develops when the thermal environment is changed. Marked acclimatization can be developed within about ten days. In cold, the usual signs of acclimatization are blunted responses of the cardiovascular system (heart rate and blood pressure) and heat production (shivering). Cold-induced vasoconstriction in hands is also attenuated (e.g., Rintamäki, 2001). Heat acclimatization involves increased sweating and earlier onset of sweating.

For healthy active people a 5 to 10 ºC decrease in temperature is not expected to result in serious effects on the maintenance of body heat balance during outdoor work. Humans can compensate for a 10 ºC decrease by wearing additional clothing or by increasing metabolic heat production by 30 to 40 W/min. If the temperature of arctic or subarctic climates increases by 5 to 10 ºC, the climate would still be cool or cold, with cold temperatures still having more impact on human physiology than heat. More serious problems could occur under extreme conditions such as during the coldest winter months in arctic or subarctic climates, if ambient temperatures decrease or the cold season increases markedly in length. There is an upper limit to the thermal insulation of winter clothing. A decrease or increase in ambient temperature, especially if the change is rapid, is a more serious threat for sick and/or elderly people than for healthy individuals capable of a physically active lifestyle.

15.3.2.2. Cold injuries

Cold-related injuries are immediate pathological consequences of cold exposure. As a consequence of direct or indirect effects of cold, the total injury rate may increase in relation to environmental cold exposure. The rate of slip and fall injuries, for example, increases with decreasing temperature. Increasing rates of slip and fall injuries are seen at temperatures of 0 ºC and below. Low temperature is often a secondary source of injury and may not be reflected at true frequencies in statistical records. Risk of unintentional injury is least at a temperature of about 20 ºC and increases with lower and higher ambient temperatures.

Injuries such as frostbite, hypothermia, and others are linked to body cooling. Cooling injuries occur most often during winter months, especially during the few coldest winter days and are also increased by wind speed. Cooling injuries show a strong relationship with temperature, i.e., the lower the temperature the more injuries occur. The majority of cooling injuries are freezing injuries (e.g., frostbite) (Taylor M., 1992).

Frostbite generally occurs on the most peripheral parts of the body (head, hands, feet). For the head, frostbite of the ears is almost twice as common as frostbite of the nose and cheek. Several areas of the body may be injured simultaneously. Mild frostbite most commonly occurs in the head region. Frostbite of the feet and hands frequently causes severe tissue damage and requires medical treatment or hospitalization. Young Finnish men reported a 2% annual incidence in frostbite over their lifetimes. Twenty-five percent was blister grade or more severe. In general, the incidence of frostbite varies annually from 0 to 27% among different outdoor occupations. Also, urban people experience more frostbite than rural people for the same thermal environments (Ramsey et al., 1983). Frostbites are comparable to burns in their immediate consequence. The immediate effect of frostbite can be a mild or more severe functional limitation of the injured area, requiring medical attention, and in some cases, hospitalization. The most common latent symptoms of frostbite are local hypersensitivity to cold and pain in the injured area, cold-induced sensations and disturbances in muscular function, and potentially excessive sweating. These latent symptoms may have negative impacts on occupational activities in 13 to 43% of cases. Permanent post-symptoms or invalidity commonly develop as a result of severe frostbite requiring hospitalization (Miller and Chasmar, 1980). Factors known to cause a predisposition to frostbite include cold-provoked white finger phenomenon, sensitivity to cold, diabetic vascular disease, psychiatric disorders, prior frostbite, older age, and tobacco smoking (Hassi and Mäkinen, 2000). Use of certain drugs or alcohol, "cold protective ointment" on the face, and inadequate clothing increase risk of frostbite during cold exposure

(Lehmuskallio, 1999). Accidents, fatigue, and poor nutrition are also associated with increased frostbite risk.

15.3.2.3. Cold-related diseases

Cold-related diseases are either caused by cold or are affected by cold exposure. The rate of cooling in different sites of the human body is also modified by individual factors like cardiovascular diseases, diseases of peripheral circulation, respiratory diseases, musculoskeletal diseases, and skin diseases.

Cardiovascular diseases

The higher incidence of cardiovascular events in colder regions and during winter is well known, and several mechanisms have been suggested based on increased blood pressure, hematological changes, and respiratory infections (Keatinge, 1991). Most investigations have used ecological data such as daily temperatures recorded at weather stations and mortality in the general population. Cause-specific mortality is the outcome measure most commonly used. Hospital discharge records, linked with out-of-hospital deaths, provide a powerful tool for detecting even weak effects of temperature. The association of coronary heart disease mortality and temperature is usually U-shaped, mortality being lowest within the range 10 to 20 ºC and higher either side. However, the temperature at which mortality reaches a minimum is lower in colder countries (Fig. 15.7). For example, in Yakutsk, Siberia, temperatures as low as -48 ºC had no effect on coronary mortality rates (Donaldson et al., 1998a; Näyhä, 2002).

The increase in mortality on the colder side is about 1% per 1 ºC decrease in temperature, but the increase on the warmer side may be very steep. The exact point of the minimum temperature and the magnitude of the effect vary between countries. In Finland, the winter excess mortality from coronary heart disease has leveled off over recent decades. The share of annual mortality from cardiovascular diseases due to cold is estimated at 5 to 20%. The detailed mechanisms by which cold is related to cardiovascular mortality, either directly or by respiratory infections or indirect effects of winter behaviors such as shoveling snow, have not been clarified. Cold exposure causes an increase in blood pressure and hemoconcentration resulting from fluid shifts, leading to coronary thromboses one to two days after cold exposure. Following the recent decline in influenza mortality, around half the excess winter deaths are now due to coronary thrombosis. These peak about two days after the coldest part of a long period of very cold weather. Around half the remaining winter deaths are due to respiratory disease, and these peak about 12 days after maximum cold days.

Cerebral vascular diseases

The association of temperature and cerebral vascular accidents is similar to that for coronary heart diseases with morbidity and mortality increasing with a decline in temperature. The pattern is often U-shaped, with some increase in numbers at warmer temperatures. The morbidity and mortality of stroke is usually lowest at temperatures of 15 to 20 ºC, however some variations exist. In northeastern Russia stroke mortality only increases at temperatures below 0 ºC (Donaldson et al., 1998b; Näyhä, 2002).

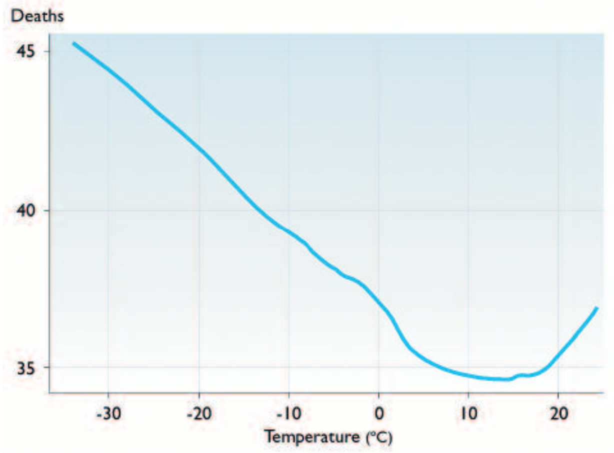

Fig. 15.7. Deaths from coronary heart disease and mean daily temperature in Finland, 1971–1995 (Donaldson et al., 2003).

The gradient of cerebral vascular accidents against temperature is around 1% per 1 ºC decrease in temperature, as for coronary heart diseases. In Japan, the dose–response relationship was similar for intracerebral hemorrhages and cerebral infarctions, whereas in Finland a greater winter excess was observed in the incidence of intracerebral hemorrhage than for other forms of stroke, but no gradient relative to temperature has been reported. A change in temperature of at least a two-day duration is needed for stroke mortality to rise, and the time lag between the temperature change and the maximal increase in mortality is estimated at one to four days (Donaldson and Keatinge, 1999).

The long-term trends in the effect of temperature on stroke have not been determined, but the seasonal amplitude of stroke deaths in Finland has diminished since the 1920s. The proportion of stroke-related deaths attributable to the cold season was estimated at 13% in the 1960s, but had diminished to 9% by the 1990s. A British investigation which reported a decline of 57% in the stroke-temperature gradient between 1977 and 1994 also suggested that the effect of environmental temperature on stroke is being modified by other external factors (Donaldson and Keatinge, 1999).

Respiratory diseases

Common respiratory cold-related symptoms are watery rhinitis, and as a consequence of constriction of the bronchi, asthma-like symptoms which include wheezing, coughing, and breathing difficulties. Deaths related to respiratory diseases, primarily pneumonia, increase significantly during the winter months. Watery rhinitis is a physiological irritation response to cold air inhalation and is harmless.

The prevalence of breathing problems provoked by exercise and/or cold weather is high among asthmatic subjects (81.6%) and significantly elevated among allergic subjects (45.1%) and people with chronic obstructive pulmonary disease (74.6%). For people with no known respiratory disease, the prevalence is 10.0%. The risk of chronic bronchitis and bronchitic symptoms at the population scale is elevated in outdoor workers in some populations, but is not elevated in regular recreational cross-country skiers, and the risk of developing asthma is not significantly elevated by regular exercise or work in cold climates. Constriction of the laryngeal area is a momentary reflex in response to cold air and is usually harmless. In very exceptional cases of the disease, known as cold urticaria, this phenomenon may be life-threatening. Air quality and behavioral choices such as smoking are also major influences on the incidence of respiratory diseases.

Peripheral circulatory diseases

The normal responses of the peripheral circulatory system to cold stress can be affected in individuals with vascular diseases. Thermal comfort and physical performance may be decreased and risk of cold injury may be increased. In advanced stages of peripheral arteriolosclerosis, blood vessels are narrowed. Further constriction caused by cold exposure may increase risk of frostbite. A reversible episodic constriction of the blood vessels in fingers and toes is a fairly common pathological response to cold exposure and is known as the Raynaud's phenomenon. Owing to the constriction of the blood vessels, the blood flow in fingers and toes is markedly reduced at temperatures colder than 10 ºC. Originally, Raynaud's phenomenon was described as episodic white fingers provoked by cold or other stress factors, together or alone. The population prevalence is 5 to 30% and is related to gender, age, and region of residence (Maricq et al., 1993). As a clinically significant condition, it has a reported prevalence of 2 to 6%. Cold exposure in a patient with the condition may result in a cluster of different symptoms caused by transient constrictions occurring in the circulation of the heart, lung, kidneys, or brains. The symptoms may vary widely and can include migraine headaches, chest pain, and possible visual effects.

Cold urticaria

The most familiar and common abnormal skin reaction related to cold exposure is cold urticaria. It is usually a chronic condition and is often provoked by some other physical agent. Symptoms usually occur locally on exposed areas of skin. They sometimes appear during cold exposure but more frequently appear when the skin re-warms after cooling and then disappear again after 20 to 30 minutes. Fifteen percent of the population is subject to symptoms at some stage and the annual average prevalence in Finland is 2 to 4%. Cold urticaria lasts from months to several years. Prevalence of hospitalization for severely affected patients is only around one in 4000. In cold urticaria, skin reaction to cold exposure is characterized by erythema, swelling, wheals, or papules. Other symptoms on cold exposure can be more severe, such as vertigo, headache, nausea, vomiting, tachycardia, dyspnea, flushing, faintness, or rarely, life-threatening anaphylactic shock.

Musculoskeletal diseases and symptoms

There is limited scientific understanding of the relationship between musculoskeletal diseases and cold. Extensor tenosynovitis has been described with windy cold exposure in temperatures from 0 to -25 ºC (Georgitis, 1978). The increased incidence of tenosynovitis in female food industry workers was attributed to the low ambient temperature (Chen et al., 1991; Chiang et al., 1993). Local cold exposure in a frozen food factory was associated with a ten times higher incidence of carpal tunnel syndrome than in warm environments (Chiang et al., 1990). Symptoms of musculoskeletal diseases can vary, and include local or generalized feelings of pain and fatigue of muscles and joints. Low back pain, knee pain, and shoulder pain were significantly more common in cold storage workers than in a thermoneutral environment and were dependent on the duration of the work in the cold environment.

Cold-related immune effects

Cold temperatures and isolation can be immunosuppressive and, in humans who have over-wintered in the Antarctic, suppression of cell-mediated immunity is well documented (Ando, 1990; Muller et al., 1988; Tingate et al., 1997). The effect of sunlight-induced immunosuppression above (or concomitant with) this temperature/isolation induced immunosuppression remains to be determined.

15.3.2.4. Summary

Changes in the frequency or intensity of natural disasters or extreme weather events can have direct and indirect impacts on human health in the Arctic. In remote locations this is accentuated by a reduced capacity to respond to these events because of the isolated nature of the communities and the often limited health infrastructure present. The variability of such events is likely to increase with future climate changes. Changes in temperature have the potential to influence health in arctic communities in both negative and positive ways.
With the low mean annual temperature in many arctic regions, the likelihood of heat events having large health impacts on the general population is low. However, the impacts of these events on individuals with respiratory problems and other conditions can be serious. Fewer colder days associated with winter warming in some regions may actually have several positive health impacts. Impacts of cold temperature are well known and increases in the length or magnitude of extreme cold periods in some regions may have significant negative impacts on the general population, especially for individuals with conditions making them more susceptible to such exposure. Under any climate change scenario, tem-

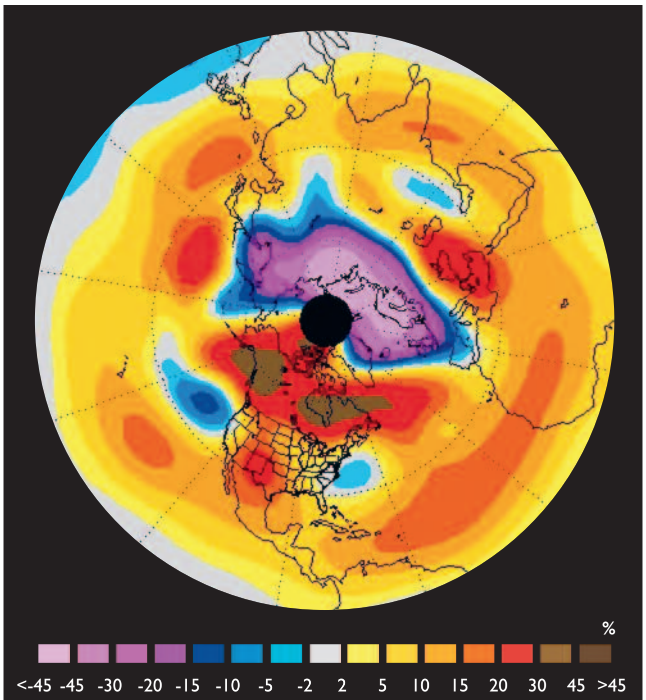

Fig. 15.8. Total ozone anomalies in the northern hemisphere for March 2003 relative to the mean March value for 1979 to 1986. Areas where the March 2003 value is within ±2% of the long-term mean are shown in light gray (data provided by NOAA, National Weather Service, 2003).

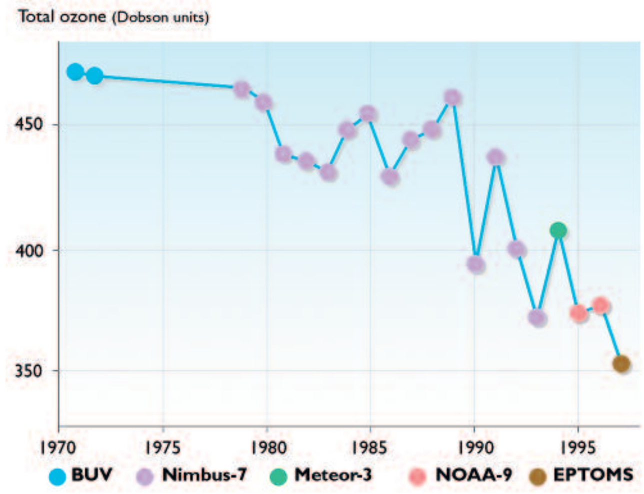

Fig. 15.9. Average total ozone over the Arctic (63° to 90° N) in March. 1971 and 1972 data are from the BUV instrument on the Nimbus-4 satellite; 1979–1993 data are from the Total Ozone Mapping Spectrometer (TOMS) on Nimbus-7; 1994 data are from the TOMS on Meteor-3; 1996 data are from the SBUV/2 on NOAA-9; 1997 data are from the TOMS on the Earth Probe satellite. (http://www.cmdl.noaa.gov/star/arcticuv2.html).

perature will continue to influence the health of arctic populations both directly and indirectly.

15.3.3. UV-B radiation and arctic human health

Stratospheric ozone loss has been observed during the winter/spring months over most of the Arctic since the early 1990s. Losses of up to 40% have been recorded in Scandinavia and Siberia, and in Canada, sporadic losses of 10 to 20% or more have been reported. The daily total ozone level in March 1997 at Point Barrow (71.3° N) in Alaska was about 6% below the previous ten-year average, and on 17–18 March 1999, Barrow experienced record low ozone levels for that location in March.

During winter and spring 2001/02, the mean March stratospheric ozone levels show a 5 to 15% loss of ozone compared to the average March value for 1979 to 1986. The 2002/03 winter also had low total ozone values over parts of the Arctic. The decrease was greater than for the previous two winters, but not as great as in the 1990s. During the winter months of 2002/03 (December, January, February, and March) parts of the Arctic, mainly but not limited to Siberia and Scandinavia, had levels up to 45% lower than comparable values for the same area in the early 1980s (NOAA National Weather Service, unpubl. data, 2003). Recent data indicate widely diverse ozone losses continuing throughout the year. Figure 15.8 shows the March 2003 anomalies for stratospheric ozone relative to the average March values for 1979 to 1986.

Figure 15.9 shows the large decline in average total ozone values in March over the Arctic (63º–90º N) during the 1990s. McKenzie et al. (1999) presented some of the strongest data to date regarding the relationship between ozone loss and increased levels of UV-B radiation. Although their data are for the southern hemisphere the same relationship is highly likely to occur in the Arctic. The data, which reflect ozone levels for the austral summers between 1978/79 and 1998/99 and UV-B radiation levels for the austral summers between 1989/90 and 1998/99 at 45° S (Fig. 15.10), provide strong evidence for increases in UV-B radiation levels in areas where baseline levels were already high, suggesting that man-made perturbations to the ozone layer are occurring as predicted (see also Chapter 5).

UV-B related human health effects include increases in the incidence of skin cancer, potential effects associated with increased suppression of the immune system including weakened resistance to some types of infectious disease (Sleijffers et al., 2002), and increased incidence of cataracts as well as changes in Vitamin D_3 production in the skin (IASC, 1995). In the Arctic, increases in UV-B radiation may also interact with other environmental stressors such as chemical pollutants, cold temperature, isolation, and viral illnesses in some populations (IASC, 1995). The rest of this section describes potential UV-B related health effects.

15.3.3.1. Immunosuppression

Ultraviolet-B radiation can initiate a selective down regulation of cell-mediated immunity in mammals, including humans. It is speculated that this may be a natural regulatory mechanism, selected through evolutionary pressure, to prevent autoimmune attack on sunlight-damaged skin (De Fabo and Noonan, 1983). The unusu-

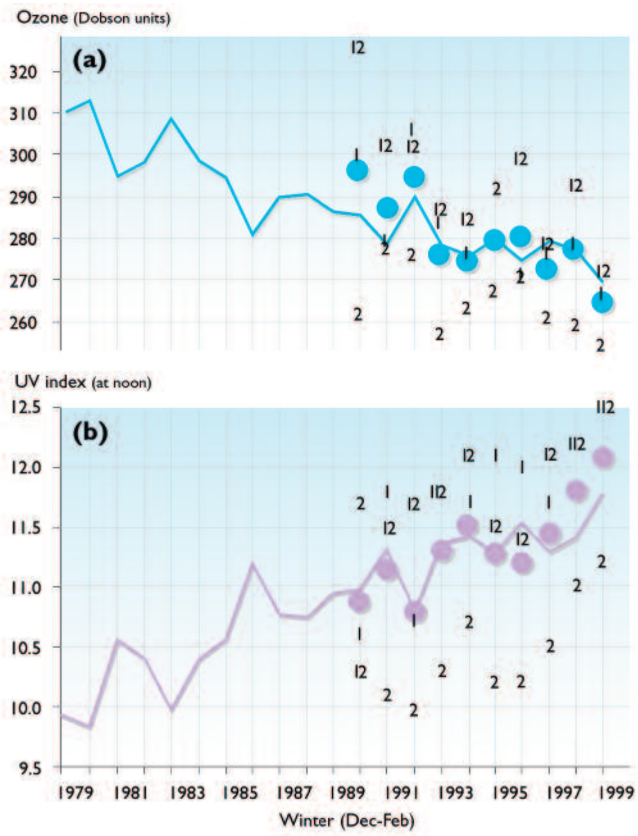

Fig. 15.10. Association between (a) ozone loss and (b) increased levels of UV-B radiation (Mackenzie et al., 1999).

al feature of UV-B-induced immunosuppression is that it redirects cell-mediated immunity to sensitizing antigens from an up or "effector" type response to a down or "suppressor" type response. These antigens can include chemical, viral, and tumor antigens (Noonan and De Fabo, 1992). Significantly, skin pigmentation is not an efficient protection factor against UV-B induced immune suppression. Immunosuppressive effects of UV-B radiation play an important role in UV-B induced skin cancer by preventing the destruction of highly antigenic skin cancers by the immune system (De Fabo and Kripke, 1979, 1980).

An in vivo wavelength dependence study by De Fabo and Noonan, (1983) for immune suppression of contact hypersensitivity in mice has identified a light-absorbing substance, residing on skin, as *trans*-urocanic acid (UCA). The *cis* structure of UCA (*cis*-UCA) formed upon absorption of light by *trans*-UCA, is known to cause immunosuppression in humans similar to that in mice caused by UV-B radiation (van Strien and Korstanje, 1995). In addition to sunlight modulation of cell-mediated immunity, which may involve susceptibility to certain infectious diseases (Sleijffers et al., 2002), *cis*-UCA may be important for arctic populations for another reason. A recent report indicated that a binding receptor for *cis*-UCA has been identified as the neurotransmitter 5-hydroxytryptamine, or 5HT (Serotonin) (Nghiem et al., 2002; Walterscheid et al., 2002). Lack of sunlight is known to play a role in mood disorders (Nilssen et al., 1997), among other factors (Näyhä et al., 1994), in arctic populations (Nilssen et al., 1999). Future studies are needed on the role of UCA in human immunity, as well as on mood disorders linked to sunlight deprivation. Box 15.2 describes the action spectra and biological amplification of UV radiation.

Genetically determined susceptibilities to UV-induced immunosuppression have been shown to exist and appear to be controlled by several interacting *Uvs* genes involving autosomal and X-linked genes. Such an interaction for UV-immunosuppression had not been described previously and may be unique for this mechanism (Noonan and Hoffman, 1994). A genetically determined high susceptibility to UV-induced immunosuppression may be an important risk factor for UV-related human diseases not just in arctic populations but in other populations as well.

15.3.3.2. Skin cancer

Immunosuppressive effects of UV-B radiation play an important role in UV-induced skin cancer by preventing the destruction of highly antigenic skin cancers by the immune system (De Fabo and Kripke, 1979, 1980). There are three main types of skin cancer. Two tend not to metastasize and are known as basal and squamous cell carcinoma, and are often referred to collectively as non-melanoma skin cancer. The third type, which shows a higher mortality, and which can metastasize aggressively, is malignant melanoma of which several subtypes exist (Fears et al., 1976; McGovern et al., 1973). It should be noted however that any potential increase in skin cancer incidence related to reflectance from snow is likely to be mitigated by the projected decrease in snow cover.

There is much experimental evidence of a clear connection between sunlight exposure and non-melanoma skin cancer, and which implicates UV-B radiation as a carcinogen (Armstrong et al., 1997; Fears et al., 1976; Parsons P. and Musk, 1982). A relationship between sunlight and malignant melanoma, while less clear, is considered a near certainty (Armstrong and Kricker, 1993; Berwick, 2000; Bulliard, 2000; Fears et al., 1976; Jemal et al., 2001; Mack and Floderus, 1991). Epidemiological evidence indicates that sporadic or intermittent sunlight exposure can be a very important factor in malignant melanoma development, especially in childhood (Autier et al., 1997). But not all sunburn leads to melanoma, as other predisposing factors are needed. The molecular mechanisms underlying the relationship between malignant melanoma and exposure to UV radiation, particularly wavelength specific mechanisms, such as the importance of UV-B radiation, as opposed to UV-A radiation are, at present, unclear. To help clarify these mechanistic pathways, recent developments include, among others, the genetic engineering of a transgenic mouse capable of producing melanoma tumors following UV radiation of neonatal animals. These tumors show a striking similarity to human melanoma (Noonan et al., 2001). Once the active waveband for melanoma induction is identified, an

Box 15.2. Action spectra and biological amplification of UV radiation

Photobiological responses are by definition wavelength dependent. However, to compare the biologically-inducing activity of the many spectrally different sources available, from sunlight to sun tanning lamps, it is necessary to consider differences in wavelength efficiency in initiating the biological response, whether it is skin cancer, sunburn, photosynthesis, or immune suppression. In order to make such comparisons, it is necessary to calculate, and then deliver "biologically effective" doses from the optical source. Differences in wavelength efficiency can be accounted for by using an appropriate wavelength-dependence or "action spectrum". An action spectrum describes the relative efficiency of radiation at different wavelengths to produce a given effect. Health effects experts, for example, rely upon action spectra to provide information regarding which wavelengths in the full spectrum of sunlight or the full spectrum of artificial sunlamps cause sunburn, or DNA damage (Sutherland, 1995; Young et al., 1998), or immune suppression (De Fabo and Noonan, 1983). Once experimentally derived, the action spectrum can be multiplied by the spectral output of any given source. In the case of sunburn, the International Commission on Illumination action spectrum for erythema (McKinlay and Diffey, 1987) is used to calculate the UV Index, a measure of sun burning effectiveness used worldwide (Long, 2003).

Action spectra are also useful in determining increases in biologically effective UV radiation doses due to ozone depletion, known as the "radiation amplification factor" (RAF), and how these increases in UV-B radiation result in "biological amplification" for a given response. For example, to predict changes in skin cancer incidence as a function of stratospheric ozone depletion, two processes are necessary. First, the increase in biologically effective UV-B radiation that results from an ozone loss of 1% must be determined, i.e., the RAF. Second, the ratio of the percentage change in biological effect to the proportional change in biologically effective irradiance – the BAF – needs to be determined. Thus, the total amplification factor for the biological impact is a product of the two: amplification factor = RAF x BAF. More detailed information on ozone depletion, skin cancer, and RAF/BAF determinations is reported by Moan et al. (1989), Jones (1992), and Strzhizhovskii (1998).

In addition to providing a weighting function to determine biologically-effective doses, action spectra are useful for helping to identify the initial light-absorbing photoreceptor responsible for triggering a light-driven biological response (De Fabo, 1980; Noonan and De Fabo, 1993). Such information can help direct further research on a given photobiological response (De Fabo and Noonan, 1983).

action spectrum can be constructed. A skin cancer action spectrum has been used to predict increases in non-melanoma skin cancer by increased UV-B radiation resulting from ozone destruction between 1979 and 1994 (Slaper et al., 1996).

In the Arctic, skin cancer rates are in general low. This is due primarily to the low UV-B radiation levels relative to equatorial regions. Also, skin cancer is rare in arctic indigenous populations consistent with findings elsewhere that skin pigmentation is protective against skin cancer. A recent study, however, involving Danes working in Greenland and cancer risk indicated an elevated risk of melanoma in females. A role for excessive UV radiation exposure in this regard has been suggested (Nielsen L. et al., 1997). With increasing numbers of non-indigenous people living in the Arctic, the incidence of melanoma and non-melanoma skin cancer must be carefully monitored in both groups. Some indigenous groups in the Arctic are reporting evidence of increased UV-B radiation exposure and are experiencing skin rashes and burns for the first time. They report a sense that the "sun is hotter" (Fox S., 2002; Furgal et al., 2002; see also Chapter 3).

> *The sun burns us easily, it was not very hot in the past.* Kuujjuaq, man aged 62 as quoted in Furgal et al., 2002

> *The sun was not that hot in the past. Nowadays, it's really hot. My skin burns when I'm out for a while. Sometimes, we stay indoors in a shack.* Kuujjuaq, man aged 70 as quoted in Furgal et al., 2002

15.3.3.3. Non-Hodgkin's lymphoma

Certain epidemiological evidence suggests a link between non-Hodgkin's lymphoma and sunlight exposure (Langford et al., 1998; Zheng and Owens, 2000). This is suggested to be via the immunosuppressive effects of UV-B radiation (Langford et al., 1998; McKenna et al., 2000; McMichael and Giles, 1996; Zheng and Owens, 2000). A correlation between the occurrence of skin cancer and the occurrence of non-Hodgkin's lymphoma has also been described (Cliff and Mortimer, 1999). However, in contrast to non-melanoma skin cancer, non-Hodgkin's lymphoma does not show a latitudinal gradient in the United States, suggesting that UV-B radiation may be a co-factor rather than a primary causative agent of this disease. Danish women working in Greenland are reported to show an excess of lymphatic malignancies, which raises the question of a role for excess UV-B radiation (Nielsen L. et al., 1997). Autoimmune diseases such as Type-I diabetes and multiple sclerosis may also have an immunosuppressive connection with UV-B radiation

(Staples et al., 2003). The continued reports regarding correlations between health problems and UV radiation indicate the need for further investigation in relation to ozone loss over the Arctic (McKenna et al., 2003; Okada et al., 2003).

15.3.3.4. Cataract

Cataract is a major cause of blindness. In 2002, there were an estimated 180 million people worldwide who were visually disabled. Between 40 and 45 million people are blind (http://www.who.int/pbd/en). Epidemiological reports and experimental studies indicate that cataract formation is a complicated process with many associated risk factors. The precise mechanism of action is not known although UV-B radiation is very strongly implicated and associations with latitude and climatically different countries have been reported (Hockwin et al., 1999; Katoh et al., 2001; Sasaki H. et al., 2000; Sasaki K. et al., 1999; Taylor A. et al., 2002; Taylor H., 1989; West, 1999). Furthermore, a recent action spectrum indicated that after correcting for corneal transmittance, the biological sensitivity of the rat lens to UV-B is at least as great at 295 nm as at 300 nm. After correcting for transmittance by the atmosphere, UV-B at 305 nm is suggested to be the most likely wave band to damage the rat lens (Merriam et al., 2000).

Several types of cataract exist with a varying degree of association with sunlight (Hockwin et al., 1999; Katoh et al., 2001; Sasaki H. et al., 2000; Sasaki K. et al., 1999; West, 1999). Published evidence tends to support the concept that cortical cataract is more likely to be related to UV-B radiation (Hockwin et al., 1999; Katoh et al., 2001; Sasaki H. et al., 2000; Sasaki K. et al., 1999; West, 1999). Another study, however, suggests the opposite when lifetime cumulative UV-B radiation exposure and exposure after teenage years are considered (Hayashi et al., 2003), underscoring the need for further study including detailed wavelength or action spectrum studies on cataract. The importance of dietary factors and cataract also requires further research (Taylor A. et al., 2002; Valero et al., 2002; Wegener et al., 2002).

15.3.3.5. Vitamin D

Vitamin D (calciferol) is a fat-soluble vitamin. It is present in food, but can also be made in human skin after exposure to UV-B radiation from the sun. In general, skin synthesis provides most of the vitamin D to the body (80 to 100%; Glerup et al., 2000) and with adequate sunlight exposure, dietary vitamin D may be unnecessary (Holick, 2001).

Many factors can affect vitamin D production such as season, latitude, age, skin color, time spent outdoors, and sun angle. Few foods contain significant amounts of vitamin D that can act as a substitute for sunshine exposure. Fish with a high fat content, such as sardines, salmon, herring, and mackerel are excellent sources of vitamin D. Other important sources are meat, milk, eggs, and fortified foodstuffs. Fortified foodstuffs however, may not be sufficient to preclude the need for sunlight exposure. In one study it was reported that dark-skinned, veiled, pregnant women, their infants, and elderly in residential care had the highest vitamin D deficiency of subjects studied (Nowson and Margerison, 2002). This suggests that vitamin D deficiency may be a bigger risk factor in populations worldwide when other factors reducing exposure to sunlight are considered e.g., arctic populations during long, dark winters. A balance is thus needed between sunshine exposure and risk of excessive sunlight leading to skin cancer or other UV-B related health effects, or insufficient sunlight exposure and hence vitamin D deficiency for diseases such as rickets and certain non-skeletal diseases (Fahrleitner et al., 2002; Pasco et al., 2001).

Vitamin D exists in several forms, each with a different activity, and is involved in a large variety of biological functions, including regulatory functions (for a comprehensive review of vitamin D see Feldman, 2003). Briefly, the liver and kidney help convert vitamin D to its active hormone form (calcitriol). For example, in skin vitamin D is produced from UV-B-induced photoconversion of 7-dehydrocholesterol (7-DHC; provitamin D). Vitamin D then undergoes hydroxylation to calcidiol (25-OHD_3) in the liver and becomes the major circulating form, and then to calcitriol (vitamin D_3 hormone; 1alpha 25-$(OH)_2D_3$) in the kidney. 1alpha, 25-$(OH)_2D_3$ is carried systemically to distal target organs where it binds to a vast array of nuclear receptors to generate its appropriate biological response. Vitamin D appears, therefore, to be involved in various aspects of fundamental cell regulation.

The major function of vitamin D is to maintain normal blood levels of calcium and phosphorus. Vitamin D aids calcium absorption, helping to form and maintain a strong skeletal structure. Without vitamin D, bones can become thin, brittle, soft, or deformed. Vitamin D prevents rickets in children and osteomalacia in adults, which are skeletal diseases that result in defects that weaken bones. A recent study reports for the first time a link between UV-B radiation exposure and calcitriol synthesis in human skin (Lehmann et al., 2003).

Given the six months of darkness in winter followed in spring/summer by potential excess exposure to UV-B radiation due to ozone depletion, studies in arctic communities on UV-B induction of vitamin D in liver and kidney and vitamin D hormone in skin are of high priority.

15.3.3.6. Other factors

Pollutants

Many types of pollutant have been identified in arctic biota and the arctic environment, including polyaromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and heavy metals (AMAP, 2002). There is some evidence of interaction between UV-B radiation and chemical pollutants. For example, aquatic organisms that have ingested UV-B-absorbing PAHs have been shown to exhibit phototoxic effects following exposure to UV-B radiation (Huovinen, 2000). A number of persistent organic pollutants, including PCBs, are immunologically damaging even without exposure to UV-B radiation. At present there is little information on the potential for the combined effects of these agents or on immunosuppression from exposure to UV-B radiation alone. In view of such findings and the high levels of persistent organic pollutants in areas of the Arctic, research is required on the combined effects of UV-B radiation, PAHs, and PCBs.

Dietary factors

Diet may also be important in UV-B effects in arctic populations. Experimental evidence shows that UV-related immunosuppression in mice can be increased by increasing dietary histidine (Reilly and De Fabo, 1991) and correlates with a modulating increase in *trans*-urocanic acid (De Fabo et al., 1997). High levels of dietary fat have also been demonstrated to enhance UV-induced immunosuppression in experimental systems (Black et al., 1995) and may be a factor in arctic populations as well as high histidine levels in some species of fish (Suzuki et al., 1987) and seal (Hoppner et al., 1978).

Viral interactions

Activation of viruses by UV radiation is well-documented (Ando, 1990; Coetzee and Pollard, 1974; Tingate et al., 1997; Zhang et al., 1999; Zmudzka et al., 1996). Indigenous populations appear predisposed to cancers such as nasopharyngeal and salivary gland cancer (Nielsen L. et al., 1997). These cancers are thought to be associated with the high viral load in these populations, and genetic factors also appear to be involved. Salivary gland cancer has been linked to UV radiation exposure in several studies on non-arctic populations (Nielsen N. et al., 1996) although a latitude gradient has not been demonstrated. UV-B radiation may be a co-factor. Herpes simplex virus (HSV) is found in all races, cultures, and continents. The virus affects 80 to 90% of the world's population. Most people have herpes simplex as cold sores or genital herpes. In experimental animal models UV-B radiation was shown to release immune inhibition on HSV expression and lead to HSV manifestation. A similar effect may occur in the human population (Taylor J. et al., 1994). Whether enhanced levels of UV-B radiation due to ozone depletion will exacerbate HSV or other viral infections in the arctic population remains to be determined.

Infectious diseases

The emergence of new infectious diseases and the re-emergence of old infectious diseases is also an issue in the Arctic (Butler et al., 1999). Given an association between the lowering of resistance to some infectious diseases by UV-B induced immunosuppression in experimental animal systems (Sleijffers et al., 2002), plus a lowering of the cellular immune response against hepatitis B vaccination in humans by urocanic acid (Sleijffers et al., 2003; section 15.3.3.1), attention to increases in infectious diseases as a consequence of increased exposure to UV-B due to ozone depletion is of high priority.

15.3.3.7. Summary

A lack of detailed information on human health effects due to increased exposure to UV-B radiation in the Arctic precludes an evaluation of risk assessment at present. Skin cancer appears to be a low risk phenomenon in the Arctic particularly in indigenous populations. However, given the long-term likelihood of ozone loss and increased levels of UV-B radiation, it is not clear how long this low risk will be maintained. Indigenous and non-indigenous populations should both be monitored routinely for skin cancers, cataracts, and precursors to such conditions. The effect of UV-B induced immune suppression, alone or in combination with arctic stressors and pollutants, on human or animal populations is also unknown. The implications of increased UV-B exposure on the incidence of viral and infectious diseases in arctic populations need to be addressed. Also, understanding of the interactions between UV-B radiation, pollutants, and traditional diets requires significant effort in the future. Population effects related to UV-B health effects following stratospheric ozone depletion is a major research topic for the Arctic as the stratospheric ozone layer will remain vulnerable for the next decade or so even with full compliance with the Montreal Protocol (UNEP, 2003).

15.4. Potential impacts of indirect mechanisms of climate change on human health

In addition to direct impacts of climate-related changes on human health, human health in northern communities is affected by a number of indirect impacts. These refer to those health consequences resulting from indirect interactions mediated via human behavior and components of the environment that have changed or are changing with local climate. These indirect effects include critical impact mechanisms such as social and mental stress related to changes in the environment or lifestyle which are related to changes in local climatic regimes. They include such things as effects on diet (decreased subsistence/cultural food species abundance and/or availability) as a result of climate-related impacts on wildlife species or environmental factors influencing indigenous peoples' access to these resources (e.g., ice distribution, land stability, weather predictability); effects on health as a result of changed access to good quality drinking water sources; effects on rates of diseases resulting from climate effects on sanitation infrastructure; and changes in human disease incidence associated with climate impact on zoonotic diseases.

15.4.1. Changes in animal and plant populations

Climate change can have dramatic effects on the numbers and distribution of species in an ecosystem and these changes may have significant social, cultural, and health effects on indigenous human populations. All ecosystems are a dynamic equilibrium of species and climate is one of the most important factors in this delicate balance. Climate changes, even subtle changes, may shift this balance to favor some species, stress other species sometimes to the point of extinction, and allow new species to enter the system. Other chapters of this report address the significant and sometimes dramatic affects of climate change on species. Infectious disease agents of plants, animals, and humans are integral components of all ecosystems and may increase, decrease, or spread into new regions as a result of climate change. The dynamics of these changes and how they may affect human health are described in this section.

15.4.1.1. Species responses

Since the late 19th century, global temperatures have risen by an average of 0.6 °C with the increases more pronounced at higher latitudes and higher elevations (IPCC, 2001). A review of 143 studies involving range distributions of nearly 1500 species showed that over this period 80% had shifted their ranges toward the poles (Root et al., 2003). These shifts are likely to be greater in polar regions where the temperature increase has been greater.

Increased warming from the mid-1970s to the mid-1990s is thought to have been the major reason for a rise in salmon numbers in the Bering Sea and North Pacific (Weller et al., 1999). Salmon is an important traditional food for many indigenous people and an important economic asset in the Bering Sea and North Pacific. However, the increased temperatures also had some adverse health effects. The warming caused increased productivity at all levels of the food chain including increased numbers of those algae which cause toxic red tides and paralytic shellfish poisoning (Patz et al., 2000; Weller et al., 1999). Extreme environmental events such as flooding which washes nutrients into coastal waters could also increase the occurrence of paralytic shellfish poisoning.

The warming trend that caused high salmon numbers in the North Pacific and Bering Sea may also have been the major factor responsible for the dramatic reduction in Alaska salmon since 1997 (Mathews-Amos and Berntson, 2002; Weller et al., 1999). Higher water temperatures may have increased salmon metabolism to levels that could not be sustained by existing food sources and spawning salmon were often smaller than normal.
A reduction or disappearance of traditional food species may result in indigenous populations switching from a traditional diet to less healthy diets; such dietary shifts are associated with an increased prevalence of chronic diseases such as diabetes, heart disease, and cancer among northern populations (Bjerregaard and Young, 1998). Health effects related to extreme economic hardship could also follow a decline in traditional food species.

Climate change often creates opportunities for species to move into new regions. Species may colonize a region from an adjacent area, through migration or through accidental or intentional transport by humans. In Alaska, recent warming has increased average growing degree-days by about 20% (USGCRP, 2000). This has had a significant impact on the ecosystems there. Sustained warming on the Kenai Peninsula in south-central Alaska encouraged a spruce bark beetle infestation and the largest tree death in North America. Northern expansion of the boreal forest has favored the steady advance of beaver in northern and western Alaska. Beaver make dramatic alterations in surface water and fish habitat. They may also expand the range of Giardia, a parasitic disease of beaver that can infect many other animals and humans. An expansion in the range occupied by beaver has also been reported by indigenous people in other regions of the Arctic (Furgal, 2002; Krupnik and Jolly, 2002).

> *We see moose now, and never did before. We see them more and more each year. We've seen them up as far as the bay north of here (Nain).* Nain, hunter aged 43; in Furgal et al., 2002

> *It was maybe twenty years ago that we saw the first beaver track ever up in the bay (Webb's Bay, north of Nain)...we didn't know what it was.* Nain, hunter aged 46; in Furgal et al., 2002

It is not unusual for a few individuals of a migratory species to deviate from normal pathways and arrive in a new region. Every year Alaskan bird watchers are thrilled at "exotic" Asian species that visit local bird-feeders. If the new ecosystem is favorable the species can become permanently established. Climate change may create favorable habitats in regions that could not previously be inhabited. Successful establishment of a new species alters the ecosystem and impacts upon other species (Root et al., 2003). Accidental introductions arising from human activities may also result in colonization. There is concern in Alaska about species transported into the region when ships discharge ballast waters. Climate change may create conditions in the marine environment that are favorable to species introduced in this manner. The marine ecosystem is vital to subsistence food users and the economies of Alaska and other northern regions. The introduction of competing species or diseases of existing species could be catastrophic for the fisheries and indigenous communities of the Arctic.

15.4.1.2. Infectious diseases

Infectious disease agents are part of any ecosystem and are also affected by climate change. Stresses posed by climate change may increase the susceptibility of plants and animals to disease agents causing both the rates of infection and severity of infection to increase. High incidences of diseases and die-offs were reported during recent El Niño–Southern Oscillation events (Mathews-Amos and Berntson, 2002; Weller et al., 1999). Climate warming during these events has been associated with sickness in marine mammals, birds, fish, and shellfish. Disease agents associated with these illnesses have included botulism, Newcastle disease, duck plague, influenza in seabirds, and a herpes-like virus epidemic in oysters. Diseases that attack species forming habitat for other species, such as seagrass, are also affected and can have devastating environmental impacts. If such effects arise following the temporary temperature shifts associated with El Niño–Southern Oscillation events, then it is likely that temperature changes arising from longer duration climate change will be associated with an increased occurrence of diseases and epidemics.

Species expanding into new regions will expose resident species to any disease agents they take with them. This is the case for beaver and Giardia. Giardia is a waterborne disease, and beaver dams increase the surface water habitat that promotes the spread of the parasite to other animals such as caribou and humans. Infected caribou may also increase the spread of the parasite as they migrate to other parts of their range. Other waterborne diseases are also likely to become a greater risk due to beaver-engineered surface water changes especially in areas where people use untreated surface water.

Species that benefit from climate changes are likely to increase in numbers and create more hosts for disease agents. Expansion of host species into new regions and the reformulation of ecosystems increase the probability of spread to new host species. Species that have not been exposed to a new infectious disease agent are often extremely susceptible to the infection. The catastrophic epidemics in indigenous North Americans following the introduction of smallpox, tuberculosis, influenza, and many other infectious diseases after European contact are such examples.

The West Nile virus is a recent example of how far and fast a disease agent can spread after colonizing a new region. The virus was first identified on the east coast of North America in 1999 and by the end of 2003 had spread to all lower 48 states except Washington and Oregon in the United States and seven of 13 Canadian provinces and territories (CDC, 2003; Health Canada, 2002). Nearly 9000 human cases and over 200 deaths occurred in the United States in 2003. West Nile virus is primarily a disease of birds that is transmitted by mosquitoes.

Infected migratory birds are responsible for the spread of the West Nile virus into a region, with mosquitoes responsible for the spread of the virus to other birds (and other animals and humans). Even though the virus originated in tropical Africa it has adapted to many North American mosquitoes and so far to over 130 species of North American bird, some of which migrate to the Arctic (CDC, 2003). Mosquito species known to transmit the virus are also found in the American Arctic.

Climate has always posed a barrier for insect-borne diseases but climate change and the extremely adaptive nature of the West Nile virus may favor continued northerly expansion. The extent of future expansion and the possibility of transmission to the Arctic remain to be seen. Some northern regions, such as Alaska, have initiated a West Nile virus surveillance program (ADHSS, 2000). If the virus does reach Alaska, migratory birds could carry it to the massive population centers of China and South Asia.

Zoonotic diseases are diseases of animals that can also be transmitted to humans. Rabies is a classic example. Rabies infects many wild and domestic animals which may then spread the disease to humans usually from saliva through a bite. In the Arctic, rabies is most often carried by fox and conditions which favor increased fox numbers can lead to rabies epidemics and to human cases. Other arctic zoonotic diseases that could be influenced by climate change include botulism, paralytic shellfish poisoning, tularemia, brucellosis, echinococcus, trichinosis, and cryptosporidium. Botulism spores occur in marine sediments and the intestinal tracts of animals and fish (Chin, 2000). In Canada and Alaska outbreaks have been associated with seal meat, salmon, and salmon eggs. Also, warmer temperatures are reported to influence traditional fermentation processes (for the preparation of fermented meat – *igunaq*) which are related to increased cases of botulism in Nunavik (Furgal et al., 2002). Alaska has established a paralytic shellfish poisoning surveillance program in areas where the algae responsible for the production of the toxin occur. Climate warming may favor the spread of these species to new regions.

The mechanisms by which climate change affects disease agents and their hosts vary. Warmer temperatures may allow species with a low rate of infection, such as brucellosis in caribou or echinococcus in voles, to survive in larger numbers increasing the number of susceptible hosts and infected animals. Disease agents that survive in soil and water may benefit by warmer temperatures. Climate change may stress host species reducing their resistance and increasing rates of infection. Host species may enter new regions bringing disease agents with them. Continental cross-over from the Americas to Eurasia and from Eurasia to the Americas, as with the West Nile virus and influenza, is also possible and perhaps even more likely with climate change.

Diseases that infect important traditional and economic species can also affect human health. Indigenous groups throughout the circumpolar north have reported a variety of abnormal conditions and diseases in salmon over recent years (Krupnik and Jolly, 2002). Of increasing concern are diseases of farmed salmon or other fish that enter Alaskan waters via ballast waters and then spread to wild salmon. Reduced salmon consumption by indigenous peoples in favor of less healthy foods could lead to increased levels of diabetes, cardiovascular disease, and cancer.

Diseases that could threaten arctic ecosystems and populations following climate change include those that already exist in the Arctic and those moving in from more southerly areas (see Box 15.3). The Arctic could also be a source of disease agents. For example, if West Nile virus reaches Alaska it could easily jump to Asia via established bird migration routes. Diseases of livestock and poultry could also expand through arctic transmission routes. Expansion of disease agents into new environments, in new hosts, and via new vectors encourages new adaptations through natural selection. These could include changes in virulence and resistance and so result in more dangerous strains.

Influenza is an example of a disease that could be disseminated by arctic bird species to populations in other parts of the world. Bird influenza viruses serve as a genetic reservoir for other animal influenza strains including those that infect humans (Webster, 2002). Migration can spread these viruses to other species and humans. Influenza is not the stuffy nose, headache, and upset digestive tract that people equate with flu. In each of the 11 epidemics of the last three decades influenza killed 20000 to 40000 Americans. The Spanish flu strain of 1918 to 1919 killed more than 20 million people. In the 1998 influenza epidemic in Hong Kong a third of all diagnosed cases died (Tam, 2002). Fortunately the outbreak was small and did not spread (see Box 15.4).

Extreme events, such as droughts, floods, and storms (see section 15.3.1), are also linked to changes in ecological systems resulting in bacterial proliferation and impacts on the availability of safe drinking water (Mayer and Avis, 1997). Abnormal rainfall events can trigger mosquito-borne disease outbreaks, flood-related disasters, and depending on existing water infrastructure and systems used in northern communities, contamination of the water supply with human and animal waste. Human health depends on an adequate supply of potable water. If climate change affects the availability of freshwater supply, sanitation systems and the efficiency of local sewage systems will also be affected. Changes in rainfall patterns may also force people to use poorer quality sources of drinking water, potentially increasing the risk of bacterial and other contamination. This is particularly important for those communities in which significant numbers of individuals still rely on traditional sources of drinking water. All these factors could result in an increased incidence of diarrheal diseases.

15.4.1.3. Summary

Arctic climate change is likely to have profound effects on living things and thus human health, both in northern communities and throughout the world. When traditional food species are affected, dietary patterns may shift to less healthy food choices and diseases such as diabetes, cardiovascular disease, and cancer are likely to increase.

Box 15.3. Zoonotic diseases, climate change, and human health

Zoonotic diseases are infectious diseases of animals that can be transmitted to humans. Humans can be infected by these diseases a number of ways. Rabies, tularemia, and many others are transmitted by direct contact with infected animals. Others such as Giardia are shed into the environment and humans are infected following environmental exposure such as consuming contaminated water. The transmission of other diseases may be more complex. Humans are exposed to the West Nile virus from mosquitoes that were infected from birds harboring the virus. Many zoonotic diseases exist in arctic host species. Climate change may influence the spread, proliferation, and transmission of these diseases to humans through a variety of means.

- Tularemia is a bacterial disease of many mammals including rabbits, muskrats, and beaver, as well as humans and could become an increased threat in stressed animals or by animals expanding into new ranges. Tularemia may cause a variety of symptoms in humans. The pneumonic form has a 30 to 60% fatality rate.
- Rabies epidemics in the Arctic are linked to the fox and the cyclical increases in fox populations (Dietrich, 1981). Climate changes which increase rodent and rabbit populations could be a factor in rabies epidemics.
- Brucellosis is a bacterial disease of many hoofed animals and carnivores. It can cause a wide variety of symptoms in humans and the fatality rate is around 2% in untreated cases (Chin, 2000). Bison, caribou, reindeer, foxes, and bears can carry the disease (Dietrich, 1981). Climate changes that affect the distribution of these species could increase or decrease the risk from brucellosis.
- Echinococcus is a tapeworm parasite of animals and humans. The natural cycle involves foxes or dogs and rodents. Humans are an incidental host when they ingest eggs passed by dogs or foxes. The parasite develops invasive destructive cysts in the abdominal cavity and the infection is often fatal (Chin, 2000).
- An arctic strain of trichinella occurs in marine mammals such as walrus (Dietrich, 1981) and accounts for trichinosis outbreaks in some northern regions (e.g., Nunavik). Climate warming that reduces numbers of marine mammals or eliminates them from their current range may decrease the threat and occurrence of human cases of trichinella.
- Cryptosporidium is a protozoan parasite of many animals and humans (Chin, 2000). Some recent epidemics involved contamination of community water sources. Climate changes could favor the spread of the parasite to arctic communities that consume untreated surface water.

Changes in the traditional food lifestyle are also likely to affect human health through changes in social and cultural activities. Changes that affect commercially important species and so increase or decrease local income can also affect human health. Infectious diseases of plants, animals, and humans are also affected by climatic changes. Owing to the indirect nature of these influences, predictions of their likelihood are not possible; however, the potential impacts on human health related to these changes clearly warrant further attention.

15.4.2. Changes in the physical environment

15.4.2.1. Ice and snow

Climate warming scenarios project changes in sea-ice distribution and ice thickness in the Arctic (see Chapter 4). The direct human health effects of a reduction in ice thickness include injuries and death. Travel over increasingly thin ice for fishing, hunting, or recreation activities becomes increasingly dangerous. Mortality statistics show that accidents cause a significant number of deaths in some Inuit populations (e.g., Hodgins, 1997). Inuit in northern Canada report a decrease in ice extent and thickness during key traveling and hunting times in some communities (Furgal et al., 2002; Nickels et al., 2002).

The indirect health effects related to these changes are associated with marine productivity. Sea ice has a major influence on primary production and the ecology of species such as seals, walrus, and polar bear (see Chapter 9). Ice algae are a major source of food for a wide range of zooplankton and crustaceans. A reduction in sea-ice extent would reduce the substrate available for the ice algae and so reduce the food source for the ice-associated zooplankton and crustaceans. Greater melting of sea ice would decrease the salinity of the water column and the rate of the vertical flow which brings nutrients up from deeper waters (Conover et al., 1986), further reducing the productivity of the phytoplankton. A decrease in primary productivity would affect the crustacean and fish populations upon which seal populations rely (Welch et al., 1992). Also, populations of seals and walrus, which require sea ice for breeding and pupping, may decline as ice-covered areas recede (Maxwell, 1997). This would affect polar bear populations as seals are their major food supply. Polar bears in Hudson and James Bay are particularly vulnerable in this respect. Some species could be extirpated or become extinct if the Arctic Ocean becomes ice-free for much of the year (Maxwell, 1997). Arctic foxes, normally scavenging polar bear kills, may be forced to increase predation on nesting birds in the summer (Welch et al., 1992).

Cooling, as is projected for some arctic regions, could have both positive and negative impacts on indigenous food security. During the major cooling of the Arctic around AD 1400 to 1700, the Inuit are thought to have adapted by hunting ringed seals (*Phoca hispida*) which became more plentiful as the sea ice extended (McGhee, 1987). Similarly, changes in the timing, amount, and composition of snow can affect the health of arctic residents as it influences their abilities to hunt, travel, and access traditional foods at certain times of the year. The changes projected in ice and snow under the various climate change scenarios (see Chapter 4) could have potential impacts on individual and community social health and well-being (see Box 15.5).

> *…and all of a sudden we had a storm and everyone was lost, years ago you'd get the good snow for snow houses but now, you wouldn't be able to make one [snow house] if you had to.* Nain, hunter aged 49; in Furgal et al., 2002

Many villages in the Arctic are connected to other settlements only by sea or air. Because air service to the vil-

Box 15.4. Climate change, arctic birds, and influenza

Wild birds host many species of virus including influenza. Birds may serve as the source of genetic material or of new influenza strains that could infect humans.

The role and mechanism of wild birds in this process is now better understood (Snacken, 1999; Tam, 2002; Webster, 2002). Numerous influenza strains are found in wild water birds. The bird–flu relationship is very stable and most infections even with multiple strains cause no symptoms. Many millions of these birds with their associated influenza viruses inhabit the Arctic. Peak numbers in birds and viruses occur in autumn and move south during migration. As the huge flocks move southward influenza strains circulate and recombine within the migrating birds and infect domestic birds and swine along the flyways. Influenza in domestic species brings the viruses closer to humans. The right combination of strains in domestic animals could be the source of a new human strain and a global epidemic. Climate change that favors nesting success, expansion to new ranges, and intermingling of bird species could contribute to this process.

The Spanish flu strain of 1918 to 1919 that killed more than 20 million people was thought to have emerged from a swine or bird strain (Snacken, 1999). The Asian flu strain of 1957 and the Hong Kong strain of 1968 may have been the product of human and bird strains. The 1997 to 1998 influenza epidemic in Hong Kong originated in poultry (Tam, 2002). That epidemic, even though it was small with only 18 confirmed cases, was especially alarming because six of these cases resulted in fatalities.

lages in many regions is irregular, villages are otherwise isolated for two to five weeks every autumn and spring when there is too much ice in the water to go by boat but not enough ice to go by dog sledge or snowmobile. During this period, hunting, fishing, and travel between villages is limited by means other than plane and there is often reduced provision of goods to local stores, and reduced availability of fresh meat or vegetables in some communities. For short periods, the weather can become so stormy that normal everyday activities within the village are difficult. This increased sense of isolation is reported to be associated with increased incidences of interpersonal conflict, depression, and other forms of social stress (Furgal et al., 2002).

15.4.2.2. Permafrost

Permafrost is very sensitive to temperature fluctuations. The top layer of permafrost, known as the active layer, thaws in summer and freezes again in winter. A warming of 4 to 5 ºC would cause more than half of the discontinuous permafrost zone in Canada to disappear. Under such a scenario, the boundary between the continuous and discontinuous permafrost zones is expected to shift northward by hundreds of kilometers and the active layer in the discontinuous zone is projected to increase to twice its current depth (Maxwell, 1997). The uneven pitted terrain which results can severely affect animal activities and can damage or destroy the ecosystems based on the permafrost (Osterkamp, 1982, 1994). Several impacts of thawing permafrost have already been observed in Alaska (IASC, 1997).

- Destruction of trees and reduction in areas of boreal forest.
- Expansion of thawed lakes, grasslands, and wetlands.
- Destruction of habitat for caribou and terrestrial birds and mammals.

Box 15.5. Climate change and traditional food security

Traditional foods collected from the land, sea, lakes, and rivers are important sources of health and well-being to many indigenous communities. Such foods continue to contribute significant amounts of protein to the total diet and help individuals to meet or exceed daily requirements for several vitamins and essential elements (AMAP, 2003; Blanchet et al., 2000; Kuhnlein et al., 2000; Van Oostdam et al., 1999). Historically, by eating all animal parts, northern indigenous diets provided the nutrients and essential elements required to sustain life in this harsh climate. Such items are still important today as they contribute, for example, nearly 50% of the weekly protein, iron, and vitamin A intake in Nunavik women under 45 years old (Jetté, 1992) and nearly 50% in Labrador Inuit (Lawn and Langer, 1994). Components of the Inuit diet, particularly omega-3 fatty acids in fish oils, have been shown to provide protection against arteriosclerosis and ischemic heart disease (Bjerregaard et al., 1997) and some cancers. Also, marine species are the main source of selenium in northern diets; an antioxidant and a known anticarcinogen that may also help protect individuals from mercury toxicity (Blanchet et al., 2000). In addition to the substantial nutritional benefits, traditional foods provide many cultural, social, and economic benefits to individuals and communities.

Climate changes may affect the consumption of traditional foods by northern people through a variety of means. Impacts may occur via changes in access to food sources, for example by:

- a change in the distribution of important food species;
- the unpredictable nature of weather, as this can influence the possibilities for hunting or fishing;
- low water levels in lakes and streams, the timing of snow, and ice extent and stability, as these can influence access to hunting locations and key species; and by
- a shorter winter season and increased snowfall (two effects of a warmer climate), as these may decrease the ability of northern people to hunt and trap (Maxwell, 1997).

Climate changes may influence the availability and health of traditional food species via:

- impacts on critical components of their diet (e.g., climate impacts on vegetation may influence caribou health and abundance);
- impacts on their ability to forage and survive critical seasons (e.g., deeper snow and changes in freezing rain incidents can negatively affect the ability of caribou and reindeer to forage in winter);
- warming, as this may increase the exposure of some species to insects, pests, and parasites; and via
- temperature changes as these may influence migration and breeding patterns.

The impacts of a decline in the proportion of traditional foods consumed by northern peoples are significant. Shifts away from a traditional diet toward a more western diet, higher in carbohydrates and sugars, are associated with increased levels of cardiovascular diseases, diabetes, vitamin-deficiency disorders, dental cavities, anemia, obesity, and lower resistance to infections. Both climate warming and cooling are as likely to impact on aspects of indigenous food security in the future as they have in the past.

- Clogging of salmon spawning streams with sediment and debris.

Such impacts could further affect traditional food sources (e.g., caribou, salmon) and the related activities (e.g., hunting, gathering, fishing) (AMAP, 2003).

15.4.2.3. Summary

Through changes in the timing and conditions of ice formation, stability, and break up, the amount and timing of snow, and the stability of critical land (e.g., permafrost) in the regions used by indigenous communities, climate change can result in significant negative impacts on the health of community residents. According to some indigenous communities these changes and their effects are already occurring. Such changes are likely to continue to affect the safety of land- and water-based travel, and availability and access to traditional food species by arctic residents and will thus continue to challenge the health of indigenous communities in the future.

15.4.3. Built environments in the north

Infrastructure promotes safe and healthy community environments and provides access to health-related services. In northern regions, housing provides protection against harsh environmental conditions and, with adequate ventilation, a healthy living environment. Sanitation facilities are needed to prevent the spread of disease and are increasingly important when population densities are high, or when even small populations are fixed in one location. In small remote communities transportation is often necessary to gain access to health-care or emergency services. It is likely that climate change will adversely affect infrastructure and housing throughout the Arctic.

15.4.3.1. Sanitation infrastructure

Unsafe drinking water combined with inadequate sanitation and hygiene is listed sixth in the top ten health risk factors leading to disease, disability, and death worldwide (WHO, 2002). The provision of high quality water can protect against chemical constituents and waterborne diseases such as hepatitis, gastroenteritis, typhoid, cryptosporidiosis, and giardiasis (American Public Health Association, 2001; Smith D. et al., 1996). Sufficient quantities of water are required for personal hygiene, cleaning, and laundry. Epidemics of otherwise commonly preventable diseases such as hepatitis A, hepatitis B, bronchitis, otitis media (a serious ear infection), impetigo, and meningitis in remote Alaskan communities are often attributed to poor sanitation. Alaskan Native villages with inadequate sanitation systems accounted for more than 72% of 596 reported cases of hepatitis A in Alaska in 1988 (US OTA, 1994). The spread of diseases caused by contaminated drinking water or inadequate sanitation is a concern for communities throughout the world.

Sanitation facilities can consist of individual facilities such as septic systems or pit privies (outhouses) or community facilities such as organized haul systems or pipeline networks. The level of health in a community depends on the type of sanitation facilities (US OTA, 1994). Water hauled by individual residents may be safe at the point of collection, but might become contaminated in the containers used for transport and storage. Closed haul systems (sealed containers) or piped utilities can reduce the potential for contaminating water supplies or human contact with sewage (US OTA, 1994). Sanitation facilities can include different levels of service. In the most basic form, water and wastes are hauled to and from the residence by hand. Providing a community water and wastewater haul system can raise the level of service. Such systems provide greater amounts of water for sanitation purposes and therefore improve the level of community health. Piped utility systems provide the highest level of service and commensurate health benefits.
The level of sanitation service provided to arctic communities varies. For example, few Russian arctic communities are served by piped systems, while virtually 100% of Norwegian arctic communities have piped systems or adequate individual facilities. In Canada, Greenland, and the United States, the level of service provided to communities varies substantially from region to region.
In some cases, communities must support utility operation via local user fees. In other cases, the cost of utility operation is supplemented by sources outside the community. In the Arctic, where residents may rely heavily upon subsistence and where economic conditions are often strained, even minor increases in costs may negatively affect utility operation and maintenance.

15.4.3.2. Water supply systems

Water supply systems include a water source, storage facility, and distribution system. Water sources contaminated by biological, chemical, or mineral constituents may require treatment to render the water supply safe for human consumption. In the United States it is estimated that contaminated drinking water causes more than 900000 people to become ill and up to 900 to die each year (American Public Health Association, 2001). In 1993, inadequate water treatment in one city caused an outbreak of approximately 403000 illnesses, 440 hospitalizations, and 50 deaths (Craun et al., 2002).

Water supplies are required for personal hygiene, cleaning, drinking, and cooking. Owing to the labor involved, when water is hauled individually it is used for drinking and cooking and tends to be used sparingly for hygiene and cleaning (Smith D. et al., 1996). In more sophisticated sanitation systems, water is used to transmit human waste from residences through pipelines or via haul tanks to the point of treatment and/or disposal.

Source

Water sources exist as surface supplies or groundwater wells. The highest quality source with adequate quantity available to the local community is typically used. Sources with significant levels of contaminants require more complex treatment and are undesirable due to increased treatment costs and complexity.

Arctic surface water sources include streams, rivers, lakes, tundra ponds, or man-made impoundments that capture snow and rain. Surface water sources require some form of treatment to ensure that the water is safe for drinking owing to the potential for contamination by pathogens (US EPA, 1992). Groundwater sources generally have less risk of contamination by pathogens. Naturally occurring organic or inorganic substances can exist in surface water and groundwater supplies. These contaminants are often removed early in the treatment process to avoid the possibility of transforming them – through chemical reactions with disinfectants – into potentially dangerous byproducts.

Although high quality arctic groundwater sources exist, permafrost often restricts the volume these aquifers can produce. Alternatively, there might be a sufficient volume of groundwater to meet a community's needs but it may be so highly mineralized that it requires sophisticated and costly treatment.

Climate change can cause water sources to become inadequate in volume or unfit in quality in a number of ways. For example:

- Groundwater supplies can be reduced by less frequent precipitation. Intense but less frequent rainstorms limit aquifer recharge by the majority of the water being lost to runoff.
- Drought or short intense storms can affect surface water impoundments. The water supply in small impoundments or lakes can be depleted during long dry periods. Intense storms may cause watersheds to release water too rapidly creating high but short-duration flows and with most of the precipitation being lost to runoff.
- Coastal communities can experience increased levels of salinity, dissolved solids, or other contaminants in groundwater due to a climate change induced sea-level rise (Linsley et al., 1992). The groundwater may become brackish and unfit for human consumption.
- Flooding of coastal areas by storm surges may become more frequent and severe. Tundra ponds or lakes, located near the coast, can become contaminated by seawater with their water becoming brackish and thus unfit for human consumption.
- Levels of salinity and bromide may increase in river intakes due to rising sea levels. The saline wedge can penetrate farther upstream potentially contaminating river intakes with seawater (Smith O., 2001).
- Intense storms can create high runoff rates that may exceed the design capacity of a water diversion or dam overflow structure. This may result in damage or the complete loss of the facility.
- Thawing permafrost may also damage water diversion or dam structures. As permafrost thaws, structures founded on frozen soil can become unstable. This may compromise the ability of the structure to impound or divert the necessary volumes of water.
- Flooding caused by ice jams in northern rivers often occurs in the spring or early summer when riverbanks are frozen. Flooding of rivers in late summer or autumn is rare. Intense rainstorms that cause flooding when soils are thawed will accelerate riverbank erosion and increase the potential for damage to adjacent structures.
- Northern communities often have limited economies – many based on subsistence. Contaminated water sources or damaged intake structures will require repair, modification, or replacement. If resources are not available for repairs or facility replacement, residents may be forced to use an unsafe water supply.

Treatment

Water treatment systems are designed to remove contaminants and inactivate pathogens. Designs differ, and are based on the properties of a water source. Climate change can result in a decrease in the quality of a water source which can then overwhelm the treatment system. The treated water may be safe for consumption but unpalatable due to taste, smell, or color. This can result in residents seeking alternative sources that are untreated and potentially unsafe. Climate change can adversely affect water treatment systems in a number of ways. For example:

- Rising sea levels can contaminate groundwater or surface water sources. A consequent rise in bromide concentrations may increase the formation of dangerous byproducts during disinfection (Singer, 1999). The process required to treat a water source contaminated by bromide is complex and costly; operation and maintenance of such systems may be prohibitively difficult and expensive for small, remote communities.
- Intense rainstorms can increase turbidity, pathogen, and organic contaminants in a water source. A substantial increase in these contaminants can exceed the ability of a water treatment system to produce safe and palatable water. High levels of suspended material can overwhelm a filtration process and reduce the effectiveness of a disinfectant to inactivate pathogens. Increased levels of organic contaminants can overwhelm a treatment process and increase the formation of dangerous disinfection byproducts (Singer, 1999).
- Warming weather and longer dry periods can cause more frequent and severe algal blooms in lakes or ponds used as a surface water supply. Algae may clog water treatment filters and so reduce the ability of the system to meet demand. The presence of algae can also increase the formation of disinfec-

tion byproducts or cause foul tastes and odors making the water unpalatable (Linsley et al., 1992; Singer, 1999).

Distribution

Water distribution in northern communities consists of self-haul, community-haul, or piped utility systems. Self-haul systems require minimal infrastructure because water can be hauled by foot, sled, or small all-terrain vehicle (Fig. 15.11). Community-haul systems use larger haul containers, which require larger vehicles and therefore substantial all-weather access ways. Self-haul and community-haul systems both require convenient access to the bulk treated water storage tank to be viable.

Access roads and boardwalks must be maintained in passable condition for haul systems to operate (Fig. 15.12). The road, bridge, or boardwalk must be structurally sound and capable of supporting relatively heavily loaded vehicles under repetitive daily cycles of operation.

Piped utilities rest on aboveground supports or are buried below ground. The more desirable and conventional belowground installation requires thaw-stable soils. When thaw-stable soils do not exist, piped utilities are usually constructed aboveground to minimize the potential for thawing of the permafrost and subsequent loss of foundation support for the structure (Fig. 15.13).

When a piped distribution system is used, pipelines must remain sound to ensure the water supply remains safe for human consumption. A breech in a pipeline can allow contamination of the water to occur within the distribution system (Geldreich, 1992). In 1989, contamination of the water supply caused by a pipeline breech in Cabool, Missouri, resulted in 243 people becoming ill and four dying (Fox K., 1993).

Often, arctic piped distribution systems continuously circulate water for freeze protection. Loss of water in a distribution system during cold weather can result in loss of circulation and complete freeze failure of the system (Smith D. et al., 1996).

Large structures such as water storage tanks cannot accommodate significant movement of the foundation. Movement of the foundation or loss of foundation support can cause a breech in the shell of a water storage tank, potentially rendering the facility unusable.

Climate change, can adversely affect water distribution systems in many ways. For example:

- Flooding caused by storm surges or heavy rainstorms can damage roads, boardwalks (Fig. 15.14), water storage facilities, and aboveground pipelines. In some areas, floodwaters can include ice, which may substantially increase floodwater damage.
- Roads, boardwalks, pipelines, and water storage facilities can be adversely affected by erosion. Riverbank erosion may accelerate during late season flooding. Coastal communities may experience accelerated erosion along shorelines due to thawing permafrost, severe storms, rising sea levels, or reduced periods of sea-ice cover.
- Frozen seas protect shorelines and reduce the generation of waves created by severe winter storms. Indigenous people report that the extent and duration of sea-ice cover is changing (e.g., Furgal et al., 2002; Krupnik and Jolly, 2002; Nickels et al., 2002; see Chapters 3 and 6).
- Thawing permafrost can result in the loss of foundation support for aboveground or belowground pipelines, water storage facilities, access roads, or boardwalks. Loss of foundation support for a pipeline can damage the facility and allow contamination of the water supply (Geldreich, 1992). Damage to storage facilities, access roads, or boardwalks can render a water distribution system inoperable.

15.4.3.3. Wastewater systems

Wastewater systems transport human waste from residences, provide treatment, and dispose of effluent. Improper methods of collecting, treating, or disposing of human waste have been attributed to numerous

Fig. 15.11. All-terrain vehicle water haul system, Mekoryuk, Alaska (photo by Mark Baron).

Fig. 15.12. New boardwalk access, Chefornak, Alaska (photo by John Warren).

Fig. 15.13. Aboveground water and sewer utilidor, Selawik, Alaska (photo by John Warren).

Fig. 15.14. Boardwalk damaged by storm surge flooding, Kipnuk, Alaska (photo by Mike Marcaurele).

outbreaks of infectious disease (US OTA, 1994). In Sweden, 3600 people became ill at a ski resort through a cross connection between a drinking water reservoir and a sewage pipeline (Fewtrell and Bartram, 2001). In Alaska, between 1972 and 1995 more than 7000 cases of hepatitis A were reported to the Epidemiology Section of the Health and Social Services Department. The method of transmission was via the fecal–oral route. Inadequate sewage disposal in many remote communities was cited as the cause.

The level of service provided by wastewater collection, treatment, and disposal systems varies throughout the Arctic. In some remote Alaskan villages, residents use small buckets to collect human waste. Buckets are then carried by hand to central disposal points where wastes are dumped into receptacles (Fig. 15.15), or carried directly by the resident to sewage disposal facilities. This is often referred to as a "honey bucket" haul system. A plastic liner is often used to line the bucket and contain the waste. Hauling wastewater from residences by hand is the most unsanitary form of collection and represents the lowest level of wastewater service.

Improved levels of service include pit privies and holding tanks. Pit privies are frequently used when homes are scattered and soil and groundwater conditions are favorable. Holding tanks are used when homes are located in close proximity, or when soil conditions or high groundwater makes septic systems infeasible. Holding tanks are sited at residences and emptied by a community-owned or commercial pumping service. The holding tank size in a particular community is determined by economics and access. Because many villages have narrow roads and boardwalks, large vehicle access is limited and holding tank volumes are typically small (Fig. 15.16). Thus, the amount of water available for personal hygiene and cleaning is minimal. Piped utilities provide the highest level of service. Flush toilets are normally used in piped systems, and water supplies and wastewater removal systems can provide ample water for personal hygiene, cleaning, laundry, or other sanitation needs.

Collection

Wastewater collection systems are designed to minimize the potential for human contact with sewage. Disease transmission can occur in populations where collection systems are inadequate and contact with wastewater is not controlled (IHS, 1999a; Schliessmann et al., 1958). Failed collection systems can discharge human waste to the environment, contaminate water supplies, and transmit disease via human contact. Many of the effects of climate change on water distribution systems also apply to wastewater collection infrastructure. Roads must remain in passable condition throughout the year for haul systems to operate; pipeline integrity must be maintained for piped wastewater collection systems to function properly.

Treatment and disposal

Wastewater treatment for small remote arctic communities is generally limited to simple systems. Mechanical treatment methods, such as aeration, are not typically used due to cost and complexity of operation (Smith D. et al., 1996).

In the Arctic, individual wastewater treatment facilities include pit privies and septic systems. Community facili-

Fig. 15.15. Honey bucket disposal container, Shishmaref, Alaska (photo by John Warren).

Fig. 15.16. Small sewage haul system, Mekoryuk, Alaska (photo by Mark Baron).

ties typically include earthen lagoons, tundra ponds, septic tanks with ocean outfalls, and septic tanks with drainfields. When communities are located near water and favorable soils exist, drainfields are placed within the thaw bulbs of rivers or along seashores.

Wastewater treatment and disposal systems are designed to ensure wastewater remains separate from the water supply, human contact with waste does not occur, and the potential for vector transport is limited.

Climate change can adversely affect wastewater treatment and disposal systems in a number of ways. For example:

- Flooding caused by storm surges or swollen rivers can adversely affect wastewater lagoons, tundra ponds, bunkers, pit privies, or septic systems. Floodwaters may enter these facilities and spread partially treated waste throughout communities or into water supplies (Fig. 15.17).
- Riverbank or shoreline erosion can damage wastewater facilities located along seashores or within the thaw bulb of a river. Erosion can also intercept wastewater lagoons and tundra ponds.
- The warming of ice-rich permafrost beneath lagoon dikes can cause the loss of structural support. As dikes settle, a breech may occur resulting in the discharge of human waste into the environment. In such circumstances, increased maintenance – at a minimum – is required to sustain operational wastewater volumes and treatment efficiencies.
- However, warming weather and longer summers can also increase biological activity in wastewater lagoons and natural tundra ponds used for treatment. This increase in biological activity can improve treatment efficiencies resulting in increased treatment capacity and potentially delaying the need to expand or replace facilities due to community growth.

15.4.3.4. Solid waste systems

Solid waste collection and disposal in the Arctic is performed with relatively conventional methods. Recycling, incineration, and baling facilities are rare and generally

Fig. 15.17. Lagoon waste washed through fence by storm surge flooding, Kipnuk, Alaska (photo by Brian Aklin).

limited to larger communities. Collection in very small communities is typically by self-haul. Larger communities often use community-haul systems, which are preferred because wastes are more likely to be discarded in proper locations.

Solid waste disposal sites in the Arctic are generally frozen. Landfill wastes are often inadvertently mixed with snow due to winter operations and later covered with soil. Therefore wastes remain stable as long as materials remain frozen.

Many of the effects of climate change on water and wastewater systems also apply to solid waste collection infrastructure. Landfill access routes must remain passable for collection and disposal to occur. Flooding and erosion of solid waste landfills can spread waste, contaminate water supplies, and transmit disease through human contact. As frozen solid waste materials thaw, they can release contaminants into the environment through runoff.

15.4.3.5. Building structures

Critical requirements for housing in the Arctic include efficient and dependable heating and adequate ventila-

Fig. 15.18. Access road damage by coastal erosion, Shishmaref, Alaska (photo by Tony Weyionanna).

tion. Northern economies are often limited and houses are typically small, and so less costly to construct and heat. Such conditions may result in overcrowding. Also, building envelopes are usually tightly constructed to reduce heat loss and minimize heating costs. This combination of overcrowding and poor ventilation can lead to poor indoor air quality and potentially unhealthy living conditions.

Indoor air pollutants dangerous to health include mold, radon, tobacco smoke, carbon monoxide, and chemical emissions from household products and furnishings. Adverse short-term health effects of poor indoor air include asthma, hypersensitivity pneumonitis, and humidifier fever. Long-term health effects include respiratory disease, heart disease, and cancer.

Climate change can result in the destruction of housing via flooding and erosion, through loss of foundational support due to thawing permafrost, or by severe storm damage. Lost housing can cause further overcrowding, respiratory illness, and mental stress in small communities.

Health service buildings within remote communities offer quick access to basic health care and emergency services. When these structures are damaged by climate change, community health care is disrupted.

Transportation infrastructure

Transportation infrastructure provides access to health services located outside remote communities. Emergency transport of individuals from northern communities, usually by medical evacuation, to sites where comprehensive health services exist is critical. Infrastructure such as airstrips, roads (Fig. 15.18), and docks can be damaged by climate change. This damage can limit access to critical health care and emergency services.

15.4.3.6. Summary

The potential effects of climate change include increased variability in precipitation, reductions in the extent of sea ice, and climate warming and cooling. These changes can increase the frequency and severity of river and coastal flooding and erosion, drought, and degradation of permafrost. Such changes are very likely to impact on arctic infrastructure and housing.

Water sources may be subject to saltwater intrusion and increased contaminant levels, which may overwhelm treatment processes and jeopardize the safety of drinking water supplies. The quantities of water available for basic hygiene can become limited due to drought and damaged infrastructure. The incidence of

Box 15.6. Infrastructure, climate and public health: Shishmaref, Alaska

Recent studies indicate reductions in sea-ice thickness and shorter periods of sea-ice cover in Alaska. These climatic changes have increased shoreline erosion of Shishmaref, an Iñupiat village of 560 people located on Sarichef Island in the Chukchi Sea.

Archaeological finds indicate centuries of human habitation in Shishmaref. Villagers state that erosion has been accelerated by soils no longer frozen, limited sea-ice cover, and increasingly violent weather. During the winters of 2000/01 and 2002/03, erosion caused the bluff line to recede more than 12 meters, destroying structures and forcing other homes to be moved. Several other communities in the region, including Kivalina, Wainwright, and Barrow, face similar challenges related to coastal erosion.

Shishmaref uses two different haul systems for water and wastewater transport. One system consists of small water and sewage holding tanks within homes that are filled and emptied by small motorized haul vehicles operated by the community. Remaining residents haul their own water and use a community-operated honey bucket haul system for waste disposal. The community's water source is a rain/snow catchment impoundment located near sea level. Water is treated by a simple unaided sand filtration system with activated carbon enhancement.

Recent storms in Shishmaref have prompted evacuations, washed away a number of boats used for subsistence, and destroyed buildings and roads. Erosion is threatening the sewage lagoon and the village sanitation system, and local officials are concerned that seawater has contaminated the community's water source (Anchorage Daily News, November 23, 2003, Severe Storms Pound Shishmaref).

The destruction, property loss, threatened sanitation systems, and realization that the community will ultimately have to be moved is creating significant stress within the community. In summary, climate-related changes in Shishmaref will have both short-term and long-term effects on human health.

Coastal erosion damage, Shishmaref, Alaska (photo by Curtis Nayokpuk).

disease caused by contact with human waste can increase when sewage is spread by flooding, damaged infrastructure, or inadequate hygiene. Damaged infrastructure increases repair costs and further stresses fragile arctic economies.

The positive effects of climate change include reduced heating costs for buildings and pipelines. Treatment efficiencies in wastewater lagoons may also improve due to warmer water temperatures resulting from longer periods of warm weather. This increased efficiency may delay the need to expand natural wastewater treatment systems as local populations grow. As an example, Box 15.6 summarizes the links between infrastructure, climate, and public health in Shishmaref, Alaska.

15.4.4. Contaminants

Human and ecosystem health in the Arctic is affected by the accumulation of heavy metals and biologically persistent man-made compounds of industrial and agricultural origin, known as persistent organic pollutants (POPs). These contaminants are mostly generated at lower latitudes and transported by various natural mechanisms (termed contaminant pathways) to the Arctic. They then enter the arctic food chain, and are ultimately consumed by human residents who are often highly dependent on wildlife for food.

15.4.4.1. Human health effects

Health effects of chronic low-level exposure to POPs and heavy metals, such as lead, mercury, and cadmium, are, in general, incompletely understood. An assessment on this topic was published recently by AMAP (2003). Several points require emphasizing:

- in terms of low-level chronic food-borne exposure, pregnant women, the developing fetus, and the developing infant are the most sensitive stages of human life;
- the exposure is to a mixture, never a single compound, making assignment of cause and effect very difficult;
- toxicological models and wildlife studies suggest that neurodevelopment, growth, immunological development, and endocrine function are the most likely targets for effects from exposure;
- sensitivity to these compounds varies widely in wildlife and laboratory species, and is not always useful in predicting the toxicity of tissue levels in humans;
- the developmental effects potentially attributable in human infants exposed to these compounds can also be caused by many other exposures, confounding study results;
- arctic communities are often small, making statistically significant sampling difficult;
- long-term studies are further complicated by difficult access to remote communities for follow-up; and
- the arctic marine subsistence diet is rich in antioxidants such as selenium, omega-3 fatty acids, and other micronutrients. Selenium has the potential to mitigate the toxicity of mercury.

15.4.4.2. Major transport pathways

Major contaminant transport pathways include winds, ocean currents, and river outflow, all of which are affected by climate. Important mechanisms within the Arctic also affect contaminant transfer, such as surface ice movement, thawing of permafrost and glaciers, season length, changes in freshwater lakes, and the partitioning of chemical compounds between gas, liquid, and solid phases. Migratory species, which spend significant parts of their life cycle at lower latitudes, can accumulate these contaminants and bring them into the Arctic. Also, increased levels of human activity in the Arctic, including maritime transport, represent a potential mechanism for contaminant transport and release. Each of these mechanisms is reviewed in this section within the context of potential impacts on human health. It must be understood that all these pathways, and their impact on transport, have the same limitations as climate models: (1) it is difficult to detect trends, due to short instrumental records, and (2) linking change in the various pathways to climate change, and predicting their effect on each other is poorly understood in many cases. A more complete discussion on this topic was published recently by AMAP (Macdonald et al., 2003).

Season length

The length of time air masses remain at, or above, critical temperatures influences the extent to which an organic contaminant can volatilize and remain easily within the gas phase, or attached to airborne particles. Air mass movements can be rapid and cover long distances. With the projected increase in season length, contaminant movement could significantly increase, both into and out of the Arctic. Season length, by its effect on ice melt, the active layer of permafrost, periods of ice-free river flow, and longer growing periods has the major mediating influence on contaminant movement into, out of, and within the Arctic (Macdonald et al., 2003).

Atmospheric transport

Atmospheric circulation in the Northern Hemisphere is influenced by atmospheric pressure. Established patterns of pressure variation, including the Northern Hemisphere Annual mode, often referred to as the Arctic Oscillation (AO) have major influence on surface wind (Wallace and Thompson, 2002).

The AO, while a major influence on arctic climate, is thought to account for only 20% of variance in atmospheric pressure (see Chapter 2). Short (5- to 7-year) and longer term (50- to 80-year) variations in the sea-level atmospheric pressure fields, possible contributions from greenhouse gas warming, and the lack of long-term instrumental records make interpretation of AO variations since the 1960s difficult (Fyfe, 2003; Wang and Ikeda, 2001). Major winds into the Arctic fluctuate in intensity, duration, and to some extent, direction based on atmospheric pressure fields.

Various forms of precipitation, including snow and rain, act to remove contaminants from transporting air masses, and add them to land, surface ice, snow, and surface water. Increasing precipitation as a result of climate change could result in increased levels of contaminant deposition (Li et al., 2002).

Winds are the major source of mercury to the Arctic, mostly in its metallic gaseous form (AMAP, 2004). Loss of ozone in the upper layers of the atmosphere allows increased levels of UV-B radiation to reach the earth's surface in the Arctic. This initiates a complex mercury–halide interaction changing mercury to reactive gaseous mercury, which is easily removed from the atmosphere and taken up by the ecosystem in the early spring during the intense growth period. This atmospheric removal of mercury, termed a mercury depletion event, is most prominent during the period of "polar sunrise" in spring. The combination of possibly increased transport of gaseous mercury, less atmospheric ozone to block UV-B radiation, earlier ice-free periods along the Arctic Ocean shoreline, and abundant supplies of bromine and chlorine salts, could impact upon food web and human mercury accumulation. Extreme events might also increase rates of transport and contaminant deposition (see Fig. 8.22).

Ocean currents

Contaminant transport by ocean currents occurs primarily at the surface (Morison et al., 1998) and the largest input is from the North Atlantic between Greenland and Norway, with a smaller input from the North Pacific via the Bering Sea. A significant input from freshwater occurs via rivers entering the Arctic Ocean. The AO and season length influence these inflows.

A large volume of water and ice exits the Arctic Ocean via the Canadian Archipelago, carrying with it suspended and dissolved contaminants brought into the Arctic by wind, rivers, and ocean currents. Climatic conditions favoring increased ocean current transport to the Arctic Ocean would potentially expose all human residents, but might expose those of the Canadian Archipelago, as well as those of West Greenland and eastern Labrador, to higher levels.

Sea ice and glaciers

Ice, in the form of sea ice or land-based glaciers, is capable of storing contaminants deposited by wind. As climate warming causes melting, the ice releases contaminants, either by volatilization or by release of particulate-associated contaminants into surface water, where further transport or entry into the food chain occurs.

Exposure of Arctic Ocean surface water, as a result of decreasing ice cover, could increase the movement of contaminants such as hexachlorocyclohexanes (HCHs) and toxaphene into the atmosphere, speeding movement within or out of the Arctic (Macdonald et al., 2000a,b).

Sea ice can also transport contaminants by other means, particularly by accumulating contaminants in sediment, from grounding on shallow coastal shelves, particularly where rivers enter the Arctic basin (Barrie et al., 1998). Sediment-rich shallow water can also be incorporated into sea ice by freezing as surface ice is formed. The contaminant-bearing ice can then follow established circulation patterns in the Arctic Ocean, influenced by wind and surface air temperature, releasing contaminant-containing sediment as it melts. While the components of this cycle are well described, climate change could affect any particular step, regionally or throughout the Arctic Ocean, with unpredictable effects on contaminant transport and human health.

Rivers and lakes

River flow into the Arctic Ocean will increase if, as projected by the ACIA-designated climate models, there is an increase in precipitation and the length of the ice-free period for much of the Arctic and subarctic. This will promote increased river transport of contaminants from industrial and agricultural sources further south.

Arctic lakes are thought to have functioned as temporary storage for contaminants deposited in snow during the winter, with rapid runoff removal in spring (Macdonald et al., 2000a). It is possible that an earlier melt, increased contaminant inputs to the lake water, and an earlier onset of spring growth in the lake ecosystem could result in greater amounts of contaminants being incorporated into the ecosystem, and thus into organisms consumed by humans (Macdonald et al., 2002).

Permafrost

Permafrost underlies much of the Arctic. In regions of discontinuous permafrost, contaminants deposited onto the surface by wind, rain, and snow are released during thawing and mobilized into active biological systems or into runoff, eventually draining into lakes, rivers, and the ocean. Permafrost also acts as a containment mechanism for man-made waste sites, such as landfills, sewage lagoons, mine tailings, and dumpsites. Increasing season length and surface air temperatures could allow contaminants to migrate through active permafrost layers to surface water sources used by humans and wildlife. Entry into runoff during periods of increased rainfall is also a possibility. The overall effect of permafrost thawing is likely to be increased contaminant exposure by a variety of mechanisms, and represents a "new" transport pathway.

Wildlife

Pacific salmon (*Oncorhynchus* spp.) spawn and die in freshwater streams and lakes. Contaminants accumulated by a salmon during that part of its lifecycle spent in the North Pacific are deposited into the local freshwater ecosystem where it dies. Over the past decades, as warming has occurred, Pacific salmon species have gradually extended their range north into the Arctic, adding contaminant loads to the predators and local biomass where they spawn and die (Babaluk et al., 2000). The magnitude of this input, for some freshwater systems, has been shown to exceed the input from atmospheric pathways (Ewald et al., 1998). Some contaminants, which are present at higher concentrations in the North Pacific than the Arctic, notably β-HCH, could thus increase in local arctic freshwater systems to levels higher than at present, so increasing the potential for human exposure and possible health effects.

Humans

Potentially, the greatest impact from human activities is from increased maritime traffic during ice-free periods with the sudden catastrophic release of hazardous materials into the local, regional, and eventually circumpolar environment. The possible increase in extreme weather events could increase the likelihood of such an event.

15.4.4.3. Summary

The transport mechanisms and pathways for contaminants in the Arctic are incompletely understood. Time trends are not available for the concentrations of most contaminants in most media, and instrumental records for major forcing factors are equally sparse. Models that link contaminant movement to climate events do not yet exist. All components of all contaminant pathways are affected by climate. The degree of uncertainty in the climate processes precludes prediction based on current climate models, but makes a powerful case for further research, as well as environmental, wildlife, and human health monitoring.

Monitoring and research on contaminant health effects in arctic residents and ecosystems is ongoing, and must now be linked to systematic research on contaminant movements into, and out of the Arctic. A warming climate in the Arctic could offer a variety of new economic opportunities to arctic residents, including increased maritime activity. International efforts should continue at preventing massive contaminant spills in the Arctic: such spills could be the most damaging contaminant event for local and regional ecosystems and residents.

15.5. Environmental change and social, cultural, and mental health

The potential impacts resulting from direct (section 15.3) and indirect (section 15.4) mechanisms of climate change on human health have been presented in previous sections of this chapter. This section addresses climate change and its link with social, cultural, and mental health.

The association between health and social, cultural, and economic factors has been reported extensively. A gradient has been consistently demonstrated across different socio-economic classes, regardless of how they are defined, for various measures of mortality and morbidity, both for individual diseases and for all causes combined (Marmot and Wilkinson, 1999). This gradient exists in many countries around the world, and has persisted despite major improvements in the overall health and wealth of populations. Also, numerous studies have shown correlations between unemployment and morbidity and mortality (e.g., Morris et al., 1994; Moser et al., 1984). The disparity in health status between Inuit and the larger national populations to which they belong (Canada, Denmark, Russia, United States) has often been attributed to their relatively poorer socio-economic status. Furthermore, the link between socio-economic conditions and health has been demonstrated within arctic populations. In a study of 49 Inuit and Dene communities in the Northwest Territories, based on community-level data from the 1992 NWT Housing Survey and routinely reported health and social service agency data, Young and Mollins (1996) found a correlation between most indicators for housing and socio-economic status with the rate of health center visits, used as a proxy measurement of morbidity. Among Canadian Inuit the proportion of respondents reporting excellent/very good health increased with the level of formal education (Bjerregaard and Young, 1998; Statistics Canada, 1991). Those in the highest income category are also more likely to report excellent health than those in lower income categories. The association between education and positive self-reported health was also found in the 1993-94 Greenland Health Interview Survey (controlled for age and sex) (Bjerregaard and Young, 1998). Among those with the most formal schooling, self-rated health was better in all age groups and with fewer reported longstanding illnesses.

Figure 15.19 represents one view of the interrelationship between health and social, cultural, and environmental factors. At the center of the model is the individual with his or her genetic endowment, physiological adaptation, and personal life experience. Everyday life, for example, work and lifestyle, determine the extent to which individuals are exposed to factors within their immediate surroundings that directly affect health. Such factors include tobacco, alcohol, diet, contaminants, microorganisms, and psychological factors. Everyday life is in turn determined by social, economic, and cultural factors within the wider society. All the individual, social, cultural, and socio-economic factors are influenced by the environment within which they are embedded and by possible changes in this environment (e.g., see Box 15.1).

The effect of change on communities resulting from climate related impacts, for example, by flooding and ero-

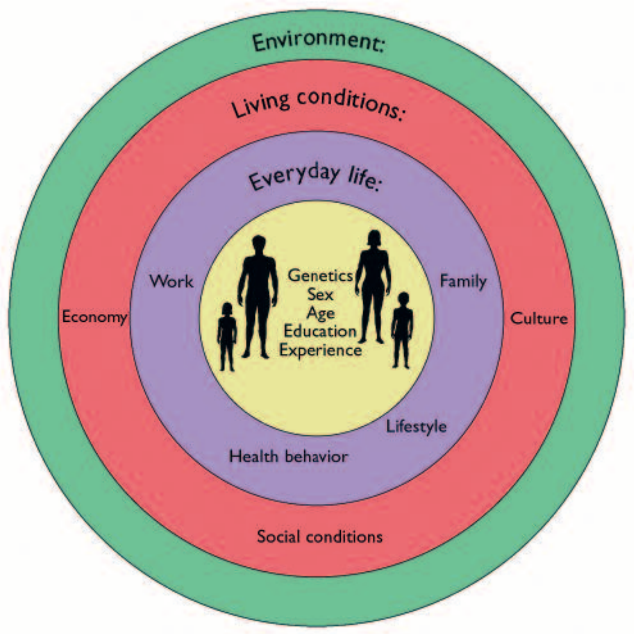

Fig. 15.19. Interrelationship between social, cultural, and environmental factors known to affect health.

sion, or warming temperatures and shifts in local resource access and availability, and the links between these changes in the physical environment and individual health are clear. Research using an ecological approach has also shown that the social environment of the community affects population health (Macintyre and Ellaway, 2000). Studies have focused on the extent to which social relations, social capital, and the social vitality of communities influence individual health status (Berkman, 1995; Kawachi et al., 1997; Veenstra, 2002). Although the relationship between the social environment of the community and the health of the individuals is still not clear, studies have shown associations between, for example, social isolation and mortality (Berkman and Syme, 1979) and social capital and poor self-rated health (Kawachi et al., 1999). In both cases the association was present even after adjusting for individual risk factors. Even though the health advantages are not fully understood, research has shown that a healthy community can be characterized as a safe environment that provides opportunities for social integration, and is neither conflictual, abusive, nor violent (Taylor J. et al., 1994).

Research and practice in health promotion have focused on the community level rather than on disease prevention in individuals. The role of the social environment for individual health argues this inclusion. Also, it is widely believed that the positive effects of health interventions result from a high degree of community ownership and participation in defining objectives, planning, and implementation of the initiative (Bracht, 1999; Green and Kreuter, 1999).

Research on health promotion and community health shows that community members' involvement in the social life and their shared pursuit of broader social goals through psychosocial processes can positively affect health, and that participation is a condition for positive outcome of health promotion efforts.

The potential for future health promotion in combining these two perspectives on community health is obvious as increasing communities' capacity to address problems and to work together to solve them will strengthen the effect of health promotion projects and help to improve the health of the population. Arctic communities have recently undergone rapid socio-cultural change and these changes will be further accentuated by the projected climate changes addressed in Chapter 4. Building communities' capacity to meet these changes is an area that needs further attention throughout the Arctic.

15.5.5.1. Acculturative stress and mental health

The concept of *acculturation* describes the cultural and psychological changes that result from continuous contact between people belonging to different cultural or ethnic groups (Berry et al., 1986; Redfield et al., 1936). At the population level, changes in social structure, economic base, and political organization frequently occur as a result of this contact, whereas at the individual level the changes are in such areas as behavior, identity, values, and attitudes. Berry et al. (1986) described this process in indigenous cultures in relation to the impact of modernization on indigenous people and traditional groups (Fig. 15.20). Climate change can also impact on the traditional way of living via influences on reindeer herding, fishing, and hunting. Alterations of the physical environment can lead to a rapid and a long-term cultural change and loss of traditional culture which can, in turn, create psychological distress and mental health challenges (see Box 15.7).

Group strategies for dealing with changes in ways of living can vary from readily and easily adapting to the changes, to resisting them, or to collapsing under their weight (Berry, 1985). Individuals adopt different acculturation strategies and their mental health is expected to vary both as a function of the strategy itself and in relation to the balance between the strategy which is possible or preferred by the individual and that of the majority group (see Fig. 15.20). From the mental health perspective, integration seems the most successful strategy and marginalization the most problematic, with separation and assimilation being intermediate in relation to mental health (Berry, 1990a; Berry and Sam,

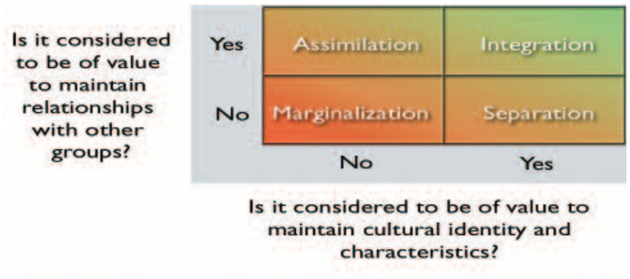

Fig. 15.20. Four modes of acculturation (Berry, 1990b).

Box 15.7. Climate, reindeer herding, and Saami culture

The Saami are indigenous reindeer herding people originally inhabiting arctic regions of Norway, Sweden, Finland, and western Russia. The Saami live in communities which have undergone rapid modernization and cultural revitalization. Some communities are more traditional while others are more modern with regard to the average lifestyle of their residents. In terms of mental health and social well-being, Saami people living in areas strong in culture and traditional ways of life appear just as healthy as the average population in these regions.

However, climate changes could have significant impacts on Saami communities and culture. Increasing temperatures may influence the seasonal migration of reindeer (see Chapters 11 and 12). The consequences of the climate changes are likely to be varied and include causing reindeer to stay for extended periods on less productive fields. Throughout the 1990s, overuse of the pasture lands by reindeer contributed to a crisis within the reindeer herding industry leading to a forced reduction in numbers of reindeer. This in turn forced several reindeer herders to stop herding. According to social workers in the Saami highlands, this led to higher rates of unemployment and dependence on social welfare in these communities. As reindeer herding is seen as a Saami activity, and reindeer herders as the carrier of the Saami culture, those individuals who left herding lost not just an important occupation but also status as an important protector of the Saami culture. Exclusion from this group has been a considerable stress for families and has had significant and far reaching impacts on the Saami culture as a whole.

1997). Marginalization reflects alienation and anomie and is a risk factor for mental health (Berry and Kim, 1988). In integration, relationships to both cultures may provide the strongest socio-cultural foundation for good mental health including bicultural competence and coping strategies necessary for adaptation to both cultures (Berry and Kim, 1988).

The concept of *acculturative stress* refers to stress in which the stressors are identified as being rooted in the process of cultural change or acculturation. For arctic peoples these stressors can be loss of traditional food resources and habitats, unemployment, loss of cultural practices, and migration. Climate change can be an external factor that indirectly initiates the acculturation process by forcing people to behave in new ways, to change their ways of living, and to replace or drop old traditions (see Box 15.7).

Acculturative stress may be associated with psychological changes such as psychosomatic symptoms, feelings of alienation and marginality, and identity confusion (Berry, 1997). If the acculturation experience overwhelms the individual with a feeling of loss of control, psychopathology may occur such as depression and anxiety, substance abuse, and suicide (Fig. 15.21). For instance, if climate change leads to a loss of herding, hunting, or fishing opportunities for people who are closely connected to and dependent upon such activities, this can result in feelings of loss and grief. This might result in longer-term feelings of marginalization which can contribute to substance abuse, depression, and suicide. A study of Saami males living in remote areas found a close relationship between marginalization and depression/anxiety (Kvernmo and Heyerdahl, 2003), while a study conducted in Greenland found that growing up in a town and being fully bilingual, as compared to growing up in a small village and speaking only Greenlandic, was associated with better mental health status (Bjerregaard and Curtis, 2002). This disagrees with the assumptions previously held that the social and psychological outcomes of acculturation are inevitably negative (Berry and Kim, 1988; Malzberg and Lee, 1956). It appears that successful integration depends on having and taking advantage of the opportunities necessary to meet changing conditions.

15.5.5.2. Examples of the influence of rapid change on psychosocial health

Several examples are used here to illustrate the relationship between the rapid socio-cultural and economic change witnessed in the Arctic over the past 20 to 50 years and the psychosocial health of the populations living there. A good understanding of such links is important in relation to the climate changes projected for the Arctic over the next hundred years (see Chapter 4). Further changes may result from climate-related changes in economic opportunities, traditional lifestyles, and subsistence activities.

A change in occupational patterns from hunting and small-scale fishing to an increase in wage-earning employment is seen across the Arctic. In Greenland villages, wage earning has been introduced along with institutions and service deliveries such as schools, stores, and sanitation infrastructure. In towns, there are factories and enterprises, banks, shops, and administrative services. The changes in occupational patterns are associated with decreased physical activity and a change from a traditional marine diet to a more western diet in many coastal indigenous groups and this is of particular importance in relation to cardiovascular diseases (Bjerregaard and Young, 1998). In many studies, cardiovascular risk increases with modernization and urbanization, but although mortality from ischemic heart disease is slightly lower among Inuit than in the general population of Denmark, Canada, and the United States, it has decreased over recent years while marine food has been increasingly replaced by store bought food. In contrast, mortality from other heart

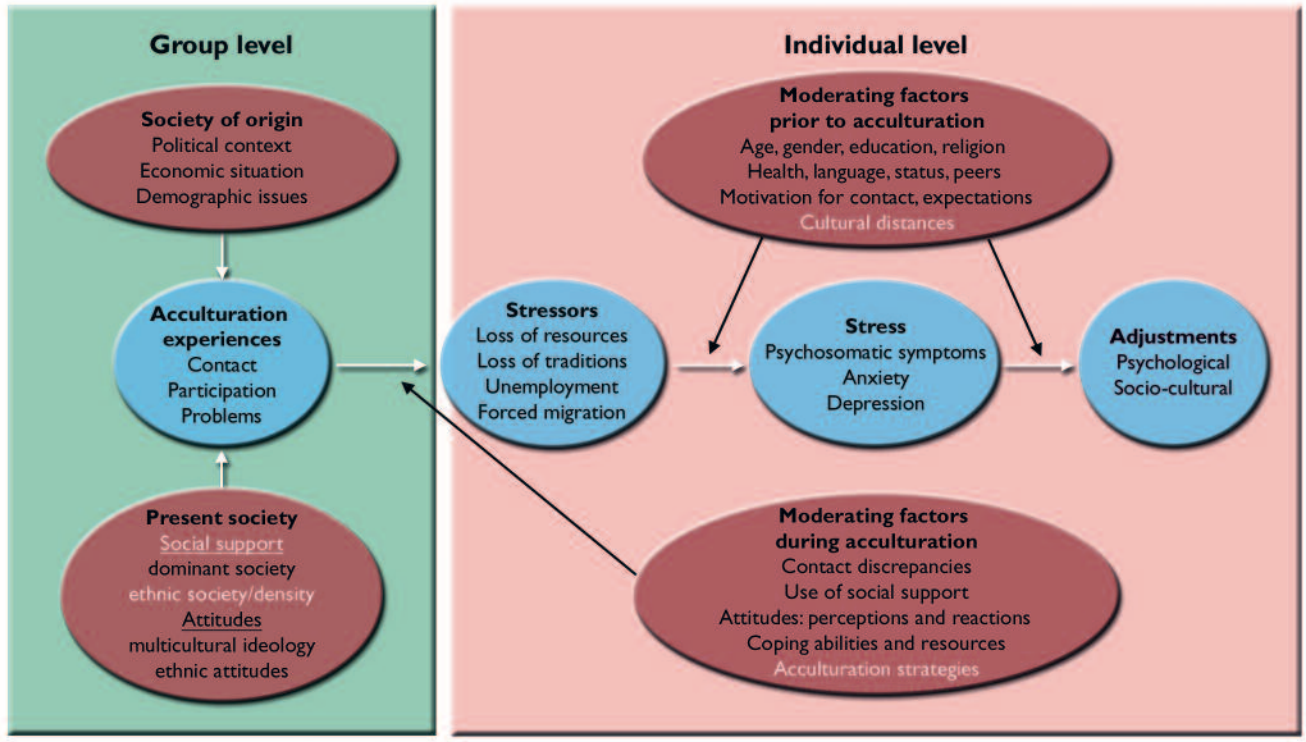

Fig. 15.21. Acculturation stress and moderating factors (based on Sam and Berry, 1995).

diseases and stroke is considerably higher in Inuit and shows an uncertain time trend (Bjerregaard et al., 2003). Type 2 diabetes increased considerably over the last 40 years among the Inuit in parallel with processes of modernization (Ebbesson et al., 1998; Murphy et al., 1992). In Greenland, type 2 diabetes is now more prevalent than in Denmark (9.8 and 7.9% in the 40 to 64 year old age range, respectively; Bjerregaard et al., 2003), which leads to speculation about increased genetic sensitivity to environmental pressure in the Inuit. The change in dietary patterns from traditional foods to a more western diet with a higher consumption of store bought foods is important in relation to both the connection with obesity and other cardiovascular risk factors and with the loss of the sociocultural values related to eating and sharing traditional foods and their significance for health.

The amount of traditional food and the specific species consumed vary considerably among regions and population groups (Bjerregaard and Young, 1998; Blanchet et al., 2000; Kuhnlein et al., 2000). Older people and people in villages who fish and hunt themselves eat more traditional food, whereas the young wage earners consume more store bought foods often related to their convenience. However, regardless of the levels of consumption, traditional foods are highly valued by all population groups. They are considered filling and healthy and to provide strength, warmth, and energy in ways that store bought food does not (S. Bernier, Public Health Research Unit, Université Laval, Canada, pers. comm., 2002; Borré, 1994; Furgal et al., 2001). Traditional food is also reported to be a significant contributor to cultural identity, tradition, and social cohesion in Inuit communities. To eat and like traditional food is perceived as a marker of identity in the same way as is speaking the Inuit language (Kleivan, 1996; Searles, 2002).

> *Inuit food has sustained us, nourished us, brought us together, and given us a sense of who we are.*
> Egede 1995

> *… in order to have a Greenlandic identity the person must eat … and like dried fish, raw mattak, etc.*
> Petersen 1985

> *I can't do without kalaalimernit [traditional Greenlandic food]. I eat it a lot. I was brought up with people who eat kalaalimernit. It tastes good and it feels good for you. For instance when I do sports I feel kind of stronger when I have eaten kalaalimernit.*
> Focus group study: Ilulissat, wage earners

The rapid changes that have taken place within arctic communities and the migration from villages to larger towns has lead to psychosocial stress among populations that within little more than one generation have had to adapt to significantly different ways of life. Those who move may experience a lack of social relations in towns, where still more people live in single-family households and social relations are chosen and individualized. Traditional values may appear irrelevant, as language skills and formal education become the means to succeed and avoid unemployment. However, traditional knowledge and expertise in traditional activities is still very relevant, if not increasingly so, when aspects of the environment become more unpredictable or "risky" in which to practice subsistence activities and travel on land or sea.

Psychosocial stress is reflected in the incidence of social problems seen in many arctic communities today. Whereas alcohol abuse in western societies is usually characterized by an increasing daily consumption over many years, it is the occasional, sometimes regular, drinking spree or binge drinking which creates many problems in arctic communities (Bjerregaard and Young, 1998). The most important health implications are accidents and violence resulting in intentional and non-intentional traumas (cuts, bruises, fractures, head injuries). Drowning, falls, frostbite, burns, and pneumonia also result from intoxication and a direct association between alcohol use and incidence of suicides has been shown. Alcohol consumption is also associated with economic problems and job loss due to instability at work and to domestic abuse.

Studies have shown a high occurrence of violence and sexual abuse in some arctic populations (Bjerregaard and Young, 1998). A survey in Greenland showed that women and men have equally often been victims of violence (47% for women and 48% for men) but that women had more often been sexually abused (25% and 6%, respectively) (Curtis et al., 2002). Having been the victim of violence or sexual abuse was significantly associated with a number of health problems: chronic disease, recent illness, poor self-rated health, and mental health problems. The association between having been the victim of violence or sexual abuse and current health status was stronger for women than for men (Curtis et al., 2002).

Similarly, suicide has played a significant role in many arctic communities and individuals' lives. It has been argued, based on the much higher suicide rate in men than women that women in the Arctic have been more successful than men in adapting to social change. While women have been able to continue their traditional roles as caregivers, both in the family and in the labor market, the transition from hunter and sole breadwinner to wage-earner in a subordinate position or even unemployment has been a difficult transition for many arctic males. On the other hand, studies have shown that women more often than men have suicidal thoughts and mental health problems (Bjerregaard and Curtis, 2002). The finding that men suffer more from socio-cultural change related stress than women may be in part based on the more visible and more commonly reported manifestations of this stress or frustration common among men (i.e., they are more likely to become violent or to commit suicide). A population survey of adults in Greenland showed significant associations between suicidal thoughts and a number of social and cultural factors, the most important determinants being the occurrence of alcohol problems in the parental home and the experience of sexual violence during childhood (Bjerregaard, 2001). Among Greenlanders who had neither experienced alcohol problems nor sexual violence in childhood, 10% reported suicidal thoughts, while for those who had experienced both, 82% reported suicidal thoughts (Table 15.1).

Table 15.1. Prevalence of serious suicidal thoughts in Greenland Inuit according to childhood experience of alcohol misuse and sexual violence (Curtis et al., 2002).

	No sexual violence during childhood (n=1150)	Sexual violence experienced during childhood (n=65)
	%	%
No alcohol problems in parental home (N=760)	10.3	21.7
Occasional alcohol problems in parental home (N=355)	18.2	48
Often alcohol problems in parental home (N=100)	39.8	82.4

Alteration in subsistence species, changes in habitability of buildings, erosion of village sites (see Box 15.6), and disappearance of commercially critical species (see Box 15.1) may all cause dislocation of residents from smaller to larger communities, with a subsequent overload of scant resources in the receiving community. This combination of factors and interaction with the capacity of individuals and communities to adapt to or change with these climate and environmentally influenced shifts may have a significant bearing on the social, cultural, and mental health of individuals in arctic communities (for a discussion of community capacity and resilience see Chapter 17).

15.5.5.3. Example scenario of interactions between climate warming, ocean temperature, and health

Climate change can influence health in the Arctic in many ways. These fall into two groups: direct (section 15.3) and indirect (section 15.4) influences. Two indirect pathways are of significance to individual and community health issues related to socio-cultural and economic transition. The first results in reduced opportunities for subsistence hunting and fishing as a result of changes in animal or plant populations, an increase in extreme events, and changes in sea-ice distribution and thickness, while the second forces populations to move. These factors include the movement or loss of crucial species for subsistence hunting, coastal erosion, breakdown of sanitation infrastructure, and increasing difficulties in maintaining transportation systems for goods and people. Both pathways, of which the latter is also a consequence of the former, may be related to climate changes and may be seen as mediated through acculturation and cultural loss. However, the modernization process in arctic communities over the last 50 years has been accompanied by a growth in the cash economy, making it increasingly difficult to maintain a livelihood from hunting and fishing and therefore encouraging people to move to more regional economic centers.

Figure 15.22 shows two possible pathways between a cooling of ocean temperatures and decreased health status in indigenous communities. The first is via a reduction in the catch of commercially important species. This happened in Greenland in the 1960s when Atlantic cod disappeared from coastal waters off West Greenland (see Box 15.1). Unless new sources of income are generated, reduced catches will result in deterioration in economic conditions and unemployment. Unemployment is associated with social and mental health problems in communities, increased use of alcohol and violence, and suicide.

The second pathway of impacts is via a change in the availability of subsistence species. Historically, indigenous groups have responded to such a change by moving with the animals to places with better catches, however, human migrations are now far less easy with today's settled villages. Decreased opportunities for catching seals, for example, result in both dietary changes and a loss of the knowledge required to recognize, harvest, and prepare traditional foods (Kuhnlein and Receveur, 1996), and in a sense of cultural loss as hunting and food sharing is important for the identity and maintenance of the social well-being of the community (Borré, 1994). The lack of subsistence species also drives an eventual migration of individuals to towns where some will face unemployment. The shift from a traditional marine diet to a more western diet, along with other behavioral changes that follow the transition from a lifestyle based on hunting and fishing to a more sedentary wage-based economy lifestyle, is of major importance in relation to the occurrence of cardiovascular disease in Inuit populations.

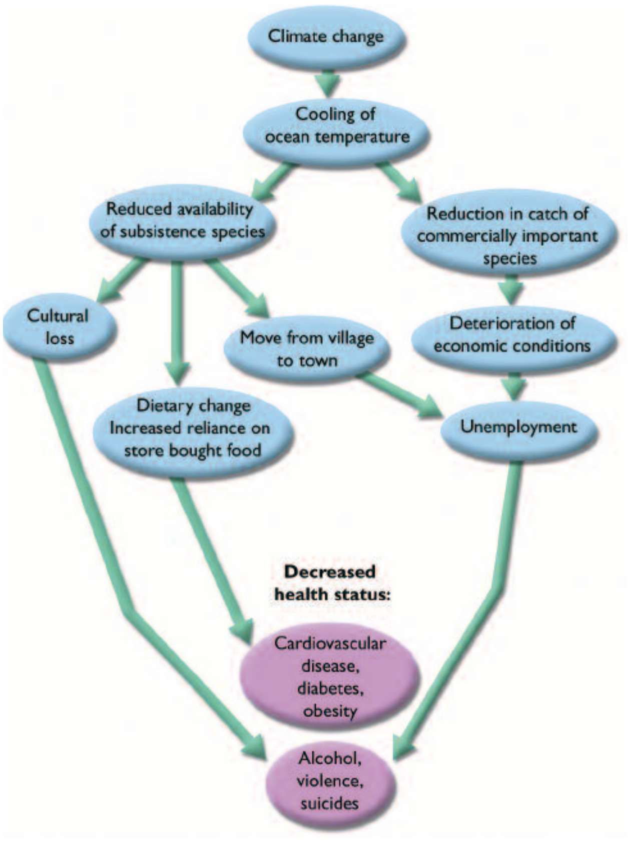

Fig. 15.22. Example scenario of the link between climate-related changes, and community and individual health in indigenous communities in Greenland.

In spite of of the present cooling trend in parts of Greenland, the climate scenarios described in Chapter 4 project a warming trend for Greenland over the next 100 years. The health impacts of this warming are likely to be mediated by the same indirect mechanisms discussed in section 15.4. Changes in the distribution of commercially important fish species, as well as in subsistence species could affect health in the same way as ocean cooling. Increased risk to hunters and travelers due to ice changes, and political and economic policy decisions which result in the relocation of populations are also likely to have major health impacts.

It is unlikely that periodic warmer weather could result in the same detectable changes in mortality from cardiovascular disease and stroke that are seen in large populations in the northern temperate zones of Europe and North America. The scattered, sparse population of the present cooling region of Greenland is too small for a significant number of well-documented mortality events.

Significant warming in Alaska since the 1970s has resulted in significant impacts. Permafrost thawing and lack of sea-ice protection have resulted in the imminent threat of forced village dislocation, with severe stress on families. River and coastal erosion with continued warming will make this more widespread. In addition, the northward spread of beaver populations has resulted in the obstruction of many streams traditionally used by villages for surface water supply. Contamination of these sources by the zoonotic parasite *Giardia lamblia* makes outbreaks of human disease much more likely. At the same time, moose have extended their range into new regions and waterfowl habitat is increasing, making new subsistence foods available. Thus, in Alaska, new risks and new opportunities have resulted from warming. This makes the development of community monitoring a more urgent task, as only data will enable policy and public health responses to mitigate risks and maximize opportunity.

Despite the arguments made here for the connections between environmental change, socio-cultural transition, and health in the Arctic, many negative health outcomes are attributable to causes other than climate change. The modernization process in indigenous communities in the Arctic since the 1950s has been accompanied by many such health outcomes (e.g., increased use of alcohol, more violence, and higher mortality from suicides, heart disease, and diabetes), without any yet-reported association with climate change.

15.5.5.4. Summary

Health is a multifactorial concept, influenced by a variety of determinants, climate change being one of many environmental factors. Many of these determinants are still poorly understood. The rapid social, cultural, and economic transition that arctic communities have seen over the past 50 years has influenced lifestyles and individual and community health. These changes are very likely to be affected and even accentuated by climate change in the future. The influence of adaptive behaviors resulting in changes to lifestyle and cultural loss further influence acculturative stress in arctic communities. Climate change has the potential to influence the rapid changes ongoing in communities today by challenging individuals' and community's relationship with their local environment, which has for thousands of years, been the basis of their identity, culture, and well-being.

15.6. Developing a community response to climate change and health

Health impacts related to climate change in the Arctic are likely to vary across communities and regions, with some changes being positive and others adversely affecting the health of individuals. In response to these impacts, communities need to develop strategies to take advantage of opportunities and to minimize risks. In some cases, communities have already started to adapt to climate related changes with potential impact on aspects of health. For example, in Inuit communities of the western Canadian Arctic, individuals report now taking bottled water on trips due to the lack of fresh water sources while on the land and hunters have adapted their hunting and fishing times to compensate for the changes in species availability and access to continue to procure fresh traditional foods (Nickels et al., 2002). A key component in this ability to adapt and respond is the development of a better understanding of the relationship between climate and the health of northern peoples and access to locally relevant information on the changes taking place. The identification, selection, and monitoring of some basic indicators for climate and health is one tool communities can use to help in the development of their response to these changes. This information can support the community's capacity to know what changes are occurring, what changes are likely to take place in the future, and what impacts these changes may have. Linking these indicators to the projected scenarios of change reported in other chapters of this assessment allow communities to monitor, and where required develop strategies to minimize negative impacts in the future. This section proposes some candidate indicators for this purpose based on the scientific review of direct and indirect climate–human health interactions presented in this chapter.

15.6.1. Goals of community indicators

The identification, selection, and monitoring of indicators is one way in which communities can gather the information to support their diagnostic needs and to support the development of potential response strategies. Within this context, indicators for climate change impacts on human health are measurements or observations of a parameter (e.g., snow, ice, water, temperature, UV-B radiation, permafrost, a component of human health) that link climate, the environment, and an aspect of community or individual health. The indicators selected by the community need to be issue-specific and must be presented in a way that makes the information they generate easy to understand and useful in making decisions about climate change and health impacts at the community level.

Indicators can potentially serve many purposes. For example:

- To confirm changes or trends in a condition over time (e.g., date of freeze-up of the local bay).
- To assess the current condition of the environment to judge its adequacy with reference to a standard (e.g., safety of ice for travel).
- To anticipate hazardous conditions before negative impacts occur (e.g., to know when a severe storm event is coming or to predict a shortage of a fresh source of a specific traditional food in the community related to difficulties with access and availability).
- To identify causes of effects and to identify appropriate action (e.g., windchill factor to warn people about cold injury).

The type(s) of indicators chosen by a community or region for a monitoring program must be determined by the specific goals of the community. For example, whether it is the intent to be able to warn individuals of future dangerous conditions, whether it is to determine if an increase in accidents experienced by residents while on the land or water is associated with changes in local climate conditions, or whether it is to determine if changes in local food security (access and availability of traditional food species) are associated with changes in climate and whether this situation will become sufficiently bad in the future that they must be prepared to take early action. In many cases, regional and community public health and other authorities (e.g., Meteorological Service/Weather Bureau, Wildlife Dept.) can be helpful in selecting and gathering such indicator-based data. A good definition of goals for the monitoring activity will provide direction as to what indicators are best suited to their needs and are most appropriate to the community or region. The scale at which the indicators are gathered is also critical as some changes can be detected and are best managed at a regional scale (e.g. changes in access to market foods to supplement local diets at critical times of the year) while others require a more local-scale approach (e.g., monitoring permafrost stability at the airstrip of a community). In all cases, for indicators to be appropriate, meaningful, and useful to local communities, community individuals must be directly involved in their identification and selection as well as in the design and implementation of the data gathering monitoring programs (Eyles and Furgal, 2002).

15.6.2. Characteristics of useful indicators

Criteria can be used to guide indicator identification and selection to ensure that appropriate indicators are chosen to help meet community objectives. It is essential that each community or region develops its own criteria, although many may be general and useful to all regions. Two general types of criteria that are often used are scientific and use-based criteria.

Scientific criteria are intrinsic to the issue of scientific quality (sensitivity, reliability, and statistical validity) and are often addressed by using indicators from existing and recognized lists. Indicators based on traditional or indigenous knowledge are very useful and should include a description, where possible, of the understanding of the link between the indicator and the specific health impact. It is also important to consider other "use-based" criteria, such as:

- Feasibility (are they already available and if not, what is the feasibility of collecting new information, taking account of cost, ease and time for collection, capacity to gather data, etc.).
- Perceived importance of the indicator to those affected (community representatives).
- Number of indicators (a manageable number is needed to attain specified goals, but this number must not be too cumbersome for community monitoring system managers).
- Balance (a rough balance among the various aspects of the issue).
- Catalyst for action (those that act as a catalyst to drive action are also useful, e.g., ice thickness on travel routes).
- Understandability by the media, local decision-makers, and policy-makers.
- Minimal environmental impact to collect.
- Relevance to all members of the population.

The candidate indicators listed in the following section are proposed on the basis of the review presented in this chapter and all meet the following basic criteria:

- The indicator relates climate changes, directly or indirectly, to potential human health impacts.
- The data are already being gathered by regional or national governments or are readily available from other sources.
- Where the indicator data are not already gathered, they could be easily collected by communities using standard methods.
- Time trend data for the indicator exist or can be easily gathered.

15.6.3. Proposed candidate indicators

This section lists indicators proposed as potential candidates for community selection. They are not an exhaustive or complete list but are proposed as tools to assist communities in discussing and identifying their own indicators. They are derived from the review of direct and indirect climate–human health interactions presented in this chapter and assume the collection of general environmental data related to climate changes at the local and regional scale (e.g., temperature, precipitation, ice cover).

15.6.3.1. Direct impact mechanism indicators

The collection of some basic indicator data can help communities monitor the direct impacts of climate on health in northern communities. Table 15.2 identifies indicators of health impacts related to direct interactions with climate variables such as accidents while on the land or ice (unintentional trauma) related to bad weather conditions, deaths or injuries related to extreme weather events, and the health impacts of increased UV-B exposure.

15.6.3.2. Indirect impact mechanism indicators

Similarly, the monitoring of basic indicators, such as those presented in Table 15.3 can be used to help

Table 15.2. Direct impact mechanism indicators.

Useful health indicators
• General health statistics (see AMAP, 2003)
• Rates of cold injuries (e.g., frostbite)
• Rates of coronary heart disease
• Rates of unintentional injury
• Rates of intentional injury
Extreme weather events, thermal stress, and health
• Extreme event-related use of regional and community rescue services
• Unintentional injury mortality associated with extreme weather events
• Highest and lowest seasonal temperature
• Number of days in winter with extreme low temperature (where extreme is defined as deviation of more than 20% below the average monthly temperature in winter)
• Number of days in summer with extreme high temperature (where extreme is defined as deviation of more than 20% above the monthly average temperature in summer)
• Reports of respiratory trouble (hospitalization)
• Deaths due to exposure in winter
UV-B radiation and health
• Incidence of skin cancers in arctic regions
• UV-B radiation measurement/ozone depletion measurement in arctic regions
Indicators for annual monitoring[a]
• Measurements of UV-B radiation at ground level and at the personal level by integrating or spectral radiometers and personal dosimeters
• Incidence of sunburns especially the time at which increases in sunburn begin to be noted throughout the Arctic
• Number of cases of snow blindness and frequency of reports
• Increases in cold sore occurrences which may indicate suppression of immunity against Herpes simplex virus (Type 1) and other aspects of cell-mediated immunity by UV-B radiation
• Increases in cataract on an annual basis throughout the Arctic

[a] with emphasis on ozone depletion episodes as sunlight increases throughout the arctic spring and summer

Table 15.3. Indirect impact mechanism indicators.

Wildlife populations and health

- Government harvest data by species of interest (key country food species, sentinel species)
- Stock assessments of species of interest and importance to local economies and diet
- Local arrival/departure dates of migratory species
- Frequency of reports of new species to a region
- Important animal disease frequency (e.g., rabies, brucellosis)
- Appearance of new zoonotic diseases (e.g., West Nile virus)
- Local hunter/fisher reports of animal/fish abnormalities
- Registry of reportable infectious diseases spread from animals to humans and through contaminated water
- Incidence of human cases of zoonotic diseases

Ice, snow, and health

- Rates of cold injuries (e.g., frostbite)
- Mortality rates from coronary heart disease
- Rates of unintentional injury

Infrastructure and health

- Movement measurements of structures on permafrost
- Measurements of key shoreline and river bank erosion rates
- Measurement of trends in flood depth and frequency
- Increased repair costs for sanitation infrastructure, boardwalks, and roads
- Increased operational costs for water treatment systems
- Increase in regulatory noncompliance events for sanitation systems
- Increases in pollution of waterways caused by human waste or solid waste leachate
- Increased incidence of waterborne disease outbreaks
- Increased incidence of certain cancers caused by waterborne contaminants
- Increased incidence of diseases associated with poor personal hygiene
- Increased incidence of diseases caused by contact with wastewater contaminants
- Increased reports of damage to sanitation infrastructure caused by erosion, flooding, or foundation failures
- Increased reports of water rationing caused by drought

Society, culture, and health

- Number of in-migrants to regional hub communities per year, and by number of families
- Number of out-migrants from a region's villages, per year
- Incidence of legal encounters for child abuse, assault, and alcohol-related offences
- Community and regional trends in unemployment
- Community and regional rates of completion of 12 years formal education
- Incidences of treatment for depression and post-traumatic stress disorder
- Consumption of traditional food species (frequency, total amount, and percentage composition of total diet)
- Self-reported health status from regional health surveys

communities identify, understand, and track the indirect impacts climate variables may be having on community and individual health in the circumpolar North. Impacts related to exposure to zoonotic diseases, indirect injuries related to environmental conditions, changes in the stability and safety of community infrastructure, and the combined impacts of climate-related changes on social and mental health and well-being can be monitored via the collection of such data.

15.7. Conclusions and recommendations

This chapter discusses direct and indirect relationships and impacts, both positive and negative, between climate-related changes and human health in northern communities. The likelihood of these impacts occurring in any specific community or region is difficult to determine. The risk of impact depends on many factors, both current and future. The most obvious conclusion that can be drawn is that much research remains to be done on the relationship between climate change and individual and community health in the Arctic. Climate will continue to influence public health in the small remote communities of the Arctic. The recent record warming, and the scenario of future warming, combined with the multiple mechanisms by which climate impacts on health indicate urgent need for adopting community-based monitoring strategies. A network of such communities, within and across regions, reporting a common set of similarly measured climate, health status, infrastructure, and ecosystem observations would serve to identify both emerging threats, and opportunities. In addition, this would allow utilization of public health data to quantify impact, and provide the basis for resource advocacy, and to suggest mitigation strategies, as well as jurisdictional policy. Communities must monitor changes that may represent threats or adverse impacts. Where possible, they must proactively develop coping or adaptation strategies. Similarly, they must take advantage of potential opportunities that these environmental changes present. Thus, regional and national governments need to assist in the design, and provide support for community based monitoring and mitigation strategies to cope with climate change.

15.7.1. Principal conclusions and recommendations

1. **There is a lack of comparability in health status data between countries.**

   A core group of health status indicators, gathered and defined identically, should be a high priority for Arctic Council member nations.

2. **There is a need for a carefully planned strategy, at the community and regional level, to monitor and document environmental change.**

   Arctic Council members and program workgroups should provide technical assistance regarding monitoring strategies, climate impact mitigation and pilot studies, data analysis, and evaluation.

3. **There is a lack of an organized effort to collect and utilize indigenous knowledge regarding climate and climate changes.**

   Indigenous knowledge, and its preservation, should be encouraged among Arctic Council member nations.

4. **There are few data on the impact of changing UV-B exposure in the Arctic on the biota and human residents. There is little systematic monitoring of ground-level UV-B radiation.**

   Academic and United Nations organizations have created UV-B research strategies. With regional and community collaboration, research and monitoring strategies relevant to circumpolar populations should be created.

5. **There are few data on climate change impacts on regional biota. A critical need exists for the monitoring of wildlife diseases, and human–wildlife disease interaction. There are few data on climate-induced changes in the diet of subsistence species, which affects their nutritional value in traditional diets.**

   Arctic Council programs have the expertise to design effective regional and international monitoring programs in cooperation with communities. This critical activity should be given a high priority.

6. **There is no systematic monitoring in all regions for safety of snow and ice conditions for local/regional travel and subsistence activities.**

   Regional governments should collaborate with communities to establish appropriate monitoring and communication networks; dissemination of appropriate traditional and modern survival skills should be systematically taught to children and young people.

7. **Monitoring is critical in regions of the Arctic where physical infrastructure depends on permafrost or where a village site depends on sea ice protection from storm erosion.**

   Regional governments should assist in developing community-based monitoring.

8. **Data on contaminant transport into and out of the Arctic is critical for projecting impact and risk for arctic wildlife and residents. Changing climate makes monitoring essential.**

   International coordinated research and monitoring of changing contaminant transport pathways should continue and expand where needed.

In all areas, there is a need for local and regional integrated analyses of the associations between arctic health status and climate variables. This can be accomplished by the establishment of monitoring and data collection mechanisms where they do not already exist. Also, public health education programs should incorporate, where possible, information on risks associated with the environmental changes most relevant to their region.

15.7.2. Recommendations for monitoring and research

Specific recommendations for monitoring and research are as follows.

Thermal stress and arctic human health

Establish organized monitoring and data collection programs (inclusive of local perspectives and indigenous knowledge) involving, but not limited to, the indicators identified in this chapter to support community understanding of changes in arctic health owing to thermal stress.

UV-B radiation and arctic human health

Measure incident UV-B radiation at ground and individual levels using personal dosimeters and ground-based integrating and spectral radiometers.

Carry out cross-sectional population based surveys and follow-up studies in the Arctic and other areas to investigate the causal relationship between UV-B irradiance and cataract and other UV-B induced health effects to the eye such as climatic droplet keratopathy.

Compile local residents' knowledge and perceptions of UV-B radiation and its effects on health in order to supplement scientific data and obtain new knowledge about existing UV-B related habits, particularly with regard to skin, and immune system and eye impacts.

Establish an international network of UV radiation research centers and monitoring programs.

Expand collection of epidemiological data on key UV-B and health issues (e.g., arctic cataract data are difficult to obtain as are sunburn and cold-sore data).

Wildlife, diet, and health

Establish community based and regional scale monitoring programs for the indicators identified in this chapter.

Where problems are identified (e.g., increasing incidences of exposure to zoonotic diseases), establish surveillance programs to protect the health, social, economic, and cultural benefits of harvesting subsistence species while maintaining confidence in and the benefits of consuming these foods.

Snow, ice, and arctic community health

Establish surveillance and communication networks at the community level to support early warning of dangerous conditions for travel and land-based activities (weather, ice conditions, etc.).

Provide support for community freezers and other food supplement and food safety programs to ensure access to safe and healthy traditional foods in arctic communities.

Develop education programs for young people, based on traditional survival skills, to enhance individual capacity to continue aspects of a traditional lifestyle.

Infrastructure and arctic human health

Establish local level monitoring programs for data collection on permafrost and infrastructure stability.

Monitor ground temperatures and compare to historic measurements.

Monitor basal depth of permafrost and compare to historic measurements.

Monitor coastal and river bank erosion and compare to historic measurements.

Monitor incidence of flooding caused by storm surges or heavy precipitation.

Monitor emergency projects for repair of failing infrastructure.

Society, culture, climate, and arctic health

Research the role of the environment, specifically climate-related variables, in community change for small remote locations.

Research to support the understanding of the cultural context and variables influencing individual and community vulnerability, capacity, and resilience in relation to the impacts these changes represent.

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