Climate change, its impact on human health in the Arctic and the public health response to threats of emerging infectious diseases

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The Arctic has warmed substantially over the last few decades. A recent study shows that temperatures over the last century increased almost three times faster in the Arctic than elsewhere in the Northern Hemisphere, reversing a 2000-year cooling trend, and outpacing current climate model predictions (1). This rapid warming trend is anticipated to continue into the next century with temperature increases exceeding those predicted in the rest of the Northern Hemisphere and will result in accelerated loss of land and sea ice, and an increased rate of sea level rise, with global consequences. These changes are already impacting local communities, which have observed profound changes in their local environments, and are leading to significant economic and cultural upheaval particularly for the indigenous peoples of the Arctic (2). Because climate change is more advanced in the Arctic than other regions of the world, the Arctic can play a vital role in preparing the world for what is to come.

Resident indigenous populations of the Arctic are uniquely vulnerable to climate change because of their close relationship with, and dependence on, the land, sea and natural resources for their well-being (3). Direct health threats from climate change include morbidity and mortality resulting from increasing extreme events (storms, floods, increased heat and cold) and an increased incidence of injury and mortality associated with unpredictable ice and storm conditions. Indirect effects include increased mental and social stress related to changes in environment and loss of traditional lifestyle; potential changes in bacterial and viral diseases; and decreased access to quality water sources (4, 5). Some regions are at risk for increasing illness due to failing sanitation infrastructure resulting from changes in permafrost and storm surges. Some regions will also experience changes in diet resulting from changes in subsistence species distribution and accessibility (6). This may result in a shift away from a traditional subsistence diet to a more Western diet. While this shift may be beneficial, providing a more varied and reliable diet, the increased accessibility to processed foods, high in saturated fats and sugar, may result in an increase in the incidence of obesity, diabetes, cardiovascular disease and cancer (7, 8). Projected warming will affect the transport, distribution and behaviour of contaminants, further threatening the safety of the traditional food supply and potentially increasing human exposure (9). Higher temperatures at lower latitudes will increase volatisation of contaminants resulting in increased delivery of contaminants to the Arctic. As precipitation increases over land, river flow will increase resulting in greater delivery of contaminants to the coasts and oceans.

These health impacts are taking place in the context of ongoing cultural and socioeconomic changes occurring in Arctic communities. Climate change represents another of many sources of stress on these northern societies and cultures as it affects the relationship between the people and the land and environment, which will further stress communities and individual psychosocial health. The potential impact on human health will differ from place to place depending on regional, and even local, differences in climate change as well as variations in health status and adaptive capacity of different populations (3).

Arctic populations have a long history of both endemic and epidemic infectious diseases (10). Despite advances in antimicrobial therapy, and availability of vaccines, high rates of invasive diseases caused by *Streptococcus pneumoniae*, *Haemophilus influenzae* and *Mycobacterium tuberculosis* persist. Sharp seasonal epidemics of viral respiratory infections also commonly occur. The over-use of antimicrobial drugs in some regions has led to the emergence of multi-resistant *S. pneumoniae*, *Helicobacter pylori* and methicillin-resistant *Staphylococcus aureus.*

The impact of climate on the incidence of these existing infectious disease challenges is unknown. However, it is

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known that inadequate housing and sanitation are already important determinants of infectious disease transmission in many Arctic regions. Damage to the sanitation infrastructure by melting permafrost or flooding may therefore result in increased rates of hospitalisation among children for respiratory infections, as well as an increased rate of skin infections, and diarrhoeal diseases caused by bacterial, viral and parasitic pathogens (11).

Some infectious diseases are unique to the Arctic and lifestyles of the indigenous populations, and may increase in a warming Arctic. For example, many Arctic residents depend on subsistence hunting, fishing and gathering for food, and a predictable climate for food storage. Food storage methods often include above ground air-drying of fish and meat at ambient temperature, below ground cold storage on or near the permafrost, and fermentation. Changes in climate may prevent the drying of fish or meat, resulting in spoilage. Similarly, loss of the permafrost may result in spoilage of food stored below ground. Outbreaks of food-borne botulism occur sporadically in communities in the Arctic and are caused by ingestion of improperly prepared fermented traditional foods (12–14). Because germination of *Clostridium botulinum* spores and toxin production occurs at temperatures above 4°C, it is possible that warmer ambient temperatures in these regions associated with climate change may result in an increase the rates of food-borne botulism. Outbreaks of *Vibrio parahemolyticus* gastroenteritis are commonly associated with sea water temperatures above 15°C. An outbreak of gastroenteritis caused by *V. parahemolyticus* was documented among cruise ship passengers consuming raw oysters in Prince William Sound, Alaska (15) and provides direct evidence of an association between rising sea water temperature and onset of illness. In order to prevent further oyster farm outbreaks, a water temperature monitoring and shell-fish testing programme has been recommended. No additional outbreaks have been reported.

Warmer temperatures may allow an infected host animal species to survive winters in larger numbers, increase in population and expand their range of habitation and thus increase the opportunity to pass infections to humans. For example, the climate-related northern expansion of the boreal forest in Alaska and northern Canada has favoured the steady northward advance of the beaver, extending the range of *Giardia lamblia*, a parasitic infection of the beaver that can infect other mammals, including humans who use untreated surface water (2). Similarly, warmer temperatures in the Arctic and sub-Arctic regions could support the expansion of the geographical range and populations of foxes and voles, common carriers of *Echinococcus multilocularis* and the cause of alveolar echinococcus in humans (16, 17).

Climate change may influence the density and distribution of animal hosts and mosquito vectors which could result in an increase in human illness or a shift in the geographical range of disease caused by these agents. West Nile virus entered the USA in 1999, and in subsequent years infected human, horse, mosquito and bird populations across the USA, and as far north as northern Manitoba (18). In the Russian Federation infected birds and humans have been detected as far north as the region of Novosibirsk (19). In Sweden the incidence of tick-borne encephalitis (TBE) has substantially increased since the mid-1980s. This increase corresponds to a trend of milder winters and an earlier onset of spring resulting in an increase in the tick population (*Ixodes ricinus*) that carries the virus responsible for TBE and other potential pathogens. Similarly in Northeastern Canada, climate change is projected to result in a northward shift in the range of *Ixodes scapularis*, a tick that carries *Borrelia burgdorferi* the etiologic agent of Lyme disease (20). Major increases in the prevalence of hantavirus and tick-borne infections in human populations in northern Europe and central Asia during the last decade have been associated with rodent population irruptions linked to a series of exceptionally warm winters (21, 22). In the unexpected outbreak of Puumula virus (a Hanta virus) in northern Sweden in 2007, the incidence was found to be 313/100,000 inhabitants in Västerbotten County. The increase in the rodent population, milder weather and less snow cover were probably contributing factors (21). Similar outbreaks have been noted in the Russian Federation (19). Whether or not disease in humans is a result of these climate-induced alterations of vector range depends on many other factors, such as land-use practices, human behaviour, human population density and adequacy of the public health response.

The public health response to these emerging microbial threats should be focused regionally include enhancing the public health capacity to monitor diseases with potentially large public health impacts, including respiratory diseases in children, skin infections and diarrhoeal diseases, particularly in communities being undermined by melting permafrost that is damaging water and sewage systems. Monitoring certain vector-borne diseases, such as West Nile virus, Lyme disease, TBE and Puumula virus should be priorities in areas at the margins of focal regions known to support both animal and insect vectors and where climate change may promote the geographic expansion of vectors.

Because Arctic populations are relatively small and widely dispersed, region-specific detection of significant trends in emerging climate-related infectious diseases may be delayed. This difficulty may be overcome by linking regional monitoring systems for the purposes of sharing standardised information on climate-sensitive infectious diseases of mutual concern over larger areas. Efforts should be made to harmonise notifiable disease registries, laboratory methods and clinical surveillance definitions across administrative jurisdictions to allow comparable disease reporting and analysis. An example of such a network is the International Circumpolar Surveillance system for emerging infectious diseases. This network links hospital and public health laboratories together for the purposes of monitoring invasive bacterial diseases and tuberculosis in Arctic populations (10).

Public health capacity should be enhanced to promptly respond to infectious disease food and water-borne outbreaks (botulism or gastroenteritis caused by *G. lamblia*, *Cryptosporidium* or *V. parahemolyticus*). Public health research is needed to determine the baseline prevalence of potential climate-sensitive infectious diseases (e.g. West Nile virus, Puumula virus, *Borrelia spp.*, *Brucella spp.*, *Echinococcus spp., Toxoplasma spp.*, and intestinal protozoa) in both human and animal hosts in regions where emergence may be expected. Such studies can be used to accumulate additional evidence of the effect of climate change or weather on infectious disease emergence, to guide early detection and public health intervention strategies, and to provide science-based support for public health actions on climate change.

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