THE POTENTIAL IMPACT OF CLIMATE CHANGE ON INFECTIOUS DISEASES OF ARCTIC FAUNA

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ABSTRACT

Climate change is already affecting Arctic species including infectious disease agents and greater changes are expected. Some infectious diseases are already increasing but future changes are difficult to predict because of the complexity of host – agent – environment relationships. However mechanisms related to climate change that will influence disease patterns are understood.

Warmer temperatures will benefit free living bacteria and parasites whose survival and development is limited by temperature. Warmer temperatures could promote survivability, shorter development rates and transmission. Insects such as mosquitoes and ticks that transmit disease agents may also benefit from climate change as well as the diseases they spread.

Climate change will have significant impacts on biodiversity. Disease agents of species that benefit from warming will likely become more prevalent. Host species stressed by changing environmental conditions may be more vulnerable to disease agents.

Warming could lead to increased agriculture and other economic opportunities in the Arctic bringing people, domestic food animals, pets and invasive species and their disease agents into Northern regions. Climate warming may also favor the release of persistent environmental pollutants some of which can affect the immune system and may favor increased rates of some diseases. (*Int J Circumpolar Health 2005;64(5):468-477.*)

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INTRODUCTION

The recently released Arctic Climate Impact Assessment (ACIA) Scientific Report focused on the changes in Arctic ecosystems as a result of climate change (1). Disease pathogens are integral elements of all ecosystems and changing patterns of infectious diseases in Arctic biota may be one of the earliest expressions of these changes (2).

The impact of climate change on infectious diseases in Arctic species is difficult to predict. One problem is that infectious disease patterns in Arctic wildlife are often not well defined where vast distances, difficult logistics, and high costs have traditionally limited scientific research and documentation of wildlife diseases (3-7). Also disease trends even in a stable ecosystem are difficult to predict because of the complexity of host - agent - environment relationships.

While specific disease patterns are hard to predict, the factors related to climate change that will influence infectious diseases can be identified. These include increasing environmental temperatures, changes in biodiversity, introduction of domestic animals and invasive species, and increase in the level of persistent environmental contaminants.

DISEASE AGENTS FAVORED BY INCREASING ENVIRONMENTAL TEMPERATURE

A key finding of the ACIA Scientific Report is that the Arctic climate is warming rapidly and continued warming is projected (1). Disease agents that have developmental stages outside a warm blooded host and are limited by environmental temperature are most apt to be affected from increased warming (3). These include parasites with free-living stages in soil and water or that require cold blooded intermediate hosts, cold sensative bacteria that exist outside a host and pathogens transmitted by insect vectors. However, warming could also create conditions such as drought that are detrimental to some pathogens and rates of some diseases may decline.

Diseases of marine fish

In 1997 Alaskans began noticing increasing numbers of salmon with abnormalities suggestive of diseases such as furunculous, ichthyophonus and whirling disease (8). This occurred at the same time as the dramatic reduction in the number of salmon returning to spawn. Warming of the North Pacific - Bering Sea may have been the major factor in this reduction (9, 10). Stressed fish may have become susceptible to infectious agents and warmer water temperatures could have favored free living stages of fish pathogens.

Terrestrial parasitic diseases

Temperature and moisture strongly influence development and survival rates of nematode parasites and even small changes in temperature can have tremendous impacts on Arctic parasite epizootiology (11-13). Nematode eggs are shed in feces and warmer soil temperatures accelerate development to infective larvae (3). Shorter, milder winters and wetter summers allow more eggs and larva to survive (6). However, increased summer temperatures and drought or increased frequency of freeze-thaw cycles may increase parasite mortality and at least partially offset the beneficial impacts of climate warming (3, 14).

Models utilizing surface temperature and parasite development parameters have been developed for Arctic and Sub-arctic Canada to predict parasitic abundance and risk of expansion into other regions (6) Protostrongylid parasite larvae such as *Umingmakstrongylus pallikuukensis*, *Parelaphostrongylus odocoilei* and *Elaphostrongylus rangiferi*, are shed in the feces of their northern hoofed hosts. Larvae enter a gastropod (slug or snail) intermediate host where they develop into the infective stage. Mammal hosts become infected by eating gastropods containing infective larvae or by ingesting larvae that have emerged from gastropods (15, 16). Development rates in gastropods are highly temperature dependent and the threshold below which infective third-stage larvae do not develop is 8-10°C (15-17). Warmer summers in recent years have been shown to increase the rate of development of the larval stages of *U. pallikuukensis*, and shorten the time to the infective stage (13).

Predictive models suggests that under ‘normal’ summer temperatures that occurred between 1961-1990; development of *U. pallikuukensis* could not occur in a single summer and larvae had to survive over the winter in gastropods and resume development to the infective stage the following summer (13). Winter mortality of gastropods and larvae would result in a smaller number of infective larvae the following summer.

However, in warmer years that began in 1997, development could occur within a single summer, and larvae are available to infect muskoxen (*Ovibos moschatus*) within one season. This could result in both a greater parasite load in individual animals and a greater number of animals infected (13, 18). Single year development cycles of *U. pallikuukensis* will become more common in a future of climate warming.

A similar model has been developed for *P. odocoilei*, a pathogenic protostrongylid muscle-worm recently discovered in Dall’s (*Ovis dalli dalli*) and Stone’s sheep (*Ovis dalli stonei*) (19, 20). Under current climatic conditions, *P. odocoilei* is able to develop to its infective stage within a single summer throughout most of its range. Modeling suggests climate warming may lead to an increased transmission season, greater parasite loads and increased severity of clinical disease in sheep populations (21). Warming could also allow range expansion, possibly leading to clinical disease in immunologically naïve sheep populations.

Climate warming and shortened parasite development time could be the cause of increased prevalence of *Elaphostrongylus rangiferi* in Europe (21, 22). *E. rangiferi* causes cerebrospinal elaphostrongylosis (CSE) characterized by posterior paresis in small domestic ruminants and reindeer/caribou (23, 24). A study of *E. rangiferi* in northern Norway indicated that above normal mean summer temperatures were associated with higher prevalence of clinical disease in reindeer (21) and in small ruminants (22). CSE in sheep and goats was also associated with the presence of reindeer (*Rangifer tarandus*) in the pasture area (22). Occurrence of the disease in sheep and goats was tracked over 11 different seasons and it was found that higher prevalence years were associated with elevated mean temperatures during the previous summer.

Bacterial diseases

Bacteria pathogens may also benefit from warming. A marked increase in canine Leptospirosis was observed in Ontario Canada in the fall of 2002 following the warmest fall and the third wettest in a decade (25). Although references state Leptospirosis is not found in the Arctic, serosurveys of Alaska wildlife antibodies to *Leptospira serovars* were found in one of 61 (2%) caribou (*Rangifer tarandus*), one of 37 (3%) moose (*Alces alces*), six of 122 (5%) grizzly bear (*Ursus arctus*) and one of 28 (4%) black bear (*Ursus Americans*) (26). As in Ontario warmer weather and increased precipitation could increase the occurrence of Leptospirosis in the Arctic.

Insect-borne diseases

Insect-borne diseases could also be affected by climate change. Over the last three decades there has been a worldwide resurgence of insect-borne diseases and much speculation has arisen about the role of climate change in these trends (27). Many of these diseases are tropical/semi-tropical but some have temperate ranges and some occur in the Arctic.

Temperature is a limiting factor in insect-borne diseases. Insect-borne pathogens have a temperature range within which they develop in the insect vector. Temperature and precipitation are also important determinants in the distribution of insect vectors. Increased temperature and precipitation, both associated with climate warming, will favor increased rates of some diseases as well as expansion to other regions (2, 27). This was documented in Sweden in the mid 1980s where tick-borne encephalitis increased substantially following two consecutive mild winters, favorable spring temperatures and extended autumn temperatures (28).

Serological surveys show surprising prevalence rates of mosquito-borne encephalitides viruses in the Arctic. Alaska studies in the 1980s revealed antibodies to Jamestown Canyon virus in 89 percent of bison (*Bison bison*), 51% of Dall sheep (*Ovis dalli*), 43% of snowshoe hare (*Lepus Americans*) and 3% of Arctic fox (*Lagopus alopus*) (29). Snowshoe hare virus antibody was found in 89% of bison, 41% of Dall sheep and 65% of snowshoe hare. Northway antibody occurred in 94% of bison, 84% of Dall sheep, 43% of caribou and 3% of snowshoe hare. Evidence of clinical disease in animals is sketchy but the snowshoe hare virus has been associated with increased mortality in snowshoe hares (30). Both Jamestown Canyon and snowshoe virus can cause encephalitis in humans. Increased warming and associated precipitation could increase the rates of these viruses and their associated diseases.

CLIMATE INFLUENCED RANGE CHANGES AND ASSOCIATED INFECTIOUS DISEASES

Another key finding of the ACIA report that will impact infectious diseases is that species' diversity and ranges are changing. Climate change has already influenced habitat, distribution, and seasonal patterns for many species (31-35). Free living disease agents may expand into other regions where ecological conditions have become more favorable for survival of pathogens. Other pathogens will be carried to new regions on hosts that expand their range.

Range expansion of free living disease agents as a result of warming

An example of range expansion of a disease agent made possible by warming occurred in Alaskan waters in the fall of 2004. An outbreak of vomiting and diarrhea caused by the parasite *Vibrio parahaemolyticus* was traced to oyster farms in Prince William Sound (36). This was the first documented occurrence of *V. parahaemolyticus* in the region. *V. parahaemolyticus* requires water temperature of at least 16.7°C to survive which limited the northern range of the bacteria but investigation of the source oysters found water temperatures were an unprecedented 16.7-17.2°C.

Expansion of disease agents through host range changes

Scientific observations illustrate that range changes are happening on a large scale. A review of 143 recent studies involving range distributions of nearly 1500 species indicated that 80% had shifted their ranges toward the poles (37). These shifts are likely to be greater in Polar Regions where the temperature increase has been greater. When species move into other regions they are apt to bring their pathogens with them.

Cold temperature may limit the range of a species through a number of mechanisms. A study of grey seal pups (*Halichoerus grypus*) in the North Atlantic demonstrated that pup survivability at temperatures below -7.1°C was a limiting factor in the northern breeding range of the species (38). Increasing temperatures could bring grey seals in contact with other ecosystems and species. Their presence could stress resident populations through food and breeding site competition and through introduction of infectious diseases.

Harp seals (*Phoca groenlandica*) of eastern Canada migrate to the high Arctic each summer (39). Studies have shown that 50% of the seals carried *Giardia spp.* protozoan parasites (39) and 83% harbored phocine distemper virus (40). *Giardia* can infect many species and can cause diarrhea and interfere with the absorption of nutrients. Phocine distemper virus and other related morbillivirus infections can cause rapid, devastating epizootics in marine mammals (41). Phocine distemper virus was also found in ringed seals (*Phoca hispida*) of the high Canadian Arctic and was highest in regions where ringed seals were in contact with harp seals (40). This suggests harp seals may be a source of the virus to ringed seals. It also suggests that if climate change favors summer range expansion of harp seals more marine mammals may be exposed to their pathogens.

Introduction of diseases to immunologically naïve host populations is often associated with increased prevalence and severity of clinical disease. *Elaphostrongylus rangiferi* cited earlier has only recently become established in the caribou herd on the Avalon Peninsula of Newfoundland, Canada (42). In this naïve herd prevalence was higher, and cerebrospinal elaphostrongylosis (CSE) disease outbreaks were more frequently reported and were more severe in adult animals than in the other herds monitored in Newfoundland.

The protostrongylid parasites mentioned earlier (*U. pallikuukensis* and *P. odocoilei*) that can complete a life cycle in one summer could also expand north infecting populations in the high Arctic. If they infect species that have not been exposed before (naïve hosts) they could produce outbreaks and clinical disease similar to that observed for *E. rangiferi* in naïve caribou (21).

The range expansion of red fox to extreme Northern Alaska may have had a role in the documentation of the range expansion of *Echinococcus multilocularis* in brown lemmings (*Lemmus trimucronatus*) from the Northern Coast of Alaska (43). The parasite *E. multilocularis* can be fatal to humans.

DISEASES OF DOMESTIC ANIMALS INTRODUCED INTO OR MAINTAINED IN A WARMING ARCTIC

Climate warming has made it possible for animal husbandry to expand into the Arctic. While this could be an important new economic resource, domestic animals could also be a source of new disease agents that could threaten Arctic populations. For example, domestic sheep and goats carry strains of *Mannheimia* and *Pasteurella* spp. Bacteria that are extremely pathogenic for wild sheep. In the United States, catastrophic die-offs in bighorn sheep populations frequently occur when these sheep have direct contact with domestic sheep or goats (44, 45).

There is serological evidence that transmission from livestock to Arctic wildlife has already occurred in east central Alaska. Serum antibody levels for parainfluenza 3 virus in bison (*Bison bison*) in the Delta Junction region were negative in 1977 but antibodies were detected in another survey in 1984 after a cattle industry had developed in the region (46).

Parasites of domestic animals could pose a significant risk to Arctic species. A study of *Giardia* and *Cryptosporidium* parasites in the Canadian North Saskatchewan River watershed indicated highest levels of both parasites in cattle feces, a lesser concentration in sewage and lowest in wildlife (47). Both parasites can infect many species and if they become established in migratory mammals such as caribou their range could expand considerably. The molecular characterization of a *Cryptosporidium spp.* isolated from the northern Alaska Western Arctic caribou herd indicates this may have already occurred (48).

Climate warming could result in more people from southern regions moving to the Arctic to take advantage of economic opportunities. Domestic pets such as dogs and cats that accompany them could bring diseases that threaten Arctic wildlife. Serosurveys of lynx (*Lynx canadensis*) conducted in 1993-2001 in northwest Canada and Alaska indicated that exposure to feline parvovirus, feline infectious peritonitis virus/feline enteric corona virus and canine distemper virus has occurred (49). The surveys showed that feline parvovirus prevalence was higher in southern populations than in those farther north. The difference may not necessarily reflect environmental temperature but rather more exposure to domestic animals and/or wild feline species. As more people and their domestic pets invade the Arctic and Subarctic, chances of exposure of wildlife to domestic animal diseases will increase.

Domestic animals introduced into the Arctic could also become part of the life cycle for indigenous pathogens. Fox and lemmings sustain the parasite *Echinococcus multilocularis* in Alaska but domestic dogs can also efficiently spread the parasite (50). Domestic dogs could amplify the parasite increasing the prevalence in both fox and lemmings.

Toxoplasmosis is a cause of mortality in southern sea otters (*Enhydra lutris nereis*) (51) but does not appear to be a factor in the decline of Alaskan sea otters (*Enhydra lutris nereis*) in the Aleutians (52). Toxoplasma is thought to enter the marine ecosystem through oocysts from cat feces flushed down toilets or through storm runoff ‘pathogen pollution’ (53). Recently a sea otter found injured in Resurrection Bay in Southcentral Alaska was diagnosed with Toxoplasmosis (54). How the animal was infected is unknown but the case raises concern about the risk to the Alaskan sea otter population.

CLIMATE CHANGE AND ARCTIC WATERFOWL: GLOBAL IMPLICATIONS

About 280 avian species numbering around 100 million birds inhabit the Arctic (1). Around 85 million are migratory water birds. The impact of climate change on these populations is hard to predict but many of them nest in the shrinking tundra of the far north. Food sources, habitat, migratory timing and distribution patterns will change which will affect reproductive success and survival. Some species may benefit others will not (55). The effect this will have on avian pathogens is even harder to predict.

Arctic wild water birds play an important role in the occurrence of both animal and human disease. They have been implicated as important carriers of poultry pathogens including Newcastle, paramyxo and avian influenza viruses (56-58). These diseases are often sub clinical in wild water birds but can cause devastating infections with high mortality and huge economic loss in domestic poultry. These viruses readily infect migratory water birds that disseminate them along migratory pathways.

Wild aquatic water birds are the primary reservoir of influenza A viruses and bird influenza viruses serve as a genetic reservoir for other animal influenza strains including those that infect humans (59, 60). The avian H5N1 strain is highly virulent to people with a mortality rate over 50% (61). The greatest concern is that the H5N1 virus will recombine with a human virus that will give the new strain the capacity to become readily transmitted person to person. The H5N1 virus has become established in bird populations of Southeast Asia and it has probably already reached the Arctic through migratory water birds. Mixing and recombination of American and Eurasian influenza strains occurs in regions such as Alaska where these species mix and breed (59). When birds migrate south they carry and disseminate these viruses along their migratory pathways. Climate changes that influence wild Arctic water bird habitat, ranges and migration could be a factor in global distribution of avian virus agents and possibly the emergence of a new pandemic influenza strain.

Climate change - persistent organic pollutants – host – infectious agent interactions

Another article in this journal reviews the effect of climate change on levels of persistent environmental contaminants. Warming may increase the levels of contaminants in the Arctic environment. Some organochlorine contaminants are known to inhibit the immune system. A study of Arctic char exposed to levels of polychlorinated biphenyls (PCB) that occur in some Arctic regions had greater mortality when exposed to infectious bacteria than fish with lower levels (62).

Over the last decade sporadic ozone losses of up to 40 percent have been reported and halogenated organic pollutants have been implicated as contributing to ozone depletion (1). Ozone screens out ultraviolet - B (UV-B) radiation which has been found to suppress the cell-mediated immune response in mammals and UV-B exposure has been associated with viral infections. UV-B induced immune suppression could be a factor in viral infections in Arctic species.

CONCLUSIONS AND RECOMMENDATIONS

Climate change will have significant impacts in the Arctic and all ecosystems will be affected. The effect of climate change on the epidemiology of infectious diseases in Arctic species is difficult to predict. Some infectious diseases have already increased and others have expanded into the Arctic. Disease agents that live free in the environment or have stages outside a warm blooded host are most apt to be favored by climate warming through increased survivability and shortened generation time. Other agents may enter the Arctic through host species that are able to establish new ranges because of climate change. Changing climate may bring more people, resource development, livestock and domestic pets and their diseases to the Arctic. These agents may spread to naïve Arctic species that are more vulnerable because of a lack of natural immunity which could result in high rates of morbidity and mortality.

Capacity to establish baselines and track trends and impacts of infectious disease in wildlife should be developed for Arctic regions. This should include research surveys and monitoring utilizing Arctic communities. Veterinary diagnostic capability to provide timely, accurate and pertinent animal disease diagnostic services to include serology, necropsy, histopathology, bacteriology, virology, toxicology, cytogenetics and molecular diagnostics should be made available. The service should support fish and game managers, wildlife and fisheries biologists, veterinarians; and local communities.

A community-based program for monitoring disease in wildlife recently established in the Sahtu region of the Northwest Territories may serve as a model for other arctic and subarctic regions. This program includes education of youth and hunters, engaging hunters in standardized, long term sample collections from animals that they harvest for subsistence purposes, and focus-group interviews and information exchanges with elders and other experienced harvesters to establish disease baselines for the past (http://wildlife1.usask.ca/Sahtu/). The Sahtu program works on the principle that by working together, community members, scientists, veterinarians, and wildlife managers can efficiently and effectively monitor and detect changes in the health of wildlife in remote regions.

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