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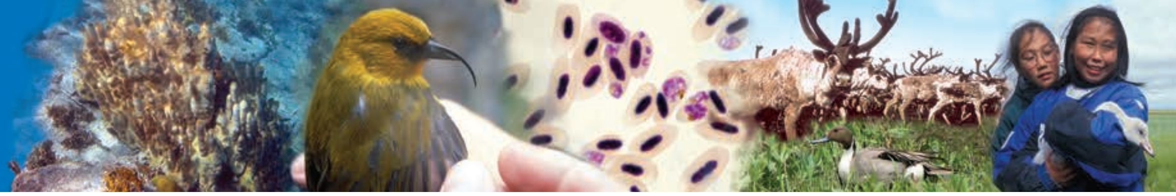

# Climate Change and Wildlife Health: Direct and Indirect Effects

Climate change will have significant effects on the health of wildlife, domestic animals, and humans, according to scientists. The Intergovernmental Panel on Climate Change projects that unprecedented rates of climate change will result in increasing average global temperatures; rising sea levels; changing global precipitation patterns, including increasing amounts and variability; and increasing midcontinental summer drought (Intergovernmental Panel on Climate Change, 2007). Increasing temperatures, combined with changes in rainfall and humidity, may have significant impacts on wildlife, domestic animal, and human health and diseases. When combined with expanding human populations, these changes could increase demand on limited water resources, lead to more habitat destruction, and provide yet more opportunities for infectious diseases to cross from one species to another.

Awareness has been growing in recent years about zoonotic diseases— that is, diseases that are transmissible between animals and humans, such as Lyme disease and West Nile virus. The rise of such diseases results from closer relationships among wildlife, domestic animals, and people, allowing more contact with diseased animals, organisms that carry and transmit a disease from one animal to another (vectors), and people. Disease vectors include insects, such as mosquitoes, and arachnids, such as ticks. Thus, it is impossible to separate the effects of global warming on wildlife from its effects on the health of domestic animals or people (fig. 1).

Climate change, habitat destruction and urbanization, the introduction of exotic and invasive species, and pollution—all affect ecosystem and human health. Climate change can also be viewed within the context of other physical and climate cycles, such as the El Niño Southern Oscillation (El Niño), the North Atlantic Oscillation, and cycles in solar radiation that have profound effects on the Earth's climate. The effects of climate change on wildlife disease are summarized in several areas of scientific study discussed briefly below: geographic range and distribution of wildlife diseases, plant and animal phenology (Walther and others, 2002), and patterns of wildlife disease, community and ecosystem composition, and habitat degradation.

## Geographic Range and Distribution of Wildlife Diseases

In the Northern Hemisphere, global warming has likely played a role in geographic shifts of disease vectors and parasitic diseases that have complex life cycles. For example, the black-legged tick, which carries and transmits Lyme disease and several other tick-borne zoonotic diseases in North America, has been expanding north into southern Ontario (fig. 2) and western Ontario and Manitoba (Ogden and others, 2006), and, more recently, into Quebec and the Canadian Maritime Provinces (Ogden and others, 2005, 2009, and 2010).

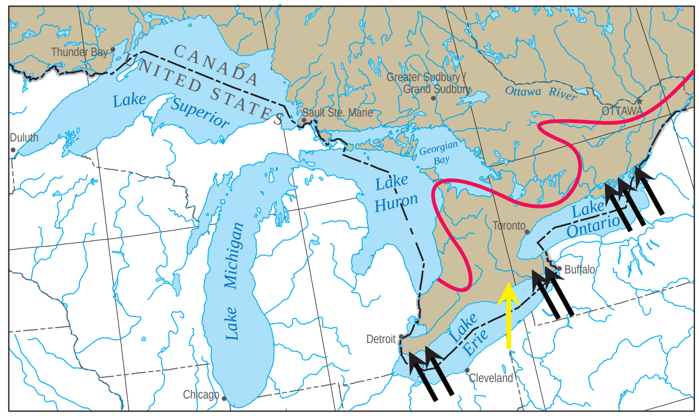


**Figure 2.** Surveillance for the black-legged tick identified a single resident population in 1991 (yellow arrow). Between 1991 and 2003 additional resident populations were reported (black arrows) showing the expanding distribution of the tick in southern Ontario. The red line shows the approximate current temperature limits for the black-legged tick (Ogden and others, 2005). Adapted with permission from the Ecological Society of America and D.H. Ogden, Public Health Agency of Canada.

In Europe, a similar northward expansion of the European castor bean tick, which also carries and transmits Lyme disease, tick-borne encephalitis (TBE), and other diseases, has been reported in Norway (Hasle, 2009) and Sweden (Tälleklint and Jaenson, 1998; Lindgren, 2000). On both continents, migrating birds carrying feeding ticks are likely the source of long-range expansion of the tick vectors (Ogden and others, 2008; Hasle and others, 2009; Brinckerhoff and others, 2011), and increasing environmental temperatures have likely permitted the ticks to become established in larger geographic areas (Lindgren, 2000).

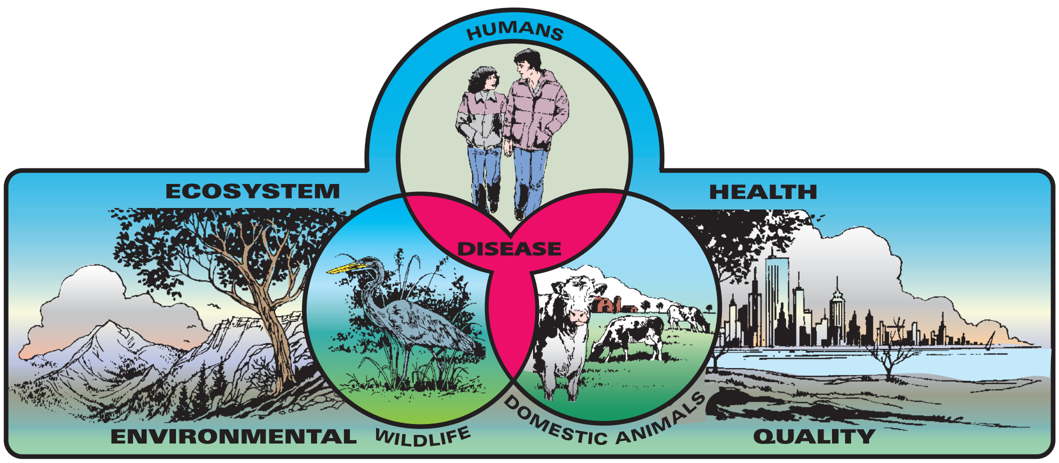


**Figure 1.** Ecosystem health reflects environmental quality, an important factor in the well-being of humans, domestic animals, and wildlife. Prevention of disease occurring at the interface between these components requires a holistic approach of "one health" for the benefit of all (Friend, 2006). (Drawing by John Evans)


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Scientists also expect changes in disease distribution with changes in altitude. For example, climate warming may lead to year-round transmission of mosquito-borne avian malaria at higher elevations in the Hawaiian Islands, further threatening endangered native Hawaiian birds that have little or no resistance to the introduced disease. Currently, on the island of Hawai'i, avian malaria, caused by the parasite *Plasmodium relictum*, is limited to warmer elevations below 1,500 meters (or 4,920 feet; fig. 3) (Van Riper, III, and others, 1986). If the higher elevations become warmer as projected, mosquito activity and parasite development in these areas will increase. Conservationists are concerned that climate change may lead to increased avian malaria transmission throughout the year at increasingly higher elevations.

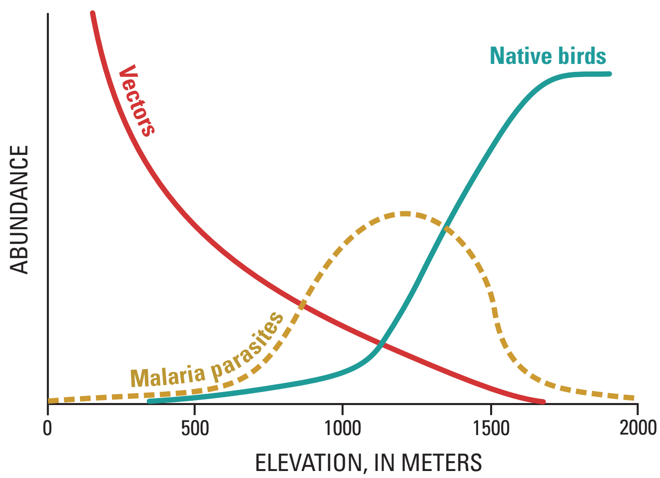


**Figure 3** Abundance of avian malaria parasites in Hawaiian birds, disease-carrying mosquitoes, and native Hawaiian birds, in relation to elevation on the island of Hawai'i (Van Riper, III, and others, 1986).

## Phenology: Effects on Wildlife Disease

The timing of recurring seasonal biologic cycles of some plant and animal species has already been affected by climate change (Walther and others, 2002). The study of these seasonal cycles is called phenology. The timing of biological cycles, such as the arrival of a bird species in the spring and the availability of its preferred food source, is critical for successful breeding and survival. Several studies in Europe show that some migratory birds have changed their migration patterns in response to climate change by arriving earlier than records show historically (Lehikoinen and others, 2004; Jonzen and others, 2006; Thorup and others, 2007). Significant population declines were reported recently for bird species that have not responded with earlier arrival (Saino and others, 2011), and the population declines have been interpreted as indicating the magnitude, and negative effect, in mismatch between bird arrival time and the onset of plants emerging from dormancy in spring. When an earlier emergence of plants from dormancy is combined with a mismatch in bird arrival time, critical food sources for returning birds might be past the period when they are most nutritious.

Variability in the timing of these biological cycles also can lead to increases or decreases in the risk for infectious disease, particularly diseases transmitted by mosquitoes or ticks. In Europe, transmission of TBE to humans often increases when warmer temperatures in the early spring result in the overlap of feeding activity of virus-infected nymphal and uninfected larval European castor bean ticks. Under these conditions, TBE is more readily passed between ticks feeding on small rodents. The period of viral infection is brief in tick-infested rodents, so when both stages of tick feed at the same time, more larval ticks become infected, and the risk for human infection increases (Randolph, 2009). Cooler spring temperatures result in less feeding overlap of nymphal and larval ticks, and under these conditions, the virus-infected rodents have time to recover from infection and are less likely to pass the virus to feeding larval ticks (fig. 4).

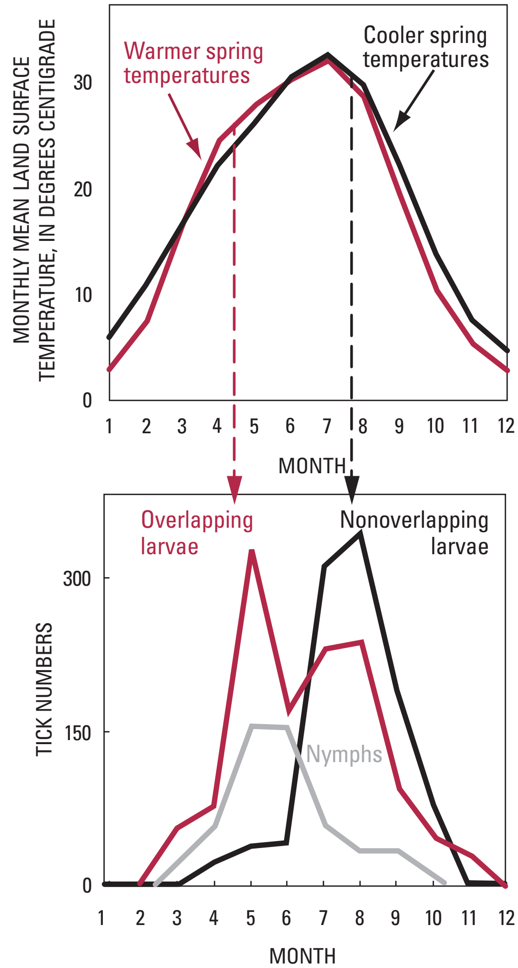


**Figure 4.** Human risk for tick-borne encephalitis in Europe is heightened in some years by slightly warmer temperatures in early spring (red line and arrow, top figure) that are associated with overlapping feeding of infected nymphal ticks and uninfected larval ticks (grey and red line, bottom figure). A slower rise in spring temperatures (black line, top figure) is associated with nonoverlapping feeding (graphs provided by S. Randolph, 2010).

At sites in North America, the same seasonal temperature effect has been observed in the transmission of the bacterium *Borrelia burgdorferi*, the pathogen or cause of Lyme disease, from infected nymphal black-legged ticks to uninfected larval ticks. When larval and nymphal ticks feed simultaneously, this not only contributes to the successful transmission of the pathogen to larvae, it also results in greater genetic diversity in this zoonotic pathogen (Gatewood and others, 2009). Climate change, by altering seasonal weather patterns, has the potential to affect these natural cycles.

## Changing Patterns of Wildlife Disease

In nature, pathogens can be transmitted directly between animals or indirectly through intermediate "hosts," such as infected prey or biting insects. Indirect transmission cycles are often affected by environmental conditions such as temperature and rainfall. Higher temperatures associated with climate change may contribute to an increase in pathogens within intermediate hosts and vectors, or increased survival of animals that harbor disease. For example, warmer summer temperatures in the Arctic now allow the lung nematode larvae often found in muskoxen to develop to the infectious stage within the intermediate host, the marsh slug, at a rate that has reduced the parasite's life cycle from 2 years to 1 year (Kutz and others, 2005).

Survival of another nematode, the brain worm of white-tailed deer, may also be increased by recently warmer temperatures and milder winters in the north-central United States and southern Canada. The parasite, which overwinters as larvae in snails and is accidentally eaten with plants, causes neurological disease in moose. Moose are already heat stressed by climate change (Lenarz and others, 2009) and may be more susceptible to parasitic and infectious diseases (Murray and others, 2009), including the brain worm of white-tailed deer (fig. 5).

Changes in precipitation patterns also have a significant potential to affect patterns of wildlife disease through survival of disease agents or vectors and through effects on host parasite relationships. In the example of the brain worm of deer, increased precipitation also may result in increased survival of the snail populations, resulting in more exposure of deer to infected snails.

**Figure 5.** Healthy North American bull moose (U.S. Fish and Wildlife Service). Diseased North American cow moose in the final stages of a brain worm infection in St. Louis County, Minn. (Mike Schrage, Wildlife Biologist, Fond du Lac Band).

## Questions to Ponder about Climate Change

Because of the uncertainty associated with the effects of climate change on the health of wildlife, domestic animals, and humans, we recommend four areas of study.

1. Long-term interdisciplinary projects can help determine climatic effects on biological factors associated with disease emergence, including species abundance, animal interactions and movements, vector populations). How might various physical, social, and economic factors contribute to disease emergence, persistence, and spread?
2. How are threatened and endangered free-ranging wildlife populations currently threatened by disease? How might climate change affect the current situation?
3. How will climate change play a role in the threat of wildlife-associated water- or vector-borne diseases for free-ranging wildlife, other animals, and humans?
4. How will climate change play a role in the lives of native peoples who are dependent upon wildlife as a major source of food? Will wildlife population declines or wildlife-associated food-borne diseases threaten native peoples?

## Community and Ecosystem Changes

Determining the effects of climate change on communities and ecosystems is difficult because the effects are likely to be highly variable, and this may be especially true for marine ecosystems. Since the 1980s, coral reefs in the Western Atlantic have suffered massive declines due to disease (Porter and others, 2001). It is likely that coral mortalities were initially due to widespread mortality of sea urchins, which allowed algal overgrowth of reefs, followed by environmental degradation and increased coral susceptibility to disease (Lessios, 1988). Since the early 1980s, mass “coral bleaching” has been observed worldwide, especially following the major 1998 El Niño event, and it has been linked to higher sea-surface temperatures (Hoegh-Guldberg, 1999) and to rising carbon dioxide levels that increase acidification of the oceans, which further weakens the coral structure (Kleypas and Yates, 2009). Corals are able to survive in nutrient-deficient waters because corals and the photosynthetic algae that live on them support each other. Corals that have lost these algae due to increased water temperature, changes in salinity or pollution may be susceptible to disease, leaving white coral skeletons, referred to as “coral bleaching” (fig. 6). Elevated temperatures will likely increase coral bleaching, which can lead to coral die-offs (Baker and others, 2008). Corals that fail to recover sufficiently may lead to loss of coral reefs and associated tropical marine life that depend on them for food and shelter. Coral bleaching has already been associated with significant declines in the diversity and population size of reef fish (Jones and others, 2004; Wilson and others, 2006). Coral bleaching and declines in the physical integrity of reef systems also are anticipated to lead to further reductions in the complexity of coral reef ecosystems (Pratchett and others, 2008). As a result, local economies that depend on coral reefs for sustenance or tourism could be significantly affected by climate change (Pandolfi and others, 2005).

**Figure 6.** Extensive coral bleaching on a reef, St. John, U.S. Virgin Islands (Caroline S. Rogers, U.S. Geological Survey).

## Habitat Alteration

Climate change has caused dramatic changes in several macro- and microhabitats on Earth. While wildlife species are likely to be adaptable, within their physiological limits, in dealing with direct impacts of climate change on temperature and precipitation, their ability to respond to major physical changes in their environment, short of migration, is more limited. Along the Antarctic Peninsula, populations of Adelie Penguins are declining, because coastal ice no longer persists through the winter in many locations. In Antarctica, the Adelie Penguin is commonly a coastal bird found in areas where sea ice persists throughout the winter, because it relies on sea ice for access to feeding areas where upwelling ocean currents contain many krill and fish.

Climate change is also having a detrimental effect on microhabitats. Amphibian and reptilian populations have declined in the lowland forests in Costa Rica in part through the effect of climate change on the humid leaf litter microhabitat of the forest floor (Whitfield and others, 2007). Weather conditions also significantly affect the microclimates for nests and burrows. For example, in sea turtles, elevated temperatures may lead to altered sex ratios or loss of nesting beaches secondary to sea level rises. Temperatures outside the range of those that turtles can tolerate result in the death of the developing sea turtle embryos (Morreale and others, 1982).

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