Zoonoses

[zoo/NO/seez]

Climate change affects the modes by which diseases are passed from animals to humans.

Dominique Charron, David Waltner-Toews, Kelly Butt and Abdel R. Maarouf

ACCORDING TO THE World Health Organization, zoonoses are diseases naturally transmitted to people from non-human vertebrates. Even before the current concerns about climate change emerged, it was well established that many infectious diseases of people and animals follow seasonal patterns, and that much of this seasonal variation can be attributed directly or indirectly to variations in weather and climate.[1]

Direct links between climate and disease are relatively easy to identify. Heat stress in humans, animals and plants is caused by extreme heat. Tornadoes and hurricanes cause death and injury. More difficult to discern, however, are the complex *indirect* effects of climate variability and change on diseases. These include effects on the organisms that cause disease, on the organisms that transmit diseases (called *vectors*), the animals that "store" disease (called *disease reservoirs*) and their habitat, and on the disease victim. These multiple effects can be challenging to identify and predict (see "Climate Change", p. 27)

People can be infected by some zoonotic diseases (like rabies) through direct contact with infected animals. Other zoonoses are transmitted by vectors or through contaminated food or water.

Some zoonoses are transmitted directly through contact with animals or animal products. Other zoonoses are transmitted from their animal sources to humans by certain species of insects. The pathogens, their animal hosts and the insects that transmit them are directly affected by temperature, humidity, and other environmental factors. Many factors combined determine whether or not individual organisms or communities will be affected by disease. Climate change may affect one or more of these factors in a variety of ways, making it difficult to predict actual outcomes.

Zoonotic diseases are transmitted from animals to people in a number of ways. Some diseases, such as rabies, brucellosis and tuberculosis, are acquired by people through direct contact with infected animals or animal products and wastes. Other zoonoses are transmitted by vectors or through contaminated food or water.

It is clear that many wild and domestic animal diseases occur seasonally. Climate variability affects the population dynamics of wild animals (and to a much lesser extent, domestic animals), and these dynamics affect the transmission of diseases within the animal populations as well as the transmission to other animal populations or people.[2] Climate can affect the reproductive success and population densities of some species, and hence can increase the probability that a zoonotic disease will spread – the greater the number of the affected animal, the greater the chances of contact and transmission both within and between species.

Rodents are sources of a number of zoonoses (including Hantavirus, plague and leptospirosis). Outbreaks of Hantavirus in the southwestern United States have clearly been linked to El Niño impacts on rodent populations.[3] Population dynamics of foxes have been shown to be an important factor in the success of rabies vaccination programs.[4] Climate variability may also lead to a change in the range of area over which wildlife can live, as well as expand the current limits of agricultural activities, increasing the chance of contact between species that have not normally interacted in that area.[5]

Many diseases are transmitted by ticks and insects in the tropics, and to a somewhat lesser extent in temperate latitudes. Diseases like Lyme disease and West Nile virus are the best known of the few vector-borne zoonoses occurring in Canada.[6] Temperature and humidity levels directly affect the feeding activities of these insects, as well as their reproductive success, survival rates and ability to transmit disease. Low winter temperatures kill many exposed ticks and insects and the diseases they carry, so that cycles of disease transmission are interrupted and need to be restarted in spring.

For effective establishment and spread of vector-borne diseases, conditions must favour increased human-vector contact, increased survival and density of hosts or animal sources. Climate may affect the vectors, the disease organisms, the hosts, the pathways by which the disease is transmitted or more likely, some combination of these. In Canada east of the Rockies, a possible northward movement of Lyme disease (which can cause chronic arthritis and nerve and heart dysfunction if left untreated) could be influenced by temperature effects on the ticks that transmit it,[7] and by increased human population pressure on wilderness areas.

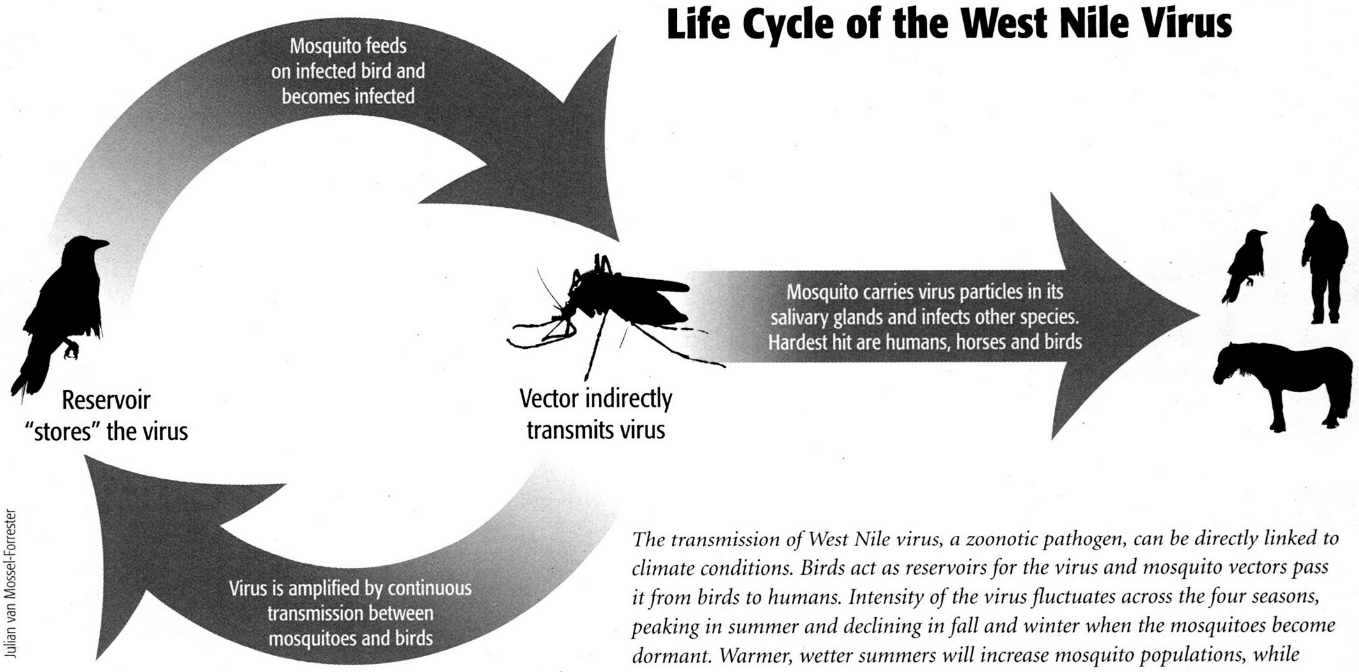
Indeed, biodiversity, which is itself affected by climate changes, serves important functions in modifying vector-borne disease ecology and its study.[8] Changing rainfall patterns and milder temperatures may affect the survival and number of ticks and mosquitoes, and allow diseases previously considered exotic or rare to invade and survive in northern climes like Ontario. For example, mosquitoes infected with eastern equine encephalitis viruses could be carried in trucks, airplanes or by wind from the eastern coastal United States into Canada and, if climatic and other environmental conditions were appropriate, cause disease outbreaks in horses and people.

West Nile virus was accidentally imported into North America possibly by air travel or migratory birds. The virus found many suitable insect vectors among our native mosquitoes, and many suitable hosts among the native bird population. Warmer temperatures and changes in precipitation could enhance the transmission of West Nile virus by favouring mosquito reproduction and virus activity. Projected temperature increases will probably lengthen the theoretical transmission season in Ontario and elsewhere for all vector-borne diseases.

Most food- and water-borne diseases are zoonotic. The pathogens reside in livestock and wildlife, and are passed into the environment in the animals' feces or urine, which then contaminate food and water destined for human consumption. Climate change may alter the ecology of many food-borne and water-borne diseases, as well as foo\d and water consumption and preparation patterns. Warmer summer temperatures and humid conditions enhance the survival of microbes in the environment, leading to increased contamination of food and water, and increased risk of infection. Some seasonal behaviour exacerbates the risk of food- or water-borne disease transmission (outdoor grilling, al fresco meals, consumption of untreated water while camping).[9]

Produce contaminated with fecal matter (of human or animal origin) can be a significant source of food-

Life Cycle of the West Nile Virus



The transmission of West Nile virus, a zoonotic pathogen, can be directly linked to climate conditions. Birds act as reservoirs for the virus and mosquito vectors pass it from birds to humans. Intensity of the virus fluctuates across the four seasons, peaking in summer and declining in fall and winter when the mosquitoes become dormant. Warmer, wetter summers will increase mosquito populations, while warmer winters will allow the virus to migrate into areas where it otherwise would have been interrupted by colder weather.

Although birds, particularly crows and jays, infected with West Nile virus become ill or die, most infected birds survive and become reservoirs for the virus. About 20 percent of infected humans will become ill and about one in 86 people will develop life-threatening symptoms. Horses fare far worse – approximately 40 percent of equine West Nile virus cases results in the death of the horse.

Climate vs Weather

THE TERM "climate" refers to the normal meteorological conditions for a given place, usually averaged over as many as 30 years of daily observational records. These "normals" include not only the average conditions but also the frequency of extreme events such as blizzards, heat waves, tornadoes, etc. On the other hand, "weather" refers to the short-term, typically day-to-day meteorological conditions in a place. Current concerns over global climate change refer to the recent and sustained departure from previously normal climate conditions in most places in the world, due in large part to the accumulation of greenhouse gases (by-products of fossil-fuel burning) in the atmosphere. Climate change projections include milder winters, warmer summers (with more smog days), more frequent extremes of weather and changes in precipitation patterns, such as heavier rainfall separated by longer dry spells.

borne illness if it is not washed properly. Pathogen levels in imported produce will have been influenced not only by the climate at source, but also by environmental conditions during transport and processing, and by the hygiene of the handlers throughout. Warmer temperatures also increase the demand on refrigeration systems, with power failures or other breaks in refrigeration causing food spoilage. On farms, the microbial ecology may change with altered climate, potentially changing the species composition of pathogens and their infectivity to people. Elevated temperatures projected in the coming decades may exacerbate the problem of enteric pathogen contamination during livestock rearing, food processing and food preparation. Outbreaks of zoonotic diarrhea in heat-stressed livestock may also cause contamination, increasing the hazard to human health.

Water contamination events are affected by the rates and timing of precipitation, among other factors.[10] When drought is followed by heavy rain, fecal matter containing human pathogens may be flushed into surface water, contaminate drinking water, and can result in greater probability of disease outbreaks. The E. coli O157:H7 water contamination in Walkerton, Ontario, in 2000 was preceded by a severe rainstorm. This rainfall flushed E. coli into the drinking water system through a faulty well, and the contamination was improperly reported by water utility personnel.[11] Complex interactions among environmental factors, animal sources of disease, pathogen ecology, as well as social, political and economic factors relating to food- and water-borne diseases exacerbate our vulnerability to climate change effects.

Even though zoonoses are officially defined as diseases that are naturally transmitted to people from non-human vertebrates, in practice, workers in this field have expanded the definition to include other diseases, such as some fungal infections that people and other animals acquire from shared environments.[12] Some diseases, such as toxic fungi, live in the environment and can cause illness in many species. Such organisms are influenced in some way by weather patterns and, more generally, by climate.

Blastomyces dermatitidis is a type of fungus that is prevalent within central Canada, particularly in those regions with sandy, acidic soils near freshwater sources. The fungal form of the organism releases spores that subsequently become airborne. When inhaled, the infective spores may cause blastomycosis, a disease that commonly presents as an acute to chronic pneumonia in susceptible animals and people. Most infected individuals, however, will show no symptoms of infection. Because the organism is so commonly found in the environment, it is virtually impossible to control.

Decaying wood, animal excrement or other organic matter are believed to influence its growth. Conditions promoting release of spores include high humidity or the disturbance of colonized soil through excavation or similar activities.[13] Therefore, any changes in rainfall and temperature patterns could affect the occurrence of the disease.

In the coming decades, people and animals will likely experience different health issues than before, and some of these will be affected by climate variability and change. Because the role of climate in health outcomes is complex, and because interactions among human health, animal health, and the environment are complex, it is impossible to predict exactly the effects of climate change on health. However, it is clear that a number of diseases are vulnerable to the effects of climate variability and change.

Like all diseases, those that may be affected by climate change are embedded in particular ecosystem dynamics. The most straightforward way to prevent some of these diseases would appear to involve direct intervention in the ecosystem. Planting trees, improving water management, and zoning critical watersheds to reduce contamination of sources of drinking water could help avoid outbreaks of waterborne disease, for example. However, it is often not clear what kinds of ecosystem-level interventions would be most appropriate, given that ecosystem dynamics are complex and that local effects are often embedded in larger systems. This is especially the case in areas where wildlife habitat, agriculture and human communities are part of the same ecological mosaic on the landscape.

Certain steps may be taken immediately to help mitigate some of the potential human health hazards associated with climate change. Some of these, such as public education and awareness to reduce exposure to disease (e.g., Lyme disease and West Nile virus), extreme weather alerts (e.g., develop heavy rainfall

Climate Change and Disease Transmission

Transmission Mode	Possible Effects of Climate Change	Examples
Vector (an organism that transmits disease from one vertebrate host to another)	Lengthened transmission season, increased over-winter survival, increased vector ability to transmit disease agent, range expansion of vector and reservoir hosts, more frequent transmission. Human behavioural changes that may alter risk of transmission (protection from vectors) Change to vector habitat that may enhance human-vector contact	*West Nile virus*: transferred to humans by mosquitos (after biting infected birds) with flu-like symptoms and may lead to encephalitis and meningitis *Lyme disease*: a bacterial infection carried by ticks which affects the skin in its early stage and then the central nervous system (named after a town in Connecticut) *Eastern equine encephalitis*: a mosquito-borne viral disease with flu-like symptoms which may lead to inflammation of the brain (found mainly on the eastern seaboard) *St. Louis encephalitis*: the most common viral encephalitis with flu-like symptoms and may be lethal (first found in St. Louis in 1933) *Leishmaniasis*: a parasitic disease carried by sand flies that affects skin and occasionally internal organs
Food	Increased risk of food contamination, increased environmental survival of pathogens, changes in prevalence of pathogens in animal reservoirs Changes in food preparation and consumption patterns may enhance risk of food-borne disease Changes in the ecology of enteric pathogens internationally may increase risk of outbreaks linked to imported foods Changes in host-parasite ecology	*Salmonellosis*: a bacterial infection in the lining of the small intestine with symptoms ranging from mild to severe diarrhea, fever, cramps and abdominal pain *Campylobacteriosis*: a bacterial infection that affects the intestinal tract with symptoms ranging from diarrhea, cramping, abdominal pain to fever *E. coli O157:H7*: a bacterial infection of the intestines, leads to bloody diarrhea and occasionally kidney failure and other chronic health problems (responsible for tragedy in Walkerton, Ontario, in 2000) *Listeriosis*: a bacterial infection caused by eating contaminated food and may affect the central nervous system *Brucellosis*: a bacterial disease causing muscle aches and pains, fatigue and mental illness – may become chronic with relapses *Trichinellosis*: a parasitic disease with flu-like symptoms which is caused by eating raw or undercooked meat infected with worms (may even lead to death)
Water	Increased risk of contamination linked to extreme precipitation events Potential decrease in efficacy of treatment due to reduced flow, increased turbidity, and increased demand during drought	*Giardia lamblia*: a protozoan which infects the host intestine and may cause diarrhea, nausea and abdominal cramping
Direct	Alterations in ranges and population dynamics of animal reservoirs (e.g., fox, deer, raccoon) Changes in peoples' behaviour that alter risk of exposure	*Rabies*: an often fatal viral disease which attacks the central nervous system and causes acute encephalitis *Hantavirus*: an air-borne virus typically in areas with infected rodents which causes a respiratory syndrome *Q Fever*: a bacterial disease typically acquired by inhaling droplets excreted by infected animals and may lead to pneumonia and hepatitis *Sylvatic/bovine tuberculosis*: a bacterial disease primarily affecting the lungs and intestines of cattle and wild ungulates, transmitted through droplets from a cough or sneeze *Blastomycosis*: a fungal infection caused by inhaling a fungus, found in wood and soil, and which primarily affects the lungs and skin

warnings to add to existing UV, smog and heat wave alerts) or even pet vaccination (e.g., rabies) involve simple behaviour changes and are easily implemented right now. Other steps, such as implementing watershed management plans or developing alternatives to fossil fuel, involve large-scale changes in how we relate to the ecosystems that support us.

Our understanding of the health impacts of climate change is still limited. Researchers should continue to expand our knowledge of how climate and weather influence health outcomes. Physical, biological, health and social scientists must collaborate to better understand what makes certain people or groups more vulnerable to the health impacts of climate variability and change, and how people adapt to emerging disease threats, and to climate variability. Ecosystem approaches, which attempt to look at the broader system and the interactions between various factors within that system, could be used to develop climate change adaptation plans.[14]

Meanwhile, more practical regional climate change projections, which will require more highly refined modelling and better (more expensive) computer resources, will contribute to researchers' abilities to project the health impacts of climate change. Medical interventions will include developing new and more effective vaccines and drugs, as well as designing public health responses that effectively reduce vulnerability to climate variability and change (infectious disease emergency planning and insect control, for example). To mitigate the effects of climate change and to better adapt, we need policies that adapt as our needs and the needs of ecosystems change.

The global climate is changing, and this is affecting not only short-term weather patterns but also human and animal disease hazards that we must prevent or manage. The likelihood of climate change impacts on various diseases, and the vulnerability of human and animal populations to them, need to be identified. Improving our knowledge base and our ability to respond at local, regional and national levels is important to maintaining our current levels of health. This strategy will also enable us to face the coming challenges, adapt to them, learn from them, and continue to create sustainable and healthy communities.

Dominique Charron is a senior epidemiologist in the Division of Infectious Foodborne, Waterborne and Zoonotic Diseases at the Public Health Agency of Canada. David Waltner-Toews is a professor in the Department of Population Medicine at the University of Guelph, specializing in the epidemiology of zoonoses, and ecosystem health. Both direct the Ecosystems, Climate Change and Health Omnibus Project (ECCHO). Kelly Butt worked as a research assistant with ECCHO. Abdel Maarouf is a biometeorologist with Environment Canada in Toronto and an ECCHO collaborator.

Notes

1 *This article is a condensation of a report prepared for the Ontario Ministry of Natural Resources and focuses on relationships between projected climate changes and the epidemiology of zoonoses specifically in Ontario. Climate change effects have been documented in other parts of the country, but these may differ from effects in Ontario because of differing climate and environmental conditions. D.F. Charron, et al., "A Synopsis of Known and Potential Diseases and Parasites of Animals and Humans Associated with Climate Change in Ontario," in* ***A Synopsis of Known and Potential Diseases and Parasites of Animals and Humans Associated with Climate Change****, S. Greifenhagen and T. Noland, eds. (Sault Ste Marie: Ontario Ministry of Natural Resources, Ontario Forestry Research Institute, 2003), Forest Research Information Paper #154.*

2 *J.M. Ireland, R.A. Norman, J.V. Greenman, "The Effect of Seasonal Host Birth Rates on Population Dynamics: The Importance of Resonance,"* ***Journal of Theoretical Biology****, 231:2 (2004), pp. 229-38.*

3 *G.E. Glass, et al., "Satellite Imagery Characterizes Local Animal Reservoir Populations of SinNombre Virus in the Southwestern United States,"* ***Proceedings of the National Academy of Sciences of the USA****, 99:26 (2002), pp. 16817-22; and B. Hjelle, G.E. Glass, "Outbreak of Hantavirus Infection in the Four Corners Region of the United States in the Wake of the 1997-1998 El Niño-southern Oscillation,"* ***The Journal of Infectious Diseases****, 181:5 (2000), pp. 1569-73*

4 *G.C. Smith , D. Wilkinson, "Modeling Control of Rabies Outbreaks in Red Fox Populations to Evaluate Culling, Vaccination, and Vaccination combined with fertility control,"* ***Journal of Wildlife Diseases****, 39:2 (2003), pp. 278-86.*

5 *J. Hoeve, D.G. Joachim, E.M. Addison, "Parasites of Moose (Alces alces) from an Agricultural Area of Eastern Ontario,"* ***Journal of Wildlife Diseases****, 24:2 (1988), pp. 371-4.*

6 *I.K. Barker, L.R. Lindsay, "Lyme Borreliosis in Ontario: Determining the Risks,"* ***Canadian Medical Association Journal****, 162 (2000), pp. 1573-74; and Health Canada National Advisory Committee on Immunization, "Statement on immunization for Lyme disease. Canada Communicable Disease Report," 26, Advisory Committee Statement 3 (2000, accessed 08/02) <www.hcsc.gc.ca/hpb/lcdc/publicat/ccdr/00vol26/26sup/acs3.html.>*

7 *N.H. Ogden, et al., "A Dynamic Population Model to Investigate Potential Effects of Climate on Geographic Range and Seasonality of the Tick* ***Ixodes scapularis****,"* ***International Journal of Parasitology****, 35:4 (2005), pp. 375-89.*

8 *R. Ostfeld, F. Keesing, "The Function of Biodiversity in the Ecology of Vectorborne Diseases,"* ***Canadian Journal of Zoology****, 78:12 (2000), pp. 2061-78.*

9 *E.D.C. Todd, "****Escherichia coli*** *O157:H7 Infections Associated with Ground Beef and Their Control in Canada,"* ***Canada Communicable Disease Report****, 26:3 (2000, accessed 08/02) <www.hc-sc.gc.ca/hpb/lcdc/publicat/ccdr/00vol26/dr2613eb.html>.*

10 *F.C. Curriero, et al., "The Association Between Extreme Precipitation and Waterborne Disease Outbreaks in the United States, 1948-1994,"* ***American Journal of Public Health****, 91:8 (2001), pp. 1194-9; and M. K. Thomas, et al., "The Role Of High Impact Weather In Waterborne Disease Outbreaks in Canada", (submitted).*

11 *D.R. O'Connor,* ***Report of the Walkerton Inquiry: Part I. The Events of May 2000 and Related Issues*** *(Toronto: Ontario Ministry of the Attorney General, Queen's Printer for Ontario, 2002), chapter 4, pp 103-97.*

12 *C.W. Schwabe,* ***Veterinary Medicine and Human Health*** *(London UK: Williams and Wilkins, 1994), p. 68; and N. Marano, Pappaioanou, "Historical, New and Reemerging Links Between Human and Animal Health,"* ***Emerging Infectious Diseases****, 10 (2004), pp. 2065-66*

13 *Sandra Lefebvre, Department of Population Medicine, University of Guelph, Ontario. slefebvr@uoguelph.ca (personal communication).*

14 *J.J. Kay, et al., "An Ecosystem Approach for Sustainability: Addressing the Challenge of Complexity,"* ***Futures****, 31 (1999), pp. 721-42; and D. Waltner-Toews, et al., 2004. "Adaptive Methodology for Ecosystem Sustainability and Health (AMESH): An Introduction," in* ***Community Operational Research: Systems Thinking for Community Development****, G. Midgley and A.E. Ochoa-Arias, eds. (New York: Plenum Publications / Kluwer Academic, 2004)*

The ECCHO (Ecosystems, Climate Change and Health Omnibus) Project works to promote multi-disciplinary, multi-sectoral and multi-stakeholder projects in the fields of ecosystem health and human health as related to climate change research, both in Canada and overseas. Their website has information of interest to researchers, policy makers and the public: www.eccho.ca