Chapter 5

The Impacts of Climate Change on Water-, Food-, Vector- and Rodent-Borne Diseases

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Chapter 5

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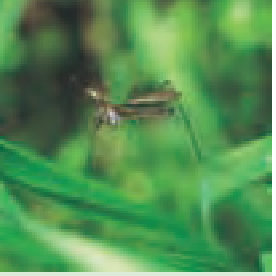


5.1 INTRODUCTION

This chapter examines the potential effects of climate change on the risk in Canada from food-, water-, vector- and rodent-borne diseases, many of which are zoonoses. It concludes with a discussion of the future actions required to minimize the impact of these diseases on human health. Characterizing changes in disease patterns in Canada resulting from climate change is fundamental to reducing any potential additional burden of illness. There has been a resurgence of infectious diseases in many parts of the world, and the incidence of food- and water-related contamination is also increasing (Becker et al., 2006). This situation reflects an unprecedented convergence of a number of diverse and globally important factors that include climate change, as well as population growth, density of settlement, travel, trade, agricultural intensification, urbanization and the overuse of antibacterial agents and pesticides.

Vector-borne and zoonotic diseases

Diseases that must be transmitted by an invertebrate host (such as a mosquito or tick) are termed vector-borne diseases. Zoonoses are infections that occur in animals that can also infect humans. All rodent-borne and many food-, water- and vector-borne infections are zoonotic.

Climate variability influences risks and patterns of disease and health. Many infectious diseases occur seasonally. For example, food- and vector-borne illnesses peak during warmer months in temperate climates like Canada's, whereas influenza and gastroenteric viruses predominate in winter (Grassley and Fraser, 2006). The effects of weather and climate on the majority of food-, water-, vector- and rodent-borne diseases are mediated through influences on pathogens, their transportation routes, their invertebrate vectors, their animal hosts, or on human behaviour. Furthermore, people perform different activities at different times of the year, thus resulting in "seasonality" in their risk of injury, infection or illness, depending on the activity. Therefore, relationships between climate and illness arising from food-, water-, vector- and rodent-borne sources are more complex than the direct effects of climate and weather on, for example, mortality from extreme heat or cold, or injuries from extreme weather.

Climate change is very likely to affect the normal patterns of disease across the country, and may result in the emergence of diseases that are currently thought rare or exotic to Canada. The increased average temperatures projected as a result of climate change could increase the survival or replication rates of vectors and some food- and water-borne pathogens, but could hamper the survival of others. Longer and warmer summers could increase pathogen survival in certain types of food, or in food improperly prepared or stored during summer months. More frequent and intense rainfall events may increase

water contamination and lead to water-borne disease outbreaks. Milder winters followed by hotter and more humid summers could favour West Nile virus and Lyme disease, but drought or heavy rainfall may keep them in control.

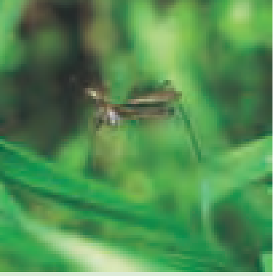
Changes in the expected seasonal and geographic patterns of food-, water-, vector-borne and zoonotic infections have implications for public health. Many of these infections can be prevented through targeted health promotion messages that encourage people to modify their behaviour to reduce their risk. Because foreknowledge of increased risk in certain areas or at certain times may heighten clinical recognition and diagnosis, health practitioners need to know when and what to expect. For example, some early symptoms of Lyme disease have a high diagnostic value (that is, they allow effective treatment if detected early), and practitioner awareness of these symptoms will allow early detection and treatment, which is key to reducing the impact of this disease. There is, however, much experience in managing disease risks in Canada to protect public health. Considerable effort is expended in ensuring that foods are free from contamination from farm-to-fork, and that drinking water is free from contamination with infective or other agents that are harmful to health. Thus, while effects of climate change may result in some completely new or increased health risks, existing infrastructure could protect against some risks being realized as public health problems.

5.1.1 Method and Approach

This chapter is based on a review of key Canadian and international scientific literature, Internet sites and reports of Canadian and international public health organizations. For many reasons, including the uncertainties associated with climate change projections themselves, most current literature can suggest only possible futures under given climate change scenarios, based on global climate model simulations. As such, this chapter reviews possible effects of climate change based on changes to climate expected for Canada, according to the Intergovernmental Panel on Climate Change (IPCC, 2007a, 2007b), with the understanding that actual future conditions could be different. In particular, it should be recognized that the potential impacts of climate change on disease in Canada are at early stages of investigation, and that this review may not represent the complete range of potential risks.

The review covers current knowledge of the effects of climate and climate change on risks of diseases that are endemic to Canada, where these data exist. Where they do not, the review considers potential effects of climate and climate change on disease risks using current understanding of these relationships (actual or potential) based on studies elsewhere in the world. The potential for exotic diseases (i.e. those not currently present in Canada) to become established here as a consequence of climate change is also reviewed although, where possible, geographically close risks are differentiated from those that are much more distant.

The review scans across a wide range of disease risks from food-, water-, vector- and rodent-borne sources that may increase, decrease or emerge as a consequence of climate change. Prioritization of particular risks for action in terms of adaptation efforts will require a more systematic risk assessment; the conclusions section (5.5) provides suggestions for the adaptation process, from risk assessment to surveillance and intervention. Until a more systematic risk assessment and prioritization is complete, the precautionary principle can be used to minimize impacts and provide general protection against emerging disease risks (Soskolne, 2004).



5.2 FOOD- AND WATER-BORNE DISEASES

5.2.1 Food-Borne Diseases

Food-borne illnesses are defined as diseases that are infectious, parasitic or toxic in nature, and that are acquired through the ingestion of contaminated food. The symptoms resulting from food-borne pathogens vary from gastrointestinal (nausea, vomiting, diarrhoea and abdominal pain) to neurological (e.g. Guillain-Barré syndrome, which can be caused by *Campylobacter* infection), acute kidney failure and hemolytic uremic syndrome caused by infection with *Escherichia coli* O157:H7, and congenital malformations due to *Toxoplasma gondii* infection (Centers for Disease Control (CDC), 2005b). The most common food-borne pathogens in Canada are *Salmonella, Campylobacter* and *E. coli* (Public Health Agency of Canada (PHAC), 2003).

Canadians rely on safe food. Many systems exist to ensure food safety, from the farm through harvest and processing, to retail and consumption. Along the food production chain, there are links where these systems may be vulnerable to climatic influences. For example:

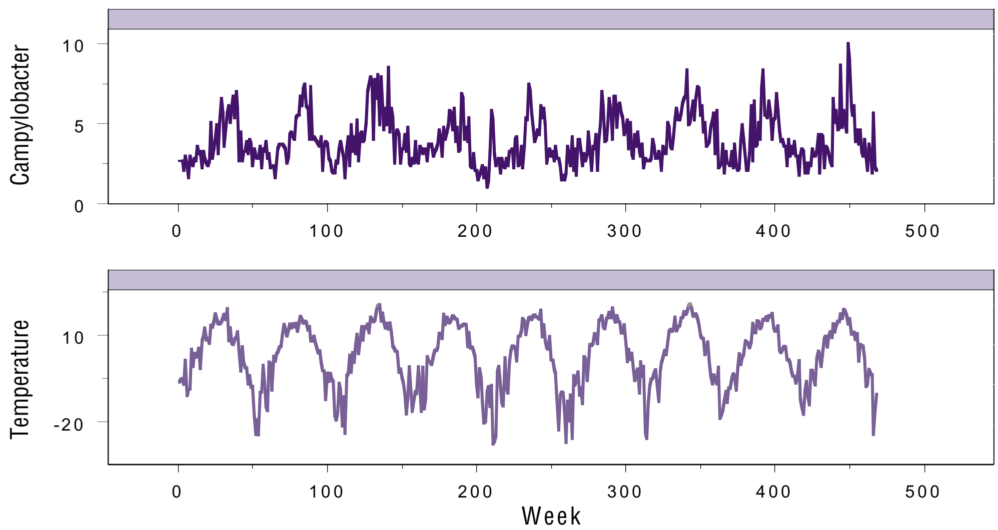
- Livestock stressed by temperature or other factors on-farm or during transport may be more likely to become ill or to shed greater amounts of harmful bacteria and viruses (Keen et al., 2003). Increased local risk of contamination would ensue, along with the potential for enhanced survival or even replication of pathogens, leading to a greater risk of meat contamination during processing. Ill livestock may require antimicrobials, contributing to the development of antimicrobial resistance; this could make both animal and human infections more difficult to treat (Nicholls et al., 2001; Danish Integrated Antimicrobial resistance Monitoring and Research Programme, 2002; World Health Organization, 2002).
- Agriculture may be affected by climate change (McGinn et al., 1999). Environmental changes as a result of increased drought, crop failure as a result of drought or ill-timed heavy rainfall, and loss of soil fertility can result in decreased yields or total loss of production.
- Climate-related changes in wild bird and wild animal population health may bring about new bio-security issues for Canadian farmers, potentially leading to the emergence of new food-borne pathogens.
- Heat waves and power outages related to high-energy demands or to extreme weather could cause refrigeration failure during food processing and storage, compromising food safety.

Food-borne infections may be linked to foods originating from infected animals, or from food that has been contaminated by fecal matter directly from an animal or person, or indirectly via contaminated water (Rose and Slifko, 1992; Chin, 2000; Rose et al., 2001; Hall et al., 2002). Reports of food-borne illness peak in the summer in Canada (Isaacs et al., 1998). Figure 5.1 shows the relationship between weekly case counts of *Campylobacter* and average weekly air temperature. The survival rates of most enteric pathogens in the

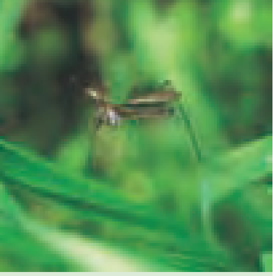
environment are, within limits, positively correlated with ambient temperature (Hall et al., 2002). Indeed, many food-borne diseases show a strong seasonal pattern in most temperate developed countries. Some of the increase is likely attributable to changes in certain social behaviours associated with a higher risk of food-borne illness (e.g. barbeques, picnics, camping) and to increased risk of food spoilage. However, some of this seasonal increase is more directly associated with increased temperature. A recent study in Canada found a link between ambient temperature and the occurrence of *Salmonella, Campylobacter* and *E. coli* O157 infections, above and beyond any seasonal trend. It was found that the relative risk of disease increased by 1.2 to 6.0% per degree Celsius above a statistical temperature threshold level (Fleury et al., 2006). These findings were consistent with studies conducted in Australia and the U.K. (Bentham and Langford, 1995, 2001; D'Souza et al., 2004; Kovats et al., 2004a, 2004b).

Climate change could affect the risks of food-borne diseases in two ways. Longer summers will extend the period associated with higher risk behaviours, and hotter temperatures exceeding a certain threshold will contribute to higher incidence of disease. As a result, the summer food-borne disease incidence peak could include a greater number of cases over a longer period. With increased temperatures due to climate change, home and restaurant food preparation practices would likely need to change to adapt to the increased risk of spoilage and contamination during warmer months.

Figure 5.1 Seasonal pattern of mean temperature and weekly case counts of *Campylobacter* in Alberta by week from the first week of January 1992 to the last week of December 2000



The Canadian Arctic has already demonstrated ecological change as a result of a changing climate. Seasonal shifts involving earlier spring onset and later ice formation and overall warmer temperatures have implications for traditional lifestyles, wild food availability, and food preparation and storage. Some animal populations upon which Aboriginal people depend may disappear entirely because of habitat loss attributable to climate change (Weller and Lange, 1999; Nuttall et al., 2005). Traditional food preparation and storage that rely on refrigeration in permafrost may no longer be possible. Higher ambient temperatures in the Arctic may result in an increase in some temperature-sensitive food-borne diseases, such as gastroenteritis, paralytic shellfish poisoning and botulism (Parkinson and Butler, 2005). Outbreaks of botulism poisoning in northern Canada have been linked to modifications of



traditional food practices or practices implemented in inappropriate climates (Proulx et al., 1997; Horn et al., 2001). Furthermore, there may be an increase in the range and type of animal hosts of diseases transmissible to humans, including hydatid disease caused by the larvae of tapeworms that usually live in wild and domestic ruminants and canids. The larvae may cause dangerous infections in people in northern Canada who hunt game and keep dogs (Rausch, 2003; Parkinson and Butler, 2005).

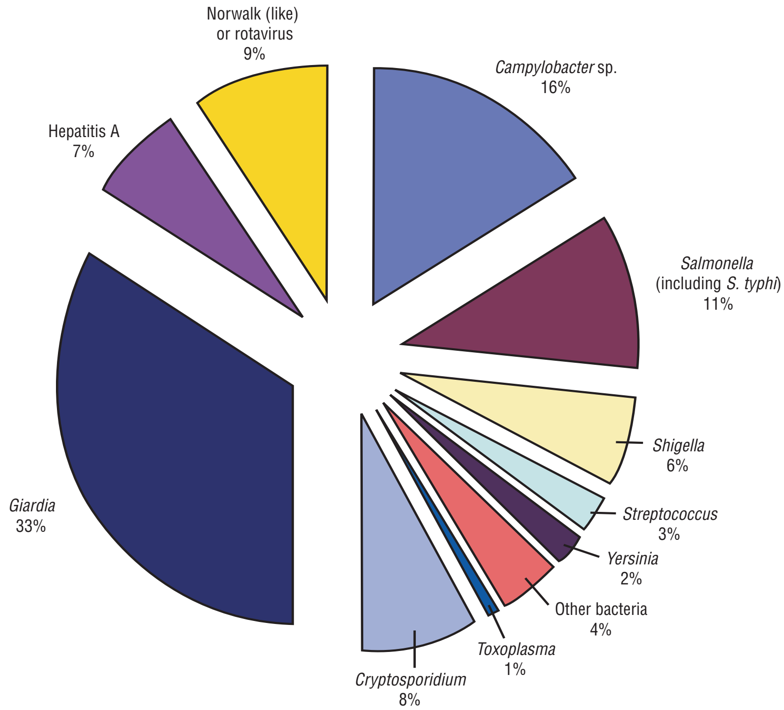
Other risks to Canadians living in coastal areas are microalgae that form the basis of the marine food chain, and toxin-producing species that may seriously disrupt the food web and lead to fish kills and human toxicity through the ingestion of contaminated fish (CDC, 2005d; Peperzak, 2005). The Canadian Food Inspection Agency (CFIA) monitors shellfish for the toxins that cause several types of poisoning with neurological or gastrointestinal symptoms (CFIA, 2003). Toxic freshwater and marine algae associated with eutrophication (the nutrient enrichment of a body of water which leads to more productivity), are present in Canadian waters and can become a danger to public health during the warm season (McCarthy et al., 2001; Weise et al., 2001). Warmer temperatures will affect the geographic range and the magnitude of certain algal blooms, and may induce oceanic changes that favour potentially harmful species (Zingone and Enevoldsen, 2000).

5.2.2 Water-Borne Illnesses

Water-borne illnesses result from exposure to pathogenic microorganisms or chemicals in drinking water or recreational water. Contaminated water most often enters the body by ingestion, but contaminants in water can also be inhaled or adsorbed, or enter the body through contact with open sores or wounds. The majority of symptoms resulting from water-borne pathogens are enteric (nausea, vomiting and diarrhoea and, in rare circumstances, colitis). However, other symptoms can be neurological, cardiovascular, respiratory (*Legionella*), ocular (toxoplasmosis), haematological (septicaemia from *E. coli* O157:H7) or dermatological (Payment and Pintar, 2006). Not only do exposure sources vary, but so do exposure lengths, dose-responses, incubation times and illness onset times, depending on the type of contamination (both general and specific). For example, microbiological contamination generally has a small exposure time, faster onset of illness and a lower dose-response than chemical or radiological contamination.

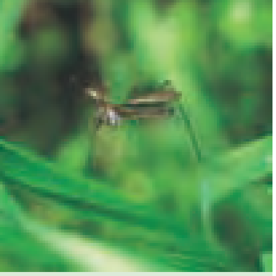
Gastroenteric pathogens, such as *Giardia, Cryptosporidium, Campylobacter, Shigella* and verotoxigenic *E. coli* are by far the most common endemic water-borne disease hazards in Canada and are reported to the National Notifiable Disease Registry database (Charron et al., 2004). In Canada, water-borne disease outbreaks have been associated with *E. coli* O157:H7, *Campylobacter,* occasionally *Shigella* and other pathogens (Levy et al., 1998; Lee et al., 2002; Oliver et al., 2003; Charron et al., 2004; Schuster et al., 2005) (Figure 5.2). Cholera has been reported in Canada and other pathogens such as hepatitis A, leptospirosis and Legionnaire's disease can also be considered as water-borne illnesses (Health Canada, 2002; Charron et al., 2004). Water-borne pathogens have a combination of human, wild and domesticated animal reservoirs and are released into the environment through waste products that can be deposited directly on the ground, spread as a result of agricultural activity or leach from septic systems or sewage pipes. Contamination of water with these pathogens can occur in several ways, but the most common is from overland flow (or storm water runoff in urban environments) that flushes contaminants into streams, rivers and lakes and that can transport contaminants into groundwater under certain environmental conditions. Weather has been linked to a number of reported water-borne disease outbreaks in Canada (Hrudey et al., 2003; Schuster et al., 2005). Sea water can also be a source of infection, as demonstrated in the food-borne diseases section (5.2.1). In 1997, *Vibrio parahaemolyticus,* a gastrointestinal pathogen that can also cause infection of open wounds, was associated with an outbreak from raw and undercooked oysters in British Columbia (Fyfe et al., 1997). It has also been associated with wound infections as a result of swimming in the ocean off the west coast of Canada (Todd, 1997).

Figure 5.2 Types of pathogens identified in outbreaks in Canada from 1974 to 2001 (n = 150) (other bacteria include *Aeromonas hydrophilia, Bacillus cereus, Enterobacter hafniae,* pathogenic *E. coli, Pseudomonas* spp., *Staphylococcus aureus)*



Interventions are primarily geared to immediate, acute public health risks that occur through exposure to microbiological contaminants. Risks of illness from water-borne chemical contaminants have been extensively investigated in Canada, particularly nitrates in groundwater (Arbuckle et al., 1988; Levallois et al., 1998, 2000; VanLeeuwen et al., 1999; Thompson, 2001), metals (Bernier et al., 1995; Mao et al., 1995; Baldwin et al., 1999; Eisler, 2004), persistent organic pollutants (Chiu et al., 2004) and pharmaceuticals (Ternes et al., 1999; Metcalfe et al., 2003). Water-borne radiological contamination can also occur, generally a result of natural background radiation. Drinking water guidelines reflect the fact that the contribution of radiation and chemical contamination from drinking water is a very small fraction of total exposure (Health Canada, 2004). To date no illnesses have been attributed to chemical contaminants in drinking water in Canada. Research is ongoing to further examine the potential health effects of chemical contaminants and to assess the effectiveness of current drinking water and wastewater treatment technologies. Findings continually inform the development of Water Quality Guidelines in Canada led by the Federal-Provincial-Territorial Committee on Drinking Water, and support the management of water quality in Canada.

Increased temperatures and greater variation in precipitation with climate change are likely to alter the risk of enteric water-borne disease through a number of mechanisms. Increases in precipitation intensity and frequency are likely to enhance overland flow or flooding and increase erosion, with the potential for surface and groundwater contamination by enteric pathogens and decreased effectiveness of water treatment. Previous water-borne outbreaks in Canada have been associated with heavy precipitation, spring melt, snowmelt and flooding (Bowie et al., 1997; Charron et al., 2004; Schuster et al., 2005; Thomas et al., 2006). In May 2001, excess rainfall resulted in contamination of groundwater and contributed to the Walkerton outbreak of *E. coli* O157:H7 in which 2,300 people became sick and seven people died (Auld et al., 2004). Curriero et al. (2001) quantified links between precipitation and water-borne disease outbreaks (enteric) in the U.S. The findings demonstrated that 51% of the 548 reported outbreaks



were preceded by monthly accumulated precipitation events greater than the 90th percentile (P=0.002) and that 68% were preceded by events greater than the 80th percentile (P=0.001). A study in Canada by Thomas et al. (2006) demonstrated that accumulated rainfall totals over the six weeks prior to an outbreak greater than the 93rd percentile doubled the risk of an outbreak. Heavy rainfall resulting in flooding can cause chemical contamination. Threats of chemical contamination after flooding have been reported, but the resulting health impacts are less well described (Wing et al., 2002; Euripidou and Murray, 2004).

Drought increases the demand for water when the supply is significantly reduced and vulnerable. It concentrates pathogens and chemical and radiological contaminants in water, and has implications for hygiene practices in light of water use restrictions. Furthermore, heavy rain following drought can lead to overland flow events and increased risk of water contamination (Charron et al., 2004). Increased ambient temperatures are likely to be associated with increased survival and abundance of microorganisms, and thus an enhanced water-borne infection risk. Thomas et al. (2006) found that for every 1°C increase in the six-week maximum positive degree-days total increased the relative odds of a water-borne disease outbreak by 1.007 times. Although this odds ratio is small per degree day, the practical implications are important; for example, a 5°C increase in maximum daily temperature over a 42-day period would result in a more than four-fold increase in risk.

Changes in contaminant transport are already being noted as a result of climate change, particularly in the Arctic due to permafrost thaw (Macdonald et al., 2005). Martin et al. (2005) found that 30% of the Inuit population in Nunavik depend on untreated water for consumption, such as rivers and lakes in the summer and melting snow or ice in the winter and spring. There is an increased risk of water-borne diseases to this population given climate warming, and increased rates of illness are already being seen compared to the rest of Quebec. There are additional concerns that shoreline erosion and flooding as a result of sea level rise could lead to contamination of aquifers with leakage from subterranean chemical dumps. The rise in sea level may displace Canadians in coastal communities, resulting in temporary disruptions in water supply. Further, saltwater intrusion can result in a need for alternate fresh water sources.

There is evidence that climate variables influence the risk of water-borne disease pathogens in Canada. How climate change will change conditions to favour the introduction of new disease to Canada or the re-establishment of diseases that have been eradicated is also of concern. Two emerging or potential water-borne diseases of concern for Canada are leptospirosis and cholera. Peak occurrences of leptospirosis in animals have been associated with high precipitation levels and warm, wet late-summer and autumn conditions in eastern Canada (Vinetz et al., 1996). In Canada, it is recognized as an uncommon disease but one that may be underestimated (Levesque et al., 1995). Warmer winters and increased temperature are likely to allow leptospires to survive longer in standing water in many parts of Canada, possibly contributing to increased risk of exposure through bathing or swimming (Jansen et al., 2005). It is among a few diseases at risk of a global resurgence under conditions of climate change (Epstein et al., 1995; Koelle et al., 2005) with implications for Canadians at home and abroad. Cholera, or acute enteritis caused by the bacterium *Vibrio cholerae,* is another example. It is extremely rare and not endemic to Canada, although it does occur in Canadians who have travelled abroad to areas where the disease is endemic (PHAC, 2007a). Cholera was common in Canada up to the late 19th century, but the likelihood of it becoming endemic again is minimal because of modern sanitation and public health practices, even though the causative organism is present along the east and gulf coasts of the U.S. in and on blue-green algae and copepods ("water fleas") and perhaps also in shellfish (Huq et al., 2001). A warming of the Canadian coastal waters in the Maritimes and Quebec might therefore enable a northward spread of *V. cholerae.*

5.3 VECTOR- AND RODENT-BORNE DISEASES

In 2001, Kovats et al. (2001) concluded that the literature to date contained no strong evidence that the change in climate observed in the previous few decades had affected vector-borne diseases. At that time, concerns that climate change could alter the risk from vector-borne disease rested on scarce and often speculative evidence (Githeko et al., 2000). However, more recent studies provide more certainty that climate change is already affecting some vector-borne disease risks, and that changing patterns could further affect human health in the future (McMichael et al., 2004; Purse et al., 2005).

5.3.1 West Nile Virus and Other Mosquito-Borne Diseases

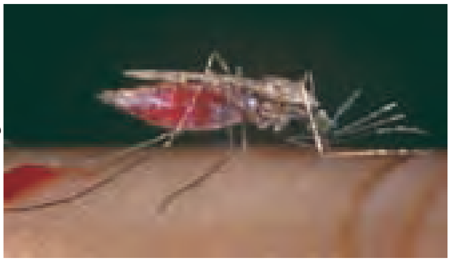
In North America, mosquitoes and some ticks carry several zoonotic viral pathogens that can cause disease in humans. These viruses include West Nile virus, St. Louis encephalitis, western equine encephalitis and eastern equine encephalitis viruses. Most people infected with these pathogens may not show symptoms, although of the ones who do, the symptoms are often similar and start as mild flu-like symptoms, occasionally progressing to severe encephalitis (inflammation of the brain), at times resulting in death (Pepperell et al., 2003).

Arthropods and arboviruses

Arthropods are members of the phylum Arthropoda, which includes such familiar forms as spiders, insects, centipedes and millipedes as well as disease vectors such as mosquitoes and ticks. Arboviruses (a contraction of "arthropod-borne viruses") are viruses that can develop within, and be transmitted by, arthropods.

West Nile virus is a mosquito-borne illness brought to Canada by migratory birds in 2001 (Pepperell et al., 2003), which has spread across Canada, with the exception of British Columbia, Newfoundland and Labrador, Yukon, Nunavut and the Northwest Territories. Over 1,800 human cases have been reported in Canada from 2002 to 2005, with 46 of these resulting in death. The long-term effects of West Nile virus are not fully understood; some people with serious symptoms recover fully whereas others experience prolonged neurological health problems (PHAC, 2006). Cases have been concentrated in a number of urban and semi-urban areas of southern Quebec and southern Ontario, and in rural populations in the Prairies (Pepperell et al., 2003; Gaulin et al., 2004; Manitoba Health, 2007). The outbreaks correlate with the presence and abundance of the mosquito species primarily responsible for West Nile virus spread and transmission to people.

The ecology, development, behaviour and survival of arthropod vectors, and the transmission dynamics of arboviruses are strongly influenced by climatic factors (Reiter, 2001). Temperature determines the speed and success of the arthropod life cycle and adult survival, and determines whether viruses replicate and spread from the mosquito gut to the salivary glands fast enough for the vector to transmit infection before it dies—the "extrinsic incubation period" (Randolph, 1998). Many arboviruses cause diseases in animals and can infect humans. The viruses are transmitted to humans by "bridge" vectors, species that feed on both animal hosts and humans (CDC, 2003; Turell et al., 2003).



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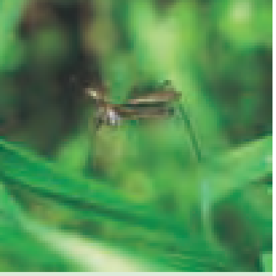


Canada lies at what is currently the northern margin for efficient transmission of most arboviruses, so disease outbreaks tend to be rare and have historically tended to occur in late summer.

The life cycles of mosquito and pathogen transmission are temperature dependent. Higher summer temperatures would speed up the life cycles of mosquitoes, which might lengthen the overall transmission season (Patz and Reisen, 2001) and could expand the geographic range of mosquito vectors. All of these conditions would increase the likelihood of virus amplification and transmission to humans. Specifically, warm winters and heat waves may favour West Nile virus, while in some parts of the world droughts may enhance transmission (Epstein, 2001a). Mild winters favour the overwintering survival of female *Culex* mosquitoes, and drought conditions may also force birds to congregate around shrinking water bodies, thus potentially enhancing local cycles of virus amplification (Epstein, 2001b; Epstein and Defilippo, 2001).

Like West Nile virus, St. Louis encephalitis virus cycles between wild birds and mosquitoes (*Culex* spp.) that prefer birds, and is occasionally transmitted to humans by infected mosquitoes. There are usually fewer than 50 cases of St. Louis encephalitis virus infection reported per year in the U.S.; however, periodically, large epidemics involving hundreds of infected individuals occur, primarily in the midwest and southeast states (CDC, 2006a). The only major outbreak of St. Louis encephalitis in Canada occurred in 1975 and 1976 in southern Ontario, apparently an extension of the outbreak that occurred in the midwestern U.S. (Spence et al., 1977). Outbreaks of St. Louis encephalitis have occurred in the U.S. as recently as 2001 (Jones et al., 2002).

Climate change is expected to alter the distribution of St. Louis encephalitis in North America, possibly ceasing its endemic cycle in the southwestern U.S. due to unfavourably warm temperatures projected for this area. A northward expansion of the virus into Canada is possible (Reeves et al., 1994).

Both western equine encephalitis and eastern equine encephalitis viruses can cause illness in humans. Sporadic equine epizootics (disease outbreaks among animal populations) of eastern equine encephalitis occur in Ontario and Quebec, while western equine encephalitis has been reported across Canada from Lake Superior to the Rocky Mountains and in British Columbia (Artsob, 1986; Keane and Little, 1987; Carman et al., 1995; Duncan et al., 1998; Leighton, 2000). Outbreaks of western equine encephalitis (typically involving horses) have occurred in Canada in each decade since 1930. Human infections of western equine encephalitis are now fortunately rare and only occasionally result in severe illness. Sporadic cases are reported, more often in early June or July (Leighton, 2000). In contrast, eastern equine encephalitis virus infections can cause severe illness in people, with a case fatality rate near 33% and possible long-term debilitating sequelae in many survivors (Leighton, 2000; CDC, 2005c). Indigenous cases of eastern equine encephalitis infection in humans have not been observed in Canada.

In most years, western equine encephalitis transmission occurs at a low level in the rural West. The virus' maintenance cycle principally involves birds and *Cx. tarsalis* and human and equine infections that occur outside the maintenance cycle, resulting in small numbers of sporadically occurring cases (Hayes, 1981; Tsai and Monath, 1987). However, at intervals of 5 to 10 years and for reasons poorly understood, viral transmission in the maintenance cycle is more intense, and humans and equines become infected at epidemic and epizootic levels. Outbreaks have often affected wide areas of the western U.S. and Canada. In 1941, more than 3,400 cases among humans occurred in Canada with an attack rate of 167 per 100,000,

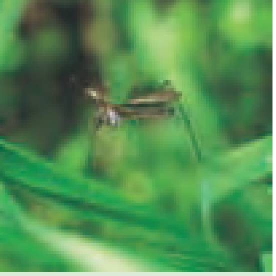
affecting populations in the northern plains states and in the provinces of Manitoba, Alberta and Saskatchewan (Leake, 1941). The most recent outbreak was in 1975 in the Red River Valley with 277 reported cases among humans and 281 among equines (Potter et al., 1977; Leech et al., 1981).

The principal vectors for western equine encephalitis and eastern equine encephalitis viruses are endemic in some parts of Canada. Current temperature conditions in Canada may be generally too cold for replication of eastern equine encephalitis viruses in these vectors such that transmission cycles can persist (Reeves et al., 1994), but to what extent eastern equine encephalitis is endemic to Canada (as opposed to only intermittently expanding its ranges into the country) is unclear. Increased temperatures with climate change may favour local amplification of the viruses, as is predicted for other arboviruses (Patz et al., 1998). Outbreaks of eastern equine encephalitis have been associated with warm, wet summers along the east coast of the U.S. (Freier, 1993). Heavy rainfall may increase vector abundance and precipitate mosquito-borne disease epidemics; indeed, the Red River Valley western equine encephalitis outbreak of 1975 followed severe flooding (Nasci and Moore, 1998).

It is likely that public health systems in Canada are not yet prepared to respond specifically to any health risks from St. Louis encephalitis, or western and eastern equine encephalitides. Because they are rare in Canada, they are currently unlikely to be considered as differential diagnoses. However, serological diagnosis of clinical encephalitis cases in humans in Canada, for which West Nile virus is a suspected cause, is mostly performed at the National Microbiology Laboratory, Winnipeg, where samples are routinely tested for St. Louis encephalitis, western equine encephalitis and eastern equine encephalitis as well as for West Nile virus. Therefore, the presence of these viruses in Canada would be expected to be alerted by the occurrence of human cases. However, control of West Nile virus rests on surveillance for infection in sentinel animals and vector populations, which allows control, prior to the occurrence of human cases (PHAC, 2007b). At present, there is no such surveillance for St. Louis encephalitis, western equine encephalitis and eastern equine encephalitis.

Introduction of vector-borne diseases from more distant geographic locations internationally is possible, as demonstrated by the West Nile virus epidemic in North America (see the importation of exotic diseases, section 5.3.4). Some diseases, such as West Nile virus, could become endemic if a suitable community of animal reservoirs and arthropod vectors existed in Canada. Of particular concern is the potential for vector-borne diseases of global importance, such as dengue fever and malaria, to become established in Canada as the climate warms.

Dengue fever is an arboviral infection that is endemic in most of the world. Over 2.5 billion people live in endemic regions and are at risk. The incidence of this disease is estimated at over 50 million infections per year (CDC, 2006a). The principal vector for dengue transmission to humans, *Aedes aegypti,* is exotic to Canada, but is present in the southern U.S.. Another mosquito, *Ae. albopictus,* is capable of transmitting dengue and other arboviruses to humans; it was inadvertently introduced into the southern U.S. in the early 1980s (Reiter, 1998; O'Meara et al., 1995). It has spread throughout the southeastern U.S., as far north as Wisconsin. There is speculation that climate change could facilitate further range expansion of *Ae. albopictus,* and this may have implications for Canada. There have been conflicting assessments of climate change impacts on risks from dengue and malaria, at least in part because these are mostly transmitted from human to human by mosquitoes, rather than from wildlife as is the case for West Nile virus and St. Louis



encephalitis. For example, Patz et al. (1998) suggested that the risk of dengue fever was likely to increase markedly with climate change because of increased temperature suitability for transmission cycles. However, Rogers and Randolph (2000) suggested that a number of factors may limit the effects of climate change. Furthermore, Reiter (2001) concluded that it was unreasonable to use climate to predict future patterns of dengue and malaria because these are more profoundly affected by human factors that affect risk. For cases of human dengue to occur in Canada, some of the introduced *Ae. albopictus* would have to be infected with the virus and have optimal climatic conditions for transmission. At present, there is insufficient information to assess whether dengue could become established in Canada.

The World Health Organization estimates that malaria, which is caused by *Plasmodium* spp. parasites, results in more than 300 million acute cases of disease worldwide and at least one million deaths annually. Malaria was endemic to certain regions of southwestern Canada in the 17th to early 20th centuries. It is possible that persistently infected immigrant workers introduced malaria, which was then maintained by vectors endemic to Canada. Malaria has long since been eradicated (Zucker, 1996), probably due to appropriate treatment of cases, destruction of breeding sites, use of window screens and reduction in malaria levels in Europe over the 19th century (MacLean and Ward, 1999).

Global climate change is projected to alter the endemic range of both dengue and malaria (Rogers and Randolph, 2000; Sutherst, 2004), although to what extent and where range expansion will occur is very much debated (Rogers and Randolph, 2006). Climate change related alterations in the worldwide distribution and intensity of various vector-borne diseases could significantly affect the health of Canadian travellers and the demand for specialized diagnostic and treatment at home. Global increases in endemic malaria, increased resistance to anti-malarial drug therapy, and a significant increase in global travel have resulted in thousands of cases of malaria transported into Europe and North America annually, with a few giving rise to transmission by indigenous mosquitoes (Fayer, 2000). Travel between Canada and endemic regions also has potential for pathogen introduction and localized transmission in areas where competent vectors are present and climate permits. This may create new health risks for Canadian travellers abroad who may be exposed to new endemic foci.

5.3.2 Lyme Disease and Other Tick-Borne Zoonoses

Lyme disease (also called Lyme borreliosis) is a bacterial infection that causes a skin rash, chronic arthritis, nervous system disorders and debilitation. It is caused by the bacterium *Borrelia burgdorferi.* The ticks transmit infection when they attach to the skin in order to feed on blood. Lyme disease is a zoonosis; ticks transmit *B. burgdorferi* from one wild animal host (rodents are particularly important) to another but, because the ticks are unselective in their choice of hosts, they can feed on humans and infect them with the bacterium. Humans do not take part in cycles of transmission and are dead-end hosts for *B. burgdorferi.*

The blacklegged or deer tick, *Ixodes scapularis,* is the most common vector in North America, except on the West Coast where a related tick, *I. pacificus,* is the vector. Studies have shown that the life cycle of *I. scapularis* is temperature dependent, and warmer temperatures will shorten the tick life cycle and increase its survival (Ogden et al., 2004, 2005a). *I. pacificus* is widespread in British Columbia and its distribution may not be as greatly affected by climate, although the tick may become more common in the Canadian North and at higher altitudes, as seen with related ticks in Europe (Lindgren et al., 2000). *I. scapularis* is distributed widely across eastern and north central U.S. Tick densities and the incidence of Lyme disease continue to increase, giving rise to more cases, particularly in the northeastern and north central United States where the incidence rates and tick abundance are highest (Steere et al., 2004). Lyme disease is the most common vector-borne disease in the U.S., with up to 20,000 cases reported each year (CDC, 2004).

Resident populations of *I. scapularis* occur in Canada. Up until 1991, only one population was known to occur, at Long Point on the northern shore of Lake Erie (Lindsay et al., 1998). Since then, the number of populations has increased to 13, including those in southeastern Manitoba, southern Ontario and southeastern Nova Scotia (Barker and Lindsay, 2000; Ogden et al., 2005a; Lindsay, L.R., personal communication). Further suspected populations are under investigation. Vector surveillance over the last 17 years has identified *I. scapularis* (nearly all adults) in most populated areas of Canada from Saskatchewan east, far beyond the known resident populations (Ogden et al., 2006a). It is believed that most of these ticks are dispersed from resident populations in Canada and the U.S. by migratory birds (Ogden et al., 2006a).

Migratory birds probably facilitate the spread of ticks into southeastern Canada (Klich et al., 1996; Smith et al., 1996; Morshed et al., 1999; Scott et al., 2001). Huge numbers of birds migrate northward, from their southern wintering grounds, over southeastern Canada each year. Spring migration coincides with the seasonal activity period of nymphal *I. scapularis* in "source locations" in the U.S. and Canada (Smith et al., 1996). Many bird species make feeding stops in habitats that are densely populated with *I. scapularis.* Nymphal ticks can attach to the birds and be transported up to 800 km before dropping off their host (Scott et al., 2001; Marra et al., 2005). Ticks can thus be dispersed over great distances in spite of formidable geographic barriers, such as the Great Lakes and intensively farmed land in southern Ontario and Quebec, that would otherwise prevent dispersal on mammalian hosts.

Climate change may alter the risk of Lyme disease in Canada. Higher ambient temperatures will shorten tick life cycles, create more favourable conditions for host-seeking activity and increase tick survival (Ogden et al., 2004, 2005a). Such effects are likely to increase the probability that new tick populations become established from ticks seeded into Canadian habitats by migratory birds. Climate change is therefore likely to create additional endemic foci of tick-borne zoonoses, such as Lyme disease, beyond the current northern limit of the tick's range (Ogden et al., 2006b) (Figure 5.3).

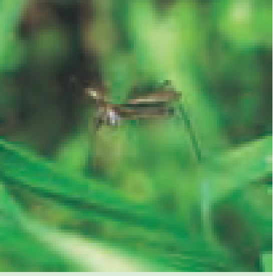
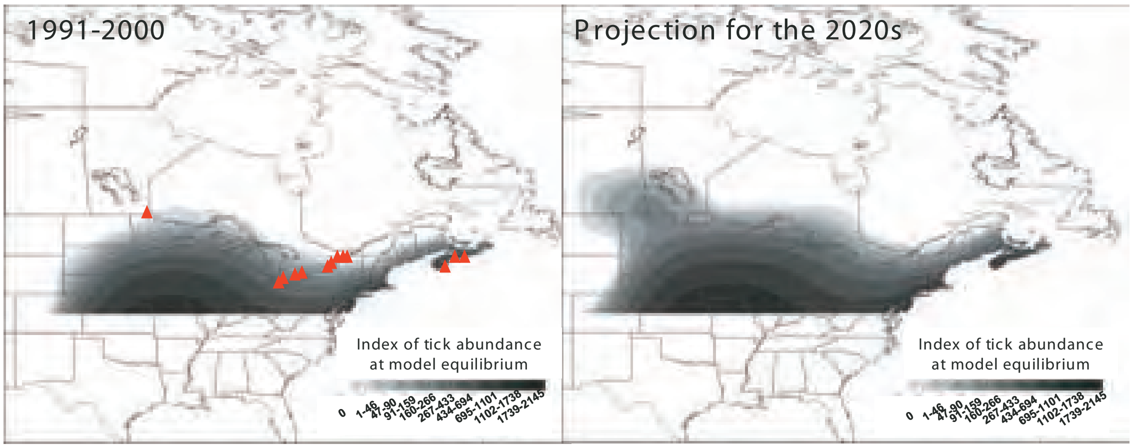


Figure 5.3 Model simulation results suggest that *Ixodes scapularis* populations in Canada (red triangles) occur at the limit of temperature suitability for the tick. Temperature may be a significant factor limiting northward expansion of the geographic range of *I. scapularis,* but this is expected to change rapidly with projected climate change



Source: Ogden et al., 2006b.

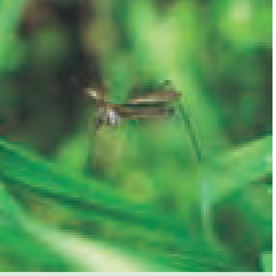
There is a risk of Lyme borreliosis in British Columbia because *I. pacificus,* the tick vector of Lyme disease in western North America already has a wide geographic distribution (British Columbia Centre for Disease Control, unpublished data). Despite widespread presence of the vector, efficiency of Lyme disease transmission is less than in eastern Canada. This is due to ecological differences among the ticks, such as their seasonality and their choice of hosts.

I. scapularis and *I. pacificus* are also vectors of *Babesia microti* (the pathogen causing human babesiosis), and *Anaplasma phagocytophilum* (the agent of human granulocytic anaplasmosis). Because *A. phagocytophilum, B. microti* and *B. burgdorferi* share the same rodent reservoirs and tick vectors, human co-infection with human babesiosis and Lyme disease could occur in endemic areas. The severity of symptoms and duration of illness in patients with concurrent babesiosis and Lyme disease is reported to be greater than that of either infection alone (Krause et al., 1996).

Climate change may also affect the human health risk due to a number of other infections transmissible by *I. scapularis* and other tick species in North America (Table 5.1). These include rickettsial diseases such as Rocky Mountain spotted fever (*Rickettsia rickettsii*), human granulocytic anaplasmosis (*A. phagocytophilum*) and Q fever (*Coxiella burnetii*), and tick-borne viruses (e.g. Powassan encephalitis virus) that are already present in Canada (Calisher, 1994).

Table 5.1 Diseases transmissible by *Ixodes scapularis* and other tick species in North America

Disease	Vector	Symptoms	Canadian Distribution
Tick-borne pathogens known to be endemic to Canada			
Lyme disease (*Borrelia burgdorferi*)	Blacklegged or deer tick (*Ixodes scapularis or I. pacificus*)	Skin rash, chronic arthritis, nervous system disorders, debilitation; has caused paralysis in children	Ont., N.S. and as far west as Sask. (*I. pacificus found in B.C.*)
Rocky Mountain spotted fever (*Rickettsia rickettsii*)	Rocky Mountain wood tick (*Dermacentor andersoni*) and Amercian dog tick (*D. variabilis*)	Moderate to high fever, local to widespread rash; potentially fatal if not treated	Human cases in B.C., Alta., Sask. and Ont.
Tularaemia (*Francisella tularensis*)	American dog tick (*Dermacentor variabilis*), Rocky Mountain wood tick (*D. andersoni*), blacklegged tick (*Ixodes scapularis*), other ticks	Skin ulcers, lymphadenitis, pneumonia; occasionally fatal, but can cause mild malaise and fever also	Widespread, but much of human infection via other non-tick routes
Human granulocytic anaplasmosis (*Anaplasma phagocytophilum*)	Blacklegged tick (*Ixodes scapularis*)	Mild febrile illness, but increased susceptibility to secondary infections that can be fatal	Possibly in tick-endemic localities across Canada
Q fever (*Coxiella burnetii*)	Generally through exposure to infected animal tissues or non-pasteurized milk; cases from tick bites are rare	About 50% of people infected show symptoms ranging from mild flu-like syndrome to pneumonia and hepatitis; occasionally fatal	Widespread in livestock
Powassan encephalitis virus	Rocky Mountain wood tick (*Dermacentor andersoni*), groundhog tick (*Ixodes cookei*) (*I. marxi* and *I. spinipalpus* may carry a variant Powassan virus), blacklegged tick (*I. scapularis*)	Mild fever and flu-like symptoms to encephalitis; occasionally fatal or causing long-term neurological problems	Very sporadic geographic and temporal occurrence; geographically widespread in the northern hemisphere with some human infections in Ont., the Prairies and the United States
Tick-borne pathogens known to be endemic in northeastern United States, but not known in Canada			
Human babesiosis (*Babesia microti*)	Blacklegged tick (*Ixodes scapularis*)	High fever, flu-like symptoms possibly with jaundice; severe symptoms (congestive heart failure, renal failure, acute respiratory distress syndrome) and death mostly in immunocompromised people	



Climate change is expected to increase the risk from diseases (e.g. Lyme disease) that are associated with the tick *I. scapularis.* To what extent climate change may alter the risk from other tick-borne diseases is unknown and uninvestigated; at present, there is no infrastructure to identify any changes before human disease cases occur. The impact of tick-borne pathogens can be amplified by infection of blood used for transfusions (Cable and Leiby, 2003), as has been the case for West Nile virus (Vamvakas et al., 2006).

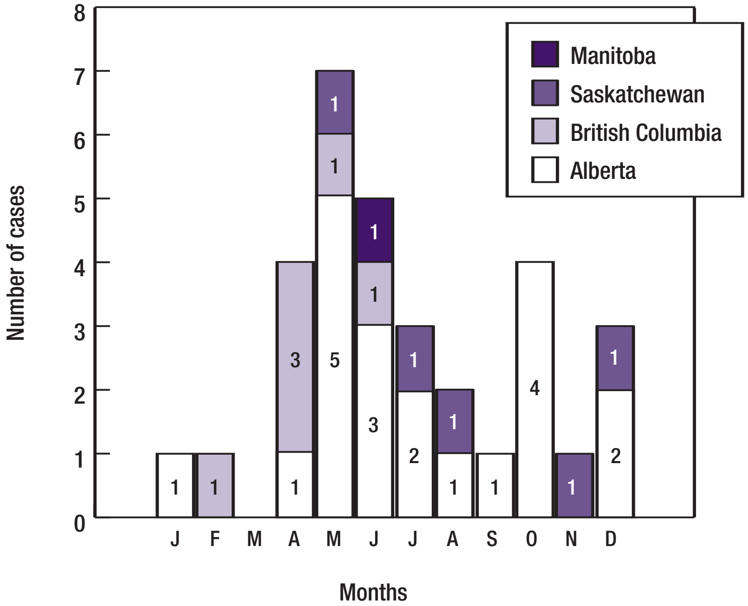
5.3.3 Rodent-Borne Diseases

Rodents are among the most abundant of wild animal hosts of zoonoses (Gubler et al., 2001). They are the main reservoirs of tick-borne zoonoses (as described in section 5.3.2) but are also hosts of diseases that are transmitted by close contact with humans, either by fleas or directly without the mediation of a tick or insect vector. The diseases they transmit are reviewed here because they constitute environmental health risks that may vary with climate and therefore possibly with climate change. For example, warmer winters and increased rainfall are likely to improve rodent survival, and thus the abundance of rodent reservoirs of disease may increase in some regions (Lewellen and Vessey, 1998). Extreme weather events such as high rainfall accompanied by flooding may increase the likelihood of humans coming into contact with rodents, their fleas and their potentially infective faeces and urine (Gubler et al., 2001; Karande et al., 2003). Other wild animal hosts may be important reservoirs of zoonoses, but their roles are poorly studied in general as well as in Canada. Rodent-borne diseases such as hantavirus, leptospirosis (which is also water-borne: see section 5.2.2), bartonellosis and plague are very probably common within many rodent populations in Canada. Plague and hantavirus are nationally reportable so it is known that these are rare infections in humans, presumably because contact between rodents and humans is infrequent. Leptospirosis and bartonellosis are not reportable so their incidence in Canada is unknown, but possibly underestimated (Levesque et al., 1995; Jardine et al., 2005). Furthermore, there are alternative domesticated and wild animal reservoirs for both diseases, and human disease cases may not be easily attributed to rodents alone. Even if these diseases are rare in humans in Canada, they are still of concern because all can cause serious disease in humans and some can be fatal (Gubler et al., 2001; Boulouis et al., 2005).

Hantaviruses cause infections of wild rodent and insectivorous mammal populations and can cause hantavirus pulmonary syndrome, a fever followed by acute pulmonary edema and shock. There is no specific treatment for hantavirus pulmonary syndrome; the case fatality rate is 38% in Canada (Drebot et al., 2000). Humans become infected by contact with infected rodents or their excretions, particularly aerosolized urine or feces (Weir, 2005). Thirty-six cases were reported in Canada between 1989 and 2001, or two to eight cases per year (Drebot et al., 2000). Cases seem to be confined to the western provinces (British Columbia, Alberta, Saskatchewan and Manitoba) and one case has been reported in Quebec (Weir, 2005). The presence of infected mice throughout Canada suggests that the potential for hantavirus pulmonary syndrome exists across the country (Drebot et al., 2000). In Canada, human cases tend to occur in spring and late fall (Figure 5.4), possibly a result of both human and rodent behavioural factors that increase risk of exposure.

Chapter 5

Figure 5.4 Seasonal distribution of hantavirus pulmonary syndrome cases reported in Canada from 1989–99

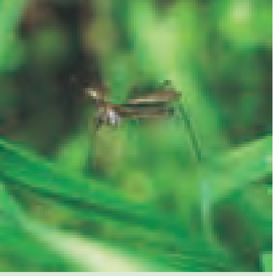


Source: Drebot et al., 2000.

Hantavirus pulmonary syndrome occurrence has been linked to an upsurge in rodent populations related to climate and ecological conditions (Wenzel, 1994; Glass et al., 2000). Mild winters and drought followed by heavy rain appears to significantly increase rodent populations and disease risk (Mills and Childs, 1998; Hjelle and Glass, 2000). Like that of other rodent-related diseases (e.g. plague, Lyme disease), the risk of hantavirus pulmonary syndrome may increase where climate change creates conditions favourable to rodent populations. Infected mice have been found in all provinces and territories except Nova Scotia, Prince Edward Island and the Yukon (Drebot et al., 2000).

Plague is caused by infection with the bacterium *Yersinia pestis.* It is maintained in rodents, and transmitted among rodents by fleas. Humans become infected most often by the bite of an infected flea. In humans, plague infections can manifest in three forms, bubonic, septicemic and pneumonic, all of which have high case-fatality rates if left untreated. *Y. pestis* is maintained in wild rodent populations in southern Alberta and Saskatchewan (Leighton et al., 2001) and in the western U.S. (Cheney, 1998). Although human cases of plague have not been reported in Canada since 1924, the World Health Organization reports 1,000 to 3,000 cases of plague worldwide every year. During recent decades, about 10 to 15 people a year have been infected with plague in California and elsewhere in the southwestern U.S. (CDC, 2005a). Changes in land-use patterns and in climate (mostly linked to the El Niño-Southern Oscillation (ENSO) ocean-current phenomenon) have been associated with an increase in plague in the U.S. in the 1980s and 1990s (Parmenter et al., 1999). Rapid urbanization in endemic areas has increased the likelihood of human-to-rodent contact and transmission of infections (Duplantier et al., 2005). The ENSO-related heavy rains of 1993 were strongly associated with increased numbers of human cases of plague, possibly by increasing available feed and winter survival of rodents, and hence their abundance (Parmenter et al., 1999). Similar effects due to increased maximum daily summer temperature values, following heavy winter rains one to two years prior, have also been suggested (Enscore et al., 2002).

The relationships between climate and rodent-borne diseases outlined here are examples, but the range of zoonoses maintained by wildlife, and potentially influenced by climate and climate change, is much wider (Bengis et al., 2004).



5.3.4 The Importation of Exotic Diseases

In the era of globalization, Canada must extend its consideration of the health impacts of climate change to an international, even global scale. The emergence of a global market place, hypermobility of goods, capital and people, and increasing access to worldwide travel and to instantaneous communication technologies have major implications for health in Canada and abroad (Labonté and Schrecker, 2006). Disease vectors can travel in boats, airplanes and suitcases, food-borne pathogens move with imported foods, and people can be carriers of pathogens. In all cases, a key issue is the speed with which exotic disease agents may move about the globe, eventually reaching Canada, as demonstrated by the West Nile virus epidemic in North America. It is thought that West Nile virus in North America originated from the import of an infected mosquito into New York on an aeroplane that came from the Middle East (Glaser, 2004). Within four years, it was endemic almost continent wide. At present, health and agricultural authorities monitor known health threats in travellers and in imported animals and foods. With climate change, expected patterns of animal and human disease may vary worldwide, resulting in a changed global landscape of health risk (McMichael et al., 2003). Significant impacts of climate change on agriculture, markets and transportation are projected for Africa and parts of Asia, with grave consequences for health in those regions (United Kingdom Department for Environment, Food and Rural Affairs, 2005; Field, 2005). Thousands of people could be displaced and Canadian trade partners could be affected, which in turn could affect conditions at home. Travelling Canadians returning with illnesses from endemic areas of the world are already a burden to local health care systems. The consequences of these global changes in disease risk for Canadians' health and health care sector are not yet well understood. Authorities responsible for disease surveillance, mitigation and treatment already monitor the immediate changes that affect health risks in the Canadian population. What is less common is the integration of future risks arising from changing climatic conditions in planning processes in order to determine future levels and responses needed, or what actions can be taken.

Canada has a very diverse population, and many people travel to visit family, vacation or conduct business across the globe. This mass movement, augmented by immigration and the deployment of military personnel, increases the potential for a person to become exposed to illnesses in one country and then to expose others to the infection in a location thousands of miles from the original source of infection. For example, travellers are estimated to run a 20-50% risk of contracting food-borne disease depending on their destination (Käferstein et al., 1997). Several hundred cases of malaria are imported into Canada each year, with peaks in imported cases mirroring epidemics elsewhere (MacLean et al., 2004). In the U.S.,

61% of cholera cases are attributed to international travel (Käferstein et al., 1997; Steinberg et al., 2001), while in Canada almost all cases are imported (PHAC, 2005a). Public health authorities at all levels of government disseminate information to travellers on health risks abroad and advocate protective measures. The timing and content of these public service messages may need to change as the geographic patterns and seasonal occurrence of exotic diseases are altered by climate change (PHAC, 2000).

Exotic diseases may pose a diagnostic challenge to physicians unaccustomed to their presenting symptoms, or unaware of the patient's travel history. The outbreak of severe acute respiratory syndrome (SARS) in Ontario and British Columbia in 2003 highlighted the difficulties of dealing with a previously unknown and infectious agent. Lessons learned will enable Canada to deal with future public health crisis situations (PHAC, 2005b). Since 2003, health care practitioners and public health practitioners have learned many lessons in dealing with highly infectious, imported diseases. Where possible, the best method of control is to inform travellers ahead of time of the potential exposure risks and recommend appropriate vaccinations or medication to prevent illness.

5.3.5 Key Knowledge Gaps

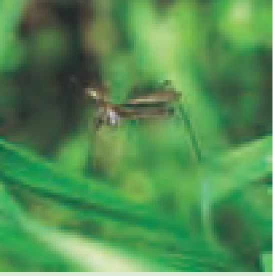
The following knowledge gaps have been identified in this review, as well as by previous studies.

Capacity

- interdisciplinary approaches are required to address the complex problems associated with research on food-, water-, vector- and rodent-borne diseases and climate change;
- researchers will need to be trained in interdisciplinary approaches;
- research networks linking this relatively small research community are vital to creating the critical mass needed to accomplish the research; and
- specialized technical expertise is needed to enhance response capacity.

Research

- the ecology of disease from the environmental source to the human case of the disease, including the ecology of hosts and vectors (this knowledge is required to identify where and how a change in climatic conditions might alter the hazards posed by these diseases);
- effects of climate and climate change in the hydrology of watersheds and other water sources (e.g. private wells, beaches, estuarine water) and on the contamination of water;
- effects of climate change on diseases, particularly vector-borne diseases, that are not yet in Canada but are geographically nearby, and on exotic vector-borne diseases where travel and unintentional vector importation are possible;
- effects of climate and climate change on transmission of pathogens in domesticated livestock and food processing, and on health risks associated with imported food and livestock;
- effects of climate change on the interaction of individual, population, ecosystem and infrastructure factors in vulnerability to infectious diseases;



- understanding the ecology of zoonoses in a wider range of wild animal hosts such as marine mammals and wild ungulates; and
- changing behaviour to reduce vulnerability to food-borne illness, particularly as it relates to cultural, social and societal preferences and food-handling and -processing norms.

Enumeration of current disease risks

More detailed quantification is needed of the infectious diseases that are affecting, or could affect, the human population in Canada. For example, the burden of illness from water-borne pathogens in Canada is not known, mostly because of source attribution problems; gastrointestinal infections can be transmitted person to person, in water and in food (Mead et al., 1999), and investigation of the source of endemic cases is not as routine. Perhaps only one out of 300 gastrointestinal infections are reported (Majowicz et al., 2004), which seriously limits burden of illness estimates. The geographic distribution of zoonoses in wildlife and of vectors is poorly understood, which limits the power to predict human populations at risk if effects of climate change on risk were to be identified.

Assessment of surveillance systems

There is a need to assess the adequacy of surveillance systems to detect significant changes in the incidence and geographic distribution of pathogens in humans and in important sentinel non-human species. At the 2006 Canadian National Consensus Conference on Lyme disease, current surveillance case definitions, which rely on current knowledge of endemic areas, were identified as a potential obstacle to identifying the new endemic areas that are anticipated to arise as a consequence of climate change.

Development of warning systems

There is a need to improve the linkage between pathogen surveillance and meteorological information where climate is an indicator for a potential disease event. There is a pressing need to develop a better understanding of the impacts of extreme weather events on public health infrastructure and vulnerability to infectious disease outbreaks in order to develop warning systems. For example, heavy rainfall may contribute to water supply contamination as well as provide breeding areas for mosquitoes.

5.4 ADAPTING TO CLIMATE CHANGE: RISK ASSESSMENT, SURVEILLANCE, INTERVENTION AND ADAPTATION

Existing health and public health systems already protect Canadians from many disease risks by identifying risks and carrying out surveillance, interventions, and the diagnosis and treatment of infected and infectious individuals. Previous sections have reviewed current knowledge on the potential effects of climate change on water-, food-, vector- and rodent-borne disease risks in Canada. However, the extent of climate change effects on health risks and the challenge they pose to existing health and public health systems still need to be fully investigated.

This analysis reflects the knowledge of the effectiveness of current measures that help individuals reduce exposure to risks, mitigate and manage these risks and provide adequate, appropriate diagnosis and treatment. The next steps in minimizing the potential increases in these risks are:

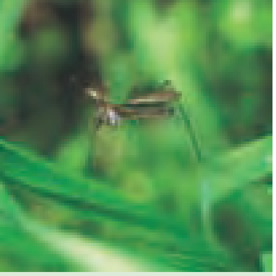
- determining baseline data on infectious disease occurrence and the associated burden of illness;
- a comprehensive risk assessment to prioritize public health threats for action; and
- a consultative approach to adaptation via:
  - enhanced surveillance
  - targeted intervention.

5.4.1 Risk Assessment

A risk assessment comprises four elements to estimate the likelihood and severity of risk: hazard identification; exposure assessment; dose-response assessment or hazard characterization; and risk characterization (Coleman and Marks, 1999). Risk assessment methods are used to prioritize risks and hazards and to help with policy development (Gibson et al., 1998).

The broad review of potential health risks associated with climate change, presented here, is a first step in a rational approach to preparing for these risks. However, a more far-reaching and systematic risk assessment is required to identify priorities for action. One way of structuring the many decisions involved, the capturing of the information on which to base those decisions and the many answers often required, is through a multi-criteria decision analysis (MCDA). It is used increasingly to aid decision making in environmental health (Linkov et al., 2006). MCDA is a useful vehicle to capture the many decisions and many possible answers involved in risk assessment across the country. MCDA sets out an explicit pathway for identifying the criteria for selection and ranking, for weighting these criteria according to the requirements and objectives of different stakeholders, and then for analyzing and ranking on the basis of all criteria and weights. In the climate change context, there are likely many criteria in selecting and ranking disease risks, but examples include the following:

- Pathogenicity: More pathogenic or lethal pathogens may merit particular attention.
- Estimated case numbers and incidence rates: How common diseases are, or are likely to become, may affect their priority.



- Probability that risks are realized: Confidence that climate change will cause a change in risk, or cause a new risk to emerge, may vary among different pathogens.
- Immediacy of risk: Some disease risks may be more immediate because they are geographically close to Canadian populations at risk or are likely to be affected first by climate change.

The need to understand climatic drivers for current disease patterns, so that effects of climate change can be predicted to inform the risk assessment process, presents a key public health challenge. The case has been made for the use of process-based simulation models that use understanding of the ecology of vectors and pathogenic microparasites to predict their occurrence in time and space (Kurtenbach et al., 2006). Such models have already been developed for some vector-borne and enteric pathogens (Bigras-Poulin et al., 2004; Ogden et al., 2005a, 2007). Where the detailed data on the ecology of vectors and microorganisms are not available, statistical models that demonstrate associations between disease incidence and climate variables can be used to predict or estimate climate change effects (Fleury et al., 2006; Thomas et al., 2006). However, in either case researchers have just begun to scratch the surface in terms of gathering the information required for comprehensive projections of the wide range of infectious disease risks that may arise in Canada due to climate change.

Once key selection criteria have been identified, these need to be weighted according to the importance allotted to each criterion by stakeholders that reflect the diversity of the Canadian population. For example, in contrast to urban water supplies, water treatment in smaller systems or rural areas generally does not have the same resilience and redundancies, the tax base to support large financial investments, or the same accompanying access to health care. As well as these community risks, individuals at risk of food- and water-borne disease include the young, seniors and immunocompromised individuals (Rosenberg et al., 1997). Some Canadians are more vulnerable than others to mosquito- or tick-borne diseases because of their age or health status, outdoor occupation or activities, or because they live in areas with abundant tick or mosquito populations. Risk groups include outdoor enthusiasts and members of Aboriginal communities, particularly those pursuing traditional livelihoods. Arctic communities may face threats from vector-borne diseases as the climate warms rapidly in the North (Berner et al., 2005).

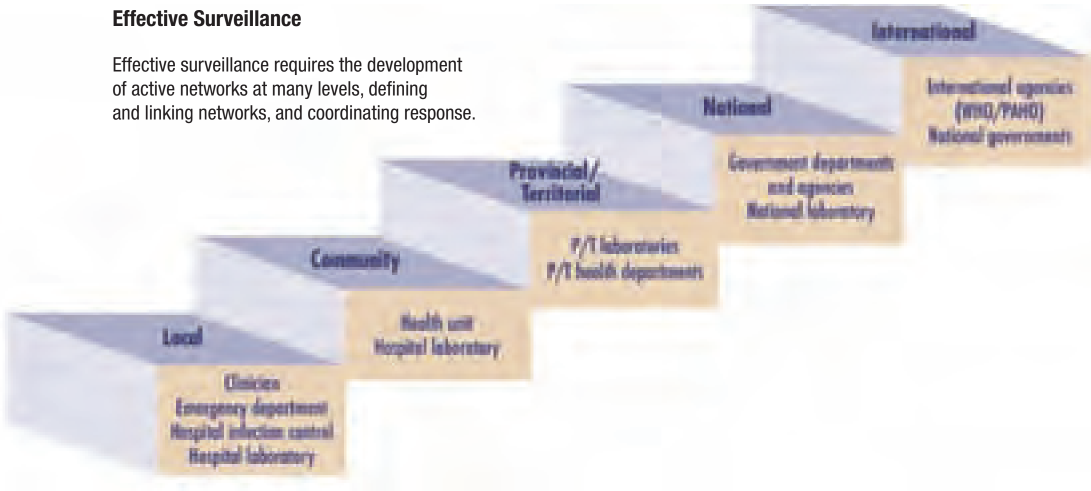
5.4.2 Surveillance

Once key health risks have been identified and prioritized, the next process is to establish that surveillance systems are (i) capable of identifying changing disease patterns and emerging risks in a timely fashion, and (ii) able to trigger appropriate interventions to control disease risks, again in a timely fashion.

In Canada, disease surveillance has moved from the traditional work of recording past events to a more active, anticipatory approach designed to identify health threats as early as possible. To be effective, such an approach requires a collaborative effort among health professionals and their allies at all levels of government, as well as internationally (Figure 5.5). Surveillance needs to be linked more tightly to action with a feedback loop at each scale for all surveillance programs. For example, individuals and public health units may not report a disease unless they see a benefit or the broader impacts on health. Local, provincial and federal health departments each maintain registries of health data on certain diseases, infections, hospitalizations and injuries, while the World Health Organization monitors similar data at a global level. These data, collected by recording events as they occur, contribute to passive surveillance and may be enhanced by active surveillance programs that obtain data on particular health problems (e.g. emerging infections) (Pinner et al., 2003). The creation of the Public Health Agency of Canada was a major step toward improving infectious disease surveillance and control, and the National Notifiable Diseases On-Line and the *Canadian Communicable Disease Report* allow access to information on case reports and surveillance results of infectious diseases.

Chapter 5

Figure 5.5 Effective surveillance framework

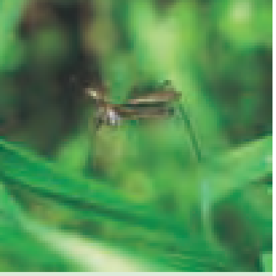


Note: P/T, provincial and territorial; WHO, World Health Organization; PAHO, Pan American Health Organization.

Source: Charron and Sockett, 2005.

As well as tracking individual human disease cases, a number of alternate surveillance activities can be useful in identifying disease risks and triggering interventions. These include monitoring zoonotic diseases (diseases transmissible between animals and people) in sentinel animal and vector populations. For example, Canadian public health authorities routinely monitor West Nile virus activity in birds and mosquitoes to measure the human health risk (PHAC, 2006). A resurgence of leptospirosis in domestic dogs in Canada may prove to be both a sentinel for increased human risk from wildlife sources of the disease and a potential source itself (Hrinivitch and Prescott, 1997; Carmichael, 1999; Kalin et al., 1999; Prescott et al., 1999; Warshawsky et al., 2000; Prescott et al., 2002). Research is also underway to understand how trends in over-the-counter medication (e.g. antidiarrhoeal remedies) may help detect water-borne illness in communities (Edge et al., 2004). Newspapers have also been useful in monitoring health problems related to extreme weather events (Soskolne et al., 2004). The importance of alternative systems of surveillance such as these is likely to increase due to global environmental change in times of competing demands on limited resources. Local communities may also contribute helpful information often not captured by health surveillance activities alone. Sources such as these are especially important when studying the impacts of weather and climate on health. For example, First Nations elders may contribute pertinent observations on changes taking place in their communities and environments (MacKinnon, 2005). Farmers may understand the significance of weather patterns and can provide useful insights regarding health impacts. Similarly, hunters and fishers may observe changes in the health of wildlife that represent a human health risk (Sang et al., 2004).

Adapting surveillance systems to increased or altered health risks due to climate change will require imaginative development and intelligent use of both current and new surveillance methods. The process of surveillance method selection will be an MCDA that engages a wide variety of stakeholders. In the climate change context, surveillance systems must be dynamic and capable of responding to observed changes or to projections obtained from simulation or statistical models. In either case, increasing capacity to link these to geographic information systems technology provides powerful tools to direct and rationalize surveillance activities once they have been developed.



5.4.3 Intervention and Adaptation

The Canadian public health and health care infrastructures have evolved over many years, and in many ways, to reduce the health risks related to weather and climate. Provinces have vested authority in Medical Officers of Health to issue boil water advisories under adverse water quality situations; the federal government operates a centre for emergency preparedness and response; and various non-government organizations have delivered public education and outreach on a range of related topics. As a result, Canadians are generally well protected from current weather- and climate-related health risks. For example, during floods or high-impact rain events, the contamination of surface water and compromised wells is widely assumed, and boil water advisories are issued. The most recent example in Canada was an advisory for the Greater Vancouver Regional District in British Columbia in November 2006. A large storm event caused extremely high turbidity in the systems reservoirs and a precautionary advisory was issued and was in effect for 12 days (CBC News, 2006). A similar situation occurred in the Red River Valley, southeastern Manitoba, as a result of the flood of 1997; the flood caused no direct loss of life, but resulted in property damage and the evacuation of 28,000 people from their homes (Burn and Goel, 2001).

Water- and food-borne diseases

The systems in place to help to manage existing water- and food-borne diseases provide the foundation for dealing with the new water- and food-borne health impacts related to climate change. In general, methods of control of water- and food-borne diseases are well established. Key aspects of controlling microbial drinking water contamination include a multiple barrier approach, with emphasis on source-water protection, and site-specific water treatment technologies with built-in redundancies (source-to-tap initiatives). Existing water treatment and food-processing regulations (e.g. Hazard Analysis and Critical Control Point) may well be robust in the face of climate change. Furthermore, many of the measures already in place to reduce weather-related health risks (e.g. severe weather warnings, boil water advisories, monitoring and surveillance, emergency preparedness) will continue to offer protection from the same risks under a changed climate. However, these systems are by no means comprehensive. For example, it is still impossible to calculate the burden of illness associated with water-borne disease under current data collection and reporting formats. Food-borne disease outbreaks continue to be observed despite these systems, such as the 2006 fresh spinach outbreak (CDC, 2006b). Furthermore, as the climate continues to change, some of these systems may reach or exceed the limits of their effectiveness.

In assessing the capacity of drinking-water systems to respond to new challenges with climate change, a number of criteria need to be examined, including design, redundancy, resilience and maintenance issues. Infrastructure and processes are designed to a maximum threshold based on historical climate records. As rainfall events intensify and become more frequent, existing multiple safety barriers may fail more often or require greater maintenance (Watt et al., 2003), increasing the risk for contamination and subsequent disease. For example, the 2001 Battlefords (Saskatchewan) *Cryptosporidium* outbreak occurred because the water treatment

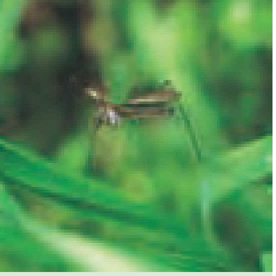
was functioning at a sub-optimal level. The source water was contaminated through poor location choice (downstream from the sewage discharge pipe), and weather impacts affected water quality (Stirling et al., 2001). The encysted stages of *Cryptosporidium* and some strains of *Giardia* are known to be resistant to simple chlorination water treatment. In general, *Giardia* can be inactivated with chlorine, but the chemical concentrations and contact times required make it an inefficient treatment method in most cases (Hibler et al., 1987; Korich et al., 1990). Canada's aging and increasingly urban population puts more people at risk; aging and deteriorating infrastructure may compromise the reliability of water treatment systems (Schuster et al., 2005); and the robustness of such systems will influence how well they can respond to new health risks. Individual contaminants have their own idiosyncrasies that must be taken into account in planning. These demographic, geographic and contaminant-based variations in risk and intervention requirements must be taken into account via stakeholder-driven weighting of criteria for selection of intervention methods.

Vector- and rodent-borne diseases

Some of the pathogens responsible for vector- and rodent-borne diseases are endemic to Canada, but many risks associated with climate change involve emergence of pathogens new to Canada. These are likely to require different interventions (i.e. the prevention of epidemics and spread–and even eradication–of newly emerging pathogens versus minimizing risks from endemic diseases). In both cases, the methods, intensity and point of use of interventions will be highly variable and pathogen specific. Again, criteria for interventions need to be established and weighted according to pathogen, objective, location and populations at risk in a stakeholder-led process. For example, populations susceptible to Lyme disease include people who spend time in woodlands and woodland-edge environments, outdoor workers, outdoor sports enthusiasts, dog owners, hunters and hikers, as well as rural and suburban home owners and their families (Dister et al., 1997).

Available interventions are those generally borrowed from regions where vector- or rodent-borne pathogens are currently a problem and endemic. In almost all cases, there are no vaccines available and none are likely to become available in the foreseeable future. Interventions rest on vector control or public health messages, as exemplified by the response to the West Nile virus in recent years. In this outbreak, provincial and municipal health authorities made considerable efforts to control mosquitoes by destroying larval mosquitoes with biological or chemical larvacides and by killing adult mosquitoes with residual (applied to surfaces) or broadcast (in the air) adulticides (Nasci et al., 2001; Thier, 2001; Herrington, 2003; Shapiro and Micucci, 2003). Public health messages were put in place to reduce mosquito larval development sites, such as standing water, and reduce human biting. The latter included advice on using mosquito repellents, wearing protective clothing, avoiding outdoor activities at dusk and dawn, when mosquitoes are most active, and limiting activity in areas where mosquitoes are abundant (Moore, 2003).

Tick-borne diseases can similarly be controlled by a variety of vector control methods and by the vaccination of wild host species (Schmidt and Ostfeld, 2001; Dolan et al., 2004; Rand et al., 2004; Tsao et al., 2004; Schulze et al., 2005). Experiences from other countries suggest caution in the chemical control of ticks (Ogden et al., 2005b). Public health messaging is again important because tick bites and tick-borne infections can be avoided by wearing suitably protective clothing, and by checking for ticks on clothing and the body after being in tick habitats (Health Canada, 2006). Public health messaging about vector-borne disease symptoms may also limit the impact of these diseases. For example, early Lyme disease is often easily diagnosed by clinicians and usually readily cured with antibiotics. Later-stage infections are more difficult to diagnose and treat, and cause considerable debilitation in affected patients (Wormser, 2005).



5.5 CONCLUSIONS

This chapter has identified that the potential exists for climate change to affect public health in Canada, via effects on the risk from food-, water-, rodent- and vector-borne diseases. It is essential to act upon these observations and to prepare for coming risks and challenges. A range of actions should be considered, including assessment of risks and risk-management measures through the establishment of necessary surveillance systems linked to effective intervention and control processes. As well, training of professionals and public education aimed at the adoption of behaviours to minimize health risks is necessary. The Public Health Agency of Canada is strategically placed to take a lead role in this process in partnerships with federal organizations such as Health Canada, the Canadian Food Inspection Agency, non-government organizations, research networks (e.g. Canadian Water Network, ArcticNet) and public health organizations in provinces, territories and municipalities. A wider engagement of stakeholders from different cultural, geographic and demographic groups is essential to create the diversity of opinion needed to develop and implement inclusive and adaptive mechanisms to protect the Canadian public.

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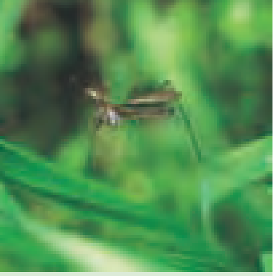

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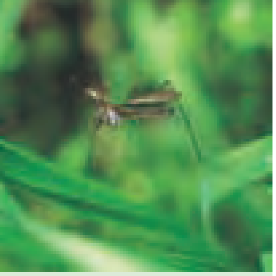

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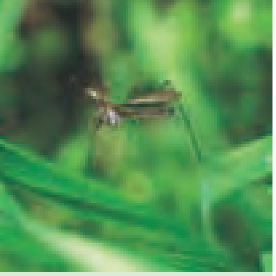

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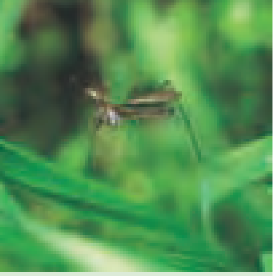

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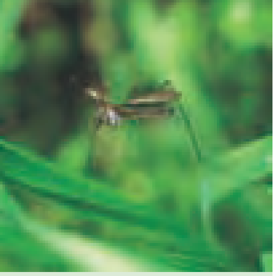

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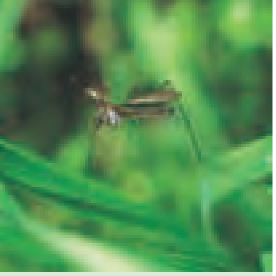

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