Infections in the natural environment of British Columbia, Canada

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**Summary** The Canadian province of British Columbia has a luxurious environment, complete with the multitude of wildlife and insects, and would at first glance appear to be suitable for the transmission of diseases in nature communicable to humans. Despite this potential, such diseases are relatively uncommon, although several have the potential for serious consequences. Attention has been recently focused on hantavirus infection, water-borne toxoplasmosis and parasitic diarrheal diseases, cryptococcosis on Vancouver Island, and rabies. West Nile virus has not yet caused endemic human infection in this province as of 2008. We review the cumulative science in this area.

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**Introduction**

The abundance of forests in British Columbia (B.C.), Canada (Fig. 1) intermingled with both industry and public recreation would seem sufficient to ensure that people suffer from diseases acquired in nature. Such reports however are uncommon, although under-reporting is likely. Nevertheless, many such diseases have had considerable discussion given the potential for illness and given heightened awareness generated by media and other reports. For example, there are thousands of investigations requested yearly for Lyme disease even though the reported yearly cases can usually be counted on two hands [1].

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Communicability

Infection in nature is spread to humans either directly from the infected or colonized source or through transmission by an insect (arthropod) vector (Table 1) [2–7]. Direct transmission may occur by ingestion of the microbe, direct contamination of skin (especially with an open wound) or mucous membranes, or by inhalation. Insect vectors may include ticks, fleas, mosquitoes, or lice. The latter vectors will usually act as an intermediary between humans and another mammal or a bird. In nature, the cycle of transmission will continue between insect and the non-human reservoir, sometimes causing a relatively asymptomatic infection while at other times causing morbidity or even death. Humans very rarely act to maintain this cycle of infectious burden in nature and rather become infected mostly as by-standers. An exception to the infectious characteristic is tick paralysis which is toxin mediated.

Whereas some diseases communicable to humans from nature have been cited for many decades (Table 2), others seem to have had an increasing frequency. The latter perception must be tempered by the understanding that some agents have been newly recognized and that, therefore, the epidemiological patterns are new observations.

Insect vectors of several types may be important intermediates. In B.C., the hard ticks *Ixodes pacificus* (Western black-legged) and *Dermacentor andersoni* (wood tick) are medically significant as is the soft tick *Ornithodoros hermsi* (Fig. 2) [3,6]. Mosquitoes could conceivably be carriers of Western equine encephalitis virus, West Nile virus, California encephalitis virus, and St. Louis encephalitis virus. Fleas can assist the transmission of plague, murine typhus, and cat scratch disease. Body lice (*Pediculus humanus*) are capable of transmitting *Bartonella quintana*.

Diseases in nature of concern

**Anaplasmosis (ehrlichiosis)**

*Anaplasma* spp. and *Ehrlichia* spp. closely resemble rickettsiae. These intracellular bacteria are tick-transmitted. Morshed cites three infections over 1993–1997 [1]. It is not clear whether such infections were imported. Infection with *A. equi* was documented in a horse from Vancouver Island [8]. Canine infection with *A. phagocytophilum* is detailed from Vancouver Island [9]. Such bacteria are believed to be carried by *Ixodes pacificus*. Deer, rodents, and other small mammals serve as reservoirs. Magnarelli et al. detected bacteria which were apparently similar to the above, although an exact characterization was not possible [10]. Among 20 female *Ixodes pacificus* ticks tested, 7 had evidence of rickettsia-like organisms.

**Anthrax**

*Anthrax* (*Bacillus anthracis*) is rare. Most infected animals in Canada are domestic cattle, and cattle vaccination programs have been initiated. One human skin infection was identified in B.C. although the source was uncertain [11,12]. A large domestic prairie outbreak in provinces east of B.C. affected cattle in 2006. In the wild, anthrax has been found among bison from Alberta and the former Northwest Territories and may have arisen as spread from domestic animals to wildlife [13].

**Bartonellosis**

In B.C., *Bartonella henselae* has been associated with cat scratch disease which is transmitted by felines or their fleas [14–16]. Infections are found on the Lower Mainland (southeast area close to Vancouver) and Vancouver Island. *Bartonella quintana* infection (systemic) has been rarely documented, and the major mode of transmission is from the body louse *Pediculus humanus* [15,17]. The potential role of other bartonellae in nature is also largely unexplored, but it is evident that many wildlife have unique bartonellae [18].
Table 1  Diseases in nature potentially communicable to humans in British Columbia

<table>
<thead>
<tr>
<th>Disease</th>
<th>Agent</th>
<th>Mode of transmission</th>
<th>Vector</th>
<th>Reservoir</th>
<th>Frequency</th>
<th>Locale in British Columbia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacterial Anaplasmosis</td>
<td>Anaplasma spp. (Ehrlichia spp.)</td>
<td>Tick bites</td>
<td>Black-legged tick</td>
<td>Infected animals</td>
<td>Rare</td>
<td>Not yet well studied but one equine and one canine infection were both found on Vancouver Island</td>
</tr>
<tr>
<td>Anthrax</td>
<td>Bacillus anthracis</td>
<td>Inhalation or direct contact</td>
<td>None</td>
<td>Infected animal</td>
<td>Rare</td>
<td>No endemic focus yet identified</td>
</tr>
<tr>
<td>Bartonellosis</td>
<td>(a) Bartonella henselae; (b) Bartonella quintana</td>
<td>(a) Cat bites or scratches; (b) louse exposure</td>
<td>(a) None (possibly fleas); (b) body louse</td>
<td>Infected animal and soil (a) Cats</td>
<td>Rare, very rare</td>
<td>At least Vancouver Island and Lower Mainland uncertain</td>
</tr>
<tr>
<td>Brucellosis</td>
<td>Brucella spp.</td>
<td>Direct contact with infected animal</td>
<td>None</td>
<td>Infected animals</td>
<td>Not published</td>
<td>None detailed among wildlife</td>
</tr>
<tr>
<td>Leptospirosis</td>
<td>Leptospira spp.</td>
<td>Infected animal urine, contaminated waters</td>
<td>None</td>
<td>Infected animals</td>
<td>Rare</td>
<td>Mainly documented in domestic animals</td>
</tr>
<tr>
<td>Lyme disease</td>
<td>Borrelia burgdorferi</td>
<td>Tick bites</td>
<td>Black-legged tick</td>
<td>Infected animals</td>
<td>Few yearly infections</td>
<td>Mainly southwestern province but distribution not fully conclusive</td>
</tr>
<tr>
<td>Plague</td>
<td>Yersinia pestis</td>
<td>Flea bite, direct contact with infected animals</td>
<td>Flea</td>
<td>Infected animals</td>
<td>No human cases</td>
<td>Lilloet</td>
</tr>
<tr>
<td>Q (Query) fever</td>
<td>Coxiella burneti</td>
<td>Aerosols, milk, tick bites</td>
<td>Rarely wood tick</td>
<td>Infected animals</td>
<td>Rare</td>
<td>Likely throughout but not intensively detailed in B.C.; mainly in domestic animals</td>
</tr>
<tr>
<td>Disease</td>
<td>Agent</td>
<td>Mode of transmission</td>
<td>Vector</td>
<td>Reservoir</td>
<td>Frequency</td>
<td>Locale in British Columbia</td>
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</tr>
<tr>
<td>Relapsing fever</td>
<td><em>Borrelia hermsii</em></td>
<td>Tick bite</td>
<td>Soft tick; <em>Ornithodoros hermsi</em></td>
<td>Infected animals</td>
<td>Rare</td>
<td>Mainly southcentral regions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Hard ticks including; <em>Dermacentor andersoni</em></td>
<td>Small mammals</td>
<td>Rare</td>
<td>Potentially southeastern B.C.</td>
</tr>
<tr>
<td>Rocky Mountain spotted fever</td>
<td><em>Rickettsia rickettsii</em></td>
<td>Tick bite</td>
<td>Hard ticks including; <em>Dermacentor andersoni</em></td>
<td>Small mammals</td>
<td>Rare</td>
<td>Potentially southeastern B.C.</td>
</tr>
<tr>
<td>Tularemia</td>
<td><em>Francisella tularensis</em></td>
<td>Tick bite, Infected animals, contaminated waters in rodent infested areas</td>
<td>Wood tick, rabbit tick</td>
<td>Infected animals</td>
<td>Rare</td>
<td>Throughout the province (see text for cited locations)</td>
</tr>
<tr>
<td>Viral</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>California viral encephalitis</td>
<td><em>California encephalitis virus</em></td>
<td>Mosquito bite</td>
<td><em>Aedes</em> spp.</td>
<td>Small mammals</td>
<td>Not published</td>
<td>None cited in B.C.</td>
</tr>
<tr>
<td>Colorado tick fever</td>
<td><em>Colorado tick fever virus</em></td>
<td>Tick bite</td>
<td>Wood tick</td>
<td>Infected animals</td>
<td>Not published</td>
<td>Mainly Kootenay region</td>
</tr>
<tr>
<td>Hantavirus pulmonary syndrome</td>
<td><em>Hantavirus</em></td>
<td>Aerosol exposure to infected rodent urine, feces, and saliva</td>
<td>None</td>
<td>Infected rodents</td>
<td>Rare</td>
<td>Mainly southern interior</td>
</tr>
<tr>
<td>Powassan virus encephalitis</td>
<td><em>Powassan virus</em></td>
<td>Mosquito bite</td>
<td>Ticks including the wood tick</td>
<td>Small mammals</td>
<td>Not published</td>
<td>None cited in B.C.</td>
</tr>
<tr>
<td>Rabies</td>
<td><em>Rabies virus</em></td>
<td>Bite or saliva from infected animal, possible aerosol transmission</td>
<td>None</td>
<td>Bats (in British Columbia)</td>
<td>One reported case</td>
<td>Throughout the province</td>
</tr>
<tr>
<td>St. Louis encephalitis</td>
<td><em>St. Louis encephalitis virus</em></td>
<td>Mosquito bite</td>
<td><em>Culex</em> mosquitoes</td>
<td>Small mammals</td>
<td>Not published</td>
<td>None cited in B.C.</td>
</tr>
<tr>
<td>West Nile virus infection</td>
<td><em>West Nile virus</em></td>
<td>Mosquito bite</td>
<td><em>Culex</em> and <em>Anopheles</em> mosquitoes</td>
<td>Birds</td>
<td>Not published</td>
<td>None endemic in B.C. up to 2007</td>
</tr>
<tr>
<td>Western equine encephalitis</td>
<td><em>Western equine encephalitis virus</em></td>
<td>Mosquito bite</td>
<td><em>Culex</em> mosquitoes</td>
<td>Small mammals, birds</td>
<td>Rare</td>
<td>Okanagan and Kootenays</td>
</tr>
<tr>
<td>Parasitic Infections</td>
<td>Pathogens</td>
<td>Mode of Acquisition</td>
<td>Hosts</td>
<td>Frequency</td>
<td>Distribution</td>
<td></td>
</tr>
<tr>
<td>----------------------</td>
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<td>--------------</td>
<td></td>
</tr>
<tr>
<td>Cryptosporidiosis</td>
<td><em>Cryptosporidium</em> spp.</td>
<td>Oral ingestion of contaminated waters</td>
<td>None</td>
<td>Humans, cattle, beavers, otters, other small mammals</td>
<td>Common Throughout British Columbia</td>
<td></td>
</tr>
<tr>
<td>Giardiasis</td>
<td><em>Giardia duodenalis</em></td>
<td>Oral ingestion of contaminated waters, rarely person-to-person</td>
<td>None</td>
<td>Humans, cattle, beavers, muskrats, otters, other small mammals</td>
<td>Common Throughout British Columbia</td>
<td></td>
</tr>
<tr>
<td>Hydatid disease</td>
<td>Dog tapeworms <em>Echinococcus granulosus</em> and <em>Echinococcus multilocularis</em></td>
<td>Acquisition from contaminated vegetation and water</td>
<td>None</td>
<td>Canines such as wolves, coyotes, foxes, and dogs</td>
<td>Rare Mainly in the northern province</td>
<td></td>
</tr>
<tr>
<td>Schistosome dermatitis</td>
<td>Bird schistosomes</td>
<td>Direct contact in fresh waters</td>
<td>None</td>
<td>Snails (intermediate hosts)</td>
<td>Common among fresh water recreationists Widely in fresh waters where snails and birds abide</td>
<td></td>
</tr>
<tr>
<td>Tick paralysis</td>
<td>Tick neurotoxin</td>
<td>Tick bites</td>
<td><em>Dermacentor andersoni</em></td>
<td>Ticks</td>
<td>Rare In the distribution of <em>Dermacentor andersoni</em></td>
<td></td>
</tr>
<tr>
<td>Toxoplasmosis</td>
<td><em>Toxoplasma gondii</em></td>
<td>Feline feces, undercooked meat, contaminated waters</td>
<td>None</td>
<td>Felines and infected mammalian meat</td>
<td>Many cases reported Likely throughout the province</td>
<td></td>
</tr>
<tr>
<td>Trichinosis</td>
<td><em>Trichinella spiralis</em></td>
<td>Ingestion of infected meat</td>
<td>None</td>
<td>Infected animals</td>
<td>Rare Throughout the province</td>
<td></td>
</tr>
<tr>
<td>Fungal Infections</td>
<td><em>Cryptococcus gattii</em></td>
<td>Direct contact, aerosol</td>
<td>None</td>
<td>Soil, water, vegetation</td>
<td>Emerging infection Vancouver Island and lower mainland</td>
<td></td>
</tr>
</tbody>
</table>
Table 2  Historically important dates in the recognition of diseases communicable in nature to humans in British Columbia

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1912</td>
<td>Todd first describes tick paralysis in B.C.</td>
</tr>
<tr>
<td>1917</td>
<td>First reported Rocky Mountain spotted fever infection</td>
</tr>
<tr>
<td>1933</td>
<td>First citations of relapsing fever caused by <em>Borrelia hermsii</em></td>
</tr>
<tr>
<td>1934–1935</td>
<td>First citations of human tularemia caused by <em>Francisella tularensis</em></td>
</tr>
<tr>
<td>1950s</td>
<td>First isolation of Colorado Tick Fever virus from resident <em>Dermacentor andersoni</em></td>
</tr>
<tr>
<td>1971</td>
<td>Large outbreak of ursine trichinosis in undercooked bear meat and adulterated pork sausages</td>
</tr>
<tr>
<td>1989</td>
<td>First descriptions of sylvatic plague caused by <em>Yersinia pestis</em></td>
</tr>
<tr>
<td>1990s</td>
<td>First isolations of <em>Borrelia burgdorferi</em> from ticks and rodents in B.C.</td>
</tr>
<tr>
<td>1994</td>
<td>First reported confirmed cases of hantavirus infection in B.C. and Canada</td>
</tr>
<tr>
<td>1995</td>
<td>Recognition of large water-borne outbreak of toxoplasmosis in Greater Victoria</td>
</tr>
<tr>
<td>1996–1998</td>
<td>Documented large cryptosporidiosis outbreaks in the Kootenays and southern interior</td>
</tr>
<tr>
<td>1999</td>
<td><em>Cryptococcus gattii</em> infections become increasingly recognized on central Vancouver Island</td>
</tr>
<tr>
<td>2000s</td>
<td>West Nile virus and human infections found in Canada (none endemic to B.C. as of 2007)</td>
</tr>
<tr>
<td>2003</td>
<td>First reported human rabies infection acquired in B.C. (probable bat source)</td>
</tr>
<tr>
<td>2005</td>
<td>First confirmation of anaplasmosis native to this province in a dog from Vancouver Island</td>
</tr>
</tbody>
</table>

Brucellosis

Native acquisition of this systemic infection has not been published, but bovine brucellosis has been detailed in the past. There is a theoretical potential for domestic bovine brucellosis to infect wildlife such as moose or bison [19], but no bovine brucellosis has been documented in this province recently. Brucellosis among some free ranging wood bison in the east neighboring Alberta province is known [20].

California encephalitis virus (Snowshoe Hare type)

California encephalitis virus can be subdivided into several groups, one of which is the snowshoe hare variant. It is transmitted from small mammals by *Aedes* spp. mosquitoes. Human infections are somewhat similar to those caused by Powassan virus and Western equine encephalitis virus [21,22].

Human infection with this virus is not yet recorded in B.C., but the virus has been isolated from mosquito pools near Penticton (southeastern province) [23]. Small mammals in the province have shown neutralizing immunity to the virus, thus implying past infection [23–25]. Students and adults have shown neutralizing immunity in regions including the Lower Mainland, Okanagan valley (southeast), Kootenays (southeast), north interior, and the Peace River district (northeast) [24,26,27]. Infected mosquitoes have existed in the far north [28–33].

Colorado Tick Fever

Human infections with Colorado Tick Fever virus are unreported in B.C., although one such citation arose in nearby southeastern Alberta province [34]. The vector in western Canada is *Dermacentor andersoni*, and infected ticks have been found in this province [35,36]. The golden mantled ground squirrel is one example of a natural reservoir [26].

In B.C., infested ticks are mainly in the Kootenay area (southeast) [35,36], and in Alberta, infested ticks have been found in Banff National Park and the mountainous areas west of Calgary, Alberta [35,37]. Human infection and infected ticks have been documented in northeast Washington State, United States. Studies of human exposure were conducted throughout the province, especially the Kootenay region. Only 8 of nearly 3300 patient specimens had some evidence of Colorado Tick Fever virus exposure, and only 1 could be supported by confirmatory tests [26,27].
Cryptococcosis

Historically, cryptococcal infections were recognized worldwide due to *Cryptococcus neoformans*. The *Cryptococcus* species which has become newsworthy locally is *C. gattii*. Formerly a variant of *C. neoformans*, it has been raised to species status. Whereas *C. gattii* was thought to cause infection in tropical and subtropical climates, research has now identified its residence locally [38]. B.C. appears to have the highest global incidence of *C. gattii* infection (~5–10 infections/million population/year). Infections usually involve lung, central nervous system, and skin. Over 100 human infections have been documented including deaths. In the last five years, two dozen or more have been reported yearly [39].

*C. gattii* was initially documented among veterinary animals in 1999, but disease among humans soon emerged. The focus is the southeastern coast of Vancouver Island. Subsequently, *C. gattii* infection and environmental contamination have been found in the Island’s bordering maritime zone and in the lower mainland [38]. An exported infection to Denmark has also been cited [40]. Although initial infections occurred largely among people venturing to the Island, recent findings document infection among lower mainlanders who have not visited the Island during the incubation period of infection [39].

There are unique genetic types common to local isolations [41]. Infected animals have included mainly cats and dogs but also ferrets and llamas [42]. Asymptomatic colonization of wildlife (squirrels) has been found [43]. Colonized environmental sources have included plants, soils, and waters (both freshwater and marine). Given the presence of *C. gattii* on eucalyptus trees elsewhere, there was speculation that the importation of such trees may have introduced *C. gattii* to Vancouver Island. The latter are not colonized with *C. gattii* in B.C., but a number of other trees with colonization have been documented.

Trees are more commonly colonized in central Vancouver Island (centering on the mideast Parksville), and the frequency decreases in either longitudinal direction [44,45]. Airborne *C. gattii* is more common in dry summer months as opposed to other seasons where rainfall is greater and presumably serves to precipitate the airborne propagules [38]. Given the presence of *C. gattii* in soil [38], the germ may be aerosolized by wind. Movement of fungus via other human activities (e.g., vehicle tires, raw wood product transport, footwear) is also possible.

Whereas it may initially be considered a new germ causing new outbreaks, previous *C. gattii* infection may not have been easily recognized due to methodological issues. An infection from Seattle, Washington, U.S. in ~1971 has raised considerable interest [39].

Cryptosporidiosis

*Cryptosporidium* is a water-borne parasite whose cysts are resistant to environmental conditions. Infections peak in late summer and early fall, and occur among humans, cattle, beavers, otters, and small mammals; these excrete infectious cysts into the water supply [46–48]. Epidemics are related to water supplies especially watersheds that run distal to cattle ranching [49]. Both raw surface and treated water may yield the parasite, although much less after water treatment and/or filtration.

During 1996–1998, large water-borne outbreaks were recorded in Cranbrook (southeast), Kelowna, Penticton, Kamloops (latter three southcentral), and Chilliwack (southwestern). Human exposure to this parasite is common [50]. The British Columbia Centre for Disease Control (BCCDC) reported approximately 100–200 infections per year and throughout the province [51].

Giardiasis

*Giardia duodenalis* is acquired from water supplies whether of raw source or treated. Although historically thought to be from small mammal excreta into water systems (e.g., beavers, muskrats, otters) [48], bovine sources for contamination figure highly [46,47,49]. Human to human transmission is also possible. Outbreaks of infection may have more than one epidemic strain of parasite. Giardiasis is very common throughout B.C.: some 600–1200 infections/year have been reported during 1997–2006 [52,53].

Hantavirus pulmonary syndrome

Hantavirus pulmonary syndrome, although rare, has a high fatality rate (~50%) [54]. Infection begins with a non-specific influenza-like illness which can rapidly progress to pulmonary edema and shock. Strains of hantavirus show diversity, but disease-causing forms in B.C. are called Sin Nombre. They are similar to isolates in the western United States [55].

Rodents, especially deer mice, are reservoirs in Western Canada. Transmission arises when virus is inhaled from aerosolized components of rodent urine, feces, and saliva.
There are less than a dozen infections reported provincially since 1994 [56,57], but recognition only became more apparent once diagnostic methods were available first in the U.S. Local infections are largely restricted to the dry southern interior. One study (1984) found past evidence of human exposure [58]. Humans may encounter the germ in dry dusty confines where deer mice inhabit — old buildings, barns, and cabins, especially those unkept for a long period of time [59].

Hydatid Disease (Echinococcosis)

This parasitic infection is caused worldwide by the dog tapeworm Echinococcus spp.; two species are in British Columbia — E. granulosus and E. multilocularis. Human infection mostly occurred among First Nations people and other northern residents [60—62], but infection is becoming more rare.

The adult tapeworm grows in canine intestines. Tapeworm eggs are fecally shed. Humans encounter eggs from water or contaminated vegetation. Infections are often found incidentally from chest x-rays or abdominal ultrasounds. E. granulosus is associated more with single cysts, although potentially quite large, whereas E. multilocularis infection may result in multiple cyst formation and more secondary spread when cysts erupt.

In nature, carriers are mostly wolves, coyotes, and foxes. Excretion of the parasite eggs leads to infection of herbivores such as moose, caribou, deer, and bison who accidentally ingest eggs on vegetation. Retransmission to carnivores is completed when the latter feed on herbivores, e.g., feeding of moose offals to companion dogs creates a focus for human infection. Cats and mice have also been infected [63]. Miller reported that 25/72 dogs from northern reserves were infected [60].

Leptospirosis

Leptospira spp. bacteria are ubiquitous pathogens of animals, and there are many subspecies. These spiral bacteria gain entry via mucous membranes or skin, and may cause systemic infections. Animals which are infected with Leptospira spp. excrete them into urine, and nearby waters or soil may be thus contaminated.

Human disease in B.C. is rare. Infected animals in B.C. have included cattle [e.g. South Okanagan (southcentral)] [64], sheep [65], rodents [66], pigs, dogs, and horses [67]. Canine infection was described in 1970 [68], and canine leptospirosis has been noted recently in nearby Washington State, United States. Animals are often asymptomatic when shedding the bacterium into urine. There is potential for exchange of bacterium between domestic animals and wildlife.

Lyme disease

The diversity of Lyme disease manifestations can cause confusion because there are many non-infectious diseases which have similar manifestations. Diagnostic tests taken early after tick bite may be negative. There is dispute about whether diagnostic methods are sufficiently sensitive, and thus an open mind should be maintained [69,70].

The spiral bacterium, Borrelia burgdorferi, was isolated from ticks and rodents in B.C. by the 1990s [71—73]. The province is now known to be endemic for B. burgdorferi infected ticks and animals, but human disease is relatively uncommon; as reported by BCCDC, some 2—9 infections per year are confirmed despite thousands of requests testing yearly (16,286 requests over 1986—1993) [74]. Morshed reported 23 infections being diagnosed during 1993—1997 [1]. Many of the latter, however, relate to acquisition outside of the province. Horses and dogs have also been infected [73,75]. Thus far, most B. burgdorferi are found in ticks from southwestern B.C. which follows the predominant distribution of Ixodes pacificus [76,77]. The latter tick has been found to parasitize up to 55 vertebrate hosts including lizards. Adult I. pacificus ticks typically acquire a blood feed from large mammals such as deer, cattle, horses, dogs, and humans whereas their larvae or nymphal stages attach to birds, small mammals, and lizards. B. burgdorferi has now been isolated from two other similar ticks locally: I. angustus and I. auritulus [74,77,78]. Morshed estimated that less than 2% of Ixodes ticks are infected with B. burgdorferi [1]. Both I. auritulus and I. pacificus can migrate with passerine song birds. The association of I. auritulus with ground-dwelling passerines would seemingly give credibility to the association between birds and small mammals. I. auritulus does not apparently attack humans.

Plague

The bacterium (Yersinia pestis) is acquired from infected animals by flea bites and handling of infected tissues. The first report of plague bacterium was made by Lewis [79] upon recovery from deceased bushy-tailed woodrats in the Lil-loet region. He also cited the 1984 occurrence of a bubonic plague in a Washington state (U.S.) trapper. A survey among rats and fleas on west coast seaports did not find sylvatic plague [80] nor was it
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found elsewhere in 1938 [81] or in a larger survey during 1939–1946 [82].

**Powassan encephalitis**

Powassan virus is cited mainly from eastern North America, but there is reason to believe that it may occur locally. One of the potential vectors, *Dermacentor andersoni*, is found in the southeast province. Disease is maintained between small mammals and ticks. Asymptomatic or mild infection is most likely, but central nervous system disease is a rare but dreaded consequence.

Other reasons for anticipating Powassan virus locally emanate from study during the 1960s. Small mammals near Penticton (southcentral) and Cranbrook (southeast) were found to have evidence of neutralizing immunity to this virus, thus indicating past infection [23–25,83]. No such neutralizing antibody was found in humans however [26,27].

**Q (Query) fever**

*Coxiella burnetii* is the bacterial cause of Q fever. Infection is acquired mainly from sheep, goats, and cattle whether from milk or aerosols of dust that contain dried bacterium. High numbers may be shed from parturient animals.

Tick (*Dermacentor andersoni*) vectors are possible [84], but infection directly from animals is more common. Infection is uncommonly reported here, although the illness is probably underestimated. In 1993–1997, the BCCDC reported five infections [1]. Samples from dairy cattle throughout the province did not have evidence of Q fever [85], but subsequent assessment for cattle throughout the province demonstrated a low frequency of probable infection in regions such as the Okanagan, Fraser Valley, and Vancouver Island [86].

**Rabies**

Rabies is acquired from the scratch or bite of infected animals. Aerosol transmission has been proposed, and not all rabies acquisitions have a history of animal bite [87,88]. Infected mammals in the wild are reservoirs.

Human infection occurs in Canada [89], but there were no patients whose infection was acquired in B.C. during 1924–2000 [90]. In 2003, however, this province’s first endemic infection was reported of a Greater Vancouverite who was an avid hiker [91].

There are many mammals that can become rabid, but in B.C., the majority of non-human infections have occurred among bats, although rare citations have been made for a beaver, a horse, and three cats [91–94]. This is very much unlike neighboring Alberta and nearby Saskatchewan provinces where skunks, dogs, cats, coyotes, wolves, domestic cattle, and domestic pigs have been cited in addition to bats. Bat rabies was first cited in B.C. in 1960 [95]. There can be considerable yearly differences in the frequency of positive bats among those which have been sampled for investigation [96,97]. Most infected bats are found during summer months and are more commonly investigated in heavily populated areas of southern B.C. and Vancouver Island due to the increased potential for human-bat contact. Infected bats were initially found on Vancouver Island, the lower mainland/Fraser Valley, and Kamloops (southcentral) [98], but subsequent investigations have found rabid bats throughout including areas north of Williams Lake (central) and as far north as Hudson’s Hope (northeast). Of bats tested, the frequency over several year periods have ranged from 3.0 to 10.9% [92,94,96,97,99]. Up to seven different bat species have been implicated, especially the big brown bat. The infected species also include forest-dwelling bats such as the silver bat and the hoary bat.

When humans are investigated and treated for possible wildlife rabies exposure in B.C., about two-thirds involve bats. The bat variant of rabies virus is unique [100], and it is different from the rabies commonly found in terrestrial animals from the prairie provinces. Both the single human infection and the horse infection had evidence of bat variant rabies virus [92,100]. In 2004, four positive juvenile skunks were discovered in Stanley Park, Vancouver, but the viruses were also of the bat variant type.

**Relapsing fever**

Relapsing fever is caused by *Borrelia hermsii*. Patients develop high fever and an influenza-like illness [101]. The symptoms appear to fade until days later when another relapse returns. Relapses can occur several times (0–6 times) before the infection fades or is successfully treated. The spiral bacterium has been incidentally visualized in patients’ blood when other laboratory analyses were conducted.

* B. hermsii is transmitted locally by *Ornithodoros hermsi* whose bite is usually painless and nocturnal. Rodents (especially chipmunks) and birds may be the reservoirs, but propagation may also occur from adult tick to their offspring. Isolation of the bacterium from patients in this province has been achieved [102].

Relapsing fever in North America is widespread [101,103], but most local infections have occurred in the south central region especially in the
Rocky Mountain spotted fever

Rocky Mountain spotted fever is characterized by sudden high fever, headache, muscle aches, and a spotted rash. It is caused by the intracellular *Rickettsia rickettsii*. Few cases have occurred in this province [1], and most have likely been imported from the United States. Citations of infection date back to 1917 and 1935 [81], and isolation of the bacterium was noted from a deceased patient [82]. The bacterium may be carried by *Dermacentor andersoni* in the southeastern region of B.C. Isolation from ticks in areas where human infection has occurred is difficult but has been achieved [81,82].

Schistosome dermatitis (swimmer’s itch)

Schistosomes are blood flukes. The dermatitis is caused by a variety of species which cycle between birds (definitive host) and snails (intermediate hosts) in freshwaters. Sexual reproduction of the fluke occurs in birds which shed eggs into fresh waters. Eggs release free-swimming forms that infect snails in the same water. Snails allow multiplication of the latter and then release a second free-swimming form which will penetrate the skin of the avian in order to thereafter complete the cycle. As the second free-swimming form awaits an attack on the avian skin, human skin may likewise be penetrated by the parasite. In humans, the parasite is unable to replicate, but in so doing, produces an intense local inflammatory allergic reaction. Humans will thus develop a rash, swimmer’s itch. Exposed areas of feet and lower legs will manifest the rash in a stocking distribution. If the swimmer immerses the entire body in infested waters, the rash will be diffuse.

Schistosome dermatitis can be acquired in many fresh waters across North America. Snails are more likely to be located near the edge of lakes where humans are more often entering water [108]. Leighton et al. provide interesting details of these phenomena at Cultus Lake [upper Fraser Valley (southwest)] [109], but infested waters in B.C. are plentiful [110,111]. They are more commonly reported for southern parts of the province, although it may be that the exposure potential is greater for those lakes where humans are more likely to enter during July and August and especially in shallow areas.

St. Louis encephalitis virus

The virus is a cousin of the West Nile virus and is transmitted by *Culex* mosquitoes [112]. No human infections in B.C. have been documented, although virus activity has been known in Yakima County, Washington State [113]. Neutralizing immunity has been found among humans and small mammals from the Kootenays (southeast) [25,27,83]. The illness would be analogous to that of other viruses from the wild such as California encephalitis virus, Powassan virus, and Western equine encephalitis virus, except that the severity of disease increases with age. Given the similarity between West Nile virus and St. Louis encephalitis virus, one wonders if the aforementioned mammalian immunity reflects cross-reactivity to West Nile virus which perhaps has been in North America longer than originally believed.

Tick paralysis

Tick paralysis is caused by tick-transmitted toxin [114]. The toxin is not well characterized, but interferes with the interface of nerve and muscle [115]. In B.C., *Dermacentor andersoni* is implicated, and hence the illness is found in the Kootenays (southeast), the Okanagan (southcentral), and elsewhere in the dry interior [116]. It is curious that *D. andersoni* from Alberta do not appear to cause tick paralysis whereas those from B.C. may [117].

After the wood tick begins its feed, it secretes the unidentified toxin through saliva, but ascending paralysis will be recognized only after 4–5 days of attachment. Initial indicators will be numbness in the feet and legs or in the facial region. The illness will progress to immobilize arm, neck, and trunk regions, and it may contribute to visual, oral, and nasal impairments. Eventually, the severity of symptoms will steadily increase until the host succumbs to respiratory failure. Although fatality from tick paralysis predominantly occurs among chil-
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dren, multiple tick attachments may increase the chances of adult fatalities through increased levels of toxin. The symptoms will quickly fade after the tick has been physically removed, or after it detaches from its host. Ill patients are usually diagnosed during the late spring and early summer [118].

Tick paralysis became an issue in B.C. as both man and animal were noted to succumb to a common illness in the late 19th century. During this time, there were clinical reports of human paralysis and mortality from ticks, but a definitive correlation could not be established. In 1913, Hadwen investigated after complaints were received from a farmer who lost many sheep from an unrecognizable paralysis [119,120].

Todd described early cases of human disease in B.C. [121]. Some 300 cases and 30 deaths were compiled by the national entomology laboratory during the period 1900—1968 [116,117,122]. As recent as April 2007, two children and an adult were diagnosed with tick paralysis and treated at Kelowna General Hospital (southcentral) [123].

Toxoplasmosis

The parasite *Toxoplasma gondii* has an intestinal cycle in felines which yield cysts in feces. Ingested cysts cross the human intestinal barrier and may disseminate to almost any tissue. Transmission was historically linked to such feline exposure and to ingestion of poorly cooked mammalian meat (given the parasite's encystment in muscle tissue). Despite the aforementioned, a large water-borne outbreak in Victoria (south Vancouver Island) caused an unprecedented number of human infections mainly within a particular potable water distribution [124]. Infestation was thought to have arisen possibly from cougars that may have shed viable toxoplasmas into the municipal water system [125].

Trichinosis

This disease is caused by the roundworm *Trichinella spiralis*. The parasite has historically been associated with the consumption of infected pork meat, but the latter has been nullified by rigid surveillance of commercial meat. The parasite is now known to exist in many wildlife. Larvae of the parasite encyst in animal muscle. Carnivores that consume such raw meat will acquire the parasite which thereafter matures into adult worms in the intestinal tract. Larvae which develop from eggs that are shed by the female worm are able to migrate across the intestinal barrier and then relocate to the carnivores' muscle.

The consumption of raw or poorly cooked bear meat is a risk factor for trichinosis in B.C. [126,127]. During 1972—1975, Schmitt et al. found high rates of trichinosis among grizzly bears, martens, and wolverines (27—35%) and lesser frequencies among bobcats, black bears, coyotes, lynxes, cougars, weasels, skunks, and minks [128]. Shrews, white-footed mice, and squirrels were less often infected (<1%). The majority of infected animals were found in southern and central B.C. Humans can be infected when consuming poorly cooked game and secondarily, when such sylvatic meat is admixed with pork and beef (e.g. sausage production) [127]. The parasite survives in frozen raw meat.

Tularemia

Tularemia is caused by the bacterium *Francisella tularensis* and may include both local and systemic infections. Humans may be infected via ticks (*Dermacentor andersoni* or rabbit tick *Haemophysalis leporis-palustris*) which have fed off infected lagomorphs, directly from infested waters where infected animals such as rodents (vole, muskrat, and beaver) are present, and directly from infected live but especially ill animals or their carcasses.

There are very few reported infections yearly in B.C. Black and Thomson detailed six infections from 1934—1956 which were seemingly acquired by a cat scratch, tick bite, skinning of coyote or hare or rabbit, and accidental laboratory infection [129]. The locations included Louis Creek, Cherry Creek, Williams Lake, 70 Mile House, and Kamloops (all central or southcentral). Shaw detailed on five laboratory isolations at BCCDC emanating from hospitals at Mission (southwest), Vernon, Penticton (latter two southcentral), and Bulkley Valley (central) [130]. The latter were from environmental contacts including a squirrel bite, insect bite, raccoon, and spring water. Morshed recorded three infections for 1993—1997 [1]. Infestations of beavers were documented in 1999 near Salmon Arm (central) and Vanderhoof/Chetwynd (northeast) and in 2003 near Wells (central) [131]. Surveys of ticks in 1938 demonstrated the presence of *F. tularensis* in the Kootenay (southeast) district and north-central B.C. (Yavenby area). Another large survey (1939—1946) found the bacterium in *Dermacentor andersoni* and a house mouse [82].

West Nile virus

Infection with West Nile virus has already commanded considerable attention provincially even
though no infection is confirmed as of 2007; all locally diagnosed human infections are presumed to have been acquired outside the province. There is concern, however, that endemic infection in B.C. is imminent [132]. It has been proposed that West Nile virus was newly introduced into North America in 1999, having been recognized elsewhere in the world for decades.

Mosquitoes appear to be key vectors between birds, but humans and horses may be secondarily infected. A number of mosquitoes found in this province are capable of potentially carrying virus [133,134], although elsewhere in Canada, Culex spp. are most commonly implicated. Various birds are potentially susceptible, but the corvid family (crows, ravens, jays, magpies, and nutcrackers) are most at risk for infection and death [135]. During peak activity, there is an increase in corvid death some 2–3 weeks prior to human infections, and therefore, dead corvid sightings have been proposed as a sentinel marker. Testing of birds and mosquitoes is currently being carried out (all such samplings in British Columbia in 2007 were negative for the virus). The quantity of virus in nature is influenced by climate (e.g., rainfall) and hence is cyclical [136]. Currently, investigators are attempting to devise predictive models of spread and infection which incorporate frequencies of dead corvids, adult mosquito burdens, and interactions with data from the Geographic Information System [132,135]. It is predicted that the areas for greatest risk will be southeastern Vancouver Island, Vancouver, the Fraser Valley (southwest), and the Thompson-Okanagan region (southcentral) [137].

**Western equine encephalitis**

Western equine encephalitis virus has caused infection in the Okanagan region (southcentral), e.g., an outbreak of five patients with encephalitis (two deaths) was recorded for 1971 [27]. Formerly, the virus was known to infect horses in the Okanagan and Kootenays (southeast) [26]. Accordingly, an equine vaccination program was established. Considerable virus activity is also known to have occurred in Yakima County, Washington State, U.S., and the virus was isolated from Culex tarsalis mosquitoes [112,113]. Blood specimens from B.C. students and adults obtained in 1967–1969 was found to neutralize the virus therefore indicating exposure [26,27]. It is only transmitted by mosquitoes, and human infection would be most common in the summer. Birds serve as the viral reservoir.

**Prevention and diseases in nature**

Human activities in nature require a balance between the potential for harm and the likelihood of encountering such infections. There are many prevention strategies, some of which may be disease specific. Table 3 outlines some important categories of control tactics. Prevention strategies need to strike a balance between excess of concern and practical safety.

Gregson [118] aptly captured the potential for excess concern with the term “insectophobia”. As he cites, “An extreme case ... is recorded in the files ... victim had visited a tick-infested mining area south of Nelson, B.C., in May 1935 and had at that time become concerned about ticks 'digging in under the skin'... the following December he wrote that 'now most of them have worked from the lower parts of the body up to the upper parts of the body, neck, and head, right to the top of my head, and they keep boring in night and day, so I can’t sleep ... I have reason to believe there is one of them there now, and I keep scraping it with a knife blade to keep them down.’ He was finally committed to a mental hospital.”

The following approaches are highlighted as they evoke common sense and reason in an attempt to strike a balance between excess of concern and practical safety.

**Appropriate apparel**

Wear apparel that maximizes the coverage of skin including long sleeved shirts and long pants. Pants should be tucked into boots or socks and

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<td><strong>B. Biological measures</strong></td>
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<td>1. Vaccines for humans</td>
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<td>2. Vaccines for animals</td>
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<td>4. Introduction of natural insect predators</td>
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<td><strong>C. Chemical control measures</strong></td>
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<td>1. Repellants</td>
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the shirt should be tucked into pants. Light-colored clothes are preferable. In periods of high exposure, clothing may be sprayed with DEET or permethrin-containing products.

Other personal protection

Entrance into old buildings of uncommon use should at first include a period of aeration. Avoid the generation of dust aerosols in such buildings especially when they may have been infested with rodents. The use of breathing protection (with P100 filters or N95 respirators) and goggles has been advocated by provincial authorities for the latter circumstances. Vacuuming should be avoided since it can generate more aerosols. Areas with dead rodents or obvious clusters of rodent droppings can be relatively decontaminated with 1/10 dilutions of bleach.

Personal surveillance

After exiting tick infested woods, the body should be inspected and ticks should be removed. Hard ticks will usually feed for prolonged periods. Check the protected hairline which ticks may favour.

Minimize personal contact with arthropod vectors

For mosquitoes, activity is greatest at dawn or dusk. Repellent may be used for unprotected skin during periods of high exposure. For ticks, avoid game trails where tick exposure is likely to be highest. It would be preferable to rest on bare rocks or sheets rather than directly on vegetation.

Proof human housing for insects and rodents


Sleeping in the wild

Ensure appropriate barriers for tenting. Bed netting may be of value during periods of considerable mosquito exposure. The tent should ideally have a ground covering. Wash hands after contamination with wildlife.

First-aid availability

Wash and disinfect injuries.

Drink safe water

Ensure clean water, boiled or bottled. Properly cook all meat—including game. Avoid contamination with animal wastes

Stay tuned to public health announcements

Sentinel public health and veterinary programs may identify exceptional circumstances. Minimize direct wildlife contact

Even when gloves are used, avoid touching eyes and mucous membranes. Notify wildlife personnel about suspicious or dead animals interacting with human domains

Such animals should be handled preferentially with impermeable gloves given the need as it arises. Submitted animals may be inspected for rabies by trained personnel.

Post-exposure prevention

Post-exposure prevention is available for rabies, especially to be considered after contact with bats. Wash the wound after bat bites and report to medical authorities. Given the few cases of Lyme disease in this province, there is controversy about post-exposure antibiotic use after tick bites. Seek medical attention as warranted or when there is uncertainty.

Tick removal

Preferably use tweezers to remove the tick, grasping at the head part and pulling straight upwards. Covered fingers are another alternative. The application of noxious agents to the tick such as petroleum jelly, fingernail polish, rubbing alcohol, cigarette heat, gasoline, hot matches, etc. are unreliable [138]. An alternate physical method has been anecdotally proposed [139].

References


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