PAN-CANADIAN ZOONOSES REPORT

2013 to 2022

ZOONOSES

Public Health Agency of Canada
Agence de la santé publique du Canada

Canada

CONTENTS

EXECUTIVE SUMMARY

Zoonotic diseases—those transmissible between animals and humans—represent a significant portion of the global infectious disease burden. In Canada, the burden of zoonoses is relatively low compared to many other countries, attributed in part to strong public health infrastructure, agricultural controls, and disease eradication programs. However, some diseases, such as those transmitted through vectors like mosquitoes and ticks, have been on the rise in recent years. Climate change, globalization, and increased human-animal interactions are reshaping the zoonotic landscape, necessitating a dynamic approach to surveillance and prevention.

This 10–year review from 2013 to 2022, developed by the Public Health Agency of Canada in collaboration with federal, provincial, territorial and non-government partners, highlights epidemiological and surveillance trends on some key zoonoses affecting people living in Canada. It aims to provide public health professionals, policymakers, and One Health partners with insights that inform evidence-based decision-making, guide surveillance prioritization and public education efforts, and identify opportunities for research and intersectoral collaboration.

The report covers a broad spectrum of zoonotic threats including endemic[1] diseases like hantavirus, rabies, brucellosis and tularemia and also a number of emerging threats like avian influenza, *Echinococcus multilocularis*, and several vector-borne diseases. There are special features on zoonoses acquired during international travel, enteric zoonotic illness outbreaks, and zoonotic challenges that Northern Indigenous communities are facing as the climate rapidly changes. Throughout the report, several important updates to the time of publication are also included. The value of a One Health approach is underscored throughout the narrative.

Key findings from each section are provided in this executive summary.

---

[1] Although "enzootic" refers to diseases that consistently affect non-human animals within a specific geographic area or population, and "endemic" is the analogous term for humans, this document will use "endemic" throughout for clarity and simplicity.

ZOONOTIC DISEASE TRENDS IN CANADA 2013 to 2022

BRUCELLOSIS

- Domestically-acquired brucellosis is rare due to Canada's brucellosis-free state in livestock; most cases diagnosed in Canada are acquired while living in, or travelling to, other countries. Domestically-acquired cases occur primarily in northern regions of Canada.
- Indigenous and Inuit communities engaged in traditional hunting and food practices are at increased risk for brucellosis through exposure to wildlife reservoirs (e.g., *Brucella suis* biovar 4 in caribou and muskoxen).

Brucellosis in Canada 2013 to 2022

Mean annual case count (range)	12 (6–21)
Mean annual incidence (per 100,000 population)	0.03
Total cases reported	122
Trend	Stable
Populations at higher risk	Males People over 40 Inuit and Indigenous hunters that harvest wildlife in northern Canada Travellers going to endemic areas and consuming unpasteurized or undercooked livestock products are exposed to this risk. Laboratory staff working with *Brucella*
Emerging one health and/or climate change considerations	Evidence of a change in the epidemiology of *Brucella suis* biovar 4 in caribou and muskoxen in the central Canadian Arctic. Evidence of an increased prevalence of *Brucella canis* in some imported and breeding dogs.

HANTAVIRUS

- Hantavirus Pulmonary Syndrome, caused by Sin Nombre virus (SNV) and carried in deer mice, is rare in Canada. The risk of infection varies regionally; 99% of all cases ever recorded in Canada reported exposure in the four western provinces (BC, AB, SK, MB).
- Persons engaged in activities that result in exposure to deer mice, and their excretions, are at greatest risk of infection. Most cases are acquired during the spring and summer months, which coincides with seasonal high-risk activities.

Hantavirus in Canada 2013 to 2022

Mean annual case count (range)	6 (0–13)
Mean annual incidence (per 100,000 population)	0.02
Total cases reported	61
Trend	Stable
Populations at higher risk	Males People over 40 People who live in Western Canada (BC, AB, SK, MB) People engaged in seasonal activities that expose them to rodents and their droppings, including farm workers, forestry workers, military personnel, hikers, and outdoor travellers. People who clean or enter enclosed spaces (e.g., sheds, storage areas, barns) where rodents are present
Emerging one health and/or climate change considerations	The impact of climate change on deer mouse populations in Canada is uncertain, but milder winters could contribute to population growth, which could lead to an increase or change in the risk of disease. Seoul virus, a different species of hantavirus, is emerging in domestic rats and could be a new source of hantavirus for pet owners in Canada.

LYME AND OTHER TICK-BORNE DISEASES

- Tick-borne diseases are a growing concern in Canada. Lyme disease is the most commonly reported tick-borne disease in Canada and continues to increase in recent years.
- In Canada, *Ixodes scapularis/pacificus* ticks and other tick species of public health importance have been expanding their geographic range. Diseases, such as anaplasmosis, Powassan virus disease and babesiosis are emerging and present a growing public health concern to Canadians.
- In addition to *Ixodes scapularis/pacificus*, several other tick species are of public health importance and are endemic in Canada. This includes *Dermacentor variabilis* (American dog tick, *Dermacentor andersoni* (Rocky Mountain wood tick), and *Ixodes cookei* (groundhog tick).

Lyme in Canada 2013 to 2022

Mean annual case count (range)	1,655 (522–3,147)
Mean annual incidence (per 100,000 population)	4.43
Total cases reported	16,548
Trend	Increasing
Populations at higher risk	People who engage in outdoor activities that increase their exposure to ticks Regions where *Ixodes* are established (BC, MB, ON, QC, NB, NS) Children aged 5 to 9 Adults aged 60 and over
Emerging one health and/or climate change considerations	Increasing expansion of vectors and pathogens due to climate change and other environmental/anthropogenic factors. Pets, and dogs in particular, act as sentinels for the risk of disease, but can also inadvertently carry infected ticks into homes.

RABIES

- Cases are extremely rare in Canada, largely due to widespread access to post-exposure prophylaxis. Bats have been the source of all seven domestically-acquired cases in Canada in the last 55 years, despite the virus's presence in other wildlife.
- Continued education around the need to seek care following contact with a bat, even if there is no visible bite or scratch, is imperative to preventing cases.

Rabies in Canada 2013 to 2022

Mean annual case count (range)	0 (0–1)
Mean annual incidence (per 100,000 population)	<0.001
Total cases reported	1
Trend	Stable
Populations at higher risk	People who participate in activities that increase contact with rabid animals, including hunters, trappers, veterinary personnel, animal control officers, campers, and cavers People travelling to high-risk countries where canine rabies (canine variant) is endemic Laboratory personnel working with the rabies virus
Emerging one health and/or climate change considerations	Climate change could alter the distribution and movements of wildlife, which could increase rabies outbreaks and facilitate their spread to new areas. The growing trend of dog "rescues" has led to the spread of rabies strains, including the importation of canine rabies (canine variant) into Canada.

TULAREMIA

- Cases are rare in Canada. Quebec and Manitoba accounted for the majority of cases, with Manitoba having the highest average annual incidence (0.11 per 100,000).
- Both major subspecies of tularemia are present in Canada, including the highly virulent Type A strains and the less virulent, waterborne-associated Type B strains.

Tularemia in Canada 2013 to 2022

Mean annual case count (range)	7 (4–13)
Mean annual incidence (per 100,000 population)	0.02
Total cases reported	69
Trend	Stable
Populations at higher risk	Males People over 40 Occupational or recreational activities that increase contact with infected wildlife or arthropods, including hunting, agriculture, and forestry work.
Emerging one health and/or climate change considerations	Climate change could result in human cases of tularemia being identified in higher-latitude regions following arthropod vector and host range expansion.

WEST NILE VIRUS AND OTHER MOSQUITO-BORNE DISEASES

- West Nile virus (WNV) remains the most commonly reported mosquito-borne disease (MBD) infection in Canada, with activity levels that vary by year and geography.
- California serogroup viruses (CSGV) are the second most common MBD agent causing neuroinvasive illness in North America. While seroprevalence studies suggest CSGV are widespread and common across Canada, most cases are asymptomatic and therefore, are underreported.
- The first reported case of Eastern Equine Encephalitis virus (EEEV), a rare but severe MBD, was in 2016. Two additional cases were identified in 2021 (n = 1) and 2022 (n = 1).
- One Health surveillance supports the identification of geographic risk areas and can provide early warning for MBDs in humans in Canada.

West Nile virus in Canada 2013 to 2022

Mean annual case count (range)*	123 (25–416)
Mean annual incidence (per 100,000 population)*	0.33
Total cases reported*	1,228
Trend	Fluctuates annually
Populations at higher risk	The Prairie provinces and central Canada are where the virus is circulating most actively. People over 50 are at increased risk of serious illness. Immunocompromised individuals and/or those with comorbidities have an increased risk of severe illness.
Emerging one health and/or climate change considerations	Climate change is expected to affect the range, length of transmission season, virus replication rates and local abundance of mosquito species that carry disease-causing pathogens in Canada. Climate change will likely lead to an increase in epidemics of endemic mosquito-borne diseases, while also increasing the risk of imported cases and/or the establishment of exotic mosquito-borne diseases in Canada.

*Cases domestically acquired in Canada

ZOONOTIC AND ONE HEALTH STORIES

The Evolving Threat of Avian influenza A(H5N1)

A(H5N1) is a serious zoonotic threat with pandemic potential

While human cases remain rare, A(H5N1) historically has a high case fatality rate and a demonstrated ability to mutate and reassort with other influenza strains. This raises significant concerns about its potential to cause a future pandemic, especially given the unprecedented scale of current viral circulation across species and geographies.

Surveillance and early detection are critical

Canada's public health system uses multiple surveillance mechanisms—including FluWatch+—to detect and characterize emerging respiratory viruses. Early identification of human cases is essential for timely public health response and containment.

One Health collaboration is essential

The complexity of A(H5N1)'s spread across wildlife, domestic animals, and humans necessitates a coordinated One Health approach. Public health must work closely with agricultural, veterinary, environmental, and Indigenous partners to monitor, assess, and respond to outbreaks.

COVID-19 in Canada: The Animal Angle

A One Health approach adds value when responding to novel pathogens

Canada's collaborative One Health approach—uniting federal, provincial/territorial (PT), and academic partners—was key to addressing the role of animals in the COVID-19 pandemic. Efforts included guidance, time-limited surveillance, targeted research, and investigations for SARS-CoV-2 detection in animals.

Animals appeared to play a limited role in SARS-CoV-2 transmission overall

Despite concerns over zoonotic spread, testing of several thousand animals from June 2020 to December 2022 revealed only 77 positive cases (mostly deer). Findings suggest animals played a minimal role in human transmission, reassuring the public and supporting animal welfare.

Animals harbored variants of concern with potential to transmit the virus back to humans

The detection of SARS-CoV-2 variants in wildlife, such as white-tailed deer, and also in mink on fur farms, highlighted the potential for animals to serve as reservoirs and a source of new zoonotic virus variants. These findings underscored the importance of monitoring at the human-animal interface.

Climate-Driven Zoonotic Challenges in Northern and Arctic Indigenous Communities

Climate change is affecting pathogen emergence in northern Canada

Accelerated warming in Canada, especially in northern regions, is facilitating the emergence and spread of zoonotic pathogens. This poses significant health risks to local wildlife populations and Indigenous communities that rely on hunting and trapping.

Zoonoses can threaten traditional country food diets

Indigenous hunters are increasingly exposed to zoonotic diseases through the handling of wild game. Concerns over the safety of traditional diets, which are vital to health, nutrition, and cultural identity, may lead to a shift towards less nutritious store-bought foods, exacerbating food insecurity and health inequities.

Community-led initiatives are key to detect zoonoses

Indigenous communities are leading innovative pathogen detection and disease prevention strategies, such as the Nunavut *Trichinella* Detection Program. These initiatives are vital for ensuring the safety of traditional dietary practices while building regional capacity in zoonotic pathogen detection.

Echinococcus multilocularis: An Emerging Parasite

Cases of alveolar echinococcosis (AE) are rising in Canada

Since the early 2010s, there has been a significant increase in locally-acquired cases of AE in Canada. This is a growing public health concern, as AE is a severe disease that can be fatal if left untreated.

More pathogenic European-type strains are emerging

The identification of more pathogenic European-type strains of *Echinococcus multilocularis* in Canada, along with the recent widespread expansion in canid hosts, coincides with the rapid shift in the human epidemiology of the disease. Ongoing research on wildlife and domestic animals increase understanding of the epidemiology and ecology of this parasite.

Limited surveillance and awareness can complicate detection of AE

AE is not a reportable disease in all jurisdictions, complicating efforts to assess the public health impact and burden. Diagnosing AE is also challenging due to its slow progression, nonspecific symptoms, and limited awareness among healthcare providers. Coordinated surveillance and reporting would support the further characterization and management of *E. multilocularis* as an emerging zoonotic threat in Canada.

Enteric zoonoses: A Canadian perspective

Animals are an important source of zoonotic enteric illness in Canada

Domestically-acquired zoonotic enteric illnesses, such as *Salmonella* and verotoxigenic *E. coli*, are a significant cause of human morbidity and mortality in Canada, with an estimated 85,000 enteric illnesses related to animal contact each year.

While many enteric illness outbreaks are linked to food, animals can also cause multi-jurisdictional outbreaks

Between 2013 and 2022, there were eleven multijurisdictional outbreaks in Canada linked to animals and their foods. Outbreaks linked to pet food/treats, reptiles and/or rodents accounted for almost all of the outbreaks during this time frame (n = 10, 91%).

Targeted actions and education are key to preventing enteric zoonoses

Public communication and education are crucial in controlling and preventing enteric zoonotic outbreaks. This includes targeted educational campaigns for pet owners on how to minimize their risk, safety labelling on high-risk products, and collaboration with pet industry members to promote safe handling of animals and animal foods. Certain groups, especially children under five years, are at an increased risk of severe illness from enteric zoonotic pathogens and are often overrepresented in outbreaks of enteric zoonoses.

Travel-acquired Zoonoses

International travel is a significant source of zoonotic and vector-borne diseases

International travel can be a significant source of zoonotic and vector-borne diseases for Canadians, including exotic diseases not endemic in Canada. These diseases pose a personal risk to travellers themselves and can also be a public health risk, as they may lead to disease spread and the emergence of foreign diseases into new areas

The Canadian Travel Medicine Network (CanTravNet) provides important insights into travel-acquired zoonoses

From 2013 to 2022, of the 23, 684 diseases diagnosed at CanTravNet sites, 20% (n = 4,708) were related to zoonotic and vector-borne diseases, animal exposures, and associated post-exposure prophylaxis. Vector-borne diseases were most commonly diagnosed; however, the types of diagnoses differed between people who migrated to Canada and those travelling for other reasons.

Global travel elevates risk of exposure to vector-borne disease

With international travel returning to pre-pandemic levels, and vectors expanding their range, the risk and impact of travel-acquired diseases is expected to rise. Outbreaks like chikungunya (2014) and Zika (2015 to 2018) resulted in many Canadians being infected overseas. Understanding zoonotic and vector-borne diseases that impact the travelling public is vital to prevent illness, diagnose and treat individuals, and manage public health threats to Canadians.

ACKNOWLEDGEMENTS

The Pan-Canadian Zoonoses Report: 2013 to 2022, was developed by the Zoonoses Division in the Centre for Food-borne, Environmental and Zoonotic Infectious Diseases, Public Health Agency of Canada, with input from federal, provincial, territorial, and non-government partners. We extend our sincere appreciation to all who participated in the development, review and validation process. Special thanks to colleagues from Indigenous Services Canada who collaboratively developed the section on zoonotic challenges facing northern and Arctic Indigenous communities with Nunavut Tunngavik Incorporated (NTI) and Nunavut Arctic College (NAC). In particular, thank you to NTI and NAC for sharing their experiences with a community-led *Trichinella* surveillance program.

We respectfully acknowledge that the lands on which we developed this Report are the homelands of First Nations, Inuit, and Métis Peoples. We recognize the longstanding relationship Indigenous People have with the land, water and ecosystems, which brings us together in our 'One Health' work. Respecting and supporting Indigenous place-based knowledge systems, grounded in generations of observation and stewardship, is essential to strengthening public health efforts across the country. We are committed to working in respectful partnership with Indigenous Peoples and supporting collaborative, equitable approaches that advance reconciliation and improve health outcomes for all communities.

INTRODUCTION

Zoonotic diseases, or zoonoses, are infections that are naturally transmissible between animals and humans. With over 200 known zoonotic diseases caused by a wide variety of pathogens—including bacteria, viruses, parasites, and fungi—illnesses can range from mild self-limiting illness to severe systemic infections and death. The transmission of zoonotic pathogens can occur through direct and indirect contact with animals, but also through the consumption of contaminated food or water, or via arthropod vectors such as mosquitoes and ticks.

Globally, zoonoses represent a substantial portion of the infectious disease burden and an ongoing public health concern [1]. It is estimated that over 60% of known infectious diseases and 75% of emerging diseases in humans, are zoonotic in origin [2]. The close interdependence of human, animal, and environmental health underscores the importance of zoonotic diseases and a One Health approach to understanding and managing public health threats broadly.

Zoonoses in the Canadian Context

Canada's experience with zoonotic diseases is shaped by its geography, climate, wildlife diversity, animal health, public health, and agricultural systems. Historically, Canada has faced and overcome significant zoonotic threats. In the early 20th century, diseases such as bovine tuberculosis and brucellosis were widespread in livestock, posing serious risks to both animal and human health. Through decades of coordinated federal-provincial programs, including surveillance, testing, and disease control programs, these diseases have been eliminated from domestic herds. Today, only isolated pockets of bovine tuberculosis and brucellosis remain, particularly in wildlife populations in western Canada and the North.

In contrast to many parts of the world, zoonoses are relatively uncommon in Canada, with the exception of common enteric infections such as *Salmonella*, *Campylobacter*, and *E. coli* O157:H7. These are typically associated with food-borne transmission and remain a consistent focus of public health efforts. Vector-borne diseases are also significantly on the rise, as a result of increased climate suitability for both ticks and mosquitoes [3]. The relative rarity of other zoonoses in Canada is a testament to the success of our agricultural control programs, stringent food safety regulations, and robust public health infrastructure.

Climate Change and Evolving Zoonotic Risks

Despite the successes achieved in managing many zoonoses in Canada, the disease landscape is continuing to evolve. The increasing frequency of zoonotic spillover events and emergence of novel pathogens, along with the movement and spread of existing pathogens to new areas, requires careful vigilance. One of the most pressing zoonotic disease challenges in the 21st century relates to climate change. Canada's climate is warming at nearly twice the global average, with profound implications for ecosystems, wildlife, and vector populations [4]. Rising temperatures, shifting precipitation patterns, and ecological disruptions are altering the distribution of wildlife hosts and vectors, such as ticks and mosquitoes [5].

These changes are facilitating the significant northward expansion and rising incidence of many vector-borne diseases like Lyme disease, which were previously uncommon or absent in many parts of Canada [5]. Climate-driven zoonotic challenges are particularly acute in Northern Indigenous communities, where environmental changes are challenging traditional ways of life, altering both the abundance and fitness of our wildlife populations, and increasing exposure to novel pathogens [6]. This dynamic context necessitates vigilance in our public health prioritization, preparedness, and response systems. Surveillance must be adaptive, and intersectoral collaboration must be strengthened to anticipate and respond to emerging risks.

The Importance of a One Health Approach

One Health is an integrated, unifying approach that aims to sustainably balance and optimize the health of humans, animals, plants and ecosystems. It recognizes the health of humans, domestic and wild animals, plants and the wider environment (including ecosystems) are closely linked and interdependent [7].

The complexity of zoonotic diseases necessitates a holistic, interdisciplinary approach. The One Health framework—recognizing the interconnectedness of human, animal, and environmental health—provides a comprehensive lens through which zoonotic threats can be understood and addressed.

Zoonoses of public health significance are monitored at the local, provincial/territorial and national levels in Canada. Government departments and various non-government agencies monitor zoonoses in humans, animals, and their environments. Working together, One Health partnerships have enriched our understanding of zoonotic disease dynamics. Collaborative efforts between federal and provincial/territorial partners, academia and communities are essential and have become the norm. By fostering cross-sectoral dialogue and data sharing, the One Health approach enhances our capacity to detect, prevent, and control zoonotic diseases, ultimately safeguarding the health of all Canadians.

About this Report: Objectives and Scope

The primary objective of this 10–year review (2013–2022) is to highlight epidemiological and surveillance trends on some key zoonoses affecting people living in Canada. It aims to provide public health professionals, policymakers, and One Health partners with insights that inform evidence-based decision-making, guide surveillance prioritization and public education efforts, and identify opportunities for research and intersectoral collaboration.

It draws on data from the Canadian National Notifiable Disease Surveillance System (CNDSS), enhanced vector-borne disease surveillance systems, and, where formal national surveillance is not in place, from applied research and other data sources.

The report covers a broad spectrum of zoonotic threats, including:

- A summary table of the count and incidence of notifiable zoonotic diseases in Canada; and
- A more detailed report on the status of some notifiable endemic diseases found in Canada, including brucellosis, hantavirus, Lyme disease, rabies, tularemia and West Nile virus.

In addition to these core topics, the report also includes a number of spotlights on:

- Zoonotic aspects of COVID-19 and avian influenza – One Health in action;
- The ever evolving and dynamic landscape of emerging vector-borne diseases;
- An emerging parasitic disease of public health concern, alveolar echinococcosis, caused by *Echinococcus multilocularis*;
- Climate-driven zoonotic challenges affecting Northern Indigenous communities, where traditional knowledge and public health must work hand-in-hand;
- An overview of enteric zoonotic outbreaks, with special focus on a recent outbreak linked to hedgehogs; and
- Travel-acquired zoonoses, highlighting the importance of global surveillance and our partnerships with travel clinics and tropical medicine specialists.

By synthesizing a decade of data, this report aims to enhance our collective understanding of zoonotic disease risks in Canada, and support the development of resilient, forward-looking public health strategies, incorporating a One Health lens. At the time of finalizing and publishing this report, there had been a number of important related updates, which are also highlighted throughout the document. It is our hope that this report will serve as a valuable tool for strengthening Canada's preparedness and response capacity in the face of evolving zoonotic threats.

Count and incidence of 11 nationally notifiable zoonotic diseases: 2013 to 2022

Disease*	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Anthrax										
Case count	0	0	0	0	0	0	0	0	0	0
Incidence (per 100,000)	---	---	---	---	---	---	---	---	---	---
Brucellosis										
Case count	21	6	11	9	9	17	11	12	8	18
Incidence (per 100,000)	0.07	0.02	0.03	0.02	0.02	0.05	0.03	0.03	0.02	0.05
Hantavirus pulmonary syndrome										
Case count	13	10	9	4	7	3	8	6	0	1
Incidence (per 100,000)	0.04	0.03	0.03	0.01	0.02	0.01	0.02	0.01	---	0.01
Lyme disease										
Case count	682	522	917	992	2,025	1,487	2,634	1,617	3,147	2,525
Incidence (per 100,000)	1.94	1.47	2.57	2.75	5.54	4.01	7.00	4.25	8.23	6.49
Malaria±										
Case count	490	449	552	611	603	368	424	185	197	424
Incidence (per 100,000)	1.40	1.27	1.55	1.69	1.65	0.99	1.13	0.49	0.52	1.09
Plague										
Case count	0	0	0	0	0	0	0	0	0	0
Incidence (per 100,000)	---	---	---	---	---	---	---	---	---	---
Rabies										
Case count	0	0	0	0	0	0	1	0	0	0
Incidence (per 100,000)	---	---	---	---	---	---	< 0.01	---	---	---
Tularemia										
Case count	9	10	13	7	4	6	5	5	5	5
Incidence (per 100,000)	0.03	0.02	0.04	0.02	0.01	0.02	0.01	0.01	0.01	0.01
Viral hemorrhagic fever†										
Case count	0	0	0	0	0	0	0	0	0	0
Incidence (per 100,000)	---	---	---	---	---	---	---	---	---	---
West Nile virus										
Case count	117	25	82	110	190	416	36	161	46	45
Incidence (per 100,000)	0.31	0.07	0.22	0.29	0.53	1.14	0.10	0.44	0.12	0.12
Yellow fever±										
Case count	0	4	3	2	0	1	2	1	0	1
Incidence (per 100,000)	---	0.01	0.01	0.01	---	< 0.01	0.01	< 0.01	---	< 0.01

*Captures diseases considered endemic and non-endemic in Canada, and therefore most data do not distinguish between infection/exposure acquired in Canada or due to travel outside of the country.
±Malaria and Yellow fever were made non-reportable in Ontario in 2018.
†Viral hemorrhagic fever (VHF) category constitutes a group of diseases caused by several distinct families of viruses and may include Ebola, Marburg and Lassa.
Note that changes in small case counts can produce unstable widely fluctuating rates. During the period of 2013 to 2022, data availability from each of the PTs may have varied.
Source: CNDSS, enhanced surveillance systems at PHAC, or PT submissions.

ZOONOTIC TRENDS IN CANADA 2013 TO 2022

This section presents an overview of surveillance and epidemiological trends for several nationally notifiable, endemic zoonotic diseases in Canada, based on a 10–year review (2013 to 2022). Diseases covered include brucellosis, hantavirus, Lyme disease and other tick-borne diseases, tularemia, rabies, West Nile virus and other mosquito-borne diseases. Each summary includes key data such as annual case counts and incidence rates, provides a descriptive analysis based on available data, highlights risk factors, and situates findings in the context of Canadian animal populations. The section also briefly addresses emerging considerations, including One Health perspectives and the potential influence of climate change on disease ecology and distribution.

BRUCELLOSIS

Brucellosis is a disease caused by bacteria of the *Brucella* genus (mainly *B. abortus*, *B. melitensis* and *B. suis*). It spreads to humans from wild and domestic animals such as cows, sheep, goats, and caribou, through the consumption of undercooked meat and unpasteurized dairy products, or the handling of infected carcasses [8]. Signs and symptoms in people vary but can include fever, night sweats, malaise, muscle aches, weight loss, and joint pain that can persist for weeks to months [9]. Focal infections involving one or more body sites can occur, with genitourinary involvement reported in approximately 2 to 20% of cases [10]. Brucellosis often requires long duration antibiotic therapy and even with treatment, about 5 to 15% of patients relapse [9,8]. Brucellosis is rarely fatal, though fatalities can occur as a result of endocarditis or severe central nervous system complications [9].

Human cases of brucellosis in Canada: 2013 to 2022

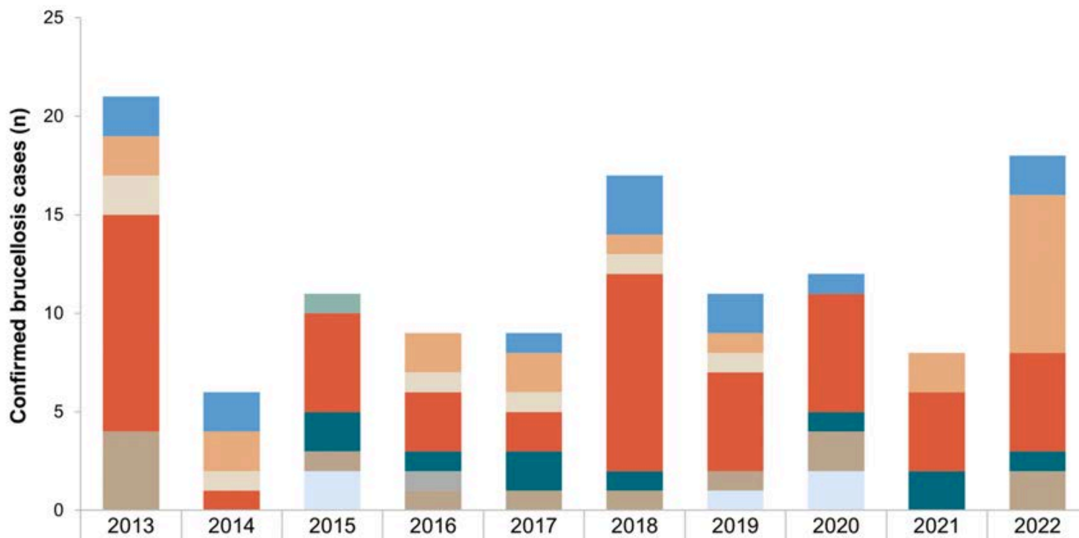
- 122 confirmed human cases of brucellosis were reported in Canada, with a range of 6 to 21 cases reported annually and an average of 12 cases per year (Table 1, Figure 1).
- Ontario reported 42.6% of all cases in Canada between 2013 to 2022, followed by Alberta (16.4%) and British Columbia (10.7%) (Table 1). Nunavut and the Northwest Territories reported 13 and 5 cases, respectively. Despite the relatively low case counts in these territories, they had the highest average annual incidence rates in Canada—3.42 and 1.13 cases per 100,000 population, respectively.
- The majority of cases were males (59.8%) of which most were 40 years old or over (50.7%) (Figure 2). Female cases (40.2%) were similar in age to males, with most female cases also being 40 years or over (63.3%) (Figure 2).

Human cases of brucellosis are rare in Canada; however, differences in incidence between provinces and territories suggest varying levels of risk across the country. Most individuals diagnosed with brucellosis in Canada likely acquired the infection through the consumption of unpasteurized or undercooked animal products outside of Canada [11]. Domestically acquired cases also occur, primarily in northern regions of Canada [12,13]. *Brucella suis* biovar 4 in caribou and muskoxen may present an exposure risk to hunters and individuals who harvest and consume wildlife. However, it is essential that this risk is communicated in a culturally sensitive and collaborative manner with local communities, to ensure it does not discourage the consumption of country foods, which are vital for nutrition and food security [12–15].

Table 1. Human brucellosis cases in Canada by province/territory and sex: 2013 to 2022 (n = 122)

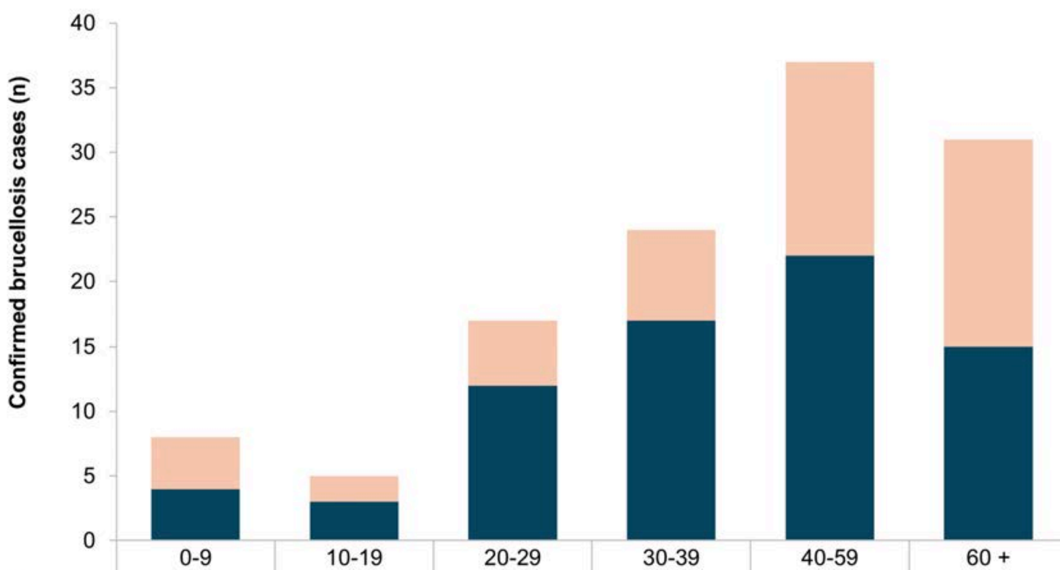
Province / Territory	Female		Male		Total		Average Annual Incidence (per 100,000 population)
	n	%	n	%	n	%	
British Columbia	3	23.1%	10	76.9%	13	10.7%	0.03
Alberta	5	25.0%	15	75.0%	20	16.4%	0.05
Saskatchewan	0	---	1	100.0%	1	0.8%	0.01
Manitoba	7	100.0%	0	---	7	5.7%	0.05
Ontario	26	50.0%	26	50.0%	52	42.6%	0.04
Quebec	4	40.0%	6	60.0%	10	8.2%	0.01
New Brunswick	0	---	1	100.0%	1	0.8%	0.01
Nunavut	3	23.1%	10	76.9%	13	10.7%	3.42
Northwest Territories	1	20.0%	4	80.0%	5	4.1%	1.13
Total: Canada	**49**	**40.2%**	**73**	**59.8%**	**122**	**100.0%**	**0.03**

Note for provinces and territories not listed, no cases were reported between 2013 and 2022.



	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
BC	2	2	0	0	1	3	2	1	0	2
AB	2	2	0	2	2	1	1	0	2	8
SK	0	0	1	0	0	0	0	0	0	0
MB	2	1	0	1	1	1	1	0	0	0
ON	11	1	5	3	2	10	5	6	4	5
QC	0	0	2	1	2	1	0	1	2	1
NB	0	0	0	1	0	0	0	0	0	0
NU	4	0	1	1	1	1	1	2	0	2
NT	0	0	2	0	0	0	1	2	0	0

Figure 1. Human brucellosis cases in Canada by year: 2013 to 2022 (n = 122)



	0-9	10-19	20-29	30-39	40-59	60 +
Females	4	2	5	7	15	16
Males	4	3	12	17	22	15

Figure 2. Human brucellosis cases in Canada by age and sex: 2013 to 2022 (n = 122)

Brucellosis in Animals in Canada

Wildlife

There are wildlife reservoirs of brucellosis in Canada that pose a risk to human health. Note that information on *Brucella* species associated with human cases is not collected at the national level.

Brucella suis biovar 4

Rangiferine brucellosis (*Brucella suis* biovar 4) is present in many caribou populations (*Rangifer tarandus groenlandicus*) across the sub-arctic and arctic regions [16]. While it is thought to be maintained by caribou, it is also found in muskoxen [17]. Recent studies have found that, *Brucella suis* biotype 4 seroprevalence has been increasing in recent years in caribou (15.5%) and muskox (10%) in the central Canadian arctic and may be re-emerging in those locations [14,18–20]. Initiatives, such as the Muskox and Caribou Health Research Program, bring together communities, governments, universities, and industry partners to collaboratively monitor the health and population of muskoxen and caribou in select regions of the Canadian Arctic [21]. This community-driven program is a key example of initiatives to address emerging wildlife health concerns and supporting food security for Inuit and Indigenous Peoples.

Brucella abortus

Bovine brucellosis (*Brucella abortus*) has historically been confirmed in free-ranging (wild) bison in and near Wood Buffalo National Park (spanning the Alberta-Northwest Territories border), with one study citing an approximately 30% seroprevalence [22]. Disease containment measures are in place to maintain geographical separation between diseased wild bison herds and susceptible species of livestock (e.g., elk, bison and cattle) in adjacent agricultural areas.

Marine *Brucella* spp.

Brucella spp. has also been identified in seals, walruses, and whales, such as beluga and narwhal, in the Arctic and other areas of Canada [23]. However, brucellosis in marine mammals is associated with the subspecies *Brucella ceti* and *Brucella pinnipedialis* and their zoonotic potential is currently unclear [17,24,25].

Livestock

In Canada, brucellosis in livestock caused by *Brucella abortus*, *Brucella suis* and *Brucella melitensis* is reportable to the Canadian Food Inspection Agency (CFIA) under the *Health of Animals Act*. *B. suis* and *B. melitensis* have never been detected in livestock in Canada [26]. In the 1940s, the CFIA established an eradication program for bovine brucellosis and by 1985, Canada declared itself free from *B. abortus* in cattle. To maintain its brucellosis-free status in livestock, the CFIA routinely collects and analyses blood samples from randomly selected mature cattle at slaughter through its Bovine Surveillance System (BSS). Enhanced surveillance measures exist to detect potential brucellosis transmission events from *B. abortus*-infected bison populations in and near Wood Buffalo National Park. Cattle within 400 kilometers of Wood Buffalo National Park are tested as part of this surveillance. The CFIA also undertakes brucellosis surveillance among mature farmed bison and cervids at abattoirs, as well as in swine.

Dogs

Brucella canis is endemic in many parts of the world, including the Americas, Asia, and Africa. In Canada, brucellosis in dogs has sporadically been identified, particularly in imported dogs [27]. Outbreaks have also been observed in dog kennels in Saskatchewan, Ontario, and Alberta [28,27]. One study from 2020 showed that 11.8% (n = 127/1,080) of dogs from 37% (n = 23/63) commercial breeding kennels in Ontario were seropositive for brucellosis, leading the authors to conclude that the disease should be considered endemic in this population [27].

Human *Brucella canis* Infections Linked to a Rescue Dog

In 2018, an individual was diagnosed with brucellosis caused by *B. canis* [29]. A public health investigation confirmed that the source of infection was a pregnant rescue dog from Mexico that had spontaneously aborted in the patient's car during transport [30]. Of the 17 clinical microbiology staff with high-risk exposures during the investigation, one tested positive for *B. canis*, also highlighting the risk of laboratory-acquired infection [30].

HANTAVIRUS

Hantaviruses are a family of RNA viruses primarily found in rodent reservoir hosts (e.g., mice, rats, other rodents) worldwide. Humans are typically infected with hantaviruses following inhalation of aerosolized virus particles from secretions such as urine and feces from rodents [31].

In Canada, a hantavirus called Sin Nombre virus (SNV) carried by the deer mouse (*Peromyscus maniculatus*), is the primary cause of hantavirus pulmonary syndrome (HPS) [32,33]. Initial symptoms of HPS include generalized flu-like illness which may progress to severe cardiopulmonary deterioration that can rapidly lead to death within 48 hours. HPS has a case fatality rate of approximately 30% [32,31].

Seoul virus, a type of hantavirus, can be found in both wild and domesticated pet rats. Human infections with Seoul virus are generally more mild than with other hantaviruses, however, in some cases, infection can lead to a disease called hemorrhagic fever with renal syndrome (HFRS), with a case fatality rate of approximately 1 to 2% [34].

Human cases of hantavirus pulmonary syndrome (HPS) in Canada: 2013 to 2022

- There were 61 confirmed human cases of HPS reported in Canada, with a range of 0 to 13 cases reported annually and an average of 6 cases per year (Table 2, Figure 3).
- Alberta reported 50.8% of all cases in Canada between 2013 to 2022, followed by Saskatchewan (21.3%) and British Columbia (18.0%) (Table 2, Figure 3). While Saskatchewan reported 21.3% of the HPS cases reported in Canada between 2013 to 2022, the province has the highest average annual incidence with 0.11 per 100,000 population.
- The majority of cases were males (68.9%), of which just under half were over 40 years old (42.9%). Female cases comprised 31.1% of all cases during the time period of interest, and of those, 57.9% were over 40 years old (Figure 4).

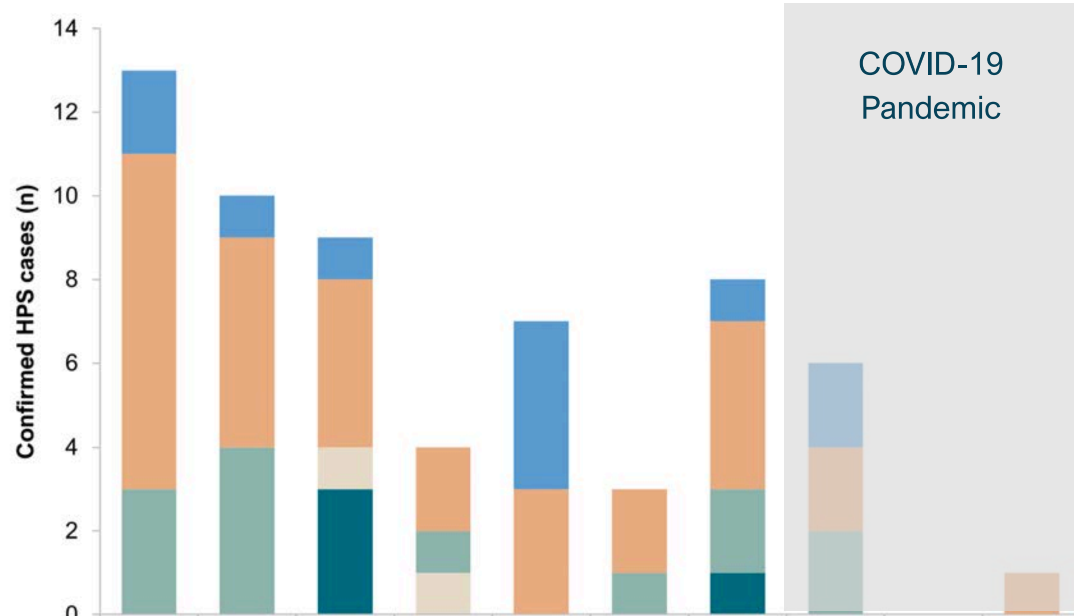
There is a clear seasonal trend to HPS cases in Canada, with most occurring during the spring and summer months, though cases have been observed throughout the year [32]. This is thought to be associated with seasonal high-risk activities, including agricultural work, cleaning cottages, cabins, and machinery that have been unused over winter, combined with seasonal increases in deer mouse populations [31,32]. Other risk groups include military personnel [35–40]. In 2015, a cluster of three cases occurred among Canadian military personnel, following exposure to aerosolized soil during training exercises and to rodent excreta near their campsite in Alberta [39]. The majority of cases in Canada are male [31]. There is a strong regional difference associated with HPS in Canada, with 99% of cases having been exposed in the four western provinces of British Columbia, Alberta, Saskatchewan, and Manitoba [32]. Only one case of locally acquired HPS has ever been reported in Quebec and occurred prior to 2013 [41]. All other cases from Quebec have involved individuals who were exposed in the Western provinces [32]. There have been two travel-related cases of HPS in Canada that occurred prior to 2013, one involving a Canadian who traveled to Bolivia and the other to Argentina [31].

A decline in reported cases of HPS was observed in Canada during the COVID-19 pandemic years (Figure 3), compared to preceding years. The reasons for this trend are not fully understood. One possible contributing factor could be that the early clinical manifestations of HPS and COVID-19—such as fever, myalgia, and respiratory symptoms—can be clinically indistinguishable, potentially leading to misclassification or underdiagnosis of HPS [42]. Co-infections of HPS and COVID-19 have been reported in other countries [43–45], with study authors suggesting that HPS was less likely to be considered as a differential diagnosis during peaks of the pandemic.

Table 2. Hantavirus pulmonary syndrome (HPS) cases in Canada by province/territory and sex: 2013 to 2022 (n = 61)

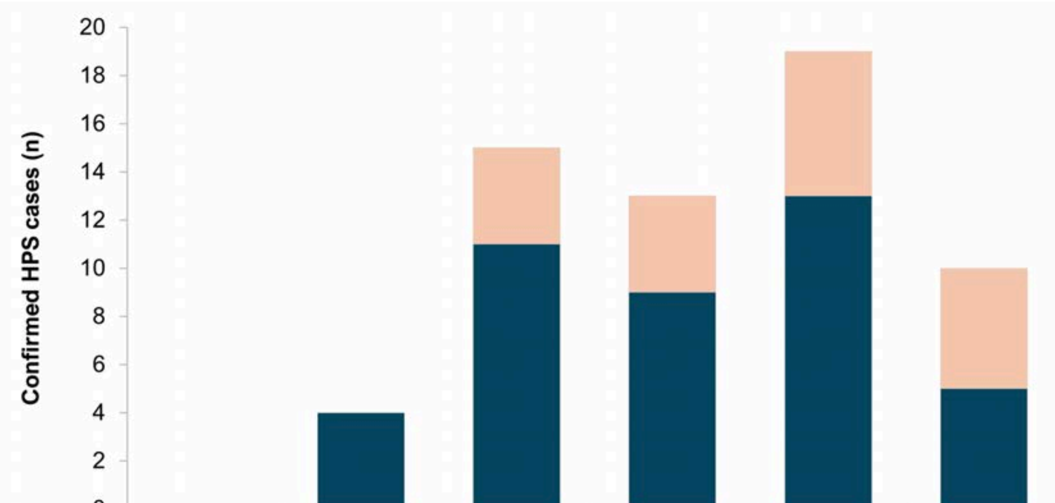
Province / Territory	Female		Male		Total		Average Annual Incidence (per 100,000 population)
	n	%	n	%	n	%	
British Columbia	3	27.3%	8	72.7%	11	18.0%	0.02
Alberta	9	29.0%	22	71.0%	31	50.8%	0.07
Saskatchewan	6	46.2%	7	53.8%	13	21.3%	0.11
Manitoba	0	---	2	100.0%	2	3.3%	0.01
Quebec	1	25.0%	3	75.0%	4	6.6%	---
Total: Canada	**19**	**31.1%**	**42**	**68.9%**	**61**	**100.0%**	**0.02**

Note for provinces and territories not listed, no cases were reported between 2013 and 2022.



	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
BC	2	1	1	0	4	0	1	2	0	0
AB	8	5	4	2	3	2	4	2	0	1
SK	3	4	0	1	0	1	2	2	0	0
MB	0	0	1	1	0	0	0	0	0	0
QC	0	0	3	0	0	0	1	0	0	0

Figure 3. Hantavirus pulmonary syndrome (HPS) cases in Canada by province/territory and year: 2013 to 2022 (n = 61)



	0-9	10-19	20-29	30-39	40-59	60+
Females	0	0	4	4	6	5
Males	0	4	11	9	13	5

Figure 4. Hantavirus pulmonary syndrome (HPS) cases in Canada by age and sex: 2013 to 2022 (n = 61)

Hantavirus in Rodent Reservoirs in Canada

The deer mouse (*Peromyscus maniculatus*) is the primary reservoir of Sin Nombre Virus (SNV), which causes HPS in Canada. The deer mouse inhabits forests and grasslands across North America, ranging from the Mexican plateau to the tree line in northern Canada [46,47]. Passive surveillance has found SNV-infected mice in all Canadian provinces except Nova Scotia and Prince Edward Island [31]. The only territory with documented evidence of SNV in deer mice is the Yukon, however this should be interpreted with caution as little surveillance of deer mice has been conducted in the Northwest Territories and Nunavut [31]. SNV infections in deer mouse populations are inconsistent, with some populations having seroprevalence rates exceeding 30%, while nearby populations show no evidence of infection [31]. Milder winters that offer more resources (such as food, water, and shelter) and fewer mouse die-offs could lead to larger populations of SNV-infected mice, potentially increasing the risk of human infections in the future [46,48].

Although deer mice are distributed across Canada, human cases of HPS show a distinct western bias. Phylogenetic analyses have identified multiple genogroups or clades of SNV, with the genotype linked to human HPS cases corresponding to a western Canadian clade. This geographic association may help explain the concentration of HPS cases in Western Canada (Grolla et al., unpublished, as cited in [31]).

Outbreak of Seoul Virus Among Rats and Rat Owners in the U.S. and Canada

In December 2016, the Wisconsin Department of Health Services reported a case of Seoul virus, a species of hantavirus carried by Norway and Black rats, in a patient who operated a domestic rat-breeding facility [49]. This led to the first known outbreak of Seoul virus infections from pet rats in the U.S. and Canada. The investigation identified 31 facilities across 11 states with infected rats and humans, including six that exchanged rats with Canadian ratteries.

Of the 163 individuals in the U.S. and 20 in Canada who consented to serologic testing, 17 (10.4%) in the U.S. and one (5%) in Canada had detectable IgM antibodies, indicating recent infection. Additionally, four (2.5%) U.S. residents and two (10%) Canadian residents had only IgG antibodies, consistent with past infection. Among the 17 U.S. cases with evidence of recent Seoul virus infection, eight reported a recent febrile illness and three were hospitalized; all recovered. No serious illnesses were reported among Canadian individuals linked to this outbreak.

Seoul virus infection linked to exposure to infected pet rats is emerging as a public health concern. A study from the United Kingdom reported a hantavirus seroprevalence of 34.1% among pet rat owners, compared to 3.3% in a baseline control group [50]. When considered alongside recent Seoul virus outbreaks in the U.S. and Canada, these findings highlight the need for targeted education on safe handling practices for pet rat owners and breeders, as well as increased awareness among healthcare providers and public health professionals.

LYME AND OTHER TICK-BORNE DISEASES

Tick-borne diseases are a growing public health concern in Canada, primarily due to the blacklegged tick (*Ixodes scapularis*) in central and eastern regions including Ontario, Quebec, New Brunswick, Nova Scotia, Prince Edward Island, and parts of Manitoba; and the western blacklegged tick (*Ixodes pacificus*) in coastal and southern British Columbia [51–53]. These ticks, part of the Ixodidae family, have been expanding their geographic range, a trend driven in part by climate change [54].

In addition to *I. scapularis* and *I. pacificus*, several other tick species of public health importance are endemic in Canada and capable of transmitting diseases:

- *Dermacentor variabilis* (American dog tick) is widely distributed in southern Canada and is a known vector of *Rickettsia rickettsii*, the agent of Rocky Mountain spotted fever, and other *Rickettsia* species of public health concern.
- *Dermacentor andersoni* (Rocky Mountain wood tick), found in western Canada, can also transmit *R. rickettsii*, as well as *Francisella tularensis* (tularemia) and Colorado tick fever virus.
- *Ixodes cookei* (groundhog tick) is present in eastern Canada and is a recognized vector of Powassan virus.
- *Haemaphysalis leporispalustris* (rabbit tick) has been found across Canada and may play a role in the ecology of *Rickettsia* species, although its direct public health impact is less well understood.

While Lyme disease is the most commonly reported tick-borne illness in Canada [55], other emerging diseases include anaplasmosis, babesiosis, and Powassan virus disease [56]. Additional pathogens such as *Borrelia* species causing relapsing fever, Colorado tick fever virus, and spotted fever group *Rickettsia* have also been detected in Canada [54,56]. These infections are primarily transmitted through tick bites, though some—like anaplasmosis and babesiosis—can also be spread rarely via blood transfusions [57,58], underscoring the expanding public health implications of tick-borne diseases in Canada.

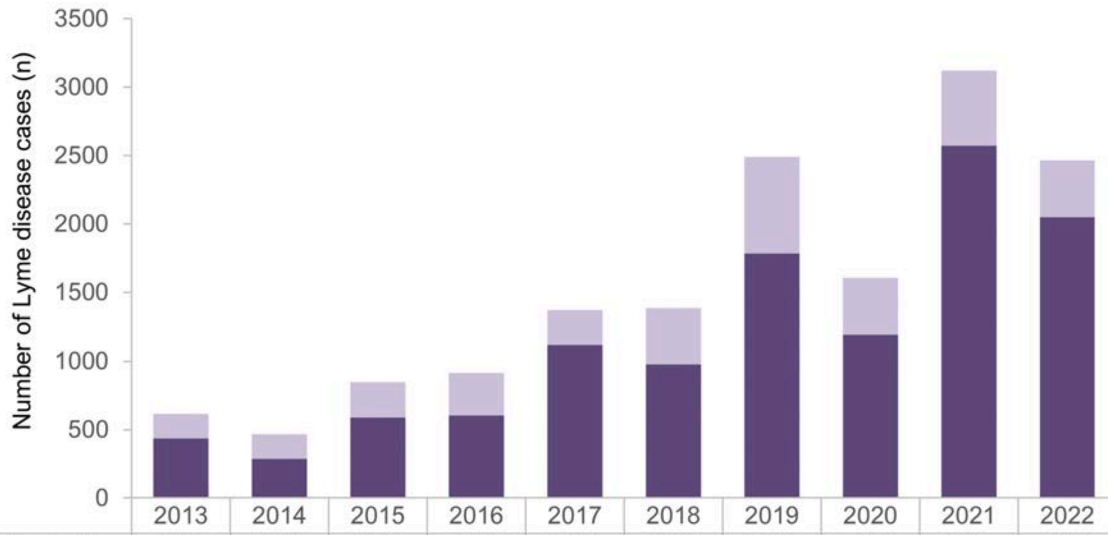
Lyme disease: 2013 to 2022

Lyme disease—the most commonly reported tick-borne zoonosis in North America and Europe—is a bacterial infection caused by the spirochete *Borrelia burgdorferi* [55]. The disease is mainly transmitted in Canada by infected blacklegged ticks (*Ixodes scapularis*) in central and eastern Canada, and western blacklegged ticks (*Ixodes pacificus*) in British Columbia [55]. Symptoms may be absent or range from mild to severe, often starting with a skin rash (erythema migrans) and flu-like symptoms, and may progress over time, particularly in untreated individuals [59,60]. Months to years post-infection, late Lyme disease can manifest with single or recurrent joint arthritis episode(s). Most cases of Lyme disease can be managed successfully with a timely diagnosis and appropriate treatment. There's currently no vaccine to prevent Lyme disease. One death attributed to complications of Lyme carditis has been recorded in Canada in 2018 [61].

Endemic transmission of *B. burgdorferi* has been reported to occur in British Columbia, Manitoba, Ontario, Quebec, New Brunswick, and Nova Scotia [54]. In other provinces, local transmission cycles have not been clearly established; detections have been limited to adventitious ticks and/or infections in animals.

In Canada, Lyme disease was made nationally notifiable in 2009; national case counts and incidence have trended upwards and are expected to keep increasing [55]. Lyme disease cases, whether locally acquired or travel-related infections, have been reported in all provinces between 2009 and 2022.

Between 2013 and 2022 there were 16,548 human cases of Lyme disease reported in Canada. Of those cases, 94% were reported in Ontario, Quebec, and Nova Scotia where *I. scapularis* tick populations are established and expanding their range (Figure 5) [62]. In 2022, Nova Scotia experienced an incidence rate that was nearly 5-fold greater than the national incidence [63]. Most locally acquired cases are reported in the summer months of June, July and August, with children aged 5–9 years and adults aged 65–69 years most often impacted [62].



	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Probable	182	181	259	310	249	407	703	413	549	416
Confirmed	435	287	588	605	1,121	977	1786	1,193	2,573	2,050

Figure 5. Number of confirmed and probable cases of Lyme disease reported to the Public Health Agency of Canada, 2013 to 2022 (n = 16,548)

Further epidemiology of Lyme disease has been described in national surveillance reports on an annual basis [55,62,64-66]. More details can be found on PHAC's website: health-infobase.canada.ca/zoonoses/ticks/

The following tick-borne diseases, that includes anaplasmosis, babesiosis and Powassan virus, were made nationally notifiable in 2024. Surveillance data is not available across all provinces/territories prior to 2024 for the period of this report [67].

Anaplasmosis: 2013 to 2022

Anaplasmosis, or human granulocytic anaplasmosis, is a bacterial infection caused by *Anaplasma phagocytophilum*, an obligate gram-negative intracellular bacterium transmitted primarily by *I. scapularis* and *I. pacificus* ticks (the same as Lyme disease) [54,57,68]. It is the second most common tick-borne disease in North America and typically presents with non-specific symptoms such as fever, chills, muscle and joint pain, headache, and gastrointestinal issues within 5 to 21 days of a tick bite [57,69]. While often mild, severe outcomes like renal failure and death can occur, particularly in older adults or those with pre-existing conditions and delayed treatment [57].

First identified in the U.S. in 1990 [70], Canada reported its first locally acquired case in Alberta in 2009 [70]. Since then, there has been increased public health attention surrounding the geographic spread of tick vectors and the emergence of confirmed human and animal cases [72,73]. Further establishment of *A. phagocytophilum* in ticks, increased surveillance of anaplasmosis and testing by provinces/territories, as well as improved awareness will also contribute to increased detection of anaplasmosis in humans in Canada.

Anaplasmosis has been on the rise in the last decade in Canada. Co-infection rates between anaplasmosis and Lyme disease have been reported to be as high as 10% in the United States [74]. Several provinces have reported cases of anaplasmosis during the period between 2015 and 2022, including Alberta, Manitoba, Ontario, Quebec, and Nova Scotia.

- A second laboratory confirmed case was documented in 2017 in Alberta, after the identification of its first case of anaplasmosis in Canada in 2009 [75].
- Manitoba has reported cases of anaplasmosis since 2015, the same year it was made reportable in that province [76]. Between 2015 and 2022, the number of annual cases in that province ranged from 2 to 21 cases, with the highest case counts in 2016 (n = 17) and 2018 (n = 21) (Table 3) [76]. Age and sex data were available for cases reported between 2015 and 2018; 63% of cases were males and incidence rates were highest amongst individuals greater than 60 years of age.
- Ontario identified its first anaplasmosis case in 2018 [77]. This resulted in a study to investigate the emergence of anaplasmosis in Ontario through patient serological and clinical data, alongside pathogen detection in *I. scapularis* ticks, from 2011 to 2017 [78]. The researchers found five probable and 78 suspected cases of anaplasmosis. They reported that seropositive patients were mainly adult females (40–59 years old).
- Quebec has reported cases of anaplasmosis since 2019 (Table 3) [79]. In 2021, 45 cases were reported, which included an unusual cluster of 25 cases in the Estrie region. These 25 cases were predominately male with a median age of 65 years. This was the largest documented cluster of confirmed anaplasmosis cases identified during a transmission season in Canada [80].

- An anaplasmosis case was first reported in Nova Scotia in 2017 followed by a subsequent case in 2018. There has been an increase in laboratory confirmed cases since 2021. By the end of 2022, a total of 199 positive laboratory results had been recorded [81]. It is expected that the number of anaplasmosis cases in humans will continue to rise, as there are an increasing number of reports of ticks infected with *A. phagocytophilum* in Nova Scotia, which also experiences the highest incidence of Lyme disease in Canada [82].

Although Ontario and Nova Scotia reported cases of anaplasmosis during the reporting period, the disease was not officially reportable at that time. As a result, the number of publicly reported cases likely underestimates the true incidence.

Table 3. Number of confirmed and probable cases of anaplasmosis reported by Manitoba and Quebec between 2015 and 2022 (n = 149)

Province / Territory [a]	2015	2016	2017	2018	2019	2020 [c]	2021	2022	Total
Manitoba [b]	4	17	10	21	7	2	7	2	70
Quebec [d]	n/a	n/a	n/a	n/a	2	4	47	29	79

[a]From 2015–2022, only two provinces, Manitoba and Quebec, had anaplasmosis listed as a provincially reportable disease. While anaplasmosis was likely more widespread than these provinces, it was not provincially reportable in other jurisdictions for the report period, and therefore are not included here.
[b]Includes both confirmed and probable cases.
[c]Data from 2020 onwards should be interpreted with caution due to possible interruption of surveillance efforts during the COVID-19 pandemic.
[d]Cases reported through INSPQ include those with a location of acquisition in Quebec, outside Quebec, and those with an unknown location.
Note n/a = not available.
Source: INSPQ, Government of Manitoba.

Babesiosis: 2013 to 2022

Babesiosis is a tick-borne disease caused by *Babesia* protozoa, most commonly *B. microti* in North America, though *B. duncani* and *B. divergens* have also been reported in Canada [68,83,84]. Transmitted primarily by *I. scapularis* ticks [85], the illness ranges from asymptomatic to life-threatening, with symptoms like fever, fatigue, and muscle aches typically appearing 7 to 30 days after infection [83,84]. Severe cases are more common in older adults or immunocompromised individuals and may involve complications such as acute respiratory distress syndrome (ARDS), anemia, or organ failure [58,85].

Locally acquired *B. microti* infections are thought to be rare in Canada; most cases have been reported from Central and Western Canada, and while is it not yet widespread, a growing number of regions in Canada are likely to see locally acquired infections of this emerging tick-borne disease [82].

In Canada, the first locally acquired case was identified in Manitoba in 2013 [86], and became reportable in that province shortly thereafter in 2015. From 2015 to 2022, two cases were reported, and both cases were thought to be acquired in that province [76,87]. Quebec was the first province to make babesiosis reportable, in 2004. Between 2004 and 2022, Quebec reported eight babesiosis cases, although all eight were acquired outside the province [79]. More recently, in July 2021, a case of babesiosis was confirmed in Nova Scotia [82].

Babesia microti can be transmitted not only through tick bites but also via blood transfusions, posing a risk for transfusion-transmitted babesiosis (TTB) [58,83,88,89]. In contrast, other tick-borne pathogens, like *B. burgdorferi*, are rarely found in high concentrations in blood and have not been shown to transmit via transfusion. A study in 2018 tested for *B. microti* by transcription-mediated amplification (TMA) in 50,752 samples and one positive result was found (from Manitoba). A randomly selected subset of 14,758 TMA-negative samples was tested for *Babesia* immunoglobulin G, with four positive results (all from southwestern Ontario) [90]. Overall, seroprevalence studies suggest the likelihood of clinically relevant TTB is low, despite the fact that prevalence appears to be slowly increasing in Canada [91].

Powassan virus: 2013 to 2022

Powassan virus (POWV) is a rare but serious tick-borne flavivirus endemic to North America that can cause severe neurological complications, including encephalitis, with symptoms typically appearing 1 to 5 weeks after a tick bite [92–94]. Powassan virus, unlike some other tick-borne diseases, can be transmitted to humans in as little as 15 minutes after a tick attaches [95]. While some infections are asymptomatic or mild, neuroinvasive cases can be fatal in about 10% of instances, and half of survivors may suffer long-term neurological effects [93]. POWV exists in two genetic lineages—Lineage I and Lineage II (deer tick virus)—transmitted by different *Ixodes* species, though they are clinically indistinguishable [92,96,97]. There is no specific treatment and care is supportive.

Powassan virus was first identified in 1958 in the small town of Powassan, Ontario [97]. A scoping review conducted by Corrin et al. found 21 POWV infections (ON = 11, QC = 8, NS = 1, NB = 1) described in surveillance and case report studies in Canada between 1958 and 2017 [99].

Reports of Other TBDs in Humans: 2013 to 2022

Colorado tick fever, tick-borne relapsing fever, and spotted fever group rickettsioses (SFGR) are lesser known but important tick-borne diseases in Canada, each involving distinct vectors and pathogens.

Colorado tick fever virus (CTFV), a *Coltivirus* transmitted by *Dermacentor andersoni*, is endemic to western Canada and can cause febrile illness with occasional neurological complications [54,100,101]. There have been two case reports published in Canada reporting on CTFV: one in Alberta (prior to 2013) and one in Saskatchewan (2017) [102,103]. For comparison, in the United States, a median of 11 cases was reported each year from 2013 to 2022 [104].

Tick-borne relapsing fever, typically caused by *Borrelia hermsii* and spread by *Ornithodoros hermsi*, is characterized by recurring fevers and potential neurologic involvement [105,106]. It is known to be present in some areas of British Columbia (e.g., West Kootenay), and the British Columbia Centre for Disease Control reports approximately 0 to 7 cases each year [105–108].

Spotted Fever Group Rickettsiosis (SFGR), a group of diseases caused by *Rickettsia* bacteria, including *Rickettsia rickettsii*, is transmitted by ticks in North America such as *D. variabilis*, *D. andersoni*, and *Rhipicephalus sanguineus*. Historically, endemic transmission, albeit rare, has been reported in western provinces such as British Columbia and Alberta [54,109]. However, serological studies conducted in Ontario (2013–2018) found evidence of past exposure to SFGR in humans, but confirmed acute infections were extremely uncommon, thus suggesting low-level exposure rather than established endemicity [110]. The most severe SFGR illness, Rocky Mountain spotted fever (RMSF), can lead to permanent disability or death if not treated promptly, with mortality rates significantly higher when antibiotic treatment is delayed beyond five days [111–115].

Important Update: Rocky Mountain Spotted Fever in Ontario, 2025

In 2025, Rocky Mountain Spotted Fever (RMSF) was detected in Ontario through the notification of a cluster of infected dogs who had all been in the Long Point area on Lake Erie. Following this notification, *R. rickettsii* was detected in American dog ticks collected from Long Point near locations where the dogs were exposed. Subsequently, two human cases with exposure in Long Point were also identified.

Historically, locally acquired cases of SFGR, including RMSF, have only been rarely reported in Canada. The long-term significance of these findings is yet to be determined. Such as in this instance, dogs can be important surveillance sentinels for human risk, emphasizing the value of a One Health approach [116].

What is the One Health story of emerging tick-borne diseases in Canada?

Tick-borne diseases in Canada exemplify the One Health concept, where human, animal, and environmental health are deeply interconnected. Wildlife plays a crucial role in the ecology of tick-borne diseases. Rodents like the white-footed mouse act as reservoir hosts for *Borrelia burgdorferi*, while larger mammals like deer support tick reproduction without necessarily carrying the pathogens themselves [54,117]. Companion animals, particularly dogs, play a significant role in this dynamic. While they do not directly transmit tick-borne pathogens to humans, they can serve as sentinels for disease risk and inadvertently transport infected ticks into homes, increasing human exposure [118]. Dogs are susceptible to several tick-borne illnesses such as Lyme disease and anaplasmosis, and their infection patterns can mirror or even precede human cases, offering valuable early warning data for public health surveillance [53].

Surveillance of tick and animal populations are beneficial to informing human disease risk. Both active and passive tick surveillance has been used alongside reported cases of human illness to identify areas where tick populations may be emerging, and where people are most at risk.

B. burgdorferi infection rates in *I. scapularis* ranged from 22% to 29% in several provinces, with higher-than-average prevalence in Newfoundland and Labrador, Nova Scotia, and Quebec [53,119]. *A. phagocytophilum* was detected in 3 to 5% of ticks in four provinces, and up to 26% of infected ticks in Ontario carried the human-pathogenic Ap-ha strain [78]. Though less common, *B. microti* and Powassan virus were also detected, with POWV lineage II found in 0.1% of ticks in Nova Scotia [118].

Tick-borne diseases and climate change

The expansion of tick populations in Canada is driven by a combination of climate change, warmer temperatures, land use changes, shifting wildlife populations, and increased habitat suitability. These factors extend the seasonal activity of ticks and heighten the risk of human exposure. Climate change influences the abundance, distribution, and activity patterns of both ticks and their animal hosts, while also affecting human behaviour—encouraging more time spent outdoors and increasing the likelihood of tick encounters throughout a longer season. Collectively, these environmental and behavioural changes contribute to a growing risk of acquiring tick-borne diseases such as Lyme disease and Powassan virus [54].

RABIES

Rabies is a fatal neurologic disease caused by a single-stranded RNA virus belonging to the genus *Lyssavirus*. The virus can infect all mammals, including humans, and is present on every continent, except Antarctica [120]. Humans are most commonly infected though direct contact with saliva from an infected animal, typically via a bite or less commonly through a scratch. Animal reservoirs vary by region. Early symptoms of rabies can include fever, tiredness, headaches, anxiety or irritability and numbness or itching at the bite site. Symptoms worsen quickly as the virus attacks the central nervous system. There is no treatment for rabies once symptoms appear, however, the disease is preventable through prompt post-exposure prophylaxis, which includes rabies immunoglobin and vaccine administration. If left untreated, rabies is almost always fatal [121].

Human cases of rabies in Canada: 2013 to 2022

- Human cases of rabies are extremely rare in Canada.
- From 2013 to 2022, there was one confirmed case of human rabies following bat exposure (in 2019).
- Bats have been the source of all domestically-acquired human rabies cases in Canada in the last 55 years, despite the virus being present in other wildlife species.

Between 2013 and 2022, one confirmed human rabies case was reported in Canada (2019). The case was a 21-year-old man from British Columbia who reported that a bat “ran into his hand”. He did not seek medical attention and did not receive rabies post-exposure prophylaxis (rPEP). The man developed symptoms approximately six weeks later and subsequently died [122].

Human rabies cases have been documented in Canada since the 1800s and the disease has been nationally notifiable since 1924 (Figure 6). Between 1924 and 2022, 27 human rabies cases have been reported in Canada [123]. Of those, 2 were infected while travelling (1984, 2012) and the remaining 25 (93%) were acquired in Canada. Significantly, since 1970, bats have been the source of all seven domestically-acquired human rabies deaths. Despite six of seven of these cases reporting that they had a history of direct bat contact, none sought medical care or received rPEP [123], emphasizing the need for education on the importance of seeking immediate medical care after any potential bat exposure, regardless of whether a bite or scratch is visible [122,124].

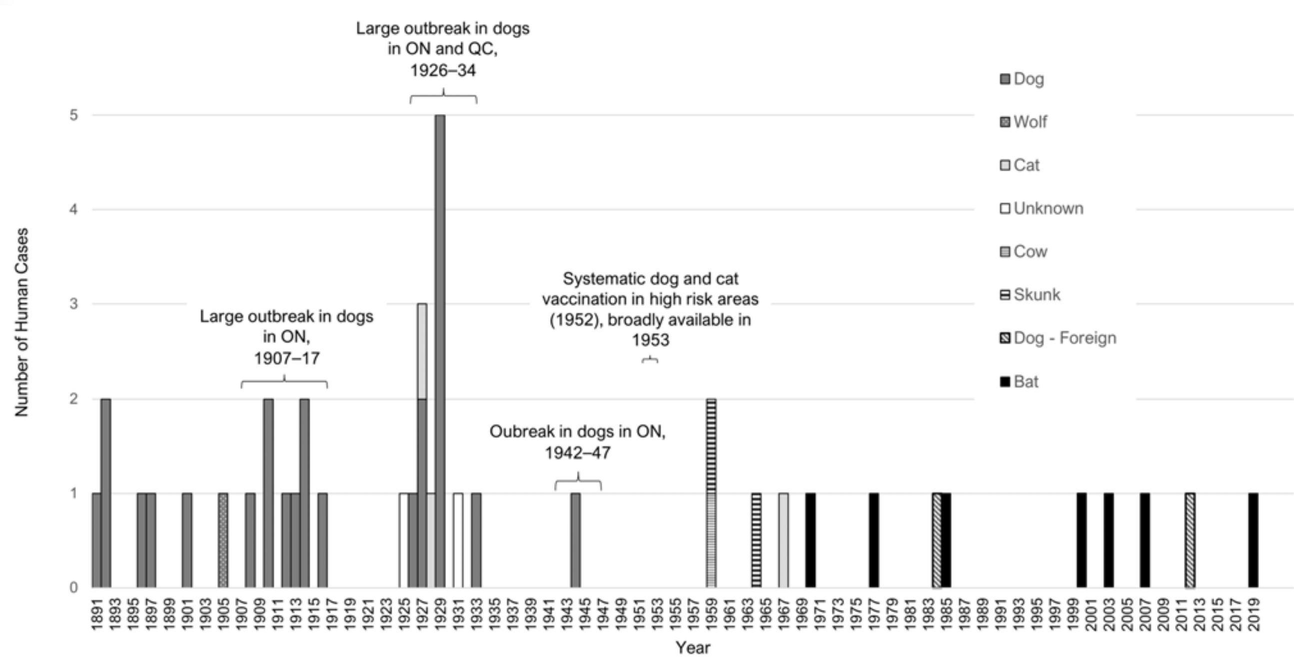


Figure 6. Human rabies cases in Canada by animal exposure, 1890 to 2022 [123]

Important update: Human Rabies Case in Ontario, 2024

In September 2024, Ontario reported a rabies case—the province's first domestically acquired case of human rabies since 1967. This rabies case is suspected to have been acquired through direct contact with a bat in Ontario [125].

Rabies post-exposure prophylaxis (rPEP)

Rabies post-exposure prophylaxis (rPEP), including thorough wound flushing and the administration of rabies immune globulin (RIG) and vaccine, is critical to rabies disease prevention [126]. Although data are not routinely collected by PHAC, some provinces and territories provided data on rPEP initiated between 2013 and 2022 (Figure 7). Of those jurisdictions with available data, rates of administration vary regionally, with the Northwest Territories having the highest average annual rate of rPEP initiated per 100,000 population (26.7), followed by Ontario (17.0) and Saskatchewan (13.1). Differences between jurisdictions can be attributed to factors such as local rabies ecology and risk, differing public and clinical risk perceptions, and differing PT guidelines for rPEP use. Challenges in transporting animal samples, particularly in remote and underserviced areas, may lead to increased use of rPEP as a precautionary measure, reflecting the vigilance of health professionals in ensuring timely administration.

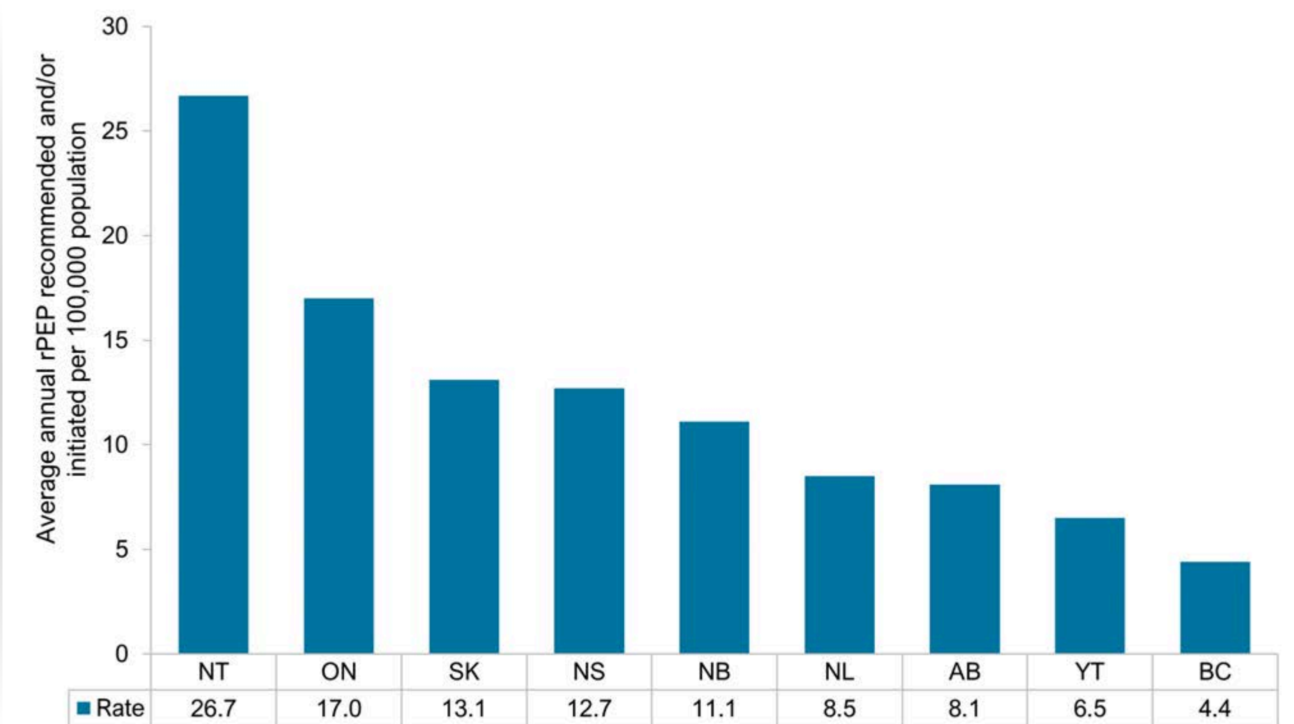


Figure 7. Average annual number rPEP recommended and/or initiated per 100,000 population, by province or territory with available information, between 2013 to 2022

Note that not all provinces and territories contributed rPEP data for every year included in this report. Data for British Columbia were obtained from previously published sources and may not reflect the most current information for the reporting period.

Distribution of rabies virus variants in Canada

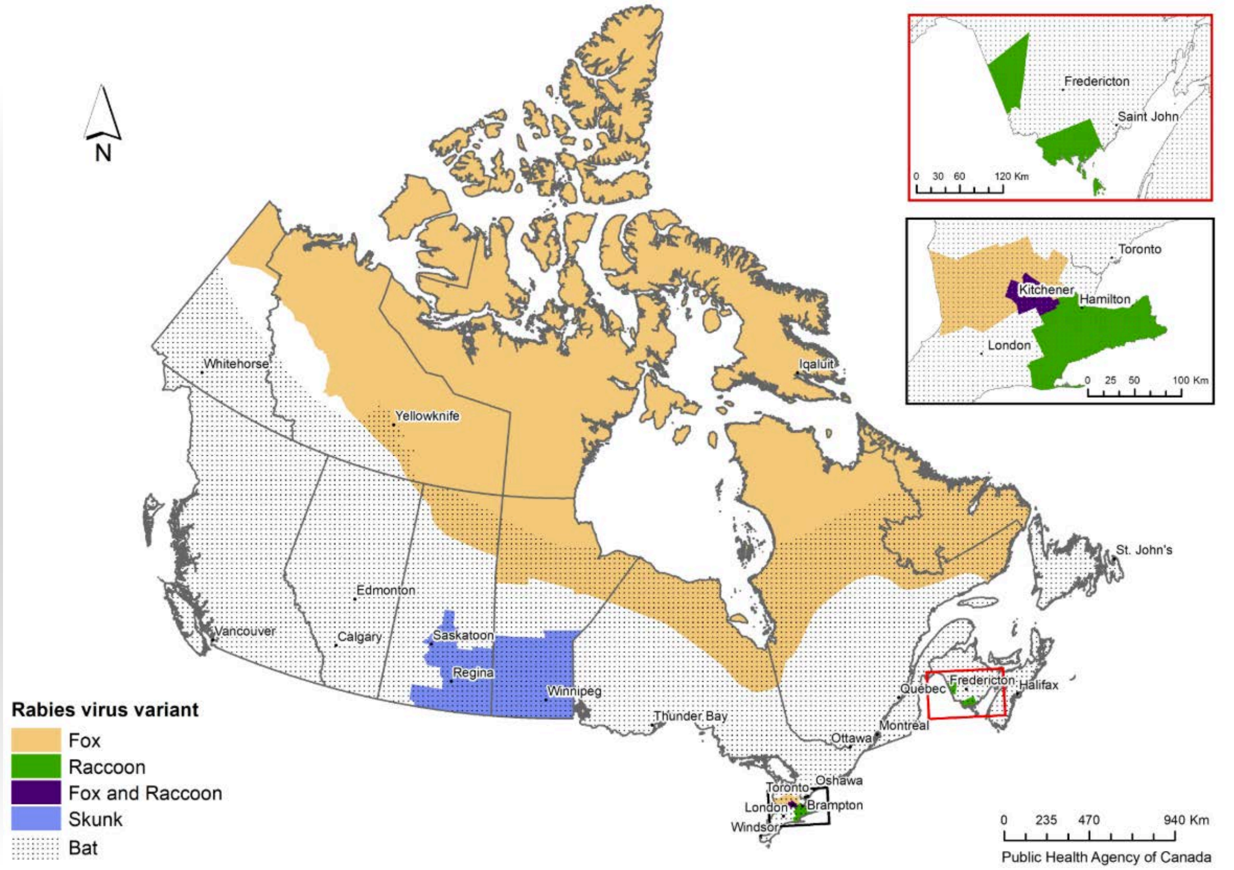


Figure 8. Distribution of rabies variant viruses (RVVs) in Canada from 2018 to 2022

Note that rabies virus variant (RVV) ranges are depicted in a map of Canada by census division, except for bat RVV and fox RVV in northern regions of Canada where host geographic ranges are used.
Data sources: Rabies ·census division data: Laboratory test results, including confirmed cases by animal species, location, and rabies virus variant, were provided to the Public Health Agency of Canada by the Canadian Food Inspection Agency for map development. Arctic fox habitat range: Base shapefiles obtained from the International Union for Conservation of Nature's Red List of Threatened Species. Bat habitat range: Base shapefiles obtained from the Committee on the Status of Endangered Wildlife in Canada and International Union for Conservation of Nature's Red List of Threatened Species.

In Canada, wildlife is the primary reservoir for rabies. There are different variants of rabies virus, each associated with a particular animal species that serves as a reservoir. All rabies virus variants (RVVs) can infect and cause disease in humans as well as other animal species. RVVs identified in Canada from 2018 to 2022 included those associated with bats, foxes, skunks, and raccoons, each circulating within distinct wildlife populations across specific geographic regions (Figure 8).

- Bats were a widespread source of rabies exposure across most of Canada, except the far north where bat populations have not been confirmed.
- Skunk RVV was endemic in southern Saskatchewan and Manitoba.

- Fox RVV was reported in a localized area of southern Ontario. It was also considered widespread across northern Canada, in alignment with the habitat range of Arctic foxes.
- Raccoon RVV has been detected in Ontario, New Brunswick and Quebec (single case in 2015) following incursions from the U.S.

Rabies Resurgence in Ontario: A Multisectoral Response

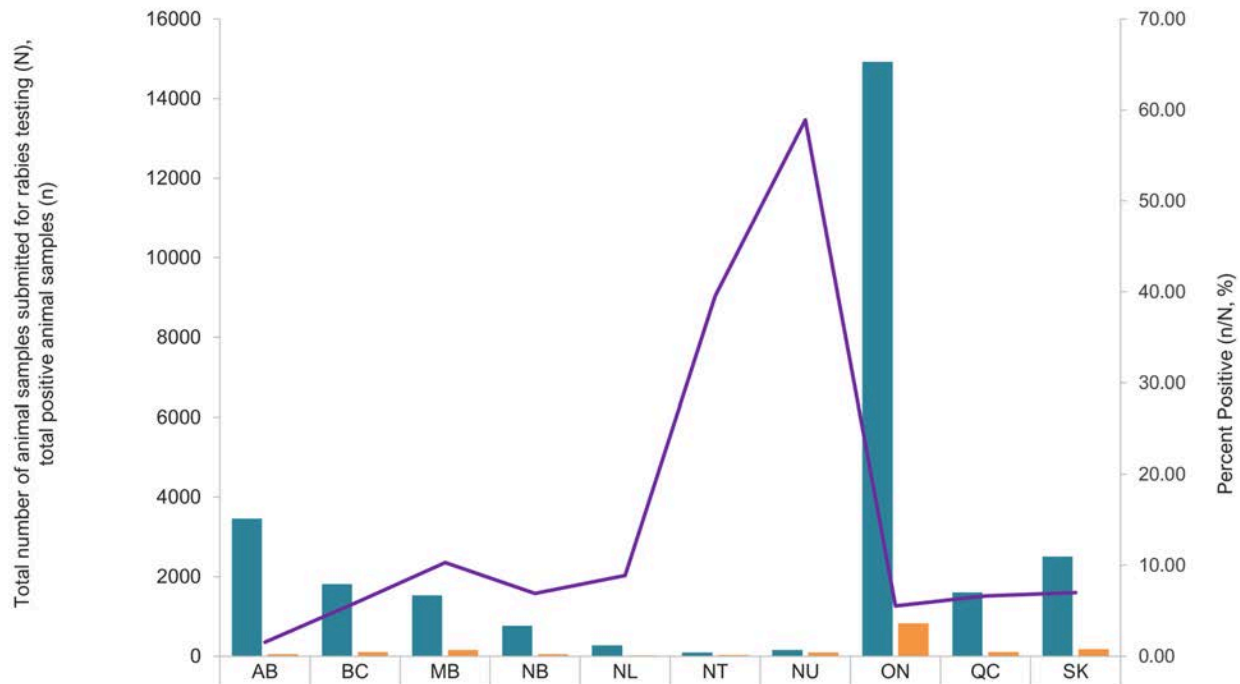
A major rabies outbreak in southwestern Ontario was detected in December 2015, marking the first detection of raccoon RVV in the province in over a decade [127]. Initially undetected due to a concurrent canine distemper outbreak causing similar clinical signs in raccoons [128], the rabies outbreak peaked in 2016 with 258 confirmed cases and included transmission to other species. Genetic analysis suggests this outbreak strain originated in southeastern New York State, likely crossing the vaccination corridor between the U.S. and Canada through long-distance translocation—possibly by a raccoon hitchhiking on a truck [129,130].

The outbreak response involved a coordinated One Health approach among federal, provincial, and local partners. One of the main strategies to reduce the spread of raccoon RVV was through the use of oral rabies vaccine wildlife baits. Between 2015 and 2017, over 1.7 million baits were distributed to affected areas. Public awareness campaigns, such as "Rabies is Real," promoted messaging to improve public reporting and understanding of rabies risk. To help protect pets from rabies as well as reduce the risk of transmission to humans, Hamilton Public Health Services partnered with local veterinarians to offer low-cost rabies vaccinations for cats and dogs through outreach clinics [129].

Despite coordinated One Health efforts, animal cases continued through 2022, underscoring the complexity of controlling rabies, particularly in urban environments [131]. Managing rabies outbreaks in urban areas presents several challenges, including the logistical constraints of manually distributing oral rabies vaccine baits instead of using aircraft, as well as preventing interference of baits by the public [129].

Animal Rabies Cases in Canada: 2013 to 2022

Between 2013 and 2022, the Canadian Food Inspection Agency (CFIA) tested 27,330 animal samples, confirming 1,634 rabies cases (Figures 9 and 10). The majority of submitted samples are from animals exhibiting clinical signs of rabies, who have had contact with a person or domestic animal.

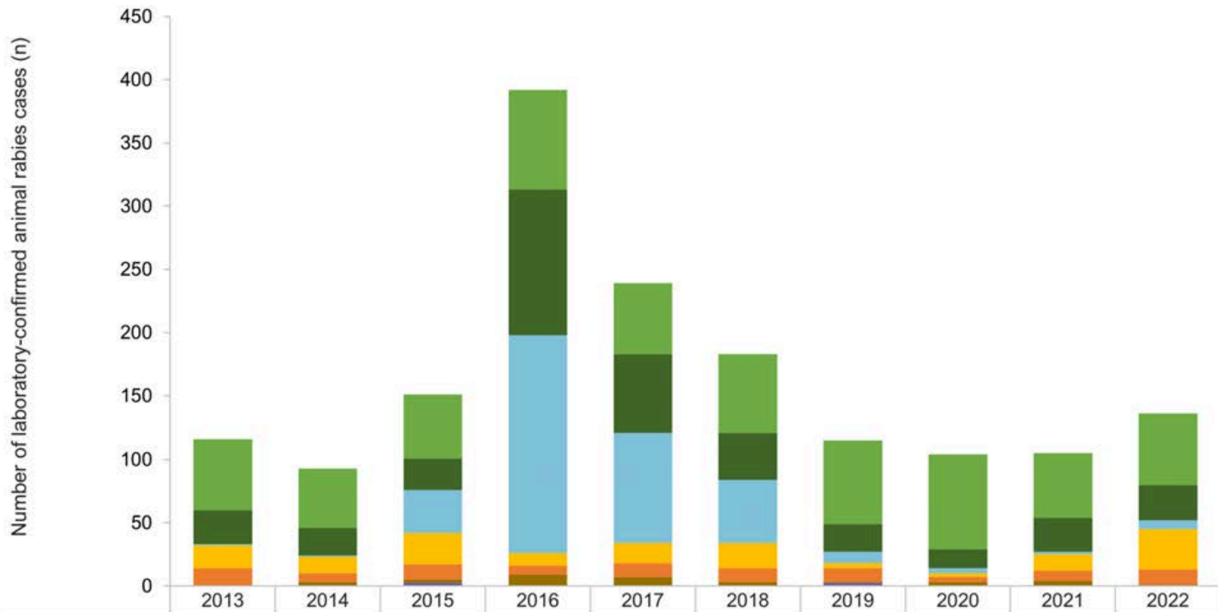


	AB	BC	MB	NB	NL	NT	NU	ON	QC	SK
Total tested (N)	3456	1809	1531	766	270	91	163	14921	1604	2504
Total positive (n)	53	106	158	53	24	36	96	828	106	175
Percent positive (%)	1.53	5.86	10.32	6.92	8.89	39.56	58.90	5.55	6.61	6.99

Figure 9. Animal samples submitted to CFIA for rabies testing and percent positivity by province/territory, 2013 to 2022

Note this figure excludes data (n = 215) from jurisdictions with no confirmed positive animal rabies cases during the reporting period. These data also exclude enhanced wildlife surveillance conducted by provinces and territories and the Canadian Wildlife Health Cooperative (CWHC), unless samples are sent to CFIA for confirmatory testing. As a result, percent positivity may be overestimated in certain jurisdictions.
Source: Canadian Food Inspection Agency.

Ontario accounted for 55% of all samples submitted over the 10–year period of this report, with approximately 30.1 % (n = 4,487) of Ontario’s samples submitted during the raccoon RVV outbreak that occurred between 2015 and 2017 (Figure 10). Nunavut and the Northwest Territories had the highest rabies percent positivity, at 58.9% and 39.6%, respectively. This likely reflects the regional rabies' ecology, which is characterized by the presence of fox RVV. This may also, in part, reflect the logistical challenges of transporting samples from remote areas. Over this 10–year period, there were no positive animal rabies cases in Nova Scotia, Prince Edward Island and the Yukon.



	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Bats	56	47	50	79	56	62	66	75	51	56
Skunks	27	22	25	115	62	37	22	15	27	28
Raccoons	1	1	34	172	87	50	9	4	2	7
Foxes	18	13	25	10	16	20	4	3	13	32
Companion animals	14	7	12	7	11	11	11	4	8	12
Livestock	0	3	3	9	7	3	1	3	4	1
Other	0	0	2	0	0	0	2	0	0	0

Figure 10. Laboratory-confirmed animal rabies cases by species, 2013 to 2022 (n = 1,634)

Note that "Companion animals" include dogs, cats, and horses; "Livestock" includes cows, goats, sheep, and llamas; "Other" includes wolves and mink.
Source: Canadian Food Inspection Agency.

Wildlife consistently represented the vast majority of confirmed rabies cases (Figure 10). Among wildlife species, bats accounted for the highest proportion of rabies cases. The raccoon RVV outbreak in Ontario significantly contributed to increased detection of rabies in raccoons and skunks between 2015 and 2017.

Rabies on the move: How dogs can translocate RVVs

RVVs can be translocated not only by hitchhiking raccoons, but also through the movement of domestic animals. In 2021 and 2022, two separate incidents involved dogs imported from Iran that developed rabies after arrival in Canada, prompting extensive and costly public health investigations and rPEP administration [132,133]. These events marked the first detections of canine-mediated RVV in Canada since typing of variants began in the 1980s [132]. Concerns about public health risks linked to importing dogs from countries with a high risk of canine-mediated RVV—such as what occurred in these cases—prompted the implementation of stricter import regulations for commercial dogs, including those brought in for adoption [134].

Dogs infected with wildlife variants of rabies have also been translocated from northern to southern Canada, posing risks of introducing RVVs into new regions and host species [135].

Climate change and rabies in Canada

Climate-driven ecological changes are likely to influence rabies virus circulation among host species populations [5]. Alterations in animal habitats, population densities, and movement patterns resulting from climate change can significantly affect rabies transmission dynamics across species.

The impacts of climate change on rabies may be more pronounced in the Arctic, which is warming at a faster rate than the rest of Canada [136]. In northern Canada, rabies has traditionally been maintained in Arctic fox populations, with periodic regional outbreaks [137]. However, between 2020 and 2022, red foxes surpassed Arctic foxes in reported rabies cases in the North [138]. This shift is likely driven by the northward expansion of red fox habitat, facilitated by anthropogenic factors such as increased food availability near inhabited areas and rising temperatures [139]. As a result, habitat overlap between red and Arctic foxes has increased, creating more opportunities for interspecies rabies transmission and this could facilitate the southward spread of fox RVV [137,139,140]. This would require substantial public health resources to implement control measures, such as oral rabies vaccination through wildlife baiting. While the long-term effects of climate change on rabies ecology remain uncertain, early signs of its influence are already emerging.

Given the impacts of climate change and human activity, the ecology of rabies in Canada could continue to change. These changes underscore the need for sustained attention, as well as adaptive surveillance and control strategies. Public education is essential, particularly in raising awareness about the risk of rabies following bat exposure, as bites or scratches may not be visible to the naked eye. Tragically, all domestically acquired rabies deaths in Canada over the past fifty years have resulted from bat exposures, a sobering statistic considering the disease is entirely preventable if exposures are recognized and rPEP is promptly administered.

Canada has made significant progress in reducing rabies-related human deaths over the past century. To maintain this progress, continued vigilance, interjurisdictional collaboration, robust surveillance, and effective educational outreach remain essential.

TULAREMIA

Tularemia is a zoonotic disease caused by the bacteria *Francisella tularensis* [141]. *F. tularensis* is a bacterium found throughout the northern hemisphere, with a broad host range that includes birds, mammals, and amphibians [142]. Humans can become infected through contact with infected animals—such as rabbits and muskrats—via tick vectors, or through ingestion of contaminated food or water [143]. Tularemia typically manifests as one of six clinical types, with the ulceroglandular form (characterized by a skin ulcer and regional lymphadenopathy) being the most common [143]. Tularemia can be successfully treated with antibiotics and mortality in treated individuals is very rare. However, if left untreated, certain strains and clinical types, such as pneumonic tularemia, can result in mortality rates as high as 50% [141].

Human cases of tularemia in Canada: 2013 to 2022

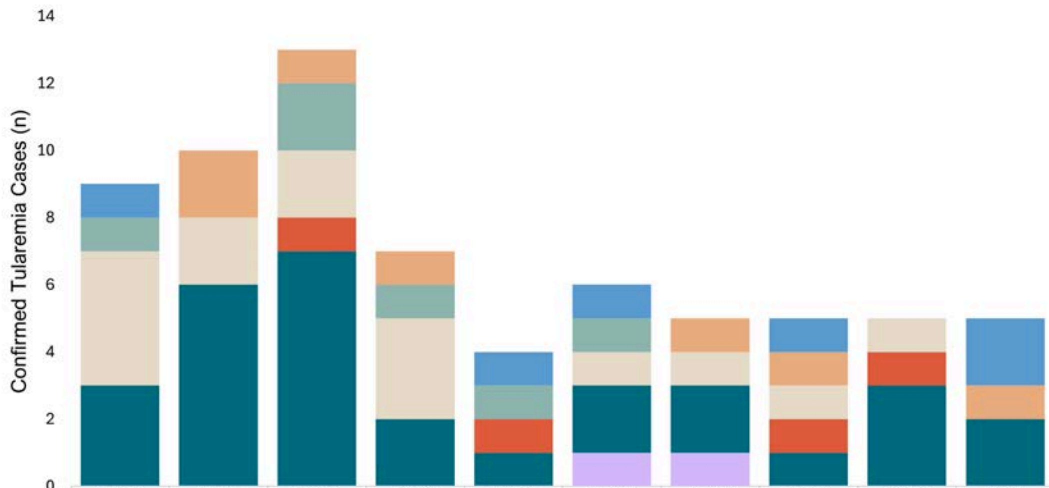
- 69 confirmed human cases of tularemia were reported in Canada, with a range from 4 to 13 cases yearly, and an average of 7 (Table 4, Figure 11).
- Quebec reported 42.0% of all cases between 2013 and 2022, followed by Manitoba (21.7%), Alberta (10.1%), Saskatchewan (8.7%), and British Columbia (8.7%) (Table 4, Figure 11).
- Manitoba has the highest average annual incidence with 0.11 per 100,000 population (Table 4).
- Most reported cases were male (68.1%), with the majority of these (78.7%) aged over 40 years. Among female cases (n = 22), a similar age trend was observed, with 61.9% (n = 13/21; one case missing age data) being over 40 years of age (Table 4, Figure 12).

Human tularemia cases are rare in Canada. The epidemiology of tularemia may be influenced by various factors, including the presence of wildlife reservoirs, environmental conditions, human behaviours and occupational exposures, as well as different surveillance practices. Overall, more males are affected than females, which may reflect activity patterns that enhance opportunities for exposure, such as hunting [142]. Region-specific activities—such as trapping and hunting of muskrats, a known reservoir for tularemia—may contribute to an increased risk of exposure. A seroprevalence study among southern Quebec trappers found a statistically significant association between muskrat hunting and *F. tularensis* exposure [144]. Another study analyzing *F. tularensis* isolates in eastern Canada found that half of the Type B (a sub-species of *F. tularensis*) isolates were from patients residing in a region of Quebec known for high muskrat population densities [145]. Differences in case definitions may partly explain the variation in confirmed cases and average annual incidence across jurisdictions. More inclusive definitions—such as those incorporating molecular diagnostic methods for confirmed cases—may lead to higher case counts.

Table 4. Human tularemia cases in Canada by province/territory and sex: 2013 to 2022 (n = 69)

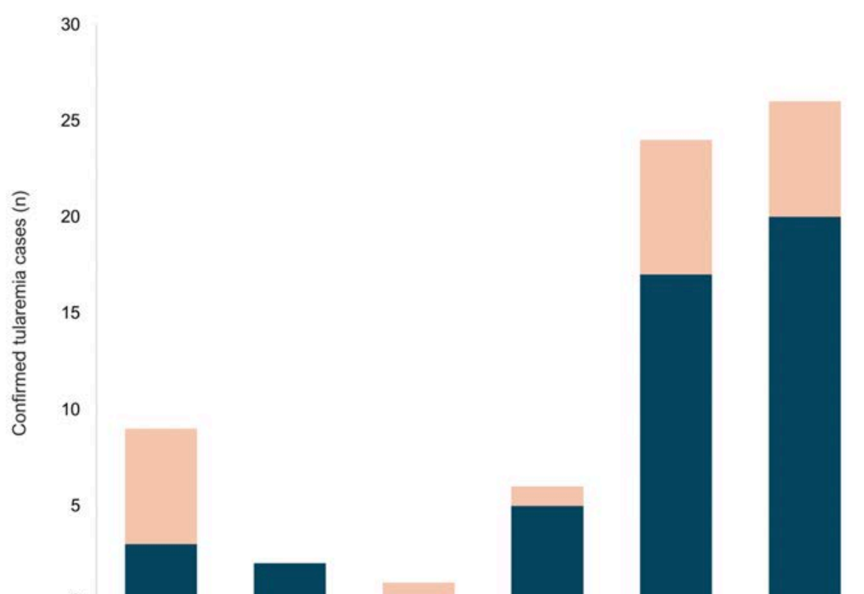
Province / Territory	*Female*		*Male*		*Total*		*Average Annual Incidence (per 100,000 population)*
	n	*%*	*n*	*%*	*n*	*%*	
British Columbia	1	16.7%	5	83.3%	6	8.7%	0.01
Alberta	3	42.9%	4	57.1%	7	10.1%	0.02
Saskatchewan	2	33.3	4	66.7%	6	8.7%	0.05
Manitoba	8	53.3%	7	46.7	15	21.7%	0.11
Ontario	1	25.0%	3	75.0%	4	5.8%	0.00
Quebec	7	24.1%	22	75.9%	29	42.0%	0.03
Newfoundland and Labrador	0	---	2	100.0%	2	2.9%	0.04
Total: Canada	**22**	**31.9%**	**47**	**68.1%**	**69**	**100.0%**	**0.02**

Note for provinces and territories not listed, no cases were reported between 2013 and 2022.



	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
BC	1	0	0	0	1	1	0	1	0	2
AB	0	2	1	1	0	0	1	1	0	1
SK	1	0	2	1	1	1	0	0	0	0
MB	4	2	2	3	0	1	1	1	1	0
ON	0	0	1	0	1	0	0	1	1	0
QC	3	6	7	2	1	2	2	1	3	2
NL	0	0	0	0	0	1	1	0	0	0

Figure 11. Human tularemia cases in Canada by province/territory and year: 2013 to 2022 (n = 69)



	0-9	10-19	20-29	30-39	40-59	60+
Female	6	0	1	1	7	6
Male	3	2	0	5	17	20

Figure 12. Human tularemia cases in Canada by age and sex: 2013 to 2022 (n = 69)

Note that total cases = 69; one case missing age.

Cases of tularemia may occur at different times of the year depending on the mode of transmission. Tularemia from ticks and deer fly bites are more likely to occur during the summer months [146]. Human illness associated with animal handling can occur at any time of the year, though may be associated with certain seasonal activities such as hunting snowshoe hares in winter or muskrats in the spring/winter [142,147]. Historically, rabbits and hares were associated with the majority of the human cases in Canada prior to 1950, but studies have suggested that since that time, contact with muskrats are increasingly important [144,148]. Transmission can also occur via consumption of contaminated water, though this route of exposure appears to be more common in Europe than in North America [149]. The season and source of exposure, as well as sub-species information, is not routinely collected at the national level in Canada. However, exposures are often associated with direct animal contact [145,147].

Tularemia in Animals in Canada

There are two types of tularemia in Canada: Type A (*F. tularensis* subsp. *tularensis*) and Type B (*F. tularensis* subsp. *holarctica*). Type A is associated with terrestrial small mammals such as rabbits and hares [147,150] and Type B is associated with a water-borne cycle and semi-aquatic rodents such as muskrats and beavers [147,150,151]. Animal studies suggest that Type B tularemia may be more prevalent than Type A in the prairie provinces; however, few isolates from wild animals in Canada have been identified to the sub-species level [152,153]. Although several studies have investigated the ecology of tularemia in Canada, the primary natural reservoirs and transmission cycles of *F. tularensis* are not yet fully understood. It is possible that multiple, overlapping transmission cycles involving diverse animal species, vectors, and tularemia subspecies occur in Canada [152].

Despite being able to readily infect smaller rodents, the occurrence of tularemia in small rodents in Canada is relatively rare [152]. Although human cases of tularemia have been linked to cottontail rabbits in the U.S., to date, the disease has not been identified in cottontail rabbits in Canada [152]. However, wildlife surveillance of tularemia is limited, so prevalence in various species could be underestimated [152].

Companion animals, such as dogs, cats, rabbits, and small rodents like hamsters, can also be infected with *F. tularensis* [154]. Domestic cats are very susceptible, and humans have been known to acquire the infection following bites from cats [149,155]. Dogs are less commonly implicated with human cases, but routes of transmission may include direct contact, handling carcasses retrieved by dogs, or the introduction of infected ticks into the home [154]. Rarely, hamsters have also been implicated in human tularemia cases [156].

Tularemia in Arthropods in Canada

Hard ticks can be persistently infected with *F. tularensis* and are important vectors of tularemia to humans and help maintain the disease in the northern hemisphere [142]. Hard ticks such as the American dog tick (*D. variabilis*), the wood tick (*D. andersoni*), and the lone star tick (*A. americanum*) have all been implicated in tularemia transmission to humans [149]. The rabbit tick (*H. leporispalustris*) is a known vector in animals (rarely humans) and plays a role in the maintenance of tularemia in animal reservoirs [142,157].

Ticks have been associated with the majority of human cases of tularemia in the U.S. since the 1960s [142,151,158]. This trend is likely associated with a decline in hunting and trapping activities, coupled with increased public participation in outdoor recreation, which may facilitate the transmission of tularemia through tick exposure [142].

Mosquito-associated tularemia is more common in Northern Europe, and there has been one documented incident of mosquito-borne tularemia in Nunavut [159,160]. Deer flies also can transmit *F. tularensis* mechanically by feeding on multiple hosts [161].

Climate change and Tularemia in Canada

Climate change could impact the geographic range, abundance and the length of seasonal activity of ticks [54], which could affect the frequency and distribution of tick-borne diseases. According to one model, the dog tick (*D. variabilis*), which is already endemic to Southern Canada, may expand northwards as a result of climate change [162]. While overall geographic disease shifts northwards may be subtle, climate-driven changes in disease activity within existing geographic ranges may require more nuanced response efforts at the level of local or regional public health [163].

WEST NILE VIRUS (WNV) AND OTHER MOSQUITO-BORNE DISEASES

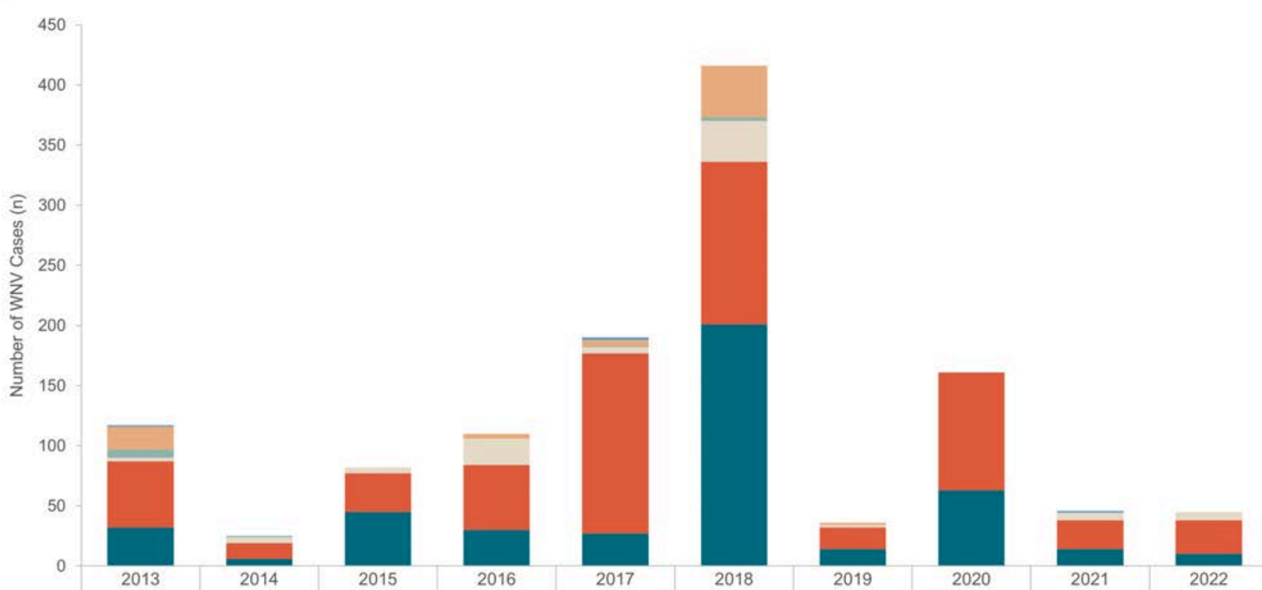
West Nile virus disease is a viral illness caused by the West Nile virus (WNV), an RNA orthoflavivirus in the Flaviviridae family. WNV is maintained in an enzootic cycle between avian hosts and competent mosquito vectors [164], which, in Canada, primarily involves members of the *Culex* genus (*Cx. tarsalis* in the west, and *Cx. pipiens* and *Cx. restuans* in the east) [165]. Humans and horses are considered incidental or dead-end hosts, in that they do not develop a sufficient viremia to infect mosquitoes and play a role in virus amplification [164]. While most infections are asymptomatic, approximately 20% of cases present with symptoms, and 1 in 150 develop neurologic disease, which can include the development of encephalitis, meningitis, acute flaccid paralysis, and movement disorders. Older individuals and those with comorbidities are at increased risk for more severe disease, long-term sequelae and mortality [166]. There is no vaccine and no specific treatment for WNV.

West Nile virus: 2013 to 2022

- 1,228 confirmed domestically acquired human cases of WNV were reported in Canada, with a range from 25 to 416 cases annually, with an average of 123.
- The majority of cases (n = 1,049, 85%) were reported in Ontario and Quebec.
- The average annual number of cases with neurological syndrome was approximately 64 cases per year (annual mean incidence of 0.17 per 100,000).

In Canada, WNV is the leading cause of human arboviral disease and became nationally notifiable in 2003, following initial human cases reported in 2002 in Ontario and Quebec [167,168]. Activity in Canada varies by year and region due to climatic factors, enzootic transmission cycles, and healthcare-seeking behavior [165]. The primary vectors are mosquitoes of the *Culex* genus: *Cx. pipiens* and *Cx. restuans* dominate in eastern Canada, whereas *Cx. tarsalis* is prevalent in the west [168,169]. Most infections are asymptomatic, with symptoms (if present) appearing 2 to 15 days post-infection [168]. Risk peaks from mid-July to early September [170]. Encephalitis is more common in older adults, while meningitis is more frequent in children. Risk factors for severe disease include age over 50, immunocompromised status, comorbidities such as cancer or alcohol use disorder, and infection via organ transplantation [161,166].

Between 2013 and 2022 there were 1,278 human cases of WNV reported in Canada. Of those cases, 95% (n = 1,228) were acquired within Canada, with a range from 25 to 416 cases yearly, and an average of 123 (Figure 13). During this period, the majority of cases (n = 1,049, 85%) were reported in two provinces: Ontario and Quebec. The majority of reported cases were clinical (> 90%) and of these, nearly half were classified as having neurological symptoms, the most severe form of WNV. The average annual number of cases with neurological syndrome was approximately 64 cases per year. This amounts to an annual average incidence of 0.17 per 100,000 Canadian population for West Nile neurological syndrome. Multiple studies have suggested that ⩽ 1% of WNV-infected patients will develop neurological syndrome, and that for every reported case of WNV neurological syndrome, there are approximately 140 to 300 total infections in the population, depending on the age of cases [171–173].



	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
BC	1	0	0	0	2	0	0	0	1	0
AB	19	0	0	4	5	43	2	0	0	0
SK	7	1	0	0	1	3	0	0	1	0
MB	3	5	5	22	5	34	2	0	6	7
ON	55	13	32	54	150	135	18	98	24	28
QC	32	6	45	30	27	201	14	63	14	10

Figure 13. Number of WNV human clinical and asymptomatic cases acquired in Canada, by province/territory, 2013 to 2022 reported to the Public Health Agency of Canada (n = 1,228)

Source is the national WNV surveillance system.

California serogroup viruses: 2013 to 2022

California serogroup (CSG) is a group of RNA orthobunyaviruses in the family *Peribunyaviridae*. The CSG includes viruses like Jamestown Canyon (JCV), Snowshoe Hare (SSHV), as well as others. Most infections are asymptomatic or subclinical [174], but symptomatic cases can range from mild febrile illness to severe neuroinvasive disease [175]. The risk for SSHV and JCV infection typically begins earlier in the season compared to WNV, extending from May to October [176]. Adults are more likely to develop severe disease from JCV, while SSHV-related neuroinvasive illness is more common in children. Approximately half of known JCV cases require hospitalization, though fatalities are rare and usually occur in immunocompromised individuals [175]. Underdiagnosis in Canada is likely due to limited awareness among healthcare providers [165,174].

CSGV are now the second most common mosquito-borne disease (MBD) agents causing neuroinvasive illness in North America [174] with documented human cases in Nova Scotia, New Brunswick, British Columbia, Alberta, and Quebec [169,177–180] and seropositivity in humans, animals, and mosquitoes reported across the country [176,177].

Unlike WNV, the primary vectors for JCV and SSHV are non-*Culex* mosquitoes, including *Aedes*, *Culiseta*, and *Anopheles* species [176].

Given CSGV infections are not nationally notifiable in Canada, and case definitions by province/territory have varied over the years, this has contributed to discrepancies regarding how a case or infection is counted. Only three provinces and territories include human CSGV infections as reportable diseases—Alberta, Quebec and the Northwest Territories. CSGV infections became reportable in Alberta in 2011 and between 2013 and 2022, 18 human cases were reported (Table 5). In Quebec, CSGV infections in humans recently became reportable in 2019. Between 2019 and 2022, 45 human cases were reported (Table 5). Several CSGV infections were reported prior to 2019; however, given it was not a reportable disease, infections were likely underreported during this time.

Table 5. Summary of CSGV detections in humans 2013 to 2022 for Alberta and Quebec (n = 124)*

Year	Alberta ±		Quebec		
	JCV	SSHV	JCV	SSHV	Undetermined
2013	2	1	n/a	n/a	n/a
2014	--	--	n/a	n/a	n/a
2015	5	1	n/a	n/a	n/a
2016	2	--	n/a	n/a	n/a
2017	1	1	--	--	31[1]
2018	--	--	--	--	21
2019	--	--	15	1	--
2020	3	1	3	3	5
2021	1	--	7	6	3
2022	--	--	11	3	1
Total	**14**	**4**	**32**	**13**	**61**

*While CSGV is more widespread than Quebec and Alberta, it is not reportable in many PTs and is not nationally notifiable.
±Some cases may have a travel history outside of province.
[1]In 2017, the province of Quebec performed an exploratory monitoring of all infections caused by CSGV. Eighty-two cases of infections caused by CSGV were identified. Of these, 31 cases met the notifiable disease definition at the time.
Note n/a = not available
Source: [181–184]

Cluster of CSGV pediatric encephalitis in British Columbia, 2024

In August 2024, Vancouver Coastal Health (VCH) identified a cluster of three pediatric encephalitis cases in Whistler, BC, all testing positive for SSHV [185]. Prior to this cluster, only ten cases of CSGV had been documented in BC since 2009, with two in the VCH region [186]. Despite low reported incidence, serological surveys around Canada have found between 1–42% of the population with evidence of infection [186]. This suggests that this may be a common cause of asymptomatic or mild summer viral illness, and an under-recognized cause of meningitis and encephalitis. The emergence of this cluster has prompted enhanced surveillance efforts in BC to better understand the prevalence and public health impact of these under-recognized arboviral infections.

Eastern equine encephalitis: 2013 to 2022

Eastern equine encephalitis (EEE) is caused by the Eastern equine encephalitis virus (EEEV), an RNA alphavirus in the Togaviridae family. The primary vector is *Culiseta melanura*, though other mosquito species may act as epidemic/epizootic bridge vectors [56]. While most infections are asymptomatic, systemic illness may include fever, chills, malaise, myalgia, and arthralgia, and fewer than 5% of cases develop neuroinvasive disease such as meningitis or encephalitis [187]. Among those with neuroinvasive disease, approximately one-third die, and most survivors experience significant long-term neurological sequalae [188].

EEE is one of the most severe mosquito-borne diseases in North America. In the last two decades, the number and frequency of human cases have increased in the northeastern United States [189]. The reasons for this increasing trend are complex and not entirely clear but likely reflect environmental changes that support mosquito densities and virus amplification [189]. Similarly, EEEV activity (positive mosquito pools, infected horses and human cases) has also increased in southeastern Canada—particularly in southern Ontario and Quebec.

As EEE infection is not nationally notifiable in humans in Canada, there is currently no official national surveillance system in place to monitor, track, and report cases. Therefore, human case counts may be underestimated. Moreover, case definitions by province/territory, if available, may vary and may lead to discrepancies regarding how a case is defined and reported.

Between 2013 and 2022, there were three confirmed human cases of EEE detected in Canada (Ontario) in 2016 (n = 1), 2021 (n = 1) and 2022 (n = 1). The case in 2016 represents the first reported case of EEE in Canada. In Ontario, these cases were reported as encephalitis due to EEE, which is a reportable condition in the province. While there is limited data for EEE cases in humans in Canada, data from the U.S. suggests that over 80% of reported human EEE cases have an illness onset date between July and September [190].

Important Update: Eastern equine encephalitis, 2023 to 2025

Between 2023 and 2025, there has been a rise in activity related to eastern equine encephalitis in Canada and the northeast United States noted in both human and animal populations. In 2023, 22 horses tested positive for EEEV in Ontario, Quebec and New Brunswick, which was higher than the average number of horses positive for EEEV in the five years prior. The following year, in 2024, 39 horses tested positive for EEEV in the same provinces. Additionally between 2024-2025, at least seven human cases (probable/confirmed) were identified across Ontario and Quebec [188]. Across the border in the United States, EEEV activity also surged during the same period, with at least 19 confirmed human cases in 2024, primarily in the Northeast including Maine and Vermont [189].

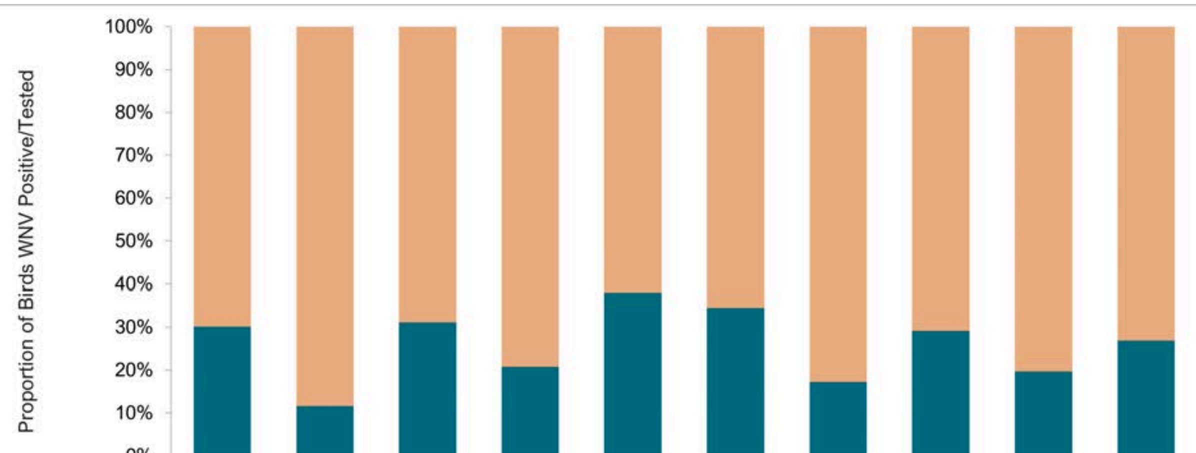
The importance of One Health surveillance in the context of mosquito-borne diseases

Mosquito-borne disease transmission is complex and relies on dynamic interactions between populations of humans, animals, and mosquitoes as well as the environment [165,168,193,194]. In the transmission cycle of WNV, EEEV and CSGV, humans are incidental hosts, and while they can become infected, they do not contribute to the pathogen's spread in the transmission cycle. Both WNV and EEEV are maintained through mosquito-bird enzootic transmission cycles [168,188]. A large variety of passerine birds act as reservoir hosts for WNV and EEEV. California serogroup viruses are thought to be amplified in an enzootic transmission cycle between mosquitoes and wild ungulates, including deer, and other small mammals, such as hares and squirrels [165,178]. Horses, while dead-end hosts, are particularly susceptible to encephalitis related to both WNV and EEEV and serve as indicators of viral activity in rural areas [168,188]. Different animal species have varying levels of susceptibility to MBD pathogens; some may carry MBDs without showing symptoms, acting as a reservoir host, while others are more likely to develop serious illness.

Birds

West Nile virus was first detected in Canada in wild bird populations in 2001, prior to any reported human cases. In the years following the introduction of the virus, widespread mortality in many bird species was recorded, which acted as an early indicator for increased WNV activity, and informed geographical risk [195,196].

Beginning in 2001, the Canadian Wildlife Health Cooperative, in conjunction with provincial/territorial jurisdictions coordinated a national surveillance project to monitor dead wild birds across Canada. Since then, monitoring has continued as part of the One Health surveillance efforts, with approximately 300 birds per year being tested for WNV since 2009 (Figure 14). Between 2013 and 2022, birds have tested positive for WNV across Canada in nearly all provinces: British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, Quebec, New Brunswick, Nova Scotia, and Prince Edward Island.

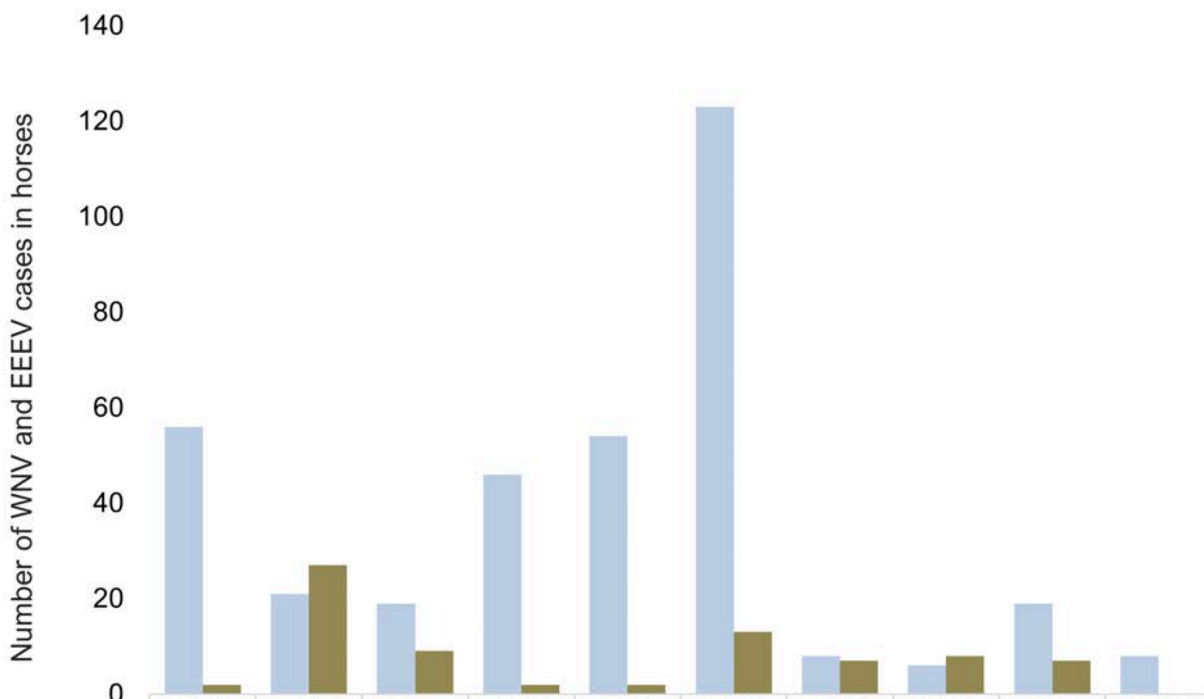


	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Number Tested	201	121	97	141	239	320	220	102	102	345
Number Positive	87	16	44	37	147	169	46	42	25	127

Figure 14. Proportion of WNV-positive birds versus birds tested for WNV, in 2013 to 2022, as reported by the Canadian Wildlife Health Cooperative to the Public Health Agency of Canada (n = 1,888)

Horses and other animals

In Canada, WNV and EEE are Immediately Notifiable Diseases in animals, whereby laboratories are required to contact the Canadian Food Inspection Agency (CFIA) regarding the suspicion or diagnosis of WNV or EEE in horses (and other domestic animals). Between 2013 and 2022, the CFIA reported 77 EEE cases in horses from three provinces: Nova Scotia, Quebec and Ontario. For WNV, 360 WNV cases in horses occurred in the following provinces: British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, Quebec (Figure 15). Mortality of horses with encephalitis from flavivirus infections (e.g., WNV) is 35–45% and from EEEV infections is 70–90% [188,197]. A vaccine is available for horses in Canada for both WNV and EEEV, so fluctuation of case counts in horses may be influenced by vaccine uptake and may be lower in years where more horses are protected by the vaccine.



	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
WNV	56	21	19	46	54	123	8	6	19	8
EEEV	2	27	9	2	2	13	7	8	7	0

Figure 15. Number of horses positive for WNV and EEEV, as reported by Canadian Food Inspection Agency, 2013 to 2022 (n = 437)

Studies have found JCV and SSHV are widespread across vertebrate species in Canada [198]. In one study looking at JCV, an arbovirus belonging to the CSG of bunyaviruses, overall seroprevalence was 88% in hunted deer in Nova Scotia [177]; another study found widespread exposure to CSGV in wildlife across northern Canada (including British Columbia, Northwest Territories, Manitoba, Quebec, Nunavut and the Yukon) with climate change thought to be playing a critical role in CSGV seroprevalence in these regions [199] .

Mosquitoes

Mosquito surveillance has been an integral part of the WNV surveillance system in the past 20 years, with these surveillance activities carried out by government, non-government agencies or academic institutions. Over time, this surveillance has evolved to include new species of public health importance, as well as the detection of new disease-causing pathogens. The number of provinces/territories participating in WNV mosquito surveillance has varied year-to-year, and during the reporting period of 2013 to 2022, percent positivity of mosquito pools for WNV ranged from <1 to ~3% in the following jurisdictions: British Columbia, Saskatchewan, Manitoba, Ontario, and Quebec.

Ontario is the only province that tests mosquito pools for the presence of EEEV. In Ontario, six mosquito pools tested positive for EEEV in 2013 (n = 1), 2017 (n = 1), 2019 (n = 1) and 2021 (n = 3), and were detected in the following species: *Coquillettidia perturbans*, *Aedes vexans*, *Culiseta melanura*, and *Culex erraticus*. Unlike WNV and CSGVs, percent positivity for EEEV ranged from <1 to 2%; however, there have been some questions raised about whether vector surveillance methods used are optimal for detection of the EEEV vector, *Culiseta melanura* [200].

In Quebec, mosquito pools were tested for CGSVs in 2016, and found that 2% were positive for these viruses [201].

In 2004, the Government of Northwest Territories commenced sampling of mosquito populations for CSGV–competent vectors, and in 2005, the seven species of adult mosquitoes known to be carriers were found [202]. In 2018, mosquito pool testing for CSGV commenced. In 2020, 30 (32.6%) of the 92 mosquito pools tested positive for CSGV, with collection dates of positive pools ranging between mid-June and mid-August. Mosquito pool testing continued in 2021 and 2022, with percent positivity ranging from 39 to 42%, respectively [203,204].

Impact of Climate Change on MBDs in Canada

Climate change has already impacted people living in Canada—with observed increases in overall temperature, extreme heat and heavy rainfall events, as well as fewer frost days [165]. Arthropod vectors like mosquitoes are cold-blooded, and therefore especially sensitive to climatic factors, causing disruption to their reproductive and feeding behaviours [165]. In particular, climate change is warming the Arctic at an increased rate and could change the diversity and activity of vectors in this area of Canada dramatically [205,206].

It is anticipated that climate change will impact the suitable range, length of transmission season, replication rates of viruses, and local abundance of mosquito species that carry the pathogens that cause human disease in Canada [188,194]. Climate change will likely lead to more epidemics of endemic MBDs (e.g., WNV), while also increasing the potential for imported cases and/or establishment of exotic MBDs into Canada [167].

As described in the report "*Health of Canadians in a Changing Climate (2022)*", there are three scenarios for the introduction of exotic MBDs into Canada:

- The importation of pathogens currently exotic to Canada through international movements and their subsequent establishment in Canada where mosquito vectors and competent hosts are already present (e.g., as has happened in the past with WNV and could occur in the future with Japanese encephalitis virus, malaria, among others) [207].

- The importation of exotic viruses (e.g., chikungunya, dengue, and Zika viruses, among others), as well as the establishment of vectors capable of transmitting these diseases, because of increased climatic and habitat suitability of these vectors.

- The local spread of endemic pathogens in bordering U.S. regions—which are not currently endemic in Canada, but where vectors and competent hosts are already established—creates conditions where endemicity is plausible via increasingly suitable conditions (e.g., St. Louis encephalitis).

Regional ecological niche models have been used to assess climatic suitability for invasive species that typically transmit dengue, chikungunya, Zika, and yellow fever viruses under current and projected climates [208]. Under the projected climates, some simulations predicted northward and northwestern expansion of ecological niches for both *Ae. albopictus* and *Ae. aegypti*, reaching the densely populated southcentral regions of Ontario, the southern border of Quebec and British Columbia by 2100, leaving a high number of people at potential risk [208].

ZOONOTIC AND ONE HEALTH STORIES

This section present a series of special topics highlighting emerging zoonotic threats and complex public health challenges that reinforce the need for a One Health approach. Featured issues include the evolving threat of avian influenza A(H5N1), the animal-related aspects of the COVID-19 pandemic in Canada, and the emergence of the tapeworm *Echinococcus multilocularis*. These narratives also address broader themes, such as climate-driven zoonotic risks affecting Northern and Arctic Indigenous communities and provide overviews of enteric zoonotic outbreaks and travel-acquired infections. Collectively, these narratives underscore the importance of collaborative action and adaptive surveillance in addressing zoonotic diseases across Canada.

THE EVOLVING THREAT OF AVIAN INFLUENZA A(H5N1)

Avian influenza, commonly referred to as bird flu, is an influenza A virus. These viruses circulate widely among wild birds and domestic poultry in many regions and can occasionally infect other animals and humans. Numerous subtypes of avian influenza exist, but the A(H5N1) subtype has been associated with major outbreaks in animals. Human infections with A(H5N1) have occurred sporadically, typically following exposure to infected animals or contaminated environments. A key concern is the potential for genetic reassortment between influenza strains, which could lead to the emergence of a pandemic strain. In humans, illness can range from mild to severe and can be fatal. While the respiratory tract is most commonly affected, gastrointestinal and central nervous system involvement have been reported [209]. Treatment is primarily supportive with the use of antiviral agents in certain cases, especially when initiated early. Historically, the case fatality rate of avian influenza A(H5N1) was approximately 50%. However, based on available human case data since 2022, the case fatality rate of current circulating strains is estimated at around 10% [209].

The unprecedented shift in the ecology and epidemiology of highly pathogenic avian influenza A(H5N1) in 2021 has had, and continues to have, profound consequences for wildlife, domestic animals, agriculture, economies, and communities in Canada and across the world. Where historically the virus had typically been geographically restricted to East and Southeast Asia, it has now spread globally, causing a panzootic in a diversity of avian and mammalian species. The magnitude of this influenza virus in new regions and in a number of human-animal-environmental interfaces is worrisome, not only for A(H5N1)'s tremendous impact on animals, but also because it is a known zoonosis. Humans have sporadically been infected with A(H5N1) typically following exposure to infected domestic poultry. Although A(H5N1) remains a sporadic zoonosis, its high case fatality rate is deeply concerning—especially given the influenza virus's inherent capacity to evolve and reassort, potentially acquiring the ability to transmit more efficiently to and among humans [210]. In order to effectively protect the health and safety of people and animals, resources and collaboration across sectors and One Health partners are required.

Origin Story: 1996

In 1996, a novel A(H5N1) lineage, A/goose/Guangdong/1/96, emerged in domestic poultry in China. This lineage wasn't recognized as a human pathogen until an outbreak in Hong Kong the next year in which 18 people were infected and 6 died [210]. Since then, this virus has continued to evolve through mutation and reassortment events, giving rise to numerous clades, subtypes and genotypes, fueled by repeated transmission between domestic poultry and wild bird populations [211].

In the intervening years between 1997 and the current panzootic, this lineage has caused die-offs in wild birds, outbreaks in poultry farms, and occasional zoonotic transmission to humans [210]. Sporadically, the virus would reach North America via migratory bird flyways in the past, where it would cause outbreaks in domestic poultry, such as in British Columbia in 2014–2015, after re-assorting with North American lineage low-pathogenicity avian influenza viruses [212]. Control measures, such as culling, helped stop these domestic poultry outbreaks and in the case of the 2014–2015 incursion, the virus disappeared from the wild bird population in North America within a year [210,212].

The Big Shift

A big shift in the ecology and epidemiology of A(H5N1) began in 2020, when clade 2.3.4.4b viruses surged and expanded in Eurasia [210]. In the fall of 2021, A(H5N1) clade 2.3.4.4b was introduced to North America in eastern Canada by migratory wild birds traveling along the Atlantic Flyway from Europe [213]. In early 2022, a second incursion involving a different A(H5N1) clade 2.3.4.4b genotype entered British Columbia through the Pacific Flyway [213]. This resulted in the concurrent circulation of both A(H5N1) strains in Canada, causing severe impacts on wild bird populations and domestic poultry and exceeding the scale of all previous avian influenza A(H5) outbreaks (Figure 16).

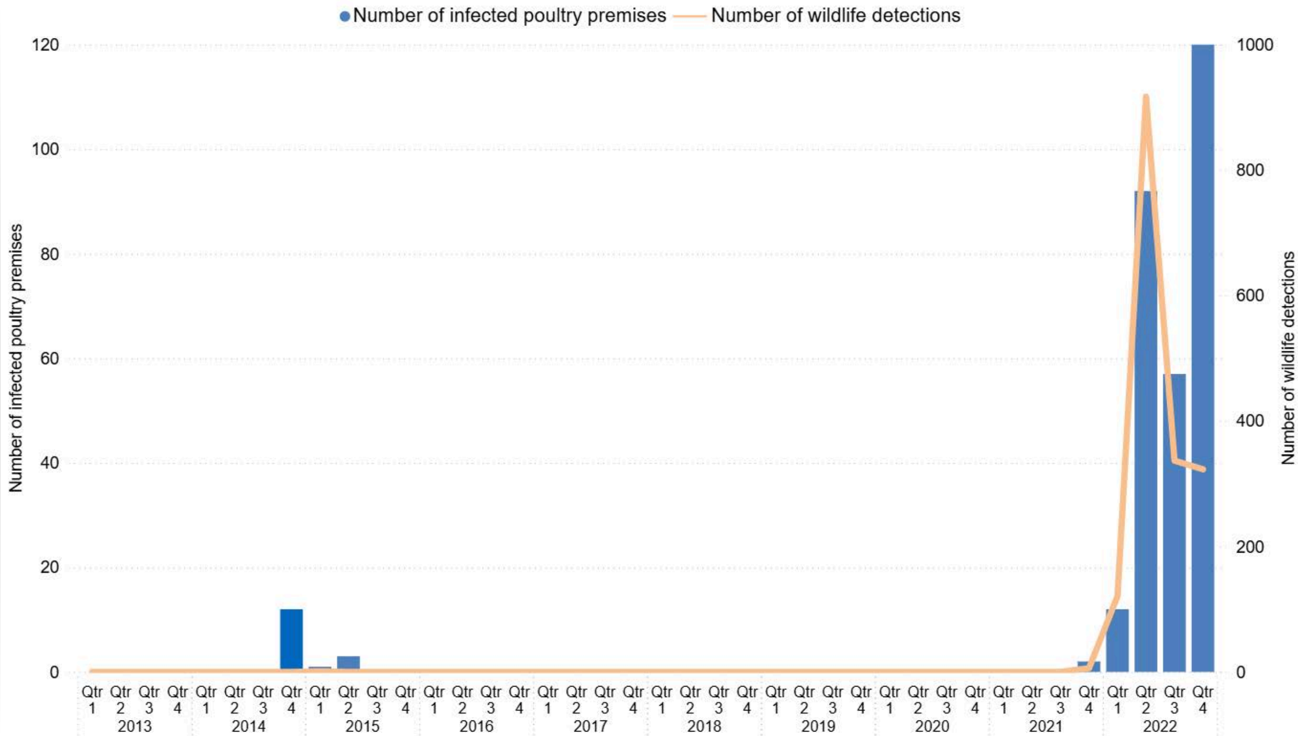


Figure 16. Highly pathogenic avian influenza A(H5NX) detections in Canada by infected poultry premises (columns) and wildlife (line), 2013 to 2022

Domestic poultry

Since the first poultry detection in Newfoundland at the end of 2021, avian influenza A(H5N1) has had a massive impact on domestic poultry in Canada, with over 14 million birds dead or culled as of June 2025 [214]. Outbreaks have affected both commercial operations and non-commercial (backyard or small holder) flocks across the country, but have been particularly concentrated in British Columbia, likely given the high-density poultry farming in the Fraser Valley being co-located with optimal habitats for waterfowl [215]. The consequences for the agricultural sector across the country have been severe, not only financially but also in terms of mental health for farmers and responders due to the stress of large-scale culling [216]. Highly pathogenic avian influenza A(H5N1) represents one of the most significant animal health emergencies Canada has ever faced. Ongoing disruptions in the poultry sector continue to pose challenges for the industry, with the potential to affect food security and pricing [216]. Importantly, farms serve as a significant point of zoonotic transmission, highlighting the critical need for robust animal surveillance to promptly identify and contain outbreaks at the wildlife-agriculture interface.

Wild Birds

A(H5N1) may also represent the most severe infectious disease event ever recorded in wild birds in Canada, in terms of both the number of individual birds affected and the diversity of species impacted [217]. Though wild aquatic birds can act as reservoirs for the virus, many susceptible wild bird species have experienced significant mortality events [217]. It is estimated that approximately 11% of the North American Northern Gannet breeding population has died as a result of A(H5N1)—with potential long-lasting population impacts [218]. Northern Gannets are just one example of at least 80 different wild bird species that have been affected by the panzootic in Canada [217]. It is important to recognize that Canada's dead bird surveillance system is largely passive and opportunistic, meaning that recorded mortalities significantly underestimate the true scale and diversity of the impact of highly pathogenic avian influenza A(H5N1) on wild bird populations [217].

Wild Mammals

In the spring of 2022, a number of wild mammals were detected with neurological signs in North America [219–221]. While rabies is typically among the first differential diagnoses considered for wild terrestrial mammals with neurological signs, it was rapidly determined that these animals were instead infected with, and often succumbing to, avian influenza A(H5N1). Although sporadic cases of A(H5N1) in mammals had been reported previously, the scale and severity of infections observed since the onset of the panzootic were unprecedented [222]. In Canada, ten different species of wild mammals have been confirmed to be infected with A(H5N1), including striped skunk, red fox, raccoon, black bear, bobcat, wild mink, ringed seal, harbor seal, gray seal, and Atlantic white-sided dolphin [223]. In the United States, additional mammalian species detected include polar bear, opossum, muskrat, mountain lion, grizzly bear, and coyote—in addition to captive mammalian species such as tiger and serval [224]. Since the onset of the panzootic, there have been 40 new mammalian species reported globally that have been naturally infected by A(H5N1) [222].

This particular strain of A(H5N1) appears to exhibit a strong neurotropism in certain mammalian species [225,226]. Most wild mammals were likely infected through the consumption of infected birds [222]. However, mass die-offs of marine mammals in South America are believed to have resulted from exposure to environments heavily contaminated by infected wild birds, with evidence also suggesting subsequent mammal-to-mammal transmission [227]. To date, Canada has not experienced mass mortality events in wild mammals comparable to those seen in South American marine mammal populations. Nonetheless, continued vigilance is essential, as further viral adaptation in mammals could increase the pandemic potential of A(H5N1) in humans.

Companion Animals

In addition to wild mammals, some domestic mammals—including cats and dogs in Canada—have also tested positive for A(H5N1), most likely after consuming or being exposed to infected birds [228]. Feline A(H5N1) cases in other countries have also been linked to contaminated raw milk and raw pet food, as well as wild bird and environmental exposures [229–231]. Although transmission from companion animals to humans has not been reported for A(H5N1), past instances involving other avian influenza subtypes such as A(H7N2) highlight the importance of ongoing awareness regarding cases in companion animals [232].

Important Update: Dairy Cattle Infections in the United States

In February 2024, dairy cattle in Texas developed a nonspecific illness that stymied veterinarians. It wasn't long before veterinarians connected the dots to A(H5N1) when they learned that wild birds on the farms were dead and dying – the case was cracked [229,233].

Hundreds of dairy farms in at least 17 U.S. states have now been affected. Pasteurization mitigates the risk of A(H5N1) transmission to the general population, but workers exposed to infected cattle and raw milk have developed mild clinical illness, after exposure to infected cattle or being splashed in the eyes with raw milk [234]. To date, Canada has not detected A(H5N1) in dairy cattle or milk, unlike the U.S., where genomic evidence suggests multiple wild bird-to-cow transmission events followed by cow-to-cow transmission. Given this risk, Canadian authorities, including the CFIA and provincial and dairy industry partners, are proactively testing milk for A(H5N1) nationwide.

A(H5N1) in Humans & Surveillance in Canada

Though human cases are rare, the possibility for severe infection with A(H5N1), combined with the potential to mutate or reassort with human-adapted influenza strains, is concerning from a pandemic potential perspective. Given that reassortment has been the underlying cause behind three of the last four influenza pandemics—and considering the increased likelihood of reassortment due to the vast scale of viral circulation in the current panzootic—public health concerns surrounding this virus are heightened [235]. To date, there is no evidence of sustained human-to-human transmission of A(H5N1), but the early identification of human cases is essential to a robust public health response.

In Canada, human A(H5N1) cases may be identified through several surveillance mechanisms. Individuals known to be exposed to avian influenza, such as on infected poultry farms, are advised to self-monitor, and consult with a health care provider if symptoms develop so that testing and preventive treatment can be offered [236]. FluWatch+ is Canada's national surveillance system that monitors endemic and emerging respiratory viruses. It is a comprehensive system with multiple surveillance objectives including the detection and assessment of emerging or re-emerging respiratory viruses.

The system is composed of several data streams aimed at identifying signals or cases of avian influenza including the Severe Acute Respiratory Infections (SARI) data stream. SARI surveillance helps detect serious respiratory illnesses of unknown origin in hospital settings. For example, if diagnostic tests identify influenza A, but subtyping results are not consistent with common human flu strains (e.g., H3N2 and H1N1), samples are sent to the National Microbiology Laboratory (NML) for further characterization. In 2014, SARI surveillance detected Canada's first and only fatal case of A(H5N1) in a Canadian that had acquired the infection when travelling in Beijing.

Important Update: Human case of A(H5N1), British Columbia, 2024

The majority of globally detected A(H5N1) human cases since 2024 have been located in the United States of America following exposures to infected dairy cattle, a surprising and unexpected host for this influenza virus. Most of these recent dairy-exposure cases in the U.S. have been mild. However, several severe cases and one death have been reported in a person exposed to backyard poultry [234,237].

In late 2024, Canada's first locally acquired human case of A(H5N1) was detected in a teenager in British Columbia. A One Health investigation, which included testing of household pets, animals from nearby premises, and environmental testing (i.e., soil and water), did not identify a definitive exposure source. The teenager had been infected with the same strain of avian influenza A(H5N1) that was concurrently circulating in wild birds and poultry in British Columbia [238]. The individual has thankfully recovered, but this is a strong reminder of the severe potential for illness and the need for continued preparedness and coordination between public health and One Health partners to prevent transmission.

Indigenous Peoples and Avian Influenza A(H5N1)

Like other major, emerging, and re-emerging zoonotic diseases, avian influenza A(H5N1) poses significant risks to Indigenous Peoples, whose health, nutrition, livelihoods and deep cultural connections to the land and surrounding environments are closely tied to traditional food. Hunting, field dressing and handling of wild birds and mammals may increase the risk of A(H5N1) exposure and infection. Mitigating risks and supporting effective public health measures that integrate Indigenous knowledge and perspectives is foundational to supporting a national response to avian influenza.

Canadian Public Health and A(H5N1)

Behind the scenes, Canada's public health system is actively working to monitor, prepare for, and mitigate the risks of avian influenza. Though the risk of A(H5N1) infection for the general population in Canada is low, the risk is increased for persons who are directly exposed to infected animals and/or highly contaminated environments [239], emphasizing the need for continued surveillance and readiness to respond. Given the wide range of regions and species now affected by the virus, the number of human–animal interfaces where exposure to A(H5N1) can occur has increased sharply compared to previous outbreaks.

A Continued One Health Response

Due to the persistent presence of A(H5N1) in Canada, local, Indigenous, provincial/territorial and federal public health organizations continue to engage with agricultural, environmental/wildlife and industry partners, both domestically and internationally. Ongoing planning and preparedness work includes risk assessments, lab capacity and testing, monitoring and surveillance, science coordination and expert engagement, guidance for health professionals and other affected occupations in Canada, educating the public, as well as medical countermeasure readiness which includes vaccines and antivirals [240].

Although A(H5N1) has been recognized as a potential pandemic threat for over 25 years, it has not yet resulted in a human pandemic—an outcome that has provided some reassurance [210]. However, the current clade 2.3.4.4b strain of A(H5N1) has undergone extensive reassortment with North American avian influenzas resulting in high genotypic diversity with a broader host range—traits that distinguish it from previous clades [210,213,241]. In Canada, response efforts have been closely coordinated across agricultural, environmental, and public health sectors. Continued collaboration with public health remains important to help mitigate the risk of human infection and to support a coordinated, cross-sectoral response to A(H5N1) clade 2.3.4.4b.

COVID-19 IN CANADA: THE ANIMAL ANGLE

SARS-CoV-2 is a coronavirus that causes COVID-19. A wide range of mammals are susceptible to coronaviruses in both experimental and natural settings [242]. Most animals infected with SARS-CoV-2 do not develop noticeable clinical signs [263]. However, some infected animals may show signs of illness, including respiratory and gastrointestinal manifestations [263]. In humans, illness most commonly affects the respiratory system, and can range from asymptomatic or mild to severe disease. Individuals with underlying medical conditions and older adults are at higher risk of severe outcomes. In Canada, approximately 80% of COVID-19 deaths in 2020 occurred among adults aged 65 years or older [243]. Despite its ability to infect many mammalian species, the COVID-19 pandemic was driven by human-to-human transmission.

In late December 2019, China reported a cluster of severe acute respiratory syndrome cases of unknown origin, which were later identified as being caused by SARS-CoV-2—the virus responsible for COVID-19 [244]. The ensuing pandemic triggered a global response which had profound health, societal, and economic impacts [245].

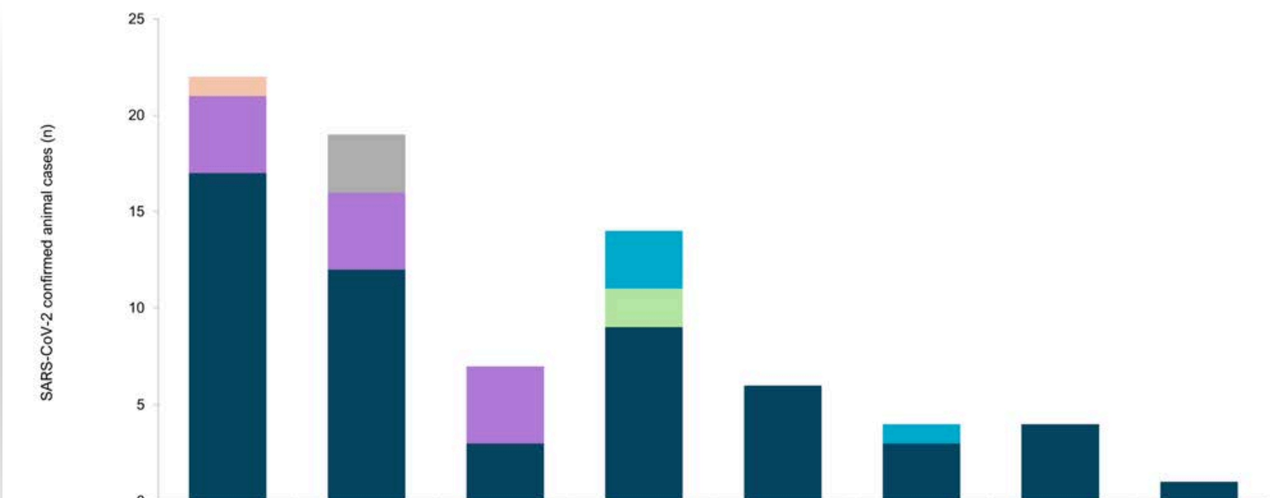
Given that coronaviruses are known to evolve rapidly, cross species barriers, and spread across diverse host ranges [246], there was widespread concern about the potential for zoonotic transmission to influence the spread and severity of SARS-CoV-2 in humans [247].

In Canada, an informal time-limited working group comprised of federal, provincial/territorial and academic representatives from human, animal and environmental sectors, were mobilized to address unresolved questions about the potential role of animals in the COVID-19 pandemic in Canada. The following sections outline how time-limited surveillance, targeted research, and One Health investigations were used to detect SARS-CoV-2 in animals in Canada and how this information helped guide public health activities.

Overall detections of SARS-CoV-2 in animals in Canada

Between June 2020 and December 2022, 77 animals (12 cats, 1 dog, 3 mink farms, 4 mule deer, 2 captive lions, and 55 white-tailed deer) were confirmed positive with RT-PCR for SARS-CoV-2 by the National Centre for Foreign Animal Disease (NCFAD) [248]. Overall numbers of animals tested are challenging to ascertain, given multiple surveillance streams and research studies. However, several thousand animals were tested during this time period, the vast majority of which were wild. Among cervids sampled between June 2020 to October 2022, 2.8% (n = 49/1727) of white-tailed deer and 1% (n = 3/300) of mule deer tested positive by RT-PCR. Over 3,000 samples from other wildlife, including moose, caribou, elk, rodents, felids, canids, skunks, raccoons, and bears, tested negative by RT-PCR [249]. Approximately 100 animals, the majority of which were companion animal species such as cats and dogs, were tested at private veterinary laboratories (PHAC, personal communication).

The number of animals confirmed to be infected with SARS-CoV-2 in Canada was relatively low, especially when considering the widespread prevalence of the virus in humans and the broad host susceptibility observed across species. Natural host resistance may have prevented infections in some species and contexts. It is also possible that additional infections went undetected due to being sub-clinical, as well as limitations in animal surveillance, including constraints related to cost, logistical feasibility, and limited awareness among partners.



	ON	BC	QC	AB	NS	MB	SK	NB
Mule deer	0	0	0	3	0	1	0	0
Mink	0	3	0	0	0	0	0	0
Lion	0	0	0	2	0	0	0	0
Dog	1	0	0	0	0	0	0	0
Cat	4	4	4	0	0	0	0	0
White-tailed deer	17	12	3	9	6	3	4	1

Figure 17. SARS-CoV-2 RT-PCR positive cases in animals confirmed by the National Centre for Foreign Animal Disease (NCFAD) in Canada by province and species: June 2020 to December 2022 (n = 77)

Note that "Mink" denotes a mink farm with multiple mink on-farm that were infected.

SARS-CoV-2 in Companion Animals

Concern around the roles that companion animals (e.g., dogs and cats) might play in SARS-CoV-2 transmission occurred early in the COVID-19 pandemic. In February 2020, a Pomeranian in Hong Kong tested positive for SARS-CoV-2 after its' owner was diagnosed with COVID-19 [247]. This first case in a dog sparked fear, with many people concerned that they might acquire COVID-19 from their pets [247]. To address uncertainties, global research and surveillance efforts aimed to shed light on what roles animals might have in the COVID-19 pandemic.

In Canada, the mobilized One Health informal time-limited working group worked together to determine priorities, objectives and mechanisms to address concerns related to SARS-CoV-2 in companion animals. Through the collaborative work of this group, guidance for the public and veterinary and other animal-related occupations was developed based on the available scientific evidence, to support best practices in preventing transmission of SARS-CoV-2 between species, including humans. Additionally, laboratory testing for animals was developed and instituted, with testing occurring via research studies, within private veterinary laboratories and select surveillance projects.

In total, 13 companion animals (12 cats and 1 dog) were confirmed infected with SARS-CoV-2 between 2020-2022 in Canada (Figure 17). International studies indicated there was no evidence for circulation of SARS-CoV-2 between cats and that most frequently, the direction of infection was from humans-to-cats [250]. Data from a Canadian study suggested that transmission of SARS-CoV-2 was typically from humans-to-animals and that certain human-animal interactions such as kissing a pet or a pet sleeping on the bed appeared to increase the risk of transmission [251]. The zoonotic risk posed by dogs is probably lower than for cats, given the lower infection rate in dogs, but further study is needed [251,252].

SARS-CoV-2 in Farmed Mink in Canada

Following an increase in mortality among mink on a fur farm in British Columbia in December 2020, testing revealed that affected animals were positive for SARS-CoV-2 [253]. Canadian animal and public health officials were concerned given experiences in the Netherlands and Denmark, where SARS-CoV-2 novel variants developed in mink farms and spread from the mink farms back into the community [253,254]. These events highlighted the possibility of variant development with the potential for increased transmissibility and/or disease severity in humans following adaptation in a novel host [253,254].

A comprehensive One Health epidemiologic investigation and response, involving provincial animal health, public health, worker safety and industry regulation organizations, was enacted in British Columbia following the detection of SARS-CoV-2 in mink. The investigation found evidence of SARS-CoV-2 transmission from humans to mink and also from mink to humans on the fur farms [252,250]. Wildlife adjacent to the farms were also captured and tested over concerns about the establishment of animal reservoirs. However, only escaped domestic mink tested positive for SARS-CoV-2 [253]. This investigation was a prime example of a One Health approach to respond to complex and evolving threats like COVID-19.

SARS-CoV-2 in Wildlife

Following the detection of SARS-CoV-2 in white-tailed deer in the United States in December 2021, concerns emerged regarding the potential implications for wildlife in Canada [249]. These concerns echoed those raised during the detection of the virus in farmed mink, particularly around the risk of variant development and the emergence of strains with increased transmissibility or severity in humans. This situation was further complicated by the possibility of SARS-CoV-2 establishing a persistent wildlife reservoir, which would pose significant challenges for disease management and control [249,257].

In response, a national SARS-CoV-2 wildlife surveillance program was developed by Environment and Climate Change Canada in collaboration with other federal agencies such as the CFIA, PHAC, and Parks Canada, as well as the provinces, territories, academic institutions, and the Canadian Wildlife Health Cooperative (CWHC) [249]. This surveillance program opportunistically sampled target wildlife species known or suspected to be susceptible to SARS-CoV-2 across much of Canada [249].

Additionally, a whole genome sequencing (WGS) study in Ontario provided evidence for a divergent SARS-CoV-2 viral lineage and transmission between deer, as well as a suspected occurrence of deer-to-human transmission [258]. These findings amplified concerns that white-tailed deer may function as a competent wildlife reservoir for SARS-CoV-2, with the potential to sustain viral circulation and facilitate the emergence of novel variants with increased pathogenicity and/or transmissibility to humans. Though wildlife reservoirs have the ability to fundamentally alter infectious disease ecology, SARS-CoV-2 in deer has not appeared to impact this species or the course of the COVID-19 pandemic in humans.

SARS-CoV-2 in Zoos

Zoos worldwide, including in Canada, reported SARS-CoV-2 infections in zoo animals during the COVID-19 pandemic [259]. Two female lions at the Calgary Zoo tested positive after showing mild respiratory signs, though they recovered without issue [260]. While detections of SARS-CoV-2 in feline species were not surprising, the detection in captive lions underscored the need to better understand the varied interfaces where SARS-CoV-2 transmission could occur, and the importance of biosecurity measures, especially with respect to rare or conserved species.

SARS-CoV-2 and Livestock

No Canadian livestock—such as horses, cows, pigs, and sheep—were confirmed to have SARS-CoV-2 during the pandemic. However, the pandemic and associated public health responses had significant indirect impacts on the livestock industry. In the spring of 2020, the rate of livestock slaughter declined in Canada (and elsewhere) due to sanitary measures, workforce shortages caused by COVID-19 illness, and reduced demand for meat following the downturn in hotel and restaurant operations. As a result, many producers were forced to keep animals on the farm for extended periods instead of sending them for slaughter, incurring substantial financial costs and negatively affecting animal welfare [261]. Livestock industries often operate within intensive and highly integrated production systems, which offer limited flexibility in the face of disruptions. The closure of slaughter plants created immediate bottlenecks in the supply chain, leading to overcrowding of animals on farms—a serious animal welfare concern [262]. This serves as a powerful reminder of the broader disruptions pandemics can cause across species—even those not directly infected.

Public Health Actions

Given the negligible role animals played in sustaining the ongoing pandemic, Canadian public health actions related to COVID-19 and animals focused primarily on reassuring the public that the risk was low [263] and on providing practical guidance to prevent SARS-CoV-2 transmission between humans and animals. One Health collaborators conducted rapid qualitative risk assessments to evaluate threats at the human-animal-environment interface and support informed decision-making. Based on these assessments, along with targeted surveillance and research, public guidance was developed and made available, offering practical recommendations to reduce transmission risks—particularly for pet owners, hunters and trappers, and wildlife professionals with occupational exposures to wild animals [264].

In addition to guidance and public reassurance, policy changes stemmed from the detection of SARS-CoV-2 in farmed mink in BC. Concerns about the virus potentially mutating within mink populations and subsequently spreading to humans, among other concerns, prompted the government of BC to begin phasing out mink farming in the province [265].

One Health Collaboration

The detection of SARS-CoV-2 in animals underscores the broad susceptibility of multiple species and highlights the critical need for vigilance against bi-directional transmission between animals and humans, which poses risks to both animal health and public health during infectious disease outbreaks. Surveillance in animals, including domestic and wild, is essential in pandemic preparedness, prevention and response. Fortunately, animals played a minimal role in the COVID-19 pandemic. However, the ability to leverage collaborative Canadian One Health networks to address key questions was crucial for maintaining scientific integrity and reassuring the public about potential risks.

CLIMATE-DRIVEN ZOONOTIC CHALLENGES IN NORTHERN AND ARCTIC INDIGENOUS COMMUNITIES

Prepared by: Indigenous Services Canada, Sharon Edmunds (Senior Research Manager, NTI) and Jamal Shirley (Director of Innovation and Research, NAC)

The effects of climate change may be more pronounced in Canada, where warming is occurring at twice the rate of the global average, and nearly three times faster in its northern regions [266]. Rising temperatures and changing precipitation patterns may facilitate the emergence and northward spread of zoonotic pathogens, impacting the health of local wildlife populations relied upon for hunting and trapping [267]. This accelerated warming intensifies climate-related pressures on Indigenous food systems in the north, particularly with respect to food safety and security.

Indigenous hunters, who maintain deep connections to their environments and play critical roles in community food systems, are increasingly exposed to zoonotic disease risks as a direct result of the handling of wild game. Heightened concerns over the safety of "country food" may reduce confidence in traditional diets, which are currently vital to health, nutrition, and cultural identity [268–270]. Coupled with a shift toward more expensive, less nutritious, and often calorie-dense and ultra-processed store-bought foods, diminished engagement in traditional dietary practices may further entrench food insecurity and deepen the health inequities faced by Indigenous Peoples [268,269].

Zoonotic pathogens, including *Toxoplasma gondii*, *Erysipelothrix rhusiopathiae*, and *Trichinella* species (spp.), are among several that pose emerging food safety and security concerns for First Nations, Métis, and Inuit. Community-led detection programs, such as those for *Trichinella* spp., highlight innovative approaches to promote safer consumption of traditional foods.

Toxoplasma gondii

Toxoplasmosis is an infection caused by the protozoan parasite, *T. gondii*, which is typically asymptomatic or associated with mild flu-like symptoms. However, it can lead to severe and potentially life-threatening illness when transmitted congenitally or to those who are immunocompromised [271–273]. Transplacental transmission may result in spontaneous abortion, stillbirth, premature birth, or neurodevelopmental and ocular disorders in offspring [271,274]. Immunocompromised individuals may experience severe flu-like symptoms and other potentially serious complications; latent infections can also reactivate following HIV infection or immunosuppressive medical treatments [273].

A study conducted in 2004 found that 59.8% of Inuit in Nunavik had measurable antibodies against *T. gondii*, compared to 10 to 20% of the general population living in North America [271,274]. More recent data from Nunavik in 2017 suggested a seroprevalence of 42%, which was still two to four times greater than that of the general North American population [275].

Other surveys have reported regional variation, with seroprevalences of 32.4% among adults in Nunavut, 11.3% in Nunatsiavut, and 7.5% in the Inuvialuit Settlement Region [276]. These rates suggest that certain Arctic populations may carry a higher burden of disease.

A regional serological screening program for pregnant women, initiated in Nunavik in the early 1980s, found that maternal seroconversion—a biomarker for congenital *T. gondii* exposure—was 1.8%, compared to 0.2% in the rest of Canada [277]. Among live births recorded in Nunavik between 1994 and 2003, 1.9% of mothers who were seronegative at the start of pregnancy experienced possible, probable, or confirmed seroconversion. With appropriate treatment, no congenital abnormalities linked to toxoplasmosis were identified in newborns. However, the study did not include pregnancies resulting in spontaneous abortion or stillbirth, and delayed presentations of congenital toxoplasmosis that may have manifested later in childhood or adolescence could not be ruled out [278]. In 2023, a maternal screening program for toxoplasmosis was also introduced in Nunavut [279]. For the general Canadian population, routine prenatal screening is not recommended for those considered at low risk [280,281].

Handling and consuming certain wildlife species, such as shellfish, fish, birds, and marine or terrestrial mammals, pose risks for *T. gondii* infection, especially when meat is eaten raw [271,273,274,277]. Among pregnant Inuit women in northern Quebec, skinning animals for fur and the traditional dietary practice of regular raw caribou meat consumption were associated with an increased risk of maternal seroconversion [282].

As climate change shifts the habitat range of both definitive (e.g., felid species) and intermediate hosts (e.g., birds, rodents, other mammals), the geographic distribution of toxoplasmosis may expand. Heavy rainfall and spring snowmelt may increase the runoff of infective oocysts—shed by definitive hosts—into lakes and rivers, facilitating the parasite's northward spread [271,273,276,283]. Warmer, wetter conditions also appear to support the environmental survival of *T. gondii* oocysts, enabling their persistence in new regions [271,283]. Loss of sea ice, rising sea levels, and flooding may reduce the available habitat for terrestrial animals, potentially increasing interspecies contact and opportunities for pathogen transmission [283]. Collectively, these climate-driven changes may lead to a higher T. gondii prevalence among animals, thereby, elevating the risk for those who harvest and consume them.

Erysipelothrix rhusiopathiae

E. rhusiopathiae is an emerging, opportunistic bacterial pathogen found in shellfish, fish, birds, and both marine and terrestrial mammals. It has more recently been associated with large-scale mortalities among muskoxen in Nunavut and the Northwest Territories, as well as population declines in moose and caribou in British Columbia [267,284–287]. The organism can persist in the environment for extended periods, including in soil and water [288].

E. rhusiopathiae may be transmitted to hunters through exposure of cuts and skin abrasions to the bodily fluids of infected animals or through the consumption of contaminated meat that has not been fully cooked [267,287,289]. Occasionally, flies, mites, and ticks may serve as vectors [284,285]. Risk factors for disease in humans include immunosuppression, diabetes, and kidney disease [287].

The most common clinical manifestation of infection is erysipeloid, a localized and typically self-limited cellulitis. In some cases, a more generalized cutaneous infection may develop [287,289]. The term, erysipeloid, is used to distinguish this condition from erysipelas, a human streptococcal skin infection that has a similar appearance but affects more superficial layers of the dermis [290]. Rarely, invasive infection and sepsis may occur, which may be complicated by infective endocarditis, meningitis, or bone and joint infections. Although severe human infections are extremely rare with a limited number of documented cases in southern regions [287], the epidemiology of *E. rhusiopathiae* in northern populations remains unclear [289]. Notably, a case was reported in the Canadian Arctic in 2019 involving a 69-year-old woman with a prosthetic joint infection caused by this bacterium [289]. At the time of publishing this report, *Erysipelothrix* is reportable only in the Northwest Territories [291].

Environmental stressors linked to climate change, including rapidly changing conditions, increased climate variability, and extreme weather events, may be contributing to the higher burden of disease observed in certain Arctic wildlife such as muskoxen [288,289]. These impacts may be intensified by reduced genetic diversity and resilience among muskoxen populations, and the possible emergence of more virulent strains [284,285,292]. As *E. rhusiopathiae* becomes more prevalent in wildlife, human exposure may also increase.

Trichinella species

Trichinella spp. are parasitic roundworms that cause a human infection known as trichinellosis (or trichinosis) following the consumption of raw, undercooked, frozen, or meat from infected animals. The species most commonly found in northern Canada—*Trichinella nativa* (genotype T2), *Trichinella* genotype T6, and *Trichinella chanchalensis* (genotype T13)—are notable for their tolerance to freezing [293,294]. Globally distributed (except in Antarctica), *Trichinella* spp. infects a wide range of carnivorous terrestrial and marine mammals, including polar bears, walruses, and belugas [267,293,294]. Seroprevalence is particularly high among polar bears and wolverines [276]. In Nunavik, nine of 15 trichinellosis outbreaks reported between 1982 and 2009 were linked to walrus consumption [295]. Since 1991, outbreaks with links to black bear meat harvested in Nunavik, northern Saskatchewan, northern Ontario, and British Columbia have also been documented [293,296].

Symptom severity in humans depends on the number of infectious larvae ingested and ranges from asymptomatic to potentially life-threatening [297]. Severe cases may involve cardiac muscle (myocarditis), the lungs and diaphragm (pneumonitis, respiratory failure), or the central nervous system (meningitis, encephalitis) [297,298]. In the Canadian Arctic, reinfection with *T. nativa* often causes prolonged diarrhea, without the more classical symptoms of fever, prominent myalgias, and periorbital swelling [294,298].

Warmer summer and winter conditions have been associated with a higher seroprevalence among polar bears, suggesting that the prevalence of *Trichinella* spp. and the risk of human infection could increase as temperatures rise [299].

Trichinellosis was nationally notifiable in Canada until 1999. During the period from 1970 to 1997, the mean annual number of reported cases was 18.2 ± 13.2 (range: 3–49) [298]. Hospital discharge data from 2001 to 2005 suggested that the standardized incidence of hospitalizations due to trichinellosis in Nunavut and northern Quebec (Nunavik, James Bay) was 41.7 hospitalizations per 1,000,000 population—780 times higher than in the rest of Canada [300].

As climate conditions shift pathogen dynamics in northern ecosystems, Inuit communities are playing a leadership role in implementing innovative pathogen detection and disease prevention strategies that help strengthen the safety of traditional dietary practices.

Community-based *Trichinella* Surveillance and Trichinellosis Prevention in northern Canada

Community-led *Trichinella* surveillance efforts in northern Canada build on decades of public health innovation. In 1992, a Nunavik Trichinellosis Prevention Program was introduced and expanded to all communities by 1996—an initiative that has since been recognized as a public health success [295].

The Nunavut *Trichinella* Detection Program (NTDP) was launched in 2017, spurred by the leadership of harvesters, together with support from Nunavut Arctic College (NAC) and Nunavut Tunngavik Incorporated (NTI). Prior to its creation, country food samples had to be sent out of the territory for testing, often resulting in long delays that limited timely decision-making. The NTDP now offers community-based diagnostic testing for *Trichinella* spp. in walrus and polar bear meat harvested for local consumption, delivering results within 48 hours of receiving a sample. By providing rapid in-territory testing "closer to home," the program supports safe and informed consumption choices for raw, frozen, and fermented wild meats that still form an integral part of the traditional Inuit diet.

Various organizations and individuals play specific and vital roles, including NAC, NTI, Nunavut's Departments of Health and Environment, the Canadian Food Inspection Agency (CFIA), local Hunters and Trappers Organizations, and individual harvesters and their families. A collaborative, adaptive approach ensures effective engagement with harvesters from sample collection and shipment to result reporting and the issuance of health advisories.

The diagnostic method, developed by the CFIA, detects *Trichinella* larvae in animal muscle tissue. While testing focuses primarily on walruses and polar bears, the procedure can be used for nearly any mammal. Based in the Iqaluit laboratory of the Nunavut Research Institute, the NTDP is the only zoonosis surveillance program in the territory operated by community-based organizations, with minimal reliance on external expertise or funding. Nunavut-based diagnostic analysts complete biannual CFIA proficiency evaluations and deliver hands-on *Trichinella* diagnostic teaching workshops to Nunavut students, researchers, and other interested groups—thus building regional capacity in zoonotic pathogen detection and preventive public health practice.

As of December 2024, analysts in Nunavut have tested 397 walruses, 83 polar bears, and one killer whale (orca) from 16 communities. *Trichinella* parasites were detected in 12 walruses, 43 polar bears, and one Orca (a first), prompting the Department of Health to issue targeted public health advisories to prevent outbreaks.

Readiness of National Zoonoses Surveillance for Indigenous Populations

Indigenous Services Canada (ISC) works with First Nations, as well as provincial and territorial partners to support the surveillance and monitoring of certain nationally notifiable communicable diseases, including zoonotic diseases. Depending on the jurisdiction, ISC's role may range from active involvement in case management, contact tracing, and epidemiological analysis to serving as only a liaison.

Federal disease surveillance of zoonoses among Indigenous populations remains largely opportunistic and reactive, often triggered by suspected increases in disease burden or significant public health concern. While climate change is likely altering the epidemiology of zoonotic diseases, current ISC surveillance systems do not systematically monitor these trends. It is unclear whether low reported case counts reflect a true low incidence or are rather due to under-detection. Expanding data sharing agreements and infrastructure would help to bolster surveillance and disease prevention activities.

Integrating Indigenous Knowledge in One Health Surveillance

Strengthening surveillance systems for zoonoses in northern and remote Indigenous communities is important in the context of climate change and growing One Health threats. These threats often have magnified impacts for Indigenous Peoples, whose traditional dietary practices, health, and cultural and spiritual well-being are deeply tied to their relationship with the land and natural environment [5]. Risk communication related to emerging One Health threats must therefore strike a careful balance of communicating the risks of zoonotic pathogens while affirming the many nutritional, cultural, and economic benefits of harvesting local wildlife.

Indigenous place-based knowledge systems, which are informed by generations of observation and relationships to wildlife, must be understood, respected, and carefully integrated into zoonosis surveillance efforts to ensure that they are credible, equitable and effective. The wealth of ecological expertise that Indigenous Peoples possess can be mobilized to support early detection of disease in wildlife populations, particularly in areas where logistical challenges limit the use of conventional methods [301]. Successful initiatives such as the NTDP demonstrate the value of community-led, participatory models that promote food safety while safeguarding traditional practices central to Indigenous identities. These approaches highlight the importance of meaningful Indigenous engagement and leadership in zoonosis surveillance, especially in remote and resource-constrained settings [301].

ECHINOCOCCUS MULTILOCULARIS: AN EMERGING PARASITE

Echinococcus multilocularis is a tapeworm found across the northern hemisphere. Definitive hosts—where the parasite reaches sexual maturity and reproduces—are canid species such as foxes and coyotes, which typically become infected by consuming intermediate hosts (e.g., rodents) that have tapeworm larval cysts. Humans can become infected by accidentally ingesting tapeworm eggs through contaminated food or water or from contact with feces from an infected canid. In humans, *E. multilocularis* forms cysts that most often develop in the liver but can also occur in other organs. These cysts grow slowly, and may take years to cause symptoms, which can mimic liver cancer and include abdominal pain, nausea and vomiting. Because the cysts are locally invasive, surgical removal—the primary treatment approach—can be challenging. Surgery is often combined with long-term administration of antiparasitic medications, which can last for several years. Prognosis is typically poor unless the entire larval mass can be completely removed [302].

Echinococcus multilocularis is a parasitic tapeworm that causes alveolar echinococcosis (AE) in humans, a rare but severe disease that can be fatal if left untreated. Since the early 2010s, at least 20 cases of AE have been documented across Canada. This represents a significant increase, as prior to this time, there were only two cases of locally acquired AE ever reported in North America (outside of Alaska). The identification of more pathogenic European-type strains in Canada, and the recent, widespread expansion in canid hosts, represents a growing public health concern. AE is not a reportable disease in all jurisdictions, which complicates efforts to monitor its spread and assess its public health impact.

Echinococcus multilocularis: Life Cycle of an Insidious Parasite

Echinococcus multilocularis is found across the northern hemisphere [303]. It completes its lifecycle between definitive hosts, such as wild canids (e.g., foxes, coyotes, and wolves), and intermediate hosts, such as wild rodents (e.g., voles, lemmings, shrews, deer mice, and muskrats) [303]. As definitive hosts, infected canids (wild and domestic) carry adult tapeworms and shed environmentally resistant, immediately infective eggs into the environment. Humans are aberrant intermediate hosts and can develop AE after accidentally ingesting *E. multilocularis* eggs [304]. Occasionally, domestic dogs can also become aberrant intermediate hosts, developing pathogenic larval cysts similar to those those in rodents. These larval cystic masses are not infectious for humans but can cause significant morbidity/mortality in dogs and their presence can serve as disease sentinels for human risk [305].

Changing Epidemiology of AE: A Growing Concern

AE is a rare disease both in North America and globally, but the changing epidemiology of AE is a growing public health concern [306]. Most of the 18,000 new cases of AE diagnosed annually around the world are located in China (around 91%) [306]. Historically, AE cases diagnosed in North America were linked to international exposures, but since the early 2010s there has been a substantial rise in the number of locally acquired AE cases reported in Canada in the literature [307–309]. Seventeen AE cases were diagnosed between 2013 and 2020 in Alberta alone [308]. AE cases have also recently been reported in Saskatchewan, Manitoba, Ontario and Quebec in patients that had never traveled outside of Canada [307,309–311]. Even in regions experiencing an increase in locally acquired cases, AE is likely still underdiagnosed and underreported [312]. The upward trend of AE diagnoses is concerning and suggests that the risk of infection and subsequent disease caused by *E. multilocularis* is rising [309].

Parasite Distribution in Animal Hosts: Sentinels for an expanding range?

The geographical range of *E. multilocularis* in Canada was thought to encompass two distinct regions: the northern tundra zone and the north-central region, including southern Alberta, Manitoba, and Saskatchewan [303,304,313]. However, in 2009, a European-type *E. multilocularis* strain was first identified in a dog from Quesnel, British Columbia that had never travelled, suggesting local acquisition [314]. Detections of European-type strains in wildlife in new regions, including Ontario, Quebec and Prince Edward Island, suggest the tapeworm's range is expanding beyond where North American strains were typically found (Figure 18) [313,315,316].

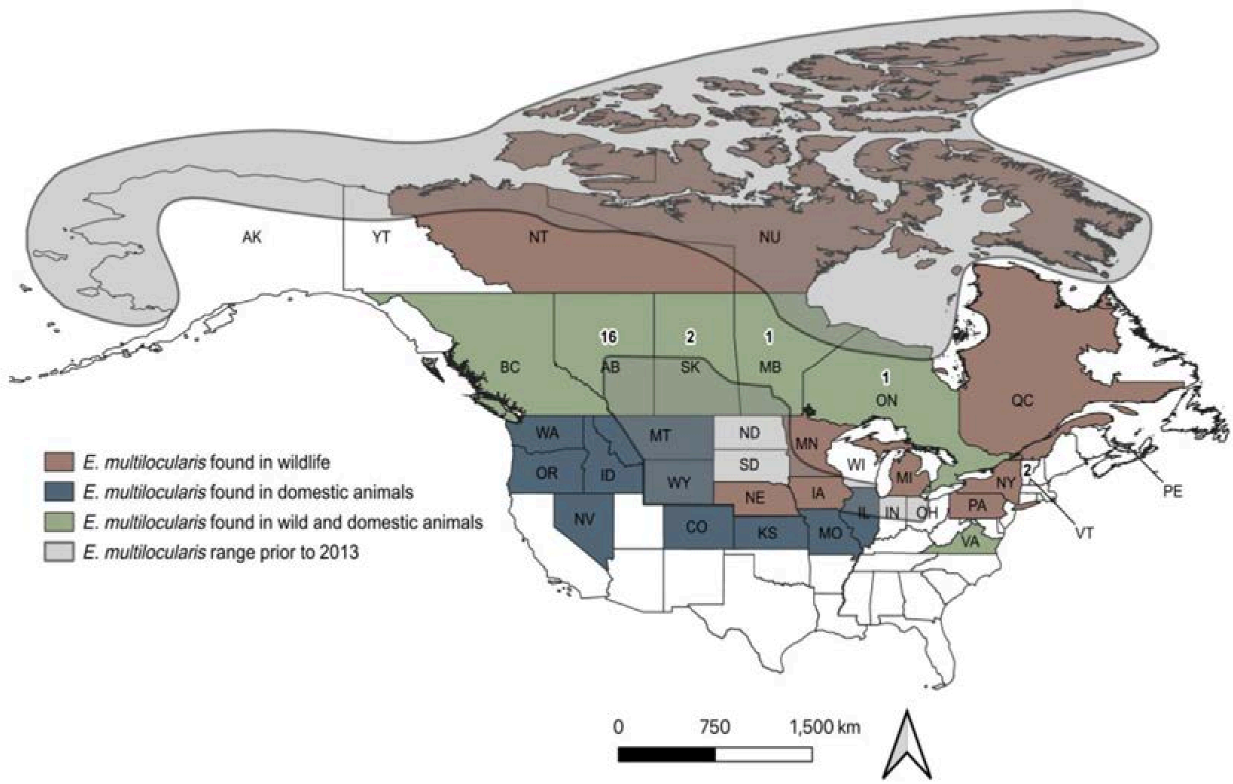


Figure 18. Provinces, Territories and States in North America with reports of *E. multilocularis* infection in humans, domestic animals, or wildlife published from 2015-June 2025, overlaid on the approximate range reported by Gesy et al. (2013). Numbers indicate human cases over the same period.

Note that a single case in a state/province/territory renders it positive, which may overestimate the range.

This map displays human cases from 2015 to 2025, which does not align with the 2013–2022 reporting period covered in this document. Additionally, this map may exclude cases not reported in peer-reviewed literature.

Source: Jenkins E, Volappi T, Malone CJ, Germitsch N, Virtanen JP, Oksanen A, Bessell E, Lundström-Stadelmann B, Frey CF. Changing distribution, diversity, and health impact of *Echinococcus multilocularis* in Europe and North America: Comparison, connections, and opportunities. Advances in Parasitology. 2025;128:159-253.

The detection of *E. multilocularis* in previously unaffected regions of Canada highlights the parasite's growing geographic distribution. Imported dogs are the most likely sources of introduction of European-type strains to North America [308,312]. Further anthropogenic and environmental factors likely contribute to the parasite's range expansion, often resulting in *E. multilocularis*' detection in urban and peri-urban areas, which may pose new exposure risks for humans and companion animals [317–320].

European-Type Strains and Increased Virulence

This spike in human AE cases in Canada has coincided with the presence of European-type strains of *E. multilocularis* in both animal hosts and humans in North America [308]. Of the human cases in Alberta for which molecular typing was available, all were European-type strains [308]. These strains are thought to have greater virulence than the North American strain, which may in part explain the rapid shift in the human epidemiology of the disease [308,314,321].

Human Alveolar Echinococcosis

After accidentally ingesting *E. multilocularis* eggs, humans may completely resist infection, developing harmless lesions where the parasite has died (called abortive lesions), or go on to develop clinical AE with noticeable symptoms [322]. Some estimates indicate that as many as 70 to 90% of persons exposed to the tapeworm, and who seroconvert following infection, are resistant to developing disease [323]. The incubation period of human AE can be between 5 and 15 years [324]. Most parasitic cystic lesions are found in the liver, though they may metastasize to other organs [324,325]. Among those who develop AE and do not receive treatment, the case fatality rate reaches as high as 90% [325,326]. Treatment generally involves radical surgery and chemotherapy [313]. Surgical excision of masses is not always feasible, and in Canada, physicians must reapply every six months for special access to costly medications—some of which patients may require for years [308,312]. Treatment challenges, the limited and costly nature of medical therapies, and the significant morbidity associated with AE underscore the importance of early detection and awareness of this disease.

Transmission and Prevention of AE in Humans

It is unclear whether human transmission predominantly occurs directly from immediately infective eggs shed in feces of dogs or wild canids or through accidental ingestion of eggs on unwashed produce or in contaminated water [305,327,328]. Eggs are highly resistant to chemicals and can persist in the environment for months to years, sticking to fur, hands, or produce [329]. Prevention of human infection focuses on frequent hand hygiene after handling pets and their feces, as well as prior to handling food. It is also important to rinse and cook all wild-picked foods and produce from gardens where dogs and wild canids have access. Additional preventive measures include limiting contact with wild canids, wearing gloves when handling carcasses if you are a hunter or trapper, ensuring dogs do not eat or come into contact with rodents or wild animals, and regularly deworming domestic dogs under the guidance of a veterinarian [305,327,329].

Challenges

Knowledge about the ecology and epidemiology of *E. multilocularis* in Canada is increasing, but further understanding of the role that animal, environmental, and anthropogenic factors play in shaping transmission and distribution of the parasite are necessary to tackle this emerging zoonosis.

Diagnosing AE can be challenging. AE progresses slowly and has nonspecific symptoms such as abdominal pain and jaundice, along with a tumor-like appearance on imaging resembling liver cancer or cirrhosis, which can lead to misdiagnosis. In non-endemic areas (that are often categorized as such due to surveillance gaps), misdiagnosis may be even more common and exacerbated. These diagnostic challenges may be further compounded by limited awareness of the disease among healthcare providers and public health professionals [330].

Historically, standardized laboratory testing for *E. multilocularis* in Canada has faced challenges, with confirmatory serologic testing previously available only in Switzerland [331]. However, laboratory capacity is improving, which will help to enhance access to standardized testing in Canada (National Reference Centre for Parasitology, personal communication). This progress will support better surveillance, as well as more timely diagnosis and prognosis of AE cases in Canada.

The lack of standardized and national-level reporting of human and animal cases creates challenges in tracking and assessing the true extent and burden of the disease. Cases of human AE are only notifiable in the provinces of Ontario (confirmed and probable) and Alberta (laboratory confirmed) [332,333]. In animals, *E. multilocularis* detections are reportable to the provincial/territorial authorities only in Ontario and Quebec.

Future considerations

In North America, *E. multilocularis* is now considered ‘emerging’ as defined by increasing prevalence and/or host and geographic distribution [312]. To address the spread of *E.*

multilocularis in Canada, a One Health approach is essential, integrating animal, human, and environmental perspectives. Improving surveillance, reporting, and coordination across jurisdictions could contribute to more accurate data collection on the incidence and burden of AE in Canada, thereby informing efforts to better understand and address the impact of this disease. Ongoing research on both wildlife and domestic animals will help to better understand the epidemiology and ecology of the parasite. Raising awareness of *E. multilocularis* among healthcare professionals might encourage broader adoption of preventive strategies and facilitate earlier diagnosis of AE cases. Finally, examining the environmental interface and the interactions between humans, companion animals, and wildlife, especially in the context of climate change and urbanization, remains critical for managing *E. multilocularis* as an emerging zoonotic threat in Canada.

ENTERIC ZOONOSES: A CANADIAN PERSPECTIVE

Prepared by: Outbreak Management Division, Centre for Foodborne, Environmental and Zoonotic Diseases, Public Health Agency of Canada

Domestically acquired zoonotic enteric illnesses are a significant cause of morbidity and mortality in Canada, with an estimated 85,000 enteric illnesses related to animal contact each year [334]. Human enteric illness linked to a zoonotic source, such as an animal or their food, waste or environment, is referred to as enteric zoonoses.

Common zoonotic enteric pathogens include *Campylobacter*, nontyphoidal *Salmonella*, and *Escherichia coli*. Symptoms of enteric illness can range from mild and self-limiting gastrointestinal symptoms, such as vomiting and diarrhea, to severe and life-threatening conditions.

Some groups are at an increased risk of severe illness, including: people who are pregnant, children ages five and under, people with weakened immune systems, and adults ages 60 and older [335]. Children ages five and under are often over-represented in outbreaks of enteric zoonoses. Because their immune systems are still developing, they have a higher risk for severe illness and health complications following infection with common enteric pathogens [335].

Multi-jurisdictional outbreaks linked to animals or animal foods

Between 2013 and 2022, there were eleven multi-jurisdictional enteric illness outbreaks investigated in Canada related to exposure to animals or animal foods. This includes *Salmonella* outbreaks linked to exposure to pet food and treats, reptiles, hedgehogs, rodents, and poultry as well as an *E. coli* outbreak linked to raw pet food. A summary of these outbreaks is included in Table 6. This table includes only the number of cases identified during the outbreak investigation that were confirmed by laboratory testing. The true number of people in Canada that were sick as a part of these outbreaks is likely much higher. Researchers estimate that each case of salmonellosis reported to public health represents 26.1 cases in the community, while each case of *E. coli* O157 reported to public health represents an estimated 20.1 cases in the community [336]. While there have also been outbreaks of enteric illness with cases in only one province or territory linked to a zoonotic source during this time period, the data below is limited to multi-jurisdictional outbreaks only.

Table 6. Summary of multijurisdictional enteric illness outbreaks linked to a zoonotic source, Canada: 2013 to 2022

Pathogen	*# of PTs with cases*	*Case count*	*Earliest case (best date)*	*Latest case (best date)*	*Suspect Source*
Salmonella Cotham	2	4	September 2013	March 2014	Bearded dragons
Salmonella Typhimurium	3	22	January 2014	May 2014	Snakes and feeder rodents
Salmonella Enteritidis	5	61	April 2015	June 2015	Mail-order baby poultry
Salmonella Typhimurium	7	106	April 2017	November 2020	Snakes, feeder rodents, and pet rats
Salmonella Typhimurium	6	31	June 2017	October 2020	Hedgehogs
Salmonella Typhimurium	3	10	February 2020	September 2020	Pig ear dog treats
E. coli O157	3	5	March 2020	May 2020	Raw pet food
Salmonella Lome	7	36	March 2020	March 2024	Geckos
Extensively drug-resistant *Salmonella* I 4,[5],12:i:-	6	44	July 2020	January 2024	Raw pet food and cattle
Salmonella Muenchen	7	25	August 2020	September 2024	Geckos
Salmonella I 4,[5],12:i:- and *Salmonella* Typhimurium	8	76	February 2022	April 2024	Snakes and feeder rodents

PHAC posts publicly online and on social media about enteric illness outbreaks linked to a zoonotic source and includes information on how to prevent illness. For the eleven outbreaks, PHAC published eleven initial Public Health Notices and 17 related updates. In that period, PHAC also published a webpage on pet food safety and *Salmonella* and reptiles; created posters on how to safely interact with rodents, reptiles and amphibians, and pet food; and designed an infographic to guide feeder rodent industry members on how to help reduce zoonosis transmission from rodents. Both during and outside of an active outbreak, posts about these topics are shared on PHAC social media channels.

Outbreak Highlight: *Salmonella* and hedgehogs

Hedgehogs as pets appeal to many families, but can be a source of several zoonoses, including salmonellosis. *Salmonella* infections in hedgehogs can result in the animal becoming ill, however many show no signs of illness, and remain asymptomatic carriers of the bacteria. In 2020, a coordinated outbreak investigation was initiated following human infections of *Salmonella* Typhimurium that were genetically related to an outbreak in the United States linked to exposure to pet hedgehogs [337,338]. There were 31 cases in six provinces, with illness onset dates from June 2017 to October 2020 in Canada. Cases ranged in age from less than one to 79 years with a median of 20 years. Twenty-three percent (7/31) of cases were children aged five years or younger. There were four hospitalizations, and no deaths reported among cases.

In the seven days prior to symptom onset (which corresponds to the incubation period of *Salmonella*), 19 out of 26 cases (73%), with available animal exposure information, reported exposure to pocket pets, all of which were hedgehogs. All cases that owned hedgehogs reported owning them for about one year or less, with almost half (47%) owning them for one month or less. Fifteen out of 18 cases (83%) reported direct contact with a hedgehog, while three (17%) reported only indirect contact. Potential routes of indirect transmission were reported by cases, including the hedgehog or their supplies being cleaned in a sink or tub that is also used for other purposes, or allowing their hedgehog to roam free in the home.

Cases were also asked about where they purchased their pet. Where possible, any identified pet stores, wholesalers and breeders were then interviewed and asked about the husbandry practices and *Salmonella* precaution protocols in their facility, the health history of their animals, and client education practices. These interviews also allowed investigators to determine if a common supplier was associated with outbreak cases. Although no single source was identified, there were common suppliers reported.

Environmental samples from hedgehog habitats and fecal samples were collected from three cases' homes, one wholesaler and two breeders. One hedgehog stool sample collected from a case's home tested positive for *Salmonella* and was found to be genetically related to the outbreak strain.

Several public health actions were taken during this outbreak. PHAC issued a Public Health Notice to notify the public about the outbreak and to share information on how to safely interact with hedgehogs. PHAC and their U.S. counterparts also held teleconferences with hedgehog industry members from Canada and the U.S. to notify them about the outbreak and provide key prevention recommendations to help reduce the risk of disease transmission from hedgehogs to humans.

Challenges

During an enteric illness outbreak investigation, several unique challenges arise. Firstly, if the outbreak source is identified as a food for human consumption, public health actions, such as product recalls, can be taken to remove the implicated product from the market and prevent future illnesses. However, when the outbreak source is an animal, the outbreak source cannot be recalled. Often, the only public health actions available are public communications and education campaigns. These actions can be effective but rely on the target groups seeing the messaging and following public health guidance.

Secondly, with many zoonotic sources, transmission can occur through contact with the animal itself, but also through contact with the animal's environment, including where they roam or eat, contact with the animal's food and treats, or items used to feed, house or handle the animal. It can be difficult to control cross-contamination within the household.

Finally, as was the case in the outbreak related to hedgehogs, animals can be carriers of a disease without showing any signs of illness themselves. This can cause pet owners to not consider themselves or their family at risk. This further emphasizes the need for targeted educational campaigns to make sure pet owners are aware of their risk and how to minimize it.

Future considerations

Public communication and education are important public health actions when it comes to controlling and preventing future enteric zoonosis outbreaks. Targeted public education and communication interventions are available to educate pet owners on how to minimize their risk. However, more information is needed at the retail level, such as product safety labeling on high-risk products, including feeder rodents and raw pet food, or educational materials provided to new pet owners. Collaboration with pet industry members has been an essential tool during outbreaks. Industry networks have been used to share PHACs communication products, to promote safe handling of animals and animal foods, and to bring awareness to on-going outbreaks. "Point of sale" interventions at the consumer level are important, as they present the safety information directly to the consumer right at the time of purchase, rather than relying on them seeking out the information.

Despite the numerous and complex challenges public health partners face in investigating and controlling outbreaks, communication and cooperation across all One Health partners—from industry to animal health—help to reach a wider range of networks and at-risk populations with the goal of raising awareness of and preventing zoonoses associated with pets and their food.

TRAVEL-ACQUIRED ZOONOSES

International travel can be a significant source of zoonotic and vector-borne disease (ZVB) for Canadians, including exotic diseases not endemic in Canada. These diseases pose a personal risk to the travellers themselves, but can also be a public health risk, as they may lead to disease spread and the emergence of foreign diseases into new areas. While some important travel-associated diseases such as malaria and yellow fever are notifiable to PHAC via the Canadian Notifiable Disease Surveillance System (CNDSS), others like dengue, chikungunya and Zika virus are not. Information on zoonoses acquired by Canadian residents during travel is obtained by PHAC through various routes, including formal surveillance systems such as CNDSS and CanTravNet as well as ad hoc notifications from PT partners and the NML, depending on the situation and disease of interest. Understanding the magnitude and variety of ZVB diseases acquired abroad and imported into Canada is essential to inform effective public health preparedness, policy and guidance.

Zoonoses and vector-borne diseases in Canadian travellers, CanTravNet 2013 to 2022

GeoSentinel is an international network of clinics and healthcare providers dedicated to monitoring infectious diseases and other travel-related health issues among international travellers and migrants and is funded through a cooperative agreement with the U.S. CDC, PHAC and the GeoSentinel Foundation. The Canadian Travel Medicine Network (CanTravNet) is a network composed of GeoSentinel sites that are based in Canada. From 2013 to 2022, nine sites across the country (3 in Montreal, 2 in Toronto, and 1 in each of Ottawa, Winnipeg, Calgary, and Vancouver) comprised the network. These sites are referral-based centres staffed by travel and tropical medicine specialists, serving a catchment area that covers over 40% of the Canadian population [339]. The following provides a brief overview of the ZVB diseases diagnosed in Canadian residents evaluated at a CanTravNet site, from 2013 to 2022.

When an individual is referred to a CanTravNet site following travel, information is collected on demographics, recent travel history, final diagnosis, country of exposure (only assigned when the attending physician is relatively certain of the country where the disease was acquired) and reason for travel. The data used for this analysis are from initial visits to any participating CanTravNet site that took place from 2013 to 2022. Only Canadian residents with a confirmed or probable diagnosis of a disease that was acquired outside of Canada were included. Diagnoses were divided into two cohorts: diagnoses in migrants (including refugees/asylees, asylum seekers, and immigrants) and diagnoses in non-migrants (including all other reasons for travel such as tourism, visiting family and friends, business, education, etc.). For the purpose of this report, ZVB diagnoses were defined as those resulting from a pathogen where the predominant route of transmission to humans is from direct or indirect exposure to animals or arthropod bites. Pathogens that could originate in an animal, but are predominantly acquired by humans through the consumption of contaminated food or water (e.g., *Salmonella* spp., giardia) or through human-to-human transmission (e.g., scabies) were excluded. Diagnoses indicating exposure to a mammal (e.g., bite or scratch) during travel were also included—given the potential for zoonotic transmission—as well as diagnosis codes indicating the administration of post-exposure prophylaxis (PEP) following an animal exposure.

A total of 19,449 unique patient visits occurred at a CanTravNet site from January 1, 2013 to December 31, 2022. Of these, 4,463 (23%) resulted in at least one ZVB, animal exposure or PEP diagnosis. At the time of their initial visit, these 4,463 individuals had an average age of 39 years and 51% (n = 2,291) were female. The majority (80%) travelled for reasons other than migration (e.g., tourism, visiting family/friends), with only 20% of visits attributed to those migrating to Canada.

Overall, 23,684 diagnoses were made at the CanTravNet sites over the study period. The number of diagnoses made each year remained fairly consistent with an average of 3,118 per year (2,488–3,459) from 2013 to 2019; however, the number of diagnoses declined dramatically in 2020 (n = 731) as a result of the declaration of COVID-19 as a Public Health Emergency of International Concern (PHEIC) and its impact on international travel. The number of active sites contributing to the dataset changed throughout the study period, ranging from six in 2013 and 2014, to a maximum of nine in 2019 (Figure 19).

Of the 23,684 diagnoses, 4,708 (20%) were related to ZVB disease or animal exposures, including 3,625 (15%) specific ZVB disease diagnoses, 954 (4%) animal exposures, and 129 (1%) related to post-exposure prophylaxis (PEP) following animal exposure. The remaining 18,976 (80%) diagnoses did not fall into one of these categories and were thus excluded from the remainder of the analysis (Figure 19).

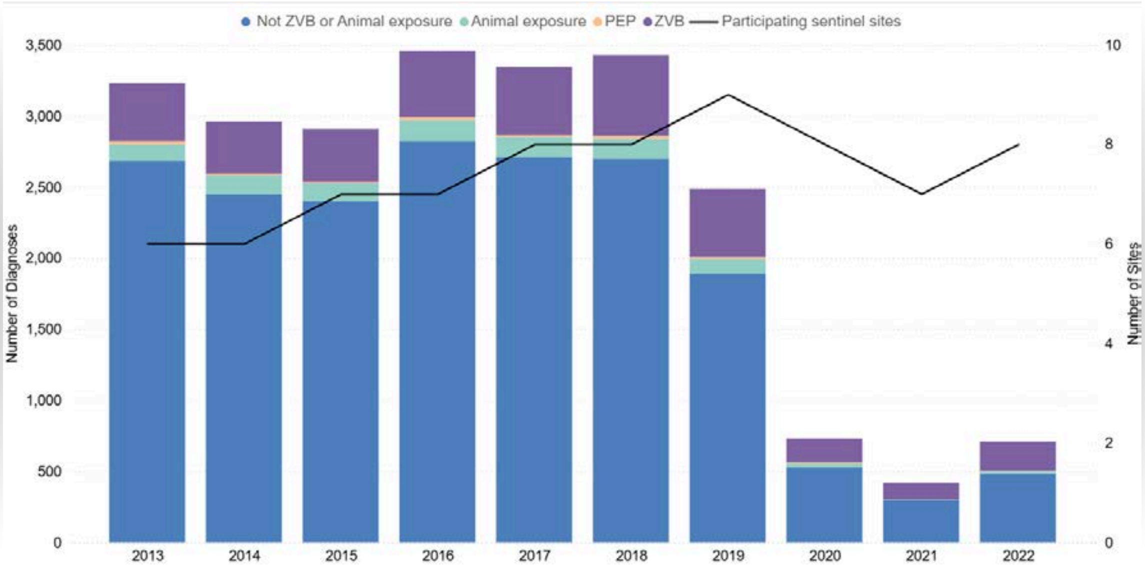


Figure 19. Number of annual diagnoses and participating CanTravNet sites: 2013 to 2022

The 4,708 diagnoses related to ZVB disease or animal exposures, were acquired from 158 different countries across the globe, with most attributed to travel to countries in Sub-Saharan Africa (n = 1,284; 27%), the Caribbean (n = 683; 14%) and Central America (n = 424; 9%) (Figure 20).

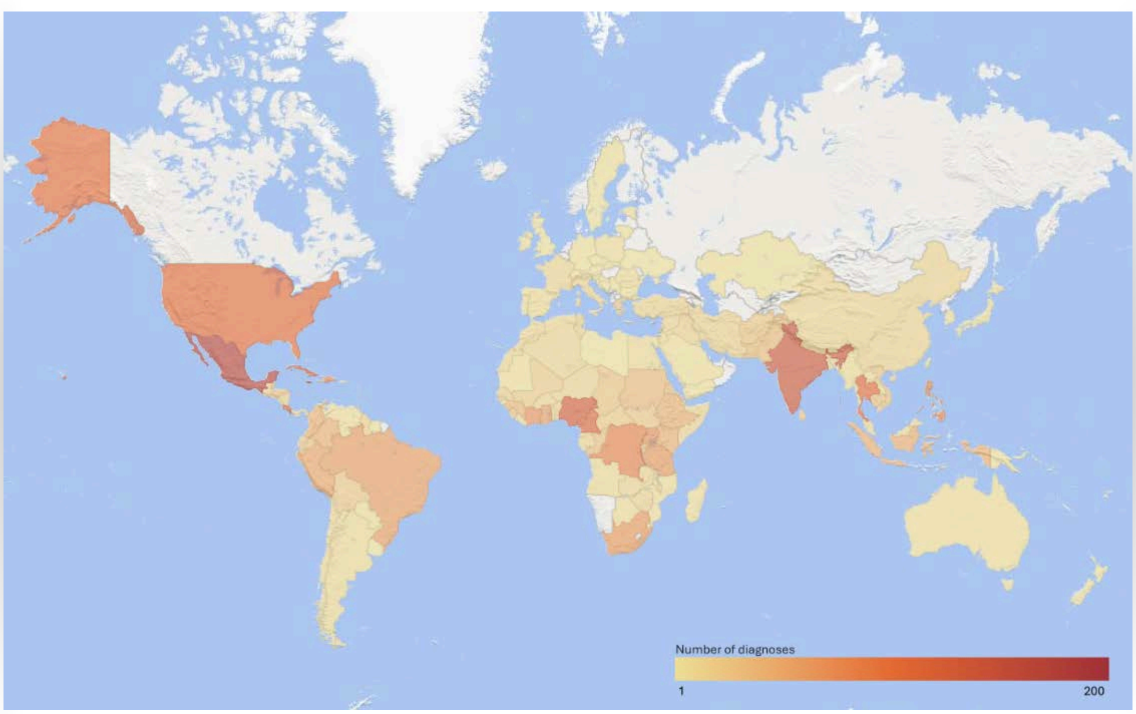


Figure 20. The 158 countries where diagnoses related to ZVB diseases and animal exposures were acquired by Canadian travellers who presented to a CanTravNet site: 2013 to 2022

Of the 3,625 specific ZVB diseases diagnosed over the study period, 57% (n = 2,054) were diseases associated with vector-borne transmission, primarily from mosquitoes (n = 1,692; 47%), but also other vector species, such as lice and fleas (n = 224; 6%), ticks (n = 120; 3%) and pathogens transmitted by multiple vector species (n = 18; <1%). The remaining 43% (n = 1,571) of diagnoses were zoonotic. Overall, the top five ZVB diseases diagnosed were malaria (24.0%), schistosomiasis (20.4%), cutaneous larval migrans (14.3%), dengue (12.5%) and chikungunya (4.6%).

Of the 954 animal exposures, the majority were exposures to an insect or other arthropod (80.8%), bites from monkeys (7.1%) or dogs (5.0%). All but one of the 129 post-exposure prophylaxis administered were for rabies virus, the other was for herpes B virus (Table 7).

Diagnoses differed amongst those who travelled for the purpose of migration compared to those who did not. Following travel for migration, schistosomiasis, malaria, echinococcosis, filariasis and chagas were the most common diagnoses; whereas, those who travelled for reasons other than migration (tourism, visiting family/friends, work, education, etc.), were more often diagnosed with an insect or other arthropod bite, malaria, cutaneous larval migrans, dengue and schistosomiasis (Table 7).

Table 7. Number and proportion of ZVB and animal exposure diagnoses at CanTravNet sites, by travel reason: 2013 to 2022

Diagnosis	*Migration n = 949*		*Not migration n = 3,748*		*Grand total N = 4,708* †	
	n	*%*	*n*	*%*	*N*	*%*
ZVB diagnoses						
Vector-borne transmission						
Malaria	151	16.0%	714	26.7%	870*	24.0%
Dengue	3	0.3%	451	16.9%	454	12.5%
Chikungunya	0	---	165	6.2%	165	4.6%
Leishmaniasis	31	3.3%	124	4.6%	155	4.3%
Filariasis	87	9.2%	43	1.6%	130	3.6%
Rickettsia	0	---	95	3.6%	95	2.6%
Zika virus infection	0	---	68	2.5%	68	1.9%
Lyme disease	0	---	55	2.0%	55	1.5%
Chagas	31	3.3%	7	0.3%	38	1.0%
Tungiasis	0	---	8	0.3%	8	0.2%
West Nile virus disease	0	---	3	0.1%	3	0.1%
Relapsing fever	0	---	2	0.1%	2	0.1%
African trypanosomiasis	0	---	3	0.1%	3	0.1%
Ross river virus infection	0	---	2	0.1%	2	0.1%
Anaplasmosis	0	---	1	<0.1%	1	<0.1%
Japanese encephalitis	0	---	1	<0.1%	1	<0.1%
Ehrlichiosis	0	---	1	<0.1%	1	<0.1%
Zoonotic transmission						
Schistosomiasis	513	54.5%	220	8.2%	738*	20.4%
Cutaneous larva migrans	3	0.3%	517	19.3%	520	14.3%
Echinococcosis	118	12.5%	32	1.2%	150	4.1%
Myiasis	0	---	68	2.5%	68	1.9%
Leptospirosis	0	---	28	1.0%	28	0.8%
Brucellosis	0	---	26	1.0%	26	0.7%
Histoplasmosis	0	---	18	0.7%	18	0.5%
Toxoplasma gondii	3	0.3%	8	0.3%	11	0.3%
Q fever	1	0.1%	5	0.2%	6	0.2%
Cat scratch disease	0	---	4	0.1%	4	0.1%
Bartonella henselae infection (other than cat scratch disease)	1	0.1%	2	0.1%	3	0.1%
Cryptococcosis	0	---	1	<0.1%	1	<0.1%
Bartonella bacilliformis infection	0	---	1	<0.1%	1	<0.1%
ZVB diagnoses total	**944**	---	**2671**	---	**3625**	---

continued on next page

Table 7. (continued)

Diagnosis	*Migration n = 949*		*Not migration n = 3,748*		*Grand total N = 4,708* [†]	
	n	**%**	***n***	**%**	***N***	**%**
Insect or animal exposure diagnoses						
Insect or other arthropod bite/sting	5	100.0%	766	80.8%	**772**[^]	80.9%
Monkey bite	0	---	67	7.1%	**67**	7.0%
Dog bite	0	---	47	5.0%	**47**	4.9%
Other animal bite	0	---	15	1.6%	**15**	1.6%
Monkey exposure (non-bite)	0	---	13	1.4%	**13**	1.4%
Cat bite	0	---	12	1.3%	**12**	1.3%
Other animal exposure (non-bite)	0	---	11	1.2%	**11**	1.2%
Cat exposure (non-bite)	0	---	6	0.6%	**6**	0.6%
Dog exposure (non-bite)	0	---	5	0.5%	**5**	0.5%
Bat bite	0	---	4	0.4%	**4**	0.4%
Bat exposure (non-bite)	0	---	2	0.2%	**2**	0.2%
Insect or animal exposure diagnoses total	**5**	---	**948**	---	**954**	---
Post exposure prophylaxis (PEP)						
Rabies virus PEP	0	---	128	99.2%	**128**	99.2%
Herpes B virus PEP	0	---	1	0.8%	**1**	0.8%
PEP total	**0**	---	**129**	---	**129**	---

[†]11 diagnoses with unknown travel reason
*5 diagnoses with unknown travel reason
^1 diagnosis with unknown travel reason

Understanding the ZVB diseases acquired and animal exposures encountered by Canadian travellers enables opportunities for public health action including intervention and education. The majority of ZVB diseases acquired abroad are vector-borne; however, diagnoses differ depending on travel reason. While malaria was commonly diagnosed among all travellers, higher proportions of schistosomiasis and echinococcosis were observed among those travelling for migration compared to cutaneous larval migrans and dengue among non-migration travellers. Exposures during travel and immune status as well as screening protocols for immigrants and refugees likely contribute to these differences.

Ensuring Canadian travellers have the education and resources they require to limit exposure to insects and other animals while abroad can reduce the risk of exposure and overall travel-acquired illnesses. Additionally, understanding the types of zoonoses affecting migrants upon arrival can help strengthen the breadth of specialized care available to new residents of Canada.

While the CanTravNet database provides insight into the various ZVB diseases and animal exposures acquired by Canadian travellers by place and time, certain limitations must be highlighted. Given that CanTravNet sites are typically referral-based, mild, self-limiting diseases may be underrepresented. Additionally, the residents of Canada evaluated at the sentinel surveillance sites may not be representative of the overall population of Canadian travellers. While the number of visits across sites remained fairly constant in the first seven years of the study, the number of patients seen and diagnoses made, declined dramatically in 2020 as a result of both the withdrawal of a large sentinel site in Toronto and the COVID-19 pandemic. Outside of reducing the overall number of diagnoses, it is unclear how these events may impact the trends associated with the types of ZVB diseases and animal exposures acquired, as well as country of acquisition in the long term.

Spotlight on international outbreaks of emerging vector-borne diseases in Canadian travellers

With increasing globalization and international travel, vector-borne diseases (VBDs), in particular those transmitted by mosquitoes, comprise a significant proportion of recent emerging infectious disease events [340]. From 2013 to 2022, we saw the emergence of both chikungunya and Zika viruses in the Americas, resulting in associated outbreaks in Canadian travellers returning from abroad.

Chikungunya virus outbreak, 2014

In December 2013, two locally acquired cases of chikungunya, on the Caribbean island of Saint-Martin/Sint Maarten, were reported to the Pan American Health Organization (PAHO). This marked the first incursion of chikungunya virus into the western hemisphere, and was followed by a large outbreak, with local transmission detected in over 40 countries or territories in the Caribbean, Central America, South America, Mexico, and the United States during 2014 [341]. At the time of the outbreak, chikungunya testing in Canada was conducted at the NML, which enabled tracking the impact of the outbreak on Canadians. By the end of 2014 (December 9), 320 confirmed and 159 probable laboratory-based cases had been reported in Canadian travellers, with over 100 additional suspect cases under investigation. Cases were reported in eight provinces, with the majority of cases reporting having travelled to the Caribbean [341]. It is interesting to note that approximately 20% of patients tested in Canada were viremic—the presence of viruses in the blood—based on PCR detection of viral RNA in serum samples [341]. This is an important consideration in the context of climate change and increasing local suitability for establishment of invasive mosquito species.

Zika virus outbreak in the Americas, 2015 to 2018

In early 2015, Brazil reported a large increase in cases with mild illness and rash that was subsequently confirmed to be Zika virus (ZIKV) [342]. By 2016, the outbreak had spread to Central and South America and the Caribbean islands, and the World Health Organization (WHO) declared the association of Zika virus infection with clusters of microcephaly and other neurologic disorders a PHEIC, and requested international response and collaboration [342]. Canada reported its first case associated with this outbreak in December 2015, and following the WHO's declaration, federal, provincial and territorial (FPT) partners agreed to temporary national case reporting to monitor the situation and understand the risk to Canadians. By the end of 2016, 486 cases had been reported among Canadians. Case counts decreased to 75 in 2017 and 21 in 2018, for a total of 582 laboratory confirmed cases reported during the outbreak period (PHAC, unpublished data).

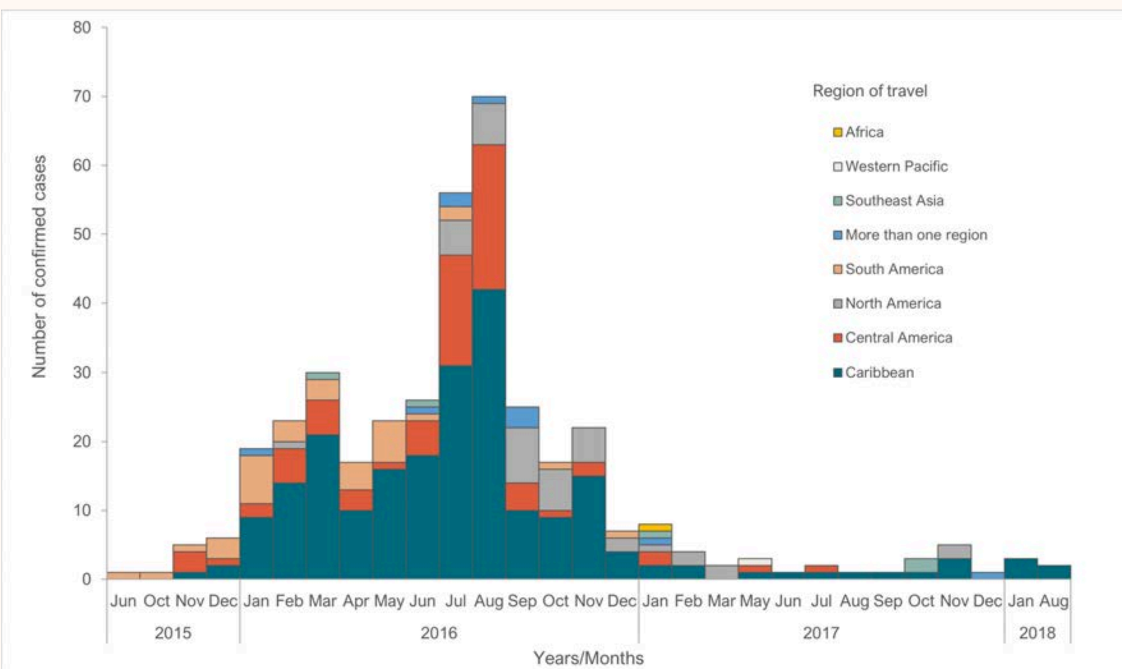


Figure 21. Cumulative number of confirmed symptomatic travel-associated Zika virus cases by month of symptom onset and region of travel, Canada, June 2015 to December 31, 2018 (n = 384, cases with no symptom onset date available are excluded)

Overall, 63% of Canadian travellers were infected while visiting the Caribbean, 14% in Central America, 10% in North America (Mexico) and 8% in South America, with the remaining infected in other regions (PHAC, unpublished data; Figure 21). Illness in Canadian travellers generally coincided with outbreak intensity in the country of exposure rather than travel volume [343].

The chikungunya and Zika outbreaks highlight how international travel can be an important risk factor for zoonotic, particularly mosquito-borne, infections. As globalization and international travel and trade continue, we must continue to prepare for and respond to emerging disease outbreaks on an international scale.

Although the risk in Canada for autochthonous transmission of mosquito-borne diseases like chikungunya, Zika and dengue is currently very low, climate models predict increasing suitability for invasive vector species over time, especially in certain regions of Canada [344]. Previously, the primary mosquito vectors for chikungunya and ZIKV (*Aedes aegptyi* and *Aedes albopictus*), were not considered endemic or established in Canada. However in more recent years, *Ae. albopictus* has been found to be established in limited regions of southern Ontario and *Ae. aegypti* has also been detected in low numbers in southern Ontario and a single egg was found at one site in southern Quebec in 2017 [165,169,345]. Climate models predict that over time, *Ae. albopictus* in particular, could establish in several other parts of southern Canada [169,346]. This will be important to continue to monitor under Canada's evolving environmental conditions.

With international travel returning to pre-pandemic levels, vectors continuing to expand their range, and as the magnitude of vector-borne disease outbreaks increase globally, the risk and impact of travel-acquired diseases is expected to rise. As such, a continued understanding of the ZVB diseases and animal exposures that impact the travelling public is vital to prevent illness, diagnose and treat individuals, and manage public health threats to Canadians.

METHODS

The methods section outlines the surveillance structure, data sources, inherent limitations, and analytical approach used to compile this 10–year review of zoonotic diseases in Canada.

SURVEILLANCE AND MONITORING OF ZOONOTIC DISEASES IN HUMANS IN CANADA

In Canada, provincial and territorial laws mandate that healthcare providers, hospitals and laboratories report human cases of specified diseases/conditions (known as reportable diseases) to public health authorities within their jurisdiction. At the national level, a list of nationally notifiable diseases is also maintained, developed through a collaborative agreement between federal, provincial and territorial (FPT) public health authorities. Reporting of nationally notifiable diseases to PHAC is not legally mandated.

Many zoonoses of public health importance in Canada are nationally notifiable and are therefore reported federally. In circumstances where the disease is not nationally notifiable, but is of growing public health concern, PHAC utilizes other data sources, or conducts applied research to better understand things like burden of illness and trends over time.

SURVEILLANCE AND MONITORING OF ZOONOTIC DISEASES IN ANIMALS IN CANADA

In animal health, provincial and territorial laws also mandate reporting within their jurisdictions. In contrast to public health, national reporting of certain diseases (those with significant importance to human health, animal health, or the Canadian economy) are mandated under the federal Health of Animals Act and Reportable Diseases Regulations.

Many diseases of zoonotic importance are nationally reportable and are therefore reported to the Canadian Food Inspection Agency (CFIA). Similarly to public health, in circumstances where the disease is not reportable but of growing public health concern, other data sources and research can be used to better understand the issue.

A non-exhaustive list of non-enteric zoonoses which require some level of notification to either public or animal health authorities at the FPT level in Canada is provided in the section titled “Table of Zoonotic Diseases Reported to Public Health and Animal Health Authorities”.

GENERAL DATA NOTES AND LIMITATIONS

Surveillance systems have inherent limitations that apply broadly to the data used in this report. Examples of these limitations, which may differentially impact the usefulness and interpretation of data, include underreporting, lack of representativeness, and lack of timeliness. Subsequently, reported cases may not represent all the cases in a population. Underreporting and lack of data representativeness may occur for any or all the following:

- Not all people who are infected will seek medical attention.
- Reporting of diagnosed cases is not complete.
- Diagnostic tests may result in a false negative or false positive.
- Case definitions of reporting jurisdictions may differ from the national case definition for a particular disease.
- Not all provinces or territories are able to report on all diseases in every year. This does not necessarily mean that there have been no cases of the selected disease in that jurisdiction.
- Lab-confirmed only cases include laboratory criteria only and therefore, may not represent the true number of cases in Canada.

In addition, detection, exposure, lab testing and reporting may have been impacted or interrupted during 2020 to 2022 due to competing priorities during the COVID-19 pandemic.

While every effort is made to ensure data aligns with our provincial/territorial partners, discrepancies in data may occur. For limitations specific to the disease and/or dataset, please refer to ***Data Sources*** section below.

DATA SOURCES

In addition to cited literature, there were a number of data sources used in this report:

PHAC–Canadian National Notifiable Disease Surveillance System (CNDSS)

The Canadian Notifiable Disease Surveillance System (CNDSS) monitors approximately 60 nationally notifiable infectious diseases that are deemed as priorities for monitoring and control. Provinces and territories (PTs) voluntarily report data annually to CNDSS or, in some circumstances, to disease-specific program areas conducting enhanced surveillance.

Human case data on nationally notifiable zoonotic diseases were obtained from CNDSS, unless otherwise specified. Case counts and associated data were reviewed by PT partners, and if discrepancies were noted, data were updated to reflect PT input.

Sections of this report using CNDSS as data source

- Brucellosis, hantavirus, rabies, tularemia

Limitations of CNDSS data

- Voluntary reporting; may vary by jurisdiction and year.
- Core data elements are limited, and include province/territory, age, sex and case classification.
- Observed differences in the data published here and the data published in PT surveillance products may be due to differences in the date data were extracted from the PT surveillance databases or other reporting variations. Where such differences are noted, it is recommended that data and results from PT products be used.
- Some nationally notifiable diseases are not reportable at the PT level. In those cases, PTs do not provide data to CNDSS.

Other notes

- Brucellosis: From 2013 to 2016, QC data may include probable cases.
- Hantavirus Pulmonary Syndrome: NB began reporting in 2015, therefore from 2013 to 2015, there is no data from NB.
- Tularemia: From 2013 to 2016, QC data may include probable cases.

PHAC–Mosquito-borne Disease Surveillance System (formerly National Surveillance–West Nile Virus)

In conjunction with PT partners, other government departments and non-government organizations, PHAC conducts surveillance on human cases of West Nile virus (WNV), but also surveys birds, horses and mosquitoes. Animal surveillance provides important information on viral circulation in an area and can provide an early warning of increased risk to humans. Timely data collection from surveillance partners occurs over the warmer months when disease transmission occurs.

In recent years, PHAC has initiated monitoring of other mosquito-borne diseases (MBD) such as Eastern equine encephalitis virus (EEEV) and California serogroup viruses (CSGV). EEEV and CSGV infections in humans are not nationally notifiable diseases and do not have a national case definition. Despite this, PHAC does receive some information on these infections in humans from the NML. Other indicators, such as horse infections and detection in mosquitoes, are monitored by the CFIA and a limited number of PTs. These data are now incorporated into mosquito-borne disease surveillance reporting.

Sections of this report using MBD surveillance as data source

- West Nile Virus and Other Mosquito-Borne Diseases

Limitations of MBD Surveillance data

- There is variability in human WNV case reporting by jurisdiction and year.
- There may be small discrepancies between cases reported by PTs and PHAC.
- Human EEEV and CSGV are not nationally notifiable and are likely underreported.
- Case definitions by PT, if available, vary.
- The number of PTs conducting mosquito surveillance varies yearly.

Other notes

- As of 2014, Saskatchewan only reports WNV neurological cases.
- For a comprehensive list of technical notes, visit the Technical Notes section the PHAC MBD surveillance dashboard.

PHAC–Lyme Disease Enhanced Surveillance System (LDESS)

In conjunction with PT partners, PHAC conducts surveillance on human cases of Lyme disease through the LDESS. The LDESS captures information including clinical manifestations, laboratory testing results, and potential locations of exposure for both locally acquired and travel-related cases. Timely data collection from surveillance partners occurs over the warmer months when disease transmission occurs.

Sections of this report using LDESS as data source

- Lyme and Other Tick-Borne Diseases

Limitations of TBD Surveillance data

- Reported Lyme disease cases and incidence rates may be underestimated due to underreporting.
- There may be small discrepancies between cases reported by PTs and PHAC.
- There is variability in human Lyme case reporting by jurisdiction and year.

Other notes

- The Lyme disease case definition was revised in 2016 which impacted reporting.
- Methodology for counting Lyme disease cases in Nova Scotia changed in 2023 towards reporting of laboratory data. This has resulted in increased case counts, and data are of limited comparability compared to previous years.

PHAC–PulseNet Canada (PNC)

PulseNet Canada is a national surveillance system for identifying and responding to enteric illness outbreaks. It is comprised of a network of public health laboratories across Canada linked by databases, that provides a means for health officials to link cases in an outbreak investigation through the identification of enteric illness clusters that are related by whole genome sequencing (WGS).

Sections of this report using PNC as data source

- Enteric Zoonoses: A Canadian Perspective

Limitations of PNC surveillance data

- Enteric diseases like *Salmonella* and *E. coli* are often under-reported. It is estimated that each case of salmonellosis reported to public health represents 26.1 cases in the community, while each case of *E. coli* O157 reported to public health represents an estimated 20.1 cases in the community.
- Only multi-jurisdictional outbreaks (i.e., clusters and outbreaks in which there is a case in more than one province or territory, or a Canadian case as well as an international case), were included in this report.

Other notes

- Multi-jurisdictional *Salmonella* and *E. coli* clusters are identified using a threshold of two or more isolates that are related within 0–10 whole genome multi-locus sequence typing (wgMLST) allele differences and have isolation dates within the past 60 days.

Nunavut *Trichinella* Detection Program (NTDP)

The Nunavut Arctic College (NAC) and Nunavut Tunngavik Incorporated (NTI) work together to offer a unique *Trichinella* diagnostic testing service for Nunavummiut, which helps to prevent cases of trichinellosis infection and supports Nunavummiut in continuing to enjoy traditional country foods.

Sections of this report using NTDP data source

- Climate-Driven Zoonotic Challenges in Northern and Arctic Indigenous Communities

Provincial and Territorial public health representatives–Rabies post-exposure prophylaxis administration data (PT-RPEP)

Rabies post-exposure prophylaxis is not systematically tracked at the national level; however, some jurisdictions do collect data on treatment initiated. Data were requested ad-hoc to inform this report.

Sections of this report using PT-RPEP data source

- Rabies

Limitations of PT-RPEP data

- Data are limited to RPEP recommendation or initiation, and do not indicate whether the full prophylactic series was completed.
- Not all jurisdictions provided RPEP data every year.
- Variations in RPEP administration across PTs may reflect differences in regional guidelines, and risk tolerance.
- Initiation of RPEP does not infer exposure to a rabid animal. The risk tolerance amongst practitioners is generally considered low, given rabies is fatal without preventative treatment.

Other notes

- Data from BC were sourced from published material and may not represent the most up-to-date information for the period of interest.

GeoSentinel Canadian Travel Medicine Network (CanTravNet)

CanTravNet is a network of clinical experts in travel and tropical medicine from across Canada, supporting surveillance and detection of travel-associated illness among Canadians. CanTravNet is made up of Canadian GeoSentinel sites—the global research and surveillance network of the International Society of Travel Medicine (ISTM)—and additional affiliate members of ISTM. CanTravNet includes a network of nine Sites and 55 Affiliate Members with the sentinel sites providing data on an estimated 15 to 20% of all returning Canadian travellers.

Sections of this report using CanTravNet data source

- Travel-acquired zoonoses

Limitations of CanTravNet data

- CanTravNet data may not be representative, quantitatively or qualitatively, of the overall population of Canadian travellers.

Other notes

- Data was acquired from GeoSentinel's Canadian sites (CanTravNet).

Canadian Food Inspection Agency (CFIA)

The Canadian Food Inspection Agency conducts inspections and has surveillance programs in place to detect and monitor important animal diseases. Relevant public health data are shared with PHAC, including data on WNV, avian influenzas and rabies. These data may act as indicators for risk to the human population.

- Suspect cases of animal rabies must be reported to the CFIA, and CFIA conducts most of the confirmatory testing in Canada. Test results are reported monthly on the CFIA website.

- The Canadian Notifiable Avian Influenza Surveillance System (CanNAISS) is led by CFIA—in collaboration with PT and industry partners—and reports on notifiable avian influenza in domestic poultry flocks.

Sections of this report using CFIA data source
- Rabies
- The Evolving Threat of Avian Influenza A(H5N1)

Limitations of CFIA data
- Some suspect rabid animals who did not expose a human or domestic animal may not undergo confirmatory testing at a CFIA laboratory.
- Non-commercial or small/backyard flock infections of avian influenza may be underreported.

Other notes
- The number of animals tested for rabies per PT was not available for 2013.

Canadian Animal Health Surveillance System (CAHSS)

Animal Health Canada's CAHSS, is an independent, collaborative network of networks with broad-based participation and support from FPT government and industry. Networks include those on poultry, dairy, equine, companion animals, and more. CAHSS supports numerous surveillance initiatives including maintaining animal disease dashboards.

Sections of this report using CAHSS data source

- COVID-19 in Canada: The Animal Angle

Limitations of CAHSS data

- Surveillance is regionally variable, therefore absence of cases in a PT or species does not mean the absence of infection.
- Animals were sampled opportunistically or passively as part of pre-existing programs or through veterinarians. Biases in species detection, driven by sampling convenience, should be considered when interpreting the data.

Canadian Wildlife Health Cooperative (CWHC)

The Canadian Wildlife Health Cooperative is a cross-Canada network of partners and collaborators dedicated to wildlife health (including representatives from five veterinary colleges and the BC Animal Health Centre). The CWHC supports wildlife health surveillance primarily through recording wildlife mortality events, helping to identify and assess emerging zoonotic issues. CWHC leads Canada's National Avian Influenza Surveillance in wild birds program. CWHC also works in collaboration with PHAC on surveillance of endemic mosquito-borne diseases (i.e. West Nile virus), to monitor activity in wild birds.

Sections of this report using CWHC data source

- The Evolving Threat of Avian Influenza A(H5N1)
- West Nile Virus and Other Mosquito-Borne Diseases

Limitations of CWHC data

- The absence of detection does not necessarily indicate the absence of infection or mortality in wildlife species.
- Sick and dead wild bird carcasses are submitted opportunistically by individuals and organizations, resulting in bias toward more populated areas and those in closer proximity to diagnostic centers.
- Submission rates may also be influenced by species (e.g., animal size, perceived value, etc.).
- Live and hunter-harvested wild bird surveillance is opportunistic, as it is conducted alongside existing targeted monitoring programs. This may impact the effectiveness of this surveillance method in detecting infections.

Other notes

- Canada's Interagency Surveillance Program for Avian Influenza Viruses in Wild Birds, provides the data for the CWHC's Highly Pathogenic Avian Influenza - Wildlife Dashboard. There are two components:
    i. Morbidity and mortality surveillance in wild birds, and
    ii. Surveillance in live and hunter-harvested wild birds.

REPORT TIMEFRAME

Data presented are for the time period from 2013 to 2022, unless stated otherwise throughout the report.

DATA ANALYSIS

Data analysis provided in this report is descriptive in nature with case counts for diseases listed in the "*Count and incidence of 11 nationally notifiable zoonotic diseases, Canada, 2013 to 2022*" table.

Incidence rates were calculated using Statistics Canada July 1 population estimates. A data extract was downloaded for the reporting period of 2013 to 2022 and totals from all ages for each year were captured as the denominator. Case counts were divided by the annual population estimates and multiplied by 100,000 to achieve the appropriate incidence rate.

TABLE OF ZOONOTIC DISEASES REPORTED TO PUBLIC HEALTH AND ANIMAL HEALTH AUTHORITIES

This table presents a non-exhaustive list of non-enteric zoonoses and pathogens that require formal communication (such as reporting or notification) to human and or animal health authorities in provinces, territories as well as federally. It is meant as a supplementary resource and demonstrates the variable and complex reporting landscape of zoonoses in Canada.

NON-ENTERIC ZOONOSES REPORTED TO HUMAN AND/OR ANIMAL HEALTH AUTHORITIES IN CANADA

In Canada, the reporting of zoonotic diseases is governed by a complex and nuanced legislative landscape. There are some differences in public and animal health reporting across FPT jurisdictions:

- Provincial and territorial laws mandate that healthcare providers, hospitals and laboratories report human cases of specified diseases or conditions (known as reportable diseases) to public health authorities within their jurisdiction. At the national level, a list of nationally notifiable diseases is also maintained, developed through a collaborative agreement between FPT public health authorities. Reporting nationally notifiable diseases to PHAC is not legally mandated and considered voluntary.

- In animal health, provincial and territorial laws also mandate reporting within their jurisdictions. However, in contrast to public health, national reporting of certain diseases (those with significant importance to human health, animal health, or the Canadian economy) are mandated under the federal Health of Animals Act and Reportable Diseases Regulations.

- Some provincial public health jurisdictions extend reporting requirements to include veterinarians and veterinary labs to report instances of disease in animals to public health (e.g., avian influenza).

A jurisdictional scan of reporting requirements was conducted and revealed several key observations. There are only a small number of diseases that are unanimously reported across all jurisdictions: anthrax, avian influenza, bovine tuberculosis, brucellosis (*melitensis*, *abortus*, *suis*), rabies, Rift Valley fever, tularemia, and West Nile virus. Across other diseases, there can be significant variability, both within, and also across sectors. These differences are understandable, as some diseases have greater implications for either human or animal health, however the variability can pose challenges for harmonized surveillance and coordinated response efforts. Many public health jurisdictions also include broader reporting categories (e.g., unusual/ unknown/ emerging illness), aimed to capture rare diseases of public health concern. Therefore, although not explicitly stated, diseases such as Hendra virus disease in humans would be reported through this route. These legislative and structural nuances underscore the importance and need for cross-sectoral collaboration to strengthen zoonotic disease surveillance and public health preparedness in Canada.

This table provides a generalized reference guide, indicating where some key diseases require notification to either human or animal health.

Scope

The zoonoses listed in the table are not exhaustive. Diseases only listed in a small number of jurisdictions are not included. For reporting purposes, official jurisdictional legislation should be consulted. In some cases, notification requirements may apply only to specific animal species, depending on the disease/pathogen and jurisdiction.

Terminology and categorization

The table reflects the terminology used by each jurisdiction and includes both broad disease categories and specific disease/pathogen names. When a disease/pathogen could fit under multiple categories, it was assigned to a single category to avoid duplication (e.g. Rift Valley Fever is both an arbovirus and a viral hemorrhagic fever (VHF), but was only assigned to VHF).

Legend for indicators

- A black checkmark (✓) indicates the disease is *explicitly* named in the legislation of that FPT jurisdiction.
- A grey checkmark (✓) indicates the disease is *implicitly* included under a broader disease category within the legislation, or requires reporting under federal animal health legislation.

Legislation links

Where available, jurisdictional legislation has been linked via icons under each FPT:

- 👤 for human-related legislation
- 🐾 for animal-related legislation

	Canada		YT		NT		NU		BC		AB		SK		MB		ON		QC		NB		NS		PE		NL	
	👤	🐾	👤	🐾	👤	🐾	👤	🐾	👤	🐾	👤±	🐾	👤	🐾	👤	🐾	👤	🐾	👤	🐾	👤	🐾	👤	🐾	👤	🐾	👤	🐾
Arbovirus infection (*neuroinvasive)			✓		✓ (grey)						✓								✓ *	✓					✓	✓	✓	✓
California serogroup virus (including Jamestown Canyon and snowshoe hare)			✓ (grey)		✓						✓								✓	✓ (grey)					✓ (grey)	✓ (grey)	✓ (grey)	✓ (grey)
Cache Valley Virus			✓ (grey)		✓ (grey)						✓ (grey)							✓	✓ (grey)	✓ (grey)		✓		✓	✓ (grey)	✓	✓ (grey)	✓ (grey)
Chikungunya			✓		✓		✓				✓								✓	✓ (grey)					✓ (grey)	✓ (grey)	✓ (grey)	✓ (grey)
Dengue			✓		✓		✓		✓		✓								✓	✓ (grey)					✓ (grey)	✓ (grey)	✓ (grey)	✓ (grey)
Eastern equine encephalitis		✓	✓ (grey)	✓ (grey)	✓ (grey)	✓ (grey)		✓ (grey)		✓	✓	✓ (grey)		✓ (grey)		✓ (grey)		✓	✓ (grey)	✓		✓ (grey)		✓	✓ (grey)	✓ (grey)	✓ (grey)	✓ (grey)
Japanese encephalitis virus		✓	✓ (grey)	✓ (grey)	✓	✓ (grey)		✓ (grey)		✓ (grey)	✓	✓ (grey)		✓ (grey)		✓ (grey)		✓	✓ (grey)	✓		✓ (grey)		✓ (grey)	✓ (grey)	✓ (grey)	✓ (grey)	✓ (grey)
Venezuelan equine encephalitis		✓	✓ (grey)	✓ (grey)	✓ (grey)	✓ (grey)		✓ (grey)		✓	✓ (grey)	✓ (grey)		✓ (grey)		✓ (grey)		✓	✓ (grey)	✓		✓ (grey)		✓ (grey)	✓ (grey)	✓	✓ (grey)	✓ (grey)
Western equine encephalitis		✓	✓ (grey)	✓ (grey)	✓ (grey)	✓ (grey)		✓ (grey)		✓	✓	✓ (grey)		✓ (grey)	✓	✓ (grey)		✓	✓ (grey)	✓		✓ (grey)		✓	✓ (grey)	✓ (grey)	✓ (grey)	✓ (grey)
West Nile virus	✓	✓	✓	✓ (grey)	✓	✓ (grey)	✓	✓ (grey)	✓	✓	✓	✓	✓	✓	✓	✓ (grey)	✓	✓	✓	✓	✓	✓	✓	✓	✓ (grey)	✓	✓	✓ (grey)
Yellow fever	✓		✓		✓		✓		✓	✓	✓		✓		✓		✓		✓	✓ (grey)	✓		✓		✓ (grey)	✓ (grey)	✓	✓ (grey)
Zika virus			✓		✓		✓		✓		✓								✓	✓ (grey)					✓ (grey)	✓ (grey)	✓	✓ (grey)

	Canada		YT		NT		NU		BC		AB		SK		MB		ON		QC		NB		NS		PE		NL	
	Human	Animal	Human	Animal	Human	Animal	Human	Animal	Human	Animal	Human ±	Animal	Human	Animal	Human	Animal	Human	Animal	Human	Animal	Human	Animal	Human	Animal	Human	Animal	Human	Animal
Louse or tick-borne diseases																												
Anaplasmosis (*A. ovis / **A. phagocytophilum	✓	✓ **	✓	(✓) **		(✓) **		(✓) **		✓		✓		(✓) **	✓	(✓) **	✓	✓ */**	✓	(✓) **	✓	(✓) **	✓	(✓)	✓	(✓)	(✓)	(✓)
Babesiosis (*B. bovis)	✓	✓ *	✓	(✓) *		(✓) *		(✓) *		(✓) *		(✓) *		(✓) *	✓	(✓) *	✓	✓ *	✓		✓	(✓) *	✓	✓	✓	(✓)	✓	(✓)
Lyme disease	✓		✓		✓		✓		✓	✓	✓	✓	✓	✓	✓		✓	✓	✓		✓		✓	(✓)	✓	(✓)	✓	(✓)
Powassan	✓		✓								✓						✓				✓		✓	✓	✓	(✓)	✓	(✓)
Rickettsial infection (*R. rickettsii / **Neorickettsia spp.)			✓						✓	✓ *	✓		✓					✓ **			✓			✓ *	(✓)	(✓)	(✓)	(✓)
Viral hemorrhagic fevers																												
Crimean-Congo hemorrhagic fever	(✓)		✓		(✓)		(✓)		✓	✓	✓		(✓)		✓		(✓)		(✓)		(✓)		✓		(✓)		(✓)	
Ebola	(✓)		✓		✓		(✓)		✓	✓	✓		(✓)		✓		✓		(✓)	✓	(✓)		✓		(✓)		✓	
Lassa fever	(✓)		✓		✓		(✓)		✓	✓	✓		(✓)		✓		✓		(✓)		(✓)		✓		(✓)		✓	
Marburg	(✓)		✓		✓		(✓)		✓	✓	✓		(✓)		✓		✓		(✓)	✓	(✓)		✓		(✓)		✓	
Rift Valley Fever	(✓)	✓	✓	(✓)	(✓)	(✓)	(✓)	(✓)	✓	✓	✓	(✓)	(✓)	(✓)	✓	(✓)	(✓)	✓	(✓)	✓	(✓)	(✓)	✓	(✓)	(✓)	✓	(✓)	(✓)

	Canada		YT		NT		NU		BC		AB		SK		MB		ON		QC		NB		NS		PE		NL	
	Human	Animal	Human	Animal	Human	Animal	Human	Animal	Human	Animal	Human ±	Animal	Human	Animal	Human	Animal	Human	Animal	Human	Animal	Human	Animal	Human	Animal	Human	Animal	Human	Animal
Other zoonoses																												
Anthrax	✓	✓	✓	✓	✓	(✓)	✓	✓	✓	✓	✓	✓	✓	✓	✓	(✓)	✓	✓	✓	✓	✓	(✓)	✓	✓	✓	✓	✓	✓
Bovine tuberculosis	✓	✓	✓	✓	✓	(✓)	✓	✓	✓	✓	✓	✓	✓	(✓)	✓	(✓)	✓	✓	✓	✓	✓	(✓)	✓	✓	✓	✓	✓	✓
Brucellosis (**B. canis* / ***B. abortus*, *suis*, *melitensis*)	✓	✓ **	✓	✓	✓	(✓) **	✓	✓	✓	✓	✓	✓	✓	(✓) **	✓	(✓) **	✓	✓ */**	✓	✓	✓	(✓) **	✓	✓	✓	✓	✓	✓
Chagas disease (Trypanosomiasis)		✓		(✓)		(✓)		(✓)		(✓)		(✓)		(✓)		(✓)		✓	✓	✓		(✓)		(✓)		(✓)		(✓)
Echinococcosis - *E. granulosus*		✓		(✓)	✓	(✓)	✓	(✓)		(✓)		(✓)		(✓)		(✓)		(✓)		(✓)		(✓)		(✓)		(✓)		✓
Echinococcosis - *E. multilocularis*		✓		(✓)	✓	(✓)	✓	(✓)		(✓)	✓	(✓)		(✓)		(✓)	✓	✓		✓		(✓)		(✓)		(✓)		(✓)
Hantavirus	✓		✓	✓	✓		✓		✓	✓	✓		✓		✓		✓	✓	✓	✓	✓		✓		✓		✓	✓
Hendra virus		✓		(✓)		(✓)		(✓)		(✓)		(✓)		(✓)		(✓)		✓		✓		(✓)		(✓)		(✓)		(✓)
Influenza - Avian	✓	✓	✓	✓	✓	(✓)	✓	(✓)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Influenza - Swine	✓		✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
Leptospirosis (**L. interrogans*)							✓		✓				✓					✓	✓	✓ *	✓					✓		

	Canada		YT		NT		NU		BC		AB		SK		MB		ON		QC		NB		NS		PE		NL	
	Human	Animal	Human	Animal	Human	Animal	Human	Animal	Human	Animal	Human[±]	Animal	Human	Animal	Human	Animal	Human	Animal	Human	Animal	Human	Animal	Human	Animal	Human	Animal	Human	Animal
Other zoonoses (continued)																												
Malaria	✓		✓		✓		✓		✓		✓		✓		✓				✓		✓		✓		✓		✓	
MERS-CoV			✓		✓		✓		✓		✓						✓			✓								
Mpox	✓		✓		✓				✓		✓						✓			✓	✓		✓		✓		✓	
Nipah virus		✓		✓ (grey)		✓ (grey)		✓ (grey)		✓ (grey)		✓ (grey)		✓ (grey)		✓ (grey)		✓		✓		✓ (grey)		✓ (grey)		✓ (grey)		✓ (grey)
Plague	✓		✓		✓		✓		✓	✓	✓		✓		✓		✓	✓	✓	✓	✓	✓	✓		✓		✓	✓
Psittacosis (avian chlamydiosis)		✓	✓	✓	✓	✓ (grey)		✓ (grey)	✓	✓	✓	✓	✓	✓ (grey)		✓ (grey)	✓	✓	✓	✓	✓	✓		✓		✓		✓
Rabies	✓	✓	✓	✓	✓	✓ (grey)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓ (grey)	✓	✓	✓	✓	✓	✓ (grey)	✓	✓	✓	✓	✓	✓
Tularemia	✓	✓	✓	✓	✓	✓ (grey)	✓	✓	✓	✓	✓	✓ (grey)	✓	✓ (grey)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓ (grey)	✓	✓
Q fever		✓	✓	✓	✓	✓ (grey)	✓	✓ (grey)	✓	✓	✓	✓ (grey)		✓	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓ (grey)	✓	✓
Unusual/unknown/emerging illness	✓		✓		✓		✓		✓	✓	✓				✓	✓		✓	✓		✓		✓		✓	✓	✓	

± Additional reference: https://open.alberta.ca/publications/laboratory-reporting-reference

GLOSSARY & ACRONYMS

GLOSSARY

Adventitious ticks	Ticks brought in by migratory animals such as birds and deer or other hosts from outside of Canada. Some of these adventitious ticks have become established in Canada in areas where habitats are suitable for reproducing.
Arboviral disease	A specific category of viral infections transmitted to humans by arthropod vectors, such as mosquitoes and ticks.
Arthropod	Invertebrate animals which include mosquitoes, ticks, biting midges, lice, flies, fleas, and mites, which can transmit pathogens between animals and humans.
Asymptomatic	An infection in which an individual is infected by a pathogen, but shows no signs or symptoms of illness.
Autochthonous	Referring to a disease or infection that is locally acquired within a given geographic area.
Case fatality rate	An epidemiological measure indicating the proportion of people diagnosed with a disease who die from that disease.
Co-infection	Simultaneous infection by two or more different pathogens.
Country food	Foods that are locally available from natural resources that have cultural significance for Indigenous Peoples in Canada. Traditional food is the preferred term for First Nations and Métis peoples, and country food is the preferred term for Inuit.
Dead-end host	Hosts that become infected but do not transmit the pathogen further, effectively ending the transmission cycle.
Definitive hosts	In parasitic life cycles, the host in which the parasite reaches maturity and reproduces sexually.
Ecological niche	The role and position a species has in its environment, including its interactions with biotic and abiotic factors.

GLOSSARY (CON'T)

Enteric zoonoses
Refers to human enteric illness linked to a zoonotic source, such as an animal or their food, waste or environment. May include common enteric pathogens such as *Salmonella* and verotoxigenic *Escherichia coli* (*E. coli*).

Endemic
A disease that is consistently present within a population or geographic area.

Enzootic
A disease that consistently affects non-human animals within a specific geographic area or population. Often used interchangeably with the term endemic.

Epidemiology
The study of the factors affecting the health and illness of populations and how disease is distributed. Epidemiology focuses on understanding the causes, patterns, and determinants of health-related states and events within specified populations.

Epizootic
Disease outbreak occurring in an animal population, analogous to the term epidemic in human populations.

Food security
The state of having reliable access to a sufficient quantity of affordable, nutritious food.

Incidental host
Hosts that can become infected but do not typically transmit the pathogen to other hosts.

Incubation period
The time interval between initial exposure to a pathogen and the appearance of the first symptoms of the disease.

Intermediate hosts
In parasitic life cycles, the host in which the parasite undergoes development but does not reach sexual maturity.

Neuroinvasive disease/illness
A severe manifestation of certain infections where the pathogen affects the central nervous system.

GLOSSARY (CON'T)

Northern and Arctic Indigenous communities
Refers to First Nations, Inuit, and Métis populations residing in the northern and Arctic regions of Canada, including territories such as Yukon, Northwest Territories, and Nunavut, as well as northern parts of provinces like British Columbia, Alberta, Manitoba, Ontario, and Quebec. These communities often maintain distinct cultural traditions, languages, and governance systems.

Non-enteric zoonoses
Infectious diseases transmitted between animals and humans that are primarily spread through routes other than via contaminated food or water, such as direct contact, inhalation, or vector-borne transmission. Examples include avian influenza, hantavirus pulmonary syndrome, and rabies, as well as vector-borne diseases like Lyme disease and West Nile virus.

One Health
An integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals and ecosystems. It recognizes the health of humans, domestic and wild animals, plants, and the wider environment (including ecosystems) are closely linked and inter-dependent. The approach mobilizes multiple sectors, disciplines and communities at varying levels of society to work together to foster well-being and tackle threats to health and ecosystems, while addressing the collective need for clean water, energy and air, safe and nutritious food, taking action on climate change, and contributing to sustainable development.

Panzootic
An epidemic affecting animals over a very wide area, similar to a pandemic in humans.

Post-exposure prophylaxis
Treatment given after suspected exposure to prevent disease.

Pathogen
A bacterium, virus, or other microorganism that can cause disease.

Reassortment
A process where two or more influenza viruses, infecting the same host, exchange genetic material, leading to new virus strains with potentially altered characteristics.

GLOSSARY (CON'T)

Re-emergence Reappearance of a disease after a period of decline.

Reservoir host A population or species in which a pathogen naturally occurs and is maintained and can serve as a source of infection for other animals or humans.

Sentinel surveillance A surveillance strategy that involves monitoring specific, predetermined sites or groups (e.g., travel clinics, specific animal populations) to detect early signals of disease activity or trends.

Seroprevalence An epidemiological measure indicating the percentage of individuals in a population who have antibodies against a specific pathogen, suggesting past or present infection.

Spillover event Transmission of a pathogen from one species (usually the reservoir host) to a novel susceptible species, especially from animals to humans, or between different animal populations.

Symptomatic An infection where an individual exhibits observable signs or symptoms of illness.

Transfusion-transmitted A route of disease transmission that occurs through contaminated blood products.

Vector-borne diseases Vectors, such as ticks and mosquitoes, can spread infectious agents between animals and humans, typically through bites. Diseases spread by vectors are called vector-borne diseases and include tick-borne and mosquito-borne diseases.

Viremic The presence of viruses in the blood, indicating active infection and potential for transmission.

Virulence The degree of pathogenicity within a group or species of microorganisms or viruses, indicating the severity of disease they can cause.

GLOSSARY (CON'T)

Whole genome sequencing
A laboratory technique used to determine the complete DNA or RNA sequence of an organism's genome, important for identifying pathogen strains, tracing outbreaks, and understanding transmission pathways.

Zoonoses
Infectious diseases caused by pathogens that originate in animals and are transmitted to humans. Transmission can occur through direct contact with infected animals, indirect contact via the environment, consumption of contaminated food or water or through vectors such as ticks and mosquitoes.

ACRONYMS

Acronym	Expanded Form
AB	Alberta
AE	Alveolar echinococcosis
A(H5N1)	Avian influenza A(H5N1)
ARDS	Acute Respiratory Distress Syndrome
BC	British Columbia
BSS	Bovine surveillance system
CAHSS	Canadian Animal Health Surveillance System
CanNAISS	Canadian Notifiable Avian Influenza Surveillance System
CanTravNet	Canadian Travel Medicine Network
CDC	U.S. Centers for Disease Control
CFIA	Canadian Food Inspection Agency
CNDSS	Canadian Notifiable Disease Surveillance System
CTF	Colorado tick fever
CWHC	Canadian Wildlife Health Cooperative
CSG	California serogroup
CSGV	California serogroup viruses
EEE	Eastern equine encephalitis
EEEV	Eastern equine encephalitis virus
ECCC	Environment and Climate Change Canada
FAO	Food and Agriculture Organization

ACRONYMS (CON'T)

Acronym	Expanded Form
FPT	federal provincial and territorial
HIV	Human immunodeficiency viruses
HPS	Hantavirus pulmonary syndrome
INSPQ	Institut national de santé publique du Québec
ISC	Indigenous Services Canada
ISTM	International Society of Travel Medicine
JCV	Jamestown canyon virus
LDES	Lyme Disease Enhanced Surveillance
MB	Manitoba
MBD	Mosquito-borne diseases
NAC	Nunavut Arctic College
NCFAD	National Centre for Foreign Animal Disease
NB	New Brunswick
NL	Newfoundland and Labrador
NML	National Microbiology Laboratory
NS	Nova Scotia
NTDP	Nunavut *Trichinella* Detection Program
NTI	Nunavut Tunngavik Incorporated
NU	Nunavut
NWT	Northwest Territories
ON	Ontario

ACRONYMS (CON'T)

Acronym	Expanded Form
PAHO	Pan American Health Organization
PCR	Polymerase chain reaction
PEP	Post-exposure prophylaxis
PE	Prince Edward Island
PHEIC	Public Health Emergency of International Concern
PHAC	Public Health Agency of Canada
PNC	PulseNet Canada
POWV	Powassan virus
PT	Province/Territory
QC	Quebec
RVV	Rabies virus variants
RIG	Rabies immune globulin
RMSF	Rocky Mountain spotted fever
RNA	Ribonucleic acid
rPEP	Rabies post-exposure prophylaxis
RT-PCR	Reverse transcription polymerase chain reaction
SARI	Severe acute respiratory infection
SARS-CoV-2	Severe acute respiratory syndrome coronavirus 2
SFGR	Spotted fever group rickettsiosis
SK	Saskatchewan

ACRONYMS (CON'T)

Acronym	Expanded Form
spp.	Species plural
SSHV	Snowshoe hare virus
TBDs	Tick-borne diseases
TTB	Transfusion-transmitted babesiosis
U.S.	United States
VHFs	Viral hemorrhagic fevers
WGS	Whole genome sequencing
wgMLST	Whole genome multi-locus sequence typing
WHO	World Health Organization
WNV	West Nile virus
YK	Yukon
ZIKV	Zika virus
ZVB	Zoonotic and Vector-Borne

REFERENCES

REFERENCES

1 World Health Organization. Zoonotic disease: emerging public health threats in the Region. [Internet]. n.d. [cited 2025-06-12]. https://www.emro.who.int/about-who/rc61/zoonotic-diseases.html

2 Jones KE, Patel NG, Levy MA, Storeygard A, Balk D, Gittleman JL, Daszak P. Global trends in emerging infectious diseases. Nature. 2008;451(7181):990-993.

3 George AM, Ansumana R, de Souza DK, Niyas VKM, Zumla A, Bockarie MJ. Climate change and increased incidence of vector-borne diseases worldwide. International Journal of Infectious Diseases. 2024;139:143-145.

4 Environment and Climate Change Canada. Canada's climate is warming twice as fast as global average. [Internet]. 2019-04-02 [cited 2025-05-12]. https://www.canada.ca/en/environment-climate-change/news/2019/04/canadas-climate-is-warming-twice-as-fast-as-global-average.html

5 Ogden NH, Bouchard, C., Brankston, G., Brown, E. M., Corrin, T., Dibernardo, A., Drebot, M. A., Fisman, D. N., Galanis, E., Greer, A., Jenkins, E., Kus, J. V., Leighton, P. A., Lindsay, L. R., Lowe, A.-M., Ludwig, A., Morris, S. K., Ng, V., Vrbova, L., Waddell, L., & Wood, H. Infectious Diseases. In: Berry P, & Schnitter, R., ed. Health of Canadians in a Changing Climate: Advancing our Knowledge for Action. 2022:366-443. https://changingclimate.ca/health-in-a-changing-climate/chapter/6-0/

6 Stephen C, Duncan C. Can wildlife surveillance contribute to public health preparedness for climate change? A Canadian perspective. Climatic Change. 2017;141:259–271.

7 Food and Agriculture Organization of the United Nations, World Health Organization, World Organisation for Animal Health, United Nations Environment Programme. One Health Joint Plan of Action (2022-2026): Working together for the health of humans, animals, plants and the environment. [Internet]. 2022 [cited 2025-07-07]. https://iris.who.int/server/api/core/bitstreams/578db93c-0ada-4c37-bcb5-e1dff68f4a0d/content

8 Dean AS, Crump L, Greter H, Hattendorf J, Schelling E, Zinsstag J. Clinical Manifestations of Human Brucellosis: A Systematic Review and Meta-Analysis. *PLoS Neglected Tropical Diseases, 6(12)*. 2012;6(12).

9 Bush LM, Vazquez-Pertejo MT. Brucellosis. [Internet]. Merck Manual Professional Version; 2024-06-01 [cited 2025-01-25]. https://www.merckmanuals.com/en-ca/professional/infectious-diseases/gram-negative-bacilli/brucellosis

10 Khan M, Akhtar N. Brucellosis. In: Control of Communicable Diseases Manual. 2025:doi:10.2105/ccdm.2745.037

11 Di Pierdomenico A, Borgia SM, Richardson D, Baqi M. Brucellosis in a returned traveller. *CMAJ: Canadian Medical Association Journal*. 2011;183(10):690-692.

12 Kanji JN, Saxinger L. *Brucella* infection at cardiac pacemaker site in a patient who had consumed raw caribou meat in Northern Canada. *CMAJ: Canadian Medical Association Journal*. 2018;190(37).

13 Turvey S, Hui C, Tyrrell G, Singh A. *Brucella* suis as a cause of late prosthetic joint infection: A case report and review of the literature. *Official Journal of the Association of Medical Microbiology and Infectious Disease Canada*. 2017;2(1).

14 Tomaselli M, Gerlach S, Kutz S, Checkley S, The Community Of Iqaluktutiaq. Iqaluktutiaq voices: Local perspectives about the importance of muskoxen, contemporary and traditional use and practices. *Arctic*. 2018;71(1):1-14.

15 Aguilar XF, Mavrot F, Surujballi O, Leclerc LM, Kugluktuk Angoniatit Association, Ekaluktutiak Hunters and Trappers Organization, . . . Kutz S. Brucellosis emergence in the Canadian Arctic. *One Health*. 2024;18:100712.

16 Tryland M, ed. *Arctic One Health: Challenges for Northern Animals and People*. 1 ed. Springer Cham; 2022. doi:https://doi.org/10.1007/978-3-030-87853-5

17 Aguilar XF, Nymo IH, Beckmen K, Dresvyanikova S, Egorova I, Kutz S. Brucellosis in the Arctic and Northern Regions. In: Tryland M, ed. *Arctic One Health*. Springer, Cham; 2022:227-267 doi:https://doi.org/10.1007/978-3-030-87853-5_10

18 Carlsson AM, Curry P, Elkin B, Russell D, Veitch A, Branigan M, . . . Kutz SJ. Multi-pathogen serological survey of migratory caribou herds: A snapshot in time. *PloS One*. 2019;14(7):e0219838.

19 Tessaro SV. The existing and potential importance of brucellosis and tuberculosis in canadian wildlife: a review. *Canadian Veterinary Journal*. 1986;27(3):119-124.

20 Tomaselli M, Elkin B, Kutz S, Harms NJ, Nymo HI, Davison T, . . . Checkley S. A Transdisciplinary Approach to *Brucella* in Muskoxen of the Western Canadian Arctic 1989-2016. *Ecohealth*. 2019;16(3):488-501.

21 Kutz Research Group (University of Calgary). Muskox and Caribou Health Monitoring Program - Activity Update. [Internet]. University of Calgary; [cited 2025-05-12]. https://www.ucalgary.ca/live-uc-ucalgary-site/sites/default/files/teams/657/ActivityUpdate_June2021.pdf

22 Joly DO, Messier F. Factors affecting apparent prevalence of tuberculosis and brucellosis in wood bison. *Journal of Animal Ecology*. 2004;73.

23 Leighton FA. Wildlife pathogens and diseases in Canada. Ottawa. Technical Thematic Report 7. 2011. iv + 53 p. https://publications.gc.ca/collections/collection_2011/ec/En14-43-7-2011-eng.pdf

24 Attia El Hili H, Maatouk K. Potentiel zoonotique de la brucellose des mammifères marins. *Médecine Tropicale et Santé Internationale*. 2024;4(1).

25 Nymo IH, Tryland M, Godfroid J. A review of *Brucella* infection in marine mammals, with special emphasis on *Brucella pinnipedialis* in the hooded seal (Cystophora cristata). *Veterinary Research*. 2011;42(1):93.

26 World Organisation for Animal Health. World Animal Health Information System (WAHIS) Six-monthly Report. [Database]. Accessed 2025-01-31. https://wahis.woah.org/#/smr-management

27 Weese J, Hrinivich K, Anderson M. *Brucella canis* in Commercial Dog Breeding Kennels, Ontario, Canada. *Emerging Infectious Diseases*. 2020;26(12).

28 Cosford KL. *Brucella canis*: An update on research and clinical management. *Canadian Veterinary Journal*. 2018;59(1):74-81.

29 Galanis E, Trerise S, Ahmed-Bentley J, Deans GD, Fraser E. Brucellosis and other diseases imported with dogs. *British Columbia Medical Journal*. 2019;61(4):177-190.

30 Ahmed-Bentley J, Roman S, Mirzanejad Y, Fraser E, Hoang L, Young EJ, . . . Deans G. Laboratory Exposures from an Unsuspected Case of Human Infection with *Brucella canis*. *Emerging Infectious Diseases*. 2021;27(9):2489-2491.

31 Drebot MA, Jones S, Grolla A, Safronetz D, Strong JE, Kobinger G, Lindsay RL. Hantavirus pulmonary syndrome in Canada: An overview of clinical features, diagnostics, epidemiology and prevention. *Canada Communicable Disease Report*. 2015;41(6):124-131.

32 Warner BM, Dowhanik S, Audet J, Grolla A, Dick D, Strong JE, . . . Safronetz D. Hantavirus Cardiopulmonary Syndrome in Canada. *Emerging Infectious Diseases*. 2020;26(12):3020-3024.

33 Prevost J, Tailor N, Leung A, Warner B, Safronetz D. Sin Nombre Virus as Unlikely Reverse Zoonotic Threat. *Emerging Infectious Diseases*. 2025;31(2):385-388.

34 Public Health Agency of Canada. Public Health Bulletin: Information for Canadians regarding Seoul virus. [Internet]. 2017-03-01 [cited 2025-06-1]. https://www.canada.ca/en/public-health/services/public-health-advice/2017/public-health-bulletin-information-canadians-regarding-seoul-virus.html

35 Clement J, Underwood P, Ward D, Pilaski J, LeDuc J. Hantavirus outbreak during military manoeuvres in Germany. *Lancet*. 1996;347(8997):336.

36 Kim HC, Kim WK, Klein TA, Chong ST, Nunn PV, Kim JA, . . . Song JW. Hantavirus surveillance and genetic diversity targeting small mammals at Camp Humphreys, a US military installation and new expansion site, Republic of Korea. *PloS One*. 2017;12(4):e0176514.

37 McCormic ZD, Balihe MN, Havas KA, Baty SA. Puumala hantavirus outbreak among U.S. military health care beneficiaries, Stuttgart, Germany--2012. *Medical Surveillance Monthly Report*. 2013;20(12):12-15.

38 Mustonen J, Henttonen H, Vaheri A. Hantavirus Infections among Military Forces. *Military Medicine*. 2024;189(3-4):551-555.

39 Parkes LO, Nguyen TT, Longtin J, Beaudoin MC, Bestman-Smith J, Vinh DC, . . . Loo VG. A Cluster of Three Cases of Hantavirus Pulmonary Syndrome among Canadian Military Personnel. *Canadian Journal of Infectious Diseases & Medical Microbiology*. 2016;2016:2757969.

40 Rouabhia R, Dinh DT, Kua SC, Washington MA. Lessons Learned From the U.S. Military Experience With Hantavirus During the Korean War. *Military Medicine*. 2023;188(9-10):3205-3209.

41 Weir E. Hantavirus: 'tis the season. *CMAJ: Canadian Medical Association Journal*. 2005;173(2):147.

42 Joyce AK, Oliver TT, Kofman AD, Talker DL, Safaeian S, Peker Barclift D, . . . Antone-Nez R. Hantavirus Disease and COVID-19. *American Journal of Clinical Pathology*. 2022;157(3):470-475.

43 Coelho RM, Periolo N, Duhalde CP, Alonso DO, Bellomo CM, Corazza M, . . . Martinez VP. Hantavirus Pulmonary Syndrome in a COVID-19 Patient, Argentina, 2020. *Emerging Infectious Diseases*. 2022;28(4):876-878.

44 Hesse S, Nunez H, Salazar JR, Salinas TP, Barrera E, Chong R, . . . Armien B. Case Report: First Confirmed Case of Coinfection of SARS-CoV-2 With Choclo orthohantavirus. *Frontiers in Tropical Diseases*. 2021;2:769330.

45 Villamil-Gomez WE, Gross R, Pacheco-Jimenez CD, Aza-Rivera M, Rodriguez-Morales AJ. Hantavirus pulmonary syndrome in a COVID-19 patient, Bolivia, 2022. *New Microbes and New Infections*. 2025;63:101564.

46 Mills JN, Amman BR, Glass GE. Ecology of hantaviruses and their hosts in North America. *Vector-Borne and Zoonotic Diseases*. 2010;10(6):563-574.

47 Sullivan TP, Sullivan DS, Boonstra R, Krebs CJ, Vyse A. Population regulation in the deer mouse (Peromyscus maniculatus) in old-growth coniferous forests of southern British Columbia: insights from a long-term study. *Mammal Research*. 2023;68(1):37-51.

48 Lonner BN, Douglass RJ, Kuenzi AJ, Hughes K. Seroprevalence against Sin Nombre virus in resident and dispersing deer mice. *Vector-Borne and Zoonotic Diseases*. 2008;8(4):433-441.

49 Kerins JL, Koske SE, Kazmierczak J, Austin C, Gowdy K, Dibernardo A, . . . Contributors. Outbreak of Seoul Virus Among Rats and Rat Owners - United States and Canada, 2017. *MMWR: Morbidity and Mortality Weekly Report*. 2018;67(4):131-134.

50 Duggan JM, Close R, McCann L, Wright D, Keys M, McCarthy N, . . . Brooks TJG. A seroprevalence study to determine the frequency of hantavirus infection in people exposed to wild and pet fancy rats in England. *Epidemiology and Infection*. 2017;145(12):2458-2465.

51 Crandall KE, Millien V, Kerr JT. Historical associations and spatiotemporal changes of pathogen presence in ticks in Canada: A systematic review. *Zoonoses and Public Health*. 2024;71(1):18-33.

52 Ogden NH, Trudel L, Artsob H, Barker IK, Beauchamp G, Charron DF, . . . Lindsay LR. *Ixodes scapularis* ticks collected by passive surveillance in Canada: analysis of geographic distribution and infection with Lyme borreliosis agent *Borrelia burgdorferi*. *Journal of Medical Entomology*. 2006;43(3):600-609.

53 Wilson C, Gasmi S, Bourgeois AC, Badcock J, Carr J, Chahil N, . . . Koffi, J. Surveillance for *Ixodes scapularis* and *Ixodes pacificus* ticks and their associated pathogens in Canada, 2020. Canada Communicable Disease Report. 2023;49(6):288-298.

54 Bouchard C, Dibernardo A, Koffi J, Wood H, Leighton PA, Lindsay LR. Increased risk of tick-borne diseases with climate and environmental changes. *Canada Communicable Disease Report*. 2019;45(4):83-89.

55 Gasmi S, Koffi JK, Nelder MP, Russell C, Graham-Derham S, Lachance L, . . . Bourgeois AC. Surveillance for Lyme disease in Canada, 2009-2019. *Canada Communicable Disease Report*. 2022;48(5):219-227.

56 Kulkarni MA, Berrang-Ford L, Buck PA, Drebot MA, Lindsay LR, Ogden NH. Major emerging vector-borne zoonotic diseases of public health importance in Canada. *Emerging Microbes and Infections*. 2015;4(6):e33.

57 Dumic I, Jevtic D, Veselinovic M, Nordstrom CW, Jovanovic M, Mogulla V, . . . Ramanan P. Human Granulocytic Anaplasmosis-A Systematic Review of Published Cases. *Microorganisms*. 2022;10(7).

58 Kumar A, O'Bryan J, Krause PJ. The Global Emergence of Human Babesiosis. *Pathogens*. 2021;10(11).

59 Public Health Agency of Canada. Lyme disease: For health professionals. [Internet]. 2025-06-30 [cited 2025-08-12]. https://www.canada.ca/en/public-health/services/diseases/lyme-disease/health-professionals-lyme-disease.html#a3

60 Wormser GP, Dattwyler RJ, Shapiro ED, Halperin JJ, Steere AC, Klempner MS, . . . Nadelman RB. The clinical assessment, treatment, and prevention of lyme disease, human granulocytic anaplasmosis, and babesiosis: clinical practice guidelines by the Infectious Diseases Society of America. *Clinical Infectious Diseases*. 2006;43(9):1089-1134.

61 Semproni M, Rusk R, Wuerz T. Fatal Lyme carditis presenting as fluctuating high-grade atrioventricular block. *CMAJ: Canadian Medical Association Journal*. 2020;192(21):E574-E577.

62 Public Health Agency of Canada. Lyme disease surveillance in Canada: Annual edition 2022. [Internet]. 2024-04-29 [cited 2025-03-15]. https://www.canada.ca/en/public-health/services/publications/diseases-conditions/lyme-disease-surveillance-canada-annual-edition-2022.html

63 Nova Scotia Department of Health and Wellness. 2022 Notifiable Diseases in Nova Scotia Surveillance Report 2022. https://novascotia.ca/dhw/populationhealth/documents/Annual-Notifiable-Disease-Surveillance-Report-2022.pdf

64 Public Health Agency of Canada. Lyme disease surveillance in Canada: Annual edition 2021. [Internet]. 2024-02-19 [cited 2025-03-12]. https://www.canada.ca/en/public-health/services/publications/diseases-conditions/lyme-disease-surveillance-canada-2021-annual-edition.html

65 Public Health Agency of Canada. Lyme disease surveillance in Canada: Annual edition 2020. [Internet]. 2023-07-27 [cited 2025-03-12]. https://www.canada.ca/en/public-health/services/publications/diseases-conditions/lyme-disease-surveillance-canada-2020-annual-edition.html

66 Public Health Agency of Canada. Tick-borne disease surveillance: Maps. [Internet]. 2025-03-19 [cited 2025-03-20]. https://health-infobase.canada.ca/zoonoses/ticks/maps.html

67 Public Health Agency of Canada. Case definitions: Nationally notifiable diseases. [Internet]. 2025-06-12 [cited 2025-07-07]. https://diseases.canada.ca/notifiable

68 Elmieh N. A review of ticks in Canada and health risks from exposure. [Internet]. National Collaborating Centre for Envrionment Health (NCCEH); 2022-08-17 [cited 2024-04-17]. https://ncceh.ca/resources/evidence-reviews/review-ticks-canada-and-health-risks-exposure

69 Public Health Agency of Canada. Anaplasmosis: Symptoms and treatment. [Internet]. 2024-09-24 [cited 2024-10-10]. https://www.canada.ca/en/public-health/services/diseases/ticks-tick-transmitted-diseases/anaplasmosis.html

70 Chen SM, Dumler JS, Bakken JS, Walker DH. Identification of a granulocytotropic Ehrlichia species as the etiologic agent of human disease. *Journal of Clinical Microbiology*. 1994;32(3):589-595.

71 Parkins MD, Church DL, Jiang XY, Gregson DB. Human Granulocytic Anaplasmosis: First Reported Case in Canada. *Canadian Journal of Infectious Diseases and Medical Microbiology*. 2009;20:124173.

72 Pelletier J, Guillot C, Rocheleau JP, Bouchard C, Baron G, Bedard C, . . . Aenishaenslin C. The added value of One Health surveillance: data from questing ticks can provide an early signal for anaplasmosis outbreaks in animals and humans. *Canadian Journal of Public Health. Revue Canadienne de Santé Publique*. 2023;114(2):317-324.

73 Uminski K, Kadkhoda K, Houston BL, Lopez A, MacKenzie LJ, Lindsay R, . . . Zarychanski R. Anaplasmosis: An emerging tick-borne disease of importance in Canada. *IDCases*. 2018;14:e00472.

74 Horowitz HW, Aguero-Rosenfeld ME, Holmgren D, McKenna D, Schwartz I, Cox ME, Wormser GP. Lyme disease and human granulocytic anaplasmosis coinfection: impact of case definition on coinfection rates and illness severity. *Clinical Infectious Diseases*. 2013;56(1):93-99.

75 Stokes W, Lisboa LF, Lindsay LR, Fonseca K. Case Report: Anaplasmosis in Canada: Locally Acquired Anaplasma phagocytophilum Infection in Alberta. *American Journal of Tropical Medicine and Hygiene*. 2020;103(6):2478-2480.

76 Manitoba Health. Tick-Borne Diseases. [Internet]. [cited 2024-07-04]. https://www.gov.mb.ca/health/publichealth/cdc/tickborne/index.html

77 Edginton S, Guan TH, Evans G, Srivastava S. Human granulocytic anaplasmosis acquired from a blacklegged tick in Ontario. *CMAJ: Canadian Medical Association Journal*. 2018;190(12):E363-E366.

78 Nelder MP, Russell CB, Lindsay LR, Dibernardo A, Brandon NC, Pritchard J, . . . Patel SN. Recent Emergence of Anaplasma phagocytophilum in Ontario, Canada: Early Serological and Entomological Indicators. *American Journal of Tropical Medicine and Hygiene*. 2019;101(6):1249-1258.

79 Institut national de santé publique du Québec. Résultats annuels de surveillance des maladies transmises par les tiques : 2023. [Internet]. 2024-06-19 [cited 2024-10-11]. https://www.inspq.qc.ca/zoonoses/tiques/surveillance/2023

80 Campeau L, Roy V, Petit G, Baron G, Blouin J, Carignan A. Identification of an unusual cluster of human granulocytic anaplasmosis in the Estrie region, Quebec, Canada in 2021. *Canada Communicable Disease Report*. 2022;48(5):188-195.

81 Government of Nova Scotia. Tick Borne Disease Response Plan. [Internet]. 2024-06-01 [cited 2024-07-12]. https://novascotia.ca/dhw/CDPC/documents/Tick-Borne-Disease-Response-Plan.pdf

82 Allehebi ZO, Khan FM, Robbins M, Simms E, Xiang R, Shawwa A, . . . Haldane DJ. Lyme Disease, Anaplasmosis, and Babesiosis, Atlantic Canada. *Emerging Infectious Diseases*. 2022;28(6):1292-1294.

83 Vannier E, Krause PJ. Human babesiosis. *New England Journal of Medicine*. 2012;366(25):2397-2407.

84 Young KM, Corrin T, Wilhelm B, Uhland C, Greig J, Mascarenhas M, Waddell LA. Zoonotic Babesia: A scoping review of the global evidence. *PloS One*. 2019;14(12):e0226781.

85 Public Health Agency of Canada. Babesiosis: For health professionals. [Internet]. 2025-06-30 [cited 2025-07-12]. https://www.canada.ca/en/public-health/services/diseases/ticks-tick-transmitted-diseases/babesiosis/health-professionals.html

86 Bullard JM, Ahsanuddin AN, Perry AM, Lindsay LR, Iranpour M, Dibernardo A, Van Caeseele PG. The first case of locally acquired tick-borne Babesia microti infection in Canada. *Canadian Journal of Infectious Diseases & Medical Microbiology*. 2014;25(6):e87-89.

87 Yang J, Smith C, Battad A. Babesia microti acquired in Canada. *CMAJ: Canadian Medical Association Journal*. 2021;193(31):E1213-E1217.

88 Herwaldt BL, Linden JV, Bosserman E, Young C, Olkowska D, Wilson M. Transfusion-associated babesiosis in the United States: a description of cases. *Annals of Internal Medicine*. 2011;155(8):509-519.

89 Linden JV, Prusinski MA, Crowder LA, Tonnetti L, Stramer SL, Kessler DA, . . . Olkowska D. Transfusion-transmitted and community-acquired babesiosis in New York, 2004 to 2015. *Transfusion*. 2018;58(3):660-668.

90 O'Brien SF, Delage G, Scalia V, Lindsay R, Bernier F, Dubuc S, . . . Fearon MA. Seroprevalence of Babesia microti infection in Canadian blood donors. *Transfusion*. 2016;56(1):237-243.

91 O'Brien SF, Drews SJ, Yi QL, Bloch EM, Ogden NH, Koffi JK, . . . Delage G. Risk of transfusion-transmitted Babesia microti in Canada. *Transfusion*. 2021;61(10):2958-2968.

92 Hermance ME, Thangamani S. Powassan Virus: An Emerging Arbovirus of Public Health Concern in North America. *Vector-Borne and Zoonotic Diseases*. 2017;17(7):453-462.

93 Kakoullis L, Vaz VR, Kaur D, Kakoulli S, Panos G, Chen LH, Behlau I. Powassan Virus Infections: A Systematic Review of Published Cases. *Tropical Medicine and Infectious Disease*. 2023;8(12).

94 Public Health Agency of Canada. Powassan virus disease: Prevention and risks. [Internet]. 2024-11-28 [cited 2024-12-15]. https://www.canada.ca/en/public-health/services/diseases/powassan-virus/risks.html

95 Eisen L. Pathogen transmission in relation to duration of attachment by *Ixodes scapularis* ticks. *Ticks and Tick-Borne Diseases*. 2018;9(3):535-542.

96 Beasley DW, Suderman MT, Holbrook MR, Barrett AD. Nucleotide sequencing and serological evidence that the recently recognized deer tick virus is a genotype of Powassan virus. *Virus Research*. 2001;79(1-2):81-89.

97 Kapoor AK ZR. Powassan Virus. [Internet]. Treasure Island (FL): StatPearls Publishing; 2023-03-27 [cited 2024-07-16]. https://www.ncbi.nlm.nih.gov/books/NBK570599/

98 McLean DM, Donohue WL. Powassan virus: isolation of virus from a fatal case of encephalitis. *Canadian Medical Association Journal*. 1959;80(9):708-711.

99 Corrin T, Greig J, Harding S, Young I, Mascarenhas M, Waddell LA. Powassan virus, a scoping review of the global evidence. *Zoonoses and Public Health*. 2018;65(6):595-624.

100 Centers for Disease Control and Prevention. Colorado Tick Fever: Symptoms, Diagnosis, and Treatment. [Internet]. 2024-05-15 [cited 2024-07-17]. https://www.cdc.gov/colorado-tick-fever/symptoms-diagnosis-treatment/index.html

101 Romero JR, Simonsen KA. Powassan encephalitis and Colorado tick fever. *Infectious Disease Clinics of North America*. 2008;22(3):545-559, x.

102 Kadkhoda K, Semus M, Jelic T, Walkty A. Case Report: A Case of Colorado Tick Fever Acquired in Southwestern Saskatchewan. *American Journal of Tropical Medicine and Hygiene*. 2018;98(3):891-893.

103 Cimolai N, Anand CM, Gish GJ, Calisher CH, Fishbein DB. Human Colorado tick fever in southern Alberta. *CMAJ: Canadian Medical Association Journal*. 1988;139(1):45-46.

104 Fagre A, Lehman J, Hills SL. Colorado Tick Fever in the United States, 2013-2022. *American Journal of Tropical Medicine and Hygiene*. 2024;111(3):598-602.

105 Banerjee SN, Banerjee M, Fernando K, Burgdorfer W, Schwan TG. Tick-borne relapsing fever in British Columbia, Canada: first isolation of *Borrelia hermsii*. *Journal of Clinical Microbiology*. 1998;36(12):3505-3508.

106 British Columbia Centre for Disease Control. Tick-borne Relapsing Fever. [Internet]. [cited July 17]. http://www.bccdc.ca/health-info/diseases-conditions/tick-borne-diseases/tick-borne-relapsing-fever

107 Hussein H, Showler A, Tan DH. Tick-borne relapsing fever in pregnancy. *CMAJ: Canadian Medical Association Journal*. 2014;186(2):131-134.

108 Muhammad Morshed, Steven J. Drews, Min-Kuang Lee, Keerthi Fernando, Stephanie Man, Sunny Mak, . . . Patrick DM. Tick-borne relapsing fever in British Columbia: A 10-year review (2006–2015). *British Columbia Medical Journal*. 2017;59(8):412-417.

109 Wood H, Artsob H. Spotted fever group *rickettsiae*: a brief review and a Canadian perspective. *Zoonoses and Public Health*. 2012;59 Suppl 2:65-79.

110 Nelder MP, Russell CB, Johnson S, Li Y, Cronin K, Warshawsky B, . . . Patel SN. Assessing human exposure to spotted fever and typhus group *rickettsiae* in Ontario, Canada (2013-2018): a retrospective, cross-sectional study. *BMC Infectious Diseases*. 2020;20(1):523.

111 T.A. S, Wood H, Russell CB, Nelder MP, Patel SN. An apparent, locally acquired case of rickettsialpox (*Rickettsia akari*) in Ontario, Canada. *Journal of the Association of Medical Microbiology and Infectious Disease Canada*. 2020;5(2):115-119.

112 Ontario Ministry of Health. Rocky Mountain Spotted Fever Exposures at Long Point, ON [Internet]. 2025-09-15 [cited 2025-12-07]. https://healthunit.org/wp-content/uploads/Rocky_Mountain_Spotted_Fever.pdf

113 King A, Spurr A, Bose R. Rocky Mountain spotted fever contracted along a Canadian road trip: A case report. *SAGE Open Medical Case Reports*. 2024;12:2050313X241260980.

114 Graham J, Stockley K, Goldman RD. Tick-borne illnesses: a CME update. *Pediatric Emergency Care*. 2011;27(2):141-147; quiz 148-150.

115 Centers for Disease Control and Prevention. About Tick and Louse-borne Relapsing Fevers. [Internet]. 2024 May 15 [cited Jul 17]. https://www.cdc.gov/relapsing-fever/about/index.html

116 Public Health Ontario. Rocky Mountain Spotted Fever in Ontario. [Internet]. October 2025 [cited 2025-12-01]. https://www.publichealthontario.ca/en/Diseases-and-Conditions/Infectious-Diseases/Vector-Borne-Zoonotic-Diseases/RMSF

117 Rochlin I, Kenney J, Little E, Molaei G. Public health significance of the white-tailed deer (Odocoileus virginianus) and its role in the eco-epidemiology of tick- and mosquito-borne diseases in North America. *Parasites & Vectors*. 2025;18(1):43.

118 Public Health Agency of Canada. Tick surveillance in Canada: Infographic 2021. [Internet]. 2024-11-13 [cited 2024-12-01]. https://www.canada.ca/en/public-health/services/publications/diseases-conditions/tick-surveillance-canada-infographic-2021.html

119 Public Health Agency of Canada. Tick surveillance in Canada: Infographic 2022. [Internet]. 2024-11-13 [cited 2024-12-01]. https://www.canada.ca/en/public-health/services/publications/diseases-conditions/tick-surveillance-canada-infographic-2022.html

120 Public Health Agency of Canada. Rabies: Travel health advice. [Internet]. Government of Canada; 2025-03-04 [cited 2025-06-12]. https://www.canada.ca/en/public-health/services/diseases/rabies/travel-health-advice.html

121 Public Health Agency of Canada. Rabies: Symptoms and treatment. [Internet]. Government of Canada; 2024-04-08 [cited 2025-06-12]. https://www.canada.ca/en/public-health/services/diseases/rabies.html

122 British Columbia Ministry of Health. Confirmed case of rabies in B.C. [Internet]. 2019-07-15 [cited 2025-05-06]. https://news.gov.bc.ca/releases/2019HLTH0099-001450

123 Rupprecht CE, ed. History of Rabies in the Americas: From the Pre-Columbian to the Present, Volume II. Spring Cham; 2024. *Fascinating Life Sciences*. doi: https://doi.org/10.1007/978-3-031-25405-5

124 Brock-Fenton M, Jackson AC, Faure PA. Bat bites and rabies: the Canadian scene. *FACETS*. 2020;5(1):367-380.

125 Ontario Ministry of Health. Statement from the Chief Medical Officer of Health. [Internet]. 2024-09-06 [cited 2025-06-06]. https://news.ontario.ca/en/statement/1005019/statement-from-the-chief-medical-officer-of-health

126 Middleton D, Johnson KO, Rosatte RC, Hobbs JL, Moore SR, Rosella L, Crowcroft NS. Human Rabies Post-Exposure Prophylaxis and Animal Rabies in Ontario, Canada, 2001-2012. *Zoonoses and Public Health*. 2015;62(5):356-364.

127 Birhane MG, Cleaton JM, Monroe BP, Wadhwa A, Orciari LA, Yager P, . . . Wallace RM. Rabies surveillance in the United States during 2015. *Journal of the American Veterinary Medical Association*. 2017;250(10):1117-1130.

128 Stevenson B, Goltz J, Masse A. Preparing for and responding to recent incursions of raccoon rabies variant into Canada. *Canada Communicable Disease Report*. 2016;42(6):125-129.

129 Lobo D, DeBenedet C, Fehlner-Gardiner C, Nadin-Davis S, Anderson M, Buchanan T, . . . Hopkins J. Raccoon rabies outbreak in Hamilton, Ontario: A progress report. *Canada Communicable Disease Report*. 2018;44(5):116-121.

130 Trewby H, Nadin-Davis SA, Real LA, Biek R. Processes Underlying Rabies Virus Incursions across US-Canada Border as Revealed by Whole-Genome Phylogeography. *Emerging Infectious Diseases*. 2017;23(9):1454-1461.

131 Ma X, Boutelle C, Bonaparte S, Orciari LA, Condori RE, Kirby JD, . . . Wallace RM. Rabies surveillance in the United States during 2022. *Journal of the American Veterinary Medical Association*. 2024;262(11):1518-1525.

132 Di Salvo P, Anderson M, Fehlner-Gardiner C, Di Mauro F, Shapiro H, Miranda A, McClinchey H. Rabies in an imported dog, Ontario, Canada, 2022. *Canada Communicable Disease Report*. 2023;49(1):1-4.

133 Rebellato S, Choi M, Gitelman J, Ratiu F, Magnusson K, Armstrong B, . . . Gardner C. Rabies in an imported dog, Ontario, 2021. *Canada Communicable Disease Report*. 2022;48(6):238-242.

134 Canadian Food Inspection Agency. Notice to industry: New measure prohibiting the entry of commercial dogs from countries at high-risk for dog rabies. [Internet]. Government of Canada; 2022-06-28 [cited 2024-12-05]. https://inspection.canada.ca/en/animal-health/terrestrial-animals/diseases/reportable/rabies/industry-notice-2022-06-28

135 Curry PS, Kostiuk D, Werker DH, Baikie M, Ntiamoah W, Atherton F, . . . Mema S. Translocated dogs from Nunavut and the spread of rabies. *Canada Communicable Disease Report*. 2016;42(6):121-124.

136 Bush E, Lemmen, D.S., editors. Canada's Changing Climate Report. Government of Canada. 2019. 444 p. https://changingclimate.ca/site/assets/uploads/sites/2/2020/06/CCCR_FULLREPORT-EN-FINAL.pdf

137 Simon A, Beauchamp G, Belanger D, Bouchard C, Fehlner-Gardiner C, Lecomte N, . . . Leighton PA. Ecology of Arctic rabies: 60 years of disease surveillance in the warming climate of northern Canada. *Zoonoses and Public Health*. 2021;68(6):601-608.

138 Canadian Food Inspection Agency. Rabies in Canada. [Internet]. 2025-02-07 [cited 2025-06-13]. https://inspection.canada.ca/en/animal-health/terrestrial-animals/diseases/reportable/rabies/canada

139 Gallant D, Lecomte N, Berteaux D. Disentangling the relative influences of global drivers of change in biodiversity: A study of the twentieth-century red fox expansion into the Canadian Arctic. *Journal of Animal Ecology*. 2020;89(2):565-576.

140 Nadin-Davis SA, Falardeau E, Flynn A, Whitney H, Marshall HD. Relationships between fox populations and rabies virus spread in northern Canada. *PloS One*. 2021;16(2):e0246508.

141 Bush LM, Vazquez-Pertejo MT. Tularemia. [Internet]. Merck Manual Professional Version; 2024-06-01 [cited 2025-06-06]. https://www.merckmanuals.com/fr-ca/professional/infectious-diseases/gram-negative-bacilli/tularemia

142 Friend M. Tularemia. Reston, Virginia. U.S. Geological Survey. Circular 1297. 2006. 68. https://pubs.usgs.gov/circ/1297/report.pdf

143 Mead P. Tularemia. In: Control of Communicable Diseases Manual. 2022. doi:10.2105/ccdm.2745.148

144 Levesque B, De Serres G, Higgins R, D'Halewyn MA, Artsob H, Grondin J, . . . Duval B. Seroepidemiologic study of three zoonoses (leptospirosis, Q fever, and tularemia) among trappers in Quebec, Canada. *Clinical and Diagnostic Laboratory Immunology*. 1995;2(4):496-498.

145 Antonation KS, Bekal S, Cote G, Dallaire A, Corbett CR. Multiple-locus variable-number tandem-repeat analysis of *Francisella tularensis* from Quebec, Canada. *Letters in Applied Microbiology*. 2015;60(4):328-333.

146 Vickers F, Walkty A, Keynan Y. Pharyngeal tularemia acquired in an urban setting in Canada. *CMAJ: Canadian Medical Association Journal*. 2022;194(20):E701-E703.

147 Sullivan AP, Nicholson C, Bradbury-Squires DJ, King A, Daley P. Two cases of tularemia in hunters from rural Newfoundland. *Journal of the Association of Medical Microbiology and Infectious Disease Canada*. 2022;7(2):135-139.

148 Martin T, Holmes IH, Wobeser GA, Anthony RF, Greefkes I. Tularemia in Canada with a focus on Saskatchewan. *Canadian Medical Association Journal*. 1982;127(4):279-282.

149 Centers for Disease Control and Prevention. How Tularemia Spreads. [Internet]. 2024-05-15 [cited 2025-02-20]. https://www.cdc.gov/tularemia/causes/index.html

150 Akimana C, Kwaik YA. *Francisella*-arthropod vector interaction and its role in patho-adaptation to infect mammals. *Frontiers in Microbiology*. 2011;2:34.

151 Zellner B, Huntley JF. Ticks and Tularemia: Do We Know What We Don't Know? *Front Cell Infect Microbiol*. 2019;9:146.

152 Wobeser G, Campbell GD, Dallaire A, McBurney S. Tularemia, plague, yersiniosis, and Tyzzer's disease in wild rodents and lagomorphs in Canada: a review. *Canadian Veterinary Journal*. 2009;50(12):1251-1256.

153 Wobeser G, Ngeleka M, Appleyard G, Bryden L, Mulvey MR. Tularemia in deer mice (peromyscus maniculatus) during a population irruption in Saskatchewan, Canada. *Journal of Wildlife Diseases*. 2007;43(1):23-31.

154 Kwit NA, Schwartz A, Kugeler KJ, Mead PS, Nelson CA. Human tularaemia associated with exposure to domestic dogs-United States, 2006-2016. *Zoonoses and Public Health*. 2019;66(4):417-421.

155 Larson MA, Fey PD, Hinrichs SH, Iwen PC. *Francisella tularensis* bacteria associated with feline tularemia in the United States. *Emerging Infectious Diseases*. 2014;20(12):2068-2071.

156 Centers for Disease Control and Prevention. Tularemia associated with a hamster bite--Colorado, 2004. *MMWR: Morbidity and Mortality Weekly Report*. 2005;53(51):1202-1203.

157 Gabriele-Rivet V, Arsenault J, Badcock J, Cheng A, Edsall J, Goltz J, . . . Ogden NH. Different Ecological Niches for Ticks of Public Health Significance in Canada. *PloS One*. 2015;10(7):e0131282.

158 Isaac-Renton M, Morshed MG, Galanis E, Mak S, Loyola V, Hoang LM. Tularemia in British Columbia: A case report and review. *BC Medical Journal*. 2010;52(6).

159 Hestvik G, Warns-Petit E, Smith LA, Fox NJ, Uhlhorn H, Artois M, . . . Gavier-Widen D. The status of tularemia in Europe in a one-health context: a review. *Epidemiology and Infection*. 2015;143(10):2137-2160.

160 Silverman M, Law B, Carson J. A case of insect borne tularemia above the tree line. *Arctic Medical Research*. 1991;Suppl:377-379.

161 Petersen JM, Mead PS, Schriefer ME. *Francisella tularensis*: an arthropod-borne pathogen. *Veterinary Research*. 2009;40(2):7.

162 Minigan JN, Hager HA, Peregrine AS, Newman JA. Current and potential future distribution of the American dog tick (*Dermacentor variabilis*, Say) in North America. *Ticks and Tick-Borne Diseases*. 2018;9(2):354-362.

163 Nakazawa Y, Williams R, Peterson AT, Mead P, Staples E, Gage KL. Climate change effects on plague and tularemia in the United States. *Vector-Borne and Zoonotic Diseases*. 2007;7(4):529-540.

164 Drebot MA, Lindsay R, Barker IK, Buck PA, Fearon M, Hunter F, . . . Artsob H. West Nile virus surveillance and diagnostics: A Canadian perspective. *Canadian Journal of Infectious Diseases*. 2003;14(2):105-114.

165 Ludwig A, Zheng H, Vrbova L, Drebot MA, Iranpour M, Lindsay LR. Increased risk of endemic mosquito-borne diseases in Canada due to climate change. *Canada Communicable Disease Report*. 2019;45(4):91-97.

166 Sejvar JJ. Clinical manifestations and outcomes of West Nile virus infection. *Viruses*. 2014;6(2):606-623.

167 Ogden NH, Lindsay LR, Ludwig A, Morse AP, Zheng H, Zhu H. Weather-based forecasting of mosquito-borne disease outbreaks in Canada. *Canada Communicable Disease Report*. 2019;45(5):127-132.

168 Todoric D, Vrbova L, Mitri ME, Gasmi S, Stewart A, Connors S, . . . Buck P. An overview of the National West Nile Virus Surveillance System in Canada: A One Health approach. *Canada Communicable Disease Report*. 2022;48(5):181-187.

169 Peach DAH, Matthews BJ. The Invasive Mosquitoes of Canada: An Entomological, Medical, and Veterinary Review. *American Journal of Tropical Medicine and Hygiene*. 2022;107(2):231-244.

170 Yanagawa C. West Nile Virus. [Internet]. National Collaborating Centre for Infectious Diseases; 2022-06-01 [cited 2024-10-15]. https://nccid.ca/debrief/west-nile-virus/

171 Busch MP, Wright DJ, Custer B, Tobler LH, Stramer SL, Kleinman SH, . . . Glynn SA. West Nile virus infections projected from blood donor screening data, United States, 2003. *Emerging Infectious Diseases*. 2006;12(3):395-402.

172 Curren EJ, Shankar MB, Fischer M, Meltzer MI, Erin Staples J, Gould CV. Cost-Effectiveness and Impact of a Targeted Age- and Incidence-based West Nile Virus Vaccine Strategy. *Clinical Infectious Diseases*. 2021;73(9):1565-1570.

173 Gould CV, Staples JE, Guagliardo SAJ, Martin SW, Lyons S, Hills SL, . . . Petersen LR. West Nile Virus: A Review. *The Journal of the American Medical Association*. 2025.

174 Mincer J, Materniak S, Dimitrova K, Wood H, Iranpour M, Dibernardo A, . . . Webster D. Jamestown Canyon and snowshoe hare virus seroprevalence in New Brunswick. *Journal of the Association of Medical Microbiology and Infectious Disease Canada*. 2021;6(3):213-220.

175 Centers for Disease Control and Prevention. Clinical Signs and Symptoms of Jamestown Canyon Virus Disease. [Internet]. 2024-05-15 [cited https://www.cdc.gov/jamestown-canyon/hcp/clinical-signs/index.html]

176 Drebot MA. Emerging mosquito-borne bunyaviruses in Canada. *Canada Communicable Disease Report*. 2015;41(6):117-123.

177 Patriquin G, Drebot M, Cole T, Lindsay R, Schleihauf E, Johnston BL, . . . Hatchette TF. High Seroprevalence of Jamestown Canyon Virus among Deer and Humans, Nova Scotia, Canada. *Emerging Infectious Diseases*. 2018;24(1):118-121.

178 Rocheleau JP, Michel P, Lindsay LR, Drebot M, Dibernardo A, Ogden NH, . . . Arsenault J. Risk factors associated with seropositivity to California serogroup viruses in humans and pet dogs, Quebec, Canada. *Epidemiology and Infection*. 2018;146(9):1167-1176.

179 Meier-Stephenson V, Drebot MA, Dimitrova K, DiQuinzio M, Fonseca K, Forrest D, . . . Wood H. Case Series of Jamestown Canyon Virus Infections with Neurologic Outcomes, Canada, 2011-2016. *Emerging Infectious Diseases*. 2024;30(5):874-881.

180 Webster D, Dimitrova K, Holloway K, Makowski K, Safronetz D, Drebot MA. California Serogroup Virus Infection Associated with Encephalitis and Cognitive Decline, Canada, 2015. *Emerging Infectious Diseases*. 2017;23(8):1423-1424.

181 Institut national de santé publique du Québec. Résultats annuels de surveillance intégrée du VNO et des autres arbovirus : année 2019. [Internet]. 2020-04-27 [cited 2024-10-11]. https://www.inspq.qc.ca/zoonoses/vno/surveillance/2019

182 Institut national de santé publique du Québec. Résultats annuels de surveillance intégrée du VNO et des autres arbovirus : année 2020. [Internet]. 2021-06-10 [cited 2024-10-11]. https://www.inspq.qc.ca/zoonoses/vno/surveillance/2020

183 Institut national de santé publique du Québec. Résultats annuels de surveillance intégrée du VNO et des autres arbovirus : année 2021. [Internet]. 2022-06-22 [cited 2024-10-11]. https://www.inspq.qc.ca/zoonoses/vno/surveillance/2021

184 Institut national de santé publique du Québec. Résultats annuels de surveillance intégrée du VNO et des autres arbovirus : année 2022. [Internet]. 2023-06-08 [cited 2024-10-11]. https://www.inspq.qc.ca/zoonoses/vno/surveillance/2022

185 Morshed MV, R., Singal M, Hogan CA. What you need to know about California serogroup viruses. *British Columbia Medical Journal*. 2025;67(4):146-147.

186 Office of the Chief Medical Health Officer. Encephalitis Cluster in Whistler Area due to California Serogroup Virus. Vancouver Coastal Health; 2024. https://www.vch.ca/fr/media/29736

187 Public Health Agency of Canada. Eastern and Western Equine Encephalitis virus: Infectious substances pathogen safety data sheet. [Internet]. Government of Canada; 2025-02-20 [cited 2025-10-12]. https://www.canada.ca/en/public-health/services/laboratory-biosafety/pathogen-safety-data-sheets-risk-assessment/eastern-equine-encephalitis.html

188 Corrin T, Ackford R, Mascarenhas M, Greig J, Waddell LA. Eastern Equine Encephalitis Virus: A Scoping Review of the Global Evidence. *Vector-Borne and Zoonotic Diseases*. 2021;21(5):305-320.

189 Armstrong PM, Andreadis TG. Ecology and Epidemiology of Eastern Equine Encephalitis Virus in the Northeastern United States: An Historical Perspective. *Journal of Medical Entomology*. 2022;59(1):1-13.

190 Lindsey NP, Staples JE, Fischer M. Eastern Equine Encephalitis Virus in the United States, 2003-2016. *American Journal of Tropical Medicine and Hygiene*. 2018;98(5):1472-1477.

191 Public Health Agency of Canada. Mosquito-borne disease surveillance: Seasonal update. [Internet]. 2025-11-10 [cited 2025-11-10]. https://health-infobase.canada.ca/zoonoses/mosquito/

192 Staples JE, Gould CV. Eastern Equine Encephalitis in the US. *The Journal of the American Medical Association*. 2025;334(6):530-531.

193 Rupasinghe R, Chomel BB, Martinez-Lopez B. Climate change and zoonoses: A review of the current status, knowledge gaps, and future trends. *Acta Tropica*. 2022;226:106225.

194 Colon-Gonzalez FJ, Sewe MO, Tompkins AM, Sjodin H, Casallas A, Rocklov J, . . . Lowe R. Projecting the risk of mosquito-borne diseases in a warmer and more populated world: a multi-model, multi-scenario intercomparison modelling study. *Lancet Planet Health*. 2021;5(7):e404-e414.

195 Kilpatrick AM, LaDeau SL, Marra PP. Ecology of West Nile Virus Transmission and its Impact on Birds in the Western Hemisphere. *The Auk*. 2007;124(4):1121-1136.

196 Nemeth NM, Oesterle PT. West Nile virus from an avian conservation perspective. *International Zoo Yearbook*. 2014;48:101-115.

197 MacKay RJ, de Tonnerre D. Equine Arboviral Encephalomyelitis. [Internet]. Merck Veterinary Manual; 2025-03-01 [cited 2025-04-15]. https://www.merckvetmanual.com/nervous-system/equine-arboviral-encephalomyelitis/equine-arboviral-encephalomyelitis

198 Bergevin MD, Ng V, Sadeghieh T, Menzies P, Ludwig A, Mubareka S, Clow KM. A Scoping Review on the Epidemiology of Orthobunyaviruses in Canada, in the Context of Human, Wildlife, and Domestic Animal Host Species. *Vector-Borne and Zoonotic Diseases*. 2024;24(5):249-264.

199 Buhler KJ, Dibernardo A, Pilfold NW, Harms NJ, Fenton H, Carriere S, . . . Jenkins E. Widespread Exposure to Mosquitoborne California Serogroup Viruses in Caribou, Arctic Fox, Red Fox, and Polar Bears, Canada. *Emerging Infectious Diseases*. 2023;29(1):54-63.

200 Public Health Ontario. Eastern Equine Encephalitis Virus: History and Enhanced Surveillance in Ontario. Toronto, ON. 2014-07-01. https://www.publichealthontario.ca/-/media/documents/E/2014/eeev-report.pdf

201 Institut national de santé publique du Québec. Rapport de surveillance du virus du Nil occidental et autres arbovirus au Québec : saison 2016. [Internet]. 2017-08-31 [cited 2025-05-12]. https://www.inspq.qc.ca/publications/2294

202 Stuart T. An Overview of the West Nile Virus and California Serogroup of Vector Competent Mosquito Species in the Northwest Territories from 2004-2018. Government of Northwest Territories. 2020. https://www.gov.nt.ca/ecc/sites/ecc/files/resources/an_overview_of_the_west_nile_virus_and_california_serogroup_of_vector_competent_mosquito_species_in_the_northwest_territories_from_2004-2018.pdf

203 Public Health Agency of Canada. West Nile virus and other mosquito-borne diseases surveillance report: Annual edition 2021. [Internet]. 2024-12-01 [cited 2025-02-15]. https://www.canada.ca/content/dam/phac-aspc/documents/services/publications/diseases-conditions/west-nile-virus-surveillance/2021/annual-edition/mbd-report-2021-en.pdf

204 Public Health Agency of Canada. West Nile virus and other mosquito-borne diseases surveillance report: Annual edition 2022. [Internet]. 2024-12-01 [cited 2025-02-12]. https://www.canada.ca/content/dam/phac-aspc/documents/services/publications/diseases-conditions/west-nile-virus-surveillance/2022/annual-edition/annual-edition.pdf

205 Ng V, Rees EE, Lindsay LR, Drebot MA, Brownstone T, Sadeghieh T, Khan SU. Could exotic mosquito-borne diseases emerge in Canada with climate change? *Canada Communicable Disease Report*. 2019;45(4):98-107.

206 Snyman J, Snyman LP, Buhler KJ, Villeneuve CA, Leighton PA, Jenkins EJ, Kumar A. California Serogroup Viruses in a Changing Canadian Arctic: A Review. *Viruses*. 2023;15(6).

207 Berry P, & Schnitter, R., ed. Health of Canadians in a Changing Climate: Advancing Our Knowledge for Action. Government of Canada; 2022. https://changingclimate.ca/health-in-a-changing-climate/

208 Khan SU, Ogden NH, Fazil AA, Gachon PH, Dueymes GU, Greer AL, Ng V. Current and Projected Distributions of *Aedes aegypti* and *Ae. albopictus* in Canada and the U.S. *Environmental Health Perspectives*. 2020;128(5):57007.

209 Public Health Agency of Canada. Avian influenza A(H5N1): For health professionals. [Internet]. 2025-07-10 [cited 2025-08-16]. https://www.canada.ca/en/public-health/services/diseases/avian-flu-h5n1/health-professionals.html

210 Krammer F, Hermann E, Rasmussen AL. Highly pathogenic avian influenza H5N1: history, current situation, and outlook. *Journal of Virology*. 2025;99(4):e0220924.

211 Koopmans MPG, Barton Behravesh C, Cunningham AA, Adisasmito WB, Almuhairi S, Bilivogui P, . . . One Health High-Level Expert P. The panzootic spread of highly pathogenic avian influenza H5N1 sublineage 2.3.4.4b: a critical appraisal of One Health preparedness and prevention. *Lancet Infectious Diseases*. 2024;24(12):e774-e781.

212 Xu W, Berhane Y, Dube C, Liang B, Pasick J, VanDomselaar G, Alexandersen S. Epidemiological and Evolutionary Inference of the Transmission Network of the 2014 Highly Pathogenic Avian Influenza H5N2 Outbreak in British Columbia, Canada. *Scientific Reports*. 2016;6:30858.

213 Alkie TN, Lopes S, Hisanaga T, Xu W, Suderman M, Koziuk J, . . . Berhane Y. A threat from both sides: Multiple introductions of genetically distinct H5 HPAI viruses into Canada via both East Asia-Australasia/Pacific and Atlantic flyways. *Virus Evol*. 2022;8(2):veac077.

214 Canadian Food Inspection Agency. Status of ongoing avian influenza response by province. [Database]. Accessed 2025-02-02. https://inspection.canada.ca/en/animal-health/terrestrial-animals/diseases/reportable/avian-flu/most-recent-avian-flu situation/avian-flu-control-status

215 Himsworth CG, Caleta JM, Jassem AN, Yang KC, Zlosnik JEA, Tyson JR, . . . Russell SL. Highly Pathogenic Avian Influenza A(H5N1) in Wild Birds and a Human, British Columbia, Canada, 2024. *Emerging Infectious Diseases*. 2025;31(6):1216-1221.

216 Chief Science Advisor of Canada. Managing Avian Flu: A Science Roadmap and Action Plan. [Internet]. Government of Canada; 2025-02-01 [cited 2025-04-10]. https://science.gc.ca/site/science/sites/default/files/documents/h5n1-report.pdf

217 Giacinti JA, Signore AV, Jones MEB, Bourque L, Lair S, Jardine C, . . . Soos C. Avian influenza viruses in wild birds in Canada following incursions of highly pathogenic H5N1 virus from Eurasia in 2021-2022. *mBio*. 2024;15(8):e0320323.

218 Lane J, Jeglinski J, Avery-Gomm S, Ballstaedt E, Banyard A, Barychka T, . . . Danielsen J. High pathogenicity avian influenza (H5N1) in Northern Gannets (Morus bassanus): Global spread, clinical signs and demographic consequences. *International Journal of Avian Science*. 2024;166:633-650.

219 Andrew CL, Russell SL, Coombe M, Zlosnik JEA, Kuchinski KS, Caleta J, . . . Himsworth C. Descriptive Epidemiology and Phylodynamics of the "First Wave" of an Outbreak of Highly Pathogenic Avian Influenza (H5N1 Clade 2.3.4.4b) in British Columbia and the Yukon, Canada, April to September 2022. *Transboundary and Emerging Diseases*. 2024;2024:2327939.

220 Elsmo EJ, Wunschmann A, Beckmen KB, Broughton-Neiswanger LE, Buckles EL, Ellis J, . . . Lim AL. Highly Pathogenic Avian Influenza A(H5N1) Virus Clade 2.3.4.4b Infections in Wild Terrestrial Mammals, United States, 2022. *Emerging Infectious Diseases*. 2023;29(12):2451-2460.

221 Lair S, Quesnel L, Signore AV, Delnatte P, Embury-Hyatt C, Nadeau MS, . . . Berhane Y. Outbreak of Highly Pathogenic Avian Influenza A(H5N1) Virus in Seals, St. Lawrence Estuary, Quebec, Canada(1). *Emerging Infectious Diseases*. 2024;30(6):1133-1143.

222 Plaza PI, Gamarra-Toledo V, Eugui JR, Lambertucci SA. Recent Changes in Patterns of Mammal Infection with Highly Pathogenic Avian Influenza A(H5N1) Virus Worldwide. *Emerging Infectious Diseases*. 2024;30(3):444-452.

223 Canadian Wildlife Health Cooperative. High Pathogenicity Avian Influenza in Wildlife. [Database]. Accessed 2025-01-10. https://cfia-ncr.maps.arcgis.com/apps/dashboards/89c779e98cdf492c899df23e1c38fdbc

224 United States Department of Agriculture. Detections of Highly Pathogenic Avian Influenza in Mammals. [Database]. Accessed 2025-01-10. https://www.aphis.usda.gov/livestock-poultry-disease/avian/avian-influenza/hpai-detections/mammals

225 Bordes L, Vreman S, Heutink R, Roose M, Venema S, Pritz-Verschuren SBE, . . . Beerens N. Highly Pathogenic Avian Influenza H5N1 Virus Infections in Wild Red Foxes (Vulpes vulpes) Show Neurotropism and Adaptive Virus Mutations. *Microbiology Spectrum*. 2023;11(1):e0286722.

226 Puryear WB, Runstadler JA. High-pathogenicity avian influenza in wildlife: a changing disease dynamic that is expanding in wild birds and having an increasing impact on a growing number of mammals. *Journal of the American Veterinary Medical Association*. 2024;262(5):601-609.

227 Uhart MM, Vanstreels RET, Nelson MI, Olivera V, Campagna J, Zavattieri V, . . . Rimondi A. Epidemiological data of an influenza A/H5N1 outbreak in elephant seals in Argentina indicates mammal-to-mammal transmission. *Nature Communications*. 2024;15(1):9516.

228 World Organisation for Animal Health. Canada - Influenza A viruses of high pathogenicity (Inf. with) (non-poultry including wild birds) (2017-) -Follow up report 8. [Internet]. World Organisation for Animal Health; 2025-07-15 [cited 2025-08-12]. https://wahis.woah.org/#/in-review/5065?fromPage=event-dashboard-url%20.

229 Burrough ER, Magstadt DR, Petersen B, Timmermans SJ, Gauger PC, Zhang J, . . . Main R. Highly Pathogenic Avian Influenza A(H5N1) Clade 2.3.4.4b Virus Infection in Domestic Dairy Cattle and Cats, United States, 2024. *Emerging Infectious Diseases*. 2024;30(7):1335-1343.

230 Kang YM, Heo GB, An SH, Lee H, Park E, Cha RM, . . . Lee KN. Highly Pathogenic Avian Influenza A(H5N1) Virus Infection in Cats, South Korea, 2023. *Emerging Infectious Diseases*. 2024;30(12):2510-2520.

231 Rabalski L, Milewska A, Pohlmann A, Gackowska K, Lepionka T, Szczepaniak K, . . . Pyrc K. Emergence and potential transmission route of avian influenza A (H5N1) virus in domestic cats in Poland, June 2023. *Eurosurveillance*. 2023;28(31).

232 Marinova-Petkova A, Laplante J, Jang Y, Lynch B, Zanders N, Rodriguez M, . . . Davis CT. Avian Influenza A(H7N2) Virus in Human Exposed to Sick Cats, New York, USA, 2016. *Emerging Infectious Diseases*. 2017;23(12):2046-2049.

233 Oguzie JU, Marushchak LV, Shittu I, Lednicky JA, Miller AL, Hao H, . . . Gray GC. Avian Influenza A(H5N1) Virus among Dairy Cattle, Texas, USA. *Emerging Infectious Diseases*. 2024;30(7):1425-1429.

234 Garg S, Reinhart K, Couture A, Kniss K, Davis CT, Kirby MK, . . . Olsen SJ. Highly Pathogenic Avian Influenza A(H5N1) Virus Infections in Humans. *New England Journal of Medicine*. 2024;392(9):843-854.

235 Kumar B, Asha K, Khanna M, Ronsard L, Meseko CA, Sanicas M. The emerging influenza virus threat: status and new prospects for its therapy and control. *Archives of Virology*. 2018;163(4):831-844.

236 Public Health Agency of Canada. Public health management of human cases of avian influenza and associated human contacts. [Internet]. Government of Canada; 2025-06-20 [cited 2025-07-19]. https://www.canada.ca/en/public-health/services/diseases/avian-flu-h5n1/health-professionals/human-case-management-of-associated-contacts.html

237 Centers for Disease Control and Prevention. First H5 Bird Flu Death Reported in United States. [Internet]. 2025-01-06 [cited 2025-03-01]. https://www.cdc.gov/media/releases/2025/m0106-h5-birdflu-death.html

238 British Columbia Ministry of Health. Final update on human avian influenza case in B.C. [Internet]. 2024-11-24 [cited https://news.gov.bc.ca/releases/2024HLTH0155-001601]

239 Public Health Agency of Canada. Rapid risk assessment update: Avian influenza A(H5N1) clade 2.3.4.4b, public health implications for Canada. [Internet]. Government of Canada; 2024-11-29 [cited 2025-05-30]. https://www.canada.ca/en/public-health/services/emergency-response/rapid-occupational-risk-assessments/avian-flu-h5n1-clade-2-3-4-4b-update.html

240 Public Health Agency of Canada. Avian influenza A(H5N1): Canada's response. [Internet]. Government of Canada; 2025-06-24 [cited 2025-07-08]. https://www.canada.ca/en/public-health/services/diseases/avian-flu-h5n1/canada-response.html

241 Giacinti JA, Jarvis-Cross M, Lewis H, Provencher JF, Berhane Y, Kuchinski K, . . . Sharp CM. Transmission dynamics of highly pathogenic avian influenza virus at the wildlife-poultry-environmental interface: A case study. *One Health*. 2024;19:100932.

242 World Organisation for Animal Health. SARS-CoV-2. [Internet]. n.d. [cited 2025-11-01]. https://www.woah.org/fr/disease/sars-cov-2/

243 Public Health Agency of Canada. COVID-19 and deaths in older Canadians: Excess mortality and the impacts of age and comorbidity. [Internet]. 2021-12-14 [cited 2025-06-19]. https://www.canada.ca/en/public-health/services/diseases/coronavirus-disease-covid-19/epidemiological-economic-research-data/incidence-excess-mortality-age-comorbidities.html

244 Wang C, Horby PW, Hayden FG, Gao GF. A novel coronavirus outbreak of global health concern. *Lancet*. 2020;395(10223):470-473.

245 Sachs JD, Karim SSA, Aknin L, Allen J, Brosbol K, Colombo F, . . . Michie S. The Lancet Commission on lessons for the future from the COVID-19 pandemic. *Lancet*. 2022;400(10359):1224-1280.

246 Li Q, Shah T, Wang B, Qu L, Wang R, Hou Y, . . . Xia X. Cross-species transmission, evolution and zoonotic potential of coronaviruses. *Front Cell Infect Microbiol*. 2022;12:1081370.

247 Parry NMA. COVID-19 and pets: When pandemic meets panic. *Forensic Science International Reports*. 2020;2:100090.

248 Canadian Animal Health Surveillance System. SARS-CoV-2 Animal Dashboard. [Database]. 2024. Accessed December 31, 2024. https://cahss.ca/cahss-tools/sars-cov-2-dashboard

249 Environment and Climate Change Canada. Update on SARS-CoV-2 Surveillance in Canadian Wildlife, January 2020 - October 2022. Government of Canada. 2023. https://www.cwhc-rcsf.ca/docs/covid/Update%20on%20SARS-CoV-2%20Surveillance%20in%20Canadian%20Wildlife,%20January%202020%20-%20October%202022.pdf

250 Doliff R, Martens P. Cats and SARS-CoV-2: A Scoping Review. *Animals (Basel)*. 2022;12(11).

251 Bienzle D, Rousseau J, Marom D, MacNicol J, Jacobson L, Sparling S, . . . Weese JS. Risk Factors for SARS-CoV-2 Infection and Illness in Cats and Dogs. *Emerging Infectious Diseases*. 2022;28(6).

252 Hoppe JM, Fuessl LU, Hartmann K, Hofmann-Lehmann R, Graf A, Krebs S, . . . Muenchhoff M. Secondary zoonotic dog-to-human transmission of SARS-CoV-2 suggested by timeline but refuted by viral genome sequencing. *Infection*. 2023;51(1):253-259.

253 Paiero A, Newhouse E, Chan E, Clair V, Russell S, Zlonsnik J, . . . Fraser E. SARS-CoV-2 in mink farms in British Columbia, Canada: A report of two outbreaks in 2020-2021. *Canada Communicable Disease Report*. 2022;48(6):274-281.

254 Larsen HD, Fonager J, Lomholt FK, Dalby T, Benedetti G, Kristensen B, . . . Molbak K. Preliminary report of an outbreak of SARS-CoV-2 in mink and mink farmers associated with community spread, Denmark, June to November 2020. *Eurosurveillance*. 2021;26(5).

255 Clair V, Chan E, Paiero A, Fraser E, Gunvaldsen R, Newhouse E. One Health response to SARS-CoV-2-associated risk from mink farming in British Columbia, Canada, October 2020 to October 2021. *Canada Communicable Disease Report*. 2022;48(6):261-273.

256 Strang T, Flockhart L, Thacker C, Schwantje H, Soos C, Dibernardo A, . . . Himsworth C. SARS-CoV-2 wildlife surveillance surrounding mink farms in British Columbia, Canada. *Canada Communicable Disease Report*. 2022;48(6):252-260.

257 Environment and Climate Change Canada. Wildlife and SARS-CoV-2: FAQ Version 2. Government of Canada. 2022-03-14. https://www.cwhc-rcsf.ca/docs/covid/EN_WildlifeSWG_FAQ-Wildlife-and-SARS-CoV-2-v2_14Mar2022.pdf

258 Pickering B, Lung O, Maguire F, Kruczkiewicz P, Kotwa JD, Buchanan T, . . . Bowman J. Divergent SARS-CoV-2 variant emerges in white-tailed deer with deer-to-human transmission. *Nature Microbiology*. 2022;7(12):2011-2024.

259 Food and Agriculture Organization of the United Nations. SARS-CoV-2 in animals situation update. [Internet]. Food and Agriculture Organization of the United Nations; 2024-12-03 [cited https://www.fao.org/animal-health/situation-updates/sars-cov-2-in-animals/en]

260 World Organisation for Animal Health. Canada - SARS-CoV-2 in animals (Inf. with) - Immediate notification [FINAL]. [Internet]. World Organisation for Animal Health; 2022-12-16 [cited 2025-07-05]. https://wahis.woah.org/#/in-review/4751?fromPage=event-dashboard-url

261 Agriculture et Agroalimentaire Canada. Le gouvernement du Canada et le gouvernement du Quebec offrent une aide financière aux éleveurs touchés par le ralentissement des abattoirs. [Internet]. 15 avril 2021 [consulté le 12 septembre 2025]. https://www.canada.ca/fr/agriculture-agroalimentaire/nouvelles/2021/04/le-gouvernement-du-canada-et-le-gouvernement-du-Quebec-offrent-une-aide-financière-aux-éleveurs-touchés-par-le-ralentissement-des-abattoirs.html

262 Marchant-Forde JN, Boyle LA. COVID-19 Effects on Livestock Production: A One Welfare Issue. *Frontiers in Veterinary Science*. 2020;7:585787.

263 Public Health Agency of Canada. COVID-19 and animals. [Internet]. Government of Canada; 2025-06-03 [cited 2025-07-12]. https://www.canada.ca/en/public-health/services/diseases/2019-novel-coronavirus-infection/prevention-risks/animals-covid-19.html

264 Environment and Climate Change Canada. Wildlife health and SARS-CoV-2: Handling Guidelines (Version 2). Government of Canada. 2022-03-07. https://www.cwhc-rcsf.ca/sars-cov-2.php

265 Ministry of Agriculture Food and Fisheries. Mink farming phase out planned in B.C. [Internet]. Government of British Columbia; 2021-11-05 [cited 2025-05-01]. https://news.gov.bc.ca/releases/2021AFF0066-002112

266 Environment and Climate Change Canada. Canadian Environmental Sustainability Indicators: Temperature change in Canada. Government of Canada. 2024. Accessed 2025-05-01. https://www.canada.ca/content/dam/eccc/documents/pdf/cesindicators/temperature-change/2024/temperature-change-en.pdf

267 Keatts LO, Robards M, Olson SH, Hueffer K, Insley SJ, Joly DO, . . . Walzer C. Implications of Zoonoses From Hunting and Use of Wildlife in North American Arctic and Boreal Biomes: Pandemic Potential, Monitoring, and Mitigation. *Frontiers in Public Health*. 2021;9:627654.

268 Batal M, Chan HM, Fediuk K, Ing A, Berti PR, Mercille G, . . . Johnson-Down L. First Nations households living on-reserve experience food insecurity: prevalence and predictors among ninety-two First Nations communities across Canada. *Canadian Journal of Public Health. Revue Canadienne de Santé Publique*. 2021;112(Suppl 1):52-63.

269 Furgal C, Powell S, Myers H. Digesting the Message about Contaminants and Country Foods in the Canadian North: A Review and Recommendations for Future Research and Action. *Arctic*. 2005;58(2):103–114.

270 Wheatley MA, Wheatley B. The Effect of Eating Habits on Mercury Levels among Inuit Residents of Sugluk, P.Q. National Collaborating Center for Indigenous Health. 1981. https://www.nccih.ca/fr/publicationsExternalview.aspx?sortcode=2.21.0.0&id=2069&col=4

271 Bouchard É, Jokelainen P, Sharma R, Fenton H, Jenkins E. Toxoplasmosis in northern regions. In: *Arctic One Health: Challenges for northern animals and people*. Springer Nature Switzerland; 2022:297–314. doi:10.1007/978-3-030-87853-5_13

272 Hampton MM. Congenital Toxoplasmosis: A Review. *Neonatal Network*. 2015;34(5):274-278.

273 Reiling SJ, Dixon BR. *Toxoplasma gondii*: How an Amazonian parasite became an Inuit health issue. *Canada Communicable Disease Report*. 2019;45(7-8):183-190.

274 Messier V, Levesque B, Proulx JF, Rochette L, Libman MD, Ward BJ, . . . Dixon B. Seroprevalence of Toxoplasma gondii among Nunavik Inuit (Canada). *Zoonoses and Public Health*. 2009;56(4):188-197.

275 Ducrocq J, Lévesque B, Lemire M, de Serres G. Zoonotic and Gastrointestinal Diseases. Nunavik Inuit Health Survey 2017 Qanuilirpitaa? How are we now?. Nunavik Regional Board of Health and Social Services (NRBHSS) & Institut national de santé publique du Québec (INSPQ). 2021. https://nrbhss.ca/sites/default/files/health_surveys/Zoonotic_and_Gastrointestinal_Diseases_report_en.pdf

276 Goyette S, Cao Z, Libman M, Ndao M, Ward BJ. Seroprevalence of parasitic zoonoses and their relationship with social factors among the Canadian Inuit in Arctic regions. *Diagnostic Microbiology and Infectious Disease*. 2014;78(4):404-410.

277 Bachand N, Ravel A, Leighton P, Stephen C, Ndao M, Avard E, Jenkins E. Serological and molecular detection of *Toxoplasma gondii* in terrestrial and marine wildlife harvested for food in Nunavik, Canada. *Parasites & Vectors*. 2019;12(1):155.

278 Lavoie E, Lévesque B, Proulx JF, Grant J, Ndassebe AD, Gingras S, . . . Libman M. Evaluation du Programme de dépistage de la toxoplasmose chez les femmes enceintes du Nunavik, 1994-2003 [Evaluation of the efficacy of the *Toxoplasma gondii* screening program among pregnant women in Nunavik, 1994-2003]. *Canadian Journal of Public Health. Revue Canadienne de Santé Publique*. 2008;99(5):397-400.

279 Nunatsiaq News. Health department targets pregnant women for toxoplasmosis screening. Nunatsiaq News; 2023-11-02. https://nunatsiaq.com/stories/article/health-department-targets-pregnant-women-for-toxoplasmosis-screening/

280 Chaudhry SA, Gad N, Koren G. Toxoplasmosis and pregnancy. *Canadian Family Physician*. 2014;60(4):334-336.

281 Paquet C, Yudin MH. No. 285-Toxoplasmosis in Pregnancy: Prevention, Screening, and Treatment. *Journal of Obstetrics and Gynaecology Canada*. *Journal d'Obstétrique et Gynécologie du Canada*. 2018;40(8):e687-e693.

282 McDonald JC, Gyorkos TW, Alberton B, MacLean JD, Richer G, Juranek D. An outbreak of toxoplasmosis in pregnant women in northern Quebec. *Journal of Infectious Diseases*. 1990;161(4):769-774.

283 Douglas A. Effects of climate change and cultural practices on the risk of human toxoplasmosis in Canada’s North: recommendations for public health. [Thesis]. Faculty of Health Sciences. Simon Fraser University. Master of Public Health. 2017. https://summit.sfu.ca/_flysystem/fedora/sfu_migrate/17353/Douglas%2C%20Amelia%20-%20Capstone%20Paper.pdf.

284 Forde TL, Orsel K, Zadoks RN, Biek R, Adams LG, Checkley SL, . . . Kutz SJ. Bacterial Genomics Reveal the Complex Epidemiology of an Emerging Pathogen in Arctic and Boreal Ungulates. *Frontiers in Microbiology*. 2016;7:1759.

285 Kutz S, Bollinger T, Branigan M, Checkley S, Davison T, Dumond M, . . . Orsel K. *Erysipelothrix rhusiopathiae* associated with recent widespread muskox mortalities in the Canadian Arctic. *Canadian Veterinary Journal*. 2015;56(6):560-563.

286 Mavrot F, Orsel K, Hutchins W, Adams LG, Beckmen K, Blake JE, . . . Kutz SJ. Novel insights into serodiagnosis and epidemiology of *Erysipelothrix rhusiopathiae*, a newly recognized pathogen in muskoxen (Ovibos moschatus). *PloS One*. 2020;15(4):e0231724.

287 Tan EM, Marcelin JR, Adeel N, Lewis RJ, Enzler MJ, Tosh PK. *Erysipelothrix rhusiopathiae* bloodstream infection - A 22-year experience at Mayo Clinic, Minnesota. *Zoonoses and Public Health*. 2017;64(7):e65-e72.

288 Aleuy OA, Anholt M, Orsel K, Mavrot F, Gagnon CA, Beckmen K, . . . Kutz S. Association of Environmental Factors with Seasonal Intensity of *Erysipelothrix rhusiopathiae* Seropositivity among Arctic Caribou. *Emerging Infectious Diseases*. 2022;28(8):1650-1658.

289 Groeschel M, Forde T, Turvey S, Joffe AM, Hui C, Naidu P, . . . Singh AE. An unusual case of *Erysipelothrix rhusiopathiae* prosthetic joint infection from the Canadian Arctic: whole genome sequencing unable to identify a zoonotic source. *BMC Infectious Diseases*. 2019;19(1):282.

290 Brooke CJ, Riley TV. *Erysipelothrix rhusiopathiae*: bacteriology, epidemiology and clinical manifestations of an occupational pathogen. *Journal of Medical Microbiology*. 1999;48(9):789-799.

291 Government of Northwest Territories. Reportable Diseases – Public Health Act. [Internet]. 2024-10-22 [cited 2025-06-25]. https://www.hss.gov.nt.ca/professionals/sites/professionals/files/resources/reporting-nwt-communicable-diseases_0.pdf

292 Seru LV, Forde TL, Roberto-Charron A, Mavrot F, Niu YD, Kutz SJ. Genomic characterization and virulence gene profiling of *Erysipelothrix rhusiopathiae* isolated from widespread muskox mortalities in the Canadian Arctic Archipelago. *BMC Genomics*. 2024;25(1):691.

293 Malone CJ, Oksanen A, Mukaratirwa S, Sharma R, Jenkins E. From wildlife to humans: The global distribution of *Trichinella* species and genotypes in wildlife and wildlife-associated human trichinellosis. International Journal for Parasitology: *Parasites and Wildlife*. 2024;24:100934.

294 Oksanen A, Karssin A, Berg R, Koch A, Jokelainen P, Sharma R, . . . Loginova O. Epidemiology of *Trichinella* in the Arctic and subarctic: A review. *Food Waterborne Parasitol*. 2022;28:e00167.

295 Larrat S, Simard M, Lair S, Belanger D, Proulx JF. From science to action and from action to science: the Nunavik Trichinellosis Prevention Program. *International Journal of Circumpolar Health*. 2012;71:18595.

296 Cash-Goldwasser S, Ortbahn D, Narayan M, Fitzgerald C, Maldonado K, Currie J, . . . Holzbauer S. Outbreak of Human Trichinellosis - Arizona, Minnesota, and South Dakota, 2022. *Canada Communicable Disease Report*. 2024;50(5):153-157.

297 Diaz JH, Warren RJ, Oster MJ. The Disease Ecology, Epidemiology, Clinical Manifestations, and Management of Trichinellosis Linked to Consumption of Wild Animal Meat. *Wilderness and Environmental Medicine*. 2020;31(2):235-244.

298 Appleyard GD, Gajadhar AA. A review of trichinellosis in people and wildlife in Canada. *Canadian Journal of Public Health. Revue Canadienne de Santé Publique*. 2000;91(4):293-297.

299 Andersen-Ranberg E, Nymo IH, Jokelainen P, Emelyanova A, Jore S, Laird B, . . . Sonne C. Environmental stressors and zoonoses in the Arctic: Learning from the past to prepare for the future. *Science of the Total Environment*. 2024;957:176869.

300 Gilbert NL, Dare OK, Libman MD, Muchaal PK, Ogden NH. Hospitalization for trichinellosis and echinococcosis in Canada, 2001-2005: the tip of the iceberg? *Canadian Journal of Public Health. Revue Canadienne de Santé Publique*. 2010;101(4):337-340.

301 Tomaselli M, Kutz S, Gerlach C, Checkley S. Local knowledge to enhance wildlife population health surveillance: Conserving muskoxen and caribou in the Canadian Arctic. *Biological Conservation*. 2018;217.

302 Marie C, Petri WA. Echinococcosis. [Internet]. Merck Manual; 2025-10-01 [cited 2025-10-30]. https://www.merckmanuals.com/professional/infectious-diseases/cestodes-tapeworms/echinococcosis

303 Deplazes P, Rinaldi L, Alvarez Rojas CA, Torgerson PR, Harandi MF, Romig T, . . . Jenkins EJ. Global Distribution of Alveolar and Cystic Echinococcosis. *Advances in Parasitology*. 2017;95:315-493.

304 Santa MA, Umhang G, Klein C, Grant DM, Ruckstuhl KE, Musiani M, . . . Massolo A. It's a small world for parasites: evidence supporting the North American invasion of European *Echinococcus multilocularis*. Proceedings: *Biological Sciences*. 2023;290(1994):20230128.

305 Evason MD, Peregrine AS, Jenkins EJ, Lozoya CE, Rund LL, Weese JS, . . . Leutenegger CM. Emerging Echinococcus tapeworms: fecal PCR detection of *Echinococcus multilocularis* in 26 dogs from the United States and Canada (2022-2024). *Journal of the American Veterinary Medical Association*. 2025;263(2):1-5.

306 Torgerson PR, Keller K, Magnotta M, Ragland N. The global burden of alveolar echinococcosis. *PLoS Neglected Tropical Diseases*. 2010;4(6):e722.

307 Fortin A, Perreault G, Gaulin C. Vigie – Interventions - Échinococcose alvéolaire. Flash Vigie: Bulletin québécois vigie, de surveillance et d'intervention en protection de la santé publique. Ministère de la Santé et des Services sociaux. 2019-02-01. https://publications.msss.gouv.qc.ca/msss/fichiers/flashvigie/FlashVigie_vol14_no2.pdf

308 Houston S, Belga S, Buttenschoen K, Cooper R, Girgis S, Gottstein B, . . . Kowalewska-Grochowska K. Epidemiological and Clinical Characteristics of Alveolar Echinococcosis: An Emerging Infectious Disease in Alberta, Canada. *American Journal of Tropical Medicine and Hygiene*. 2021;104(5):1863-1869.

309 Schurer JM, Tsybina P, Gesy KM, Kolapo TU, Skinner S, Hill JE, Jenkins EJ. Molecular Evidence for Local Acquisition of Human Alveolar Echinococcosis in Saskatchewan, Canada. *Journal of Infectious Diseases*. 2021;223(6):1015-1018.

310 Joyce J, He XO, Rozovsky K, Stefanovici C, Fanella S. Disseminated *Echinococcus multilocularis* Infection without Liver Involvement in Child, Canada, 2018. *Emerging Infectious Diseases*. 2020;26(8):1856-1859.

311 Zewude RT, Corbeil A, Fung S, Moulton CA, Bogoch I. Alveolar Echinococcus in a 70-year-old man in Ontario. *Journal of the Association of Medical Microbiology and Infectious Disease Canada*. 2024;8(4):336-342.

312 Jenkins E, Volappi T, Malone CJ, Germitsch N, Virtanen JP, Oksanen A, . . . Frey CF. Changing distribution, diversity, and health impact of *Echinococcus multilocularis* in Europe and North America: Comparison, connections, and opportunities. *Advances in Parasitology*. 2025;128:159-253.

313 Kotwa JD, Isaksson M, Jardine CM, Campbell GD, Berke O, Pearl DL, . . . Peregrine AS. *Echinococcus multilocularis* Infection, Southern Ontario, Canada. *Emerging Infectious Diseases*. 2019;25(2):265-272.

314 Jenkins EJ, Peregrine AS, Hill JE, Somers C, Gesy K, Barnes B, . . . Polley L. Detection of European strain of *Echinococcus multilocularis* in North America. *Emerging Infectious Diseases*. 2012;18(6):1010-1012.

315 Lavallee-Bourget EM, Fernandez-Prada C, Masse A, Turgeon P, Arsenault J. Prevalence and geographic distribution of *Echinococcus* genus in wild canids in southern Quebec, Canada. *PloS One*. 2024;19(7):e0306600.

316 Robbins WT, Galeuzzi O, Graham K, Greenwood SJ, Jones MEB, Buote M, Conboy GA. *Echinococcus multilocularis* infection in a red fox (Vulpes vulpes) on Prince Edward Island, Canada. *Canadian Veterinary Journal*. 2022;63(9):962-966.

317 Gesy K, Hill JE, Schwantje H, Liccioli S, Jenkins EJ. Establishment of a European-type strain of *Echinococcus multilocularis* in Canadian wildlife. *Parasitology*. 2013;140(9):1133-1137.

318 Catalano S, Lejeune M, Liccioli S, Verocai GG, Gesy KM, Jenkins EJ, . . . Massolo A. *Echinococcus multilocularis* in urban coyotes, Alberta, Canada. *Emerging Infectious Diseases*. 2012;18(10):1625-1628.

319 Luong LT, Chambers JL, Moizis A, Stock TM, St Clair CC. Helminth parasites and zoonotic risk associated with urban coyotes (Canis latrans) in Alberta, Canada. *Journal of Helminthology*. 2018;94:e25.

320 Tse C, Bullard J, Rusk R, Douma D, Plourde PJ. Surveillance of Echinococcus tapeworm in coyotes and domestic dogs in Winnipeg, Manitoba. *Canada Communicable Disease Report*. 2019;45(78):171-176.

321 Massolo A, Klein C, Kowalewska-Grochowska K, Belga S, MacDonald C, Vaughan S, . . . Houston S. European *Echinococcus multilocularis* Identified in Patients in Canada. *New England Journal of Medicine*. 2019;381(4):384-385.

322 Eckert J, Deplazes P. Biological, epidemiological, and clinical aspects of echinococcosis, a zoonosis of increasing concern. *Clinical Microbiology Reviews*. 2004;17(1):107-135.

323 Gottstein B, Felleisen R. Protective immune mechanisms against the metacestode of *Echinococcus multilocularis*. *Parasitology Today*. 1995;11(9):320-326.

324 Kern P. Clinical features and treatment of alveolar echinococcosis. *Current Opinion in Infectious Diseases*. 2010;23(5):505-512.

325 Kern P, Wen H, Sato N, Vuitton DA, Gruener B, Shao Y, . . . Bresson-Hadni S. WHO classification of alveolar echinococcosis: principles and application. *Parasitology International*. 2006;55 Suppl:S283-287.

326 Baumann S, Shi R, Liu W, Bao H, Schmidberger J, Kratzer W, . . . Interdisciplinary Echinococcosis Working Group Ulm. Correction to: Worldwide literature on epidemiology of human alveolar echinococcosis: a systematic review of research published in the twenty-first century. *Infection*. 2022;50(1):287-288.

327 Jenkins EJ, Kolapo TU, Jarque MP, Ruschkowski C, Frey C. Intestinal infection with *Echinococcus multilocularis* in a dog. *Journal of the American Veterinary Medical Association*. 2023;261(9):1-3.

328 Porter E, Seguin MA, Estrada M, Szlosek D, Massolo A, Visscher DR. Assessing the potential for infections of *Echinococcus multilocularis* in dogs in a hotspot of human alveolar echinococcosis infections in North America. *Veterinary Parasitology: Regional Studies and Reports*. 2022;29:100704.

329 Eckert J, Gemmell, MA, Meslin, FX, Pawloski, ZS. WHO/OIE Manual on Echinococcosis in Humans and Animals: a Public Health Problem of Global Concern. World Health Organization/Office International des Epizooties. Paris, France. 2001. https://iris.who.int/bitstream/handle/10665/42427/929044522X.pdf?sequence=1

330 Massolo A, Liccioli S, Budke C, Klein C. *Echinococcus multilocularis* in North America: the great unknown. *Parasite*. 2014;21:73.

331 Khalid A, Muchaal PK, Julien DA. Human echinococcosis incidence in Canada: A retrospective descriptive study using administrative hospital and ambulatory visit data, 2000-2020. *Canada Communicable Disease Report*. 2024;50(9):305-311.

332 Alberta Health. Alberta Public Health Disease Management Guidelines Echinococcosis (Alveolar). [Internet]. 2021-11-01 [cited 2025-02-21]. https://open.alberta.ca/dataset/140a7c4a-d7bd-4909-b02f-24c7b35afc63/resource/65528d86-2571-42cd-a821-f4f93cbfaa9d/download/health-phdmg-echinococcus-2021-11.pdf

333 Public Health Ontario. Appendix 1: Case Definitions and Disease Specific Information Disease: *Echinococcus multilocularis* infection. [Internet]. 2022-05-01 [cited 2025-06-01]. https://files.ontario.ca/moh-ophs-echinococcus-multilocularis-infection-en-2022.pdf

334 Murray R, Tataryn J, Pintar K, Thomas MK. Estimates of the burden of illness for eight enteric pathogens associated with animal contact in Canada. *Epidemiology and Infection*. 2017;145(16):3413-3423.

335 Health Canada. Food Safety for Vulnerable Populations. [Internet]. Government of Canada; 2025-03-01 [cited 2025-04-01]. https://www.canada.ca/en/health-canada/services/food-safety-vulnerable-populations/food-safety-vulnerable-populations.html

336 Thomas MK, Murray R, Flockhart L, Pintar K, Pollari F, Fazil A, . . . Marshall B. Estimates of the burden of foodborne illness in Canada for 30 specified pathogens and unspecified agents, circa 2006. *Foodborne Pathogens and Disease*. 2013;10(7):639-648.

337 Fagan-Garcia K, Denich L, Tataryn J, Janicki R, Van Osch O, Kearney A, . . . Lowe AM. A multi-provincial *Salmonella* Typhimurium outbreak in Canada associated with exposure to pet hedgehogs, 2017-2020. *Canada Communicable Disease Report*. 2022;48(6):282-290.

338 Waltenburg MA, Nichols M, Waechter H, Higa J, Cronquist L, Lowe AM, . . . Basler C. Notes from the Field: Recurrence of a Multistate Outbreak of *Salmonella* Typhimurium Infections Linked to Contact with Hedgehogs - United States and Canada, 2020. *MMWR: Morbidity and Mortality Weekly Report*. 2021;70(32):1100-1102.

339 Stevens MS, Geduld J, Libman M, Ward BJ, McCarthy AE, Vincelette J, . . . Boggild AK. Dermatoses among returned Canadian travellers and immigrants: surveillance report based on CanTravNet data, 2009-2012. *Canadian Medical Association Journal Open*. 2015;3(1):E119-126.

340 Kulkarni MA. Global spread and impacts of emerging vector-borne diseases. *Canada Communicable Disease Report*. 2016;42(10):198-199.

341 Drebot MA, Holloway K, Zheng H, Ogden NH. Travel-related chikungunya cases in Canada, 2014. *Canada Communicable Disease Report*. 2015;41(1):2-5.

342 World Health Organization. The history of zika virus. [Internet]. 2016-02-07 [cited 2025-08-12]. https://www.who.int/news-room/feature-stories/detail/the-history-of-zika-virus

343 Tataryn J, Vrbova L, Drebot M, Wood H, Payne E, Connors S, . . . Buck PA. Travel-related Zika virus cases in Canada: October 2015-June 2017. *Canada Communicable Disease Report*. 2018;44(1):18-26.

344 Ng V, Fazil A, Gachon P, Deuymes G, Radojevic M, Mascarenhas M, . . . Ogden NH. Assessment of the Probability of Autochthonous Transmission of Chikungunya Virus in Canada under Recent and Projected Climate Change. *Environmental Health Perspectives*. 2017;125(6):067001.

345 Lowe AM, Forest-Berard K, Trudel R, Lo E, Gamache P, Tandonnet M, . . . Ludwig A. Mosquitoes Know No Borders: Surveillance of Potential Introduction of *Aedes* Species in Southern Quebec, Canada. *Pathogens*. 2021;10(8).

346 Giordano BV, Gasparotto A, Liang P, Nelder MP, Russell C, Hunter FF. Discovery of an *Aedes* (*Stegomyia*) *albopictus* population and first records of *Aedes* (*Stegomyia*) *aegypti* in Canada. *Medical and Veterinary Entomology*. 2020;34(1):10-16.

347 Public Health Agency of Canada. Mosquito-borne disease surveillance: Technical notes. [Internet]. 2025-08-26 [cited 2025-09-20]. https://health-infobase.canada.ca/zoonoses/mosquito/technical-notes.html