Summary of information, risk assessment, and recommendations regarding Arthropod-borne Zoonoses within the Northwest Territories

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Contents

List of abbreviations used in this report

AB	Alberta
ACIA	Arctic Climate Impact Assessment
BC	British Columbia
BCCDC	British Columbia Centre for Disease Control
CCH	Centre for Coastal Health
CVV	Cache valley virus
CTF	Colorado tick fever
CSG	California J serogroup viruses
EEE	Eastern equine encephalitis virus
EIP	Extrinsic incubation period
ENR	Environment and Natural Resources
ENSO	El Nino Southern Oscillation
EWHALE	Ecological Wildlife Habitat Data Analysis for the Land and Seascape
HGA	Human granulocytic anaplasmosis
IPCC	Intergovernmental Panel on Climate Change
JC	Jamestown canyon virus
LB	Lyme borreliosis
MB	Manitoba
NB	New Brunswick
NS	Nova Scotia
NT	Northwest Territories
ON	Ontario
PCR	Polymerase chain reaction
POW	Powassan virus
RNA	Ribonucleic acid
QC	Quebec
SK	Saskatchewan
SLE	St. Louis encephalitis virus
SNAP	Scenarios Network for Arctic Planning
SSH	Snowshoe hare virus
TBE	Tick-borne encephalitis
TBRF	Tick-borne relapsing fever
US	United States
VBZs	Vector-borne zoonosis/zoonoses
WEE	Western equine encephalitis virus
WN	West Nile virus

Executive summary

The Centre for Coastal Health (CCH) was retained by the Wildlife Division, Department of Environment and Natural Resources, Government of the Northwest Territories (NT) to develop evidence-based recommendations to assist NT in preparing for potential changes in vector borne disease (VBZs) risks. To do so, we catalogued surveillance and preparedness activities in NT and surrounding jurisdictions with respect to the presence, prevalence and distribution of arthropod vectors and VBZs, and reviewed these activities in light of available climate change predictions for NT. The data associated with climate change itself – at least as it relates to changing temperature in Canada – are compelling. In the 71 years since temperature data have been collected in Canada, annual temperatures have shown an overall increase of 1.7^0 C (Government of Canada, 2018), with regional increases reported from the NT of 2.8^0 C since 1941. Increasing temperatures are expected to alter the environments in which wildlife and vector arthropods can survive, and indeed, recent northward range expansion of tick vector ranges in both North America and the European continent have been observed, with subsequent incursions of pathogens like those responsible for Lyme disease and tick-borne encephalitis. Nevertheless, the relationship between climate change and changes in land use, vectors, animal hosts and other variables are complex and challenging to study, and present uncertainties in predicting how climate change might alter VBZs risks in NT.

The CCH compiled a list of diseases reported in Canada that require a mosquito, fly or tick to transmit the pathogen from an animal host to a human. Food and water-borne zoonoses (i.e. those pathogens that humans acquire through the consumption of infected food or water, such as *Giardia* and *Campylobacter* spp.), and pathogens that are transmitted between animal hosts and humans without the aid of an arthropod vector (e.g. rabies), were excluded from the compiled list. We then evaluated and summarized surveillance information provided by the NT project lead, along with publications retrieved using rapid peer-reviewed and grey literature searches, to gather baseline information. Priority VBZs were those that had previously been documented in the NT, or were diseases of public health concern that had been reported from provinces and territories adjacent to the NT. The ways in which the pathogen might enter NT was also given consideration.

Five VBZs were classified as of immediate priority. Tularemia, caused by the bacteria *Francisella tularensis*, and the California J serogroup viruses, specifically Snowshoe hare virus and Jamestown canyon virus, are known to exist in NT but appear to have minimal human health impacts. There was limited or no information on which genotypes are circulating in NT, the comparative role of various vertebrate hosts in maintaining endemic cycles, or the frequency or mechanism of arthropod-borne transmission. West Nile (WN) virus and Lyme disease are not present in NT, but have caused significant public health concerns in adjacent provinces. Key mosquito vector species implicated in the transmission of WN to humans have been identified in NT since 2004, and competent vertebrate hosts are also likely present. Climatic conditions, in particular temperature, appeared to be the factor limiting the incursion of this disease into NT, however, there is currently limited capacity to detect WN in northern regions of the prairie provinces. The key arthropod host (*Ixodes* spp. ticks) for Lyme disease is not established in NT or nearby regions. Similarly, the key vertebrate host (white footed mouse) is not present, although other vertebrate species that might act as competent hosts are. It is expected that infected ticks could be transported into NT on migrating birds, however at this time climatic conditions, in particular temperature, are an important factor limiting the establishment of *Ixodes* spp. ticks and subsequent incursion of Lyme disease into NT.

Nine additional VBZs were classified as lower priority because they were reported to rarely cause human illness, and to be present only in geographically distant regions of Canada. These were Colorado tick fever, Cache valley virus, St. Louis encephalitis, Powassan virus (POW), Eastern equine encephalitis, Western equine encephalitis (WEE), tick-borne relapsing fever, human granulocytic anaplasmosis (HGA), and babesiosis. Because WEE shares many similarities with WN in terms of vector and host species, much of the information about WN risk discussed in the main body of the report is applicable to WEE. Similarly because POW, HGA and babesiosis share a similar ecology with Lyme, including transmission by *Ixodes* spp. ticks, much of the information about Lyme risk is applicable to these pathogens as well.

We recommend strengthening the early warning and preparedness system for VBZs in NT by promoting early warning networks, generating new data through surveillance, and increasing integration and reporting of activities and data. Actions to promote and strengthen early warning networks include maintaining a strong situational awareness about VBZs across Canada; providing NT citizens with knowledge and resources about zoonotic diseases; and facilitating the investigation of unusual animal health events (e.g. bird deaths) and identification of tick species found on people and pets. To promote territory-specific early warning intelligence, we recommend that NT generates monthly (during the summer) and annual degree day maps for priority regions within the territory to monitor temperature conditions and identify periods where temperature exceeds minimums necessary to sustain infected insect vector populations. Enhanced passive surveillance in NT to identify ticks found on people and pets, either via online and web-based photo identification services, or by encouraging submission of more ticks, will increase awareness of tick species in NT. Continued systematic mosquito trapping and identification is also recommended, although logistics and resources may impact when mosquitoes are trapped and tested for VBZs. Finally, preparation and dissemination of annual reports containing summary statements and diagrams that illustrate NT's risk of, and preparedness for, VBZs, will assist in surveillance response and planning.

Overview and Introduction

What were we asked to do?

The Centre for Coastal Health (CCH) was retained by the Wildlife Division, Department of Environment and Natural Resources, Government of the Northwest Territories (NT) to summarize available information on vector-borne zoonoses (VBZs), recognizing that climate change could potentially affect the number or severity of VBZs present in the NT in the coming years. VBZs are bacterial, viral or parasitic diseases that are transmitted to humans from animals (zoonoses) through the bite of an infected insect such as a mosquito, fly or tick (arthropod vector). Our first objective was to catalogue available information on relevant surveillance and preparedness activities in NT and surrounding jurisdictions, including provided data about the presence, prevalence and distribution of arthropod vectors and VBZs in the north. We then set out to combine these findings with published information describing climate change predictions, and research on VBZs and arthropod vector surveillance, with the goal of developing evidence-based recommendations to assist NT in preparing for potential changes in VBZs risks in the territory.

Why is this important?

The data associated with climate change itself – at least as it relates to changing temperature in Canada – are compelling. In the 71 years since temperature data have been collected in Canada, mean annual temperatures have fluctuated over time and across regions, but mean annual temperature has shown an overall increase of 1.7^0 C (Government of Canada, 2018). NT has shown the highest regional increase specifically, with an increase in mean annual temperature of 2.8^0 C since 1941.

Increasing temperatures are anticipated to alter precipitation rates and habitats, with potentially significant effects on the distribution of wildlife and vector populations across the NT. This in turn could change the risk of exposure for NT residents to VBZs. The principle seems to be supported by observations of recent northward expansion of tick vector ranges in both North America and the European continent, carrying with them pathogens like the one responsible for Lyme disease (Clow, Leighton, Pearl, & Jardine, 2019) and tick-borne encephalitis (Hedlund, Blomstedt, & Schumann, 2014b). However, the relationships among climate change, changes in land use, vectors, animal hosts and other variables are complex, making it challenging to predict if and when new VBZs might enter the NT, or how existing ones might alter their presentation. It is important to understand the present situation with respect to VBZs, vectors, and climate change within the NT and its surrounding jurisdictions, and to consider information in light of recent scientific findings, in order to evaluate options NT might undertake for VBZs surveillance and preparedness in the face of climate change.

What are vector-borne zoonoses?

A vector-borne zoonosis is a human illness caused by a virus, bacteria or parasite that is maintained in nature in a cycle that involves arthropods (e.g. mosquitoes, ticks or flies) and (non-human) animal hosts (Figure 1). Vector-borne pathogens include parasites, bacteria and viruses. In Canada, four bacterial, one parasitic and nine viral VBZs have been documented (Table 1).

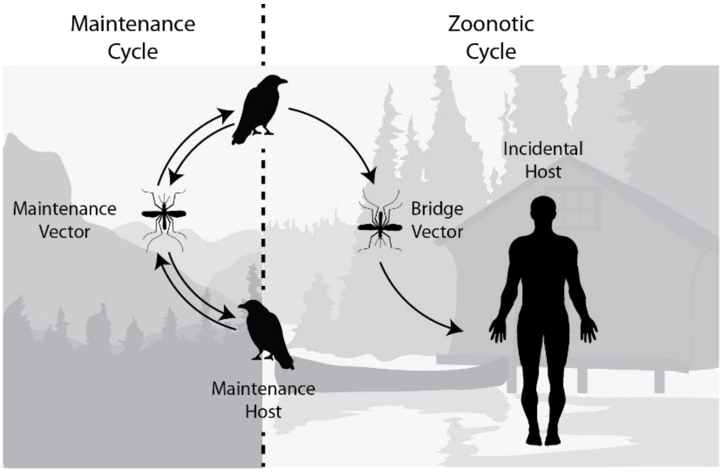


Figure 1: A vector-borne zoonoses is a human illness caused by a virus, bacteria or parasite that is maintained in nature in a cycle that involves arthropods (e.g. mosquitoes, ticks or flies) and (non-human) animal hosts.

'Arbovirus' is a widely used descriptive term for viruses that infect both blood-sucking arthropods and vertebrate hosts. The term does not indicate that viruses share close genetic relationships, i.e. viruses from different genuses may be categorized as arboviruses. Most human arboviral infections in Canada are thought to result in no clinical signs (i.e. asymptomatic) or mild illness (e.g. flu-like aches, pains and fever), although serious illness such as meningitis (inflammation of the meninges surrounding the brain) and encephalitis (inflammation of the brain tissue) can occur. Children and elderly people are most at risk of developing serious illness. Long-term neurologic changes have been reported, with potentially devastating impacts on affected individuals.

Table 1: Vector-borne zoonoses documented in Canada

Category	Zoonoses		Arthropod Host
Arbovirus			
	California J Serogroup	Snowshoe hare virus	Mosquito
		Jamestown canyon virus	Mosquito
	Bunyamwera	Cache valley virus	Mosquito
	Flavivirus	West Nile virus	Mosquito
		St Louis encephalitis virus	Mosquito
		Powassan virus	Tick
	Alphavirus	Eastern equine encephalitis virus	Mosquito
		Western equine encephalitis virus	Mosquito
	Reovirus	Colorado tick fever virus	Tick
Bacteria			
	Lyme disease	*Borrelia burgdorferi*	Tick
	Tick-borne relapsing fever	Non-Lyme *Borrelia spp.*	Tick
	Human granulocytic anaplasmosis	*Anaplasma phagocytophilum*	Tick
	Tularemia	*Francisella tularensis*	Tick, deerfly
Parasite			
	Human babesiosis	*Babesia microti*	Tick

How are vector borne zoonoses associated with climate change?

Many variables influence the risk of transmission of VBZs to people (Hedlund et al., 2014b). For example, environment, landscape (e.g. vegetation ground cover, standing water) and climate (e.g. precipitation, temperature, degree days exceeding thresholds for vector survival) are known to affect the following: 1) the geographic range of a pathogen or vector's preferred host, 2) a vector's development, density, survival and biting rates, 3) a pathogen's replication rate within the animal host(s), and vector(s), and 4) the likelihood of successful pathogen transfer from an arthropod to a human (Benelli & Duggan, 2018). Climatic variability will likely affect the occurrence and northern distribution of competent arthropod vectors and the mammalian and avian hosts that naturally cycle VBZs. However, the complex interactions between climate, environment and arthropod and animal host populations create high uncertainty in predictions of how climate change might alter VBZ impacts in NT.

How did we approach the project?

The CCH set out to compile a list of VBZs that have been reported in Canada. We did not consider food or water-borne zoonoses (i.e. those pathogens that humans acquire through the consumption of infected food or water), nor did we look at pathogens that are transmitted between animal hosts and humans without the aid of an arthropod vector.

For each VBZ, we evaluated and summarized surveillance information provided by the NT project lead, along with publications retrieved using rapid peer-reviewed and grey literature searches to gather baseline information.

Our efforts to prioritize VBZs with regards to risk to NT were centered on a decision process as follows:

1. *Has the VBZ been documented in the NT?*

All VBZs documented in the NT were assigned to the category 'present in NT - immediate priority'.

Next, for zoonotic pathogens not present in NT, we assigned priority by evaluating three factors:

2. *Was the VBZ present in a province or territory adjacent to NT?*

VBZs that were reported only from non-adjacent jurisdictions (e.g. QC, NB, etc.) were considered of lower priority than those reported from areas adjacent to NT (e.g. AB, SK). VBZs that occurred in adjacent provinces, but in areas geographically distant from NT or with very dissimilar habitat and climatic conditions, were also considered to be of lower priority.

3. *In adjacent or nearest endemic jurisdictions, what was the human health impact of the VBZ?*

We used a risk-based approach to classify human health impact, which we regard as a composite measure of the prevalence of the VBZs in a region, the potential magnitude of harm, and uncertainty in estimates of prevalence and magnitude. VBZs that were documented to have low human health impacts were considered to be of lower priority to this report than those with higher human health impacts.

4. *How might the vector-borne pathogen move into NT?*

For all VBZs not currently present in NT, we considered how they might reach NT. We assessed the potential pathways for and probability of long distance spread through the movements of animal or arthropod hosts. In the section below, we briefly review the possible mechanisms by which a VBZ pathogen might be transported over long distances (i.e. from an endemic area to a previously disease free area several hundred kilometers away) by mosquitoes, ticks or vertebrate hosts.

Three categories of mosquito movement from their breeding sites have been described (Service, 1997). The first is purposeful flights in search of hosts, nectar (food), mates, oviposition sites, and shelter. These flights are generally restricted to less than 1 km, although flight distances of up to 50 km have been reported for some species (Verdonschot & Besse-Lototskaya, 2014). The second is wind-assisted long-distance dispersal, which is strongly influenced by wind speed and direction, and passive dispersal is mostly down-wind. Reported travel distances for this type of dispersal are thought to be less than 200 km, but data is limited (Kay & Farrow, 2000). The third is passive dispersal via vehicles, including airplanes, boats, and trains. This has been documented to disperse species thousands of kilometers and introduce mosquito species and VBZs into new locations (Service, 1997). Initial incursions would be expected to occur at transportation hubs such as ports and airports.

Ticks engage in purposeful travel for only short distances (meters) (Falco & Fish, 1991). However, because ticks feed on their host for multiple days, they may be passively transported long distances on vertebrate hosts, in particular migratory birds. It has been estimated that 50 million to 175 million ticks are transported north into Canada during spring bird migrations, including some into northern Canada (Ogden et al., 2015; Ogden, Lindsay, et al., 2008).

Finally, infectious animal hosts may carry pathogens between locations independent of arthropods. For this to occur they must maintain or amplify infectious agents in their body, while also remaining healthy enough to migrate or disperse. Small mammals, which are important reservoir hosts for a number of the VBZs occurring in Canada, generally have home ranges of only a few hundred meters. Large ungulate reservoir hosts, such as moose, may travel distances of approximately 200 km (U.S. Fish and Wildlife Service, 2014). Birds are considered the most likely to be responsible for longer distance movements of VBZs, and are amplifying hosts for some VBZs found in Canada(Ogden, Lindsay, et al., 2008). Bird seasonal migratory patterns, combined with VBZ ecology, make the northward movement of tick-borne pathogens by birds probable.

Using the criteria outlined above, VBZs were assigned to one of three categories: 1) present in NT- immediate priority, 2) not present in NT- immediate priority and 3) not present in NT- long term watch list. We focused further project activity on vector-borne pathogens of immediate priority.

What zoonotic vector-borne diseases are of concern for the NT?

Using the criteria described immediately above, five VBZs were classified as immediate priority. Of these, tularemia, caused by the bacteria *Francisella (F.) tularensis*, and the California J serogroup viruses (CSG), specifically Snowshoe hare virus (SSH) and Jamestown canyon virus (JC), were classified as 'immediate priority - present in NT' (Table 2). West Nile Virus (WN) and Lyme disease were classified as of 'immediate priority - not present in NT'. The nine VBZs that were classified as lower priority included Colorado tick fever (CTF), Cache valley virus (CVV), St. Louis encephalitis (SLE), Powassan virus (POW), Eastern equine encephalitis (EEE) and Western equine encephalitis (WEE), tick-borne relapsing fever (TBRF), human granulocytic anaplasmosis (HGA), and babesiosis. Baseline information used to prioritize pathogens is included in Appendix 1. Because WEE shares many similarities with WN in terms of vector and host species, much of the information about WN risk discussed in the main body of the report is applicable to WEE. Similarly, because POW, HGA and babesiosis share similar ecology and vector with Lyme, much of the information about Lyme risk is applicable to these pathogens.

Table 2: Prioritization for NT of vector-borne zoonoses present in Canada

Pathogen	**Acronym**	**Priority level***
Snowshoe hare virus	SSH	1
Jamestown canyon virus	JC	1
Francisella tularensis	Tularemia	1
West Nile virus	WN	2
Borrelia burgdorferi	Lyme	2
Cache valley virus	CVV	3
St Louis encephalitis virus	SLE	3
Powassan virus	POW	3
Eastern equine encephalitis virus	EEE	3
Western equine encephalitis virus	WEE	3
Colorado tick fever virus	CTF	3
Non-Lyme *Borrelia* spp.	TBRF	3
Anaplasma phagocytophilum	HGA	3
Babesia microti	Babesiosis	3

* 1: NT - Immediate; 2: Non NT - Immediate; 3: Long-term watchlist

What did we find?

Although three VBZs (tularemia, SSH and JC) are present in NT, human health impacts appear to be minimal. We found very limited or no information that described genotypes circulating in NT, the comparative role of various vertebrate hosts in maintaining endemic cycles, or the frequency or mechanism of arthropod-borne transmission.

For WN, we found that although the virus has not been reported in NT, key mosquito vector species have been identified in NT since 2004. Key vertebrate hosts are also likely present. Climatic conditions, in particular temperature, appeared to be the factor limiting the incursion of this disease into NT.

For Lyme, the key vertebrate host (white-footed mouse) is not present in NT, although other species that might act as competent hosts are present. Key tick vector species are not established in NT or regions near the borders of NT, however infected ticks could on occasion be carried into NT on migrating birds. Climatic conditions, in particular temperature, may be an important factor limiting the incursion of Lyme disease into NT.

The northern climate is warming. However, the relationships among climate change, changes in land use, vectors, animal hosts and other variables are complex, making it challenging to predict if and when new VBZs may enter the NT, or how existing ones might alter their presentation.

What do we recommend?

We recommend strengthening the early warning and preparedness system for VBZs in NT by promoting early warning networks, generating new data through surveillance, and integrating interagency collaboration and reporting.

Actions to promote and strengthen early warning networks might involve:

- Maintaining strong situational awareness about VBZs from other regions of Canada,
- Ensuring NT citizens have access to knowledge resources about zoonotic diseases, and services to investigate unusual animal health events (e.g. bird deaths) and to identify ticks found on people and pets.

Actions to generate the new data towards territory-specific early warning intelligence might include:

- Generation of monthly (through the summer) and annual degree day maps for priority regions of NT to monitor minimal temperature conditions thought to increase key insect vector populations,
- Enhanced passive surveillance in NT to identify ticks found on people and pets, either via online and web-based photo identification services, or by encouraging submission of more ticks, and

- Continued systematic mosquito trapping and identification. Depending on logistics and resources, trapped mosquitoes could be tested for VBZs (WN and CSGs) routinely, or only during periods of heightened alert.

In support of interagency collaboration and reporting, consider:

- Maintaining strong interagency communication within NT so that information about human VBZs cases, and unusual animal health and arthropod population events, can be communicated and discussed in a timely manner, and
- Annual reports containing summary statements and diagrams that illustrate NT's risk of, and preparedness for, VBZs.

How is this report structured?

This report consists of an extended summary of the efforts by CCH to synthesize available information about immediate priority VBZs in and adjacent to NT and arthropod vectors present in NT, to assess the probability – and the uncertainty around that probability - that the impact of VBZs might increase in NT, and recommend actions to enhance NT's capacity to identify and address VBZs surveillance and preparedness. The report's appendices contain details in support of our VBZs priority ranking, detailed information pertaining to the arthropod vectors and VBZs in NT, as well as our summary of the science on anticipated climate change impacts in the north. Finally, a references section contains a list of the literature on which we base our discussion.

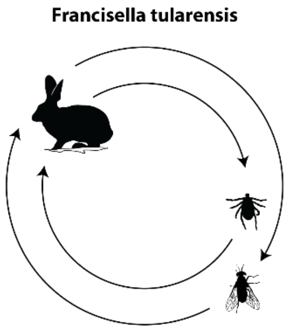
Summary of Baseline Information

This section of the report summarizes available information (from the literature, existing datasets, and interviews) on immediate priority VBZs known to be in NT (tularemia and the CSGs), immediate priority VBZs not presently in NT (WN and Lyme), potential vectors for VBZ in NT, and the influence of climate on VBZs in the north. Detailed data, including literature search strings, inventories of datasets, and findings about arthropods in NT, climate change and VBZs that support this summary, are included in Appendices 2 through 5.

Immediate priority VBZs – known to be in NT

Three VBZs, tularemia, SSH and JC, are known to be present in the NT. In the subsequent paragraphs, we provide an overview of key information, as well as a summary of NT specific data relevant to each of these agents. Because of their similarity, SSH and JC are discussed together.

Tularemia



Tularemia is caused by the gram-negative bacteria *Francisella (F.) tularensis.* Traditionally, *F. tularensis* has been separated into 2 subspecies, subspecies *tularensis* (type A) and subspecies *holarctica* (type B). Type B shows minimal genetic diversity. Type A is genetically diverse and has been subtyped into A1 (or A-east) and A2 (or A-west) (Staples, Kubota, Chalcraft, Mead, & Petersen, 2006). More recent genotyping of United States (US) isolates has identified four distinct type A genotypes, A1a, A1b, A2a and A2b (Kugeler et al., 2009). Human infections due to A1b resulted in significantly higher mortality (24%) than those caused by A1a (4%), A2a, A2b (both 0%), and type B (7%). Arthropod bites and direct animal contact each accounted for roughly one-half of reported exposures to all subtypes. For cases involving direct animal contact, lagomorphs (hares and rabbits) were most strongly epidemiologically linked to all Type A subtypes, rodents were most strongly linked to Type B strains, and cats were linked to both A and B strains. In an analysis of 12 isolates from various sources in Alaska, 10 were identified as type A1 (6 hares, 1 rodent, 3 human), one as type A2 (human), and one as type B (human) (Hansen, Vogler, Keim, Wagner, & Hueffer, 2011b).

Tularemia is a notifiable human illness in Canada. For NT, we found no reports of recent cases in people. In Alaska, the incidence rate in people is reported to be 0.13 cases per 100,000 (Hansen et al., 2011b). The Government of Canada indicates that human disease is rare, with 12 deaths reported prior to 1980, and the BCCDC reports that there are on average 0-3 cases per year in BC. We found no molecular epidemiological data from Canada that described the strains of tularemia isolated from people. Although we found no serology data from NT, *F. tularensis* antibodies have been detected in approximately 15 percent of tested individuals from Alaska and other northern regions of Canada (Hansen, Vogler, Keim, Wagner, & Hueffer, 2011a;

Sampasa-Kanyinga et al., 2013). Serious disease appears to be rare even in the face of widespread exposure.

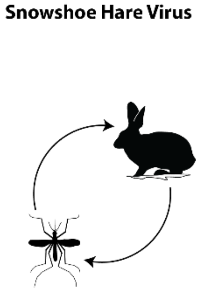
In animals, limited surveillance in various provinces has detected antibodies at low prevalence in many wildlife species including beavers, muskrats, coyotes, ground squirrels, mice and hares (Gabriele-Rivet et al., 2016; Wobeser, Campbell, Dallaire, & McBurney, 2009). One beaver from NT has been reported as infected (Wobeser et al., 2009).

Many species of biting flies, mosquitoes, lice and fleas have been shown experimentally to act as mechanical vectors for tularemia (Bourne, Unknown). The bacteria do not replicate within these arthropods, but have been estimated to survive for up to 21 days on mouthparts and body surfaces. Biting flies and mosquitoes have been linked to spatially clustered tularemia outbreaks outside of North America (Petersen, Mead, & Schriefer, 2009). Naturally infected biting flies reported from Europe include *Chrysops, Haematopota,* and *Tabanus* spp. In North America, the deer fly *C. discalis* is the only documented non-tick arthropod vector, and it has been documented to transmit Type A2 strains within the western US but not in northern regions. Tularemia transmission by mosquitoes has been documented only in Europe and Russia, where it has been linked to *Aedes (Ae.) cinereus and Ochlerotatus (Oc.) excrucians.*

Ticks are considered the key arthropod vectors for tularemia. *F. tularensis* replicates and is maintained in ticks for long periods of time. Transmission across stages of tick development (transtadial transmission) is common, but transmission from adult ticks to their eggs (transovarian transmission) appears to be rare. North American tick species that transmit tularemia to humans include the dog tick (*Dermacentor (D.) variabilis*), the wood tick (*D. andersoni*), and the lone star tick (*Amblyomma (A.) americanum*). The range of *A. americanum* is restricted to the SE US. *D. variabilis* has been documented in regions of MB and SK south of 53 degrees latitude, and *D. andersoni* has been documented in BC, AB and SK and is generally found at altitudes of 300 to 1000 m. *Dermacentor* spp. have rarely been found in NT, and only on people or dogs with travel history to southern Canada (Fenton, 2018 Unpublished data). The rabbit tick, *Haemaphysalis (H.) leporis-palutris* has been documented to be infected with tularemia and does occur across Canada, including in NT. Rabbits and hares are the most important host of this tick. It has, however, been recorded from a variety of other hosts such as ground-foraging birds and (uncommonly) larger mammals (Lindquist et al., 2016). *H. leporis-palutris* feeds on humans very rarely and is therefore thought to be an insignificant vector for human tularemia.

We found limited information about tick surveillance for tularemia in Canada. Five isolates of *F. tularensis* were isolated from *D. variabilis* in Ontario (ON) in 1979 (Artsob et al., 1984). In NT in 2017 four groups of *H. leporis-palutris* ticks retrieved from Snowshoe hares and a dog tested negative for *F. tularensis* (Fenton, 2018 Unpublished data).

California J Serogroup viruses



There are approximately 19 serogroups in the *Orthobunyavirus* genus. Two of these, SSH and JC, have been reported in Canada. Both SSH and JC are members of the California J serogroup (CSG), which includes 17 closely related viruses.

CSG serogroup viruses are not notifiable human pathogens in Canada. However, laboratory protocols generally divert samples from people with suspicious neurologic symptoms that are negative for WN to CSG screening. Human illness caused by CSG infections were detected during the 1970s and 1980s (Artsob, 1990), but from 1989 to 2005 there was no surveillance for CSG due to lack of available tests (Drebot, 2015). Since 2006, over 200 probable and confirmed cases of SSH and JC infection have been documented across Canada (Drebot, 2015). The majority of recent cases have been associated with the JC virus, as compared to historic data suggesting that more cases were caused by SSH virus (Drebot, 2015). It is unclear whether this shift is a result of true changes in epidemiology, or is due to improved serological diagnostics. Although we found no serosurveillance data from NT, antibodies to CSG viruses have been detected in approximately one-quarter of tested individuals in Alaska and other northern regions of Canada (Miernyk et al., 2019; Sampasa-Kanyinga et al., 2013). Serious disease has been reported (Lau, Wudel, Kadkhoda, & Keynan, 2017), but appears to be rare despite widespread exposure.

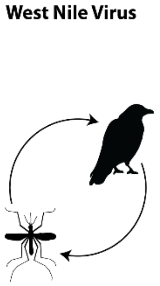
A wide range of wild mammal and domestic animal species can be infected with CSG viruses. The primary hosts for SSH are small mammals, including Snowshoe hares and squirrels, whereas larger ungulates such as white tailed deer and moose are important hosts for JC (Carson et al., 2017). In a recent study in QC, antibodies were found in 84% of horses, 19% of humans, and 12% of dogs tested (Rocheleau et al., 2017). Antibodies to JC virus were detected in 71% of 31 moose sampled in Algonquin Park in ON (Grimstad, Schmitt, & Williams, 1986).

There are more than 20 species of mosquito in Canada that can serve as a vector for the SSH and JC viruses, including various *Aedes*, *Ochlerotatus*, *Culiseta* and *Anopheles* spp. (Drebot, 2017). Species of *Aedes* have had the highest rates of infection in various surveys and appear to be the most important mosquito hosts for SSH virus (Drebot, 2017). The viruses are able to persist in adult mosquitoes during prolonged periods of cold weather, and appear to be passed from infected adult females to eggs in some species of *Aedes*. In NT and Yukon, SSH was isolated from female mosquitoes of seven species collected throughout the boreal forest and open woodland terrain between 1972 through 1982 (McLean, 1983). Infection rate was 3.8 % for *Aedes (Ae.) communis* (0.038) and 12.4% for *Culiseta (Cs.) inornata*. More recently, nine of 418 mosquito pools tested in AB were positive for SSH or JC (Pabbaraju et al., 2009).

Immediate priority VBZs – not present in NT now

Two VBZs, WN and Lyme, were classified as immediate priority but were not documented to be present in the NT at the time of writing this report. In the subsequent paragraphs, we provide an overview of key information, as well as a summary of data relevant to these two agents.

West Nile Virus



WN belongs to the Flaviviridae family. Genotype analysis has revealed two main genetic variants of WN in the US, an NY99 genotype, and a more recent WN02 genotype, each of which contains many subtypes (Di Giallonardo et al., 2016). WN genotype variants in North America have generally not clustered by geographic location (Di Giallonardo et al., 2016).

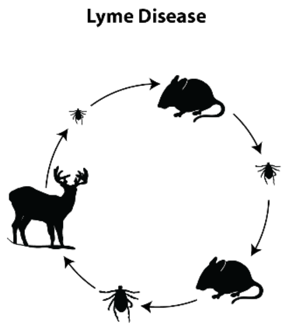
The majority of human infections are asymptomatic, with estimates that 20% of infections cause febrile illness and 1% cause serious neurologic disease. Approximately ten deaths per year in Canada are attributed to WN (Government of Canada, 2016). In 2017, there were 193 clinical cases of WN in Canada (Table 3) (Government of Canada, 2016). High incidence years do occur; epidemics in 2002 and 2012 resulted in 3.5 and 2.0 WN cases per 100,000 population respectively in ON (Mallya et al., 2018). To date, all human cases have been reported from the southern half of affected provinces (Government of Canada, 2013-2017).

Table 3. Number of human WN cases in 2017 in Canada by province

Pathogen	**Number of cases**
British Columbia	1
Alberta	7
Saskatchewan	1
Manitoba	4
Ontario	154
Quebec	26
Atlantic Canada	0
Territories	0

WN is sustained in a bird-mosquito cycle. In Canada, the virus cycles in summer and autumn months among *Culex* spp. mosquitoes and bird species that include the American robin, house finch, mourning dove, blackbirds and sparrows. . During winter, it is thought to be maintained in regions of the US where mosquitoes are present year round, then in spring it is transported north via viremic migrating birds. *Culex* spp. feed readily on both birds and mammals, take more than one blood meal, and have multiple generations per season, which all contribute to their role as key WN vectors. *Culex (Cx.) tarsalis* is the major vector for WN in western Canada, and is also the major vector for WEE and SLE viruses. In eastern Canada, *Cx. pipiens/restuans* are the most important WN vector species. In the prairie region, approximately 17 mosquito species have been shown to be infected with WN including members of the genuses *Aedes, Anopheles, Culiseta,* and *Ochlerotatus*.

Lyme Disease



Lyme disease is caused by the spirochete bacteria *Borrelia (B.) burgdorferi* sensu stricto. The bacteria is sustained in an enzootic cycle that involves *Ixodes* spp. ticks and vertebrate reservoir hosts. Humans become infected when bitten by an infected tick.

Lyme disease in humans can result in both immediate and long-term illness. Typical immediate signs include fever, headache, muscle and joint pain, weakness and an expanding or bulls-eye skin rash at the site of the tick bite. Lyme disease has high public profile, and community concerns about Lyme infection are often high, even in areas that have had very low historic prevalence of disease.

Prevalence of Lyme disease in endemic areas and incursion of Lyme disease into new areas are dependent on many factors including tick and animal host species distribution and behavior, and macro and micro climate. In Canada, *Ixodes (I.) scapularis* acts as the tick vector east of the Rocky Mountains, while *I. pacificus* and possibly *I. angustus* act as tick vectors in BC. All three tick species pass through larvae, nymph and adult stages, and ingest a blood meal from a vertebrate host at each stage. *B. burgdorferi* is not regularly transmitted from adult to eggs in ticks, therefore larval and nymph stages pick up the bacteria while feeding on infectious vertebrate hosts. Although *Ixodes* spp. are host generalists that feed on many different vertebrate species, larval and nymphal stages of *I. scapularis* preferentially seek *B. burgdorferi* amplifying hosts, while *I. pacificus* preferentially seeks dampening hosts; therefore, the infection rate of *I. scapularis* is much higher than in the western tick species.

The ability of *Ixodes* spp. ticks to survive and establish self-sustaining; reproducing populations in a new environment depends on a number of factors. Even in climate permissive regions, abundance of *I. scapularis* and *I. pacificus* is known to vary markedly over small geographic scales. Temperature is one factor linked to tick survival. Although adult ticks can overwinter in regions with winter air temperatures of -30 °C by seeking shelter, low temperatures decrease the number of ticks that survive winter and increase the duration of juvenile developmental periods. As a result, low temperatures decrease the proportion of ticks that survive to adulthood and reproduce (Ogden et al., 2004). Degree days have been used to estimate minimum temperature conditions necessary for establishing tick populations, with an estimated annual 2800 degree days required for *I. scapularis* populations to become established (Ogden et al., 2005). Localized factors, in particular woodland litter layer conditions, also affect tick survival by providing shelter from extremes in temperature and humidity. It is likely that a combination of interrelated factors including soil types, drainage, elevation and the plant community affects how favorable the litter layer is for ticks (Ogden et al., 2005).

In addition to environmental factors, absolute and relevant densities of vertebrate hosts influence whether tick populations can establish, as well as the proportion of ticks that are infected with *B. burgdorferi*. Vertebrate hosts for *Ixodes* spp. range from having a dampening effect (some lizard species) to those capable of infecting feeding ticks with low, moderate, or high efficiency (birds and small mammals) (Eisen, Eisen, Ogden, & Beard, 2016). The white-footed mouse is considered to be the most important amplifying host of *B. burgdorferi* (Eisen et al., 2016). Currently, the white footed mouse is known to be present in the far south of SK, MB, ON and QC, but not in NT. Although abundance of white tailed deer acts as a strong predictor of total *I. scapularis* numbers, white tailed deer are not important reservoirs for Lyme as they are generally fed on by adult ticks that will not feed again before finishing their life cycle. Densities of more than seven deer per square kilometer have been considered essential for tick persistence (Rand, Lubelczyk, Holman, Lacombe, & Smith, 2004). White tailed deer are found throughout NT.

Birds are important in Lyme epidemiology because they carry nymphs long distances during flight, and are therefore important in introducing ticks and *B. burgdorferi* to new geographic regions (Ogden et al., 2015; Wu, Rost, & Zou, 2016). Passerine birds such as robins and sparrows are thought to be important avian hosts, in part because they feed on the ground of forested habitat favored by *Ixodes* spp. ticks (Ogden et al., 2015).

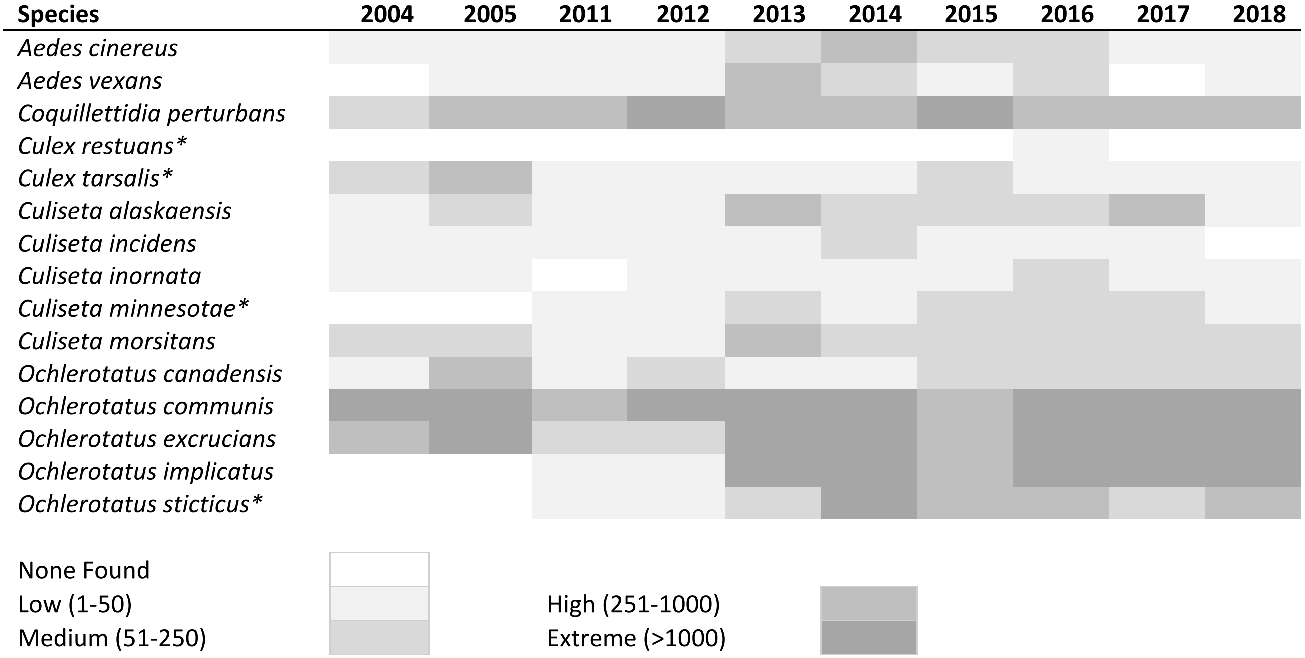
Recent studies using genotyping techniques have shown variation in *B. burgdorferi*. Individual strains might be adapted to different vertebrate hosts and could have different pathogenicity to humans (Mechai, Margos, Feil, Lindsay, & Ogden, 2015). Genetic analysis of *B. burgdorferi* collected from various locations in Canada and the US shows genetic variation within localized endemic areas, indicating that patterns of spatial mixing of *B. burgdorferi* strains might be more complex than the earlier hypotheses of direct south to north expansion (Mechai et al., 2015; Walter, Carpi, Caccone, & Diuk-Wasser, 2017).

Vectors known to be in NT now

There is limited information on tick distribution in NT. Lindquist et al. (2016) identified one tick species as present in NT (the moose winter tick, *D. albipictus),* and two with apparent range distributions from Alaska to Newfoundland (*H. leporis-palustris* and *I. angustus*). Lindquist et al. (2016) also place *I. pacificus* in Fort Smith, with a comment that this finding may have been travel related.

Of the 76 tick reports to the NT Department of Environment and Natural Resources between 1975 through 2018, 67 were *D. albipictus* (Fenton, 2018 Unpublished data). There have been four *H. leporis-palustris* identifications from snowshoe hares in Fort Smith (2016), Bannockland (2017) and Dechcho Region (2017), and from a dog in Whati (2017). Two *D. andersoni* were reported in 2017, one from a human in Fort Smith and the other from a dog in Yellowknife. In both instances, the host had recently travelled to the NT from elsewhere in Canada. *D. variabilis* was reported in 2013 from a human with travel history to Saskatoon, and in 2018 from dogs that had returned from travel to SK.

Some 124 species of black fly, deer fly, horse fly and mosquito[1], of which twelve are known or suspected to be competent vectors for the VBZs of concern to the NT, have been described as present or likely to be present in NT (Appendix 4). Mosquito trapping with species identification was available for ten different years (2004, 2005, 2011-2018). There were 8 and 14 sampling sites throughout NT in 2004 and 2005, respectively, with upwards of 6 localities sampled in 2005 and a maximum of 5 sample sites from up to 2 localities between 2011 and 2018. Mosquitos that are competent vector species for WN and CSG were identified in NT in all sampling years (Figure 2). The relative percent of known or suspected to be competent vectors counted at Stuart's trap locations was less than 15% of the total mosquito count for each township where traps were set up (Unpublished data, Stuart, 2018).



Species	2004	2005	2011	2012	2013	2014	2015	2016	2017	2018
Aedes cinereus	░	░	░	░	▒	▓	▒	▒	░	░
Aedes vexans	□	░	░	░	▓	▒	░	▒	□	░
Coquillettidia perturbans	▒	▓	▓	█	▓	▓	█	▓	▓	▓
*Culex restuans**	□	□	□	□	□	□	□	░	□	□
*Culex tarsalis**	▒	▓	░	░	░	░	▒	░	░	░
Culiseta alaskaensis	░	▒	░	░	▓	▒	▒	▒	▓	░
Culiseta incidens	░	░	░	░	░	▒	░	░	░	□
Culiseta inornata	░	░	□	░	░	░	░	▒	░	░
*Culiseta minnesotae**	□	□	░	░	▒	░	▒	▒	▒	░
Culiseta morsitans	▒	▒	░	░	▓	▒	▒	▒	▒	▒
Ochlerotatus canadensis	░	▓	░	▒	░	░	▒	▒	▒	▒
Ochlerotatus communis	█	█	▓	█	█	█	▓	█	█	█
Ochlerotatus excrucians	▓	█	▒	▒	█	█	▓	█	█	█
Ochlerotatus implicatus	□	□	░	░	█	█	▓	█	█	█
*Ochlerotatus sticticus**	□	□	░	░	▒	█	▓	▓	▒	▓

None Found □
Low (1-50) ░
Medium (51-250) ▒
High (251-1000) ▓
Extreme (>1000) █

*Mosquito species not previously known to be present in NT, by sampling year

Figure 2: Counts of identified known or suspected competent vector species for WN and CSG by sampling year

Figure 3 provides a visual summary of the arthropods that might act as vectors for VBZs in NT.

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[1] Working Group on General Status of NT Species. 2016. NT Species 2016-2020 – General Status Ranks of Wild Species in the Northwest Territories, Department of Environment and Natural Resources, Government of the Northwest Territories, Yellowknife, NT, 304 pp.

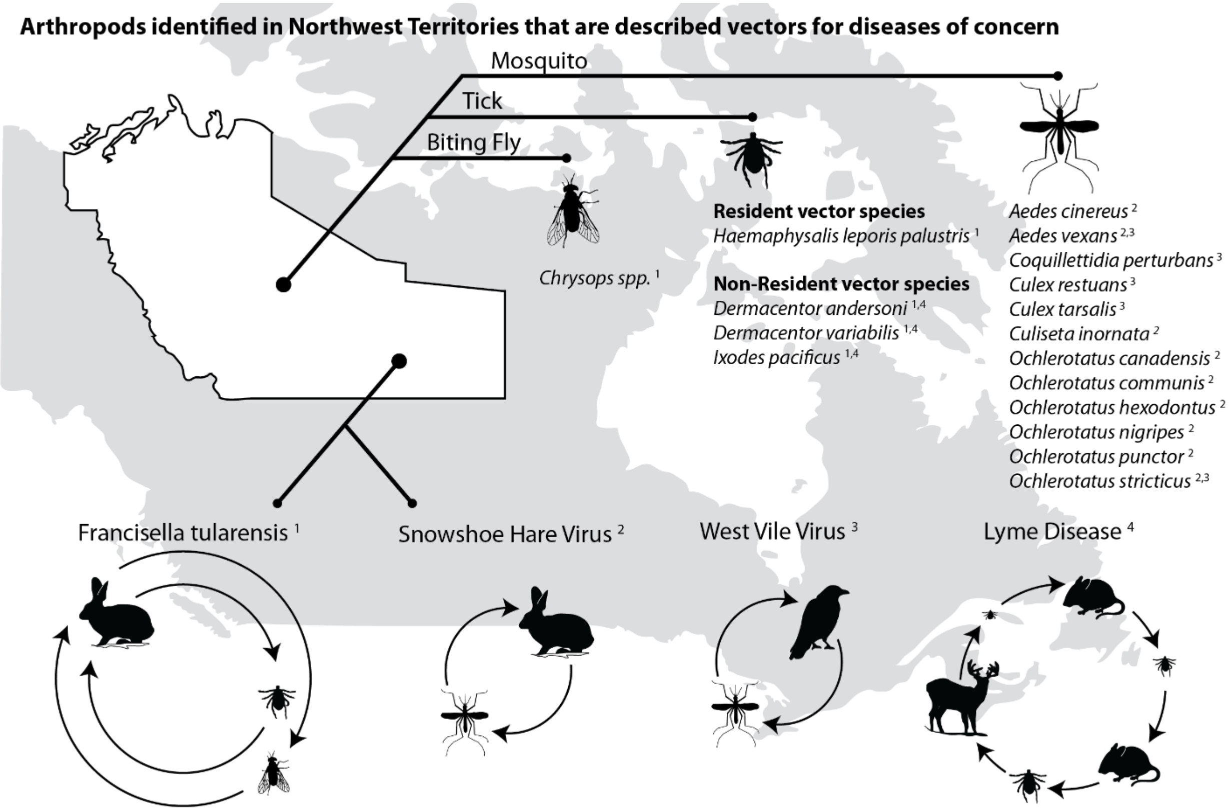

Figure 3: NT is home to a number of arthropods that have been shown to be competent transmitters of the 4 diseases of primary concern for this report. A number of ticks have been identified from NT, but are unlikely to be successfully completing their life cycle in the Territory (i.e. non-resident vector species)

Climate change and vector borne zoonoses in the north

Globally, climatic variability and the occurrence of extreme weather events that could affect the transmission of vector-borne diseases are projected to occur under most climate change scenarios; however, confidence in predicting future events is low because there is often inadequate long-term data to track variables such as the incidence of VBZs in people and animal and arthropod endemic hosts, the distribution and abundance of vectors, and other variables such as international travel, agriculture, land use changes, and urbanization (Gage, Burkot, Eisen, & Hayes, 2008). The lack of long-term studies makes it difficult to determine how much observed changes in VBZ rates can be attributed to climate change(Gage et al., 2008).

There is strong evidence of the association between climatic factors and food and waterborne disease in the Arctic and subarctic region, however, there are fewer papers that have examined linkages between climate and VBZs in the north (Hedlund, Blomstedt, & Schumann, 2014a). There is some evidence that tick-borne encephalitis, borreliosis, and some rodent-borne zoonoses (e.g. *Nephropathia epidemica*) are likely to be influenced by temperature, precipitation and changes in length of seasons, due to the effect on habitat suitability, reproduction rates, distribution and abundance of hosts (Hedlund et al., 2014a).

Rates of temperature increase in the north have been two times higher than those documented in other regions of the globe during the past 50 years (IPCC, 2014). Temperatures during the past 15 years have been generally warmer in all seasons, most notably in winter in both the McKenzie district and arctic tundra (Government of Northwest Territories, 2015). Precipitation trends associated with climate change vary across NT. The greatest departures from the norm have occurred during winter in the arctic tundra, where snowfall has increased by about 20-40%. In contrast to the arctic tundra, winter snowfall in the Mackenzie district appears more variable with some declines in the past 20 years. Spring has been wetter than normal during 25 of the past 30 years for both the McKenzie and arctic districts (Government of Northwest Territories, 2015).

Temperature projections across models range from 2^{o}C to more than 8^{o}C increases in average temperature in the NT by the end of the century (IPCC, 2014; SNAP, 2011). The Scenarios Network for Arctic Planning (SNAP) and Ecological Wildlife Habitat Data Analysis for the Land and Seascape (EWHALE) programs are being used to predict future climate change in the north. The programs use clustering methodology, existing land cover classifications, and historical and projected climate data to identify areas of Alaska, the Yukon, and NT that are likely to face the greatest or least ecological pressure as a result of climate change. SNAP and the EWHALE have been used to model changes in climate-biomes (cliomes). Cliomes are defined as *"regions of temperature and precipitation patterns that reflect assemblies of species and vegetation communities (biomes) that occur or might be expected to occur based on links with climate conditions"* (SNAP & EWHALE Lab, 2012). Changes in all existing cliomes are predicted to shift northward and shrink, particularly in the NT interior. Prairie grasslands, currently limited to the hottest most southerly portion of the Prairie Provinces, are predicted to expand to large areas of southwestern NT by 2090.

Climate warming in the Canadian arctic has resulted in environmental changes. Warmer temperatures have led to reduced extent and thickness of sea ice, delayed sea ice formation, earlier spring melt and melting permafrost. Changes in the length of the growing season and population dynamics of plant and animal species have been documented, with effects most pronounced in higher elevation and higher latitude areas (ACIA, 2005).

Later ice freeze-up, melting permafrost, ground slumping, increased sedimentation, new species of wildlife, decreased health of resident wildlife, warmer winters, less extreme cold, more freezing rain, and more intense sun have also been documented in NT communities (Ford & Pearce, 2010).

It is anticipated that climate change will likely alter the distribution and abundance of northern mammals and birds through a combination of changes in temperature, precipitation, abundance of resources, competitors, and predators (Dudley, Hoberg, Jenkins, & Parkinson, 2015). Seasonally inactive mammal species (i.e. hibernators), which are largely absent from the Canadian arctic at present, could show an increase in abundance and distribution in response to climate change, probably at the expense of continuously active mammals already present in the arctic.

There is a projected range contraction of northern birds due to the forecasted changes in the amount and distributions of the preferred habitats (Brommer, Lehikoinen, & Valkama, 2012). In Europe, there is evidence that bird species are moving the 'cold' side of their range poleward during the last few decades. Additionally, for northern boreal and Arctic species, a similar poleward latitudinal shift of their breeding range has been noted (Brommer et al., 2012). Climate change is predicted to affect Arctic breeding migratory shorebirds, with contractions and shifts in the locations of their breeding sites. These changes will likely affect the population abundance and species composition of the world's eight flyways (Wauchope et al., 2017).

Risk Assessment

In this section of the report we assess the risks that

1. VBZs already present in NT might increase in impact because of climate change and;
2. New VBZs with significant human health impacts might be introduced into NT.

In general, it has been hypothesized that climate change might increase the number of people infected by VBZs by a number of mechanisms (Mills, Gage, & Khan, 2010) that include:

1. Shifts in animal or arthropod host geographic range so that hosts come into contact with new human populations,
2. Increases in the population density of animal or arthropod hosts,
3. Increases in the prevalence of infection in animal or arthropod hosts,
4. Changes in pathogen load in animal or arthropod hosts brought about by changes in rates of pathogen reproduction, replication, or development, and
5. Shifting of pathogens to new arthropod or animal hosts.

Could VBZs already present in NT increase in significance because of climate change?

Available evidence indicates that both tularemia and CSG, although present in NT, currently result in very limited negative human health impacts. In general, health impacts might increase by 1) an increase in the number of people infected, and 2) increased severity of illness caused by infection. Future research may discover previously unrecognized negative health effects, such that infections currently considered to have a low impact on human health could become of greater interest to public health.

California Serogroup J viruses

Despite long standing evidence of widespread human exposure to CSG viruses in northern regions, their impact on human health appears to be small. Although climate change might alter the natural enzootic cycle by changing the numbers of various mosquito and animal host species and reducing the extrinsic incubation period, it is unclear how much of an effect these changes will have on human health. A change in virulence caused by a biological change in the virus itself, or by a change in people's susceptibility to the virus, could result in more severe health effects such as encephalitis. We could not find evidence that climate change has been linked to changes in virulence for viruses in general, or that it has contributed to changes in people's immune response to CSG infection specifically.

Tularemia

Despite long standing presence and evidence of widespread human exposure in Alaska and northern Canada, the effect of tularemia on human health in NT appear to be small, indicating that strains circulating today cause minimal disease. Even if human exposure to existing strains increased through increasing exposure to arthropods driven by climate change, this is unlikely to have significant negative health effects. However, it is possible that climate change might encourage the appearance of more virulent strains (e.g. A1b). Predictive modeling work suggests minimal to moderate increases in tularemia resulting from climate change driven increases in arthropod numbers (Nakazawa et al., 2007). These knowledge and surveillance gaps make it challenging to assess the probability that climate change might increase the impact of tularemia in NT.

Could new VBZs with significant human health impacts be introduced into NT with climate change?

Two pathogens, WN and Lyme, are not present in the NT but it is plausible that climate change could influence their expansion northwards.

West Nile Virus

WN replicates within the gut of vector mosquitoes before it can be transmitted; this is known as the extrinsic incubation period (EIP). The EIP is variable and influenced by environmental temperature, the genotype of WN, and likely the genetic characteristics of the mosquito. Mean monthly temperatures of 14 to 35 ^{o}C are considered necessary for WN to replicate in the mosquito (Danforth, Reisen, & Barker, 2016). Virus replication is not expected to occur in temperatures below approximately 14 ^{o}C (Reisen, Fang, & Martinez, 2006). Three different genotypes of WN were shown to require a minimum 10 day EIP at temperatures of 22 ^{o}C, while at 26 ^{o}C this deceased to 4 to 5 days (Danforth, Reisen, & Barker, 2015).

WN appears to be transported across geographic regions by bird migration. Between 1999 and 2003, WN spread explosively across the US and southern Canada (Swetnam et al., 2018). However, WN has not really expanded northward since 2003, possibly because environmental conditions outside of current endemic regions are not optimal for amplification. In NT, there has been limited active surveillance to capture and identify mosquitoes and test for WN. Active mosquito sampling for WN surveillance is ongoing in the southern half of SK[2] and Manitoba (MB)[3], but has not occurred in the northern half of SK and MB, or in AB (since 2009[4]) or BC (since 2014[5]) (Figure 4).

Bird species such as blackbirds, American robins and house sparrows that are known to be capable of sustaining WN do occur in NT. However, movement of infected birds north is plausible. *Cx. tarsalis* has been identified in NT, although at this time ecosystems infected with WN are located far south of NT. Climate monitoring data such as degree day maps that could be used to monitor changes in climate over time would be needed to determine if climate in NT was becoming more permissive for WN.

Because *Cx. tarsalis* is the primary vector mosquito species for WN in western North America, we include more details here to help describe its current distribution. *Cx. tarsalis* has been widely described in southern BC, AB, SK and MB (Peach, 2019). It is a grassland species, and is uncommon in the Aspen parkland belt (Wood, Dang, & Ellis, 1979) and in forested areas (Government of Saskatchewan, 2018). It is described as rare north of the 60th parallel (Gadawski, 2005) but has been detected in NT. A single male specimen was identified from Norman Wells, NT, as part of the Northern Insect Survey in the 1950's (Freeman, 1952 as cited in Peach, 2019); however, Wood et al. (1979) describe this finding as far beyond *Cx. tarsalis'* main center of distribution. Gadawski (2005) suggest that, as of 2004, *Cx. tarsalis* was well established at a sewage lagoon sampling site near Yellowknife; and Stuart (2018) identified *Cx. tarsalis* from his sampling sites in Fort Simpson each year between 2011 and 2017. Surveillance activities with results for western Canada are summarized in Figure 4. Modeling of habitat and temperature suitability for WN and *Cx. tarsalis* has predicted some probability of *Cx. tarsalis* becoming established in northwestern AB over the next 10 to 50 years due to climate change (Chen et al., 2013).

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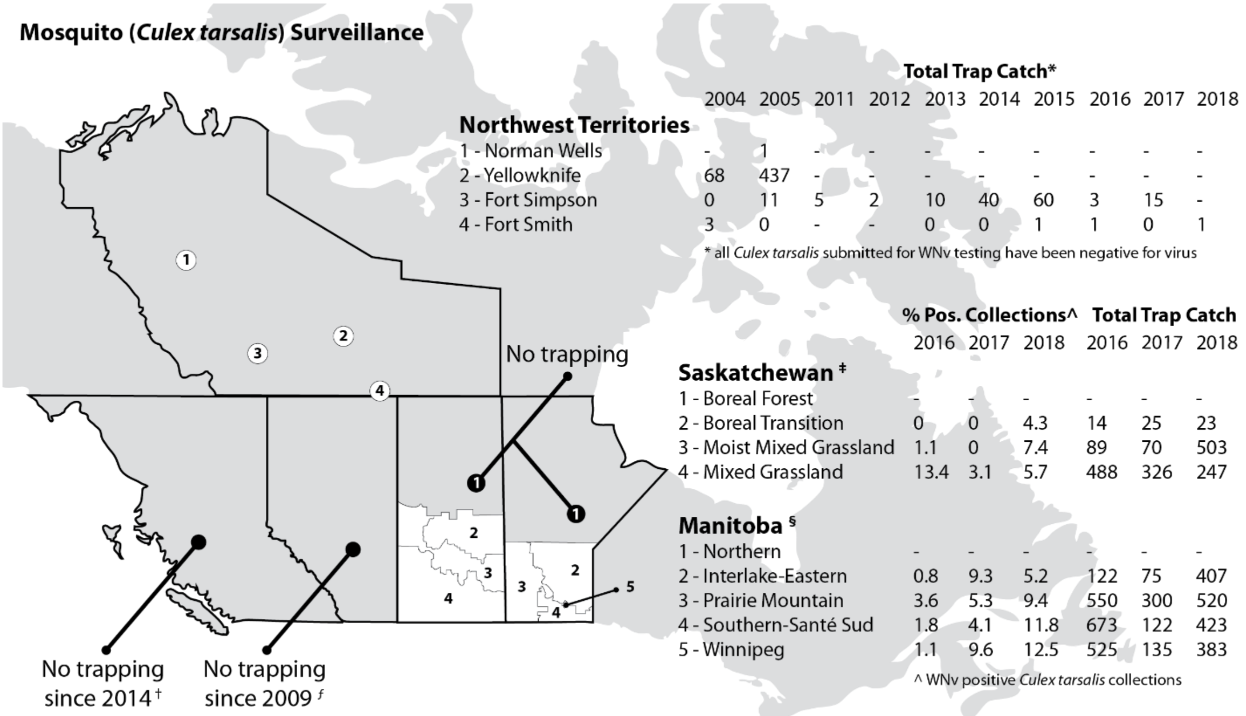
[2] https://www.saskatchewan.ca/residents/health/diseases-and-conditions/west-nile-virus/west-nile-virus-risk-level-and-surveillance-results

[3] https://www.gov.mb.ca/health/WN/stats.html

[4] https://www.alberta.ca/west-nile-virus-surveillance.aspx

[5] http://www.bccdc.ca/health-info/diseases-conditions/west-nile-virus-WN/surveillance



Mosquito (*Culex tarsalis*) Surveillance

	Total Trap Catch*									
	2004	2005	2011	2012	2013	2014	2015	2016	2017	2018
Northwest Territories										
1 - Norman Wells	-	1	-	-	-	-	-	-	-	-
2 - Yellowknife	68	437	-	-	-	-	-	-	-	-
3 - Fort Simpson	0	11	5	2	10	40	60	3	15	-
4 - Fort Smith	3	0	-	-	0	0	1	1	0	1

* all *Culex tarsalis* submitted for WNv testing have been negative for virus

	% Pos. Collections^			Total Trap Catch		
	2016	2017	2018	2016	2017	2018
Saskatchewan ‡						
1 - Boreal Forest	-	-	-	-	-	-
2 - Boreal Transition	0	0	4.3	14	25	23
3 - Moist Mixed Grassland	1.1	0	7.4	89	70	503
4 - Mixed Grassland	13.4	3.1	5.7	488	326	247
Manitoba §						
1 - Northern	-	-	-	-	-	-
2 - Interlake-Eastern	0.8	9.3	5.2	122	75	407
3 - Prairie Mountain	3.6	5.3	9.4	550	300	520
4 - Southern-Santé Sud	1.8	4.1	11.8	673	122	423
5 - Winnipeg	1.1	9.6	12.5	525	135	383

^ WNv positive *Culex tarsalis* collections

‡ https://www.saskatchewan.ca/residents/health/diseases-and-conditions/west-nile-virus/west-nile-virus-risk-level-and-surveillance-results
§ https://www.gov.mb.ca/health/wnv/stats.html
† http://www.bccdc.ca/health-info/diseases-conditions/west-nile-virus-wnv/surveillance
ƒ https://www.alberta.ca/west-nile-virus-surveillance.aspx

Figure 4. Summary of WN testing and Cx. tarsalis trapping activity across western Canada

Lyme Disease

In Canada, *I. scapularis* and Lyme first became established in ON in the 1980's. Since then, *I. scapularis* and Lyme have been generally progressing northward and westward, and are now endemic in southern ON, QC, MB, and NS, and possibly southern SK and AB. Small numbers of infected *I. scapularis* have been identified by passive surveillance near Edmonton (Government of Alberta, 2017). Active surveillance (tick drag sampling) did not detect any established infected tick populations (Government of Alberta, 2017). There have been no *I. scapularis* identified in NT, and no reported cases of locally acquired Lyme disease.

There are a number of recent publications investigating the hypothesis that climate change is expanding the northern range of *I. scapularis*, as well as the white footed mouse, and is therefore leading to increased Lyme disease risk (Leighton, Koffi, Pelcat, Lindsay, & Ogden, 2012; Ogden, Bigras-Poulin, et al., 2008; Ogden et al., 2011; Ogden et al., 2014). Nonetheless, current climate conditions in NT are likely unsuitable for establishment of *I. scapularis* tick populations, and at this time ecosystems infected with Lyme are located far south of NT. Bird species capable of acting as host for *Ixodes* spp. ticks do migrate into NT from southern areas, and as such could transport infected ticks that might result in rare, sporadic human infection. The white footed mouse is not present in NT; however, it is likely that other species of small mammals in NT could act as amplifying hosts. Climate monitoring data such as degree day maps that could be used to monitor changes in climate over time would be needed to determine if climate in NT was becoming more permissive for *Ixodes* spp. ticks.

Planning

This section of the report contains a summary of knowledge gaps and recommendations for moving forward.

Summary of knowledge and surveillance gaps

The burden of human infections and illness associated with VBZs in NT is not well understood.

- There has been no population based serosurveillance efforts for VBZs in NT.
- Although the Canadian notifiable disease system identifies serologically confirmed human cases of three priority VBZs discussed in this report of concern (tularemia, Lyme, WN);
    - Cases where individuals do not seek health care, or where health care providers do not request testing, are not counted,
    - Testing is antibody-based and therefore does not provide information about pathogen strain or genotype.
- CSG are not notifiable diseases.

In NT and adjacent regions, capacity to detect VBZs in vector and animal hosts is limited.

- There has been no ongoing trapping and testing of mosquitoes for VBZs in BC and AB, or in the northern half of SK and MB; and quite limited mosquito trapping in NT.
- There has been no ongoing active sampling, and limited ongoing passive surveillance to identify and test ticks from NT and northern regions of adjacent provinces.
- There has been no ongoing surveillance of wild animals or pets for VBZs.
- Low human populations and limited infrastructure in northern regions reduce the probability that dead animals or birds will be reported and submitted for VBZs testing.

The frequency and mechanism of arthropod-borne transmission of tularemia in NT are not well understood.

Transmission cycles for CSG between animals and arthropods in NT are not well understood.

A lack of long-term data about climate, arthropods and VBZs makes it difficult to proportionally attribute changes in VBZs rates that might occur to climate change or other factors.

Recommendations

The following recommendations might be considered:

Building and strengthening early warning networks

1. Prioritize and dedicate resources necessary to maintain strong interagency communication within NT so that information about human VBZs cases, and unusual animal health and arthropod population events, can be discussed in a timely manner. As well as building situational awareness, this would create capacity for agencies to plan and engage in response activities including targeted active surveillance of people, animals or arthropods. Scheduling bi-annual teleconference meetings could act as a strong catalyst for strengthened interagency communication.

2. Prioritize and dedicate resources necessary to maintain strong situational awareness about VBZs in other regions of Canada. This might include regular review of publicly available sources of information about VBZs such as the Public Health Agency of Canada's Notifiable diseases online (https://diseases.canada.ca/notifiable/). It might also include annual PubMed searches for new publications of high relevance using keywords such as those listed in Appendix 2. Finally, it would include dedicated efforts to maintain and strengthen professional network connections to national agencies, and those in neighboring provinces and territories, in order to receive rapid alerts about VBZs, as well as other significant public or animal health events.

3. Initiate an annual review of the NT's online and written public communication materials about VBZs to ensure that it is as easy as possible for NT citizens to access resources about zoonotic diseases, inform NT agencies of unusual animal health events (e.g. bird deaths), as well as to access services to identify ticks found on people and pets. Test and update links on the govt.nt website as part of this annual review.

Gathering data

4. Initiate a program to create and review monthly (through the summer) and annual degree day maps for warmer regions of NT to monitor minimal temperature conditions permissible for *Cx. tarsalis* and *I. scapularis* population establishment.

5. Consider enhancing current passive surveillance in NT to identify ticks found on people and pets either by photo identification or by encouraging submission of more ticks. There are 'etick' programs in other regions of Canada that might provide photo tick identification resources.

6. Consider continued systematic mosquito trapping and identification year over year in selected locations to monitor mosquito population trends. Because of their importance as vectors for WN as well as WEE, *Cx. tarsalis* and *Cx. restuans/pipiens* populations are of particular interest. Surveillance for these species is likely most efficiently carried out between mid-July and mid-September in grassland or agricultural regions near population centers. A broader range of species that are capable of acting as vectors for WN and CSG might also be of interest. Depending on logistics and resources, trapped

mosquitoes could be tested for VBZs (WN, CSG) routinely, or only during periods of heightened alert. Routine sampling and testing programs would provide the advantage of tracking of data over time.

Integrating and reporting

7. Consider generating an annual report that integrates data from recommendations 1 through 6, and uses integrated data to generate a statement or figure that summarizes NT's states of preparedness and risk for VBZs. The BC Integrated Surveillance of Foodborne Pathogens program provides a useful model for this type of reporting.

Figure 5 shows how recommended activities might be implemented over a calendar year.

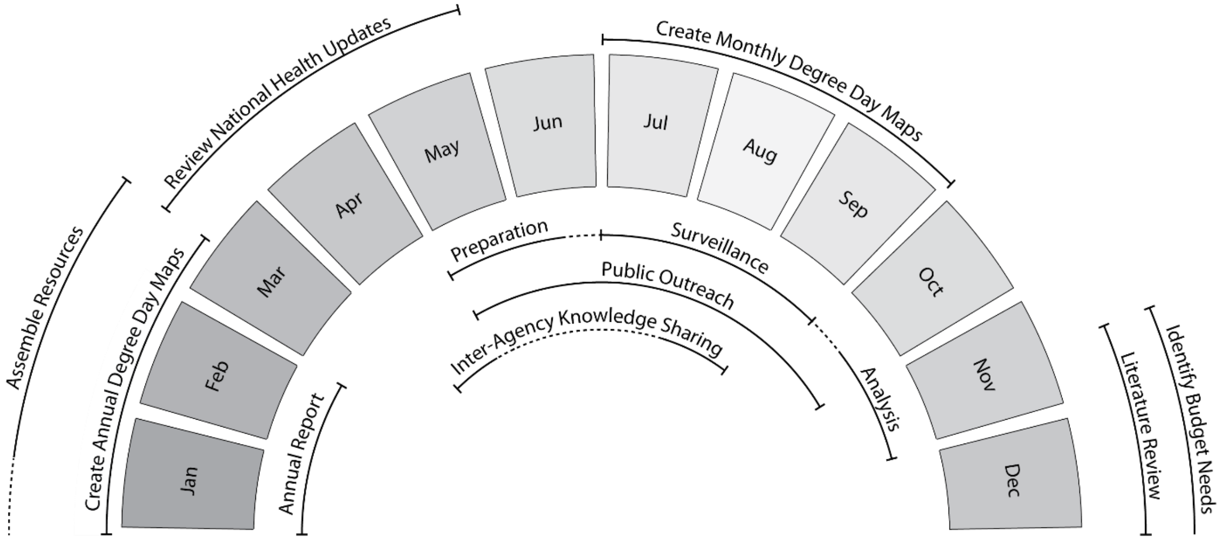


Figure 5: Proposed annual VBZs surveillance and reporting activities in NT over a calendar year

Appendix 1: Summary of Baseline Information used for decision making process

Baseline information was collected for ten arboviruses, one parasite and three bacterial arthropod-transmitted pathogens that have been reported in Canada. Baseline information is included in this Appendix for reference. Five pathogens were considered of higher priority to NT and as such, are discussed in detail in the main body of the report. Four mosquito borne zoonoses – Cache Valley virus (CVV), Eastern equine encephalitis (EEE), St. Louis encephalitis (SLE), and Western equine encephalitis (WEE) – and five tick-borne zoonoses – Colorado Tick Fever (CTF), Powassan virus (POW), Tick borne relapsing fever (TBRF), Human granulocytic anaplasmosis (HGA) and human babesiosis – were assigned lower priority for this report should be re-evaluated at a future date. WEE shares a similar ecology to WN, so risk assessment details for WN presented in the main body of the report are expected to be broadly similar for WEE. In addition, POW, HGA and babesiosis are all transmitted by *Ixodes* spp. tick vectors, so much of the information in the main body of the report about Lyme disease risk is generally applicable to these VBZs. Materials included in this appendix were mainly acquired from three sources (CDC, 2019; Habegger, 2014; Leighton, 2000).

Mosquito Borne Viral Zoonoses

Cache valley virus

Pathogen	Major arthropod hosts	Major animal hosts
Cache valley virus	Non-C*ulex* spp. mosquitoes	White tailed deer

The Cache Valley virus is an RNA virus found in the Bunyamwera serogroup of the *Orthobunyavirus* genus. CV is not a notifiable human pathogen in Canada and human cases are thought to be very rare; however, several cases of neuroinvasive disease have been documented in the US. Patients with undiagnosed illness in western Canada have been found to have antibodies to CV virus (Drebot, 2017). It was detected in three of 418 mosquito pools tested in AB (Pabbaraju et al., 2009).

Eastern equine encephalitis

Pathogen	Major arthropod hosts	Major animal hosts
Eastern equine encephalitis virus	*Cx. melanura, Coquillettidia perturbans,* *Aedes* spp., other mosquito spp.	Passerine birds Small mammals

Eastern equine encephalitis virus is an enveloped, single-stranded RNA virus in the family Togaviridae. There are multiple genotypes of EEE that vary in geographic distribution, virulence, ecology and epidemiology. EEE virus cycles endemically among passerine birds and the bird-feeding mosquito *C. melanura*. Multiple cycles of infection and amplification occur during summer months, with rapid viral replication occurring in nestlings. *C. melanura* feeds exclusively on birds and does not transmit EEE to mammals. Mosquito species that feed on both birds and mammals act as bridging vectors. Because *Cs. melanura* prefers forested wetland habitats, transmission generally occurs within eight kilometers of this type of habitat.

EEE is not a notifiable human illness. In Canada, EEE has been detected in mosquitoes and horses in QC, ON, and Nova Scotia (NS) but there have been no reported human cases (Public Health Ontraio, 2014). There have been increased numbers of equine cases in QC and NS since 2008, with similar patterns reflected in the US (Kulkarni et al., 2015). This change suggests the arrival of a novel EEE genotype (Kulkarni et al., 2015).

St. Louis encephalitis

Pathogen	Major arthropod hosts	Major animal hosts
St. Louis encephalitis virus	*Culex* spp. mosquitoes	Birds

St. Louis encephalitis virus is an enveloped, single-stranded RNA virus in the family Flaviviridae. It is very closely related to WN virus. SLE is not a notifiable human illness in Canada, but has been reported to have caused a small number of human illnesses in ON, QC and MB. Between 1993 and 2008, seven human encephalitis cases were reported (Kulkarni, Lecocq, Artsob, Drebot, & Ogden, 2013). In southern ON, SLE antibody prevalence was high in some wild mammals sampled in 1976. It has not been reported as a cause of human illness in northern Canada. In the US, the majority of human illnesses have been in central and eastern regions of the country.

Western equine encephalitis

Pathogen	Major arthropod hosts	Major animal hosts
Western equine encephalitis virus	*Cx. tarsalis*, other mosquito spp.	Passerine birds Small mammals

Western equine encephalitis virus is an enveloped, single-stranded RNA virus in the family Togaviridae. It is a not a notifiable human illness, but has been reported across southern Canada in regions west of Lake Superior. Human illness has not been reported for more than 25 years. Historically, SK and MB have reported the highest number of human and equine cases.

Cx. tarsalis is the most important mosquito vector in western Canada, although the virus has been detected in a variety of other mosquito species. Passerine birds are the most important vertebrate hosts for WEE. They act as amplifying hosts for the virus and are therefore important sources of infection for mosquitoes. In western Canada, the House Sparrow and the House Finch appear to be key hosts. Virus has been isolated from non-avian vertebrates including Richardson's ground squirrel, Snowshoe hares, garter snakes and leopard frogs.

Tick Borne Viral Zoonoses

Colorado tick fever

Pathogen	Major arthropod hosts	Major vertebrate hosts
Colorado tick fever virus	*D. andersoni*, other tick spp.	Small mammals

Colorado tick fever virus is a member of the family Reoviridae. It is related to the viruses that cause epizootic hemorrhagic disease of deer and bluetongue disease in ruminants. CTF is very rare in Canada and is thought to occur only in southwestern SK and in southern BC and AB at elevations of 1,200 to 3,000 meters (Kadkhoda, Semus, Jelic, & Walkty, 2018). The most important vector of CTF is the tick *D. andersoni*; however, at least eight other species of ticks can transmit the virus. Many species of rodent have been shown to be vectors for CTF. The species that are thought to act as hosts in western Canada are the golden-mantled ground squirrel, bushy-tailed woodrat, deer mouse, least chipmunk and porcupine. The distribution of CTF seems to closely coincide with the preferred habitat of the ground squirrel and woodrat.

Powassan virus

Pathogen	Major arthropod hosts	Major animal hosts
Powassan virus	*I. cookei* *I. marxi* *I. scapularis*	Groundhogs and mustelids Squirrels White footed mouse

Powassan virus is an enveloped, single-stranded RNA virus in the family Flaviviridae. Although it is related to WN and SLE, POW virus is transmitted primarily by ticks rather than mosquitoes. It is thought to be increasing in North America and can cause severe human neurologic illness, but nonetheless is a relatively rare cause of disease (Corrin et al., 2018; Fatmi, Zehra, & Carpenter, 2017). It has two lineages in North America, one carried by *I. scapularis* ticks (DTV lineage) and one carried by *I. cookei* and *I. marxi* (POW lineage) (Habegger, 2014).

POW is not a notifiable human disease in Canada. There have been approximately 21 human cases documented, primarily in ON, QC and New Brunswick (NB) (Government of Canada, 2017). Antibodies were detected in 12% of a sample of outdoor workers in BC (Corrin et al., 2018). It has been detected in a low proportion (<0.5%) of ticks and wild animal serological samples in ON (Artsob et al., 1984; Schillberg et al., 2018; Smith et al., 2018). Maintenance vertebrate and tick hosts appear to vary from region to region. *I. scapularis* is the primary vector that transmits the virus on the east coast of US, and *I. cookei* is the key vector in the midwest US and Canada (Fatmi et al., 2017). In central North America, the woodchuck seems to be a key vertebrate host, although antibodies have been detected in other small mammals such as squirrels (Corrin et al., 2018). Studies in eastern Europe have documented POW virus in bird species.

Tick Borne Bacterial Zoonoses

Human granulocytic anaplasmosis

Disease	Major arthropod hosts	Major vertebrate hosts
Human granulocytic anaplasmosis	*Ixodes* spp. ticks	Small mammals, especially the white-footed mouse

Human granulocytic anaplasmosis is caused by certain genotypes of the rickettsial bacteria *Anaplasma (A.) phagocytophilum.* It causes moderate to severe flu-like symptoms, and can cause clinically significant thrombocytopenia, leukopenia, and liver dysfunction. It is not a notifiable disease in Canada. It has the same general distribution as Lyme disease but at a much lower incidence (Habegger, 2014). Up to 10% of patients presenting with acute Lyme disease have been documented to be co-infected with HGA (Horowitz et al., 2013).

There are numerous genotypes of *A. phagocytophilum* that have different zoonotic potential, so interpretation of animal prevalence data is challenging. *A. phagocytophilum* was detected in 15% of ticks collected from hunter-caught deer sampled in QC in 2007 (Bouchard et al., 2013). In a large cross Canada study in 2010, *A. phagocytophilum* antibodies were found in a low proportion of dogs (<0.75%) tested between SK and QC, with no positive tests in BC, AB or atlantic Canada (Villeneuve, Goring, Marcotte, & Overvelde, 2011).

Tick-borne relapsing fever

Disease	Major arthropod hosts	Major vertebrate hosts
Tick-borne relapsing fever	*Ornithodoros* spp. ticks	Squirrels, chipmunks, prairie dogs, burrowing owls

Tick-borne relapsing fever is caused by several non-Lyme *Borrelia* species: *B. hermsii, B. parkerii,* and *B. turicatae*. Infection is thought to often be misdiagnosed as Lyme and underreported due to a lack of health service provider awareness of the disease (Banerjee, Banerjee, Fernando, Burgdorfer, & Schwan, 1998; Dworkin et al., 1998). *B. miyamotoi*, which has only recently been shown to infect humans, has been documented from regions of the US where Lyme disease occurs, including the west coast. *Ornithodoros (O.) hermsii,* the tick responsible for most cases in North America, lives in coniferous forest habitats at altitudes of 1500 to 8000 feet and feeds on squirrels and chipmunks. The two other North American tick species that transmit TBRF, *O. parkeri*i and *O. turicatae,* are generally found at lower altitudes in the southwest US, where they inhabit burrows of ground squirrels, prairie dogs, and burrowing owls. In Canada, locally acquired TBRF has only been reported from BC (Dworkin et al., 1998) and less than 20 cases have been reported since the disease was first recognized in 1933. Cases often had a history of staying in rodent-infested cabins.

Tick Borne Parasitic Zoonoses

Babesia microti

Disease	Major arthropod hosts	Major vertebrate hosts
Babesiosis	*Ixodes* spp. ticks	Small mammals, especially the white footed mouse

Human babesiosis is caused by certain zoonotic species in the protozoan genus *Babesia.* Worldwide, species that cause human illness included *B. microti, B. divergens, B. duncani*, and *B. venatorum* (Westblade, Simon, Mathison, & Kirkman, 2017). In North America, *B. bovis, B. canis, B. duncani*, and *B. microti* are all considered zoonotic; however, *B. microti* causes the majority of cases. Because babesiosis is transmitted by *Ixodes* spp. ticks, it has the same general distribution as Lyme disease. *B. microti* and *B. duncani* have both been recently reported as new causes of human illness in MB and ON respectively (Kulkarni et al., 2015; Scott, 2017). In 2016, of 13,000 blood donors screened for *B. microti* in Lyme endemic provinces, none were positive for antibody to *B. microti* (O'Brien et al., 2016). *B. microti* has been detected in a low proportion (<0.75%) of ticks tested from MB, ON, and QC (Bouchard et al., 2013; O'Brien et al., 2016).

Appendix 2: Literature search keywords

Lit Search 1 Pathogen and Place

Pathogen	"California serogroup J" OR "Snowshoe hare virus" OR "Jamestown Canyon virus" OR "La crosse virus" OR "Cache Valley Virus" OR "West Nile Virus" OR "St Louis Encephalitis" OR "Powassan Virus" OR "Eastern Equine Encephalitis" OR "Western Equine Encephalitis" OR "Colorado Tick Fever" OR "Mountain Tick fever" OR "American tick fever" OR "American Mountain Tick Fever" OR Tularemia OR "rabbit fever" OR "Francisella tularensis" OR Lyme OR "Borrelia burgdorferi" OR *Orthobunyavirus*
Place	"Northwest territories" OR Yukon OR Nunavut OR "British Columbia" OR Alberta OR Saskatchewan OR Manitoba OR Arctic OR Canada OR Alaska

Lit Search 2 Vector and Habitat (review articles only)

Vector	"Deer fly" OR "*Chrysops excitans" OR "Chrysops frigidus" OR "Coquillettidia pertubans" OR "Culex tarsalis" OR "Ixodes pacificus" OR "Ixodes angustus" OR "Aedes triseriatus" OR "Culex pipiens" OR "Dermacentor andersoni" OR "Ixodes cookie" OR "Ixodes marxi" OR "Ixodes scapularis" OR "Ixodes spinipalpis" OR "Dermacentor variabilis" OR "Aedes albopictus" OR "Anopheles quadrimaculatus" OR "Culex quinquefasciatus" OR "Culiseta melanura" OR "Amblyomma americanum" OR "Ornithodoros hermsi" OR "Dermacentor albipictus" OR "Rhipicephalus sanguineus" OR "Haemaphysalis leporispalustris" OR "Haemaphysalis chordeilis" OR "Ixodes angustus" OR "Ixodes muris" OR "Amblyomma maculatum"*
	Habitat OR environment
	"life cycle" OR "life history" OR host

Lit Search 3 Pathogen and Mosquito

Mosquito	*("Aedes cinereus" OR "Aedes vexans" OR "Coquillettidia perturbans" OR "Culex restuans" OR "Culex tarsalis" OR "Culiseta alaskaensis" OR "Culiseta incidens" OR "Culiseta inornata" OR "Culiseta minnesotae" OR "Culiseta morsitans" OR "Ochlerotatus canadensis" OR "Ochlerotatus communis" OR "Ochlerotatus excrucians" OR "Ochlerotatus implicates" OR "Ochlerotatus sticticus" OR "Culex restuans" OR " Culex tarsalis" OR "Culiseta minnesotae" OR " Ochlerotatus campestris" OR " Ochlerotatus campestris" OR "Ochlerotatus dorsalis" OR "Ochlerotatus nigromaculis" OR "Ochlerotatus spencerii" OR " Ochlerotatus sticticus")*
Pathogen	("California serogroup J" OR "Snowshoe hare virus" OR "Jamestown Canyon virus" OR "La crosse virus" OR "Cache Valley Virus" OR "West Nile Virus" OR "St Louis Encephalitis" OR "Eastern Equine Encephalitis" OR "Western Equine Encephalitis")

Lit Search 4 Climate Change

Location	**“Climate Change” AND (Yukon OR “Northwest Territories” OR Nunavut OR arctic OR Labrador OR Denmark OR Finland OR Iceland OR Norway OR Sweden OR Greenland OR Alaska OR Russia)**
	“Canadian Regional Climate model” OR “General circulation model” OR “SNAP” OR “Scenarios Network for Alaska and Arctic Planning”
	“Climate change” AND (“Vector Borne” OR preparedness)

Appendix 3: Inventory of NT documents

Seventy-four digital file documents acquired from NT staff were reviewed for this report, of which 38 were classified as moderately or highly relevant for the purposes of this report. A list of these 38 documents and a brief summary of each document is provided in Table A3-1 below.

Table A3-1. File content summary for 38 documents provided by NT staff

File Title	File Summary
128-Health_Study_Brochure_proof_v20180918	Request to NT (South Slave Region) hunters to submit cervid heads, feces, liver tissue, lower leg, muscle, kidney and fat. Information to be learned: age structure, nutritional condition, contaminants, diseases (CWD, brucellosis, tuberculosis).
2018-02-15 WN18-0001 to 19 results table	Testing in birds. All samples were negative on PCR for both WN and EEEV in NT.
Appendix A(2004 Trap Results)	Total no. of mosquitos by location and date, and species composition of subsample
Appendix C (2005 Trap results)	Total no. of mosquitos by location and date, and species composition of subsample
Brief summary of NT moose info	Winter tick in NT moose since 1975. Also found: echinococcosis, anthrax, brucellosis, bacterial infections, *Mycobacterium bovis* (bovine tuberculosis), warbles, *Taenia*, *Oncocerca cervipedis*, fibropapilloma, and *P. tenuis*. Monitoring for species of ticks not normally present in NT.
ChartsNT	Total no. of mosquitos by location and date, and species composition of subsample
ChartsNT2014	Total no. of mosquitos by location and date, and species composition of subsample
ChartsNT2016	Total no. of mosquitos by location and date, and species composition of subsample
Copy of New Species Chart1	Newly identified Cx (2 spp.), Ox. (6) and Cs (1) mosquitoes by year, in NT
Data entry Mosquito survey 2018	Number of mosquitoes trapped in the ENR and Lagoon from May 17 2018 to September 14 2018. Includes described cloud cover, comments and min, max, average number.
Decho 1 and 2 2014 Species Data	Total no. of mosquitos species by date and location
Final Copy West Nile Virus Report Week 38 2015_N_	Summary tables of human, bird and mosquito surveillance for all provinces and territories; confirms that limited (if any) testing has occurred in NT for WN
Final Report (2005)	In 2004 and 2005, mosquito trapping ID'd 5 and 2 (respectively) previously unknown species from NT; Cx tarsalis was collected from 6 locations, and represented 10% of the mosquito population; compares trap results from 1979 (published lit) against 2004 and 2005 surveys
Formatted West Nile Virus Final Report_2016_EN_	2016 summary of provinces and species in which WN, EEE and California serogroup viruses were found in Canada.

File Title	**File Summary**
hf-190201-2016-provincial-moose-winter-tick-report-BC	Report on *Dermacentor albipictus* and Provincial Moose Winter Tick Surveillance Program. Results on trends, distribution and severity of winter ticks in BC
hf-190201-KashivakuraCK_MSc_thesis - submitted for examination	Found *Dermacentor albipictus* in moose at 66 degrees north. Cannot use antibody (serology analysis) to determine exposure. Information on the geographic distribution, life cycle, and hosts of *Dermacentor albipictus*. Information of surveillance of winter ticks in the Sahtu.
hf-190207-Tick-brochure-map	Map of *Dermacentor albipictus* in Boreal Caribou and Moose and *Haemaphysalis leporis-palutris* in Snowshoe Hare in the NT.
hf-190207-Tick-surveillance-NT-2018-updatedFeb7-2019	Many reports of *Dermacentor albipictus* since 1975, mostly on moose and Caribou. One reported case of *Ixodes pacificus* with unkown date. Two reports of *Dermacentor varabilis* in 2017-2018 both with a travel history. Two reports for *Dermacentor andersoni*, one with travel history and other unknown. Four reports of *Haemaphysalis leporis palutris* with no or unknown travel history. All ticks tested in 2017 negative for *Borrelia*, *Babesia*, *Anaplasma*, and *Francisella.*
Moosecases.htm	Findings of 56 cases of submitted moose tissue diagnostics: *Echinococcus* (4), hydatid cyst (2), cysticercosis (2), brucellosis (1), fibropapilloma (4), Winter tick/*Dermacentor albipictus* (3), warble fly larvae (1), *Hypoderma tarandi* (1), *Onchocerca cervipedis* (1), liver capsule fibrosis (2), bacteria (5), rifle shots (1), deformed hooves (2), unknown cause of death (1), suspected lymphoma (1), suspected anthrax (1), no significant findings (2).
Mosquito 2004-2005 consolidated data NT	Total no. of mosquitos by location and date, and species composition of subsample
mosquito data 2019	Mosquito sampling in ENR Yard and Lagoon from May 24 2017 to September 6 2017.
Mosquito Speciation Data 2011-2013 T.Stuart	Total no. of mosquitos species by date and location
NJMarticle	Images of *Ixodes scapularis*, *Ixodes pacificus* with size reference. History of Lyme disease and human health. Clinical manifestation of Lyme disease in humans. Introduction to Powassan virus (POWV). Description of public health burden of tick-borne pathogens, diagnosis of arthropod diseases, prevention and management.
NT2017_bird samples	All samples were negative for WN in NT.
NT Blow Flies 2017	Brief summary of papers that investigate the range and occurrence of different species of blow flies in NT.
NT Final Report	No evidence of viral activity in Yellowknife, however, Cx tarsalis has been found to be well established in Yellowknife; distribution and abundance in the rest of NT is less certain
NT fleas 2017	Brief summary of available literature on the range and occurrence of different species of fleas in the NT.
NTCHARTS2017	Bar charts of total number of mosquitos (broken into different species) per sampling date in specific locations (DEHCHO 1, DEHCHO 2, Lagoon, ENR Yard, & Heliport).

File Title	File Summary
NTMosquitosummary2019-TzDocumentforReferal	Provides an overview and summary of mosquito trapping in NT between 2004 and 2018, with a focus on those mosquitoes that are competent for transmitting WN and California Serogroup viruses
NTtickmap	Map of *Dermacentor albipictus* in Boreal Caribou and Moose and *Haemaphysalis leporis-palutris* in Snowshoe Hare in the NT.
Reports of winter ticks - NT (May 2017)(3)	Winter ticks have been found on both moose and caribou in multiple areas across NT.
Research Highlight_WNClimate Change_Aug14_national MBD	A presentation on National MBD Surveillance Working Group; looking at future climate suitability for WN in Canada and Northern US. Species distribution modelling. Baseline model of current climatic suitability for WN transmission.
Schureer et al 2019 Echino wolves	Objective: report the occurrence and identity of *Echinococcus* cestodes harvested from Canadian wolves and to better define the geographic and host distribution of these parasites.
Surveillance_Grid_v3_NT	NT engages in surveillance of mosquitos, birds, and human cases but not equine cases. Human and avian cases are monitored through passive surveillance while mosquitoes are actively trapped.
Tickidentificationkey	How to identify ticks: Family Argasidae: Argas, Ornithodoros, Otobius, Antricola. Family Ixodidae: Ixodes, Amblyomma, Haemaphysalis, Rhipicephalus, Dermacentor, Anocentor/Otocentor, Boophilus.
Tick-Surveillance-Summary-2016	"Enhanced Tick Surveillance Program" (combination of active and passive surveillance) in Alberta to assess the risk of Lyme disease in Alberta and the range of *Ixodes scapularis* ticks. Graphs, maps, and tables presented for further clarification.
WN Final Report 2017	Summary of Canadian annual national surveillance report on Mosquito-borne diseases. NT is not mentioned.
WNNSR_200827	Summary tables of human, bird and mosquito surveillance for all provinces and territories; confirms that limited (if any) testing has occurred in NT for WN

Appendix 4: Arthropods in the NT

Ticks

NT tick data appears to consist primarily of opportunistic observations and submissions from hunters, biologists and Department of Environment and Natural Resources personnel. The earliest record in the NT tick dataset is *Dermacentor albipictus*, from a moose in Fort Smith in 1975. Although this dataset consists primarily of *Dermacentor albopictus*, other species of tick have been found on people, pets and wild animals. The dataset was last updated on February 8, 2019. Table A4-1 below was based on a review of Lindquist et al. (2016) and supplemented with findings from NT surveillance data (Fenton, 2018 Unpublished data). A more detailed summary of the NT surveillance data is provided in Table A4-2.

Table A4-1. Species distribution, by province and territory, of competent vector ticks

	BC	**AB**	**SK**	**MB**	**YT**	**NT**
Amblyomma americanum	-	-	-	-	-	-
Dermacentor andersoni	Y	Y	Y	-	-	Y*
Dermacentor variabilis	-	-	Y	Y	-	Y*
Ixodes cookie	-	-	-	Y	-	-
Ixodes marxi	-	-	-	-	-	-
Ixodes pacificus	Y	-	-	-	-	Y**
Ixodes scapularis	-	Y	Y	Y	-	-
Ixodes spinipalpis	Y	Y	-	-	-	-

* Identified from opportunistic sampling of humans/dogs with history of recent travel to southern Canada

** Historic case, thought to be travel related

Table A4-2: Tick species (other than Dermacentor albipictus) that have been reported from the NT

Tick Species / Yr	**Location**	**No. Ticks**	**Host Species**	**Travel History?**
Dermacentor andersoni				
2017	Fort Smith	1	Human	Yes – ON
2017	Yellowknife	1	Dog	Recently moved to Yellowknife
Dermacentor variabilis				
2013	Yellowknife	1	Human	Yes – SK
2018	Yellowknife	1	Dog	Yes – SK
Haemaphysalis leporispalutris				
2016	Fort Smith	12	Snowshoe hare	N/A
2017	Bannockland	3	Snowshoe hare	N/A
2017	Dehcho Region	7	Snowshoe hare	N/A
2017	Whati	1	Dog	No
Ixodes pacificus				
Unknown	Fort Smith	Unknown	Unknown	Unknown

Biting flies and Mosquitoes

Of the 124 biting flies and mosquitos known or expected to be present in the NT[6], 12 mosquitoes have been associated as vectors for the priority diseases discussed in this report. None of the black flies or deer flies in NT have been associated with transmitting the priority diseases reported here-in.

Table A4-3. Genus list of biting flies and mosquitos known or expected to be present in the NT. Species described in the literature as possible vectors for VBZs of concern are identified with an asterix

	Expected	Present	Total
Black Fly	**1**	**61**	**62**
Cnephia		1	1
Greniera		2	2
Gymnopais	1	1	2
Helodon		4	4
Metacnephia		3	3
Prosimulium		2	2
Simulium		45	45
Stegopterna		3	3
Deer Fly	**0**	**7**	**7**
Chrysops		7	7
ater		X	
dawsoni		X	
excitans		X	
frigidus		X	
furcatus		X	
mitis		X	
nigripes		X	
Horse Fly	**0**	**18**	**18**
Atylotus		1	1
Haematopota		1	1
Hybomitra		16	16
Mosquito	**3**	**34**	**36**
Aedes	1	4	5
cinereus *		X	
decticus		X	
mercurator		X	
rempeli	X		
Mosquito Cont.			
Culex	1	2	3
restuans *	X		
tarsalis *		X	
territans		X	
Culiseta		5	5
alaskaensis		X	
impatiens		X	
incidens		X	
inornata *		X	
morsitans		X	
Ochlerotatus	1	21	22
campestris		X	
canadensis *		X	
cataphylla		X	
communis *		X	
diantaeus		X	
dorsalis		X	
euedes		X	
excrucians		X	
fitchii		X	
flavescens		X	
hexodontus *		X	
impiger		X	
implicatus		X	
intrudens		X	
nigripes *		X	
pionips		X	

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[6] Working Group on General Status of NT Species. 2016. NT Species 2016-2020 – General Status Ranks of Wild Species in the Northwest Territories, Department of Environment and Natural Resources, Government of the Northwest Territories, Yellowknife, NT, 304 pp.

	Expected	Present	Total		Expected	Present	Total
vexans *		X		provocans		X	
Anopheles		1	1	pullatus	X		
earlei		X		punctor *		X	
Coquillettidia		1	1	riparius		X	
perturbans *		X		spencerii		X	
				sticticus *		X	
Grand Total	**4**	**120**	**124**				

Present: Species that have been recorded in NT.

Expected: Species not yet recorded in the NT, but that are expected to be present

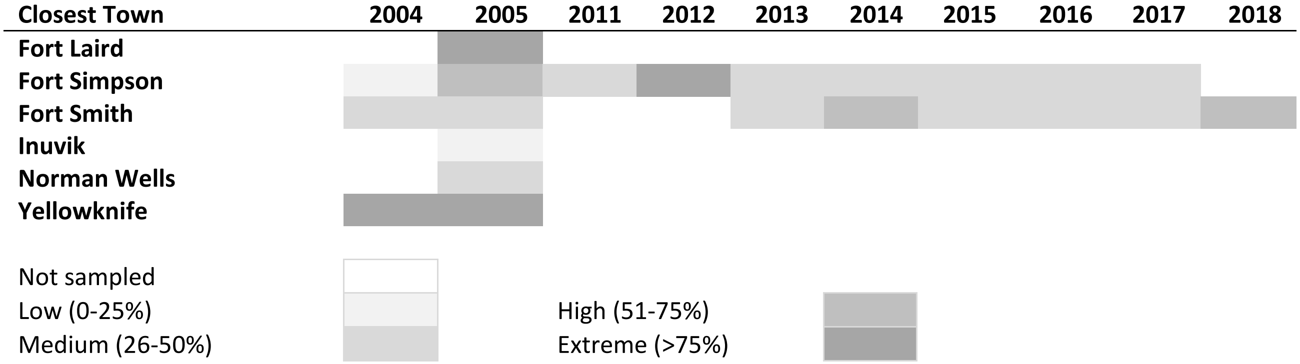
NT Mosquito surveillance data

NT mosquito trapping data was available for ten different years (2004, 2005, 2011-2018). There were eight and 14 sampling sites throughout NT in 2004 and 2005, respectively, with upwards of six localities sampled in 2005. A maximum of five sample sites from up to two localities were sampled annually between 2011 and 2018. We collated annual sampling data into one spreadsheet to facilitate analysis of mosquito trapping data by year, species and location.

Table A4-4: NT mosquito sampling sites by year. Number in parenthesis is the number of sites per locality

Year	No. of Sampling Sites	Closest Town
2004	8	Fort Simpson (1), Fort Smith (1), Yellowknife (6)
2005	14	Fort Laird (1), Fort Simpson (1), Fort Smith (1), Inuvik (1), Norman Wells (6), Yellowknife (4)
2011	2	Fort Simpson (2)
2012	2	Fort Simpson (2)
2013	4	Fort Simpson (2), Fort Smith (2)
2014	4	Fort Simpson (2), Fort Smith (2)
2015	4	Fort Simpson (2), Fort Smith (2)
2016	4	Fort Simpson (2), Fort Smith (2)
2017	5	Fort Simpson (2), Fort Smith (3)
2018	1	Fort Smith (1)

Mosquito sampling identified 21 species of mosquito in NT. The relative percentage of vector-competent (known or suspected) mosquito counts identified in each town where sampling occurred is presented in Figure A4-1 below.



Closest Town	**2004**	**2005**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Fort Laird		█								
Fort Simpson	░	▓	▒	█	▒	▒	▒	▒	▒	
Fort Smith	▒	▒			▒	▓	▒	▒	▒	▓
Inuvik		░								
Norman Wells		▒								
Yellowknife	█	█								

Not sampled □
Low (0-25%) ░
Medium (26-50%) ▒
High (51-75%) ▓
Extreme (>75%) █

Figure A4-1: Percentage of vector-competent (known or suspected) mosquito counts identified from each location (closest town) and year

Appendix 5: Assessing the potential role of climate change in vector-borne disease dynamics

Vector borne zoonoses are sensitive to climate because; 1) arthropods are ectothermic, with their internal temperature regulated by external environmental conditions; 2) arthropod larval development stages generally require the presence of bodies of water and/or specific humidity conditions; 3) vector biting rates tend to increase with temperature up to an upper threshold, after which they decrease (Scott et al., 2000); 4) the development and replication of pathogens transmitted within vectors is influenced by temperature (Reisen et al., 2006); and 5) vector development and survival is significantly affected by temperature conditions (Brady et al., 2013). The optimal temperature range for disease transmission will vary depending upon the vector-pathogen combination (Caminade, McIntyre, & Jones, 2019).

In general, there are five mechanisms by which climate change could increase VBZs; 1) range shifts in animal or arthropod host geographic range so that hosts come into contact with previously non-exposed human populations; 2) increases in the population density of animal or arthropod hosts, thereby increasing contact with humans; 3) increases in the prevalence of infection in animal or arthropod hosts; 4) changes in pathogen load in animal or arthropod hosts brought about by changes in rates of pathogen reproduction, replication, or development; and 5) shifting of pathogens to new arthropod or animal hosts (Gale, Ulrich, & Wilson, 2014; Mills et al., 2010).

One well documented climate driven shift in vector distribution is the poleward range shifts of *Ixodes* spp. ticks (Mills et al., 2010). In North America, a northerly range shift has been documented for *I. scapularis,* a vector of Lyme disease, human granulocytic anaplasmosis, Powassan virus and babesiosis. Models indicate that this tick will extend its range farther into Canada while contracting its southern range (Ogden et al., 2010; Ogden et al., 2006). In Europe, there is increasing evidence for a latitudinal and altitudinal shift in the distribution range of *I. ricinus*, the vector for Lyme borreliosis (LB) and tick-borne encephalitis (TBE) (Jore et al., 2011). *I. ricinus*, the sheep tick, has expanded its geographical range and seasonal activity in Europe over the past decade, including its distribution, shifting farther north in Sweden and Norway. This northern shift and increase in activity are related to milder winters and prolonged spring and autumn seasons beginning in the 1990s, combined with increased vegetative cover and further-ranging deer carrying ticks into newly suitable regions. Similar trends have been observed in the Baltic countries and northern parts of Poland (Caminade et al., 2019). Northern Russia has also experienced an increase in the *Ixodes* tick population and in TBE cases over the past decades. In particular, a 50-fold rise in TBE incidence was reported for the far northern province of Arkhangelsk Oblast during the 2000s compared with the 1980s. There was also a distinct correlation between TBE incidence and increases in mean annual air temperatures from 1990 to 2009 (Caminade et al., 2019).

Climate driven changes in mosquito range and populations have also been documented. El Nino Southern Oscillation (ENSO) events are associated with increased rainfall, which has been linked to increases in mosquito populations globally, for example: 1) Aedes mosquitos, which are the vector for Rift Valley fever in East Arica (Anyamba, Linthicum, & Tucker, 2001; Mills et al., 2010); and 2) increases in mosquitoes and mosquito-borne malaria in South America and southern Africa (Barrera, Grillet, Rangel, Berti, & Ache, 1999; Mills et al., 2010). Extreme rainfall events were also associated with increased risk of WN transmission. Milder winter conditions, combined with droughts during the boreal spring season, were associated with increased risk of WN transmission by urban mosquitoes in the US (Caminade et al., 2019).

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